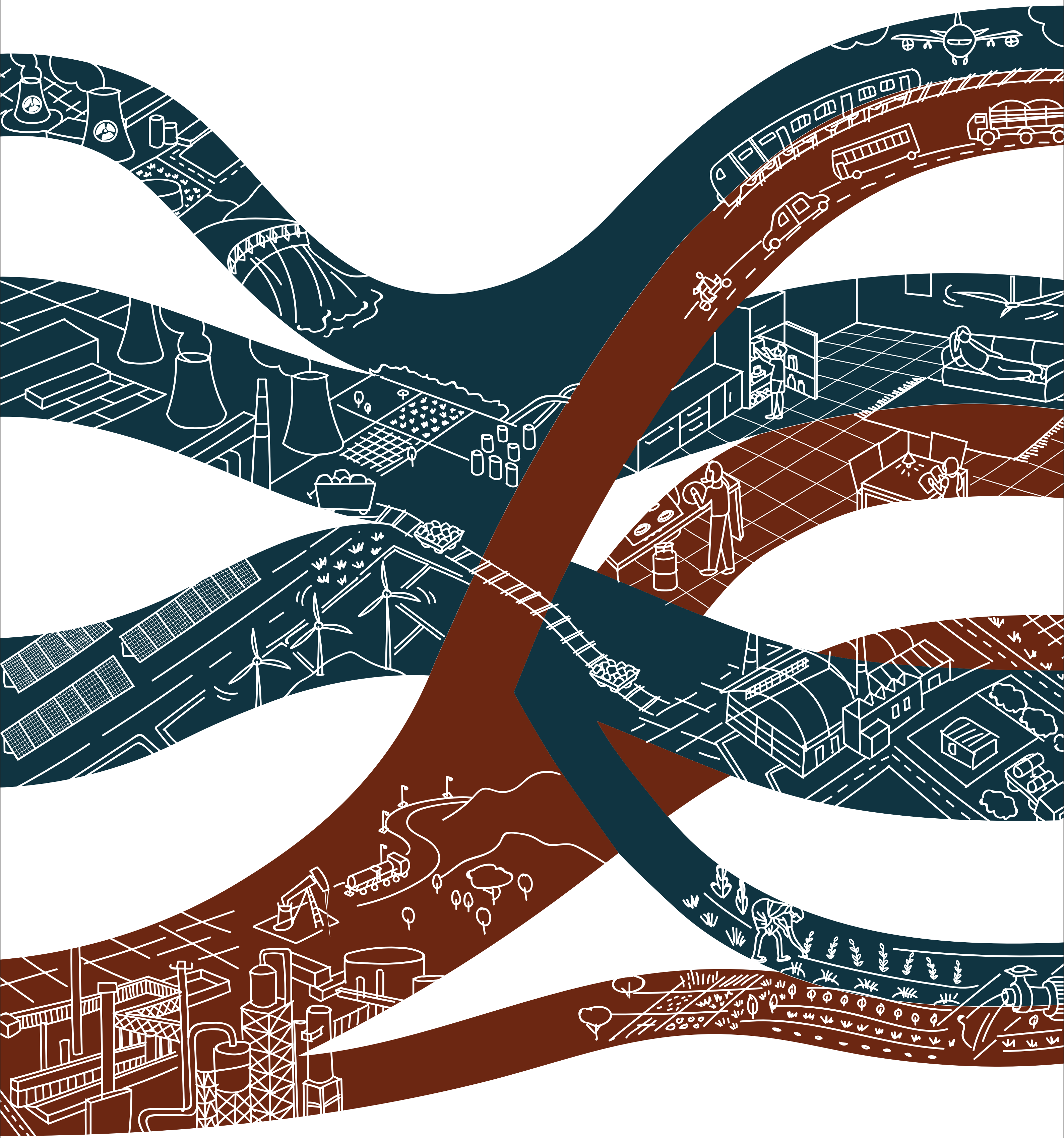
PIER: MODELLING THE INDIAN ENERGY SYSTEM THROUGH THE 2020s



प्रयास
Prayas (Energy Group)

Energy Modelling Series

RUMI

PIER: Modelling the Indian energy system through the 2020s

Prayas (Energy Group), Pune

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October 2021

Prayas (Energy Group)

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Git repositories for download
Rumi platform https://github.com/prayas-energy/Rumi
PIER model https://github.com/prayas-energy/PIER

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Executive summary

Multiple uncertainties, developments and imperatives underpin the development of the Indian energy sector through the 2020s, such as economic uncertainties due to COVID-19, rapid technological advances, growing pressures to act decisively on climate change, and the need to address the country's development challenges. In this context, it is critical to have a feature-rich, publicly accessible and usable analytical framework to examine and understand the energy sector to inform policy, investments etc. It is with this motivation that the open-source, free-to-use demand-oriented Rumi energy systems modelling platform and the PIER (Perspectives on Indian Energy based on Rumi) energy model of India through the decade of the 2020s, has been built and made available with all the code, data and assumptions. Rumi and PIER will continue to be supported and enhanced by Prayas (Energy Group) and it is hoped that the research community would also find it interesting to enrich them further.

Rumi is a generic energy systems modelling platform that gives the modeller considerable freedom to define an energy system of her choice, in terms of what geographic and temporal scope to consider, what energy carriers to model, what demand and supply options to model etc. Rumi permits specification of energy demand in multiple ways depending on the amount of detail required and data available. In particular, it also allows detailed bottom-up modelling of energy services required based on which demand is estimated. It identifies supply options to meet the demand in a cost-optimal manner at the required temporal and spatial granularity.

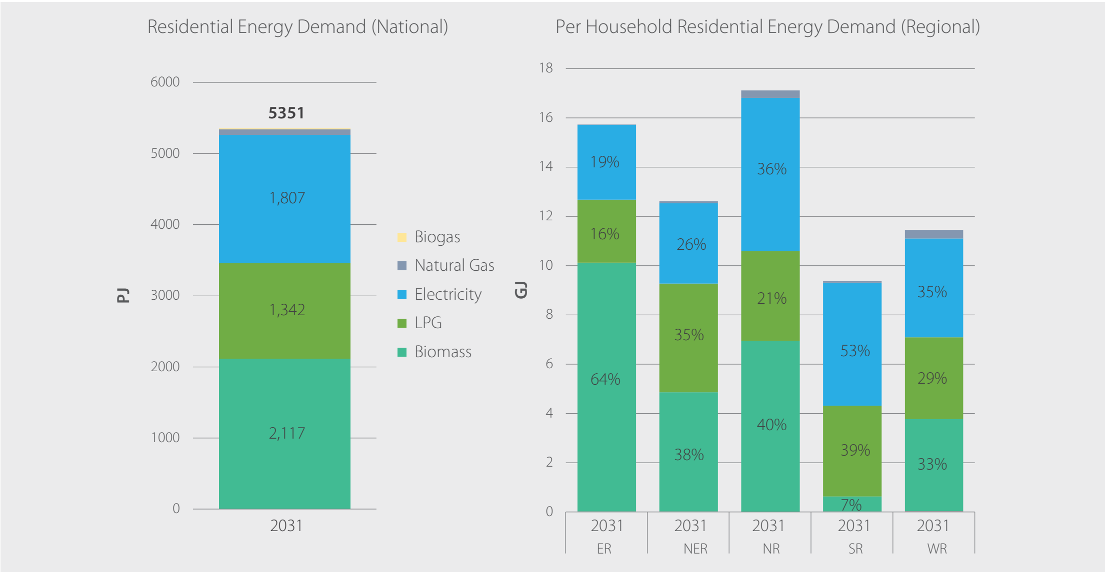
The current version of PIER models the Indian energy system from 2020-21 (FY21) to FY31. Most energy carriers of interest such as electricity, transport fuels, coal and so on have been modelled. The use of solid fuels for cooking has also been modelled. Five energy consuming sectors have been modelled in PIER, namely the residential, industrial, transport, agricultural sectors and an "others" sector which represents the rest of energy demand. Energy demand for the residential sector has been modelled in detail. 250 different types of households have been considered and four energy services have been modelled for each household type in a bottom-up manner, namely lighting, cooking, refrigeration and space cooling. Together, these energy services capture over 80% of residential energy sector demand and about two-thirds of residential electricity demand. The rest of the residential energy demand and demand from other sectors have been modelled more coarsely for now. On the supply side, nine electricity generation technologies, refineries for five petroleum products and three types of electricity storage have been modelled. Geographic and temporal granularity have been chosen such that the interesting characteristics of specific energy carriers (e.g. transportation cost of coal, and transmission and distribution losses and costs of electricity) can be modelled.

In addition to a Reference scenario, the current model includes two divergent scenarios of how India recovers from COVID-19. These scenarios give a broad understanding of the possible range of trajectories for the Indian energy sector in this decade. In addition, a set of sensitivity analyses were also made, to understand the impact of changing some key parameters on the major outcomes of the Reference scenario. Together, the scenarios and the sensitivity analyses provide a set of interesting insights into the future of the Indian energy system through the decade of 2020s.

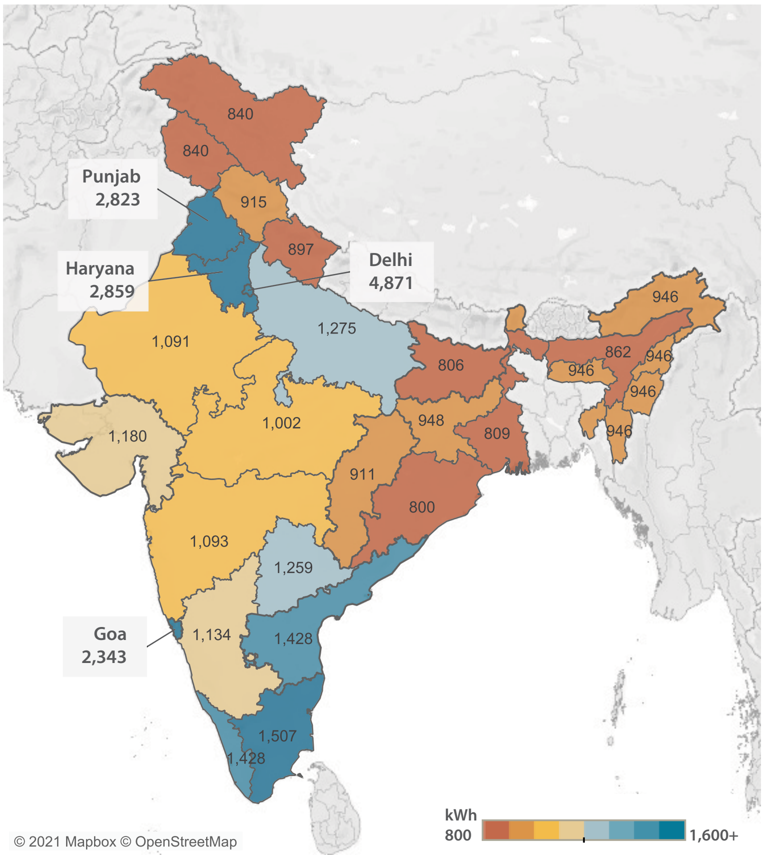
Some of the interesting results and insights from the modelling exercise are outlined below.

1. **Modern cooking fuel usage:** Even in FY31, biomass represents nearly 40% of all residential energy demand in the country (ES Figure 1). In the Eastern region, it is as high as 64%. This indicates that too many households still rely on solid fuels for cooking even in FY31, leading to severe health impacts. This calls for urgent policy attention to enable households to move to modern cooking fuels such as LPG and electricity.

ES Figure 1: Residential Energy demand



ES Figure 2: Per-Household Annual Residential Electricity Consumption in FY31

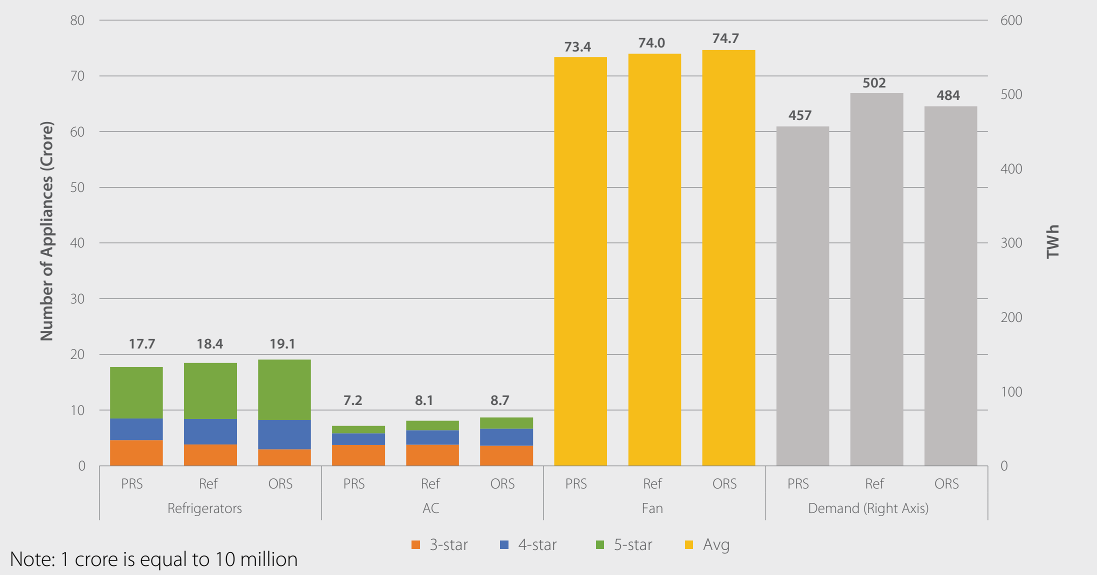


Note: The call-outs are for outlier states. Present UTs of J&K and Ladakh were modelled as one state - J&K. Non-Assam North-east states were modelled as one state - NE.

2. **Household electricity consumption:** While annual electricity consumption in an average Indian household goes up by over 25% from FY21 to FY31, it still reaches only 1260 kWh. Moreover, there is significant inequity across states (ES Figure 2) in this regard, with households in states such as Odisha and Assam consuming less than 1000 kWh annually even in FY31. This points to the need to provide reliable, affordable electricity to households, particularly in states with low consumption.

3. **Role of energy efficiency:** Focusing on systemic improvements to energy efficiency can lead to significant benefits. For example, in the Optimistic Recovery Scenario (ORS), though households own and use more fans, ACs and refrigerators, the total residential electricity demand in FY31 is only 484 TWh as compared to 502 TWh in the Reference scenario, due to greater improvements in efficiency (ES Figure 3). Similarly, despite national electricity demand in the ORS being 18 TWh greater than the Reference scenario in FY31, the electricity supply required to meet the demand is marginally lesser than the Reference scenario, due to reduced transmission and distribution losses.

ES Figure 3: Number of appliances and residential electricity demand across scenarios in FY31

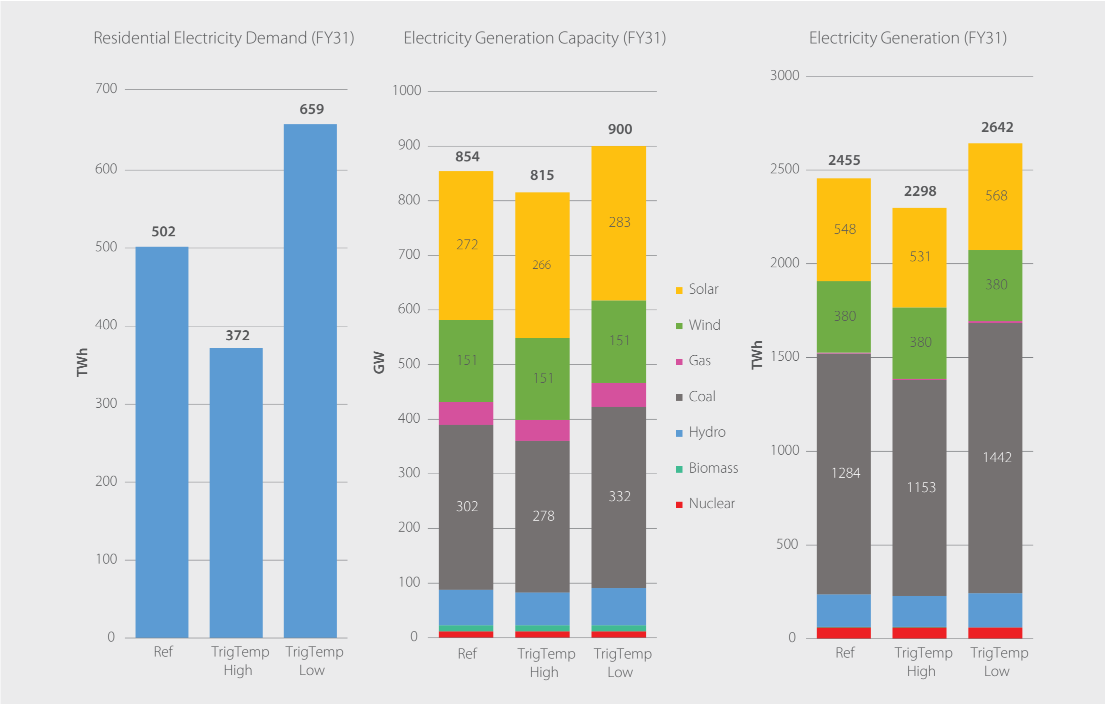


Note: 1 crore is equal to 10 million

4. **Critical role of consumer behaviour:** In addition to technical efficiency, behaviour of energy consumers can also have a huge impact on the energy system. Increasing the temperature at which households use fans, coolers and ACs by 2 °C reduces residential electricity demand from 502 TWh in FY31 to just 372 TWh. This results in the need for electricity supply falling by about 150 TWh, resulting in 24 GW lesser coal capacity and 6 GW lesser solar capacity in FY31 (ES Figure 4). This highlights the critical role of behavioural interventions in helping reduce energy demand and costs while simultaneously satisfying energy service needs.

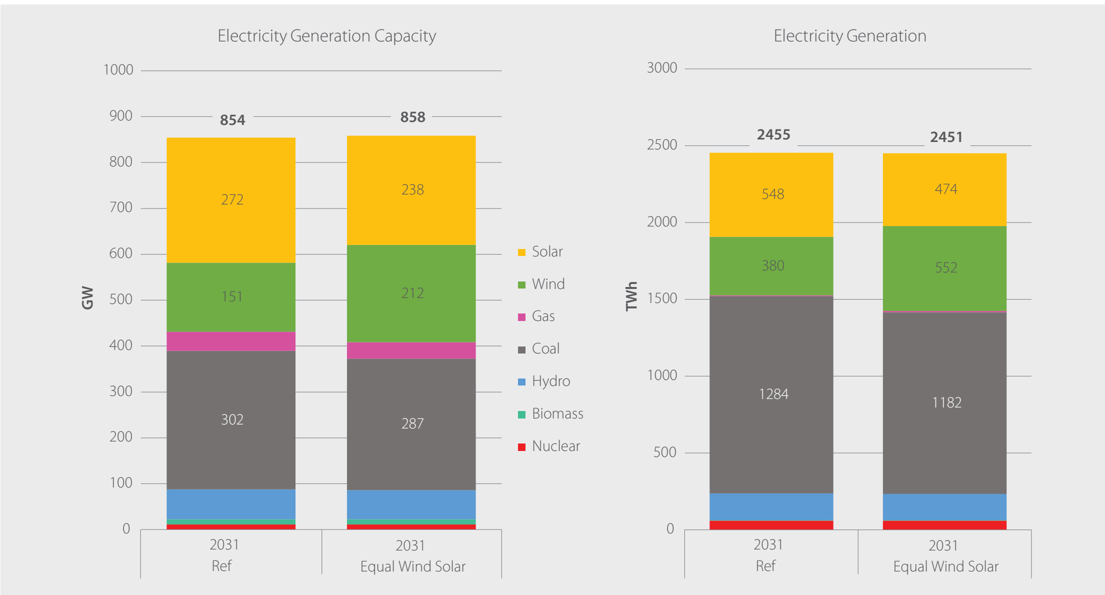
5. **Coal capacity addition:** Projections by PIER show that India needs about 302 GW of coal-based electricity generation capacity by FY31, and this capacity roughly matches the capacity that would exist if all the capacity in the construction and permissions pipeline gets commissioned. Therefore, any coal-based capacity addition beyond that would be risky and potentially lead to lock-ins and stranded assets. However, 302 GW of coal capacity is sufficient only if India can reach almost 450 GW of renewables capacity by FY31, which will be challenging.

ES Figure 4: The impact of changing trigger and reference temperature by 2 °C in FY31



6. **Renewables capacity mix:** Results from PIER (ES Figure 5) show that, rather than prioritising solar over wind, it may be beneficial to prioritise them based on their relative value to the electricity system. Such an approach results in an electricity supply mix with a lesser role for coal and greater role for renewables at roughly the same cost.

ES Figure 5: Capacity and generation mix in equal addition of Solar and Wind sensitivity case



7. **Sensitivity to costs:** The model's results are not very sensitive to the specific cost trajectory assumptions that have been made. The overall energy system is roughly similar if the costs of fossil fuels and renewables such as solar and wind are either increased or decreased by 10%. The same is true for increase or decrease in electricity storage costs, though this does affect the amount of storage that gets added.

In addition to the above insights, the report also presents various other results that may be of interest, such as the share of space cooling in residential demand and peak demand, the electricity generation mix in future years and India's import dependence for various energy sources.

Going forward, we expect to work on improving various aspects of the PIER model and the Rumi platform, and use it to address more policy relevant questions. We also hope that other researchers and modellers find Rumi and PIER useful, and deploy it to further the analytical basis for understanding India's energy sector and enrich India's energy policy formulation.

Rumi can be downloaded and used from https://github.com/prayas-energy/Rumi, and PIER can be downloaded and used from https://github.com/prayas-energy/PIER.

1 Introduction

India's energy sector has been changing rapidly driven by increased access, changing consumption patterns, technological changes on the supply and demand side, environmental and climate change considerations, and policy. Some aspects of this change include nearly 100% of households having access to electricity and LPG connections as per official statistics[1], increasing penetration of electrical appliances, a thrust on electrification of transport, a renewed push for adoption of biofuels, an attempt to introduce more stringent emission norms on coal-based power, increasing renewable purchase obligations (RPO), announcement of an ambitious 450 GW renewable capacity target for 2030 and efforts to reduce energy imports.

The increasing urgency of the climate change problem – with this decade being seen as decisive by many – lends another dimension to the changes in the energy sector. This is manifest in various forms such as the change in regime in the United States leading to increased global attention to the climate problem, reports from the IPCC and IEA regarding the need to respect the 1.5° C temperature rise limit and steps required for it (IPCC, 2018; IEA, 2021b), and the upcoming COP26 summit at Glasgow where nations are expected to submit revised Nationally Determined Contributions (NDCs).

Over and above these changes, the COVID-19 pandemic has had a severe impact on the economy at the macro-level and has had a devastating effect on many households with the number of middle-class households shrinking and the number of poor households increasing sharply (Kochhar, 2021). This would naturally reflect in consumption patterns, including energy consumption – both by households as well as by industrial and commercial consumers. It is also likely to impact the pace of investments into the sector.

India's per-capita energy and electricity consumption are only about a third of the global average. Therefore, it is expected that India's per-capita energy consumption will continue to grow for many years to come – with increasing incomes, urbanisation and a growing industrial sector. However, India – particularly its electricity sector – is generally plagued by poor planning and flawed demand estimation, as manifest in the stressed electricity generation assets problem faced by the country (Prayas (Energy Group), 2017). This complex mosaic makes energy sector policy formulation for India particularly challenging (Sreenivas and Gambhir, 2019).

The context or background for this exercise is defined by these multiple uncertainties and changes (economic uncertainties due to the COVID-19 pandemic, rapid technological changes in the sector, growing pressures of climate change and the need to act decisively, and the continuing development imperative) and the associated risks. In this context, it is important to get a good understanding of future energy demand in the country, and the likely sources of supply that could meet such demand reliably and cost-effectively. Such an understanding can help identify the infrastructure and investment requirements, identify areas that need

1. However, note that, affordable, reliable supply of electricity and LPG is still a challenge.

attention, and point to policy imperatives that need to be addressed. Moreover, given the complexity of the challenge, we believe that the more analytical power that can be brought to bear on understanding these challenges, the better it is. That is the primary motivation behind this exercise. The major objectives of this effort are as follows:

- Develop and release an open-source, free-to-use demand-oriented energy systems modelling platform called Rumi that can be used by the policy research community, academic institutions and state institutions, among others.
- Demonstrate the usefulness of Rumi by building a model called PIER (Perspectives on Indian Energy based on Rumi), which models the Indian energy system in the context of the rapid changes in the sector and the uncertainties arising out of the COVID-19 pandemic.
- As a first step, undertake detailed bottom-up energy demand modelling for the residential sector.
- Obtain interesting insights from the exercise that can inform policy to enhance well-being and identify potential risks.
- Publish all the data and methods used to build PIER for further use and refinement by others in the research community.

Going forward, we propose to further enhance both the PIER model and the Rumi platform to build richer models and provide enhanced features. The rest of this report is organized as follows.

In Section 2, we describe the Rumi modelling platform on which PIER is built. Sections 3, 4 and 5 describe the approach to setting up the PIER model, with Annexures A1, A2, A3 and A4 providing further details about how the PIER model is set up. Section 6 and Annexure A5 describe the various scenarios and sensitivity analyses that have been modelled in PIER. Section 7 presents the most interesting results and insights that emerge from the PIER modelling exercise. More results from the model run are presented in Annexure A6. In Section 8, we present some limitations of Rumi and PIER in their current form, thus also indicating some future directions of work, before concluding in Section 9. Annexure A7 has a tabular compilation of interesting outputs from the PIER model as a ready reference.

1.1 Comparable modelling literature

Energy-economy models have played some role in informing India's energy and climate policy, in response to the global debate on climate change and the need for India to take up mitigation actions while simultaneously achieving developmental goals. These models are either computable general equilibrium models with linkages to the macro-economy (Parikh *et al*., 2014; Ojha, Pohit and Ghosh, 2020), energy systems models (TERI, WWF, 2013; Byravan *et al*., 2017), or hybrid/integrated assessment models (Shukla and Chaturvedi, 2012, 2013; Shukla *et al*., 2015; Shukla, Garg and Dholakia, 2015). The Ministry of Environment and Forests (MoEF) commissioned a study in 2009, involving some of these models, to profile India's greenhouse gas emissions until the year 2030 (MoEF, 2009). In addition, greater detail of the Indian energy system has been added to world energy models enabling country specific studies (IEA, 2021a).

Detailed modelling of the Indian power system began in the mid-2010s given the strong policy push to increase the share of renewables in the Indian power system, in the context of dramatic cost reductions of solar and wind generation technologies (Palchak *et al.*, 2017; CEA, 2020; Rose *et al.*, 2020; Spencer *et al.*, 2020; Prayas (Energy Group), 2021a). Power sector models have greater temporal granularity, at hourly resolution or lower, given the variability in demand and renewable generation sources and since supply and demand have to match instantaneously given the synchronous nature of the power grid. These models are largely focused on adequacy of supply sources to reliably meet exogenously input demand at all times while minimising cost. Capacity expansion models, on the other hand, help in identifying optimal investments in generation, storage and transmission resources from a set of candidate capacities. Total (i.e., fixed and variable) costs are minimised over a period of several years, even decades. The models can be set up to take into account technical, policy, feasibility and environmental constraints, although the extent of constraints taken into account varies from model to model.

Electrification of transport and industrial energy services is increasingly being seen as a viable low carbon strategy, resulting in the increasing role of the power system in the energy sector. Thus, there is a need for a hybrid approach wherein the interactions between the energy sector and the rest of the economy are modelled (as in energy-economy models), along with a representation of the power system at sufficient granularity so that the temporal variations of demand and intermittent renewable generation are captured.

There has been limited focus on energy demand as well as its distributional aspects such as socioeconomic heterogeneity in Indian modelling studies so far (Dubash *et al.*, 2015). In addition, there are vast differences in energy demand as well as supply across different states and between urban and rural areas, and this diversity needs to be captured by modelling studies in order to better inform India's energy policies.

Moreover, not many of the energy models – with their code, data, assumptions and outputs – are made available publicly for review, use and improvement. Such availability can significantly improve the confidence in modelling results, particularly in the policy making context, as the model inputs, code and outputs would be available for anybody interested. It can also allow easier development of a bouquet of alternative models and scenarios. The Rumi modelling platform was developed to bridge some of these gaps, and provide a generic platform that can be used by energy modellers to build different kinds of energy models. PIER is one such India-focussed model built on Rumi. We hope that Rumi and PIER together can enrich the energy modelling ecosystem in India and enable a greater variety of analyses to inform policy.

2 Rumi modelling platform

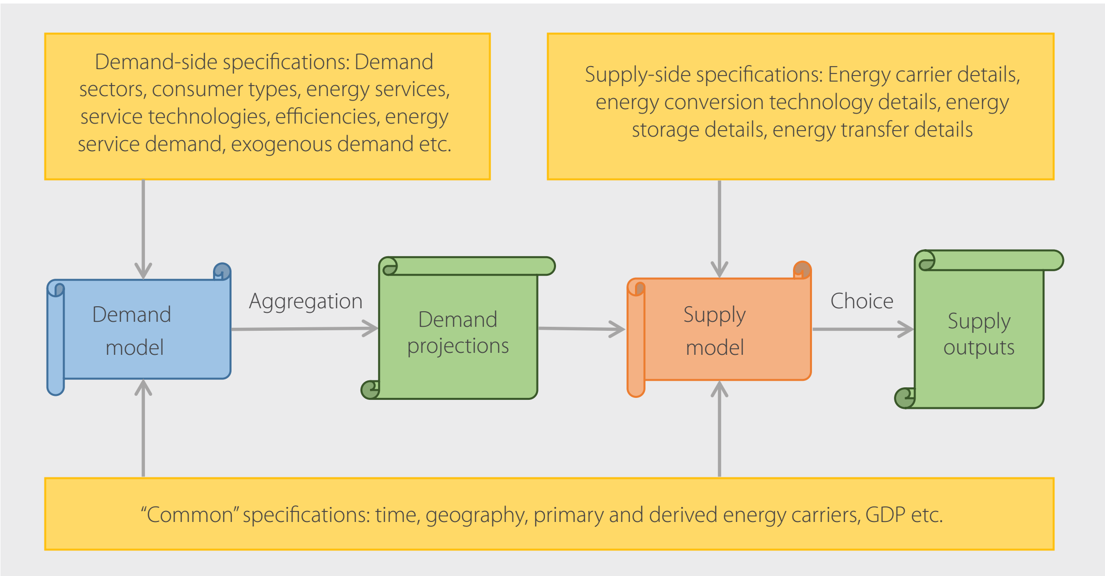
Rumi (Prayas (Energy Group), 2021b) is an open-source, demand-oriented, configurable and generic cost-optimising platform on which various energy systems models can be built. Rumi can be downloaded and used from https://github.com/prayas-energy/Rumi. In this section, we provide a brief overview of Rumi.

In order to set up a model in Rumi, various kinds of inputs need to be provided. Broadly, Rumi accepts three kinds of inputs as shown in Figure 1. These are:

- Some 'common' inputs that define the broad scope and granularity of the model, and provides some generic parameters relevant to estimating energy demand and supply
- Inputs that help to compute the energy demand and
- Inputs that help to identify the energy supply options to meet the demand.

These are elaborated further below. Detailed information about these are available in the Rumi documentation provided with the platform.

Figure 1: Rumi architecture



2.1 Common inputs

The common inputs to Rumi define the following:

- **Temporal scope and granularity:** Details of the time period over which the energy system is being modelled. Rumi operates at an annual level and hence estimates demand and supply options for all the years between the given start and end years. In addition, the modeller can optionally specify up to three further levels of temporal granularity, namely, the seasons in a year, the number of different typical day-types in a season, and the number of slices a day is broken into.

- **Geographic scope and granularity:** Similar to temporal granularity, the modeller can define up to four levels of geographic areas being modelled. The coarsest defined geographic area represents the entire geography being modelled, while the others represent successive levels of further disaggregation of the geography being modelled.
- **Energy carriers:** The various energy carriers that are being modelled are defined. Energy carriers can either be primary (i.e. occurring 'naturally', e.g. crude oil or sunlight) or derived (produced from some other energy carrier, e.g. electricity or LPG). They can also be physical (i.e. having physical characteristics such as mass or volume and energy density, e.g. coal or diesel) or non-physical (e.g. wind or electricity). For each energy carrier, a 'balancing' time and geography are defined, to indicate the granularity at which demand and supply are matched for that carrier.
- **Unmet demand value:** This input is used to define a threshold cost beyond which meeting demand for that carrier would be considered uneconomical.
- **Other inputs:** This consists of other useful inputs such as the demographics and GDP of the area being modelled, and details of different types of emissions[2].

2.2 Demand modelling in Rumi

The Rumi demand model aggregates the energy demand for the various energy carriers in the modelled geography over the model period, based on relevant inputs at the appropriate geographic and temporal granularity. Details of energy demand for an energy service can be provided in four different ways:

1. Bottom-up demand specifications, where energy demand is estimated from given inputs regarding the energy service that is required, the various energy service technologies that can provide that service and the efficiencies of the technologies
2. Extraneous or exogenous demand specification, where the energy demand is directly provided by the modeller
3. GDP-elasticity based specification, where the energy demand is calculated based on the elasticity of energy demand to GDP
4. Residual specification, where the energy demand is calculated as a residual share of the demand for some other services

For this, broadly the following kinds of inputs are accepted from the modeller:

- **Demand sectors:** The various demand sectors that are of interest to the modeller
- **Energy services:** The various energy services being modelled for each demand sector
- **Consumer details:** The different kinds of energy consumers in a demand sector, and the number of such consumers of each kind
- **Energy service technology details:** The various technologies that can provide different energy services and their details, such as their efficiencies
- **Energy service demand:** The energy service demanded by various types of energy consumers

2. Though the current version of Rumi accepts inputs related to emission types and emission intensities, it does not compute emissions from them.

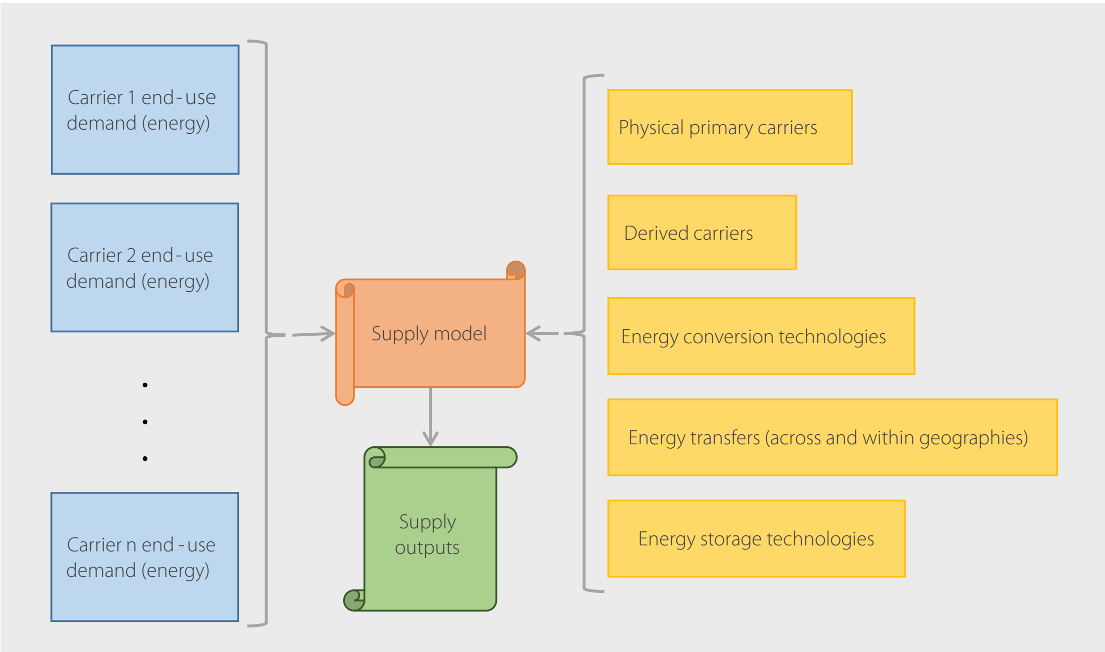
- **Service technology penetration:** The share of consumers of a given type using a particular service technology
- **Number of instances of a technology:** The number of different instances of a technology that are used by a consumer type
- **Extraneous demand specification:** If the energy demand is given exogenously by the modeller
- **GDP elasticity specification:** If the energy demand is to be calculated based on GDP elasticity
- **Residual demand share:** If the energy demand is to be calculated as a residual of other services

Given the above inputs, Rumi calculates the energy demand at the appropriate time and geographic unit for each energy carrier. In addition, it also produces a set of other fine-grained outputs that provide detailed insights into the characteristics of energy demand as modelled[3]. It should be noted that currently, demand (for energy services or energy) is provided as an input to Rumi. Thus, price-elasticity of demand is not built into Rumi, and the modeller needs to incorporate this outside Rumi if required.

2.3 Supply modelling in Rumi

Given the output of the demand model and inputs describing the supply elements, Rumi identifies the various energy supply options to meet the demand in a cost-optimal manner. This is shown in Figure 2.

Figure 2: Rumi Supply model



3. In PIER, these include, for example, energy demand for each carrier by demand sector and residential electricity demand for each energy service and by service technology.

Four types of inputs are required for the supply model:

- **Energy carrier costs and availability limits:** These define the costs of different energy carriers and the limits on domestic production or import of the carrier.
- **Energy conversion technology details:** All demand of derived energy carriers has to be met by producing it from some energy conversion technology. Details of such technologies, such as the costs, efficiency, historical capacity, fleet ramp rates and limits on future capacity addition are specified.
- **Energy storage technology details:** Some energy forms can also be stored and used. Details of such storage technologies along with their costs, efficiencies, historical capacity, limits on future capacity addition and other operational characteristics are given.
- **Energy transfer details:** Energy can be transferred across geographic areas. Details of such transfers, such as the cost of transferring energy, the losses incurred in the transfer and the limits on how much energy can be transferred are specified.

The supply model tries to satisfy the energy demand for each carrier at least cost based on the given inputs, while satisfying various applicable constraints such as production limits, capacity addition limits and so on. In this process, it makes various decisions such as how much of each primary carrier must be domestically produced and how much imported, where should they be produced or imported, how much capacity of each energy conversion technology and storage technology to install, and when and how to use the conversion technologies and storage. It makes these decisions based on 'perfect foresight' of the entire model period. The outputs of supply processing include details regarding all the above decision variables.

2.4 Scenario definitions

One set of inputs as described above defines a 'scenario' which can be run, and results obtained for it. In typical modelling exercises, one 'Reference' or 'Baseline' scenario is defined with all the inputs, and for all other scenarios, some of these inputs are changed to reflect a different storyline or situation for the future. Rumi easily allows the modeller to define a set of 'default' inputs which are used for all scenarios unless they are over-ridden specifically in that scenario.

The Rumi platform is available for public download and use from https://github.com/prayas-energy/Rumi.

3 PIER: The India model built on Rumi

PIER (Perspectives on Indian Energy based on Rumi) is a model of the Indian energy system built on Rumi. All the data and assumptions used to build PIER are publicly available for download and use from https://github.com/prayas-energy/PIER.

Figure 3 gives a high-level overview of the PIER model. In this section, we briefly describe some of the basic elements of the model. Subsequent sections detail out the demand and supply models of PIER with more details in the annexures. The data files made available with the PIER model include detailed information about the data sources that have been used.

1. **Time:** PIER models the Indian energy system over the current decade – i.e. from 2020-21 (henceforth FY21) to FY31. Each year is divided into five seasons (SUMMER, MONSOON, AUTUMN, WINTER and SPRING), where each season represents certain months of the year. Each season is modelled to consist of one typical day and each day is modelled to consist of six day-slices called EARLY, MORN, MID, AFTERNOON, EVENING, NIGHT, which represent specific time-bands in the day.

2. **Geography:** The geographic scope of PIER is India, which is further sub-divided into five regions namely, Eastern Region (ER), North Eastern Region (NER), Northern Region (NR), Southern Region (SR) and Western Region (WR). The regions are further split into a total of 25 states that together represent India. This allows different carriers to be modelled at different levels of geographic granularity.

3. **Energy carriers:** PIER models six physical primary energy carriers, namely, steam coal, coking coal, crude, natural gas, biomass, and biogas[4]. Four non-physical primary carriers too are modelled to represent sources from which electricity is generated. These are sunlight, wind, water (for hydro-generation) and atomic energy. It models six derived energy carriers consisting of five physical derived carriers representing petroleum products (Motor Spirit or MS, High Speed Diesel or HSD, Liquefied Petroleum Gas or LPG, Aviation Turbine Fuel or ATF, and Other Petroleum Products or PP_OTHER representing all other petroleum products used in the energy sector), and one non-physical derived carrier, namely electricity. Electricity is modelled to be balanced at a day-slice and regional level[5], the two kinds of coal are balanced at an annual and regional level and all other carriers are balanced at annual and national level.

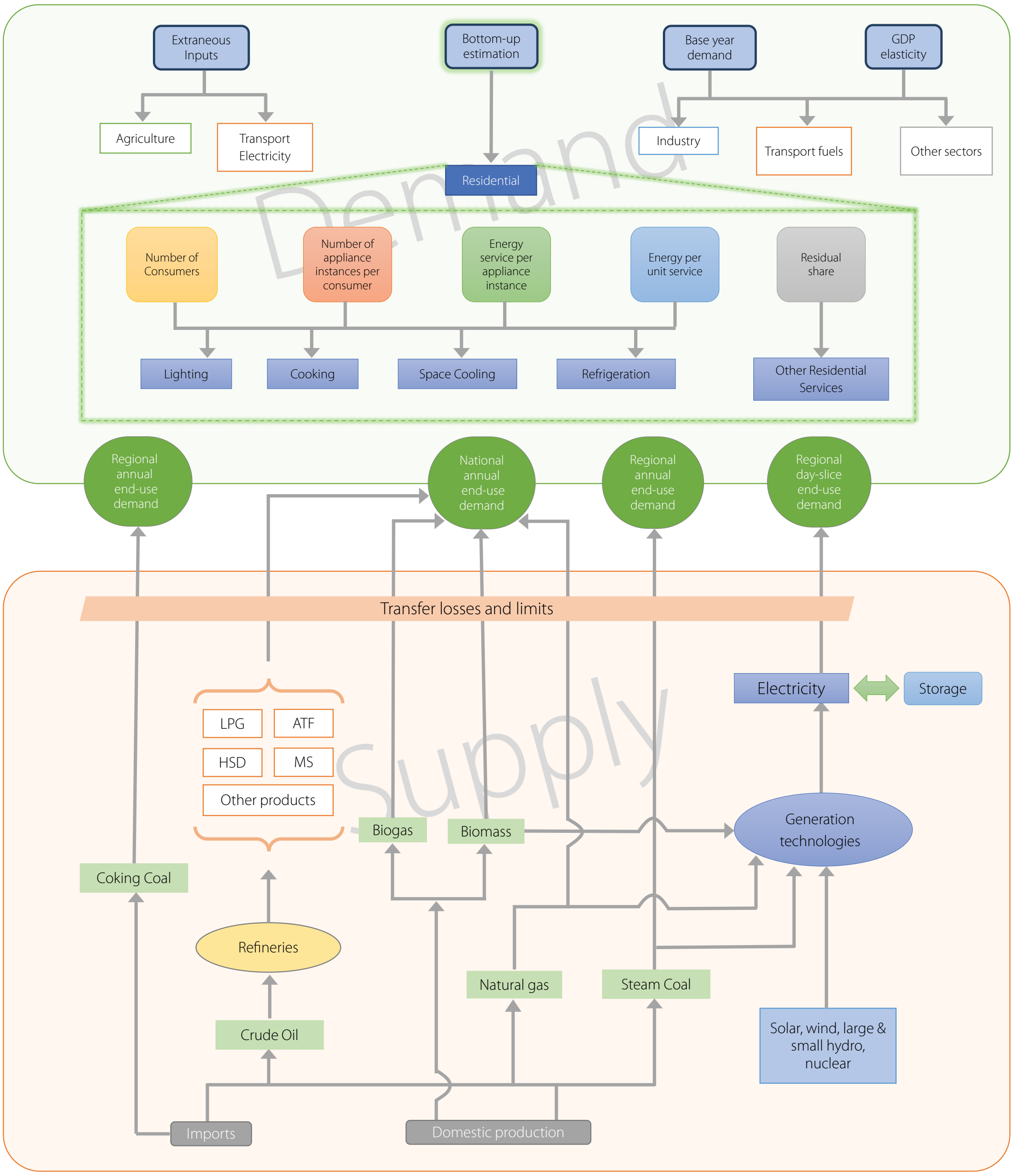
4. **Other aspects:** The currency used in PIER is Indian Rupees (INR or ₹), and all prices, costs etc. are given in constant 2019 rupees.

4. Given its sparing use, biogas is modelled as a primary carrier in this version of PIER for simplicity.

5. Electricity demand is modelled at the state level and aggregated up to the regional level.

Further details about these and other basic elements of PIER can be found in Annexure A1.

Figure 3: Reference energy system diagram for the PIER model



The next two sections present the details of the demand and supply models of PIER respectively. The specific inputs and assumptions mentioned in these sections apply to the Reference scenario. They are also applicable to all other modelled scenarios unless mentioned as over-ridden in the scenario (Section 6 and Annexure A5).

4 The PIER demand model

Energy demand has been modelled through five demand sectors in PIER. These are Residential, Industry, Transport, Agriculture and "Others", where the Others sector represents all the other sources of energy demand (such as offices, commercial establishments, and public services such as street lighting, water supply etc.). For each of these sectors, demand is specified for various energy services and energy carriers relevant to that sector. The methodology and approach used to model the various sectors is presented in this section. The Residential sector is modelled in a more detailed bottom-up manner, and hence is described in a section of its own. The other sectors are modelled more coarsely, and are covered together in one section. Further details about the assumptions and methodology used to build the PIER demand model are described in Annexures A2 and A3.

4.1 Residential demand

Energy demand from the residential sector is modelled in a bottom-up fashion. For this, a set of energy services, the demand for those services, and the energy efficiency of those services have to be specified. A 'residential consumer' is a household and is the smallest unit for which demand is specified. The following schematic equation represents how the energy demand (in a particular geographic / time-unit and for a consumer type) for an energy service from a technology[6] of a particular efficiency is calculated:

$$ED = NumCons \times TechInstPerCons \times ESPerTechInst \times EnergyPerES$$

where,

ED is the total energy demand for the chosen service from a technology (of a particular efficiency) in the time and geographic unit of interest for a particular consumer type

NumCons is the number of consumers (households) of the consumer type who demand the energy service from the technology at that efficiency level, in that geographic / time unit

TechInstPerCons is the number of instances of the particular technology providing the energy service used by a household of the consumer type

ESPerTechInst is the energy service required per instance of the technology in that geographic / time unit and

EnergyPerES is the energy required to provide one unit of energy service using this technology

For example, the energy demanded from fans of a particular efficiency in a particular day-slice in a particular area for a particular consumer type would be the product of the number of households of that consumer type, the average number of fans being used by a consumer of that type, the average number of hours of fan usage by that consumer type in that day-slice and area, and the quantity of electricity used by a fan per hour of usage.

In the rest of this section, we describe the methodology used to model each of these items. Further details are available in Annexure A2.

6. Energy service technologies in the residential sector are nothing but appliances that provide energy services.

Types and number of residential consumers (households)

An important aspect of determining energy demand from the residential sector is modelling the diversity of different types of households and their energy consumption patterns. Rumi allows a two-tier specification of consumer types for each demand sector. Using this, for each state two broad types of households, namely urban and rural, are defined. Each of these broad categories is further sub-divided into five quintiles, each representing a particular economic class, approximated by the Monthly Per-Capita Expenditure (MPCE) of that class. Each quintile (in a state and urban-rural geography) has an equal number of households. Effectively, this partitions households in India into 250 different kinds of representative consumers across the 25 states, urban-rural categories and quintiles. The number of households in a quintile is estimated based on state-wise urban-rural projections of population and household size, details of which are available in Annexure A2.1.

Energy services and energy service technologies

Four types of energy services are modelled in the residential sector, namely, lighting, cooking, space cooling and refrigeration. These four services together typically contribute to the bulk of the energy consumption in a household. Other services, which have not been explicitly modelled include entertainment (television, radio etc.), water and space heating, effort saving appliances (washing machines, mixers etc.), electronic devices (mobile phones, laptops etc.) and so on. All such unmodelled energy services have been clubbed together into one energy service called "Other residential services", all of which are assumed to be provided by electricity[7]. These have been modelled as a residual energy service, that is, the electricity demand for this service is specified as a percentage of the electricity demand discovered from the four explicitly modelled energy services. The residual share of "other services" as a percentage of the modelled services was estimated for each state separately by extrapolating the state's total annual electricity demand based on historical data published in the CEA General Review to FY21, and comparing it to the bottom-up electricity demand estimated by the model for FY21[8]. Please refer to Annexure A2.2 for details regarding the residual share calculation.

Each modelled energy service is provided by a set of service technologies, each of which could have various efficiency levels. For example, lighting is provided by the "lighting appliance technology" which has three different efficiency levels corresponding to incandescent bulbs, CFLs and LEDs. Space cooling is provided by three technologies (fans, coolers and ACs), where fans and coolers are modelled to have just one efficiency level each, while ACs are modelled to have three efficiency levels (3-star, 4-star and 5-star ACs). Refrigeration is provided by a single refrigerator technology[9] with three efficiency levels. Cooking is provided by five different technologies each of which has one efficiency level, namely biomass stoves, LPG stoves, PNG stoves, electric induction stoves and biogas stoves. The various energy service technologies modelled, and their efficiencies are detailed in Annexure A2.3.

Modelling energy service demand

For each of the modelled energy services, the amount of service demanded by a consumer type from each energy service technology is provided for each time unit. Rumi allows this

7. Thus, this does not model the use of, say, water and space heating through means such as biomass, LPG or solar due to lack of data. However, it is expected that energy usage through such means is not very large and hence the results of the current modelling exercise are likely to be robust.

8. As a result, the share of "other services" remains the same in all day-slices of all seasons and years for a state.

9. Direct-cool refrigerators in the current model

to be provided for each combination of technologies providing the same service, thus supporting the modelling of 'stacking' of multiple technologies providing the same energy service. Consider the space cooling energy service for example. In PIER, it is assumed that, while no household uses both coolers and ACs, every household that uses ACs and coolers also uses fans. So, for a consumer type in some time unit, cooling demand from fans has to be specified as three values: a) the number of fan cooling hours if the household has no coolers or ACs, b) the number of fan cooling hours if the household also has coolers and c) the number of fan cooling hours if the household also has ACs. In addition, the number of cooling hours required from a cooler and the number of cooling degree hours (cdh) required from an AC are also specified (as per the assumption above, these would always be for a household with fans). The amount of energy service required is calculated as follows for each of the relevant energy services:

1. **Lighting:** This is simply modelled as the numbers of hours of lighting required in each day-slice of each season. Thus, lighting service demand is non-zero in the evening and night hours, and in the early morning hours of monsoon and winter.
2. **Cooking:** The energy service demand is modelled as the useful heating energy required by a household, based on the normative assumption of 2.2 MJ / capita / day (van Ruijven *et al.*, 2011). For all the cooking technologies other than induction cooking, the per-household demand is just aggregated to the annual level. For induction cooking using electricity, demand has to be modelled at a day-slice level. Hence, it is specified as equivalent to one hour of cooking each in the morning and evening.
3. **Space cooling:** Space cooling demand is modelled as cooling hours (ch) for fans and coolers, and cooling degree hours (cdh) for ACs, where ch just represents the number of hours a fan or cooler has to run, while cdh also incorporates the extent of cooling required. These are calculated as a function of ambient temperature and a 'trigger temperature' at which a particular cooling appliance is turned on. Trigger temperatures for coolers and ACs[10] vary between 30 °C and 35 °C (depending on the household type's MPCE), while for fans the range is between 26 °C and 28 °C (depending on the household type's MPCE and humidity of the location). Higher MPCEs map to a lower trigger temperature for all appliances, and higher humidity maps to a lower trigger temperature for fans where relative humidity is crudely approximated based on the state in which the household is located. Using these, ch and cdh are estimated for each space cooling technology for each day-slice for each consumer type. However, this results in most ch and cdh being during the middle of the day when temperatures are highest, though houses tend to be less occupied at these times. To adjust for this and simulate the actual behaviour of space cooling appliances being more used when people 'return to a heated house', the ch and cdh estimated for the day-time slices are partially shifted to the evening and night. Further details of temperature projections and other aspects are described in Annexure A2.4.
4. **Refrigeration:** Energy service demand for refrigeration is just the number of hours the refrigerator runs. Since refrigerators are supposed to be on all the time, for every day-slice, this simply translates to the number of hours in that day-slice.

10. For ACs, a reference (or set-point) temperature of 24°C is also assumed. This is the 'target' temperature to be reached once the AC is turned on, and is used to estimate the cooling degree hours (cdh) demanded.

Estimating the number of households using a particular energy service technology

PIER assumes that the major determinants of the likelihood of a household owning and using a certain appliance (energy service technology) are

- The state in which the household exists
- Whether the household is an urban household or rural household
- Monthly Per-Capita Expenditure (as a proxy for income)
- Is the household electrified[11]?

The last nationally available data representative at state and urban-rural level for all these parameters, is the 68th major round consumer expenditure survey conducted by the NSSO in 2011-12. A logistic regression on the 2011-12 NSSO survey data is used to derive the probability of ownership and use[12] of a particular appliance as a function of these parameters. This relationship is first refined to account for some disruptions such as the PMUY programme, and then used to estimate future probabilities of ownership and use of technologies, based on future projections of MPCEs. These probabilities are interpreted as the penetration of that technology in that household type in that year. The results of this exercise for each state and at the national level for FY31 are shown in Table 1 and Table 2. Further details of the regression equation, projections of future MPCEs and some refinements that are required to this process are explained in Annexures A2.5 and A2.6.

Table 1: State-Urban/Rural Penetrations for select energy service technologies in FY31 (values in %)

State	Cooking				Cooling						Refrigeration	
	Biomass		LPG		AC		Cooler		Fan			
	RURAL	URBAN	RURAL	URBAN	RURAL	URBAN	RURAL	URBAN	RURAL	URBAN	RURAL	URBAN
AP	0.0	0.3	97.0	89.4	17.7	36.0	18.1	28.7	99.1	99.7	42.2	76.7
AS	21.6	3.6	76.6	89.7	1.4	9.1	0.5	2.4	91.6	97.8	23.8	67.8
BR	50.5	3.3	48.1	95.4	0.8	3.9	1.9	6.0	87.2	95.4	8.4	31.5
CG	68.5	11.0	31.1	88.0	5.0	21.2	15.8	33.2	82.4	94.7	9.7	43.4
DL	0.0	0.8	97.5	55.5	47.6	65.7	31.2	16.6	99.6	99.8	81.5	87.2
GA	7.0	0.0	90.7	83.0	8.0	20.4	6.3	10.0	98.7	99.5	80.8	94.1
GJ	24.8	2.9	71.5	62.1	2.7	14.1	2.2	6.4	95.7	98.9	37.5	79.6
HP	35.2	1.9	63.4	94.0	4.5	24.4	4.6	16.8	78.8	94.5	64.1	92.7
HR	22.2	1.2	76.9	83.0	45.1	71.8	22.5	18.4	99.5	99.9	75.9	95.1
JH	73.7	19.5	26.2	80.1	1.4	13.1	3.5	11.8	80.6	94.9	11.4	51.0
JK	21.6	0.0	78.4	98.0	10.0	31.6	21.5	29.1	82.6	93.8	43.9	77.7
MH	1.5	0.0	96.0	90.3	4.0	18.7	3.0	9.1	91.8	97.1	41.7	74.2
KL	33.3	23.8	64.0	69.3	6.7	18.9	2.1	2.3	96.2	98.6	64.6	87.4
MH	11.2	0.5	85.0	81.9	5.5	24.8	10.6	24.6	92.7	98.2	30.6	74.7
MP	52.6	1.2	46.0	90.9	11.9	31.7	19.3	30.0	88.2	96.4	19.4	54.2
NE	44.7	7.6	55.0	84.0	0.8	4.1	0.2	0.5	64.1	86.2	21.9	60.0
OD	68.2	9.0	31.6	90.3	4.6	29.5	7.3	18.1	90.4	97.9	15.7	63.1
PB	4.7	1.3	88.4	83.5	30.2	46.9	33.9	32.7	99.2	99.6	86.0	94.9
RJ	48.8	0.0	50.8	94.8	15.3	36.2	28.1	38.2	93.2	98.1	34.5	73.3
TN	1.4	0.1	95.5	94.3	3.9	11.8	3.1	5.9	95.7	98.4	30.8	60.8
TS	0.0	0.0	97.0	89.6	11.5	28.8	11.8	22.9	98.4	99.5	26.8	64.0
UK	28.0	0.4	71.7	97.7	9.3	29.3	11.0	17.2	78.6	91.8	43.4	76.1
UP	52.7	2.1	46.9	83.2	8.9	28.9	12.7	25.2	90.7	97.2	20.5	59.3
UT	0.0	0.2	97.5	55.9	21.4	31.7	8.5	14.9	97.3	98.8	63.1	81.4
WB	70.1	11.6	29.7	86.2	1.1	9.6	0.8	4.2	87.1	96.9	11.0	51.8

11. Even though all households are considered electrified during the model period, we explicitly model this as a driver, as the data-set used to derive the relationship between the drivers and probability of a household owning and using an appliance is from a period when many households were not electrified, and hence would have been a factor in the household owning / using some appliances.
12. The consumer expenditure survey provides ownership information which is assumed to be a proxy for use.

Table 2: National - Urban/Rural Penetrations

Energy service	Service Technology	Rural		Urban	
		2021	2031	2021	2031
Cooking	Biogas	0.8%	0.6%	0.4%	0.4%
	Biomass	53.6%	38.5%	9.3%	4.0%
	Electric	0.2%	1.0%	0.5%	2.8%
	LPG	45.4%	60.0%	85.1%	83.1%
	PNG	0.0%	0.03%	4.7%	9.6%
Cooling	AC	1.4%	7.9%	8.8%	25.4%
	Coolers	10.0%	10.6%	22.9%	17.0%
	Fans	86.1%	90.7%	96.5%	97.8%
Lighting		100.0%	100.0%	100.0%	100.0%
Refrigeration		16.2%	26.4%	55.8%	68.9%

Given all the above inputs – i.e. the number of households of each consumer type, the percentage of households of a consumer type owning and using an appliance or energy service technology at a particular efficiency level, the number of such appliances per household using the appliance, the energy service demanded from an appliance and the amount of energy required for the appliance at that efficiency level to provide one unit of energy service – the energy demand for each energy carrier for each energy service and consumer type can be calculated using the equation given at the start of this section. Note that, since the energy service demand for service technologies using electricity are given at a day-slice level, this automatically gives electricity load shape for the residential sector.

4.2 Non-residential demand

All the sectors other than the residential sector are modelled more coarsely than the residential sector at present. We hope to undertake detailed bottom-up modelling of these sectors too going forward. This section describes how all the other sectors have been modelled. Further details can be found in Annexure A3.

The Industry sector

Since industrial activity is likely to be well correlated with the overall economic activity, industrial sector energy demand has been modelled based on elasticity to national GDP. Currently, the entire sector is treated monolithically and not split into further industry types. Industry depends on various energy carriers such as electricity, coal (both steam and coking), diesel, biomass and other petroleum products such as furnace oil and LSHS. In order to capture long-term trends without being distracted by short-term variations, elasticity was estimated over a period of about 5 to 7 years[13].

For all energy carriers other than coal and electricity, GDP-elasticity of that carrier's demand was estimated at a national and annual level, based on time-series data published by various government agencies, such as the Petroleum Statistics published by the Ministry of Petroleum and Natural Gas (MoPNG). This elasticity was gradually reduced over the years for some carriers to reflect the effect of three factors: a) growing efficiency of industrial processes, b) increasing

13. One energy carrier for which robust data is not available is biomass. For this, the energy balance published by IEA was used, though these are also only estimates based on assumptions.

electrification of some processes leading to reduced use of other fuels and c) temper some unrealistically high elasticities.

For steam coal and coking coal too, a similar approach was used – except that the elasticity was applied to demand at a regional rather than national level and kept constant over the years. For this, regional historical coal consumption data by industry was sourced from the Coal Directory published by the Coal Controllers' Organization (CCO).

For electricity, industrial consumption data from both utility and captive generation (for LT and HT industry) was taken from the "All India Electricity Statistics – General Review" published by the Central Electricity Authority (CEA), and used to compute GDP elasticity of annual industrial demand. This elasticity was adjusted over the years to roughly account for increasing efficiencies (reducing elasticity) and increasing electrification (increasing elasticity). One challenge with modelling electricity demand is to translate the annual demand to a 'load shape', since electricity is modelled at a day-slice level. Unfortunately, there is no publicly available data regarding recent sectoral load shapes. Hence, relatively scanty information available from a set of consultancy reports commissioned by Energy Efficiency Services Ltd. to estimate sectoral load shapes for a set of six distribution utilities, has been used to approximate industrial load shapes (Prayas (Energy Group), 2016). However, this is an area that needs further research which can help improve the model.

The Transport sector

The energy carriers predominantly used in the transport sector are the two fuels used for road transport, namely MS and HSD. In addition, there is also usage of natural gas (in the form of CNG), ATF for aviation, and small quantities of LPG and electricity – with the latter predominantly being used for railway traction currently but expected to gain prominence in road transport in the near future.

The demand for the traditional petroleum-based transport fuels (MS, HSD and ATF) are modelled in PIER using a national GDP-elasticity approach, as mobility is likely to be well correlated to economic activity. Historical data for consumption of these fuels for transport are obtained from the Petroleum Statistics published by MoPNG[14]. However, the elasticities of both MS and HSD are reduced over time to account not only for increasing efficiencies of the transport fleet but also to reflect increased electrification of road transport (and rail transport in case of HSD). Similarly, the transport sector demand for natural gas (CNG) and the small usage of LPG are estimated based on historical GDP-elasticity.

Future growth in transport demand for electricity comes from two sources: railway traction as Indian Railways electrifies its routes, and increased penetration of electric vehicles in road transport. Historical precedent is not a predictor for future electricity demand for road transport in particular and transport in general, due to the rapid changes taking place. Hence, rather than a GDP-elasticity approach, electricity demand for transport is specified extraneously. Electricity demand for traction is estimated based on historical growth rate of electricity consumption in railways which is continued up to the target year announced by the Railways for full electrification (Ministry of Railways, 2021). After which the growth rate of electricity demand for traction declines. For road transport, the estimate is based on literature

14. All of MS and ATF are used only in the transport sector. However, HSD is used in multiple sectors and Petroleum Statistics does not give a sectoral breakdown of the usage of retail-sale HSD. Hence, the share of HSD used in transport is derived from an earlier study commissioned by the Petroleum Planning and Analysis Cell (Neilsen-PPAC, 2013).

that estimates future demand for electricity from electric vehicles (Abhyankar *et al.*, 2017; NITI Aayog-RMI, 2017; Ali, Mohd. Sahil and Tongia, Rahul, 2018; ASSOCHAM-EY, 2018; IEA, 2019, 2020). Based on these, road transport demand for electricity is assumed to be 60 TWh in FY30, which is used to interpolate demand for other years. Estimating the electricity load shape for the transport sector too is a challenge, and is based on some assumptions about vehicle charging and railway schedules.

To conclude, transport demand for electricity is specified extraneously while the demand for transport fuels is specified through GDP-elasticity.

The Agriculture sector

The agriculture sector's economic output (and hence energy input) do not seem to be correlated with national GDP. A good example is the pandemic year (FY21) when the overall GDP shrank by 7.3% but the sectoral GDP of agriculture grew by 3.4% (presumably with increased energy consumption, though this data is not yet available). Therefore, energy demand for the agriculture sector is estimated based on past trends for all energy carriers and provided extraneously in PIER.[15] Past demand data for these carriers is available from the CEA General Review and Petroleum Statistics[16] respectively. While demand for HSD, LPG and other petroleum products are modelled at the national and annual level, demand for electricity is modelled at the state and day-slice level. In order to account for increased use of electric pumping, the growth rate of HSD usage in agriculture is tempered in future years.

Past state-wise trends of electricity consumption for agriculture are used to project likely future values. Where possible and available, these have been cross-checked with regulatory orders of the respective states. Estimating the electricity load shape for agriculture has the same challenge as that of industry and transport sectors, and hence a rough estimate is made as discussed above. This load shape is modified over the years to factor in the effect of government policies to increase the role of solar energy in agriculture through schemes such as KUSUM (MNRE, 2019). As a result, the agriculture load shape increasingly shifts towards the day time over the model duration.

The "Others" sector

As mentioned earlier, this sector represents the demand from other sources that consume energy which have not been modelled explicitly and includes, inter alia, consumption in offices, commercial establishments, and for public services such as street lighting and water supply. The demand for this sector is modelled based on GDP-elasticity at a national and annual level for LPG, HSD, other petroleum products and biomass, and at a state and day-slice level for electricity, with the electricity load shape being assumed to be predominantly between 6 AM and 10 PM.

The elasticities used in PIER and the extraneous transport demand estimated are presented in Annexure A3.

15. Some unrealistically high or low past trends were tempered.

16. HSD consumption for agriculture is estimated using an approach similar to that of its use in industry.

5 The PIER supply model

The supply model of PIER consists of the following inputs:

- costs of domestic and imported variants of primary energy carriers
- details of energy conversion technologies used to produce derived carriers such as their costs, efficiencies, and pre-existing 'legacy' capacities
- details of energy storage technologies including their costs, efficiencies etc. and
- costs and losses of transferring energy across regions

We describe these elements in this section and more details are available in Annexure A4.

5.1 Energy carrier details

The physical primary energy c arriers modelled in PIER are steam coal, coking coal, crude, natural gas, biomass, and biogas, while the derived carriers are electricity, MS, HSD, LPG, ATF, and other petroleum products (PP_OTHER representing Furnace Oil, LSHS, Kerosene, LDO etc.).

Though India produces both coking and steam coal, almost all of the 'coking coal' produced is in the lowest calorific value bands and predominantly used for power generation. Therefore, we make a deliberate choice to model all Indian coal as steam coal[17], and hence available for electricity generation and other steam coal uses, while all coking coal used for the steel industry is assumed to be imported.

For all the primary energy carriers, the limits on domestic (i.e. within India) production of the carrier in future years has been defined by past production trends[18]. In case of steam coal, these limits are defined by region. Imports are permitted for the two kinds of coal, crude and natural gas. The two kinds of coal (which are balanced at a regional level) can be imported only into the Eastern, Southern or Western regions as only they have seaports. Limits on imports are defined roughly based on past trends and estimates of approximate demand in future years.

The prices of the various energy carriers are determined as follows.

- **Steam coal:** The domestic price for the initial year is determined based on weighted average of the notified price as issued by CIL, escalated at 1% a year[19] in accordance with historic trends and CERC regulations. Imported steam coal price for the initial year is estimated as the ratio of the total value of steam coal imports and quantity of steam coal imports, as published in the Coal Directory. This is escalated annually based on the growth rates derived from the World Bank Commodities Price index (World Bank Group, 2020).
- **Coking coal:** Only imported prices are relevant for coking coal, and its prices are derived similar to imported steam coal.

17. This includes lignite or brown coal.
18. Since natural gas is also significantly used for non-energy purposes, 36% of its production is set aside for non-energy use.
19. All prices and escalation (or reduction) rates are in real (2019 ₹) terms

- **Crude oil:** Imported crude price for the initial year is taken from the price reported for the Indian basket of crude imports as reported in the Petroleum Statistics, while domestic price is taken to be 90% of that value to approximately account for the difference between loading price and landing price. For future years, these prices are escalated at growth rates derived from the World Bank Commodities Price index (World Bank Group, 2020).
- **Natural gas:** Domestic price for the initial year is based on the average of the various domestic natural gas prices reported in the Petroleum Statistics, while imported price is calculated based on the value and quantity of LNG that was imported. For future years, the domestic price is escalated as per the rate given in CERC regulations while imported price is escalated at growth rates derived from the World Bank Commodities Price index (World Bank Group, 2020).

For some carriers such as biomass and biogas, prices and quantities are harder to come by, and are crudely estimated based on literature and other sources. Taxes to be levied on domestic and imported primary energy carriers, as well as on derived energy carriers, are inferred based on the current taxation regime, and kept constant through the model period. Further details on production, import, prices and taxes of energy carriers are given in Annexure A4.1.

5.2 Energy conversion technologies

In PIER, two types of energy conversion technologies are modelled: electricity generation technologies and refineries to produce petroleum products. These are described in this section. More details are available in Annexure A4.2.

Electricity generation technologies

Nine different electricity generation technologies have been modelled, namely coal-based generation, open cycle gas turbine (OCGT), combined cycle gas turbine (CCGT), biomass-based generation, large hydro, nuclear (pressurized heavy water reactor), small hydro, solar PV and onshore wind. Since the horizon of the model is only FY31, some technologies such as solar thermal, or offshore wind are not modelled, as it was felt that they would not play a significant role by then. All coal-based generation is treated as one, without separate treatment of sub-critical and super-critical technologies[20]. Note that PIER models the entire country's energy system and hence does not distinguish between utility capacity and captive capacity[21]. The current model also does not distinguish between centralized, grid-connected capacity and decentralized near-the-load capacity. For each of these technologies, the following inputs are provided:

1. **Pre-existing capacity:** The existing (legacy) state-wise capacity of each technology is obtained from CEA's publications. This forms a total of about 430 GW of electricity generation capacity in the country[22]. Recent regulatory orders have been used as far as possible to arrive at annualized fixed costs of this capacity. The retirement schedule for this capacity is inferred based on an assumed age of plants and CEA's retirement schedule. Other aspects such as self-consumption and conversion efficiency (heat rate) are obtained from regulatory orders and documents.

20. All future capacity addition is assumed to be super-critical and the assumptions reflect this.

21. Data related to captive capacity is not always easily available. In such cases, some pro-rata assumptions have been made regarding such capacity.

22. Note that this includes captive capacity.

2. **Must-add capacity:** The minimum amount of capacity from a technology that must be added in each model year in each region captures information about the capacity that is already in the construction pipeline and is expected to be commissioned. This information is obtained from various CEA reports such as the broad monitoring status reports and hydro review reports, and publications from agencies such as MNRE and NPCIL. Some adjustment for slippages due to the COVID-19 pandemic are made. About 41 GW of coal, 39 GW of solar, 12 GW of hydro, 11 GW of wind and 5 GW of nuclear capacity is considered as the must-add capacity.
3. **Maximum capacity addition:** This parameter specifies the maximum amount of capacity of a technology that may be added in any year in a particular region. For the initial years[23] of the model, this is equal to the capacity that must be installed due to the construction pipeline. For later years, the value is based on practical feasibility, historical precedent and national ambitions. In the latter years, it is 20 GW per year for coal, 30 GW per year for solar and 14 GW per year for wind.
4. **Fixed costs:** Fixed costs of installing new capacity of a technology are specified as levelized and annualized costs in PIER. These costs are arrived at from regulatory documents and literature. For the three most important technologies, the overnight capital cost assumptions are 8.75 crore (cr) ₹ / MW for coal (including 0.75 cr ₹ / MW for installation of pollution control equipment), 4 cr ₹ / MW for solar (decreasing at 2% a year in real 2019 prices) and 7 cr ₹ / MW for wind (decreasing at 1% a year in real 2019 prices).
5. **Efficiency, self-consumption and de-rating:** The conversion efficiency (heat-rate) and self-consumption of new capacity of any technology that gets added is based on regulatory standards for the technology where available. Though Rumi allows installed capacity of any technology to be 'de-rated' over time, no capacity is de-rated in the current model.
6. **Maximum capacity utilization factor (CUF):** Two kinds of maximum CUF inputs are provided for each installation year and geographic unit (region): one is the maximum CUF for every day-slice and the second is the annual limit on CUF for the technology to simulate down-time for maintenance etc. The former is relevant for intermittent technologies whose CUF varies by time and location. The latter is more relevant for conventional technologies which have limits over a longer time period, but can run fully in any given time-slot. Note that these values are given for the entire capacity installed in a year and region since Rumi does not model individual plants or units. The values are based on regulatory norms, literature and likely technological trends. Average annual CUF of new installations of solar capacity go from 21% in FY21 to 26% in FY31, and for wind capacity, it goes from 28% in FY21 to 34% in FY31. These CUF values are conservative assumptions compared to wind and solar tariff orders issued in recent years in some states (TNERC, 2018, 2019; KERC, 2019b, 2019a; MERC, 2019).
7. **Ramp rates:** Some technologies, particularly coal and nuclear, cannot 'ramp up' and 'ramp down' their generation rapidly especially if they need to start up, which affects their ability to meet demand at any particular time even if they are available. Fleet

23. "Initial years" depends on the technology and its gestation period. It is 1-2 years for solar, 2-3 years for wind, 4-5 years for coal and gas, 7-8 years for large hydro and longer than the model period for nuclear which has a gestation period of well over ten years.

ramp rates for various technologies are provided in PIER based on generally accepted norms for the technology. Thus, technologies such as hydro and OCGT are assumed to ramp up and down at 100% of installed capacity every hour, while coal can only ramp at 10% an hour and nuclear at only 1% an hour.

The exact inputs used for each technology for each of these parameters are presented in a series of tables in Annexure A4.2.

Refining technologies

Since each energy conversion technology in Rumi works on one input carrier and produces one output carrier, refineries for each of the five modelled petroleum products are modelled as separate technologies in PIER. Moreover, since Rumi currently does not support trade (import-export) of derived carriers, refinery capacity is modelled to meet domestic demand[24]. This does not have any significant impact on the model outputs, since petroleum product pricing is based on import parity and India imports most of its crude requirement. Since petroleum products are modelled at the national and annual level, inputs are required only at that granularity. The approach to modelling refining technologies are given below.

1. **Legacy capacity:** Legacy refinery capacity for each of the five refinery technologies is modelled roughly as the crude throughput capacity required to meet the demand in the year just before the model period (FY 20). This translates to just under 200 million tonne-per-annum (MTPA) of refining capacity at model start. No existing refinery is assumed to retire during the model period.
2. **Must-add capacity:** The refining capacity in the construction pipeline is modelled as the minimum capacity that must be installed, and is split across the various products roughly in proportion to the shares of the products in total demand. This is about 58 MTPA of capacity to be added by FY31 for all petroleum products together[25].
3. **Maximum capacity addition:** Fresh refinery capacity addition for each product is bounded by assuming a maximum growth rate of 10% in consumption of the product.
4. **Efficiency, self-consumption and de-rating:** Refining data over the last 7-8 years as reported in the Petroleum Statistics published by MoPNG is used to arrive at values for self-consumption (refinery fuel requirement and losses) and conversion efficiency (refinery throughput). These values are approximately 8.3% (though it varies slightly across products) and 98% respectively. Refinery capacity is also not de-rated in PIER.
5. **Fixed costs:** Annualized fixed costs for refineries are estimated based on overnight capital cost of constructing a refinery published by Compass International Benchmarks (Compass International, 2018) and roughly validated against some Indian data (MoPNG, 2019a). The overnight capital cost value used is about ₹ 3,500 cr for a one MTPA refinery.
6. **Capacity utilization factor and ramp rates:** All refining technologies are assumed to be capable of running at 100% utilization, and thus have no limits on their CUF. Refineries are also assumed to be able to ramp up and ramp down as required.

24. Whereas, in reality, India is a net exporter of petroleum products.

25. This represents the must-add capacity corresponding to the petroleum products used in the energy sector

5.3 Energy storage technologies

Three kinds of energy storage technologies are modelled in PIER, all of which store electricity. These are pumped hydro storage (PHS), and two kinds of battery electricity storage system (BESS), namely 4-hour BESS and 6-hour BESS. All three types of storage have been modelled as daily-cycling storage[26] – i.e. they return to zero charge state at the end of the day. This effectively allows all days of a season to be modelled identically – since the demand pattern across all such days is identical and the supply pattern also becomes identical with this assumption. This allows for more efficient computation while simulating a real system reasonably well. An overview of the energy storage model in PIER is given below.

1. **Charging and discharging rate:** As their name suggests, the 4-hour and 6-hour BESS have been modelled to need at least 4 or 6 hours respectively to charge or discharge. PHS has been modelled as a 5-hour storage (Sivakumar, Das and Padhy, 2014; IRADe, 2020).
2. **Lifetime:** Both the BESS types have been modelled to have a lifetime of 10 years, while PHS is assumed to have a lifetime of 40 years. Both types of BESS installed in FY21 are assumed to support 3650 charging cycles (corresponding to daily charging over 10 years), and this is assumed to increase at 2% per year for BESS installations in future years. PHS is assumed to support 50,000 charging cycles irrespective of year of installation.
3. **Must-add storage capacity:** The only type of storage with any capacity in the construction pipeline is PHS. As per CEA, there is about 7.9 GWh (about 1.6 GW) of PHS under construction, and this capacity is modelled to be commissioned between FY24 and FY26.
4. **Maximum storage capacity addition:** For PHS, given its long gestation period and other construction challenges similar to large hydro, up to FY26 only the capacity in the pipeline may be commissioned. After that, the maximum capacity that can be added is limited to 2.5 GWh (500 MW) per year. For BESS, it is assumed that capacity addition cannot begin before FY24. In FY24, a maximum of just 100 MW (i.e. 400 MWh and 600 MWh respectively of the two types of BESS) of each type of BESS may be added. This limit is rapidly increased to 12.5 GW (50 GWh and 75 GWh respectively) of each type of BESS by FY31, consistent with the expected rapid decline in BESS costs (BNEF, 2020; Deorah *et al.*, 2020). This translates to roughly doubling the amount of permitted BESS capacity addition each year from FY24. This capacity is distributed across the states based on relative shares of currently installed solar capacity.
5. **Cost assumptions:** As with energy conversion technologies, costs of storage are given as an annualized fixed cost of storage. For BESS, the battery pack price projections in (BNEF, 2020) and the moderate range of the balance-of-system cost estimates in the latest Annual Technology Baseline (NREL, 2021) are used to estimate total overnight system costs. These amount to about 201 USD/kWh and 180 USD/kWh in FY21 for 4- and 6-hour BESS respectively, going down to about 111 USD/kWh and 95 USD/kWh in FY31 respectively. An annual 2% deflation of INR with respect to USD is assumed, to

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26. Rumi also allows modelling of storage recycling at coarser intervals (including 'never'), with correspondingly higher computational costs.

convert these prices to INR. For PHS, the overnight cost is assumed to be 6.5 crore ₹/MW[27] (Sivakumar, Das and Padhy, 2014; IRADe, 2020). For all types of storage, the costs are annualized assuming a certain loan repayment tenure and interest rate.

6. **Operational parameters:** Two operational parameters are of interest for storage technologies, namely the depth-of-discharge and round-trip efficiency. The depth of discharge is assumed to be 90% for all types of storage modelled, i.e. only 90% of the available storage is effectively usable. Round-trip efficiency for both types of BESS is modelled as 80% - i.e. only 80% of energy that is stored can be retrieved[28]. For PHS, this is modelled as 75% (IRADe, 2020).

7. **Legacy storage:** About 3.3 GW (about 16.5 GWh) of PHS is assumed to exist in the country (10 GWh of this is in the southern region) at the beginning of the model period, based on data from CEA. This capacity is assumed to last through the model period, i.e. none of it is retired.

5.4 Energy transfers

Transferring energy results in some transit loss as well as incurs some transit cost[29]. In addition, there may be some limits on how much energy can be transferred across or within regions in a time unit. These three attributes are captured in this part of the model for all the major energy carriers. This is most significant for coal (with a high transportation cost) and electricity (high transmission and distribution losses, and distribution cost). Indeed, it is to ensure that these attributes of coal and electricity are adequately represented that coal and electricity are balanced at a regional level in PIER[30]. Transit costs and losses are also modelled for other carriers, though they are not as significant or relevant. Energy transfers have been modelled in PIER for various energy carriers as described below.

1. **Electricity:** Modelling transit losses, costs and limits is most important for electricity.

    a. **Transit losses:** Transit losses across two distinct regions are essentially transmission losses, and have been modelled as 3.3% based on data published by India's power system operator POSOCO[31]. Transit loss within a region corresponds to distribution losses. State-wise T&D loss data published in CEA's General Review for the last 14 years (2006 to 2019) has been used to project future state-wise T&D losses[32]. Using these T&D loss figures, purely intra-regional distribution losses are estimated for each year as explained in Annexure A4.3. This results in, for example, 19% losses in FY21 and 15% losses in FY31 for the northern region, and 27% losses in FY21 and 20% losses in FY31 for the north-eastern region.

27. This translates to about USD 183/kWh in FY21, and USD 147/kWh in FY31 at the prevailing exchange rates.

28. In other words, to store 1 kWh, one needs to supply 1.25 kWh.

29. Note that the loss and cost are incurred both for transfers across geographic units as well as for transfers within a geographic unit.

30. Electricity could have been balanced at an even finer grain of a state since much of the data is available at that granularity. However, this would have increased the computational complexity of the model significantly. Further, there are indications that the electricity system is likely to move towards larger balancing areas. Hence it is modelled at a regional level.

31. https://posoco.in/side-menu-pages/applicable-transmission-losses/

32. A couple of other constraints are added to ensure that these projections are realistic: no state's T&D loss falls below 12% and the approximate weighted average T&D loss for the country does not fall below 15%.

b. **Transit cost:** Based on data regarding national transmission costs paid by designated consumers using the inter-state transmission grid and short-term open access consumers[33], a value of 0.40 ₹/kWh is assumed for inter-regional transit cost. This is assumed to escalate at 0.01 ₹/kWh over the years. Intra-regional distribution costs are harder to assess. Regulatory orders for nine major states (Andhra Pradesh, Bihar, Chhattisgarh, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh) for a few years were consulted. Their distribution costs over the past few years were used to project distribution costs for future years and used as the basis to estimate costs for all states and hence, all regions.

c. **Transit limits:** We have attempted to model inter-regional transmission constraints in PIER. For simplicity, we assume no transmission or distribution limits within a region. Data for inter-regional transmission capacity is not easily available. Inter-regional transmission capacity in FY21 across all regions is about 105 GW, as published in CEA's monthly executive summary report for March 2021. Inter-regional transmission capacity of 139 GW across all regions for 2030 as published in (Spencer *et al.*, 2020) was used for FY31[34]. Given these values for FY21 and FY31, annual transmission capacity across each pair of regions for intermediate years is inferred.

Further details of parameters related to electricity transfer are available in Annexure A4.3.

2. **Coal:** CERC regulations regarding permitted transit loss of coal for pit-head plants (0.20%) and non-pit-head plants (0.80%) are used to define coal transit losses for intra-regional and inter-regional transfers respectively. Transit costs are the most important aspect of modelling coal transit, and have been modelled as the railway coal freight tariff for approximate distances within and across regions. These costs are not assumed to vary over the model period. Exact values used are given in Annexure A4.3. Given the rail and road network in the country, no transit limits are assumed.

3. **Crude and petroleum products:** Since these carriers are modelled at the national level, only intra-regional losses, costs and limits need to be given. PNGRB regulations on common carrier / access define 0.015% as the permitted pipeline loss for petroleum products. This value is used across years as the transit loss for both crude and petroleum products. The price break-up for some petroleum products (MS, HSD and ATF), as published by the Oil Marketing Companies, give a freight cost. This is used to approximate the transit cost of crude and petroleum products – which comes to about 650 ₹/tonne. No limits are assumed on transport of crude and petroleum products in the country as they can be transported through pipelines, rail and road.

4. **Natural gas:** According to data published in the Petroleum Statistics, the natural gas pipeline system consumes about 0.9% of natural gas. This value is used as the transit loss for natural gas. While pipeline tariff of natural gas is available from PNGRB regulations, it is not easy to get the cost of distributing natural gas. Based on one sample piped natural

33. https://posoco.in/transmission-pricing/notification-of-transmission-charges-for-the-dics/

34. A power factor of 0.95 was used to convert MVA to MW.

gas bill published by Indraprastha Gas Limited[35], a value of 9 ₹/cu m is used. Since natural gas is mostly transported through pipelines, information from PNGRB regarding pipeline authorization is used to estimate current and future natural gas pipeline capacity in the country[36]. This translates to natural gas transit capacity for energy ranging from about 80 bcm in FY21 to about 134 bcm in FY31.

35. https://www.iglonline.net//know_your_bill_revised.jpg, accessed June 2021

36. See https://pngrb.gov.in/eng-web/ngpl-auth.html (accessed August 2021). Since the pipelines would also be used to transport gas for non-energy purposes, the energy share of gas usage (64%) is used on a pro-rata basis to estimate gas pipeline capacity available for energy use.

6 Scenarios and sensitivity analyses

Three scenarios are modelled in PIER. One is the Reference scenario, which represents the 'most likely' future of India's energy sector from FY21 to FY31, and the other two represent other possibilities of recovery from COVID-19. In addition, we have undertaken a few sensitivity analyses, in which a few key parameters of the Reference scenario were changed to examine their impact on the model results.

6.1 Scenarios

The Reference scenario indicates a future in which there are no significant departures from the past regarding the country's economy, demographics and energy policy, and India's recovery from the COVID-19 pandemic is roughly as predicted by many analysts. Thus, in this scenario, GDP and household incomes grow as predicted, consumer purchase and other aspects such as behaviour patterns regarding adoption of efficiency measures and improvements in electricity T&D losses would broadly follow past trends. In addition, two other scenarios corresponding to different recovery paths from the pandemic have been modelled – one of which is an optimistic recovery path and the other a pessimistic one.

1. **Optimistic Recovery Scenario (ORS):** This scenario constructs a future that is based on a more optimistic recovery from the COVID-19 pandemic than in the Reference scenario. It is characterised by faster than predicted economic recovery from the pandemic, in particular from the impacts of the second wave. There is strong support to the economy through fiscal stimulus that increases spending and investment, requisite support is provided to the marginalized thus decreasing inequity, and measures are adopted to quickly revive growth and employment. As a result, GDP grows faster than the Reference scenario (in FY22 and FY23), and the MPCE gaps between states and across quintiles within a state decrease – leading to increased purchasing power, increased demand for products, better production capacity utilization and higher investment leading to lower unemployment. Better capital availability enables greater investments, which in turn lead to enhanced end-use efficiency and energy system efficiency. This results in changed appliance ownership and use, GDP elasticities, appliance stock efficiency, T&D loss trajectory and so on, leading to a different demand and supply mix.

2. **Pessimistic Recovery Scenario (PRS):** This scenario represents a future that is almost exactly the opposite of the ORS, in that the economic recovery is not only more sluggish in the short-term but also less equitable. There is lesser focus on supporting the marginalized, investments, job creation and improving efficiency compared to the Reference scenario.

Annexure A5.1 describes in detail all the significant changes between these scenarios and the Reference scenario.

6.2 Sensitivity analyses

In addition to constructing these three scenarios about possible future trajectories of the economy, a few sensitivity analyses were also undertaken with the specific aim of understanding the implications of changing a few critical inputs to the Reference scenario. The sensitivity exercises undertaken are:

1. **Maximum appliance efficiency:** This sensitivity analysis considers a case where, in FY31, the entire residential appliance stock in the country is at a very high efficiency. The stock efficiency is gradually improved from the model beginning until FY31 to achieve this effect. This is a totally hypothetical scenario, which is useful to understand the effect of aggressive efficiency improvement[37].

2. **Trigger and reference temperatures:** This corresponds to a pair of sensitivity analyses to test the implications of behavioural change regarding space cooling. In these runs, the 'trigger temperatures', i.e. the temperatures at which people use cooling appliances, and the reference temperature of air-conditioners, are increased or decreased by 2° C as compared to the Reference scenario.

3. **Cost-related sensitivity analyses:** Technology trajectory costs – in particular, the relative costs of renewables, fossil fuels and storage – are important assumptions made in the modelling exercise. These runs test the sensitivity of the model results to these cost inputs. Four different sensitivity analyses were made. In two of them, the costs of coal and natural gas were increased / decreased by 10% with respect to the Reference scenario while the costs of setting up solar or wind capacity were decreased / increased respectively by 10% (i.e. in the opposite direction to the change of coal and natural gas costs). In the other two sensitivity runs, the costs of BESS and PHS were increased or decreased based on upper and lower limits in literature.

4. **Investment feasibility runs:** An important determinant to how much of any technology's capacity gets added by the model depends on assumptions about how much capacity it is feasible to add in a year. Two sensitivity runs were made by changing these assumptions. In one, the assumption of high feasibility of renewable capacity addition was reduced to allow only half of what was possible in the Reference scenario. In another, the total renewable capacity addition mix was kept the same as the Reference scenario but, unlike the Reference scenario where the feasibility of solar capacity addition was much higher than wind capacity addition, it was assumed that an equal amount of solar and wind capacity could be added.

Further details of the sensitivity runs are provided in Annexure A5.2.

37. Note that, since appliance costs are not modelled in Rumi / PIER, the cost of achieving this efficiency is not factored in.

7 Interesting insights from PIER

The PIER modelling exercise throws up many results regarding India's energy demand and supply mix, disaggregated by region in some cases. One of the important objectives of any modelling exercise is to go beyond the numbers projected by the model and identify interesting insights that emerge which, in turn, can help highlight areas that need greater attention, assist policy formulation or assess the impact of policies and suggest course correction where appropriate. In this section, we present a set of such insights that emerge from the PIER exercise. Unless otherwise mentioned, the results presented below are for the Reference scenario which represents the 'most likely' future of the energy system as modelled in PIER. Detailed results are presented in Annexure A6.

7.1 Energy Access

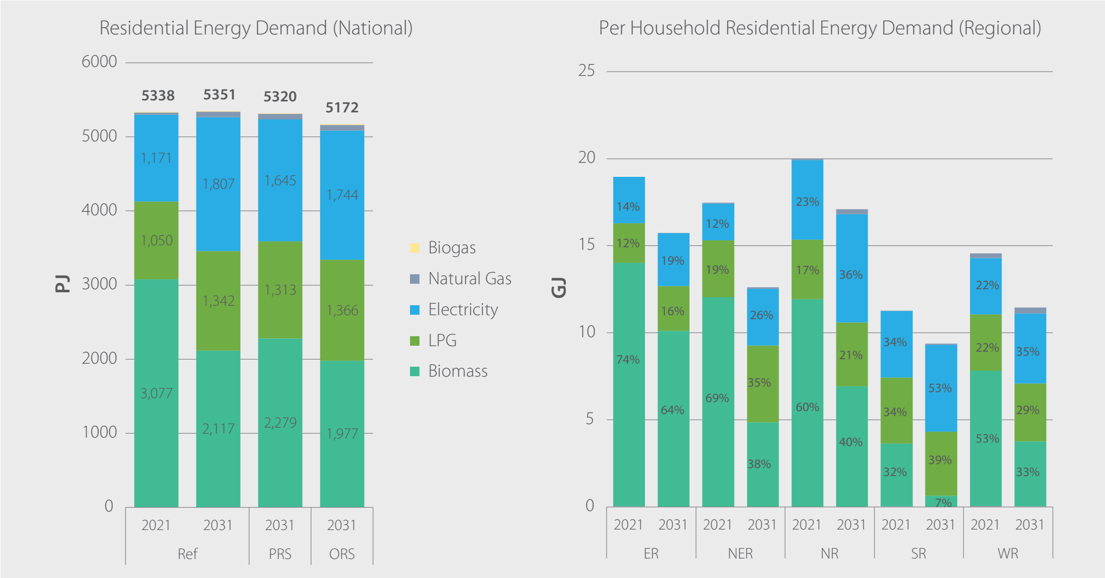
Poor energy access, affordability and reliability have been one of the serious challenges faced by India. Recent initiatives such as Saubhagya (MoP, 2019) and Ujjwala (MoPNG, 2019b) schemes have helped to significantly increase the reach of modern energy across the country. However, as the results from PIER show, this does not translate to sufficient use of modern energy forms to lead healthy and fulfilling lives. We highlight a few of these aspects below.

> Affordability and usage of modern cooking fuels continue to be quite low even in FY31, particularly in Eastern India, and calls for policy attention.

Figure 4 shows the total energy demanded by households in India in FY21 and FY31, at the national and regional level. As can be seen, even in FY31, nearly 40% of all residential energy demand is due to use of solid fuels such as biomass (2117 PJ out of 5351 PJ). Thus, though the consumption of both LPG and electricity increase between FY21 and FY31, biomass remains the single largest component of residential energy use even in FY31 despite programmes such as Ujjwala. While the situation is better in the ORS, biomass still plays a very significant role. This is an unfortunate situation, given that usage of such fuels is highly polluting and one of the leading causes of mortality and morbidity in the country. This highlights the critical need for more targeted measures to move away from traditional cooking fuels.

Further, one can also infer a regional disparity in modern cooking fuel access. In FY31, only 6.5% of residential energy demand in SR is due to biomass, suggesting that it is doing reasonably well in moving away from solid fuels. In contrast, the share of biomass even in FY31 is as high as 64% in ER, possibly due to lower initial penetrations of modern cooking fuels, combined with lower household incomes. This gives further insight into where efforts to enhance modern cooking fuel use should be focused.

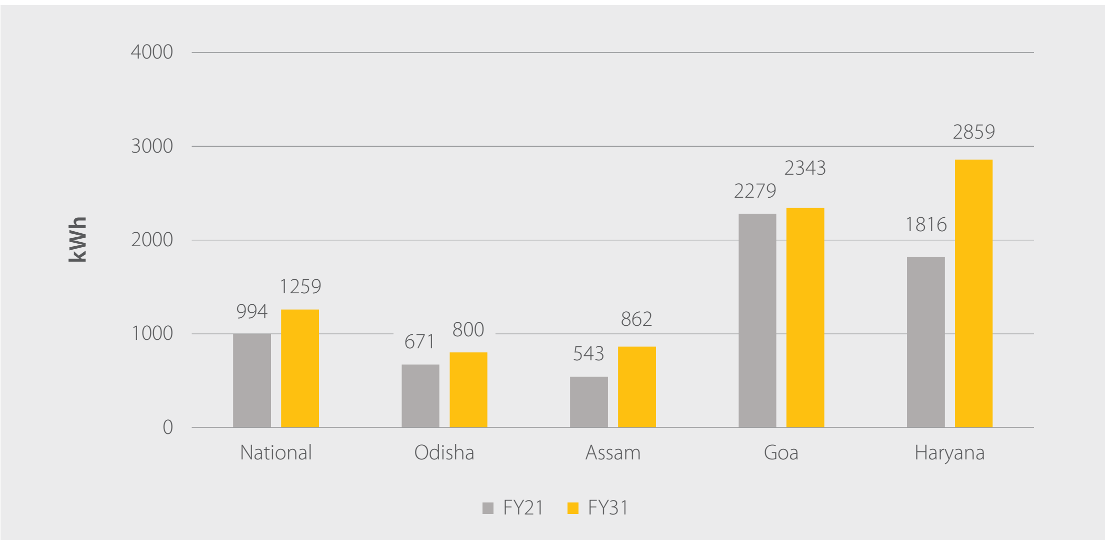
Figure 4: Residential energy demand in FY21 and FY31 projected by PIER



India's per-household residential electricity consumption continues to be quite low, particularly in some states. There is a need to focus on affordable, reliable electricity supply in such states.

Figure 5 shows the annual residential electricity consumption per household at the national level and for some states in FY21 and FY31. As can be seen, India's per-household annual residential electricity consumption goes up from just under 1000 kWh in FY21 to about 1260 kWh in FY31. This translates to just over 100 kWh per month on an average for an Indian household even in FY31, which is unlikely to be sufficient to support a desired quality of life. While states such as Haryana and Goa have a relatively high per-household consumption in FY31 of around 2850 and 2350 kWh respectively, states such as Odisha and Assam only have about 800 and 860 kWh respectively even in FY31. As with cooking fuels, this suggests the need for going beyond just access to reliable, affordable electricity supply that can be used by citizens. Similarly, the disparity across states that is seen also highlights the specific regions where focused efforts to increase electricity consumption, so as to improve quality of life, should be made.

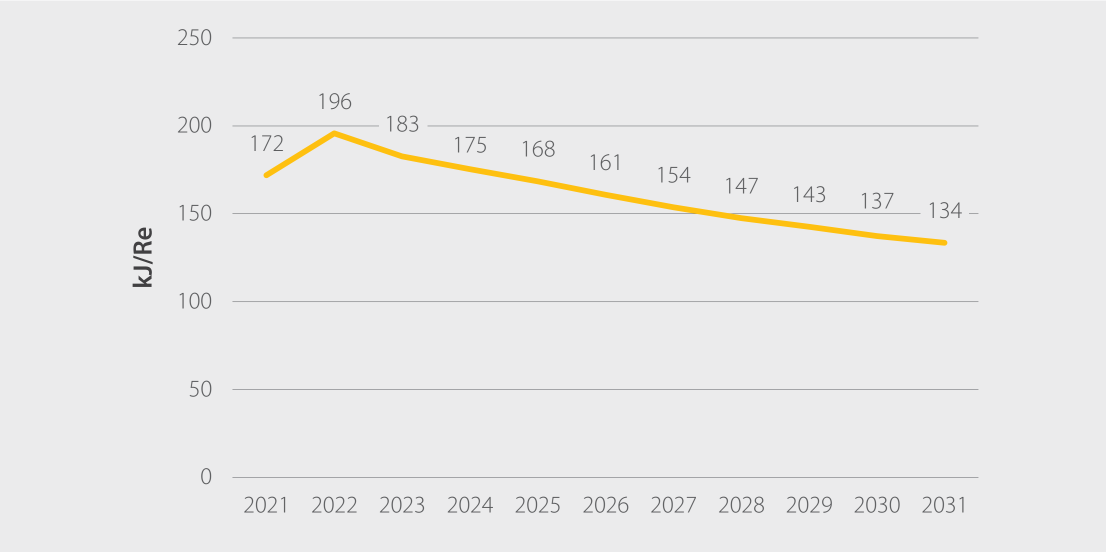
Figure 5: Residential per-household electricity consumption in India and select states



7.2 The role of energy efficiency and behavioural interventions

In the Reference scenario, the energy intensity of India's economy continues its secular decline. Between FY21 and FY31, the energy intensity of the economy falls from about 172 kJ/₹ to about 134 kJ/₹ at about 2.5% per annum. This is on account of a combination of factors such as a) improving efficiency of industrial processes, residential appliances, vehicles etc. as assumed in this scenario, b) a shift away (though still too slow) from highly inefficient and polluting solid fuels for residential cooking and c) improving efficiency of energy production and distribution. Figure 6 shows this decline in energy intensity.

Figure 6: Energy intensity of the Indian economy



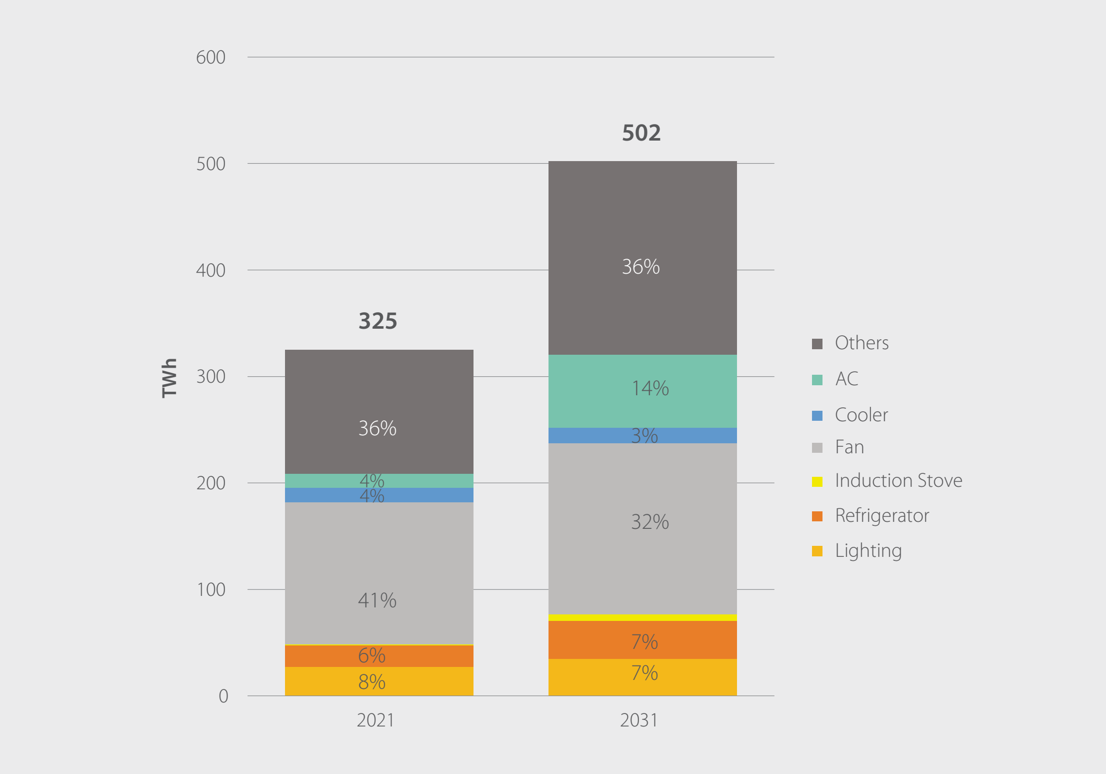
While this is encouraging, examining the results a little more closely shows room for further improvement in efficiencies and delivering better energy services for lesser energy. These are discussed below.

Importance of space cooling through appliances such as fans, coolers and ACs

Figure 7 shows India's residential electricity demand in FY21 and FY31 by energy service and service technology. While total demand goes up from 325 TWh to 502 TWh in this period at about 4.4% p.a., electricity demand from ACs grows by 18% p.a. and occupies a share of ~14% of all residential electricity demand in FY31, up from 4% in FY21. However, given their ubiquitous presence and usage at lower temperatures, fans continue to be the single largest energy consuming appliance even in FY31 with a share of 32%. Given the significant role of these two appliances, the combined share of space cooling in residential electricity demand remains at about 50% through the period that was modelled. This points to the fact that energy consumption for space cooling in general, and efficiencies of fans and ACs in particular, need policy attention.

Space cooling appliances are also important because they contribute significantly to evening load. In FY21, when the annual peak is during summer evenings, cooling appliances (fans, coolers and ACs) together contribute as much as 26% of the national peak load. The contribution of cooling appliances to evening loads in FY31 remains roughly the same (25%), though by FY31, the annual peak shifts to mid-day of autumn and summer.

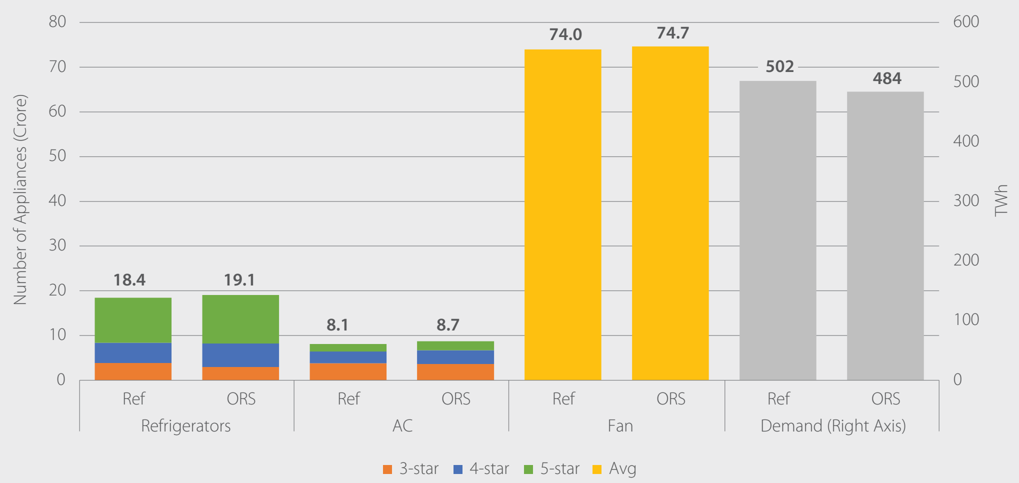
Figure 7: Residential electricity demand in FY21 and FY31 as projected by PIER



Focusing on energy efficiency through the value chain can lead to surprising gains, while enabling provision of more energy services.

The results from the ORS and Reference scenarios provide an interesting insight regarding the role of energy efficiency. Greater incomes – particularly among the poorer households – results in greater ownership and use of appliances in the ORS compared to the Reference scenario. However, despite this, residential electricity demand in FY31 reduces compared to the Reference scenario. This is because of two reasons – faster rate of improvement of the efficiency of the stock of appliances, and a behavioural shift towards using more efficient appliances (i.e. 5-star and 4-star in preference to 3-star). Thus, in the ORS, the residential electricity demand in FY31 is only 484 TWh compared to 502 TWh in the Reference scenario, in spite of greater appliances being owned and used. This is shown in Figure 8. The important insight that emerges from this is that, with supportive recovery policies targeted at the poorer households and reviving investments, and concerted efforts to improve efficiency, it is possible to provide greater residential electricity services without increasing electricity demand.

Figure 8: Number of appliances and residential electricity demand across scenarios in FY31



Note: 1 crore is equal to 10 million

The sensitivity analysis of a hypothetical situation where all residential appliances are extremely efficient in FY31 further under-scores the role of energy efficiency (see Annexure A6.3). In this analysis, residential electricity demand in FY31 falls by more than 20% from 502 TWh in the Reference scenario to just 385 TWh in this analysis. Demand from cooling appliances falls from 244 TWh to 187 TWh. This leads to a reduction in summer evening load in FY31 from 309 GW in the Reference scenario to 271 GW.

Similarly, though the overall electricity demand in the ORS increases by 18 TWh compared to the Reference scenario in FY31 (2065 TWh to 2083 TWh), electricity generation at the bus-bar in the ORS is 1 TWh lesser than in the Reference scenario (2455 TWh). This is due to lower T&D losses in the electricity system in the ORS compared to the Reference scenario, once again highlighting the important role of efficiency.

7.3 The role of consumer behaviour

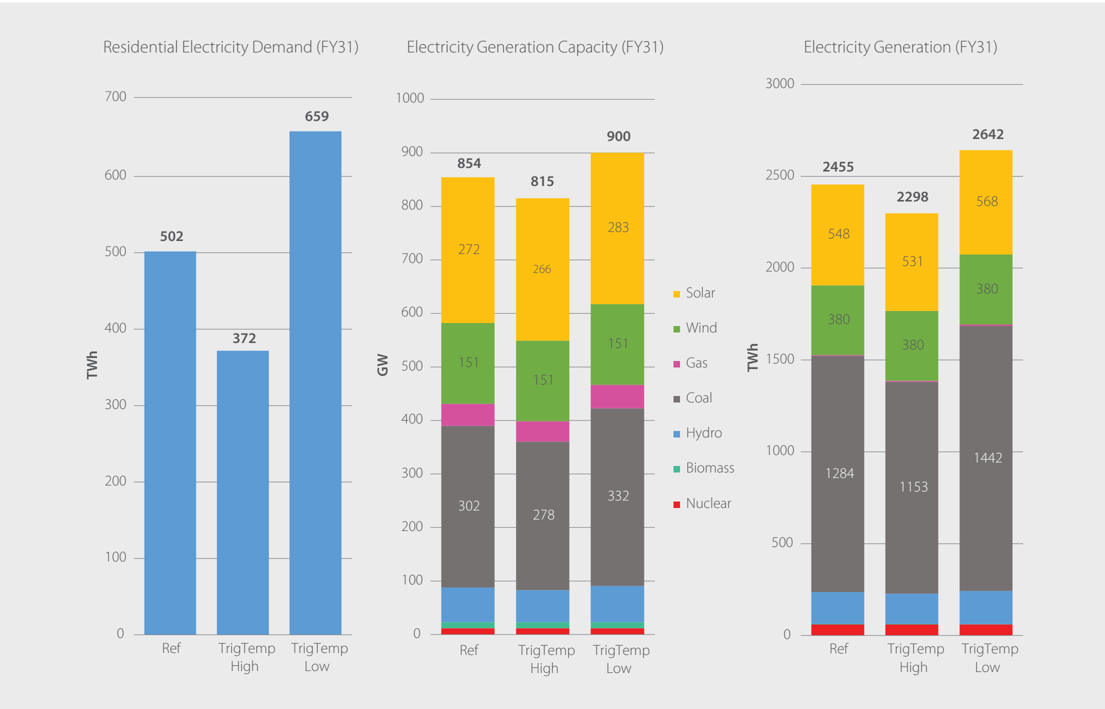
Small changes in consumer behaviour can lead to significant changes in the demand and supply mix, and can form a powerful policy lever.

In addition to efficiency, the role of consumer behaviour is also starkly highlighted by the results from two related sensitivity analyses about the trigger and reference temperatures at which residential cooling appliances are used. Increasing the trigger and reference temperatures of cooling appliances (fans, coolers and ACs) by just 2 ^{0}C in all years has a huge impact on residential electricity demand. Compared to 502 TWh in FY31 in the Reference scenario, it is only 372 TWh in FY31 in this sensitivity run – lower by about 25%. These gains are comparable to the gains from the hypothetical 'maximum appliance efficiency' case discussed above. In FY31, instead of 158 GW residential peak load in the summer evenings, this sensitivity run finds a residential peak load of 132 GW. This results in overall peak load in FY31 shifting from autumn-mid in the Reference scenario to summer-mid in this run. The cumulative impact of all these changes is significant on the supply side. Bus-bar electricity supply drops from 2455

TWh in FY31 in the Reference scenario to just 2298 TWh[38]. The supply mix required to meet this demand results in 24 GW lesser coal capacity (278 GW instead of 302 GW) in this case and 6 GW lesser solar capacity (266 GW as against 272 GW). It also results in 19 GWh lesser storage capacity being added. As a result, the share of generation from coal in this run is 50% in FY31 (as against 52% in the Reference scenario) while the share of solar and wind together is 40% in this run (as against 38% in the Reference scenario).

As expected, for the other sensitivity run (when both trigger and reference temperatures are lowered by 2 ^{0}C), there is a significant change in the reverse direction. Residential electricity demand in FY31 increases to 659 TWh in this run – about 31% more than the Reference scenario. Residential peak load in FY31 becomes 185 GW (158 GW in the Reference scenario) in summer evenings, leading to the overall peak also shifting to summer evenings (336 GW). This results in significantly higher electricity supply (2642 TWh in FY31 in this run), requiring about 30 GW more coal capacity and 10 GW more solar capacity compared to the Reference scenario[39]. Coal-based supply has a 55% share in FY31 in this run contributing 1442 TWh as against 1287 TWh in Reference. Figure 9 illustrates the importance of this behavioural parameter[40].

Figure 9: The impact of changing trigger and reference temperature by 2 °C in FY31



38. As an additional advantage, unserved demand drops to just 0.39 GWh in 2030 summer evening in this run compared to 1.8 GWh in Reference.

39. There is no unmet demand in this run, possibly due to all the extra capacity added.

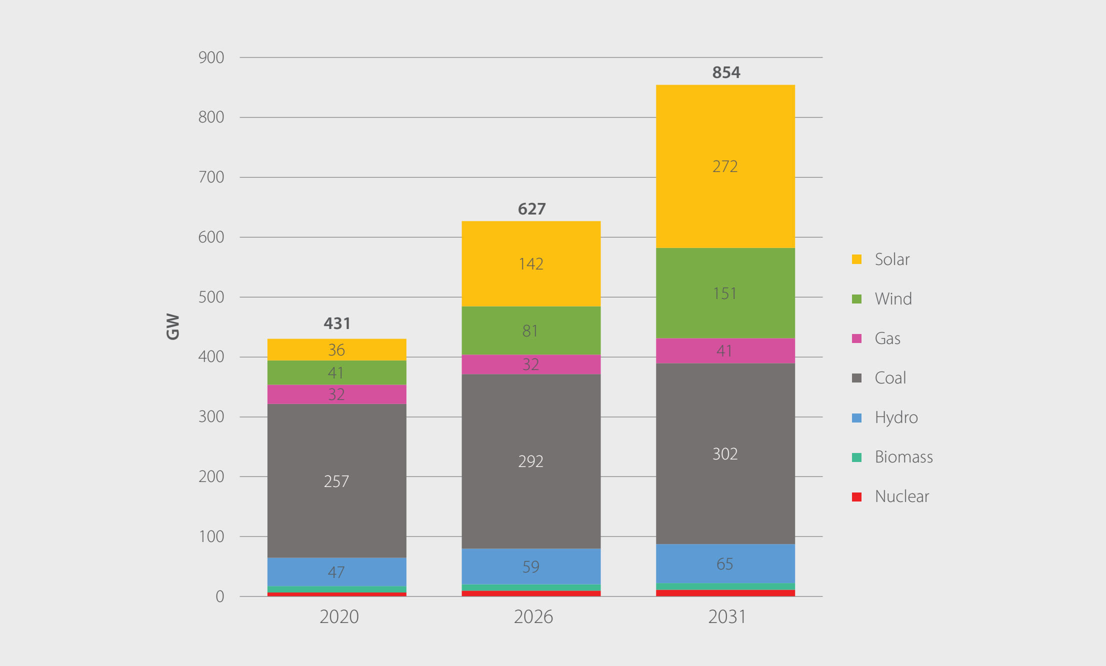
40. Effective implementation of building codes etc. can have a similar effect by raising the ambient temperature at which appliances are used.

7.4 Future coal capacity addition

Fresh coal capacity addition beyond what is in the permitting pipeline is risky and could lead to stranded assets. However, this is contingent upon renewables capacity addition at a significantly higher rate than in the past.

Figure 10 shows the installed electricity capacity projected by PIER. The total installed capacity nearly doubles from 431 GW[41] in FY20 to 854 GW in FY31. Installed coal capacity goes up from 257 GW to 302 GW in the same period, with the share of coal in installed capacity falling from 60% in FY20 to 35% in FY31. During the same period, given their increasing cost advantage, the combined share of solar and wind capacity go up massively from 18% to 50%, with total installed renewables capacity reaching 444 GW of renewables by FY31 – marginally short of the government target of 450 GW by 2030. This is supplemented by about 95 GWh of electricity storage (43 GWh of 4-hour BESS, 28 GWh of 6-hour BESS and 24 GWh of PHS[42]), with 66 GWh of the 71 GWh BESS getting added in FY29 and FY30.

Figure 10: Electricity generation capacity projected in PIER



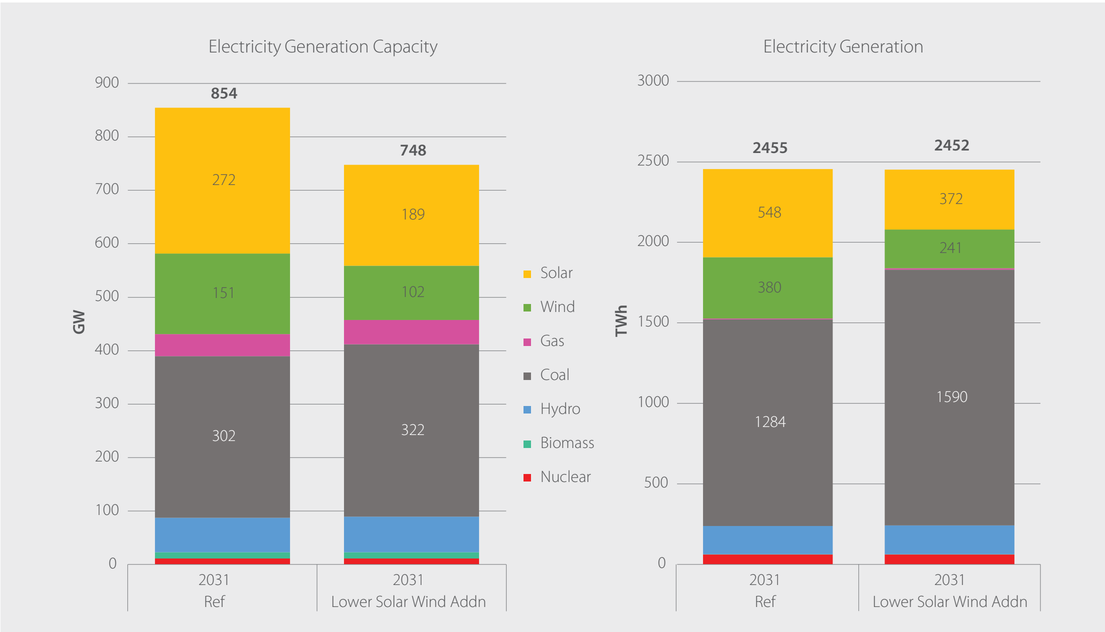
Thus, there is a net addition of only 45 GW of coal-based capacity between FY20 and FY31, reaching about 302 GW in FY31. This consists of about 77 GW of fresh capacity to be added and 32 GW of capacity being retired. Thus, the fresh capacity to be built is roughly comparable to the total capacity in the construction and clearances pipeline[43]. Hence, if India can achieve the renewables capacity addition targets it has set for itself, it should be very cautious about adding coal-based capacity beyond what is the permitting pipeline, because it could lead to long-term lock-ins and stranded assets.

41. The reader is reminded that these figures represent all the capacity and generation in the country, including captive capacity.
42. This consists of 16.5 GWh of pre-existing PHS capacity and 7.9 GWh in the construction pipeline.
43. In addition to the 41 GW of coal capacity under construction (which gets commissioned during the model period), 30-odd GW of coal capacity is in the permitting pipeline according to (Shearer *et al.*, 2020).

However, it should be noted that this is contingent upon the feasibility and realization of adding significantly higher solar and wind capacity in future years than has been done in the past in India. It requires the addition of about 40 GW of cumulative solar and wind capacity each year from FY26 to FY31 – in contrast to a maximum of about 18 GW as the highest annual solar and wind capacity addition that India has managed in the past.

This is not to say that this is impossible, since China added about 74 GW of cumulative solar and wind capacity just in 2018. But this illustrates the scale of the challenge, which is further highlighted by the results of the sensitivity run that examines the impact of being able to add only about half the capacity of solar and wind annually as compared to the Reference scenario. In this case, since coal is the next-best alternative option for India, there is significantly greater addition and use of coal capacity. Coal capacity in FY31 is now 322 GW – about 20 GW more than in the Reference case. Generation from coal in FY31 is about 1590 TWh – 300 TWh (about 24%) more than the Reference case, leading to its share in generation in FY31 in this case being 65% as against 52% in the Reference scenario. The share of solar and wind in FY31 in this case is only 25% compared to 38% in the Reference case[44]. Figure 11 illustrates the impact of reduced renewables capacity addition on both electricity capacity and generation.

Figure 11: Change in the capacity and generation mix if requisite renewables cannot be added



This highlights the necessity to focus attention on enabling the addition of adequate renewables capacity through supportive policies and business models that generate employment and are sensitive to local needs and issues. Otherwise, India would have to invest in coal capacity, which has much longer lock-ins and the potential of turning into stranded assets in future, in addition to other externalities of pollution and climate change.

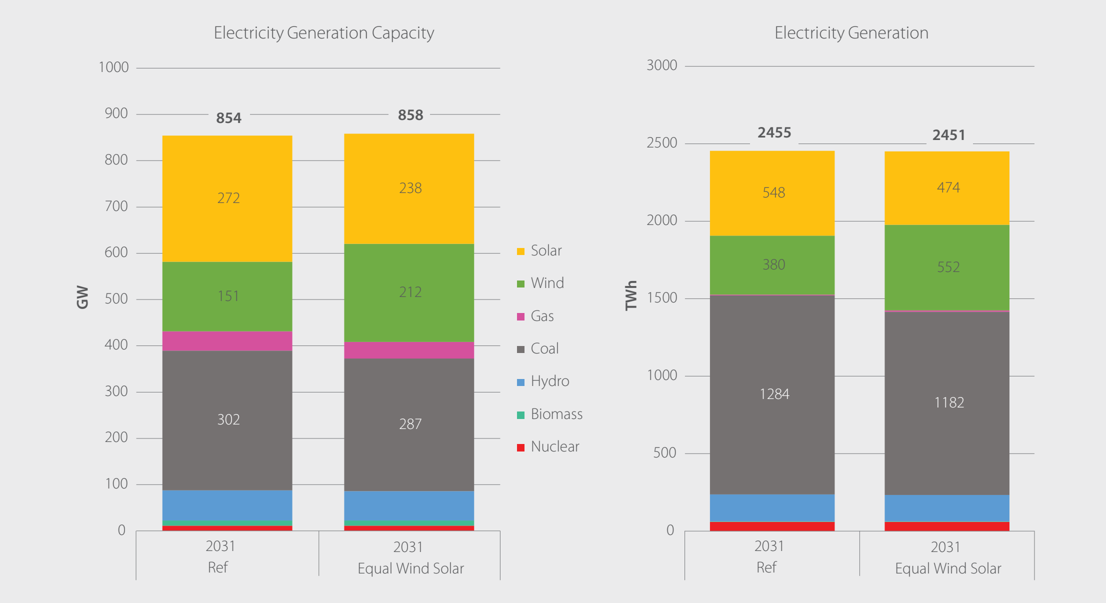
44. In this case, unmet demand increases from 1.8 GWh in the Reference scenario to about 5.6 GWh in the 2030 summer evening slice in NR (though it should be kept in mind that even 5.6 GWh is quite small).

7.5 Role of solar and wind in the electricity mix

As discussed above, solar and wind have a very significant role to play in the electricity mix going forward based on the assumptions in the Reference scenario. We present a few other interesting aspects of solar and wind capacity addition in this section.

It may be desirable to revisit the relative roles of solar and wind in the Indian renewable mix taking into account their capacity values.

Figure 12: Capacity and generation mix in the two capacity addition sensitivity cases



In the Reference scenario, more than twice as much solar is permitted to be added as wind capacity, which results in 272 GW of solar and 151 GW of wind capacity by FY31. However, the sensitivity analysis in which equal amounts of solar and wind capacity are permitted to be added (while keeping the total permitted solar+wind capacity the same) results in a significantly different capacity addition and generation mix compared to the Reference scenario. In such a situation, as shown in Figure 12, coal capacity addition is about 15 GW lower than the Reference scenario, so that the capacity in FY31 is only 287 GW. On the other hand, solar and wind capacity in FY31 reach 238 GW and 212 GW respectively, a cumulative increase of 27 GW compared to the Reference scenario. This leads to the share of generation from solar and wind becoming 42% in FY31 as against 38% in the Reference scenario. Generation from coal in FY31 is only 48% in this case as against 52% in the Reference scenario. Moreover, in this run, there is no unmet demand. This suggests that India should perhaps revisit its approach of focusing significantly more on solar than wind, given the greater capacity value and CUF of wind generation, though it should be borne in mind that wind is much more location sensitive than solar which brings in its own challenges[45]. This finding is consistent with that of (Deshmukh, Phadke and Callaway, 2021).

The electricity capacity and generation mix are not very sensitive to future cost trajectories, even though the amount of storage that gets added is sensitive.

45. PIER assumes a uniform CUF across a state.

The electricity supply mix projected by PIER seem to be quite robust regarding cost assumptions. Up to 10% variation in costs of either fossil fuels or renewable energy technologies does not make any significant difference to the overall technology mix in the country. However, the model is very sensitive to storage costs, as increasing them results in a drastic reduction in addition of storage capacity. However, even in such a case, the relative shares of the three major electricity generation technologies (coal, solar and wind) is not affected to any significant degree.

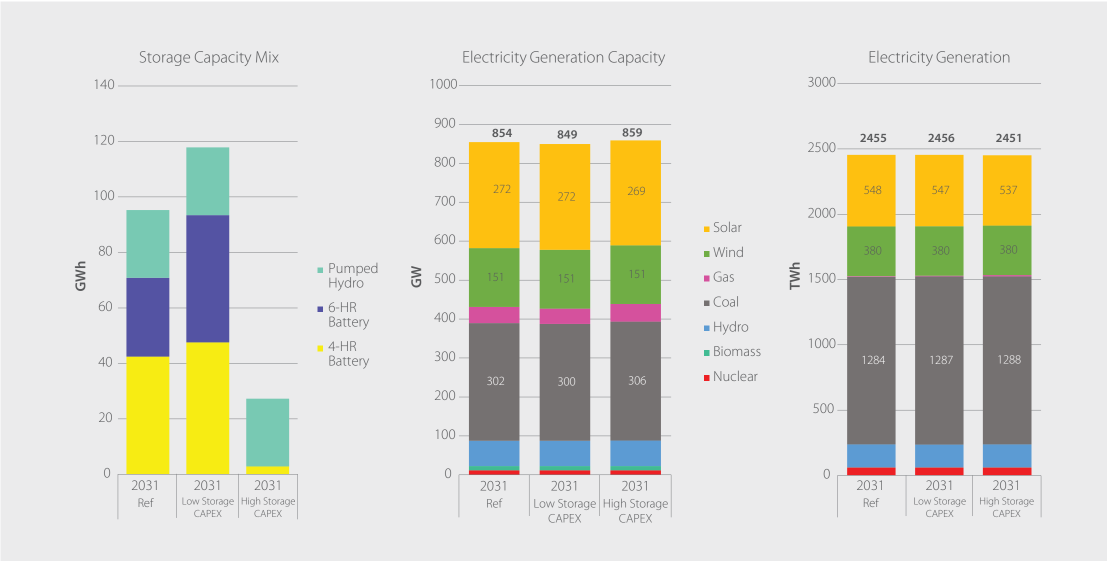
Increasing the cost of setting up new solar or wind capacity by 10% and reducing the cost of steam coal and natural gas by 10% (leading to lower cost of electricity generation from these fuels) does not significantly alter the model run results. It adds about 0.34 GW more of OCGT capacity and 1 GW more of coal capacity by FY31 in this case compared to the Reference scenario. There is no difference in the amount of wind capacity installed while solar capacity installed reduces by about 13 GW (259 GW instead of 272 GW) in this run. The difference in storage capacity installed is also marginal. Consequently, generation shares in FY31 change only by about 1 percentage point in this run. The conclusions are similar in the complementary case (though in the opposite direction) where the cost of setting up new solar and wind capacity is reduced by 10% and the cost of coal and natural gas are increased by 10%.

Addition of storage, in particular, BESS, is quite sensitive to storage costs assumed. In the sensitivity run with higher storage costs, the model adds negligible storage capacity beyond the 8 GWh of PHS that is already in the construction pipeline. However, even this does not lead to any noticeable difference in the electricity capacity or generation mix – about 4 GW more of coal capacity (1.3%) and 3 GW less of solar and wind (less than 1%) get added by FY31 compared to the Reference scenario. Generation shares of various technologies In FY31 are also roughly the same as the Reference scenario. But a greater amount of energy remains unserved in this case compared to the Reference scenario. Whereas only 1.8 GWh remains unserved in the summer evening of FY30 in NR in the Reference scenario, in this case, 5.6 GWh remains unserved in FY29 summer evening in NR and 27.1 GWh remains unserved[46] in FY30 summer evening in NR. When lower storage costs are assumed, significantly more storage is added but this too does not lead to any significant change in the overall electricity capacity or generation mix. This is summarized in Figure 13.

A related concern regarding addition of large quantities of renewables is the ability to find the requisite capital. However, our analysis suggests that this is not a major concern, since the capital requirement for all the energy related capacity (refineries and electricity) is about 1% of GDP on average over the model period, with a maximum of about 1.5% of GDP in years with significant capacity addition. Therefore, this is unlikely to be a major concern.

46. However, it should be remembered that 27.1 GWh is only a very small share of total NR summer evening demand in FY31.

Figure 13: Storage capacity, electricity capacity and generation in FY31 under different storage cost assumptions



8 Limitations and potential improvements

This report presents the results from the first published version of Rumi and PIER. As mentioned at the beginning of this report, one of the important objectives of this work is to present a fully open-source demand-oriented modelling platform, and a fully set-up model. Publication and release of PIER and Rumi is an important first step to meet that objective. The next step is to strengthen and enrich both the Rumi modelling platform and the PIER model, along some of the dimensions mentioned below. Some of these enhancements may be possible by enhancing the Rumi platform itself, while for some other requirements, it may be more prudent to link a Rumi model with some other modelling platform better suited to that function. While we would continue to work towards addressing some of these issues and enriching the model as we go along, we hope that the modelling community would also find it useful to work with Rumi and PIER, and thereby enhance them in ways that are interesting and relevant. That would really help enrich the Indian energy modelling scenario and inform research and policy better.

8.1 Potential improvements to Rumi

The following are some limitations of Rumi (in no particular order) in its current form.

- **Feedback between supply and demand:** Rumi does not provide a feedback loop between supply and demand, or between the energy system and the larger economy. Hence, any such interactions, such as the price elasticity of demand and price response to changing supply and demand situations, have to be modelled exogenously and given to Rumi.
- **Richer modelling of trade:** Currently, Rumi only permits imports of primary energy carriers while in reality import and export of both primary and derived energy carriers take place in real life. While this limitation does not limit an Indian model in any significant way, this is an issue to be addressed.
- **More sophisticated energy technologies:** Energy conversion technologies and energy service technologies currently produce one energy carrier (or provide one energy service) using one energy carrier. This can be generalized to allow multiple input carriers and output carriers or energy services. Moreover, energy service technologies currently cannot use a non-physical primary energy carrier – hence technologies such as solar water heaters or heat pumps cannot be modelled. Energy conversion and storage technologies currently do not distinguish between centralized and decentralized technologies – for example grid-connected solar and rooftop solar. These are some directions for possible future work.
- **Dealing with emissions:** The current version of Rumi accepts a range of emission related inputs but does not process them to produce emission related outputs.
- **Temporal scale and granularity:** The coarsest time unit possible in Rumi currently is a year, with its sub-components also being pre-defined. It may be useful to relax this and allow for more generic temporal scales and granularity.

8.2 Potential way forward for PIER

Since PIER is built on Rumi, its capabilities are bounded by Rumi's capabilities. For example, it is not possible (nor is it perhaps desirable, in an energy systems model) to model all technological constraints of a particular energy conversion technology, given the scale of the model. In addition, the following are some possible future directions of work for PIER.

- **Detailed modelling of other demand sectors:** Currently, only the residential sector has been modelled in detail in PIER, which has resulted in some interesting insights. Similarly, modelling other sectors in greater detail is also desirable.
- **Better modelling of the residential sector**: While the current residential sector model is quite detailed, there is still room for improvement. These include better representation of different types and sizes of houses, better representation of house occupancy and detailed modelling of more energy services to reduce the uncertainties involved in estimating the residual share of the "Other residential services".
- **Using more up-to-date data:** PIER currently uses a decade-old data-set as the basis for its bottom-up modelling, in the absence of any newer data-set. It is hoped that better data sets will become available and can be used to model the current situation better.
- **Adding more energy carriers and technologies:** The current exercise has captured most technologies and carriers that are significant. However, some energy carriers such as biofuels that are being pushed by the government have not been modelled. Similarly, emergent technologies such as hydrogen-based technologies and offshore wind have not been modelled. These are potential directions to consider for the future.

9 Conclusions

We believe that undertaking an exercise to develop and publish Rumi and PIER is very useful as it can contribute to enriching the diversity of models that exist in the country and can inform policy. Detailed bottom-up modelling is an effort-intensive exercise, but the insights and potential policy levers that could be identified as a result were quite helpful.

Availability of relevant, quality data was a persistent challenge during the modelling exercise. This is particularly challenging when doing a detailed bottom-up model. For example, lack of data regarding appliance ownership by efficiency level, electricity load shapes by consumer type, and sectoral consumption of imported energy products necessarily require some crude assumptions to be made. The situation becomes more challenging considering the nearly decade long gap in availability of official consumer expenditure statistics which is crucial to understanding residential consumer behaviour.

Nonetheless, we think that the results and the insights obtained from this modelling exercise will be useful to understand the future trajectory of the energy sector, identify areas that need attention and suggest some levers to help direct it in a more equitable and sustainable direction. Indeed, the value of such models would really come from updating and using them often to ask different questions of the model in order to regularly gain insights for policy formulation.

Therefore, we hope that the Rumi platform and the PIER model will be useful additions to the tools and models available to the energy research community, and will be used and enriched by the community to address interesting research and policy questions.

Annexures

A1 Basics of PIER

This section provides some of the details regarding the basic model elements of PIER.

1. **Time:** Time is modelled as financial years to fit with the Indian financial system, with a start year of 2020-21 (henceforth FY21) and end year of FY31. Table 3 presents details of the five seasons into which a year is divided and the six day-slices into which each typical day of a season is divided.

Table 3: Time units considered in PIER

Granularity	Name	Details
Season	SUMMER	April, May
	MONSOON	June, July, August
	AUTUMN	September, October
	WINTER	November, December, January
	SPRING	February, March
Day-slice	EARLY	6 AM – 9 AM
	MORN	9 AM – 12 PM
	MID	12 PM – 3 PM
	AFTERNOON	3 PM – 6 PM
	EVENING	6 PM – 10 PM
	NIGHT	10 PM – 6 AM

2. **Geography:** PIER divides India into five regions, which are further sub-divided into 25 "states" as detailed in Table 4.

Table 4: Geographic units in PIER

Region	States	Remarks
Eastern (ER)	Bihar (BR), Jharkhand (JH), Odisha (OD), West Bengal (WB)	
North-Eastern (NER)	Assam (AS) and North East (NE) consisting of Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura	The six non-Assam north-eastern states and Sikkim have been combined into one "state" for convenience
Northern (NR)	Delhi (DL), Haryana (HR), Himachal Pradesh (HP), Jammu and Kashmir (JK), Punjab (PB), Rajasthan (RJ), Uttarakhand (UK), Uttar Pradesh (UP)	Most of the modelling was done before Jammu & Kashmir was made a union territory and Ladakh separated from it. Past data is also mostly available for these as a single state.
Southern (SR)	Andhra Pradesh (AP), Karnataka (KA), Kerala (KL), Tamil Nadu (TN), Telangana (TS)	

Region	States	Remarks
Western (WR)	Chhattisgarh (CG), Goa (GA), Gujarat (GJ), Madhya Pradesh (MP), Maharashtra (MH), Union Territories (UT) representing Chandigarh, Daman-Diu, Dadra-Nagar-Haveli and Puducherry	• Chhattisgarh is modelled in WR for historical reasons, since it was created from MP, and hence belongs to WR in the classification by the Central Electricity Authority (CEA). • UT is classified in WR as a significant portion of its demand comes from WR (Daman-Diu and Dadra-Nagar-Haveli). • Currently UT does not include Andaman & Nicobar, and Lakshadweep for simplicity – as their demand is minuscule, and modelling them is more complex given that they are islands.

3. **Time and geographic granularity:**

   a. **Electricity:** Geographically, electricity demand is modelled at a state level and aggregated up to a region which is its balancing area. Hence, inter-region transmission losses, costs and limits are modelled separately from intra-region distribution losses and costs. Temporally, electricity demand is modelled at a day-slice level, and supply is also matched at a day-slice level. Hence, some supply characteristics such as usage factors are also modelled at this granularity. This enables better consideration of daily variation in both demand and supply of electricity[47].

   b. **Coal:** Geographically, coking coal and steam coal demand as well as supply are modelled at the regional level. This enables modelling of the cost of coal transportation across regions, which is a major contributor to electricity cost in India. Temporally, coal demand and supply are modelled at the annual level.

   c. All other energy carriers are modelled at the annual and national level of granularity[48].

4. **Unmet demand value:** The price for unmet demand is given as 100 ₹/kWh for electricity, 500,000 ₹/tonne for all solid and liquid carriers (translating to about 1000 USD/barrel for petroleum products) and 500 ₹/cu m for gaseous carriers (translating to just under 200 USD per mmbtu of natural gas). These values have deliberately been chosen to be quite high (many times their price in FY20), in order to encourage the model to meet demand as far as possible.

5. **GDP:** GDP projections are an important aspect of projecting future energy demand. India's GDP for FY21 is taken from (Reserve Bank of India, 2020). National GDP growth rate for FY22 is taken from (Reserve Bank of India, 2021). National GDP growth rates up to FY27 are as projected by the IMF World Economic Outlook of April 2021 (IMF, 2021), and the GDP growth rate for FY27 is used for all subsequent years. The estimated GDP values are given in Table 5.

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47. However, note that since Rumi does not model individual units or plants, it cannot account for some technical constraints such as technical minimums or start constraints of different generation technologies.

48. Residential demand for all carriers used in the sector is modelled at the state level and aggregated up.

PIER also projects state GDPs (GSDPs) to estimate state-wise Monthly Per Capita Expenditure (MPCE), which are used to estimate households' ownership of appliances. GSDPs up to FY19 are obtained from EPWRF (EPWRF, 2021). These values are projected into the future using the CAGR of GSDPs between FY12 and FY19. These are then further scaled in proportion to the difference with the national GDP, to ensure that the sum of GSDPs equals the national GDP. All amounts in PIER, including GDP, are in terms of constant 2018-19 Indian Rupees.

Table 5: GDP projections (Reference scenario)

FY	2021	2022	2026	2031
Real GDP Rs Billion (FY 19 Prices)	134,089	146,827	190,780	261,812

6. **Population:** Population projections of the various states of India split by urban-rural geography is taken from (Samir *et al.*, 2018).

A2 Residential sector energy demand

We provide some of the detailed assumptions and input parameters used in the bottom-up residential energy demand model in this section.

A2.1 Household counts

A count of the number of households in each expenditure quintile for each state and urban-rural geography is important to estimate household energy demand. While state-wise urban and rural projections of population were available from (Samir *et al.*, 2018), projections for the number of households are harder to make – particularly in the absence of data from more recent representative surveys or Census. Therefore, the approach adopted was to estimate the rate of change in *household size* for each of the 250 consumer types based on the last two valid major rounds of consumer expenditure survey (NSSO MOSPI, 2005, 2012). It was assumed that for each consumer type, household size would continue to change at this rate going forward, which allowed an estimation of average household size in a state and urban-rural geography (since the number of households in all quintiles are the same by definition). The number of households in a particular state and urban-rural geography was estimated from the population estimate and the household size estimate, which is then used to obtain the quintile-wise number of households for each of the 250 consumer types over the model period.

A2.2 Residual share of the un-modelled services in the residential sector

The share of the un-modelled energy services in the residential sector is estimated as a residual share of the demand from the modelled services, by extrapolating historical state residential electricity demand to FY21 and comparing against the demand estimated by the bottom-up model. This results in the following kind of residual shares for various states in India.

- In ten states, the demand from other electricity services is less than 50% of the demand from the modelled services – in other words, the modelled services account for more than two-thirds of total demand.
- In seven states, the demand from other electricity services is between 50% and 100% of the demand from modelled services, i.e. the bottom-up modelling accounted for 50% to 67% of total residential demand.
- In eight states, the share of other residential services exceeds 100% of the modelled energy services, i.e. the bottom-up modelling captures less than half of the total demand. These are typically either small states such as GA and UT, or cold states such as JK, HP and UK. We hypothesise that this could either be because of issues with the basic data[49] based on which bottom-up demand for these states was estimated or due to high space and water heating demand in cold states. However, this needs deeper investigation.

At the national level, it is seen that nearly two-thirds (64%) of all residential electricity demand

49. In particular, being small states, there could be sampling weaknesses leading to inaccurate regression relationships of appliance ownership, in turn leading to inaccurate bottom-up demand estimation.

is captured by the services modelled bottom-up. Hence, broadly, the bottom-up model may be considered to be robust, though, of course, it can be strengthened further by modelling more energy services.

A2.3 Energy service technology details

Energy service units and efficiency levels

The energy service expected from each service technology is specified in a unit appropriate to that technology. Table 6 gives the various details regarding the energy services, and technologies that provide those services as modelled in PIER.

Table 6: Energy services and technologies modelled

Service	Technology	Carrier	Energy service unit	No of Efficiency Levels
Lighting	Lighting	Electricity	Hours (of lighting required)	Incandescent bulbs, CFL, LEDs
Cooking	Biomass stove	Biomass	Useful heat (MJ)	Only one
	LPG stove	LPG	Useful heat (MJ)	Only one
	PNG stove	Natural gas	Useful heat (MJ)	Only one
	Induction stove	Electricity	Useful heat (MJ)	Only one
	Biogas stove	Biogas	Useful heat (MJ)	Only one
Space cooling	Fan	Electricity	Hours (of cooling)	Only one
	Air Cooler	Electricity	Hours (of cooling)	Only one
	Air Conditioner[50]	Electricity	Cooling degree hours (cdh)	3-star, 4-star and 5-star
Refrigeration	Direct cool refrigerators[51]	Electricity	Hours (but assumed to always run)	3-star, 4-star and 5-star

Efficiency of energy service technologies

The efficiency of each energy service technology is modelled as the amount of energy required to provide one unit of service (e.g. one hour of lighting or refrigeration or cooling)[52] as described below.

1. **Lighting appliances:** For lighting appliances, the efficiency is the wattage of the appliance. 60, 15, and 9 W have been assumed for incandescent bulbs, CFLs and LED lamps respectively in FY21, based on typical lamps available in the market. The efficiency of the stock of LED lamps is assumed to improve by 0.5% a year, whereas efficiencies for incandescent bulbs and CFLs are assumed to be constant through the modelling period.

2. **Cooking appliances:** Typical expected efficiencies of converting input heat value to useful heat from (Venkataraman *et al.*, 2010) are assumed. Thus, biomass stoves have an efficiency of 14%, while LPG, PNG and biogas stoves have efficiencies of 58% and

50. Split room air-conditioners have been considered as they are the most sold ACs in the country
51. A very high share (about 80%) of refrigerators used in India are direct cool type refrigerators and hence have been considered the representative technology.
52. Thus, strictly, it is not 'efficiency' but specific energy consumption that is modelled.

induction stoves have an efficiency of 82% in FY21. The efficiency of biomass stoves are kept constant over the model period, while the efficiency of the other stove fleets are improved at 0.5% a year.

3. **Fans and coolers:** For fans, a value of 70 W is assumed for FY21 based on typically available fans in the market. A lifetime of 20 years is assumed for fans, and the efficiency of new purchases is assumed to improve at 4% a year to reach an average of 46.5 W for new appliances and 63.5 W for entire stock by FY31. This is based on the assumption that BEE's aggressive plan to mandate efficiency standards for fans and make them stringent (BEE, 2019, 2021) results in a market transformation. For coolers, a value of 180 W is assumed for FY21 based on typical models available in the market, and this is assumed to reduce at 0.5% a year.

4. **ACs:** The energy service unit is cooling degree hours (cdh). The energy required per cdh for 3-, 4- and 5-star split ACs in the initial year is estimated based on the average of BEE's past efficiency standards (which is given in W/W EER units) and broad assumptions regarding aspects such as wall thickness, room size and wall conductivity[53]. Based on these, the rate of heat dissipation (in W) required per degree of cooling is calculated, and is used together with the EER to obtain the energy to provide one cdh of cooling. This efficiency is assumed to gradually improve over time at 1.24%, 1.54% and 2.54% a year for 3-, 4- and 5-star ACs respectively, based on proposed standards, available technology and likely AC purchase patterns.

5. **Refrigeration:** The efficiency of a refrigerator is provided based on its average annual consumption, which incorporates the aggregate effect on demand due to the compressor duty cycles. Refrigerator efficiencies are based on average of BEE standards for 3-, 4- and 5-star refrigerators for the initial year. These range from about 256 kWh / year to 182 kWh / year. These efficiencies are expected to improve at 0.5% a year.

Number of technology instances per household

There is no publicly available data for the number of appliances used by a household that is consuming a particular energy service, stratified by expenditure quintile. Hence, this value has been estimated based on the nationally representative IRES survey (Agrawal *et al.*, 2020)[54]. The MPCE values as reported in the IRES survey are significantly under-reported as compared to the NSSO 68th round household consumer expenditure survey. Hence, the IRES MPCEs have been adjusted to arrive at the MPCE bands used to determine the number of appliances owned. For simplicity, for refrigerators and cooking appliances, we assume that each household using that technology has exactly one instance of it. Of the various energy service appliances, since households tend to possess more lights and fans, not all of which may be used simultaneously (even when the service is used), we assume that 95% of fans and 85% for electric lights owned by a household would be used whenever fans or lights need to be used.

53. The assumptions are: a) brick walls of thermal conductivity of 0.6 W per metre-Kelvin, b) walls of 15 cm thickness and c) average room size of about 20 sq m (or 180 sq ft) with a standard 9-foot ceiling.

54. The number of appliances per household is determined by MPCE bands and urban-rural geography. This mapping does not vary across states, as it is not clear if the survey data can be used at that disaggregated level.

A2.4 Estimating space cooling demand based on temperatures and humidity

Monthly average temperature projections up to FY31 at a half-degree by half-degree latitude-longitude resolution are taken from the CMIP5 multi-model ensemble based CCSM4-BCSD RCP 4.5 model (Taylor, Stouffer and Meehl, 2012; Brekke *et al.*, 2013; Meehl, 2014) scenario adopted for the IPCC's fifth assessment report (IPCC, 2014). Hourly temperature profiles for 450 locations in India for the year 2018 from openweathermap.org were used in conjunction with the monthly average temperature projections to estimate hourly temperature profiles across India up to FY31 for these 450 locations. This is used to calculate cooling hours and cdh in each day-slice for each consumer type based on an assumed 'trigger' temperature at which an appliance would begin to be used. The trigger temperature is a function of household income (approximated by MPCE) and the likely humidity (for which the state in which the household is located is used as a proxy). Higher MPCEs and higher humidity may lead to lowering the trigger temperature – as the desired comfort levels may be higher or the 'perceived' temperature would be higher. Thus, the trigger temperature for coolers and ACs varies between 30 °C and 35 °C, while for fans the range is between 26 °C and 28 °C. For ACs, a reference (or set-point) temperature of 24°C is assumed to estimate the amount of cooling (i.e. heat dissipation) needed.

Thus, cooling hours and cooling degree hours for each day-slice for each consumer type up to FY31 are calculated. However, since temperatures are highest during the middle of the day when houses are typically less occupied, space cooling appliances are used more when people return to a 'heated house'. Hence, the cooling service demand determined based on the temperature profile during the day is partially shifted towards the evening and night to account for this. 30% of fan cooling hours, 40% of cooler cooling hours and 50% of AC cdh during the day-time slices are shifted to the evening and night slices.

A2.5 Details of the regression model to estimate technology penetration

The regression used to estimate appliance usage by a household type assumes that the drivers are the MPCE of the household (as a proxy for income), the state in which the household is, whether the household is urban or rural, and whether the household was electrified. All the above, except whether the household is electrified, are also assumed to be the drivers that determine whether a household uses a modern cooking fuel or traditional fuel (biomass). The logistic regression equation used to determine the relationship between the drivers and the probability of usage of the appliance is as follows:

$$\log_e\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1(\log_e MPCE) + \beta_2(S) + \beta_3(UR) + \beta_4(E)$$

where

- p is the probability of whether the household uses the appliance or technology in question
- β_0 is the intercept, and β_1 to β_4 are the coefficients of regression (see Table 7)[55]
- *MPCE* is the MPCE of the household under consideration
- *S* are the dummy variables corresponding to states, where the state of the household in question is 1 and the rest are 0

55. Built using R-package Stargazer (Hlavac, 2018).

- *UR* is the binary variable corresponding to whether the household is urban or rural
- *E* is the binary variable corresponding to whether the household is electrified. This is only relevant to estimate appliance ownership and usage, and not cooking fuels usage.

Table 7 shows the coefficients of regression, along with their statistical significance.

A2.6 Estimating the number of households demanding an energy service

The relationship defining the probability of owning and using an appliance as a function of the household location and expenditure (Annexure A2.5) is used to estimate the number of households that demand an energy service using a particular technology for each consumer type and each time-unit of interest. This is explained below.

For each consumer type (i.e. for each combination of state, urban-rural location and expenditure quintile), a representative MPCE is estimated for all modelled years. This is done by first identifying the average MPCE of households belonging to that consumer type from the two major rounds of NSSO expenditure surveys – the 61st and 68th conducted in 2004-05 and 2011-12 respectively[56], and computing the growth rate between those two years.

This growth rate is then indexed to the corresponding state's GDP (GSDP) growth rate between those two years to obtain the elasticity of MPCE growth for the consumer type to the state's GSDP. This elasticity of MPCE growth to state GSDP for each consumer type is used to estimate MPCEs for future years, using the projected GSDP for all future years. For example, let the annual MPCE growth rate of a representative household of a consumer type in a state be 6% between 2004-05 and 2011-12, and the GSDP growth rate of that state be 8% in that period. The elasticity of MPCE growth rate to GSDP for that consumer type then is 0.75 (6% / 8%). This value is multiplied by the GSDP growth for any future year to obtain that consumer type's MPCE growth rate in that year. Thus, if the GSDP grew at (say) 9% between FY22 and FY23, and (say) 6% between FY27 and FY28, then the MPCE for that consumer type grows by 6.75% and 4.5% respectively in those years.

Given the MPCE projections for all consumer types for future years, the relationship derived in Annexure A2.5 is used to estimate the probability of a household with that MPCE (i.e. in that quintile in that state and urban-rural location) owning and using the technology / appliance. For this purpose, given the nearly complete household electrification achieved after the Saubhagya programme (MoP, 2019), all households are assumed to be electrified, i.e. the variable E plugged into the regression equation is always 1. This also means that electric lighting is used in all households, i.e. a probability of 1. The probabilities thus obtained need to be adjusted in two ways as described below.

1. **Distinguishing between coolers and ACs:** The NSSO surveys do not distinguish between coolers and ACs. Hence, a separate exercise using IHDS data (Desai and Vanneman, 2012), which does distinguish between them, and the agro-climatic regions into which Indian states fall, was used to split the probability obtained for owning a cooling appliance (i.e. cooler or AC) into the separate probabilities of owning a cooler or an AC. The relative shares of coolers and ACs for a state and urban-rural

56. The 2008-09 survey is not used as it is generally considered anomalous due to the financial crisis. As stated earlier, no later survey exists.

geography in 2011-12 as available from IHDS, and a target share of ACs (among ACs and coolers) in FY31 based on the state's economic level and humidity, was used to interpolate the relative shares of ACs and coolers for each state and urban-rural geography, which in turn was used to estimate the probability of owning these appliances.

2. **Cooking fuels:** The 2011-12 NSSO data set contains various options for cooking fuels namely coal, firewood, LPG, biogas, dung cake, charcoal, kerosene, electricity, others and no cooking arrangement. Since kerosene use in the country has been rapidly reducing over the years, it is not considered. Similarly, households with no cooking arrangement are also dropped since they are a very small segment. Of the remaining fuels, all the traditional fuels (coal, firewood, dung cake and charcoal) are clubbed into one category (biomass) and all the modern fuels (LPG, biogas and electricity) are clubbed into one category to determine the regression relation. The "others" category is categorized as traditional (biomass) or modern depending on the state and an understanding of the state's cooking situation in 2011-12. In most cases, they are classified as traditional fuel since it most likely corresponds to agricultural residue. But in case of some state-geography combinations (e.g. urban Delhi, Gujarat, Maharashtra and UP), it is much more likely to indicate PNG (which is captured as "others" in the NSSO survey). Hence we categorize "others" as a modern fuel in such cases. Using this classification, the regression provides household penetration rates for modern and traditional cooking fuels. Modern fuels are split between LPG, biogas, electricity and PNG using the shares in the Cost Effectiveness of Fuel Transition in India (CEFTI) model (Prayas, 2018). Traditional fuels are all assumed to be biomass, which is the predominant part of traditional fuels.

   One challenge with using 2011-12 data to estimate cooking fuel usage is that it does not account for subsequent disruptions such as the PMUY programme (MoPNG, 2019b) which has increased the penetration of LPG usage compared to historical trends. To account for the likely impact of the PMUY programme, LPG usage as reported in the NSSO's 76th Round Drinking Water, Sanitation, Hygiene and Housing condition in India survey (NSSO MOSPI, 2018) is used to scale the penetration values obtained from regression.

The above process gives the estimate of the share of households using each energy service of interest and the technologies that are used to realize those services for each year and for each consumer type[57].

An additional task is to split the households using a technology into the different efficiency levels of that technology (applicable only for lighting, ACs and refrigerators). Unfortunately, there is no nationally representative data available for appliance usage by efficiency level. Hence, results from our limited survey (Prayas (Energy Group), 2019) are used to split households using these appliances into the different technology efficiency levels.

57. It should be noted that, since appliance use and cooking fuel use are modelled as a function of MPCEs and MPCEs are a function (also) of national GDP, the reduction of national GDP in FY21 due to the COVID-19 pandemic results in reduced MPCEs and therefore, reduced usage of various appliances / technologies compared to FY20. This is consistent with a fall in incomes for many consumers and the interpretation that the probability is of using an appliance or technology rather than owning it.

Table 7: Coefficients of regression

	Logit Models			
	Fans	Cooling Devices	Refrigerators	Modern cooking fuel
Independent Variables	**(1)**	**(2)**	**(3)**	**(4)**
log(MPCE)	1.224***	1.450***	1.675***	2.479***
	(0.067)	(0.054)	(0.063)	(0.047)
Dummies				
Urban	0.815***	0.831***	1.142***	2.653***
	(0.071)	(0.059)	(0.047)	(0.047)
Electrification	3.527***	2.166***	2.419***	NA
	(0.079)	(0.157)	(0.154)	NA
HP	-0.552***	-1.977***	0.531***	-0.381**
	(0.169)	(0.221)	(0.136)	(0.153)
PB	2.601***	0.716***	1.362***	-0.379***
	(0.376)	(0.141)	(0.136)	(0.129)
UT	1.357***	-0.986***	-0.186	0.994***
	(0.289)	(0.206)	(0.163)	(0.250)
UK	-0.181	-0.567***	0.087	0.046
	(0.186)	(0.213)	(0.189)	(0.190)
HR	2.980***	0.817***	0.557***	-0.493***
	(0.376)	(0.181)	(0.166)	(0.172)
DL	2.785***	0.623***	0.027	1.815***
	(0.388)	(0.199)	(0.189)	(0.483)
RJ	1.047***	0.507***	-0.526***	-1.089***
	(0.130)	(0.138)	(0.124)	(0.125)
UP	1.193***	0.005	-0.616***	-0.812***
	(0.123)	(0.141)	(0.108)	(0.114)
BR	1.079***	-1.992***	-1.305***	-0.844***
	(0.155)	(0.225)	(0.155)	(0.142)
NE	-0.807***	-3.542***	-0.795***	-0.042
	(0.123)	(0.218)	(0.097)	(0.122)
AS	0.798***	-3.289***	-1.038***	0.304**
	(0.145)	(0.314)	(0.124)	(0.137)
WB	0.862***	-2.665***	-1.303***	-1.220***
	(0.128)	(0.184)	(0.110)	(0.126)
JH	0.496***	-1.509***	-1.093***	-1.432***
	(0.160)	(0.222)	(0.159)	(0.177)
OD	1.146***	-0.652***	-0.850***	-1.429***
	(0.135)	(0.171)	(0.123)	(0.165)
CG	0.910***	0.544***	-0.862***	-1.675***
	(0.156)	(0.160)	(0.137)	(0.190)
MP	0.892***	0.409***	-0.876***	-0.788***

Independent Variables	Logit Models			
	Fans	Cooling Devices	Refrigerators	Modern cooking fuel
	(1)	(2)	(3)	(4)
	(0.140)	(0.142)	(0.115)	(0.133)
GJ	1.368***	-2.419***	-0.473***	-0.343**
	(0.226)	(0.203)	(0.162)	(0.152)
MH	0.832***	-1.049***	-0.806***	0.218*
	(0.127)	(0.155)	(0.108)	(0.117)
AP	2.235***	-0.821***	-1.298***	0.251**
	(0.170)	(0.140)	(0.115)	(0.119)
KA	0.036	-3.087***	-1.328***	-0.487***
	(0.129)	(0.210)	(0.121)	(0.132)
GA	2.557***	-1.425***	1.521***	1.399***
	(0.398)	(0.248)	(0.211)	(0.260)
KL	1.219***	-2.631***	0.263***	-0.923***
	(0.147)	(0.158)	(0.099)	(0.135)
TN	1.366***	-2.234***	-0.990***	0.471***
	(0.143)	(0.152)	(0.106)	(0.125)
Constant	-12.050***	-15.085***	-16.617***	-20.180***
	(0.521)	(0.460)	(0.521)	(0.379)
Observations	100,479	100,090	100,216	96,861
Log Likelihood	-30,578.570	-22,949.440	-30,305.850	-29,540.960
Akaike Inf. Crit.	61,211.150	45,952.870	60,665.710	59,133.920

*p<0.1; **p<0.05; ***p<0.01

A3 Modelling non-residential sector demand

Table 8 gives the representative GDP elasticities used in the model for industrial energy demand for a set of energy carriers.

Table 8: Representative GDP elasticities for industrial demand for some energy carriers

Carrier	2020-21	2025-26	2030-31
Steam coal	0.603	0.603	0.603
Coking coal	0.818	0.818	0.818
Electricity	0.763	0.744	0.726
HSD	0.314	0.314	0.314
Other petroleum products	1.220	1.102	0.996
Biomass	0.161	0.161	0.161

Table 9 gives the energy demand from the transport sector for some important energy carriers in various years, as computed based on GDP elasticity or extraneously.

Table 9: Energy demand for transport from various carriers

Carrier	2020-21	2025-26	2030-31
MS (PJ)	1,196	1,847	2,561
HSD (PJ)	2,434	2,808	3,172
ATF (PJ)	331	451	587
Electricity (GWh)	22,069	34,358	116,097[58]

Table 10 gives a snapshot of the estimated agricultural energy demand at the national level for the two important carriers of HSD and electricity.

Table 10: Energy demand for agriculture from various carriers

Carrier	2020-21	2025-26	2030-31
HSD (PJ)	471	537	613
Electricity (GWh)	224,144	276,960	343,018

58. This value includes demand for railways (about 26 TWh) and electric vehicles (about 90 TWh).

A4 Supply model details

A4.1 Energy carriers

National production and import constraints on coal, crude and natural gas for some years is given in Table 11.

Table 11: Limits on national production and import of primary energy carriers

Carrier	2021		2026		2031	
	Production	Import	Production	Import	Production	Import
Steam coal (MT)	805	450	989	450	1216	450
Coking coal (MT)	0	300	0	300	0	300
Crude (MT)	32	500	34	500	36	500
Natural gas (BCM)	31	100	34	100	38	100

Taxes modelled on domestic coal include the GST compensation cess, GST, royalty and contribution to the District Mineral Fund. Only GST is levied on petroleum products under GST, while all the relevant customs, excise, sales tax, VAT etc. are levied on products such as MS and HSD to reflect their high levels of taxation. These are estimated based on the price break-up of these products in the four largest cities of the country, as published in the Petroleum Statistics.

A4.2 Energy conversion technologies

Detailed assumptions made in PIER regarding various energy conversion technologies are given in this section.

Electricity generation technologies

Table 12: Legacy and under-construction capacity of the important electricity generation technologies

Technology	Legacy Capacity (GW)	Must-add capacity (GW)	Lifetime (years)
Coal	257	41	40
Gas	32	0.4	25
Large hydro	42	12	40
Nuclear	7	5	40
Solar	36	39	25
Wind	41	11	25
Total (all technologies)	431	108	

Table 13: Maximum electricity generation capacity addition permitted in a year (GW)

Technology	Max Capacity	Rationale
Coal	20	From FY26 given coal's gestation period. Roughly equal to historical highest coal capacity addition in India
Gas	4	From FY23; not much expected given non-availability of gas
Large hydro	1.5	From FY28 given hydro's gestation period
Nuclear	0	No new capacity expected in model duration given its lead times
Solar	30	From FY26. These values roughly permit addition of enough capacity to meet the GoI target of 450 GW of solar+wind by 2030. For comparison, China had added 50 GW of solar and 24 GW of wind in a single year way back in 2018.
Wind	14	

Table 14: Conversion efficiency and self-consumption of various technologies

Technology	Efficiency	Self-consumption	Remarks
Existing coal capacity	35.7%	8%	CEA data; 0.5% added to self-consumption to reflect impact of installing pollution control equipment by non-retiring capacity
New coal capacity	37.4%	7.5%	CERC 2019 regulations; 1% added to self-consumption to reflect impact of installation of pollution control equipment
CCGT	40.4%	2.75%	CERC regulations
OCGT	28.1%	1%	CERC regulations
Nuclear	N.A.	10% for existing; 9% for new	Based on past trends
Large and small hydro	N.A.	1%	CERC regulations
Biomass	23.9%	10%	CERC regulations
Solar PV	N.A.	0.25%	CERC regulations
Wind	N.A.	0%	CERC regulations

Table 15: Annualized fixed costs of new capacity of electricity generation technologies (Lakh ₹/MW/year)

Technology	Fixed cost (Lakh ₹/MW/year)	Remarks
Coal	99.3	Estimated from assumption of overnight capex being 8.75 cr ₹ / MW, which includes 0.75 cr ₹ / MW for pollution control equipment to comply with MoEFCC norms. Constant through model period.
Gas (OCGT)	64.5	Estimated from assumption of overnight capex being 5 cr ₹ / MW. Constant through model period.
Large hydro	108.7	Based on recent tariff order for Rampur hydro-electric plant. Constant through model period.
Nuclear	201.5	Estimated from approved tariff of around 3.5 ₹/kWh and actual PLF of nuclear plants. Constant through model period.
Solar	38.2	Estimated from assumption of overnight capex being 4 cr ₹ / MW. This value is for FY21, which reduces at 2% a year (in constant 2019 ₹)
Wind	61.8	Estimated from assumption of overnight capex being 7 cr ₹ / MW. This value is for FY21, which reduces at 1% a year (in constant 2019 ₹)

Table 16: Operating characteristics of new capacity of electricity generation technologies

Technology	Max annual CUF (%)	Max day-slice CUF (%)	Ramp rate (% per hour)	Remarks
Coal	85%	85%	10%	Regulatory norms
Gas	85%	85%	50% (CCGT) 100% (OCGT)	Regulatory norms
Large hydro	100%	21% - 47%	100%	Varies by season depending on CUFs seen in recent years
Nuclear	66%	66%	1%	CUF seen in practice
Solar	100%	[See Remarks]	N.A.	State-wise CUF profile taken from (Spencer *et al.*, 2020). Average annual CUF of new installations goes from 21% in FY21 to 26% in FY31.
Wind	100%	[See Remarks]	N.A.	State-wise CUF profile taken from (Spencer *et al.*, 2020). Average annual CUF of new installations goes from 28% in FY21 to 34% in FY31.

Variable input processing costs

Rumi also allows modelling additional 'variable costs' for technologies that use an input fuel (i.e. coal, gas and biomass for electricity generation technologies), to account for the costs of processing the input fuel[59]. For electricity, these are estimated from actual tariffs and approximate delivered cost of fuel, and form a very small part of the total cost.

The additional variable cost of processing crude in a refinery is hard to obtain. It has been approximated through a back-calculation by considering the difference between refinery-gate price of a product as published by the Oil Marketing Companies and crude price, and subtracting the annualized fixed cost component from this difference. These approximated values range from as little as 0.085 ₹/kg of HSD to 21 ₹/kg for ATF. Better availability of data can help improve this aspect of the model.

A4.3 Energy transfers

Intra-regional electricity losses

The reduction trajectory in state-wise T&D losses as published by the CEA in its General Review for the last 14 years (2006 to 2019) has been used to project future state-wise T&D losses, subject to the constraint that no state's T&D losses fall below 12% and the national T&D loss figure does not fall below 15%. These are then aggregated into regional T&D losses (i.e. both inter- and intra-region losses) by combining states in a region weighted by their electricity consumption. POSOCO's data for February 2021 revealed that the share of electricity used in a region imported from other regions was as follows: ER 10.2%, NER 21.3%, NR 27.5%, SR 19.2% and WR 5.4%. These values were used as the basis to calculate the intra-regional (i.e. distribution) losses for each region for each year up to FY31 based on the T&D loss projections described above. Table 17 shows the intra-regional losses modelled for the various regions.

59. The delivered cost of the fuel used is calculated separately based on the cost of the fuel, the applicable taxes and the transportation cost of the fuel.

Table 17: Intra-regional electricity transfer losses modelled in PIER

Region	FY21	FY26	FY31
ER	23.3%	20.8%	18.5%
NER	26.7%	23.1%	20%
NR	19.2%	16.7%	14.8%
SR	16.1%	15%	14.6%
WR	20%	17.4%	15%

Intra-regional electricity distribution costs

Tariff orders for nine major states (Andhra Pradesh, Bihar, Chhattisgarh, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh) over a few years were consulted to get approximate electricity distribution costs and their trends in various states. These were used to aggregate region-level electricity distribution costs. Table 18 gives the intra-regional electricity distribution costs as modelled in PIER as discovered through this approach.

Table 18: Intra-regional electricity distribution costs modelled in PIER (₹/kWh)

Region	FY21	FY26	FY31
ER	1.55	1.65	1.76
NER	1.80	1.93	2.06
NR	2.35	2.52	2.71
SR	1.75	1.87	1.99
WR	2.30	2.47	2.65

Electricity transmission limits

Inter-regional transmission capacities modelled in PIER are tabulated in Table 19. As can be seen, no electricity transmission capacity exists between NER and any other region except ER, and no transmission capacity exists between NR and SR too.

Table 19: Inter-regional electricity transmission limits modelled in PIER (GW)

Region pair	FY21	FY26	FY31
ER-NER	15.4	17.9	20.4
ER-NR	31.2	37.1	42.2
ER-SR	6.1	7.1	8.1
ER-WR	16.7	19.4	22.1
NER-NR	0	0	0
NER-SR	0	0	0
NER-WR	0	0	0
NR-SR	0	0	0
NR-WR	24.5	28.5	32.4
SR-WR	10.3	11.9	13.5

Coal transit costs

Coal transport costs as modelled in PIER are given in Table 20. These are inferred based on the coal freight costs of Indian Railways and approximate distances between regions. These are kept constant across years.

Table 20: Inter-regional coal transport costs modelled in PIER (₹ / tonne)

From/To Region	ER	WR	NR	SR	NER
ER	797.2	2399.6	2497.6	2776.7	2497.6
WR	2399.6	1054.7	1838.6	2160.3	3354.5
NR	2497.6	1838.6	926	3029.6	3174
SR	2776.7	2160.3	3029.6	926	3787.9
NER	2497.6	3354.5	3174	3787.9	926

A5 Scenarios and sensitivity runs

A5.1 Scenarios

Table 21 presents the details of all the major changes made to inputs and assumptions in the ORS and PRS scenarios compared to the Reference scenario.

Table 21: Significant parameter changes under the various scenarios modelled in PIER

Parameter	Description
GDP	GDP growth rates changed only in FY22 and FY23. Compared to 9.5% and 6.9% respectively in FY22 and FY23 in the Reference scenario, GDP growth rates are 9.95% and 8.2% respectively for these years in the ORS and 7% and 6% respectively for these years in the PRS.
MPCE	MPCE increases in ORS and decreases in PRS due to GDP growth. In addition, in the ORS, MPCE growth rates of lower two quintiles in all states and urban-rural geographies are increased by 7% and 5% respectively. Further, MPCE growth rates of all quintiles in both urban and rural areas of 'poorer' states are increased by 10%, where 'poorer' states are defined as all states that fall in the bottom tertile of per-capita GSDP in 2018-19 as per data published by MoSPI. The changes in the PRS are the reverse of changes in the ORS (i.e. the MPCE growth rates of the bottom two quintiles and poorer states are decreased by equivalent amounts). These changes lead to changed ownership and use of appliances and cooking fuel choices across scenarios.
Trigger and reference temperatures	In the ORS, compared to the Reference scenario, the trigger and reference temperatures are reduced by 0.5 ^{0}C for the top two MPCE bands, as increased incomes may lead households to seek greater comfort at lower temperatures. In the PRS, due to lower incomes, it is assumed that people would use cooling appliances at higher temperatures. Hence, the trigger and reference temperatures are increased by 1 ^{0}C each for the lower two MPCE bands and by 0.5 ^{0}C each for the top three MPCE bands.
Appliance efficiencies	Greater investments into efficiency in the ORS means that, fleet efficiencies of most appliances and technologies improve at a rate that is 10% better than the Reference scenario. In the PRS scenario they improve at a rate that is 10% slower than the Reference scenario.
Appliance ownership by efficiency	The only appliances for which the ownership by efficiency rating changes are ACs and refrigerators (the only other appliance modelled with multiple efficiency levels is lighting and their ownership does not change across scenarios). In the ORS, compared to the Reference scenario, annually 5% fewer households use 3 star ACs and refrigerators and 2.5% more households use 4 star and 5 star ACs and refrigerators. The situation is the reverse in the PRS.
Transport energy demand	Transport fuel demand is modelled based on GDP elasticity and hence automatically changes with the change in GDP. Transport electricity demand is modelled extraneously based on literature. For the ORS scenario, instead of 60 TWh as the demand from electric vehicles in FY30 in the Reference scenario, 73 TWh is assumed. For the PRS, 47 TWh is assumed as the electricity demand from electric vehicles in FY30. These values correspond to the upper and lower ends of the range of possible electricity demand from electric vehicles projected in (IEA, 2021a).

Parameter	Description
Agricultural energy demand	Agriculture fuel demand trajectories change across scenarios, whereas electricity demand does not.
Capacity addition limits	Increased GDPs, capital availability and optimism result in 10% greater limits on addition of renewables and storage capacity, and 5% greater limits on addition of capacities of all other technologies, in the ORS in all years compared to the Reference scenario. In the PRS, the situation is reversed, i.e. capacity addition limits are lower by 10% for renewables and storage and 5% for other technologies compared to the Reference scenario.
Electricity distribution losses	In the ORS, for each year and each region, the electricity transit losses from the region to itself is 5% lower than in the Reference scenario. In the PRS, the electricity transit losses from a region to itself is higher by 10% compared to the Reference scenario for each region and year. In both scenarios, there is no change in the losses across distinct regions. Note that these changes come at 'no cost' – i.e. distribution costs do not increase or decrease in the scenarios.
Retirement of old coal plants	In the PRS, due to reduced investment sentiments, older coal plants (i.e. legacy capacity) are not retired at the age of 40 years as in the Reference scenario, but retired at the age of 50 years. This leads to two changes. One, the retirement schedule of coal plants changes with lesser retirements in the PRS. Two, since these older plants are going to run longer, all old coal capacity is assumed to need pollution control equipment – increasing both its self-consumption by 1% and fixed costs by a certain amount. There are no equivalent changes in the ORS.

A5.2 Sensitivity runs

In addition to the PRS and ORS scenarios, a set of sensitivity runs were made to ascertain the role played by certain key assumptions. These runs are described below.

1. **Maximum appliance efficiency:** It is assumed that, in FY31, the stock of all residential appliances is at the highest possible efficiency level. Thus, all ACs and refrigerators are the equivalent of 5-stars in FY31 and all lighting equipment are LEDs. Similarly, all fans and coolers are very efficient (about 47 W and 140 W respectively), as are LPG / PNG cookstoves (70% efficiency) and induction cookstoves (90% efficiency). Note that, for this sensitivity run, these efficiency levels are just assumed – i.e. the costs of the appliances are not factored in. Moreover, this efficiency of the stock in FY31 is reached through stock replacement over the model period (and not an entire stock replacement in FY31). This hypothetical run helps to understand the potential impact of aggressive efficiency improvement in the residential sector.
2. **Trigger and reference temperatures:** In this pair of complementary sensitivity runs, the trigger temperatures for all cooling appliances and the reference temperature (set point) of ACs are either increased by 2 ^{0}C or reduced by 2 ^{0}C for all years, geographies and consumer types. Thus, the trigger temperature for fans increases / decreases from 28 ^{0}C in the Reference scenario to 30 ^{0}C or 26 ^{0}C. For coolers and ACs, depending on the household's MPCE, the temperature at which the cooler or AC is switched on changes from the value between 30 ^{0}C and 35 ^{0}C in the Reference scenario, to a value between 32 ^{0}C and 37 ^{0}C, or a value between 28 ^{0}C and 33 ^{0}C in the sensitivity runs respectively. These runs once again help to understand how much residential electricity demand is influenced by these behavioural parameters.

3. **Renewable and fossil-fuel costs:** A major determinant of the future trajectory of electricity generation is the relative costs of coal and renewable technologies. To assess the sensitivity of the model results to these assumptions, a pair of complementary sensitivity runs were made. In one run, the costs of input fossil fuels for electricity generation (coal and natural gas) are increased by 10% with respect to the Reference scenario while the capital costs of setting up new solar or wind plants are reduced by 10%. In the complementary run, the roles are reversed – i.e. the costs of coal and natural gas are reduced by 10% with respect to the Reference scenario and the costs of setting up a new solar or wind plant are increased by 10%.

4. **Storage costs:** Similar to the relative costs of fuels and new technologies, a potentially important determinant to absorbing a high share of renewables in the electricity system is the impact of storage costs. In this pair of sensitivity runs, storage costs (both BESS and PHS) are either increased or decreased with respect to the Reference scenario. In the increased storage costs case, for PHS, the upper limit of PHS cost provided in (IRADe, 2020), i.e. ₹ 7 cr / MW is used and for BESS, the advanced (low) trajectory[60] of projected battery pack costs and conservative (high) projections for the balance-of-system costs provided by NREL ATB (NREL, 2021) are used. In the reduced storage costs case, the battery pack costs as given by BNEF (and used in the Reference scenario) continue to be used while the advanced cost estimates from NREL ATB are used for balance of system costs. For PHS, the lower limit of the cost range given in (IRADe, 2020), i.e. ₹ 6 cr / MW, is used.

5. **Lower feasibility of renewables capacity addition:** India's renewable energy capacity addition targets are very ambitious, and a sensitivity run to check the impact of not being able to achieve such high capacity addition was made. In this run, maximum solar and wind capacity addition possible is lowered to about half the limit in the Reference scenario, i.e. a maximum of 215 GW of solar and wind capacity is permitted to be added by FY31 (including that in the construction pipeline) rather than 375 GW in the Reference scenario. This is achieved by permitting only 50% of the maximum capacity addition. Another interesting question is regarding the relative priority of solar and wind in India's capacity addition of solar and wind from FY22 and FY23[61] respectively, compared to the Reference scenario.

6. **Equal feasibility of solar and wind capacity addition:** In the Reference scenario, the maximum amount of solar capacity that can be added is more than twice as much as the amount of wind capacity (30 GW of solar and 14 GW of wind from FY26 onwards). In this sensitivity run, the maximum solar and wind capacity that can be added from FY24 are made equal while keeping the total capacity addition feasibility of solar and wind the same as the Reference scenario. Thus, the 325 GW of solar and wind capacity permitted to be added between FY24 and FY31 is now split as 162.5 GW of solar and 162.5 GW of wind capacity that is permitted to be added in that period, compared to 225 GW of solar and 100 GW of wind in that period in the Reference scenario.

60. The advanced (low) trajectory of NREL ATB battery pack projections are higher than the battery pack price projections from BNEF used in the Reference scenario.

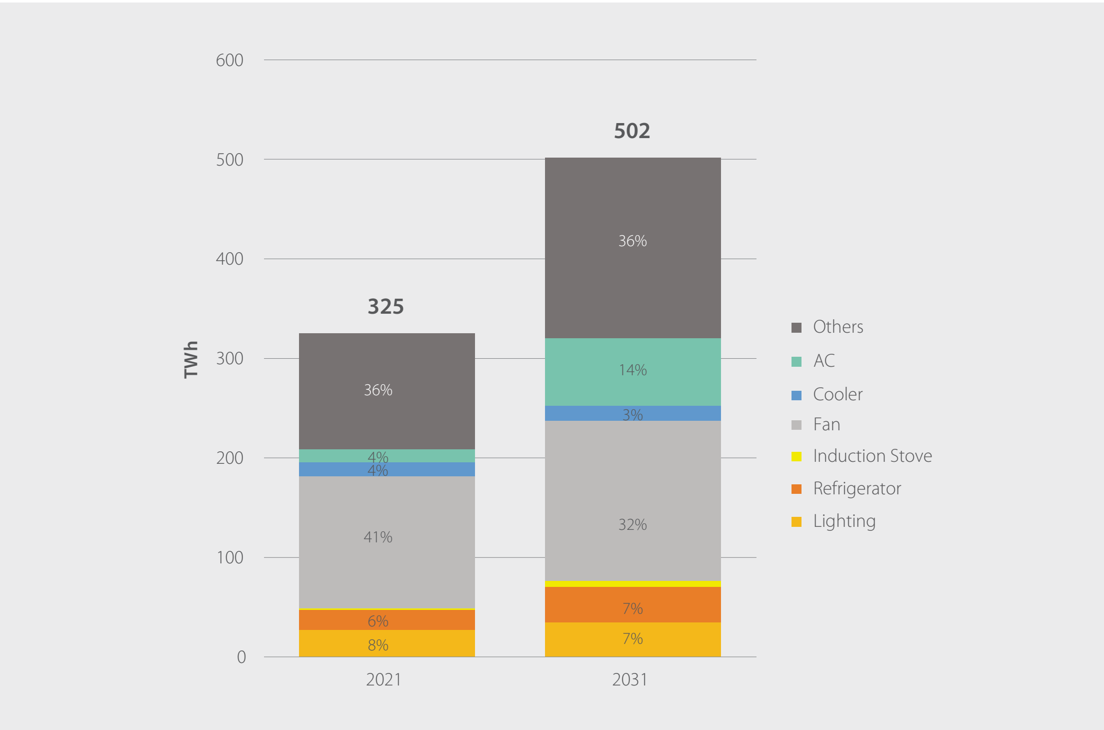
61. These years are chosen to allow the capacity in the construction pipeline to come online.

A6 Some results from the PIER model

A6.1 Results from the Reference scenario

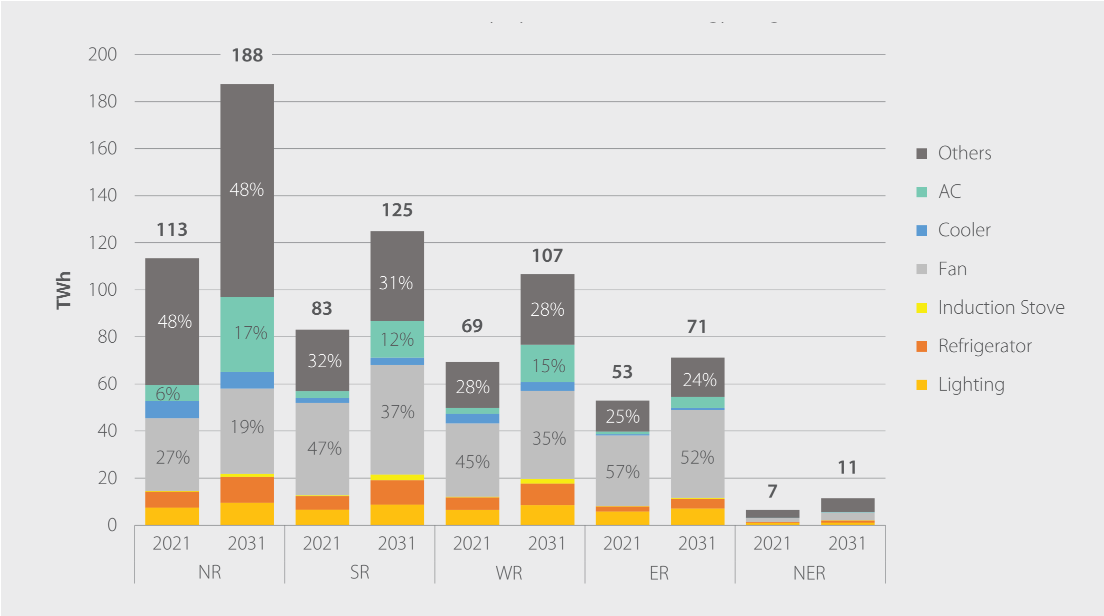
1. **Residential electricity demand:** The bottom-up model of residential electricity demand estimates that national residential electricity demand grows at 4.4% p.a. over the model period going up from 325 TWh in FY21 to 502 TWh in FY31. This is shown in Figure 14. A significant contributor to this demand growth is electricity demanded by ACs, which grows at 18% p.a. during this period and grows to occupy a share of ~14% of all residential electricity demand in FY31 from 4% in FY21. However, given their ubiquitous presence and usage even at lower temperatures, fans continue to be the single largest energy consuming appliance even in FY31, though its share in residential electricity demand drops from 41% in FY21 to 32% in FY31. Interestingly, the share of residential electricity consumed by the space cooling energy service remains roughly constant through the modelling period at about 50%.

Figure 14: Residential electricity demand in FY21 and FY31 as projected by PIER



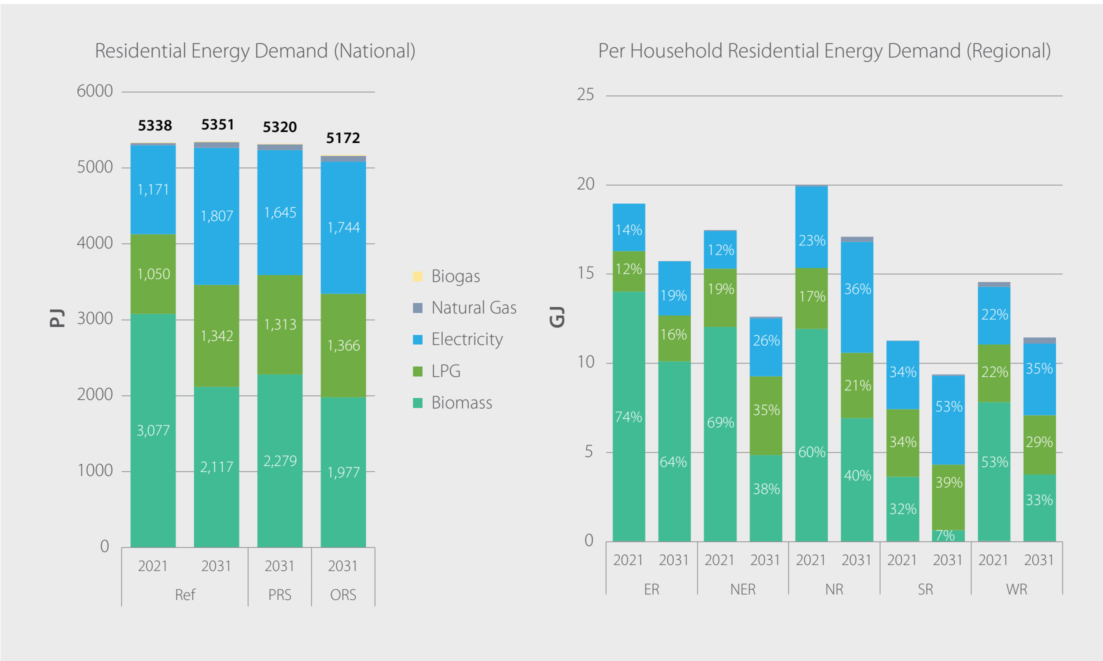
Residential electricity demand has an evening peak as expected, corresponding to lighting and cooling appliance usage. Residential peak load is about 105 GW on a summer evening in FY21 which increases to about 158 GW in FY31 summer evening. Among the regions, NR is the largest contributor to residential electricity demand with its share being about 35% to 37% across the years, with NR's AC and cooler electricity demand contributing nearly 50% to national AC and cooler electricity demand in most years.

Figure 15: Residential electricity demand by region



2. **Residential energy demand:** Figure 16 shows the total energy demanded by households in India in FY21 and FY31. As can be seen, while electricity is an important constituent of residential energy demand, energy required for cooking is an even larger component, forming almost two-thirds of total residential energy use in FY31. This is partly due to the high prevalence of use of solid fuels (biomass) for cooking, which are highly inefficient in addition to being very polluting and unhealthy. Despite programmes such as Ujjwala, they form the single largest component of residential energy use even in FY31, being responsible for about 40% of residential energy demand. In absolute terms though, usage of biomass in the residential sector reduces from 3077 PJ in FY21 to 2117 PJ in FY31.

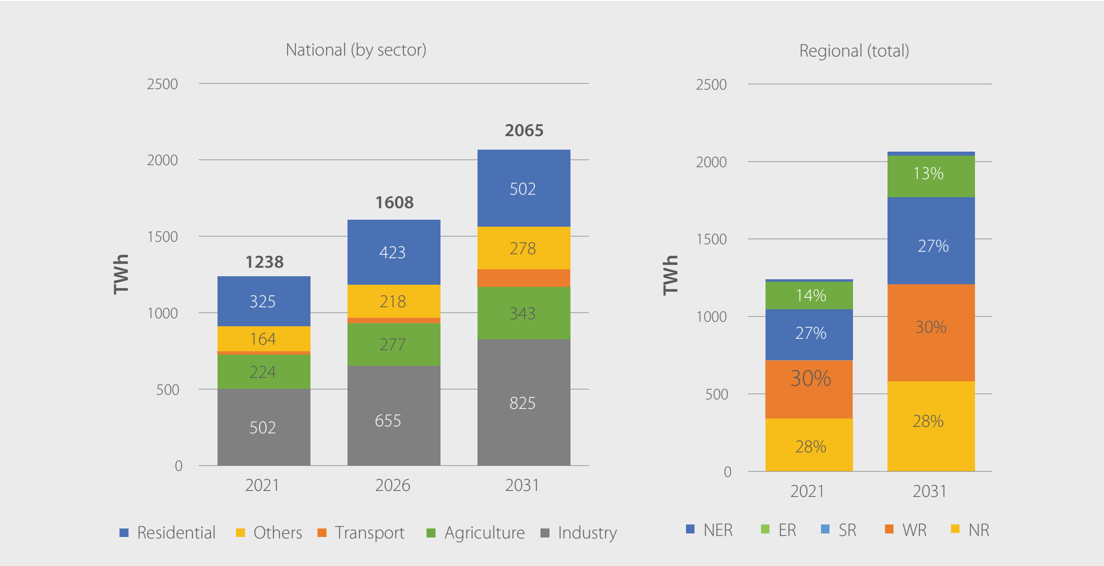
Figure 16: Residential energy demand in FY21 and FY31 projected by PIER



Largely due to this reduction in the use of inefficient biomass, total residential energy demand remains more or less flat between FY21 (5338 PJ) and FY31 (5351 PJ), despite an increase in use of electricity and modern cooking fuels. In particular, the share of electricity in residential energy demand goes up from 22% in FY21 to 34% in FY31. However, the large prevalence of biomass as a primary cooking fuel even in FY31 in the Reference scenario highlights the critical need for more targeted measures to move away from traditional cooking fuels.

3. **Overall electricity demand:** PIER projects that the total end-use electricity demand in the country will grow at a rate of 5.2% p.a. from 1238 TWh in FY21 to 2065 TWh in FY31 (Figure 17). Across regions, WR has the highest demand (about 30% of the national demand) over the years, while ER has the lowest growth rate of 4.3% p.a. The industrial sector is the largest contributor to national electricity demand at around 40% through the model period, while the share of the residential sector is around 24% - 27% over the years. Due to electrification of railways and vehicles, the transport sector has the highest growth rate of 18% p.a. but, given its very low base, it still forms only about 5.6% of end-use electricity demand in FY31.

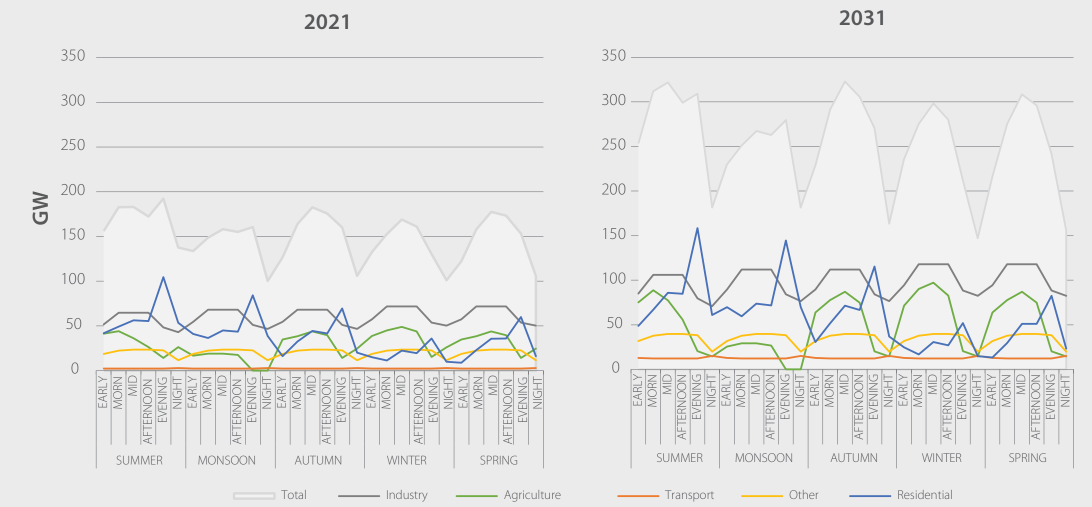
Figure 17: National electricity demand projections



One observation is that ER and NER together account for about 25% of households in the country but only account for about 15% of national electricity demand – possibly pointing to later electrification and relatively lower industrial development in these regions.

4. **Electricity load patterns:** The peak end-use electricity demand as projected by PIER increases from 192 GW in FY21 to 323 GW in FY31. One interesting observation is that while the FY21 peak demand is in summer evening (as may be expected), this shifts to mid-day of autumn (with mid-day of summer having almost the same load) – driven by the shift of agriculture to day time and increasing day-time cooling load.

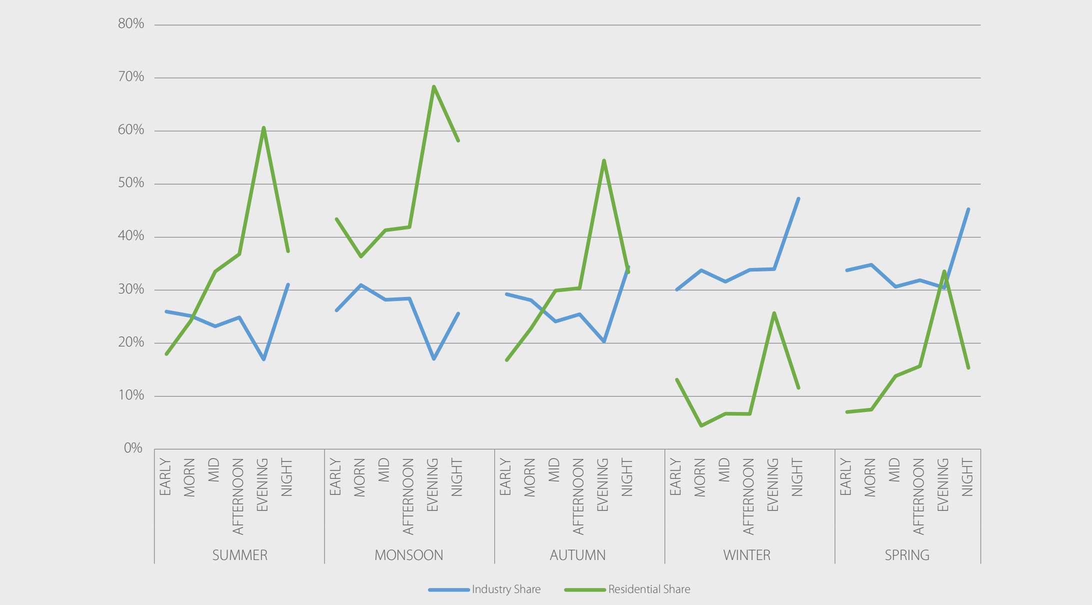
Figure 18: Day-slice-wise load pattern in FY21 and FY31



Note: This figure shows load for day-slices (unequal in hours) for a typical day in a Season, and should not be read as a continuous 'load curve'.

According to projections from PIER, the residential sector contributes to a very high share of overall load in NR in summer, monsoon and autumn, with the share of residential sector in the evening slice going up to 68% on monsoon evenings in FY31. In winter and spring of FY31, industry is the sector that dominates overall load in NR. NER also has a high share of residential load in many seasons.

Figure 19: Sectoral contribution to electricity load in NR (FY31)



It should be remembered that, as explained in Annexure A3, load shapes of all the non-residential sectors have been estimated from scanty evidence. Hence, these insights regarding load patterns may change as and when more information becomes available.

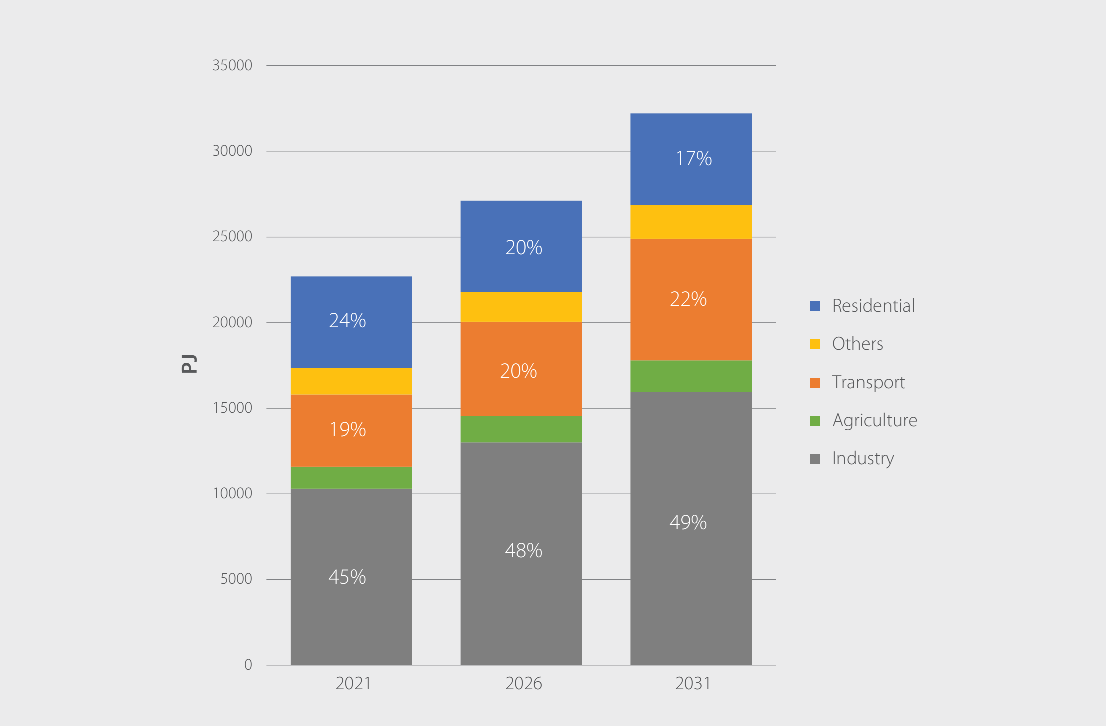
5. **End-use energy demand:** Nationally, end-use energy demand increases from about 23 EJ in FY21 to about 32 EJ in FY31, growing at 3.6% p.a. Due to its predominant role in the residential sector, biomass is the carrier with the single largest energy demand in FY21. But given the increasing demand for electricity (growing at 5.2% p.a.) due to greater electrification of many sectors, and the reducing role of biomass in the residential sector, electricity becomes the energy carrier with the highest demand in FY31 with a share of 23%, up from 20% in FY21. However, if steam coal and coking coal are treated not as separate energy carriers but together, then coal becomes the carrier with the single largest energy demand in all years including FY21, with a share of around 25%.

   Given their high GDP elasticity historically, the carriers whose demand grows fastest are MS (petrol) and PP_OTHER (other petroleum products), which grow at 8% and 7% p.a. respectively, in spite of the MS demand growth being tempered by increasing electrification of transport. LPG demand increases only at 3.1% in spite of attempts to accelerate its adoption through schemes such as Ujjwala.

Figure 20: End-use demand by energy carrier as projected in PIER

The sector with the highest end-use demand across all years is the industrial sector, comprising between 45% and 49%. Transport is the sector with the highest growth rate (5.3% p.a.) of end-use demand (as reflected in the high demand growth rates of MS, ATF and electricity for transport). As a result, its share of overall demand grows from 19% in FY21 to 22% in FY31.

Figure 21: End-use demand by sector over the years

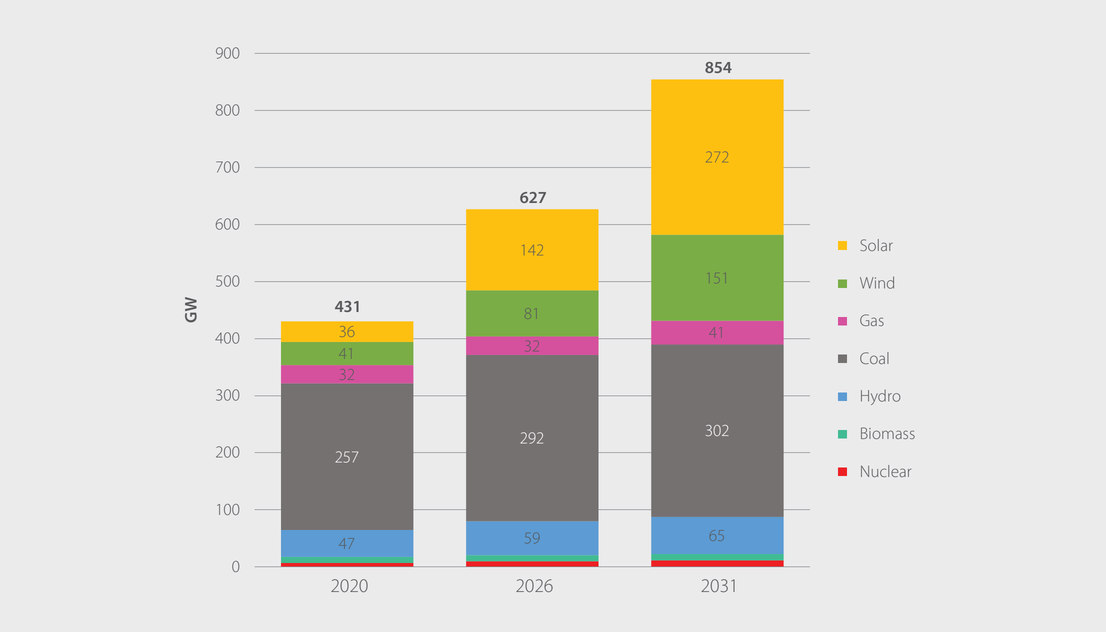


6. **Electricity capacity:** Given the rapid changes taking place in the economics of electricity supply and storage technologies, this is one of the more interesting results of the modelling exercise. We focus on results pertaining to coal, solar and wind-based generation though various other generation technologies are also modelled.

   The total installed capacity nearly doubles from 431 GW[62] at model start (i.e. FY20) to 854 GW in FY31. Installed coal capacity goes up from 257 GW to 302 GW in the same period, with the share of coal in installed capacity falling from 60% in FY20 to 35% in FY31. During the same period, installed solar and wind capacity increase from 36 GW and 41 GW respectively to 272 GW and 151 GW respectively, taking their combined share up from 18% to 50%. This aggressive addition of solar and wind capacity to minimise cost results in 444 GW of renewables[63] by FY31 – marginally short of the government target of 450 GW by 2030, but helping India to easily achieve its NDC target of 40% non-fossil electricity generation capacity by 2030. However, it should be noted that such a capacity addition is contingent on the feasibility of adding significantly higher solar and wind capacity in future years than has been done in the past. This capacity mix is supplemented by about 95 GWh of electricity storage (43 GWh of 4-hour BESS, 28 GWh of 6-hour BESS and 24 GWh of PHS[64]), with almost all the BESS getting added in the last three years of the model as BESS prices drop.

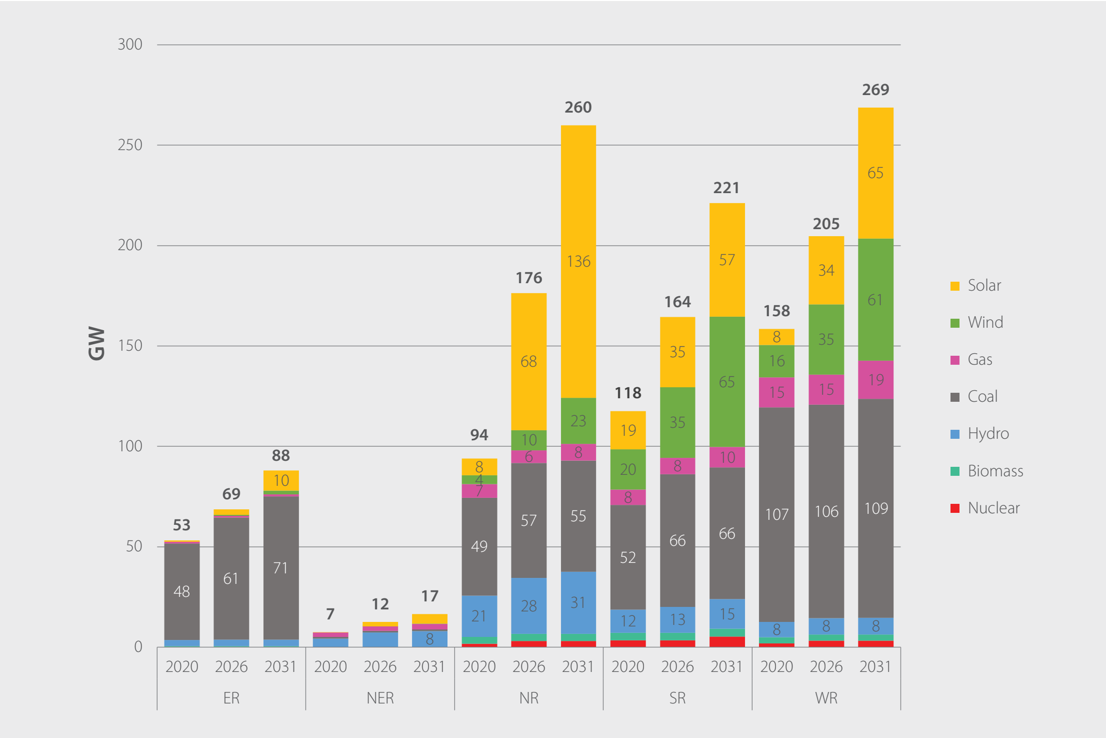
62. The reader is reminded that these figures represent all the capacity and generation in the country, including captive capacity.
63. Renewables include small hydro and biomass based electricity generation capacity, in addition to solar and wind.
64. This consists of 16.5 GWh of pre-existing PHS capacity and 7.9 GWh in the construction pipeline.

Figure 22: Electricity generation capacity projected in PIER



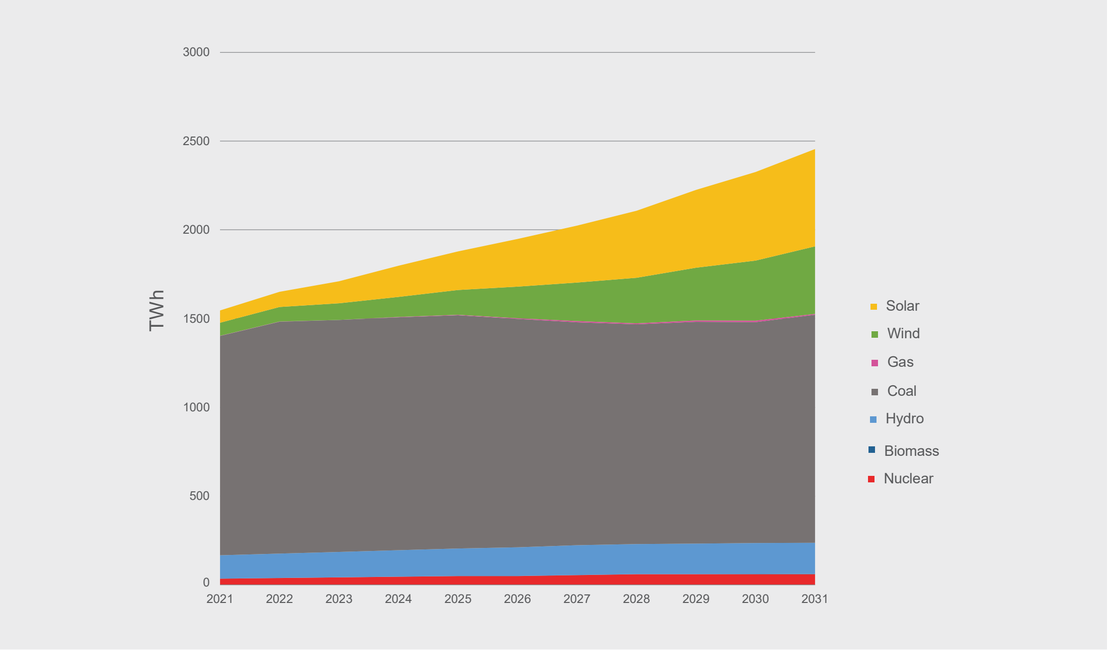
The bulk of new coal capacity addition is concentrated in the ER, where installed coal capacity increases from 49 GW in FY21 to 71 GW in FY31. Coal capacity also increases in SR where it increases from 53 GW to 66 GW. There is not much change in coal capacity in other regions. On the other hand, solar capacity addition is concentrated in NR, where it goes up from 10 GW in FY21 to 136 GW in FY31, driven by favourable potential and CUFs. It also increases significantly in WR (10 GW to 65 GW). SR, which has the highest solar capacity in FY21 (21 GW) reaches 57 GW in FY31. Wind capacity addition is concentrated mostly in SR (20 GW to 65 GW) and WR (17 GW to 61 GW).

Figure 23: Region-wise installed capacity in FY21 and FY31



7. **Electricity supply:** Electricity supply at the bus-bar increases from 1546 TWh in FY21 to 2455 TWh in FY31 at a CAGR of 4.7% p.a. – somewhat lower than the 5.2% growth rate of electricity demand, owing to reducing T&D losses over time. However, the model finds it cost-optimal to not meet the full demand in one slice and there is unserved demand of 1.8 GWh in NR in the summer evening of FY30. According to PIER, electricity supply from coal remains largely flat over the model period, beginning from 1235 TWh in FY21 to reach a peak of 1313 TWh in FY25 and falling marginally to 1285 TWh in FY31. This results in its share in overall generation falling from about 80% in FY21 to about 52% in FY31, though it remains the single largest source of generation even in FY31. This fall in coal's share is almost entirely taken up by solar and wind, whose combined share in generation goes up from about 9% (69 TWh of solar and 73 TWh of wind) in FY21 to 38% (546 TWh of solar and 380 TWh of wind) in FY31. This represents a massive 550% increase in generation from these sources corresponding to the huge capacity increase and improving CUFs. Effectively, this implies that practically all incremental electricity generation demand between FY21 and FY31 is met from solar and wind. It is interesting to note that though there is about 32 GW of CCGT (all of it from before the model period) and 9.3 GW of OCGT installed capacity in FY31, this capacity is used very sparingly[65]. In FY31, the OCGT capacity is not used at all while only 4.9 TWh is generated from the CCGT capacity – indicating that they are used almost exclusively to meet load at very specific periods, as shown in Figure 24.

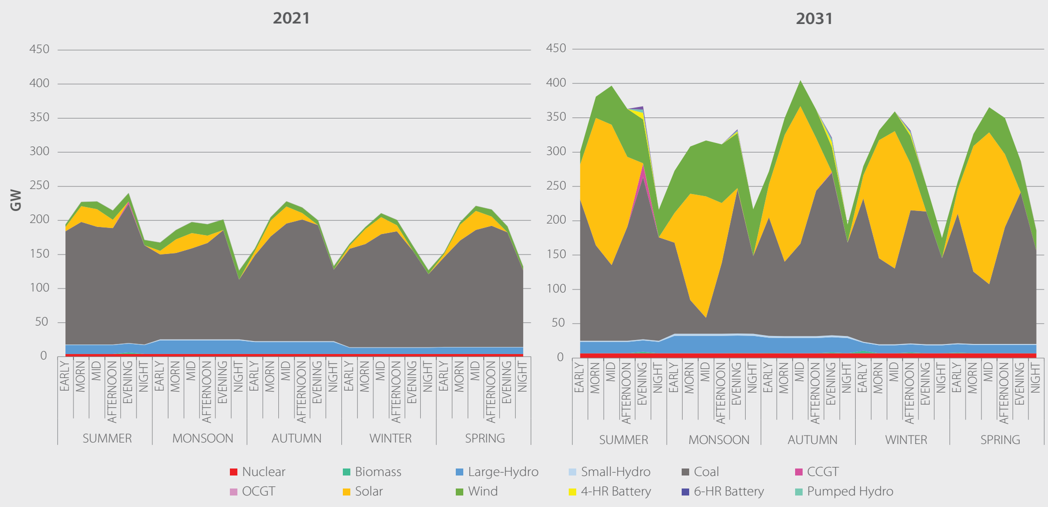
Figure 24: Electricity generation mix in PIER



65. It should be remembered that PIER works at relatively coarser time granularity compared to the operation of the electricity grid.

From supplying about 10%-13% of electricity during the morning and mid-day slices in most seasons in FY21, solar generation contributes 50% and more during both these slices in FY31, with the share of coal in monsoon mid-day supply in FY31 falling to just 7.4%. However, coal remains the mainstay of supply at evening and night even in FY31, contributing to upwards of 70% of supply in most seasons. As expected, storage discharge (in FY31) happens in periods of high load such as evenings when renewables may not be sufficiently available and coal may not be able to ramp fast enough to meet all the demand[66].

Figure 25: Electricity supply shape from various generation technologies in FY21 and FY31



Note: This figure shows supply in day-slices (unequal in hours) for a typical day in a Season, and should not be read as a continuous 'supply curve'

8. **Primary energy supply:** The total primary energy supply (TPES) in the country increases from 33.8 EJ in FY21 to 44.3 EJ in FY31. As with electricity supply, this growth at 2.7% p.a. is lower than the demand growth rate of 3.6% p.a. due to improving efficiencies including the reduction of biomass use in residential energy. As a result, the 'efficiency' of the energy system – i.e. the amount of end-use demand met per unit of supply increases from 67% in FY21 to 73% in FY31.

   Through the model period, coal (steam coal + coking coal) remains the single largest primary energy source in the country, though its share goes down from 56% in FY21 to 50% in FY31. However, the fastest growing primary energy source in the country is 'direct' electricity[67], which grows at 14% p.a. and forms about 10% of the TPES in FY31. Given the rapid rise in demand for transport fuels, the share of crude in TPES also increases from 24% in FY21 to 28% FY31. Given India's limited natural gas resources and the cost of imported gas, its role in the energy mix remains limited and forms just 3.3% in FY31. Biomass use reduces as expected and falls from 14% in FY21 to a still significant 9% in FY31.

66. It should be remembered that PIER works at coarse time-units (minimum 3 hours) which may be under-playing the role of storage.

67. This refers to electricity generated from sources without a 'fuel' (i.e. from solar, wind, large and small hydro and nuclear technologies). Though electricity is technically a derived carrier (and hence 'secondary'), electricity from such sources is considered equivalent to 'primary energy' and counted as part of total primary energy supply.

Figure 26: Total Primary Energy Supply according to PIER

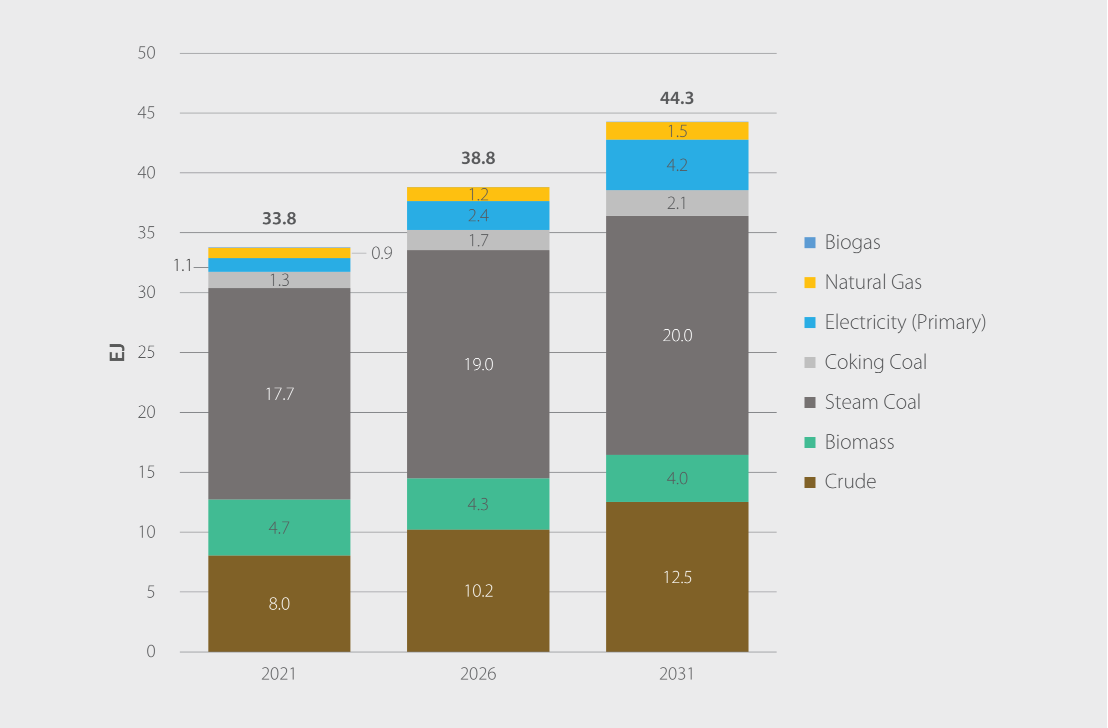
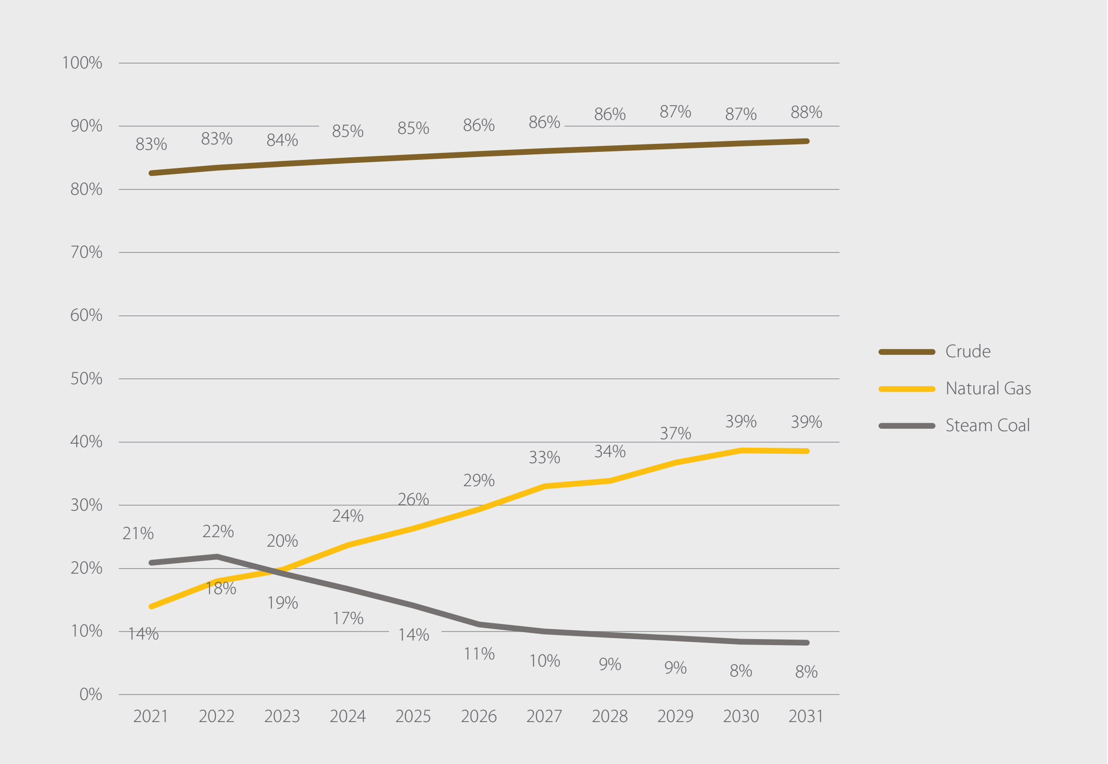


Figure 27: Import dependence for steam coal, crude and natural gas

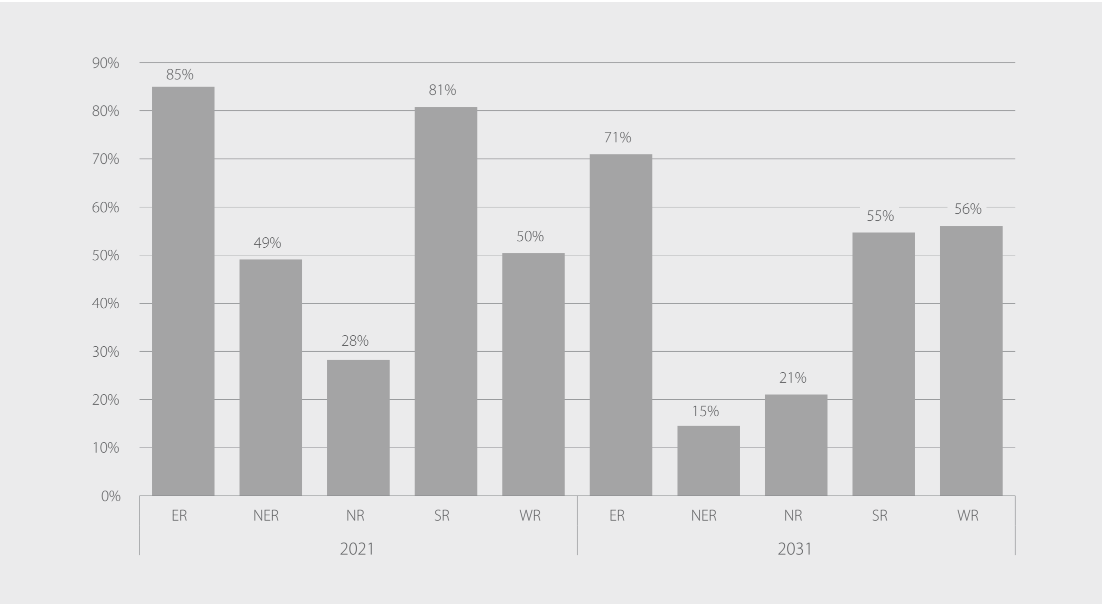


Given the slowing demand for steam coal in power generation and its increasing domestic production, import dependence for steam coal falls from 21% in FY21 to just 8% in FY31. This is in spite of the total demand for steam coal going up from 1018 MT in FY21 to 1150 MT in FY31[68].

Rapid increase in transport fuel demand, and faster increase in natural gas demand (compared to domestic production) results in the import dependence of crude and natural gas increase from 83% and 14% respectively in FY21 to 88% and 39% in FY31[69].

9. **PLF of coal capacity:** The relatively flat generation from coal over the years combined with increasing coal capacity results in the PLF of coal-based generation falling from about 59% in FY21 to 53% in FY31. But there is significant regional difference in this. The coal fleet in ER, with its low coal transportation cost, has a PLF of 71% even in FY31 (and 85% in FY21). In the case of SR, though coal capacity increases (partly driven by the huge 16 GW under construction in SR), generation actually decreases, resulting in the PLF of SR's coal plants falling from 81% in FY21 to 55% in FY31. Coal seems to be used sparingly in NR and NER as they consistently run at low PLFs – the reason for this needs to be investigated.

Figure 28: Region-wise PLF of coal plants in FY21 and FY31

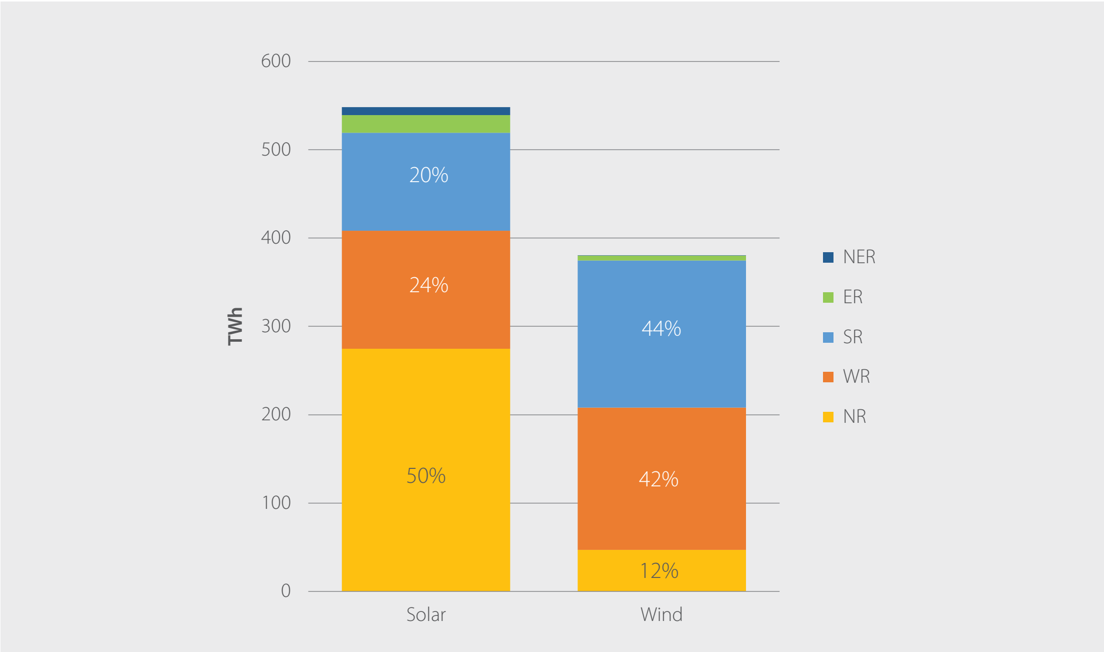


10. **Region-wise renewables generation:** As discussed above, the bulk of solar capacity addition happens in NR while the bulk of wind capacity addition happens in SR and WR. Corresponding to this, NR generates more than half the country's solar electricity in FY31 (275 TWh out of 546 TWh). Similarly, SR (44%) and WR (42%) together contribute over 85% of the country's wind generation.

68. These quantities are in 'domestic steam coal equivalent' terms, i.e. at a calorific value of about 4150 kcal/kg. Note that, as explained in Annexure A4.1, all coking coal used in India is imported by definition.

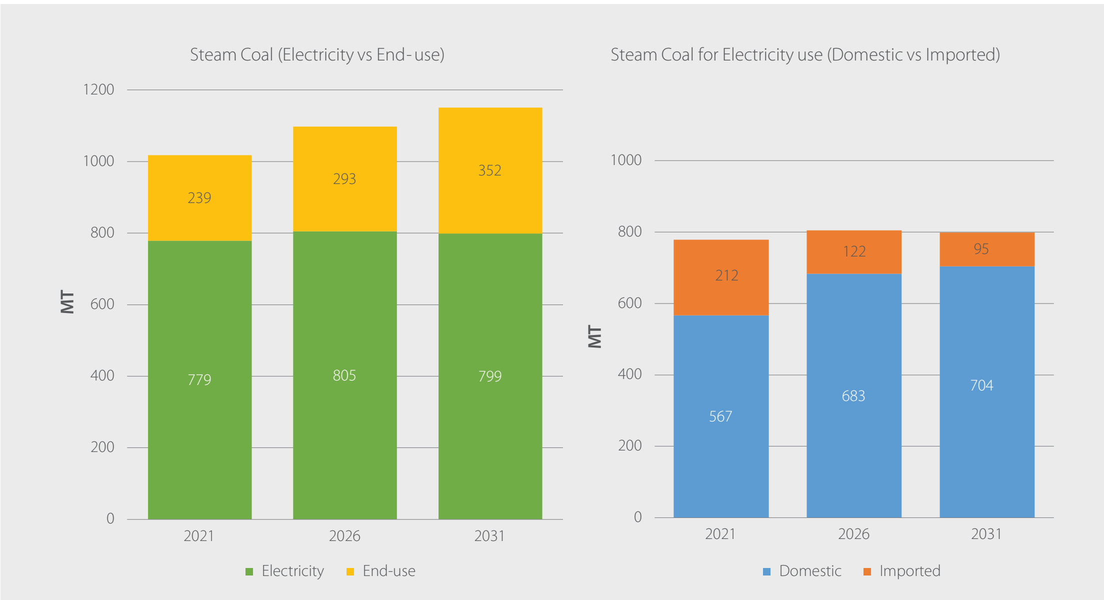
69. Note that the natural gas import dependence figure only represents its use in the energy sector.

Figure 29: Region-wise solar and wind generation



11. **Coal demand:** Of the total 1150 MT[70] of steam coal required in FY31 for all purposes, about 800 MT is required for electricity generation and about 350 MT for industrial use. In FY21, 779 MT of steam coal is used for electricity generation and 239 MT for industrial use. Thus, the share of steam coal being used for electricity generation falls from 76.5% in FY21 to 69.4% in FY31. Of the steam coal used for electricity generation in FY21, 27% (213 MT[71]) is imported. By FY31, this falls to just 12% (95 MT), due to growing domestic production and relatively lower rate of demand growth.

Figure 30: Steam coal: electricity vs end-use and domestic vs imported for electricity generation



70. Measured in 'domestic equivalent terms' of about 4143 kcal/kg

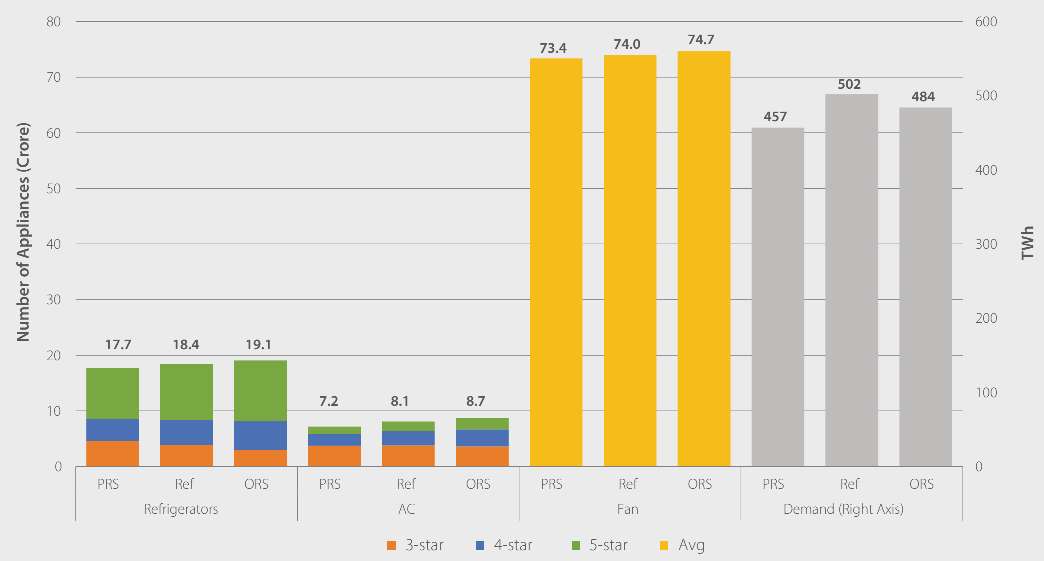
71. Also measured in domestic equivalent terms and hence comparable to total use.

A6.2 Results from the scenarios

The two scenarios representing two different trajectories of recovery from the COVID-19 pandemic present two somewhat different futures for the country and its energy sector. In these scenarios, as described in Annexure A5, various input parameters are changed consistent with the broad storylines corresponding to a pessimistic and optimistic recovery from COVID-19. Following are some of the interesting results emerging from the scenarios.

1. **Residential electricity demand:** One interesting observation is that in both the pessimistic and optimistic recovery scenarios (PRS and ORS respectively), residential electricity demand in FY31 reduces compared to the Reference scenario. This is because, in the PRS, due to reduced MPCEs – particularly of poorer households – there is reduced uptake and use of appliances. This effect is greater than the reduced rate of efficiency improvement of appliance stock and hence residential electricity demand in FY31 in the PRS scenario is only 457 TWh compared to 502 TWh in the Reference scenario. The reduction in demand in the ORS is lower (484 TWh in FY31) but driven by efficiency increases which are faster than the increase in uptake and use of appliances resulting from increased MPCEs. This is shown in Figure 32. The important insight that emerges from this is that, with supportive recovery policies targeted at the poorer households and reviving investments, and concerted efforts to improve efficiency, it is possible to provide greater residential electricity services without increasing electricity demand.

Figure 31: Number of appliances and residential electricity demand across scenarios in FY31



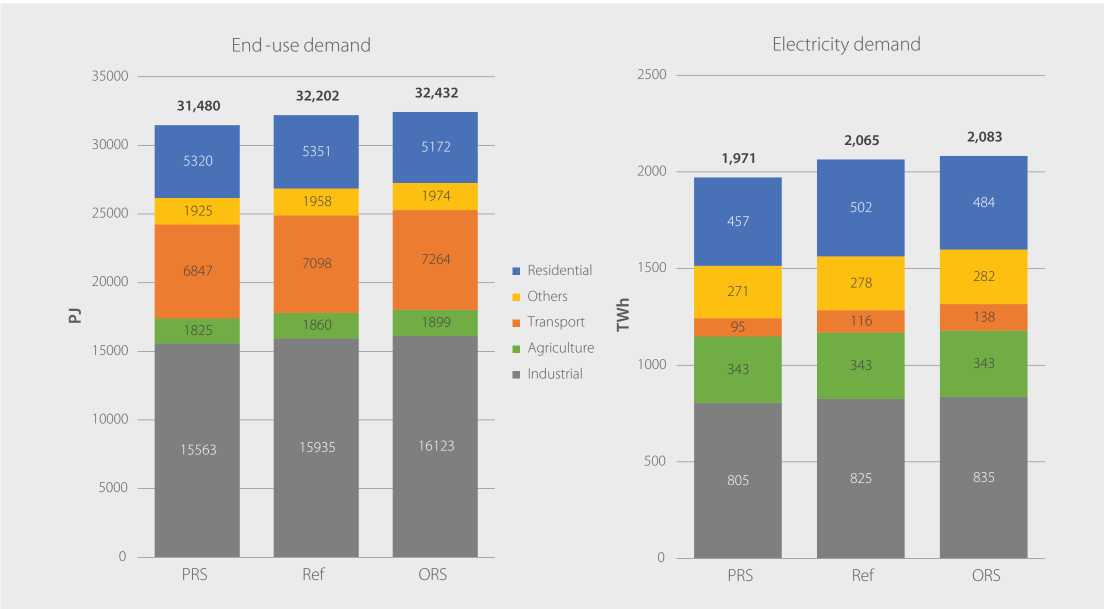
Note: 1 crore is equal to 10 million

2. **Residential energy demand:** Similar to residential electricity demand, the PRS sees a relapse (compared to the Reference scenario) towards using biomass as a cooking fuel, in light of reduced affordability of modern cooking fuels particularly by the poorer households, as indicated by an increase in biomass use of 7.6% and decrease in LPG use of 2.2% in FY31 compared to the Reference scenario. This further underscores the need for an equitable economic recovery to sustain the health and gender benefits of moving to modern cooking fuels. The change is the reverse in ORS where households can better

afford modern fuels. However, given the prices of fuels such as LPG, even with increased MPCEs, LPG use increases only by 1.8% compared to the Reference scenario in FY31, with biomass use falling only by 6.6%. This underscores the observation from the Reference scenario that it is necessary to have a targeted program to enhance adoption of modern cooking fuels in addition to enabling an equitable recovery.

3. **End-use demand:** A slower and weaker economic recovery in the PRS leads to end-use electricity demand in FY31 being only 1971 TWh (as against 2065 TWh in the Reference scenario). However, the total end-use energy demand in FY31 in the PRS is only 2.2% lower than the Reference scenario (31.5 EJ instead of 32.2 EJ) due to lower investments in efficiency improvement. In the ORS, thanks to improved efficiencies of appliances and of the economy[72], electricity demand increases only by ~1% in FY31 (2083 TWh) and end-use energy demand increases by 0.7% (32.4 EJ), pointing to the possibility of sustaining a larger economy with greater demand for energy services with a marginal increase in energy supply.

Figure 32: End-use and Electricity demand in FY31 across scenarios (by sectors)

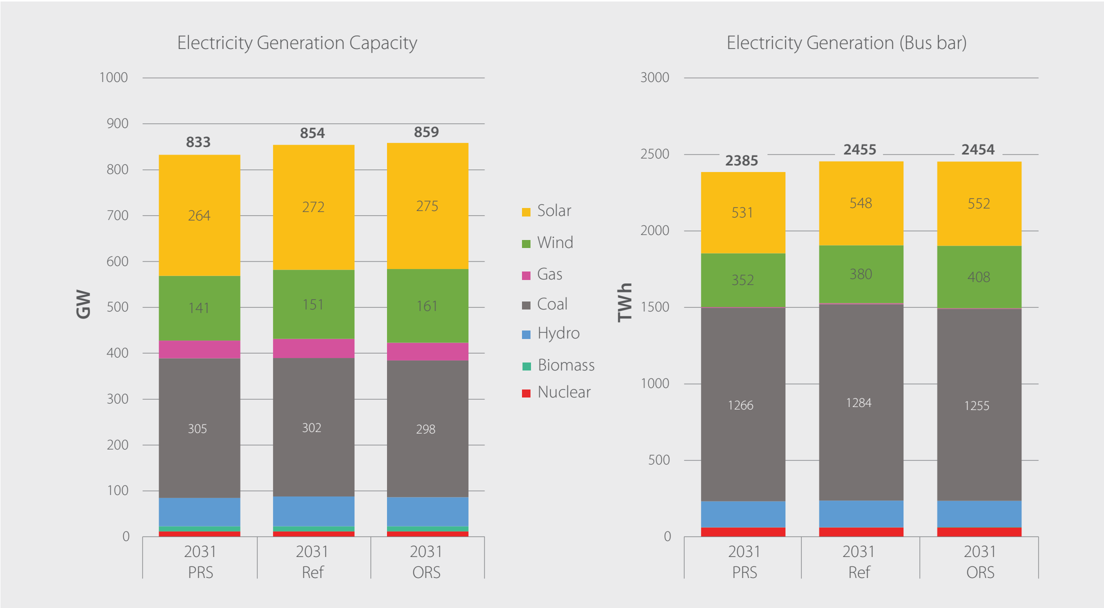


4. **Electricity supply:** The changed demand profile combined with the changed investment climate in the two scenarios leading to different feasibility of capacity addition, results in differing electricity supply mixes. In the PRS, where electricity demand in FY31 is lower by 4.5% compared to the Reference scenario, it results in 22 GW lower installed generation capacity in FY31 compared to the Reference scenario. However, it results in 2.3 GW more installed coal capacity and 18 GW lesser installed solar and wind capacity in FY31 compared to the Reference scenario, given the constraints on investment. This results in a 3% increase in the per-unit cost of electricity in FY31 in the PRS compared to the Reference scenario. In contrast, in the ORS, overall capacity addition over the model period increases by 4 GW but coal capacity addition decreases by 4 GW while about 13 GW more of solar and wind get added. The role of efficiency (of transmission and distribution) is evident in

72. That is, reduced energy intensity of the economy

the fact that, in the ORS, in FY31, the bus-bar generation is 1 TWh lesser than the Reference scenario to meet a demand which is 18 TWh greater than the Reference scenario. Moreover, given the relative economics of the various technologies, the cost per unit of electricity in the ORS in FY31 is 1.2% lower than the Reference scenario.

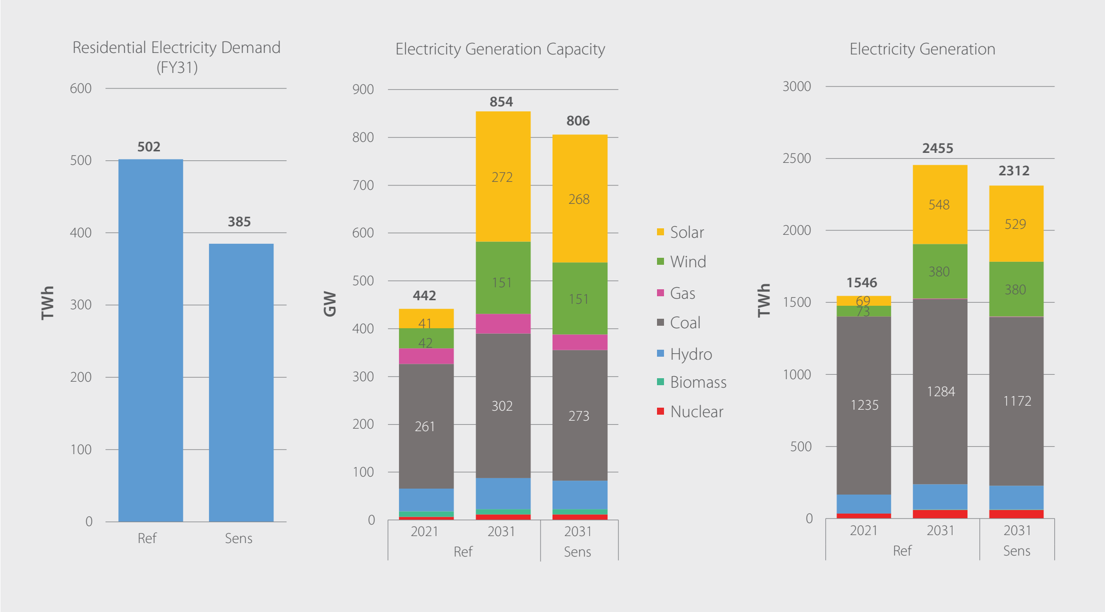
Figure 33: Installed electricity capacity and generation under the three scenarios in FY31



A6.3 Results from the maximum appliance efficiency sensitivity analysis

This sensitivity analysis of a hypothetical situation where all residential appliances being extremely efficient in FY31 yields interesting results. Residential electricity demand in FY31 drastically falls by more than 20% from 502 TWh in the Reference scenario to just 385 TWh in this analysis. Demand from cooling appliances changes from 244 TWh to 187 TWh, though together they still constitute about half the residential electricity demand. This contributes to summer evening load in FY31 changing from 309 GW in the Reference scenario to 271 GW in this scenario, with the share of residential load going from 158 GW to 120 GW. The overall peak (autumn-mid) in FY31 also reduces by 16 GW in this sensitivity run. This has interesting impacts on the generation mix in FY31. The coal capacity required falls from 302 GW (Reference) to 273 GW (sensitivity). This is accompanied by about 5 GW reduction in solar capacity in FY31. Given the load and load shape in this run, there is almost no storage capacity added beyond what is already in the construction pipeline. This results in coal-based generation falling by about 113 TWh to 1172 TWh in FY31. The total cost of electricity in this case is lower than the Reference scenario by about 4.7% (₹ 71,000 crore) in FY31. While this is admittedly a 'utopian' scenario, it nonetheless highlights the important role that energy efficiency can play in terms of reducing capacity addition (and hence costs) and shaving off peak load.

Figure 34: Residential electricity demand, electricity capacity and generation mix in FY31 under "maximum appliance efficiency"



A7 Compilation of PIER outputs

Data Annexure Table 1.1 : Energy Demand

		Reference			Optimistic Recovery Scenario (ORS)			Pessimistic Recovery Scenario (PRS)		
	Unit	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031
Energy Demand	PJ	**22,684.6**	**27,111.5**	**32,201.6**	**22,675.9**	**27,273.3**	**32,431.6**	**22,547.1**	**26,563.9**	**31,479.6**
Residential	PJ	**5,338.2**	**5,344.9**	**5,350.7**	**5,327.0**	**5,257.6**	**5,171.6**	**5,203.1**	**5,270.5**	**5,319.9**
Electricity	PJ	1,171.1	1,524.5	1,806.6	1,179.3	1,528.9	1,743.7	1,026.0	1,351.9	1,644.6
Natural Gas	PJ	29.2	42.0	75.3	29.2	42.1	75.0	29.2	41.9	75.0
LPG	PJ	1,049.6	1,228.0	1,342.4	1,055.0	1,250.6	1,366.1	1,045.8	1,201.9	1,312.6
Biomass	PJ	3,076.9	2,540.4	2,117.2	3,052.0	2,425.9	1,977.4	3,090.8	2,665.2	2,278.7
Biogas	PJ	11.4	9.9	9.3	11.4	10.1	9.4	11.3	9.7	9.1
Agriculture	PJ	**1,283.1**	**1,542.6**	**1,859.8**	**1,285.5**	**1,559.5**	**1,898.9**	**1,280.8**	**1,526.2**	**1,825.1**
Electricity	PJ	806.9	997.1	1,234.9	806.9	997.1	1,234.9	806.9	997.1	1,234.9
HSD	PJ	471.0	537.5	613.4	473.3	553.4	647.0	468.7	522.0	581.3
LPG	PJ	1.6	4.1	7.3	1.6	5.0	12.5	1.5	3.4	4.9
Other PP	PJ	3.7	4.0	4.3	3.7	4.1	4.5	3.6	3.8	4.1
Industrial	PJ	**10,298.8**	**13,001.7**	**15,935.2**	**10,298.8**	**13,150.3**	**16,122.7**	**10,298.8**	**12,706.4**	**15,562.5**
Electricity	PJ	1,808.9	2,357.4	2,971.2	1,808.9	2,386.2	3,007.5	1,808.9	2,300.2	2,899.1
Steam Coal	PJ	4,104.1	5,040.2	6,053.7	4,104.1	5,089.8	6,113.3	4,104.1	4,941.5	5,935.3
Coking Coal	PJ	1,345.9	1,715.8	2,120.7	1,345.9	1,738.3	2,148.6	1,345.9	1,671.2	2,065.6
Natural Gas	PJ	426.8	697.7	949.6	426.8	714.1	971.9	426.8	664.9	904.9
HSD	PJ	375.5	420.6	465.5	375.5	422.8	467.9	375.5	416.2	460.6
LPG	PJ	7.2	7.6	8.0	7.2	7.7	8.0	7.2	7.6	8.0
Other PP	PJ	909.2	1,361.7	1,890.6	909.2	1,386.9	1,925.6	909.2	1,311.8	1,821.3
Biomass	PJ	1,321.1	1,400.7	1,475.9	1,321.1	1,404.5	1,479.9	1,321.1	1,393.1	1,467.8
Transport	PJ	**4,224.5**	**5,497.8**	**7,098.0**	**4,224.6**	**5,570.2**	**7,264.0**	**4,224.4**	**5,358.4**	**6,846.6**
Electricity	PJ	79.4	123.7	417.9	79.6	128.9	496.2	79.3	118.0	341.3
Natural Gas	PJ	148.2	206.9	271.2	148.2	210.1	275.4	148.2	200.6	262.9
MS	PJ	1,195.9	1,846.8	2,561.4	1,195.9	1,884.0	2,613.0	1,195.9	1,772.8	2,458.8
HSD	PJ	2,433.5	2,808.2	3,171.9	2,433.5	2,826.9	3,193.0	2,433.5	2,770.7	3,129.6
ATF	PJ	331.2	451.2	587.3	331.2	457.5	595.7	331.2	438.5	570.8
LPG	PJ	8.5	7.2	6.2	8.5	7.1	6.1	8.5	7.3	6.3
Other PP	PJ	27.8	54.0	82.0	27.8	55.6	84.5	27.8	50.6	76.9
Others	PJ	**1,540.1**	**1,724.5**	**1,958.0**	**1,540.1**	**1,735.8**	**1,974.4**	**1,540.1**	**1,702.3**	**1,925.4**
Electricity	PJ	591.6	786.3	1,001.8	591.6	796.5	1,014.9	591.6	765.8	975.8
Natural Gas	PJ	243.7	168.5	121.4	243.7	165.5	119.3	243.7	174.7	125.9
HSD	PJ	213.1	222.3	230.8	213.1	222.7	231.3	213.1	221.4	229.9
LPG	PJ	111.7	174.3	230.3	111.7	178.1	235.3	111.7	166.8	220.4
Other PP	PJ	89.6	65.2	49.1	89.6	64.2	48.4	89.6	67.2	50.7
Biomass	PJ	290.4	307.9	324.4	290.4	308.7	325.3	290.4	306.2	322.7

Data Annexure Table 1.2 : Energy Demand (CAGR and Shares)

		10 Year CAGR (%)			Share of Total (%)								
		Ref	ORS	PRS	Ref			ORS			PRS		
	Unit				FY2021	FY2026	FY2031	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031
Energy Demand	%	**3.6**	**3.6**	**3.4**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Residential	%	**0.0**	**-0.3**	**0.2**	**23.5**	**19.7**	**16.6**	**23.5**	**19.3**	**15.9**	**23.1**	**19.8**	**16.9**
Electricity	%	4.4	4.0	4.8	21.9	28.5	33.8	22.1	29.1	33.7	19.7	25.6	30.9
Natural Gas	%	9.9	9.9	9.9	0.5	0.8	1.4	0.5	0.8	1.5	0.6	0.8	1.4
LPG	%	2.5	2.6	2.3	19.7	23.0	25.1	19.8	23.8	26.4	20.1	22.8	24.7
Biomass	%	-3.7	-4.2	-3.0	57.6	47.5	39.6	57.3	46.1	38.2	59.4	50.6	42.8
Biogas	%	-2.0	-1.9	-2.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Agriculture	%	**3.8**	**4.0**	**3.6**	**5.7**	**5.7**	**5.8**	**5.7**	**5.7**	**5.9**	**5.7**	**5.7**	**5.8**
Electricity	%	4.3	4.3	4.3	62.9	64.6	66.4	62.8	63.9	65.0	63.0	65.3	67.7
HSD	%	2.7	3.2	2.2	36.7	34.8	33.0	36.8	35.5	34.1	36.6	34.2	31.9
LPG	%	16.6	22.9	12.1	0.1	0.3	0.4	0.1	0.3	0.7	0.1	0.2	0.3
Other PP	%	1.6	2.1	1.1	0.3	0.3	0.2	0.3	0.3	0.2	0.3	0.3	0.2
Industrial	%	**4.5**	**4.6**	**4.2**	**45.4**	**48.0**	**49.5**	**45.4**	**48.2**	**49.7**	**45.7**	**47.8**	**49.4**
Electricity	%	5.1	5.2	4.8	17.6	18.1	18.6	17.6	18.1	18.7	17.6	18.1	18.6
Steam Coal	%	4.0	4.1	3.8	39.9	38.8	38.0	39.9	38.7	37.9	39.9	38.9	38.1
Coking Coal	%	4.7	4.8	4.4	13.1	13.2	13.3	13.1	13.2	13.3	13.1	13.2	13.3
Natural Gas	%	8.3	8.6	7.8	4.1	5.4	6.0	4.1	5.4	6.0	4.1	5.2	5.8
HSD	%	2.2	2.2	2.1	3.6	3.2	2.9	3.6	3.2	2.9	3.6	3.3	3.0
LPG	%	1.0	1.0	0.9	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
Other PP	%	7.6	7.8	7.2	8.8	10.5	11.9	8.8	10.5	11.9	8.8	10.3	11.7
Biomass	%	1.1	1.1	1.1	12.8	10.8	9.3	12.8	10.7	9.2	12.8	11.0	9.4
Transport	%	**5.3**	**5.6**	**4.9**	**18.6**	**20.3**	**22.0**	**18.6**	**20.4**	**22.4**	**18.7**	**20.2**	**21.7**
Electricity	%	18.1	20.1	15.7	1.9	2.2	5.9	1.9	2.3	6.8	1.9	2.2	5.0
Natural Gas	%	6.2	6.4	5.9	3.5	3.8	3.8	3.5	3.8	3.8	3.5	3.7	3.8
MS	%	7.9	8.1	7.5	28.3	33.6	36.1	28.3	33.8	36.0	28.3	33.1	35.9
HSD	%	2.7	2.8	2.5	57.6	51.1	44.7	57.6	50.8	44.0	57.6	51.7	45.7
ATF	%	5.9	6.0	5.6	7.8	8.2	8.3	7.8	8.2	8.2	7.8	8.2	8.3
LPG	%	-3.1	-3.2	-3.0	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1
Other PP	%	11.4	11.8	10.7	0.7	1.0	1.2	0.7	1.0	1.2	0.7	0.9	1.1
Others	%	**2.4**	**2.5**	**2.3**	**6.8**	**6.4**	**6.1**	**6.8**	**6.4**	**6.1**	**6.8**	**6.4**	**6.1**
Electricity	%	5.4	5.5	5.1	38.4	45.6	51.2	38.4	45.9	51.4	38.4	45.0	50.7
Natural Gas	%	-6.7	-6.9	-6.4	15.8	9.8	6.2	15.8	9.5	6.0	15.8	10.3	6.5
HSD	%	0.8	0.8	0.8	13.8	12.9	11.8	13.8	12.8	11.7	13.8	13.0	11.9
LPG	%	7.5	7.7	7.0	7.3	10.1	11.8	7.3	10.3	11.9	7.3	9.8	11.4
Other PP	%	-5.8	-6.0	-5.5	5.8	3.8	2.5	5.8	3.7	2.5	5.8	3.9	2.6
Biomass	%	1.1	1.1	1.1	18.9	17.9	16.6	18.9	17.8	16.5	18.9	18.0	16.8

Data Annexure Table 2.1 : End-use fuel demand, Residential electricity demand by appliances, number of appliances

		Ref			Optimistic Recovery Scenario (ORS)			Pessimistic Recovery Scenario (PRS)		
	Unit	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031
End-use Fuel Demand (Qty)										
# Steam Coal	MT	236.5	290.5	348.9	236.5	293.3	352.3	236.5	284.8	342.1
Coking Coal	MT	48.0	61.2	75.7	48.0	62.0	76.7	48.0	59.6	73.7
Natural Gas	BCM	22.5	29.6	37.6	22.5	30.0	38.3	22.5	28.7	36.3
MS	MT	26.7	41.2	57.2	26.7	42.1	58.3	26.7	39.6	54.9
HSD	MT	80.6	92.0	103.4	80.7	92.9	104.8	80.6	90.7	101.6
ATF	MT	7.4	10.1	13.2	7.4	10.3	13.4	7.4	9.8	12.8
LPG	MT	24.9	30.0	33.7	25.0	30.6	34.4	24.8	29.3	32.8
Other PP	MT	25.6	36.9	50.4	25.6	37.6	51.3	25.6	35.7	48.6
Biomass	MT	301.3	273.1	251.8	299.7	266.0	243.1	302.2	280.5	261.5
Biogas	BCM	0.5	0.4	0.4	0.5	0.4	0.4	0.5	0.4	0.4
# Domestic Equivalent (~4143 kcal/kg)										
Electricity Demand	TWh	**1,238.3**	**1,608.0**	**2,064.6**	**1,240.6**	**1,621.6**	**2,082.6**	**1,198.0**	**1,536.9**	**1,971.0**
Residential	TWh	**325.3**	**423.5**	**501.8**	**327.6**	**424.7**	**484.4**	**285.0**	**375.5**	**456.8**
Space Cooling	TWh	160.2	210.5	243.8	161.6	210.2	231.7	134.1	180.1	216.2
Air-conditioners	TWh	13.3	34.2	68.2	13.6	37.2	72.0	10.7	26.6	53.9
Coolers	TWh	13.8	19.0	14.7	14.1	19.8	14.9	11.0	16.1	13.2
Fans	TWh	133.1	157.2	160.9	133.9	153.2	144.8	112.4	137.4	149.1
Refrigeration	TWh	20.5	27.6	35.4	20.6	27.9	35.8	20.5	27.0	34.7
Cooking	TWh	1.0	2.4	6.2	1.1	2.4	6.2	1.0	2.3	6.1
Lighting	TWh	27.2	30.8	35.1	27.2	30.9	35.2	27.2	30.8	34.9
Others	TWh	116.3	152.2	181.4	117.2	153.2	175.5	102.1	135.3	164.9
Agriculture	TWh	**224.1**	**277.0**	**343.0**	**224.1**	**277.0**	**343.0**	**224.1**	**277.0**	**343.0**
Industrial	TWh	**502.5**	**654.8**	**825.3**	**502.5**	**662.8**	**835.4**	**502.5**	**638.9**	**805.3**
Transport	TWh	**22.1**	**34.4**	**116.1**	**22.1**	**35.8**	**137.8**	**22.0**	**32.8**	**94.8**
Others	TWh	**164.3**	**218.4**	**278.3**	**164.3**	**221.3**	**281.9**	**164.3**	**212.7**	**271.1**
## Number of appliances in use	Crore									
Air-conditioners	Crore	**1.5**	**3.5**	**8.1**	**1.6**	**3.7**	**8.7**	**1.5**	**3.1**	**7.2**
3-Star	Crore	0.7	1.6	3.8	0.7	1.6	3.6	0.7	1.5	3.7
4-Star	Crore	0.5	1.1	2.6	0.5	1.2	3.1	0.5	1.0	2.1
5-Star	Crore	0.3	0.7	1.7	0.3	0.8	2.0	0.3	0.6	1.3
Fans	Crore	**54.2**	**63.6**	**74.0**	**54.2**	**64.3**	**74.7**	**54.0**	**63.1**	**73.4**
Coolers	Crore	**5.6**	**6.6**	**5.6**	**5.6**	**6.7**	**5.5**	**5.6**	**6.6**	**6.0**
Refrigerators	Crore	**10.2**	**14.1**	**18.4**	**10.3**	**14.4**	**19.1**	**10.2**	**13.6**	**17.7**
3-Star	Crore	2.0	2.8	3.8	2.0	2.5	2.9	2.0	3.1	4.6
4-Star	Crore	2.5	3.4	4.6	2.5	3.8	5.3	2.4	3.1	3.9
5-Star	Crore	5.7	7.8	10.1	5.8	8.1	10.9	5.7	7.4	9.2
Lighting	Crore	**84.8**	**97.1**	**111.7**	**84.9**	**97.5**	**112.2**	**84.7**	**96.9**	**110.9**
Incandescent	Crore	8.2	9.4	10.8	8.2	9.4	10.8	8.2	9.4	10.7
CFL	Crore	19.4	22.1	25.3	19.4	22.2	25.4	19.4	22.0	25.1
LED	Crore	57.2	65.6	75.6	57.2	65.9	75.9	57.1	65.5	75.1
## 1 Crore = 10 Million										

Data Annexure Table 2.2 : End-use fuel demand, Residential electricity demand by appliances, number of appliances (CAGR and Shares)

		10 Year CAGR (%)			Share of Total (%)								
		Ref	ORS	PRS	Ref			ORS			ORS		
	Unit				FY2021	FY2026	FY2031	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031
End-use Fuel Demand (Qty)													
# Steam Coal	%	4.0	4.1	3.8									
Coking Coal	%	4.7	4.8	4.4									
Natural Gas	%	5.3	5.5	4.9									
MS	%	7.9	8.1	7.5									
HSD	%	2.5	2.6	2.3									
ATF	%	5.9	6.0	5.6									
LPG	%	3.1	3.2	2.8									
Other PP	%	7.0	7.2	6.6									
Biomass	%	-1.8	-2.1	-1.4									
Biogas	%	-2.0	-1.9	-2.2									
# Domestic Equivalent (~4143 kcal/kg)													
Electricity Demand	%	**5.2**	**5.3**	**5.1**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Residential	%	**4.4**	**4.0**	**4.8**	**26.3**	**26.3**	**24.3**	**26.4**	**26.2**	**23.3**	**23.8**	**24.4**	**23.2**
Cooling	%	4.3	3.7	4.9	49.2	49.7	48.6	49.3	49.5	47.8	47.1	47.9	47.3
Air-conditioners	%	17.8	18.1	17.5	8.3	16.3	28.0	8.4	17.7	31.1	8.0	14.8	24.9
Coolers	%	0.7	0.6	1.8	8.6	9.0	6.0	8.7	9.4	6.4	8.2	8.9	6.1
Fans	%	1.9	0.8	2.9	83.1	74.7	66.0	82.8	72.9	62.5	83.8	76.3	69.0
Refrigeration	%	5.6	5.7	5.4	6.3	6.5	7.1	6.3	6.6	7.4	7.2	7.2	7.6
Cooking	%	19.4	19.4	19.3	0.3	0.6	1.2	0.3	0.6	1.3	0.4	0.6	1.3
Lighting	%	2.6	2.6	2.5	8.4	7.3	7.0	8.3	7.3	7.3	9.5	8.2	7.6
Others	%	4.5	4.1	4.9	35.8	35.9	36.2	35.8	36.1	36.2	35.8	36.0	36.1
Agriculture	%	**4.3**	**4.3**	**4.3**	**18.1**	**17.2**	**16.6**	**18.1**	**17.1**	**16.5**	**18.7**	**18.0**	**17.4**
Industrial	%	**5.1**	**5.2**	**4.8**	**40.6**	**40.7**	**40.0**	**40.5**	**40.9**	**40.1**	**41.9**	**41.6**	**40.9**
Transport	%	**18.1**	**20.1**	**15.7**	**1.8**	**2.1**	**5.6**	**1.8**	**2.2**	**6.6**	**1.8**	**2.1**	**4.8**
Others	%	**5.4**	**5.5**	**5.1**	**13.3**	**13.6**	**13.5**	**13.2**	**13.6**	**13.5**	**13.7**	**13.8**	**13.8**
Number of appliances in use	%												
Air-conditioners	%	**18.0**	**18.8**	**16.6**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
3-Star	%	18.1	17.6	17.9	46.1	46.3	46.6	45.6	43.4	41.3	46.6	49.2	52.0
4-Star	%	18.1	19.9	15.7	32.1	32.3	32.6	32.4	33.9	35.5	31.9	30.6	29.5
5-Star	%	17.4	19.5	14.9	21.8	21.4	20.8	22.0	22.8	23.3	21.6	20.2	18.6
Fans	%	**3.2**	**3.2**	**3.1**									
Coolers	%	**0.0**	**-0.2**	**0.7**									
Refrigerators	%	**6.1**	**6.4**	**5.7**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
3-Star	%	6.7	4.1	8.5	19.6	20.2	20.7	19.1	17.4	15.5	20.1	23.1	26.0
4-Star	%	6.3	7.7	4.8	24.2	24.5	24.7	24.5	26.1	27.6	23.9	22.9	21.9
5-Star	%	5.8	6.5	4.9	56.2	55.3	54.5	56.4	56.6	56.9	56.0	54.0	52.1
Lighting	%	**2.8**	**2.8**	**2.7**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Incandescent	%	2.8	2.8	2.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7
CFL	%	2.7	2.7	2.6	22.9	22.7	22.7	22.9	22.7	22.7	22.9	22.7	22.6
LED	%	2.8	2.9	2.8	67.4	67.6	67.7	67.4	67.6	67.7	67.4	67.6	67.7

Data Annexure Table 3.1 : Annual Rural Residential Electricity Consumption Per Household

	# Number of Households (Crore)			Annual Per-Household Consumption (kWh/HH)								
				Ref			Optimistic Recovery Scenario (ORS)			Pessimistic Recovery Scenario (PRS)		
	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031
National	**20.3**	**21.6**	**22.9**	**792**	**891**	**928**	**794**	**884**	**881**	**688**	**784**	**841**
Andhra Pradesh	1.1	1.2	1.2	876	1,092	1,206	876	1,084	1,162	753	963	1,114
Assam	0.6	0.6	0.7	497	562	766	499	565	740	419	466	658
Bihar	2.0	2.1	2.3	787	717	771	789	708	720	683	626	695
Chattisgarh	0.5	0.5	0.5	712	792	747	713	780	742	620	680	664
Delhi	0.0	0.0	0.0	2,472	3,422	4,519	2,471	3,545	4,454	2,220	3,141	3,901
Goa	0.0	0.0	0.0	2,071	2,375	2,048	2,071	2,306	1,902	1,783	1,965	1,853
Gujarat	0.8	0.8	0.8	843	961	927	843	931	850	727	859	875
Himachal Pradesh	0.2	0.2	0.2	689	784	822	689	779	812	654	744	795
Haryana	0.4	0.4	0.4	1,450	1,855	2,226	1,449	1,817	2,130	1,285	1,675	2,002
Jharkhand	0.6	0.6	0.7	665	707	751	667	696	704	573	595	661
Jammu & Kashmir	0.2	0.2	0.2	580	657	696	584	671	696	538	594	629
Karnataka	0.9	1.0	1.0	654	822	914	655	819	868	576	722	853
Kerala	0.4	0.3	0.2	1,021	1,132	1,229	1,047	1,170	1,159	851	966	1,091
Maharashtra	1.7	1.8	2.0	682	798	790	682	777	748	592	695	713
Madhya Pradesh	1.4	1.6	1.8	632	771	815	634	775	788	560	676	706
Rest of North-East	0.2	0.2	0.2	561	596	780	563	593	746	489	512	678
Odisha	1.0	1.1	1.2	595	648	651	596	641	610	502	540	576
Punjab	0.4	0.4	0.4	1,834	2,206	2,492	1,834	2,310	2,470	1,662	2,001	2,274
Rajasthan	1.3	1.4	1.6	686	836	926	686	828	895	611	750	864
Tamil Nadu	1.0	1.0	1.0	1,103	1,261	1,269	1,103	1,221	1,162	949	1,122	1,184
Telangana	0.7	0.7	0.7	873	1,056	990	873	1,026	919	763	938	898
Uttarakhand	0.2	0.2	0.2	677	774	755	677	763	728	623	701	710
Uttar Pradesh	3.2	3.4	3.6	926	1,016	989	927	1,016	945	794	900	882
Union Territories	0.0	0.0	0.0	1,368	1,667	1,746	1,367	1,630	1,687	1,192	1,452	1,615
West Bengal	1.7	1.7	1.8	562	586	619	563	579	568	479	504	576
# 1 Crore = 10 Million												

Data Annexure Table 3.2 : Annual Urban Residential Electricity Consumption Per Household

	# Number of Households (Crore)			**Annual Per-Household Consumption (kWh/HH)**								
				Ref			**Optimistic Recovery Scenario (ORS)**			**Pessimistic Recovery Scenario (PRS)**		
	FY2021	**FY2026**	**FY2031**	**FY2021**	**FY2026**	**FY2031**	**FY2021**	**FY2026**	**FY2031**	**FY2021**	**FY2026**	**FY2031**
National	**12.4**	**14.5**	**17.0**	**1,326**	**1,592**	**1,703**	**1,343**	**1,611**	**1,663**	**1,172**	**1,421**	**1,556**
Andhra Pradesh	0.6	0.7	0.8	1,162	1,549	1,764	1,161	1,546	1,796	1,018	1,395	1,631
Assam	0.1	0.2	0.2	736	846	1,201	744	882	1,206	644	751	1,046
Bihar	0.3	0.3	0.4	1,049	954	1,027	1,050	932	957	909	828	913
Chattisgarh	0.2	0.2	0.2	1,177	1,354	1,327	1,178	1,350	1,288	1,007	1,182	1,183
Delhi	0.6	0.7	0.8	3,063	4,189	4,874	3,115	4,303	4,724	2,699	3,811	4,448
Goa	0.0	0.0	0.1	2,360	2,681	2,400	2,359	2,606	2,408	2,030	2,230	2,200
Gujarat	0.9	1.0	1.2	1,196	1,378	1,350	1,195	1,360	1,275	1,056	1,253	1,294
Himachal Pradesh	0.0	0.0	0.0	1,101	1,225	1,243	1,115	1,236	1,244	1,053	1,174	1,211
Haryana	0.3	0.3	0.4	2,337	3,133	3,654	2,377	3,170	3,638	2,103	2,814	3,481
Jharkhand	0.3	0.3	0.4	1,154	1,179	1,315	1,156	1,175	1,289	1,012	1,027	1,188
Jammu & Kashmir	0.1	0.1	0.1	898	1,024	1,076	900	1,042	1,084	841	957	994
Karnataka	0.8	0.9	1.0	1,040	1,272	1,358	1,069	1,299	1,346	936	1,170	1,293
Kerala	0.6	0.8	1.0	1,241	1,419	1,467	1,275	1,429	1,424	1,041	1,245	1,330
Maharashtra	1.6	1.8	2.1	1,088	1,335	1,381	1,111	1,337	1,337	970	1,191	1,242
Madhya Pradesh	0.6	0.7	0.9	1,012	1,297	1,369	1,013	1,304	1,363	910	1,148	1,208
Rest of North-East	0.1	0.1	0.2	919	968	1,210	921	961	1,149	799	857	1,088
Odisha	0.3	0.3	0.4	942	1,106	1,226	943	1,111	1,203	811	953	1,051
Punjab	0.4	0.5	0.6	2,403	2,890	3,047	2,400	2,925	3,000	2,148	2,609	2,755
Rajasthan	0.5	0.5	0.6	1,079	1,411	1,526	1,078	1,436	1,512	971	1,281	1,437
Tamil Nadu	1.2	1.4	1.5	1,447	1,605	1,661	1,458	1,673	1,567	1,273	1,444	1,544
Telangana	0.5	0.6	0.7	1,223	1,499	1,531	1,223	1,464	1,473	1,087	1,335	1,381
Uttarakhand	0.1	0.1	0.1	1,106	1,253	1,167	1,126	1,257	1,146	1,024	1,152	1,081
Uttar Pradesh	1.2	1.5	1.8	1,561	1,822	1,853	1,597	1,873	1,858	1,383	1,583	1,653
Union Territories	0.1	0.1	0.1	1,784	2,210	2,185	1,782	2,215	2,147	1,555	1,917	2,007
West Bengal	1.1	1.3	1.5	883	905	1,038	902	905	993	772	791	939

1 Crore = 10 Million

Data Annexure Table 4.1 : TPES, Electricity capacity and generation mix, storage capacity mix

		Reference			Optimistic Recovery Scenario (ORS)			Pessimistic Recovery Scenario (PRS)		
	Unit	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031
Total Primary Energy Supply-TPES	PJ	**33,758.4**	**38,817.9**	**44,270.8**	**33,576.3**	**38,786.8**	**44,253.0**	**33,689.6**	**38,206.2**	**43,545.0**
Electricity	PJ	1,131.8	2,394.5	4,221.3	1,131.8	2,455.5	4,323.9	1,131.8	2,320.8	4,039.3
Steam Coal	PJ	17,661.5	19,042.6	19,959.4	17,501.0	18,871.7	19,713.6	17,580.9	18,741.4	19,728.9
Coking Coal	PJ	1,348.6	1,719.2	2,125.0	1,348.6	1,741.8	2,152.9	1,348.6	1,674.6	2,069.7
Natural Gas	PJ	864.0	1,162.1	1,475.7	858.7	1,178.5	1,495.4	868.7	1,114.2	1,423.5
Crude	PJ	8,043.9	10,228.8	12,518.8	8,052.4	10,377.9	12,728.4	8,037.1	9,972.3	12,168.9
Biomass	PJ	4,697.3	4,260.6	3,961.3	4,672.4	4,151.2	3,829.4	4,711.2	4,373.3	4,105.6
Biogas	PJ	11.4	9.9	9.3	11.4	10.1	9.4	11.3	9.7	9.1
Electricity Generation Capacity	GW	**441.7**	**626.7**	**854.3**	**441.7**	**631.8**	**858.6**	**441.7**	**622.2**	**832.5**
Coal	GW	**260.8**	**291.5**	**302.2**	**260.8**	**289.3**	**298.1**	**260.8**	**296.4**	**304.5**
Renewables	GW	**98.7**	**240.9**	**444.2**	**98.7**	**248.3**	**455.9**	**98.7**	**231.6**	**423.4**
Solar	GW	40.8	142.2	272.4	40.8	147.0	275.0	40.8	137.8	264.0
Wind	GW	42.0	80.8	150.8	42.0	83.6	160.6	42.0	77.9	140.9
Small Hydro	GW	4.8	6.9	9.9	4.8	6.5	9.1	4.8	4.8	7.4
Biomass	GW	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
Gas	GW	**32.3**	**32.3**	**41.3**	**32.3**	**32.3**	**38.3**	**32.3**	**32.3**	**38.3**
CCGT	GW	32.3	32.3	32.0	32.3	32.3	31.8	32.3	32.3	32.0
OCGT	GW	0.0	0.0	9.3	0.0	0.0	6.5	0.0	0.0	6.3
Large Hydro	GW	**43.1**	**52.4**	**55.0**	**43.1**	**52.4**	**54.6**	**43.1**	**52.4**	**54.7**
Nuclear	GW	**6.8**	**9.6**	**11.6**	**6.8**	**9.6**	**11.6**	**6.8**	**9.6**	**11.6**
Energy Storage Capacity	GW	**3.3**	**4.9**	**20.2**	**3.3**	**4.9**	**19.2**	**3.3**	**4.9**	**16.6**
4-Hour Battery	GW	0.0	0.0	10.6	0.0	0.0	10.6	0.0	0.0	8.8
6-Hour Battery	GW	0.0	0.0	4.7	0.0	0.0	3.7	0.0	0.0	2.8
# Pumped Hydro	GW	3.3	4.9	4.9	3.3	4.9	4.9	3.3	4.9	4.9
# 5-hour charge/discharge cycle										
Electricity Generation at Bus Bar	TWh	**1,545.8**	**1,948.5**	**2,455.0**	**1,530.7**	**1,944.6**	**2,453.9**	**1,532.5**	**1,901.6**	**2,384.9**
Coal	TWh	**1,235.4**	**1,286.3**	**1,284.5**	**1,220.9**	**1,265.5**	**1,255.1**	**1,221.6**	**1,261.6**	**1,265.5**
Renewables	TWh	**151.7**	**459.4**	**948.9**	**151.7**	**476.3**	**978.8**	**151.7**	**438.8**	**898.9**
Solar	TWh	69.2	268.5	548.2	69.2	278.5	551.6	69.2	259.6	531.2
Wind	TWh	73.5	177.8	380.3	73.5	185.5	408.2	73.5	170.1	352.4
Small Hydro	TWh	8.6	12.3	17.8	8.6	11.6	16.2	8.6	8.6	13.2
Biomass	TWh	0.5	0.7	2.6	0.5	0.7	2.8	0.5	0.5	2.2
Gas	TWh	**0.9**	**4.0**	**4.9**	**0.3**	**3.9**	**4.4**	**1.4**	**2.4**	**4.6**
CCGT	TWh	0.9	4.0	4.9	0.3	3.9	4.4	1.4	2.4	4.6
OCGT	TWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Large Hydro	TWh	**122.7**	**149.0**	**156.5**	**122.7**	**149.0**	**155.3**	**122.7**	**149.0**	**155.6**
Nuclear	TWh	**35.1**	**49.8**	**60.3**	**35.1**	**49.8**	**60.3**	**35.1**	**49.8**	**60.3**

Data Annexure Table 4.2 : TPES, Electricity capacity and generation mix, storage capacity mix (CAGR and Shares)

		10-yr CAGR			Share of Total (%)								
		Ref	ORS	PRS	Ref			ORS			PRS		
	Unit				FY2021	FY2026	FY2031	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031
Total Primary Energy Supply-TPES	%	**2.7**	**2.8**	**2.6**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Electricity	%	14.1	14.3	13.6	3.4	6.2	9.5	3.4	6.3	9.8	3.4	6.1	9.3
Steam Coal	%	1.2	1.2	1.2	52.3	49.1	45.1	52.1	48.7	44.5	52.2	49.1	45.3
Coking Coal	%	4.7	4.8	4.4	4.0	4.4	4.8	4.0	4.5	4.9	4.0	4.4	4.8
Natural Gas	%	5.5	5.7	5.1	2.6	3.0	3.3	2.6	3.0	3.4	2.6	2.9	3.3
Crude	%	4.5	4.7	4.2	23.8	26.4	28.3	24.0	26.8	28.8	23.9	26.1	27.9
Biomass	%	-1.7	-2.0	-1.4	13.9	11.0	8.9	13.9	10.7	8.7	14.0	11.4	9.4
Biogas	%	-2.0	-1.9	-2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity Generation Capacity	%	**6.8**	**6.9**	**6.5**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Coal	%	**1.5**	**1.3**	**1.6**	**59.1**	**46.5**	**35.4**	**59.1**	**45.8**	**34.7**	**59.1**	**47.6**	**36.6**
Renewables	%	**16.2**	**16.5**	**15.7**	**22.3**	**38.4**	**52.0**	**22.3**	**39.3**	**53.1**	**22.3**	**37.2**	**50.9**
Solar	%	20.9	21.0	20.5	41.4	59.0	61.3	41.4	59.2	60.3	41.4	59.5	62.4
Wind	%	13.6	14.4	12.9	42.5	33.5	33.9	42.5	33.7	35.2	42.5	33.6	33.3
Small Hydro	%	7.6	6.7	4.4	4.8	2.9	2.2	4.8	2.6	2.0	4.8	2.1	1.7
Biomass	%	0.0	0.0	0.0	11.3	4.6	2.5	11.3	4.5	2.4	11.3	4.8	2.6
Gas	%	**2.5**	**1.7**	**1.7**	**7.3**	**5.1**	**4.8**	**7.3**	**5.1**	**4.5**	**7.3**	**5.2**	**4.6**
CCGT	%	-0.1	-0.1	-0.1	100.0	100.0	77.5	100.0	100.0	83.1	100.0	100.0	83.6
OCGT	%				0.0	0.0	22.5	0.0	0.0	16.9	0.0	0.0	16.4
Large Hydro	%	**2.5**	**2.4**	**2.4**	**9.8**	**8.4**	**6.4**	**9.8**	**8.3**	**6.4**	**9.8**	**8.4**	**6.6**
Nuclear	%	**5.5**	**5.5**	**5.5**	**1.5**	**1.5**	**1.4**	**1.5**	**1.5**	**1.3**	**1.5**	**1.5**	**1.4**
Energy Storage Capacity	%	**19.9**	**19.2**	**17.5**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
4-Hour Battery	%				0.0	0.0	52.5	0.0	0.0	55.3	0.0	0.0	53.3
6-Hour Battery	%				0.0	0.0	23.4	0.0	0.0	19.2	0.0	0.0	17.2
# Pumped Hydro	%	4.0	4.0	4.0	100.0	100.0	24.2	100.0	100.0	25.5	100.0	100.0	29.5
# 5-hour charge/discharge cycle													
Electricity Generation at Bus Bar	%	**4.7**	**4.8**	**4.5**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Coal	%	**0.4**	**0.3**	**0.4**	**79.9**	**66.0**	**52.3**	**79.8**	**65.1**	**51.1**	**79.7**	**66.3**	**53.1**
Renewables	%	**20.1**	**20.5**	**19.5**	**9.8**	**23.6**	**38.7**	**9.9**	**24.5**	**39.9**	**9.9**	**23.1**	**37.7**
Solar	%	23.0	23.1	22.6	45.6	58.5	57.8	45.6	58.5	56.4	45.6	59.2	59.1
Wind	%	17.9	18.7	17.0	48.4	38.7	40.1	48.4	38.9	41.7	48.4	38.8	39.2
Small Hydro	%	7.6	6.6	4.4	5.6	2.7	1.9	5.6	2.4	1.7	5.6	2.0	1.5
Biomass	%	17.4	18.1	15.2	0.3	0.2	0.3	0.3	0.2	0.3	0.3	0.1	0.2
Gas	%	**18.3**	**29.6**	**12.4**	**0.1**	**0.2**	**0.2**	**0.0**	**0.2**	**0.2**	**0.1**	**0.1**	**0.2**
CCGT	%	18.3	29.6	12.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
OCGT	%				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Large Hydro	%	**2.5**	**2.4**	**2.4**	**7.9**	**7.6**	**6.4**	**8.0**	**7.7**	**6.3**	**8.0**	**7.8**	**6.5**
Nuclear	%	**5.5**	**5.5**	**5.5**	**2.3**	**2.6**	**2.5**	**2.3**	**2.6**	**2.5**	**2.3**	**2.6**	**2.5**

Data Annexure Table 5.1 : Import dependence and fuel use split between end-use and electricity

		Reference			**Optimistic Recovery Scenario (ORS)**			**Pessimistic Recovery Scenario (PRS)**		
	Unit	**FY2021**	**FY2026**	**FY2031**	**FY2021**	**FY2026**	**FY2031**	**FY2021**	**FY2026**	**FY2031**
Import Dependence										
# Steam Coal	MT	**1,017.9**	**1,097.5**	**1,150.3**	**1,008.7**	**1,087.7**	**1,136.2**	**1,013.3**	**1,080.1**	**1,137.1**
Domestic	MT	805.2	975.6	1,055.6	805.2	968.8	1,045.2	805.2	961.4	1,045.1
Imported	MT	212.7	121.9	94.8	203.5	118.8	91.0	208.1	118.7	91.9
Coking Coal	MT	**48.1**	**61.3**	**75.8**	**48.1**	**62.1**	**76.8**	**48.1**	**59.7**	**73.8**
Domestic	MT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Imported	MT	48.1	61.3	75.8	48.1	62.1	76.8	48.1	59.7	73.8
## Natural Gas	BCM	**22.9**	**30.8**	**39.2**	**22.8**	**31.3**	**39.7**	**23.1**	**29.6**	**37.8**
Domestic	BCM	19.7	21.8	24.1	19.7	21.8	24.1	19.7	21.8	24.1
Imported	BCM	3.2	9.1	15.1	3.1	9.5	15.6	3.3	7.8	13.7
Biomass	MT	**301.9**	**273.8**	**254.6**	**300.3**	**266.8**	**246.1**	**302.8**	**281.1**	**263.9**
Domestic	MT	301.9	273.8	254.6	300.3	266.8	246.1	302.8	281.1	263.9
Imported	MT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fuel use split between end-use and electricity										
# Steam Coal	MT	**1,017.9**	**1,097.5**	**1,150.3**	**1,008.7**	**1,087.7**	**1,136.2**	**1,013.3**	**1,080.1**	**1,137.1**
Electricity	MT	778.7	804.6	798.7	769.6	791.9	781.2	774.1	793.0	792.3
End-use	MT	239.2	292.9	351.6	239.1	295.8	355.0	239.1	287.2	344.8
## Natural Gas	BCM	**22.9**	**30.8**	**39.2**	**22.8**	**31.3**	**39.7**	**23.1**	**29.6**	**37.8**
Electricity	BCM	0.2	1.0	1.2	0.1	1.0	1.1	0.3	0.6	1.1
End-use	BCM	22.7	29.9	38.0	22.7	30.3	38.6	22.7	29.0	36.7
Biomass	MT	**301.9**	**273.8**	**254.6**	**300.3**	**266.8**	**246.1**	**302.8**	**281.1**	**263.9**
Electricity	MT	0.6	0.7	2.8	0.6	0.8	3.0	0.6	0.6	2.3
End-use	MT	301.3	273.1	251.8	299.7	266.0	243.1	302.2	280.5	261.5
# Domestic Equivalent (~4143 kcal/kg)										
## energy use only										

Data Annexure Table 5.2 : Import dependence and fuel use split between end-use and electricity (CAGR and Shares)

		10-yr CAGR			Share of Total (%)								
		Ref	ORS	PRS	Ref			ORS			PRS		
	Unit				FY2021	FY2026	FY2031	FY2021	FY2026	FY2031	FY2021	FY2026	FY2031
Import Dependence													
# Steam Coal	%	**1.2**	**1.2**	**1.2**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Domestic	%	2.7	2.6	2.6	79.1	88.9	91.8	79.8	89.1	92.0	79.5	89.0	91.9
Imported	%	-7.8	-7.7	-7.8	20.9	11.1	8.2	20.2	10.9	8.0	20.5	11.0	8.1
Coking Coal	%	**4.7**	**4.8**	**4.4**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Domestic	%				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Imported	%	4.7	4.8	4.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
## Natural Gas	%	**5.5**	**5.7**	**5.1**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Domestic	%	2.0	2.0	2.0	86.1	70.7	61.4	86.6	69.7	60.6	85.6	73.7	63.7
Imported	%	16.8	17.7	15.2	13.9	29.3	38.6	13.4	30.3	39.4	14.4	26.3	36.3
Biomass	%	**-1.7**	**-2.0**	**-1.4**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Domestic	%	-1.7	-2.0	-1.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Imported	%				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fuel use split between end-use and electricity													
# Steam Coal	%	**1.2**	**1.2**	**1.2**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Electricity	%	0.3	0.1	0.2	76.5	73.3	69.4	76.3	72.8	68.8	76.4	73.4	69.7
End-use	%	3.9	4.0	3.7	23.5	26.7	30.6	23.7	27.2	31.2	23.6	26.6	30.3
## Natural Gas	%	**5.5**	**5.7**	**5.1**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Electricity	%	18.3	29.6	12.4	1.0	3.1	3.0	0.4	3.1	2.7	1.5	2.0	2.9
End-use	%	5.3	5.5	4.9	99.0	96.9	97.0	99.6	96.9	97.3	98.5	98.0	97.1
Biomass	%	**-1.7**	**-2.0**	**-1.4**	**100.0**	**100.0**	**100.0**	**29.8**	**24.5**	**21.7**	**29.9**	**26.0**	**23.2**
Electricity	%	17.4	18.1	15.2	0.2	0.3	1.1	0.1	0.1	0.3	0.1	0.1	0.2
End-use	%	-1.8	-2.1	-1.4	99.8	99.7	98.9	29.7	24.5	21.4	29.8	26.0	23.0
# Domestic Equivalent (~4143 kcal/kg)													
## energy use only													

Works cited

Abhyankar, N. *et al.* (2017) *Techno-Economic Assessment of Deep Electrification of Passenger Vehicles in India.* Available at: https://international.lbl.gov/publications/techno-economic-assessment-deep (Accessed: 2 September 2021).

Agrawal, S. *et al.* (2020) *India Residential Energy Survey (IRES) 2020.* Available at: https://www.ceew.in/india-residential-energy-survey-ires (Accessed: 2 September 2021).

Ali, Mohd. Sahil and Tongia, Rahul (2018) *Electrifying Mobility in India: Future prospects for the electric and EV ecosystem, Brookings India IMPACT Series No. 052018.* Available at: https://www.brookings.edu/wp-content/uploads/2018/05/20180528_impact-series_ev_web.pdf (Accessed: 2 September 2021).

ASSOCHAM-EY (2018) *Electrifying India: Building Blocks for a Sustainable EV Ecosystem.* Available at: https://www.business-standard.com/article/news-cm/india-s-overall-electricity-demand-from-evs-may-reach-69-6-twh-by-2030-assocham-ey-study-118061500287_1.html (Accessed: 2 September 2021).

BEE (2019) *Efficiency standards for ceiling fans (Schedule 8), Government of India.* Available at: https://www.beestarlabel.com/Content/Files/Schedule8-CF.pdf (Accessed: 2 September 2021).

BEE (2021) *The Bureau of Energy Efficiency (Particulars and Manner of their Display on Labels of Electric Ceiling Type Fans) Regulations, 2021, Government of India.* Available at: https://beeindia.gov.in/sites/default/files/228118_pre-publication%20publish.pdf (Accessed: 2 September 2021).

BNEF (2020) 'Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh', *BloombergNEF.* Available at: https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/ (Accessed: 2 September 2021).

Brekke, L. *et al.* (2013) 'Downscaled CMIP3 and CMIP5 climate projections: release of downscaled CMIP5 climate projections, comparison with preceding information, and summary of user needs', *Technical Service Center, Bureau of Reclamation, US Department of the Interior, Denver, CO, 1.* Available at: https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/techmemo/downscaled_climate.pdf.

Byravan, S. *et al.* (2017) 'Quality of life for all: A sustainable development framework for India's climate policy reduces greenhouse gas emissions', *Energy for Sustainable Development,* 39, pp. 48–58.

CEA (2020) *Report On Optimal Generation Capacity Mix For 2029-30, Central Electricity Authority.* Available at: https://cea.nic.in/old/reports/others/planning/irp/Optimal_mix_report_2029-30_FINAL.pdf (Accessed: 2 September 2021).

Compass International (2018) *CAPEX & OPEX Refinery Cost per Barrel a Day Benchmarks Total Installed Engineering, Procurement & Construction (EPC) 2018 Cost Basis.* Available at: https://compassinternational.net/wp-content/uploads/2018/02/TR_Capex.pdf (Accessed: 2 September 2021).

Deorah, S.M. *et al.* (2020) 'Estimating the Cost of Grid-Scale Lithium-Ion Battery Storage in India', *California: Lawrence Berkeley National Laboratory* [Preprint]. Available at: https://international.lbl.gov/publications/estimating-cost-grid-scale-lithium (Accessed: 2 September 2021).

Desai, S. and Vanneman, R. (2012) 'India Human Development Survey-II (IHDS-II), 2011-12'. Inter-university Consortium for Political and Social Research [distributor]. doi:10.3886/ICPSR36151.v6.

Deshmukh, R., Phadke, A. and Callaway, D.S. (2021) 'Least-cost targets and avoided fossil fuel capacity in India's pursuit of renewable energy', *Proceedings of the National Academy of Sciences,* 118(13). doi:10.1073/pnas.2008128118.

Dubash, N.K. *et al.* (2015) 'Informing India's energy and climate debate: policy lessons from modelling studies', *Research Report (New Delhi: Centre for Policy Research and Laxenburg: International Institute for Applied Systems Analysis, April 2015)* [Preprint]. Available at: https://www.cprindia.org/research/reports/informing-india%E2%80%99s-energy-and-climate-debate-policy-lessons-modelling-studies (Accessed: 2 September 2021).

EPWRF (2021) *EPWRF India Time Series – Home Page.* Available at: https://epwrfits.in/ (Accessed: 2 September 2021).

Hlavac, M. (2018) *stargazer: Well-Formatted Regression and Summary Statistics Tables.* Bratislava, Slovakia: Central European Labour Studies Institute (CELSI). Available at: https://CRAN.R-project.org/package=stargazer (Accessed: 2 September 2021).

IEA (2019) *Global EV Outlook 2019, IEA.* Available at: https://www.iea.org/reports/global-ev-outlook-2019 (Accessed: 2 September 2021).

IEA (2020) *World Energy Outlook 2020, IEA, Paris.* Available at: https://www.iea.org/reports/world-energy-outlook-2020 (Accessed: 2 September 2021).

IEA (2021a) *India Energy Outlook 2021, IEA, Paris.* Available at: https://www.iea.org/reports/india-energy-outlook-2021 (Accessed: 2 September 2021).

IEA (2021b) *Net Zero by 2050, IEA, Paris.* Available at: https://www.iea.org/news/pathway-to-critical-and-formidable-goal-of-net-zero-emissions-by-2050-is-narrow-but-brings-huge-benefits (Accessed: 2 September 2021).

IMF (2021) *World Economic Outlook, April 2021: Managing Divergent Recoveries.* Available at: https://www.imf.org/en/Publications/WEO/Issues/2021/03/23/world-economic-outlook-april-2021 (Accessed: 2 September 2021).

IPCC (2014) 'IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change'. Available at: https://www.ipcc.ch/report/ar5/syr/ (Accessed: 2 September 2021).

IPCC (2018) *Global warming of 1.5° C: an IPCC special report on the impacts of global warming of 1.5° C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* Intergovernmental Panel on Climate Change. Available at: https://www.ipcc.ch/sr15/ (Accessed: 2 September 2021).

IRADe (2020) *Role of Pumped Hydro Energy Storage in India's Renewable Transition.* Available at: https://irade.org/Role%20of%20Pumped%20Hydro%20Energy%20Storage%20in%20Indias%20Renewable%20Transition-%20Final%20Report.pdf (Accessed: 2 September 2021).

KERC (2019a) *Determination of tariff in respect of Solar Power Projects (including Solar Rooftop Photo voltaic Projects) for FY-20, Karnataka Electricity Regulatory Commission.* Available at: https://karunadu.karnataka.gov.in/kerc/Documents/Determination%20of%20tariff%20in%20respect%20of%20SOlar%20Power%20Projects%20(including%20Solar%20Rooftop%20Photovoltaic%20Projects%20for%20FY20.pdf (Accessed: 2 September 2021).

KERC (2019b) *Generic Tariff for wind Power Projects, Karnataka Electricity Regulatory Commission.* Available at: http://www.cbip.org/Regulations2018/Data/Karnataka/KR_3_Tariff_Order/2_Karnataka_wind.pdf.

Kochhar, R. (2021) 'In the pandemic, India's middle class shrinks and poverty spreads while China sees smaller changes', *Pew Research Center.* Available at: https://www.pewresearch.org/fact-tank/2021/03/18/in-the-pandemic-indias-middle-class-shrinks-and-poverty-spreads-while-china-sees-smaller-changes/ (Accessed: 18 October 2021).

Meehl, J. (2014) 'CCSM4 model run for CMIP5 future projection (2006-2300) forced by Representative Concentration Pathway 4.5, served by ESGF'. World Data Center for Climate (WDCC) at DKRZ. doi:10.1594/WDCC/CMIP5.NRS4R4.

MERC (2019) *Maharashtra Electricity Regulatory Commission (Terms And Conditions For Determination Of Renewable Energy Tariff) Regulations, 2019, Maharashtra Electricity Regulatory Commission.* Available at: https://www.mahadiscom.in/wp-content/uploads/2020/01/39.-30.12.2019-RE-Tariff-Regulations-2019-English.pdf (Accessed: 2 September 2021).

Ministry of Railways (2021) *Mission 100% Railway Electrification - Moving towards Net Zero Carbon Emission.* Available at: https://indianrailways.gov.in/railwayboard/uploads/directorate/secretary_branches/IR_Reforms/Mission%20100%25%20Railway%20Electrification%20-%20Moving%20towards%20Net%20Zero%20Carbon%20Emission.pdf (Accessed: 2 September 2021).

MNRE (2019) PM KUSUM, *Government of India.* Available at: https://mnre.gov.in/img/documents/uploads/bd0e213a2a8b4c96a59623306ac46e77.pdf (Accessed: 2 September 2021).

MoEF (2009) *India's GHG Emissions Profile: Results of Five Climate Modelling Studies*. Ministry of Environment and Forest, Government of India New Delhi. Available at: http://moef.gov.in/wp-content/uploads/2018/04/GHG_report_2.pdf (Accessed: 2 September 2021).

MoP (2019) *Saubhagya: Household Electrification Status*. Available at: https://saubhagya.gov.in/ (Accessed: 2 September 2021).

MoPNG (2019a) *Refining Capacity of Oil Refineries, Government of India.* Available at: https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1576808 (Accessed: 2 September 2021).

MoPNG (2019b) *Ujjwala Yojana achieves target of 8 crore LPG connections 7 months ahead of target date, Press Information Bureau of India.* Available at: https://pib.gov.in/PressReleseDetail.aspx?PRID=1584445 (Accessed: 4 November 2020).

Neilsen-PPAC (2013) *All India Study on Sectoral Demand of Diesel & Petrol.* Available at: https://www.ppac.gov.in/WriteReadData/Reports/201411110329450069740AllIndiaStudyonSectoralDemandofDiesel.pdf (Accessed: 2 September 2021).

NITI Aayog-RMI (2017) *India Leaps Ahead: Transformative Mobility Solutions for All.* Available at: https://rmi.org/insight/india-leaps-ahead-transformative-mobility-solutions-for-all/ (Accessed: 2 September 2021).

NREL (2021) *Annual Technology Baseline (ATB)*. Available at: https://atb.nrel.gov/electricity/2021/data (Accessed: 2 September 2021).

NSSO MOSPI (2005) *NSS Report No. 514: Household Consumer Expenditure across socio-Economic Groups, 2004-2005.* Available at: http://mospi.nic.in/sites/default/files/publication_reports/514_final.pdf (Accessed: 2 September 2021).

NSSO MOSPI (2012) *NSS Report No. 562: Household Consumer Expenditure across socio-Economic Groups, 2011-12.* Available at: http://mospi.nic.in/sites/default/files/publication_reports/nss_rep_562_27feb15.pdf (Accessed: 2 September 2021).

NSSO MOSPI (2018) *NSS Report No. 584: Drinking Water, Sanitation, Hygiene and Housing Condition in India, July - December 2018.* Available at: http://mospi.nic.in/sites/default/files/NSS7612dws/Report_584_final.pdfhttp://mospi.nic.in/sites/default/files/NSS7612dws/Report_584_final.pdf (Accessed: 2 September 2021).

Ojha, V.P., Pohit, S. and Ghosh, J. (2020) 'Recycling carbon tax for inclusive green growth: A CGE analysis of India', *Energy Policy,* 144, p. 111708. doi:10.1016/j.enpol.2020.111708.

Palchak, D. *et al.* (2017) 'GREENING THE GRID: pathways to integrate 175 gigawatts of renewable energy into India's electric grid, vol. I—national study'. Available at: https://www.nrel.gov/analysis/india-renewable-integration-study.html (Accessed: 3 September 2021).

Parikh, J. *et al.* (2014) *Low carbon development pathways for a sustainable India, IRADe: New Dehli, India.* Available at: http://awsassets.wwfindia.org/downloads/lcdp___report_low_res.pdf (Accessed: 2 September 2021).

Prayas (2018) *Fuelling the Transition: Costs and Benefits of using Modern Cooking Fuels as a Health Intervention in India, Prayas (Energy Group).* Available at: https://www.prayaspune.org/peg/publications/item/376-fuelling-the-transition-costs-and-benefits-of-using-modern-cooking-fuels-as-a-health-intervention-in-india.html (Accessed: 2 September 2021).

Prayas (Energy Group) (2016) *Residential Electricity Consumption in India: What do we know?* Available at: https://www.prayaspune.org/peg/publications/item/331-residential-electricity-consumption-in-india-what-do-we (Accessed: 2 September 2021).

Prayas (Energy Group) (2017) *The Price of Plenty: Insights from 'Surplus' Power in Indian States.* Available at: https://www.prayaspune.org/peg/publications/item/335-the-price-of-plenty-insights-from-surplus-power-in-indian-states.html (Accessed: 2 September 2021).

Prayas (Energy Group) (2019) *ECHO : Energy Consumption of Households - blog series.* Available at: https://prayaspune.org/peg/blogs/echo-energy-consumption-of-households.html (Accessed: 2 September 2021).

Prayas (Energy Group) (2021a) *Maharashtra's Electricity Supply Mix by 2030: Cost and Reliability Insights from a GridPath Production Cost Modelling Exercise.* Available at: https://www.prayaspune.org/peg/publications/item/510 (Accessed: 2 September 2021).

Prayas (Energy Group) (2021b) 'Rumi: An open-source energy systems modelling platform developed by Prayas (Energy Group).' Available at: https://github.com/prayas-energy/Rumi (Accessed: 2 September 2021).

Reserve Bank of India (2020) *Handbook of Statistics on Indian Economy, Reserve Bank of India.* Available at: https://rbidocs.rbi.org.in/rdocs/Publications/PDFs/0HBS202024D4CA0CC03F4674B040F7DEDE7E5360.PDF (Accessed: 2 September 2021).

Reserve Bank of India (2021) *Governor's Statement, June 4, 2021.* Available at: https://www.rbi.org.in/scripts/BS_PressReleaseDisplay.aspx?prid=51682 (Accessed: 2 September 2021).

Rose, A. *et al.* (2020) *Least-Cost Pathways for India's Electric Power Sector.* National Renewable Energy Lab. (NREL), Golden, CO (United States). Available at: https://www.nrel.gov/docs/fy20osti/76153.pdf (Accessed: 2 September 2021).

van Ruijven, B.J. *et al.* (2011) *Model projections for household energy use in India, Energy policy.* Elsevier. Available at: https://www.sciencedirect.com/science/article/pii/S0301421511007105.

Samir, K.C. *et al.* (2018) *Future population and human capital in heterogeneous India, Proceedings of the National Academy of Sciences.* National Acad Sciences. Available at: https://www.pnas.org/content/115/33/8328 (Accessed: 2 September 2021).

Shearer, C. *et al.* (2020) 'Boom and Bust 2020: Tracking the global coal plant pipeline', p. 28. Available at: https://endcoal.org/wp-content/uploads/2020/03/BoomAndBust_2020_English.pdf (Accessed: 2 September 2021).

Shukla, P. *et al.* (2015) 'Pathways to deep decarbonization in India'. Available at: https://orbit.dtu.dk/en/publications/pathways-to-deep-decarbonization-in-india (Accessed: 2 September 2021).

Shukla, P.R. and Chaturvedi, V. (2012) 'Low carbon and clean energy scenarios for India: Analysis of targets approach', *Energy Economics,* 34, pp. S487–S495. doi:10.1016/j.eneco.2012.05.002.

Shukla, P.R. and Chaturvedi, V. (2013) 'Sustainable energy transformations in India under climate policy', *Sustainable Development,* 21(1), pp. 48–59. doi:10.1002/sd.516.

Shukla, P.R., Garg, A. and Dholakia, H.H. (2015) *Energy-emissions trends and policy landscape for India.* Allied Publishers.

Sivakumar, N., Das, D. and Padhy, N.P. (2014) 'Economic analysis of Indian pumped storage schemes', E*nergy Conversion and Management,* 88, pp. 168–176. doi:10.1016/j.enconman.2014.08.022.

Spencer, T. *et al.* (2020) 'Renewable power pathways: modelling the integration of wind and solar in India by 2030', *Tech. Rep.* [Preprint]. Available at: https://www.teriin.org/sites/default/files/2020-07/Renewable-Power-Pathways-Report.pdf (Accessed: 2 September 2021).

Sreenivas, A. and Gambhir, A. (2019) 'Aligning Energy, Development and Mitigation', in India in a *Warming World Integrating Climate Change and Development Edited by Navroz K. Dubash*. Oxford University Press. Available at: https://oxford.universitypressscholarship.com/downloadpdf/10.1093/oso/9780199498734.001.0001/oso-9780199498734-chapter-24.pdf (Accessed: 2 September 2021).

Taylor, K.E., Stouffer, R.J. and Meehl, G.A. (2012) 'An overview of CMIP5 and the experimental design', *Bulletin of the American Meteorological Society,* 93, pp. 485–498.

TERI, WWF (2013) *The Energy Report- India; 100% renewable energy by 2050.* Available at: http://awsassets.wwfindia.org/downloads/the_energy_report_india.pdf (Accessed: 2 September 2021).

TNERC (2018) *Order on generic tariff for Wind power and related matters, Tamil Nadu Electricity Regulatory Commission.* Available at: http://www.cbip.org/Regulations2018/Data/Tamil%20Nadu/TN_Tariff_Orders/2_TN_Wind.pdf (Accessed: 2 September 2021).

TNERC (2019) *Order on generic tariff for Solar power and related issues, Tamil Nadu Electricity Regulatory Commission.* Available at: http://www.tnerc.gov.in/Orders/files/TO-Order%20No%20240220211208.pdf (Accessed: 2 September 2021).

Venkataraman, C. *et al.* (2010) 'The Indian national initiative for advanced biomass cookstoves: the benefits of clean combustion', *Energy for sustainable development,* 14(2), pp. 63–72. Available at: https://www.sciencedirect.com/science/article/pii/S0973082610000219 (Accessed: 2 September 2021).

World Bank Group (2020) *Commodity Markets Outlook—Persistence of Commodity Shocks (Oct 2020).* Available at: https://pubdocs.worldbank.org/en/478961602618430208/CMO-October-2020-Forecasts.pdf (Accessed: 2 September 2021).

List of Abbreviations

AC	Air Conditioner
ATB	Advanced Technology Baseline
ATF	Aviation Turbine Fuel
bcm	billion cubic metre
BEE	Bureau of Energy Efficiency
BESS	Battery Energy Storage System
BNEF	Bloomberg New Energy Finance
CAGR	Compounded Annual Growth Rate
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CCO	Coal Controller's Organization
CEA	Central Electricity Authority
CEFTI	Cost Effectiveness of Fuel Transition in India
CERC	Central Electricity Regulatory Commission
CFL	Compact Fluorescent Lamp
CIL	Coal India Ltd
CMIP5	Coupled Model Intercomparison Project 5
CNG	Compressed Natural Gas
COP26	Conference of the Parties 26
COVID-19	Corona Virus Disease 2019
cu.m	cubic metre
CUF	Capacity Utilization Factor
EER	Energy Efficiency Ratio
EJ	Exa Joules
ER	Eastern Region
FY	Financial Year
GDP	Gross Domestic Product
GJ	Giga Joules
GSDP	Gross State Domestic Product
GST	Goods and Services Tax
GW	Giga Watt
GWh	Giga Watt hours
HSD	High Speed Diesel
HT	High Tension
IEA	International Energy Agency
IHDS	India Human Development Survey
IMF	International Monetary Fund
IPCC	Intergovernmental Panel for Climate Change
IRES	India Residential Energy Survey
KJ	Kilo Joules
KUSUM	Kisan Urja Suraksha evam Utthaan Mahabhiyan

kW	Kilo Watt
kWh	Kilo Watt hours
LDO	Light Diesel Oil
LED	Light Emitting Diode
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LSHS	Low Sulphur Heavy Stock
LT	Low Tension
MJ	Mega Joules
MNRE	Ministry of New and Renewable Energy
MoEFCC	Ministry of Environment, Forest and Climate Change
MoP	Ministry of Power
MoPNG	Ministry of Petroleum and Natural Gas
MoSPI	Ministry of Statistics and Program Implementation
MPCE	Monthly Per Capita Expenditure
MS	Motor Spirit
MT	Million Tonnes
MTPA	Million Tonnes per Annum
MVA	Mega Volt-Amp
NDC	Nationally Determined Contribution
NE	North East
NER	North-Eastern Region
NR	Northern Region
NREL	National Renewable Energy Laboratory
NSSO	National Sample Survey Office
OCGT	Open Cycle Gas Turbine
ORS	Optimistic Recovery Scenario
PHS	Pumped Hydro Storage
PJ	Peta Joules
PLF	Plant Load Factor
PMUY	Pradhan Mantri Ujjwala Yojana
PNGRB	Petroleum and Natural Gas Regulatory Board
POSOCO	Power System Operation Corporation Limited
PRS	Pessimistic Recovery Scenario
PV	Photo Voltaic
RPO	Renewable Purchase Obligation
SAUBHAGYA	(Pradhan Mantri) Sahaj Bijli Har Ghar Yojana
SR	Southern Region
T&D	Transmission and Distribution
TWh	Tera Watt hours
Ujjwala	See PMUY above
USD	United States Dollars
UT	Union Territory
VAT	Value Added Tax
WR	Western Region

Selected Publications of Prayas (Energy Group)

1	Maharashtra's Electricity Supply Mix by 2030: Cost and Reliability Insights from a GridPath Production Cost Modelling Exercise (2021) https://www.prayaspune.org/peg/publications/item/510
2	Energy: Taxes and Transition in India (2021) https://www.prayaspune.org/peg/publications/item/485
3	Early Age-Based Retirement Of Coal Power Plants: Misplaced Emphasis? (2021) https://www.prayaspune.org/peg/publications/item/501
4	Conditioning Behaviour: Insights On Use Of Air-Conditioners In Five Indian Cities (2020) https://www.prayaspune.org/peg/publications/item/464
5	Energy Consumption Patterns in Indian Households: Insights from Uttar Pradesh and Maharashtra (2020) https://prayaspune.org/peg/publications/item/445
6	Aligning Energy, Development and Mitigation (2019) https://www.prayaspune.org/peg/publications/item/435
7	Residential Electricity Consumption in India: What do we know? (2016) https://www.prayaspune.org/peg/publications/item/331
8	The Power Perspectives portal is an initiative to provide brief commentaries and analyses of important developments in the Indian power sector, in various states and at the national level. https://prayaspune.org/peg/resources/power-perspective-portal.html

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The rapidly evolving energy sector needs a feature-rich, publicly accessible and usable analytical framework to examine and understand the sector to inform policy, investments etc. Prayas (Energy Group) has built an open-source, generic, customisable, free-to-use demand-oriented energy systems modelling platform called Rumi with this motivation, and built the PIER (Perspectives on Indian Energy based on Rumi) energy model of India through the decade of the 2020s.

The PIER modelling exercise identifies some interesting trends and policy insights for the Indian energy sector. There is a need for urgent policy attention to increase usage of modern cooking fuels, particularly in some states and regions. Systemic improvements in energy efficiency can help do 'more-with-less' in the form of providing better energy services with lesser energy. Consumer behaviour is identified as a key lever, since small changes in behavioural choices can significantly impact the country's energy demand and supply mix. Regarding electricity supply, the study suggests caution in future coal capacity addition beyond what is in the pipeline as it could lead to undesirable lock-ins if India achieves its renewables targets. The PIER exercise also suggests that it may be desirable to revisit the relative shares of solar and wind in its planned renewables portfolio.

In addition to the above insights, the report presents various other results that may be of interest, such as the share of space cooling in residential demand and peak demand, the electricity generation mix in future years and India's import dependence for various energy sources.

Rumi can be downloaded and used from https://github.com/prayas-energy/Rumi, and PIER can be downloaded and used from https://github.com/prayas-energy/PIER. We hope that the energy modelling community finds Rumi and PIER useful and will enrich them further using their own assumptions, data and methodology. Prayas will also continue to support and enhance both Rumi and PIER.