III. Sectoral transition pathways

The following sub-sections of the policy lay out the vision, goals, levers, and interventions for both supply and demand sectors including power, natural gas and refined liquids, industry, transport, buildings, and agriculture. Each sector pathway is structured as follows:

1. **Vision**: How the sector will look like in 2050?
2. **Context**: Where the sector stands today?
3. **Goals:** Key sectoral indicators in 2030 and 2050
4. **Key levers:** How to achieve the goals?

1. Power

1.1 Vision

A low-carbon, consumer-centric, and resilient power sector to provide reliable, affordable, and clean electricity services.

1.2 Context

The power sector in Rajasthan has been growing and evolving rapidly. The per capita electricity consumption (between FY 11 and FY 21) in the state rose at a CAGR of 5.59% to support the growing economy and expanding consumer base (2). The state has achieved universal village and household electrification. The share of renewable energy in the electricity installed capacity mix doubled between 2015–22 (September 2022) on account of favourable government policies and resource potential (13). Currently, Rajasthan houses ~22 GW or a sixth of India's total renewable energy capacity, the highest in the country.[e] The state is also a major exporter of renewable power to other Indian states, given its natural endowments.

Notwithstanding this progress, the state needs to accelerate efforts on three fronts. *One, meeting the rising electricity demand while decarbonising the sector.* In FY22, the state's electricity consumption was ~71 billion units (BUs), which is expected to almost double by FY30[f]. Over 70% of the state's electricity generation is currently through coal-powered generators (14). As a result, the power sector accounts for

[e] *This includes 12,590 MW of large-scale solar, 4,577 MW of wind, 835 MW of rooftop solar, 1380 MW of solar in hybrid mode, 478 MW of off-grid solar, and 125 MW of biomass-based power.*

[f] 20th Electric Power Survey, Central Electricity Authority

54% of the state's total emissions in 2020 (14). In a business-as-usual (BAU) scenario, the state's electricity demand and share of the power sector in absolute emissions in 2050 are expected to increase by 325% and 88% over 2020, respectively (14). The state will need to aggressively deploy renewable energy capacity at scale, going beyond the current targets of achieving 37.5 GW of renewable capacity by 2025. This would also require significant efforts to reliably integrate variable renewable energy with the grid.

Two, improving the financial health of power distribution companies to provide quality and cost-effective services. As of FY21, the AT&C loss of power distribution companies (discoms) in the state stood at 26.23%, a reflection of multiple legacy issues: high power-purchase costs, high cross-subsidies, poorly targeted power subsidies, and inefficiencies in consumer billing and payment collection. Poor financial health significantly restricts the discoms' ability to provide quality and affordable services.

Three, stimulating consumer participation to build a decentralised, integrated, and energy-efficient sector. Besides the rise in electricity demand, the peak power demand in Rajasthan is expected to grow faster (quadruple) between 2020–50 (15). Adopting effective strategies for demand management through decentralised renewable energy generation (e.g., rooftop solar), energy-efficiency measures, and demand response through dynamic tariffs, internet-of-things (IoT)–based technologies, and innovative business models would be essential. As per an analysis by the Council on Energy, Environment and Water (CEEW), Rajasthan has an economic potential of 5.5 GW of rooftop solar in the domestic segment.[g] However, this potential remains untapped, with just 835 MW of rooftop solar capacity installed as of September 2022 (6).

Through this policy, Rajasthan aims to build a decarbonised, decentralised, and financially healthy power sector. It plans to do so by supporting interventions to integrate and offtake large amounts of renewables, effectively manage electricity demand, and empower its discoms and consumers as enablers of the sector's transition.

1.3 Goals

The vision that the state has set out for will be achieved through the following goals.

By 2030:

- 90 GW of renewable energy capacity installed in the state.

[g] *In the residential rooftop solar sector, Rajasthan has a technical potential of 47 GW. However, the economic potential is assessed by considering that the installations are restricted up to the consumer's sanctioned load. This economic potential is estimated at 5.5 GW.*

- 100% compliance with the national Renewable Purchase Obligation (RPO) trajectory.
- AT&C loss levels of discoms come down to 12–15% (by 2025-26), from 26.23% in 2021.

By 2050:

- Non-fossil energy sources comprise 70% of the electricity generation, up from 20% in 2020.
- Sub-10% aggregate technical and commercial losses in the distribution sector, down from 26.23% in 2021.

1.4 Key levers

1.4.1 Making bulk power generation clean, inclusive, and responsible

Renewable sources of energy will be an important pillar of Rajasthan's transition to a sustainable and affordable electricity system. Large-scale generation of electricity will happen through the planned and systematic deployment of clean and efficient technologies.

- The Government of Rajasthan (GoR) has set in place ambitious and comprehensive solar, wind, and hybrid energy policies offering the necessary support framework for accelerating deployment. To continuously keep pace with market developments and shape the renewable energy future, these policies will be reviewed every five years through a stakeholder-driven process. The state will consider consolidating existing policies to meet the previously mentioned objectives.
- The state will develop a long-term integrated energy plan to determine the need for new generation and transmission lines based on granular demand forecasting, state and national resource-adequacy studies, intra-day and seasonal power flow variations within the state, feasibility of various storage solutions, existing and future land-use plans, and ecological sensitivities. This planning process will help optimise the transmission builds, leverage regional-/ national-level resources for balancing the variability, and tap the locational diversity of renewable energy resources within and outside the state. The plan will be reviewed every three years and will feed into the national electricity planning process.
- The state will establish investment-ready parks based on a robust assessment of technical, economic, environmental, ecological, and social considerations integrated with pre-development due-diligence processes.
- The state will facilitate responsible and inclusive development of large-scale RE by ensuring robust assessments of environmental and social impacts before each park or project is set up. In addition, the state nodal agency will conduct post-facto assessments across regions/districts to capture

parameters like local employment generation, economic development in the region, and other impacts and benefits related to livelihoods.

- In order to diversify the generation portfolio in the medium and long term, the state will support the exploration and deployment of innovative and diverse low-carbon power generation technologies such as nuclear (with focus on small modular reactors), carbon capture, utilisation and storage (CCUS), etc.
- The state will ensure compliance with the evolving national pollution control norms on emissions of particulate matter, sulphur dioxide, and oxides of nitrogen to reduce the power sector's contribution to ambient air pollution.

1.4.2 Ensuring reliable and cost-effective integration of renewables with the grid

Accommodating high shares of variable RE will present state institutions with challenges related to grid integration, system operations, and reliability. Rajasthan intends to proactively plan for and mitigate these challenges.

a. Accelerated deployment of intra- and inter-state transmission to absorb high levels of RE and variations in local and regional power flows

- The state load dispatch centre (SLDC) and the state transmission utility shall be segregated, and the SLDC shall function as a separate company/authority/corporation under the state government. The state government and the regulator will facilitate the corresponding transfer scheme and regulations.

- The state aims to become a net exporter of electricity and shall plan and develop new and strengthen the existing inter-regional transmission links and green energy corridors to evacuate electricity to other regions.

- The state will ensure optimal utilisation of the state transmission network for RE integration. For this, it will develop a programme to facilitate the deployment of megawatt (MW)-scale decentralised solar and hybrid RE plants that will be located near or connected to substations on the state transmission network. The state will periodically assess and notify spare transmission capacities and develop suitable bidding mechanisms for these capacities to come up.

- The state will start monetisation of existing transmission lines using instruments like the Infrastructure Investment Trust (InvIT), PPP-based models like Operation, Management and Development Agreement (OMDA), etc. to generate cash flows for future investments in the transmission infra.

b. Enhancing system flexibility through market platforms, flexible supply options, energy storage solutions

- The state discoms and system operator will actively participate in the design and implementation of regional and national market mechanisms such as the Security Constrained Economic Dispatch (SCED), Market-based Economic Dispatch (MBED), ancillary services, and capacities market to harness cost-effective options for flexible supply.

- The state will work with the discoms, the system operator, and the electricity regulator to i) develop a roadmap for the procurement of adequate energy storage capacity (coupled with the generation, transmission, distribution and behind-the-meter applications), ii) identify suitable sites for the deployment of grid-connected storage projects, and ii) develop regulatory frameworks and business models to encourage private-sector participation in the deployment of storage projects and associated grid services.

- As per the Central Electricity Authority, Rajasthan has a pumped storage hydropower (PSH) potential of 3,780 MW. Tapping this potential can provide balancing reserves for RE integration across the state, region, as well as national grid. The state nodal agency will identify prospective sites for such projects and conduct due diligence on land, hydrological, and environmental considerations for its development.

- To reliably integrate variable RE with the power grid, the state will undertake measures to enhance the flexibility of the existing and upcoming coal power plants in the following ways:

    - Test and adopt novel technologies and strategies to repurpose or enhance the flexibility of thermal power plants.

    - Develop a plan to retrofit plants with adequate systems, to lower their technical minimum and increasing their ramping capabilities.

    - Identify suitable repurposing options for plants with a low useful life remaining. The repurposing options may include renewable power generation (solar, wind, hybrid RE, biomass), storage (thermal, battery, and pumped hydro), and ancillary services.

c. Building a smart, stable, and secure grid

- The state will ensure the establishment of modern hardware and software systems for complete visibility of real-time RE generation from every plant in the state.

- The state will support the creation of a high-quality database of RE resources in Rajasthan and facilitate its use for granular and high-accuracy predictions of RE generation.

- The state will support measures to improve the reliability and flexibility of the grid, including grid-asset monitoring, system-integrity protection schemes, and digitisation of substations.

- The state will undertake measures to strengthen the technological, institutional, and regulatory capacity to protect the grid against cyber threats and ensure system security

1.4.3 Building a financially viable and modern distribution sector

Power discoms will continue to play a critical and evolving role in realising the sector's vision of providing reliable, affordable, and clean power supply in Rajasthan. The state will initiate and support interventions for the state discoms' transition to becoming financially healthy, modern, and competitive.

a. Optimising the cost of power supply

- The state will support discoms and the system operators to put in place a state-of-the-art infrastructure to conduct periodic demand forecasting at a granular level to inform optimal procurement decisions. The forecasting should account for the changing mix of generation capacity, new drivers of electricity demand (e.g., electric vehicles, electric cooking), and the expected impact of demand-side management measures at scale.

- The state regulator and discoms will work towards deepening market-based procurement over the next five years. The state regulator will develop regulatory frameworks that will allow discoms to enter shorter-term contracts (within or outside the power exchange) and harness the system's flexibility.

- The state will work with the central and state electricity regulators to introduce flexibility standards into the existing and upcoming contracts and develop payment and settlement structures to help optimise costs of power procurement while opening alternate revenue streams for generators.

- The state will work with the regulators and discoms to resolve legacy issues within the next 5–10 years that underpin the prevailing high cost of power supply in the state. This will entail the provision of cost-reflective tariffs in a timely manner, liquidation of regulatory assets (or unfunded revenue gaps), and reducing dependence on cross-subsidies.

b. Improving operational and financial efficiency of the distribution sector

- The discoms will put in place an advanced metering infrastructure (AMI) along with a robust and transparent accounting mechanism to accurately capture and communicate energy flows (and losses) and the cost and quality of supply to different consumer categories.

- The discoms will leverage the AMI data for effective management and maintenance of the distribution network for the provision of high-quality and reliable power supply, digital and transparent energy accounting and billing operations, and for targeted interventions to reduce billing losses.

- In the future, the state's public discoms would likely evolve into distribution system operators (DSOs) and be responsible for managing the network and providing network access and grid services to multiple electricity retailers. The state will create an attractive ecosystem to facilitate the testing and proliferation of innovative business models to infuse competition in the distribution sector, realise financial and operating efficiencies, and increase consumer choice.

- The state will progressively move towards a smart and dynamic tariff design that is reflective of the cost of supply (at different voltages and times of the day). The state will also work with the regulators and discoms to reduce the sector's dependence on indirect subsidies while also rationalising and targeting direct subsidies for identified customers with the help of banking and digital innovations.

- Further, smart and dynamic tariffs will be designed to encourage investments into decentralised renewables, battery energy storage systems, innovative business models for demand-response services, smart communication devices, and integration of electric vehicles with the grid. For this, the state will work with the regulator to make time-of-use tariffs robust, notify green tariffs for consumers who wish to meet their green power needs through discoms, and provide tariff signals for investments in demand-side technology for RE integration and enhanced energy efficiency.

- The state will continue to support low-income and vulnerable electricity customers and protect them from tariff shocks by instituting innovative energy safety nets. These safety nets (e.g., direct subsidy transfers for lifeline electricity consumption) will be designed and revised in response to the changing socio-economic conditions of the state's population.

- The state will continue with the forward-looking, multi-year revenue trajectories with profit-sharing mechanisms that can reward utilities for cost-saving investments and operations, aligning utilities' business incentives with the continual pursuit of novel solutions.

- The state will support the strengthening of the regulatory ecosystem, including measures to enhance regulatory capacity to facilitate robust and impartial monitoring of the sector, strict enforcement of regulations, protection of consumer rights, and nimble decision-making on emerging issues.

1.4.4 Creation of new demand frontiers for clean energy

- In addition to the supply-side measures, the state will support consumers in becoming participants to speed up the decarbonisation process.
- The state will work with the regulator to establish an appropriate rewards framework for entities that comply with and surpass their renewable purchase obligations in line with the national trajectory set out until 2030.
- The state will work with the regulator to create a conducive ecosystem to promote consumers across sectors – industry, transport, buildings, and agriculture – to increase the consumption of clean electricity through open-access or captive/group captive RE generation. Regulatory frameworks will be devised to appropriately distribute the costs of network maintenance and provision of grid services between discoms, prosumers, and consumers.
- The state will work with the regulator and discoms to develop a programme to facilitate select local communities or villages to attain energy self-reliance through appropriate financial support and innovative business models for decentralised RE generation, storage solutions, and end-use applications. Such locales (green communities or green villages) would help demonstrate the multiple co-benefits of a decentralised clean energy system that powers small businesses, improves livelihoods, and helps achieve modern health and education services.

1.4.5 Enhancing institutional capacity for a decarbonised, digitalised, decentralised power sector

The transition will unleash challenges and complexities for various power-sector institutions in the state, which will need to improve their resource capacity and assume new roles and responsibilities as the transition accelerates.

- The state will work with the regulator to define and enforce clear performance standards and a coordination mechanism for institutions spanning policy-making, planning, and implementation functions in the power sector.

- The state will support power system operators to strengthen capacity, infrastructure, and protocols for effectively balancing renewable energy through engagement with counterparts in other states.

- The state will identify new and enhanced roles and responsibilities for ensuring greater alignment between institutions, increased centre–state coordination, enhancing the ease of doing business, increasing consumer awareness, and accelerating the pace of the energy transition. For this purpose, the state will commission a robust assessment of resource availability and capacity within the discoms and other key actors in the power sector to identify gaps and develop a roadmap to strengthen resource capacity.

- The state will establish an independent state-of-the-art laboratory to undertake research on issues relating to clean-energy deployment, techno-economic feasibility studies of new and promising clean technologies, innovations and best practices in electricity planning and integration with the grid, and strategies to remove barriers to the growth of clean energy.

- A dedicated agency for the collection, management, and sharing of electricity utility data (at the generation, transmission, and distribution levels) in a transparent, accountable, and purpose-driven manner will be set up to facilitate data-driven decision-making by all actors in the electricity supply chain. This will include management, analysis, and sharing of AMI data. This agency will also support the state regulator in notifying and enforcing regulations to safeguard consumer privacy and the security of the sector against cyber threats.

- The state nodal agency for RE and energy efficiency and discoms will sensitise consumers about the benefits of clean technologies through awareness campaigns in local languages in collaboration with key stakeholders such as research institutions, grassroots organisations, industry associations, and residential welfare associations.

2. Natural gas and refined liquids

2.1 Vision

Ensure improved energy security and resilience through scaling domestic production and consumption of oil and gas as low-emission transition fuels.

2.2 Context

Rajasthan is the largest onshore producer of crude oil, making up for about 20% of India's total production. It is also the second-largest producer of natural gas in India (16). The state has four petroliferous basins spread over 150,000 square kilometres in western and eastern Rajasthan. Of these, three basins spreading in western Rajasthan belong to category-I with high prospects of hydrocarbon discovery (17).

As per Directorate of Petroleum, GoR, Rajasthan has known recoverable reserves of about 12 bcm of natural gas, of which it produced about 1.62 bcm in 2021-22. The natural gas production levels have been consistently increasing since 2015. Similarly, the state has crude oil has proven recoverable reserves of about 25.7 MMT, of which the state produced about 5.88 MMT in 2021-22. However, the production of crude oil has been continuously declining over the years which is a natural phenomenon of a naturally occurring resource.

The state is supporting further exploration activities across 14 Petroleum Exploration License (PEL) blocks in the 3 basins. HRRL, a joint venture (JV) company of the Government of Rajasthan (GoR) and Hindustan Petroleum Corporation Limited (HPCL) is setting up a 9-MMT-per-annum refinery cum petrochemical complex at Pachpadra district, Barmer. The refinery will consume 1.5–2.5 MMT of crude oil produced in the state every year with imported Arab mix. This project will fuel industrial growth in the state and accrue additional tax revenues.

Data suggests that the share of refined liquids and natural gas in the state's final energy use was 37% and 8% respectively in 2020 (14). Transport and buildings are the primary demand centres for refined liquids. In a scenario where the state aspires to become a net-zero economy, it is acknowledged that gas and refined liquids will serve as transitory fuels. Alongside the promotion of RE in the energy mix, the state also aims to deepen the exploitation of domestic oil and gas resources for both self-consumption and export to other states, thereby supporting the national requirement of fuels for transition.

2.3 Goals

By 2030:

- Double the production of natural gas from 2022 levels.
- Double the blending of bio-ethanol through increased production capacity in the state.

By 2050:

- Double the share of natural gas in final energy use from 2020 levels.

2.4 Levers

2.4.1 Strengthen the ecosystem to assure production and supply

- The state will develop and implement a comprehensive and long-term hydrocarbon production strategy that will include the following components:
    - Coordinated strategy for integrated refinery-cum-petrochemical development.

- Phased strategy for gas as a substitute for oil, exploring new possibilities such as small-scale LNG.
- Phased strategy for compressed biogas as a substitute for natural gas and liquified petroleum gas.

- The Directorate of Petroleum will facilitate the oil and gas exploration and production companies for exploration of natural gas resources of existing and prospective oil and gas basins for commercial and industrial uses. Towards this, it will:
    - Collaborate with the MoPNG (Ministry of Petroleum & Natural Gas) and Directorate General of Hydrocarbons (DGH) for due diligence of exploration and production (E&P) companies and conducting multiple exploration surveys for identification of prospective sites across basins.
    - Facilitate the development of new forms of contractual arrangements with the private sector to enable them to rejuvenate the mature fields and maximise value extraction.
- The state will partner with public sector undertakings (PSUs) in the oil and gas sector to set up refineries of crude oil and petroleum products. Through these collaborations, the state will aim to create value addition of petroleum resources and incentivise capital investments in petrochemicals and petroleum ancillary.
- Create a conducive supply-side ecosystem for increased production of biofuels including bioethanol, biodiesel, and bio-CNG to meet the demand in the industry sector and the transport sector, particularly in the freight segment. This will include:
    - Enabling evidence generation of economics and subsequent infrastructure creation for feedstock supply chains (such as through municipal solid waste and crop residues) and storage of intermediate and final products.
    - Publishing and sharing data on the availability of biomass feedstocks across the state.
    - Promoting research, development, and demonstration of successful business models and technologies for the production and supply of biofuels to demand centres, for example, industrial cluster-based approaches.
    - Contributing to the establishment of national benchmarks for the performance of bio refineries and biofuel production.

- Develop collaborations between the state government and the industry to enable the adoption of the best available technologies to produce fuels and improve the availability and competency of workforces. Towards this,
    - The state will endeavour to facilitate the oil and gas companies for piloting and development of CO_2 capture technology for enhanced oil recovery (EOR).
    - The state will provide policy and infrastructure support to oil and gas companies to accelerate the use of captured CO_2 from industries for EOR operations.

2.4.2 Support demand-side interventions to promote domestic production of oil and gas

- The state will encourage capacity expansion and setting up of greenfield refineries around dry ports and industrial corridors, including facilitating market linkages for new refineries.
- The state will encourage investment in the storage of crude and petroleum products to insure against supply disruptions; the state will offer depleted oil and gas fields to the private sector for the development of storage facilities.
- The state will work with the central government to tap the export potential of refined value-added petroleum products to neighbouring countries via existing and new bilateral and multilateral agreements.
- The Rajasthan State Gas Limited, in collaboration with the city- and town-planning authorities, will expand the city gas distribution (CGD) network to all major cities and towns. The CGD networks shall also be made accessible to bio-CNG developers in the state. For future preparedness, the CGD networks may be tested for blending a certain percentage of hydrogen.
- The state's industry and transport departments will facilitate demand creation for the use of biofuels in these sectors. This can be done through clean fuel offtake or blending mandates for Micro, Small and Medium Enterprises (MSMEs), large industries, and CGD providers. Model corporate agreements for enabling the purchase of bio-heat/bio-CNG/ biogas, in consultation with local technical institutions and industry associations, will support offtake from industries.
- The state will encourage consumers to make appropriate clean-fuel choices by periodically reviewing the state taxation regime and regulations governing the pricing of fuels and facilitating the creation of associated infrastructure for use of cleaner fuel substitutes; for example, the use of bio-CNG in place of conventional CNG.

3. Industry

3.1 Vision

Support sustainable industrial growth through the provision of low-carbon, affordable, reliable energy supply and energy-efficient end-use technologies and services.

3.2 Context

Sustainable industrial development is central to economic prosperity and public aspirations for a better quality of life in Rajasthan. As of 2020, industries account for 29% of total energy demand and 21% of total carbon emissions in the state (14). However, to support a growing economy, industrial energy demand is estimated to rise 2.6 times by 2050 (over 2020), with more than doubling of absolute emissions in a BAU scenario (14). Thus, it is critical to identify the high-impact nodes and strategies to meet the rising industrial energy demand while reducing the emissions intensity.

As of 2020, Rajasthan's industrial energy demand is met predominantly through coal (56%), followed by grid electricity (32%), natural gas[h] (8%), and refined liquids (3%) (14). Demand for coal is mainly for process heat generation and electricity production in captive power plants (CPPs). Cement, followed by textile industries, is the major consumer of coal for process heat generation (18). CPPs cater to a third of the industrial electricity demand, with the rest being sourced from the grid supply. Of the 3 GW capacity of CPPs in Rajasthan, 67% are coal-powered (remaining based on diesel, natural gas, solar, and wind), but these meet 94% of the total captive power demand (19). Cement, non-ferrous metals, and textile industries together account for 70% of the total CPPs in the state.[i] Under a BAU scenario, coal will continue to account for 56% of the total industrial energy demand, indicating the need to reduce dependence on coal and shift the industrial energy mix to low-carbon sources for sustainable and secure energy access (14).

The state of Rajasthan has undertaken several measures to help enhance the efficiency of energy use and the adoption of cleaner fuels (electricity, natural gas, and petroleum) over coal by industrial consumers (20). However, challenges of affordability, technology availability, and awareness constrain the pace of the desired transition. Through this policy, the state commits itself to rapidly decarbonise the state's industrial

---

[h] In Rajasthan, fertiliser (78%), refractory products (7%), and the glass industry (6%) are the major users of natural gas. Source: Annual Survey of Industries (ASI) data for FY2019.

[i] The data is for 380 industries having an installed capacity of captive power plants with a demand of 1MW and above. Source: CEA's All India Electricity statistics.

energy uses through the provision of reliable, affordable, and clean energy supply and associated technologies for sustainable industrial development.

3.3 Goals

By 2030:

- At least 40% share of grid electricity in the industrial energy mix, up from 32% in 2020.
- Be the leader among states in driving energy efficiency in key sectors such as cement, textile, and brick kilns.
- Commission at least one green hydrogen valley to serve demand in fertiliser plants or refineries (within Rajasthan and in other states).

By 2050:

- 50% share of grid electricity in the industrial energy mix, up from 32% in 2020.
- Achieve global best benchmarks in energy efficiency in key sectors like cement and textile, among others.
- Act as a hub for GH2 production in India and cater to demand from other states.

3.4 Key levers

3.4.1 Improving the efficiency of energy use in industries

- The state nodal agency for energy efficiency will work with relevant central agencies and state departments to:
    - Develop and periodically enhance the thresholds for minimum energy use by select industries with high carbon footprints.
    - Incentivise and support periodic energy audits by designated industries and MSMEs and participation in voluntary programmes like the GreenCo rating.
    - Provide adequate incentives (low-cost finance, subsidies, tax credits) to support the adoption of low-carbon and energy-efficient technologies.
    - Periodically monitor the adoption and impact of energy-efficiency measures on the carbon footprint of designated industries.
    - Create platforms to share best practices on the adoption and use of clean and energy-efficient technologies across industrial clusters.
- The department of the industry will support the development of model clusters for key industrial clusters (e.g., textiles) with near-universal adoption of energy-efficient process technologies and

decentralised clean energy generation (e.g., rooftop solar) to demonstrate technical feasibility and co-benefits of such a transition for industries and local communities.

3.4.2 Supporting the switch to clean fuels for energy and process heat

- The state will promote industrial consumers – both large and MSMEs – to adopt low-carbon electricity either through captive/group captive generation or open-access procurement of RE.
- The state will devise financial and non-financial incentives to support industries with a high coal dependence to switch to cleaner and low-carbon fuels including electricity, natural gas, hydrogen, and biomass. The state will also leverage the national clean air programme (NCAP) with a focus on priority cities and industrial clusters.
- The state will coordinate with relevant central ministries to build and extend the natural gas pipeline infrastructure to upcoming and select industrial clusters to facilitate the use of natural gas as a transitory fuel.
- The state will support the early phase-out of diesel-based captive power generation through the promotion of low-carbon options like captive renewable energy plants (solar, wind, or hybrid).

3.4.3 Developing green hydrogen hubs

Rajasthan consumes roughly 250 thousand metric tonnes of hydrogen.[j] Meeting this demand through in-state production of green hydrogen would require 5 GW of solar capacity, 2 GW of electrolyser capacity, and an investment worth INR 40,000 crore. Given the high potential of renewable energy sources, the state can also become a regional hub for supplying green hydrogen to fertiliser plants and refineries in neighbouring states (such as Uttar Pradesh, Haryana, and Punjab).

- The state will develop a dedicated 'Green Hydrogen Policy' and roadmap to guide the development of green hydrogen hubs in the state.
- The state will designate a nodal agency for green hydrogen that will be responsible for:
    - Identification of suitable sites to set up green hydrogen valleys based on key decision factors such as RE potential, availability of grid infrastructure, water availability, land-use type, population density, etc.
    - Commissioning studies and pilot demonstrations to assess the techno-economic feasibility of green hydrogen use in diverse sectors such as green mobility (buses, medium- to long-distance freight trucks), and select industries.
    - Devising suitable financial incentives to attract investments in green hydrogen projects. These may include viability gap funding, production-linked incentives, and tax credits.

[j] CEEW analysis using fertiliser production estimates.

- Developing a network of key stakeholders in the sector, including premier academic institutions, research laboratories, and leading private players, to deliberate on emerging issues, exchange new developments, and provide feedback for policy reforms concerning green hydrogen.
- Assessing the training needs and accordingly developing dedicated training and capacity-building modules.

4. Transport

4.1 Vision

Ensure universal access to sustainable and affordable mobility for people and goods through clean, reliable, and affordable energy services.

4.2 Context

Energy demand for moving people and goods in the state is growing rapidly. As of 2020, the transport sector contributes to nearly 18% of total carbon emissions and 27% of total energy demand in Rajasthan (14). However, with rapid urbanisation, economic growth, and rising income levels, energy demand from the transport sector is estimated to be more than double by 2050, with a two-times rise in absolute emissions in a BAU scenario (14).

This rise in demand will be largely driven by the freight sector, which is expected to comprise 86% of the total transport energy demand in 2050, up from 47% in 2020 (14). The transport service demand from the passenger segment will also nearly double (in absolute values) between 2020–50 (14). In 2020, 36% of the passenger transport demand in the state was met through non-motorised trips and public transport (14). However, this share is estimated to significantly decline to 10% by 2050 (14). This is mainly due to the rapid rise in individual mobility solutions – motorised two- and four-wheelers – which are expected to meet 70% of total passenger transport demand in 2050 (14). For instance, ownership of four-wheelers is estimated to increase from ~20 to ~90 per 1,000 people between 2020–50.

Besides the rise in energy demand and associated emissions, increasing road transport is also associated with negative externalities of congestion, noise, and pollution. A shift away from non-motorised and public transport systems would also imply rising costs, especially for low-income segments of society. It is, therefore, imperative to build a mobility ecosystem that can cater to the rising mobility needs through affordable and sustainable solutions with minimal energy and space use. To this end, the state shall work towards a modal shift to more-efficient public transport, active mobility options, and energy-efficient low-emission technologies such as electric vehicles.

4.3 Goals

By 2030:

- At least 40% modal share of non-motorised and public transport in passenger demand.
- 15%, 30%, and 5% share of EVs in new registrations of 2-W, 3-W, and 4-W, respectively.
- Electric buses comprise a notable share (at least 10%) in the total bus fleet.

By 2050:

- Maintain a healthy modal share (at least 25%) of non-motorised and public transport.
- More than 80% share of electric vehicles in new vehicle registrations (2-W, 3-W, and 4-W).
- Universal electrification of passenger buses and taxi fleets.

4.4 Key levers

Modal shift towards active mobility and public transport (e.g., buses) is the most critical strategy for low-energy modes in Rajasthan, besides a shift to energy-efficient solutions such as electric vehicles (EVs). The state will undertake a suite of measures to optimise and reduce vehicular travel demand and support a modal shift towards active mobility and public transport (e.g., buses). Additionally, it will facilitate a large-scale shift towards energy-efficient vehicles in electric passenger, light commercial vehicles, and medium- and heavy-duty segments. It is expected that the 2050 goals will result in a reduction of 16 tonnes, 3,500 tonnes, and 300 tonnes of PM2.5, CO emissions, and NOX emissions, respectively, in the total projected emissions during 2020–50.

4.4.1 Effective planning to manage transport demand and reduce energy consumption

a. The state urban development department will support the development of comprehensive mobility plans for all major cities and towns and inter-city transport within each region.
b. The state will encourage compact, dense, and mixed-income land-use design and city planning to proactively reduce travel demand. Compact and dense neighbourhoods would imply shorter commute distances and make walking and cycling convenient for daily commutes.
c. The state urban development department will work with urban local bodies to develop inclusive and user-friendly infrastructure for cycling and walking.
d. Further, these agencies will promote technology-based solutions for traffic management to reduce fuel wastage.
e. The state will support the optimisation of the freight movement via various energy-efficient and low-emission alternatives such as railways and waterways to reduce dependency on roads.

4.4.2 Strengthen the ecosystem for bus services

a. The State Road Transport Corporation, in collaboration with private bus operators, will undertake efforts to rationalise bus routes for intra-city travel.
b. The State Road Transport Corporation will work with public and private entities at the state and national levels to increase the availability of affordable finance for the procurement of buses in line with the nationally defined guidelines. These efforts will include testing and adopting innovative tendering processes, business models, and operational frameworks.
c. Develop robust intelligent transport systems (ITS) to build a more integrated and data-centric public transport network with buses, metros, railways, and other modes. The ITS will support the improvement of intra-modal transfer facilities and the fixing of appropriate modal fares to influence user choices.
d. The state will promote research and development of energy-efficient urban buses for towns and cities.

4.4.3 Supporting transition to electric vehicles to manage transport costs and emissions

a. The state transport and safety department will facilitate rapid electrification of public and shared transport, light commercial vehicles, and other modes of public and private transport through appropriate incentives for the purchase and use of electric vehicles and a conducive ecosystem to facilitate electrification of existing vehicles where feasible.
b. The state will support the deployment of EV-charging infrastructure, battery-swapping stations, and interoperability between charging networks through public and private investments.
c. The state will enable the adoption of energy-efficient and cleaner technologies in the freight sector, such as zero-emission trucks, through incentive mechanisms on the demand and supply side.
d. The state will establish long-term targets in line with the state EV policy to facilitate zero-emission vehicle adoption for different vehicle segments in the passenger and freight sectors.

5. Buildings

5.1 Vision

To ensure an affordable and healthy built environment for all through sustainable and thermally comfortable buildings and energy-efficient end-use services.

5.2 Context

Buildings consume about a third of all electricity in India; two-thirds of the building stock that will exist in India in 2040 is yet to be built (21). Consequently, the total electricity consumption in the buildings sector is expected to more than double by 2050 over 2020 levels (14). In Rajasthan, over 75% of the population resides in rural areas but the state's urbanisation rate will grow over the next few decades (14). With rising temperatures due to climate change, exacerbated by the heat island effect in urban centres, space cooling will be a key driver of energy demand. In rural households, lights and fans currently consume the major electricity share, while cooling appliances comprise over 60% of urban households' electricity consumption (20). Growing sectors such as tourism, education, healthcare, and industry will need more energy for end uses.

By 2050, higher urbanisation is estimated to lead to a growth of 6, 1.7, and 3 times in commercial, rural residential, and urban residential floor space, respectively, over 2020 (14). Consequently, the demand for cooling, cooking, and lighting is estimated to grow by 9, 2.5, and 4.5 times, respectively (14). There is a critical opportunity for the state to integrate energy efficiency in its largely unconstructed building stock, promote energy-efficient electricity end-use, and mainstream nature-based solutions to ensure an affordable and healthy built environment.

5.3 Goals

By 2030:

- 100% of new and eligible buildings compliant with the Energy Conservation Building Code (ECBC) and the Eco-Niwas Samhita (ENS) or their equivalent legal standard as notified by the relevant state authority.[k]
- Enhanced uptake of high-efficiency appliances (light bulbs, ceiling fans, air-coolers, air-conditioners, motors).

By 2050:

- 100% of the new building stock covered by and compliant with the prevailing minimum standards of energy efficiency and thermal comfort.
- 50% of new and ECBC-eligible buildings compliant with ECBC+ or its equivalent standard.
- Increase the stock of net-zero energy commercial and residential buildings.[l]

---

[k] All buildings that have received approval of their building plan by the relevant authority after the publication of this policy shall constitute 'new buildings'.

[l] Net-zero buildings produce as much energy as they consume while net-positive buildings would produce more energy than they consume.

- Ensure that urban forests and green spaces are above the prevailing global benchmark of green space per city dweller.

5.4 Key levers

5.4.1 Creating institutional capacity and coherence

- The state's nodal agency for energy efficiency will be strengthened to execute necessary functions including periodic assimilation of building stock data, monitoring compliance with energy-efficiency building codes, estimating energy savings, training and certifying energy auditors, providing capacity building on energy efficiency to other departments, etc.

- The state will adopt district, urban local body (ULB), or urban improvement trust (UIT)–level ECBC compliance targets to ensure that the principle of 'energy-efficiency as first fuel' is embodied across departmental functions and to drive innovation and investment in energy-efficient construction and end-use services.

- To facilitate the achievement of assigned targets, the state may establish offices or appoint expert personnel of the nodal agency on energy efficiency at the district, ULB, or UIT levels.

5.4.2 Facilitating a thermally comfortable and energy-efficient built environment

a. Strengthening and enforcing standards for energy-efficient buildings

- The state will undertake a robust baseline assessment of the building stock and star-labelled appliances to support monitoring and compliance activities.

- The state will widen the scope of ECBC and ENS to bring a growing share of the building stock within their mandate and support integration of building codes, like the ECBC and ENS, into the building by-laws for better implementation.

- All new public sector or public–private partnership constructions will integrate passive design measures for thermal comfort and energy-efficient active systems through increased coverage of ECBC and ENS, especially in priority sectors like tourism, education, and industry. The state will develop industrial projects like those under the Delhi-Mumbai Industrial Corridor (DMIC) and the Pradhan Mantri *Gati Shakti* scheme, as energy-efficient corridors. Slum redevelopment policies will also integrate measures like heat-reflective paints, energy-efficient building materials, and cooling appliances to provide thermal comfort to all. Old construction will gradually be retrofitted for higher efficiency.

b. Incentivising uptake of energy-efficient appliances and buildings

- The state will devise suitable incentives such as low-cost or collateral-free credit, rebates on property tax and registration charges, fast-track approvals, etc., to encourage private participation in the sustainable and affordable housing segment as well as the retrofitting of old and energy-inefficient building stock.

- The state will support new business models such as on-bill financing, cooling-as-a-service, buy-back schemes, etc., and energy-service companies (ESCOs) to facilitate the uptake of high-efficiency appliances and mandate the purchase of super-efficient appliances for public procurement programmes.

c. Mainstreaming nature-based solutions to mitigate the urban heat island effect

- The state will endeavour to integrate urban forestry into development masterplans and maintain green spaces as per the prevailing global standards to mitigate the urban heat island effect.
- Aligning with the concept of 'sponge cities', the state will maximise open spaces that absorb water to help cool the surroundings through evaporation, particularly in low-rise housing projects.

5.4.3 Leveraging behaviour change to accelerate systemic transformations

- The state will support the dissemination of guidelines for builders, building owners, construction contractors and consultants, energy auditors, and architects on the design and construction of energy-efficient and thermally comfortable structures using resources in vernacular languages and do-it-yourself parlance.
- The state will facilitate market creation by increasing awareness of the benefits of energy-efficient appliances, sustainable buildings, 'net-zero' and 'net-positive' buildings, and energy-efficient consumption behaviour by training retailers, architects, contractors, home loan executives, builders, city planners, service technicians, and end-users. The state will formalise the largely unorganised servicing sector by training and certifying technicians and promoting the uptake of good servicing practices.
- The state will support technologies, business models, and campaigns that enable individuals to monitor their energy consumption and deliver nudges towards environment-friendly energy consumption lifestyles.

5.4.4 Creating a conducive ecosystem for research, development, and deployment

- The state will integrate traditional knowledge of thermally comfortable building design and environmentally benign materials used in heritage constructions into contemporary construction standards through active research.
- The state will support pilot projects on energy-efficient, zero–global warming potential, and clean energy-based end-use systems – such as phase-change cooling materials, evaporative cooling, solar energy–based cooling, district cooling, electric cooking, thermal energy storage, IoT-based energy-use optimisation, etc. for applications across sectors.
- The state will create a conducive environment for the allied building industries (building materials, building services, etc.) to transform for enhanced market deployment of materials, practices, and appliances required for the large-scale uptake of energy-efficient and thermally comfortable buildings.

6. Agriculture

6.1 Vision

Ensure equitable access to affordable, clean, and quality energy to all agriculture value chain actors while managing the water–energy–food nexus.

6.2 Context

Agriculture and allied activities are an important part of Rajasthan's economy. On one hand, nearly 60% of the state's population is dependent on agriculture for their livelihood and the sector contributed 30.23% of the gross state value added (GSVA) in 2021–22 (3). On the other hand, 70% of irrigation is groundwater-dependent while on-farm irrigation efficiency is about 27% in a state where surface water availability is already limited and water in most river basins is over-appropriated (22). This leads to the over-exploitation of groundwater and high energy consumption. The annual groundwater extraction for irrigation alone was 130% of the total annual extractable resource in 2020, while about 41% of final electricity sales were to agricultural consumers in 2019–20 (23,24). Crops, livestock, and dairy are the largest sub-sectors in the state. Thus, managing the water–energy–food nexus is critical to ensuring the sustainability of livelihoods, water and energy resources, and national food security.

Through Energy Policy 2050, Rajasthan aims to enhance the technical and economic efficiency of the agriculture sector with a parallel focus on 1) growing crops and crop varieties with lower irrigation requirements, 2) promoting water- and energy-efficient irrigation practices, and 3) supporting efficient supply chains for low water–consuming fruits and vegetables, seed spices, dairy, and value-added agro-products to secure higher farmer incomes. The Policy also aims to facilitate access to clean and affordable energy for farm mechanisation and decentralised agri-processing enterprises to help improve productivity, enable product diversification from agriculture and allied sectors, and increase resilience to extreme climate events.

6.3 Goals

The vision that the state has set out for will be achieved through the following goals.

By 2030:

- 45% of agriculture power demand is met by renewable sources (grid and off-grid).
- On-farm irrigation efficiency increases to 40%, up from the current 27% level.

By 2050:

- 75% of the agriculture power demand to be met by renewable sources (grid and off-grid).
- On-farm irrigation efficiency increases to 70%, up from the current 27% level.

6.4 Key levers

6.4.1 Enabling clean energy and higher irrigation efficiency for sustainable management of water and energy resources

- The state will facilitate business and financial models to enable decentralised and grid-based solar power generation (by discoms, farmers, and communities) for reliable and affordable irrigation services. The state will encourage decision-makers to account for important factors such as groundwater depth and quality, sustainable groundwater yield, the proportion of marginal cultivators, farm productivity and income level, vulnerability to extreme climate events, etc. to mitigate associated sustainability risks.
- The state will accelerate efforts to facilitate daytime irrigation power supply through solar energy. The state will also promote remotely controlled smart irrigation systems for farmers to support night time irrigation practices in winters and other extreme weather conditions.
- The state will facilitate business and financial models for replacing diesel-powered irrigation pumps with cost-effective, energy-efficient solar-powered electric pumps to reduce the carbon and water footprint of energy use for irrigation.
- The state will support the adoption and sustained use of efficient irrigation technologies and practices suitable to the local agro-climatic context, such as micro-irrigation.

- The state will rationalise the subsidy on power for irrigation to incentivise the responsible use of energy and water resources while providing targeted subsidies for vulnerable farming communities.
- The state will support information and education campaigns to generate awareness among the farming community about the importance, benefits, and means of shifting to clean and efficient energy technologies for farming and allied activities.

6.4.2 Integrating energy and water concerns within agricultural and irrigation planning by promoting collaboration across energy, water, and agriculture departments

- The state will support crop diversification programmes that replace water-intensive crops with crops requiring less water, especially in regions with high energy use and water-extraction rates.
- The state will facilitate the adoption of sustainable agriculture practices such as mulching, precision farming, and natural farming that can help reduce water requirements for agriculture.
- The state will create decentralised processing and storage facilities powered through DRE to enable dairy as a reliable source of income.

6.4.3 Enabling access to clean, reliable, and affordable energy for small & marginal farmers to enhance on-farm productivity through mechanisation and value addition through decentralised agro-processing

- The state will support the deployment of small-scale, decentralised, clean energy–powered agro-processing solutions to enhance on-farm productivity, enable better incomes, and cut down on post-harvest losses. According to a market potential study undertaken by the Council on Energy, Environment and Water (CEEW), there exists a potential to deploy approximately 4 lakh solar pumps, 50,000 solar dryers, 2,000 solar cold storages, 7,000 multi-purpose food-processing machines, 50,000 grain-milling machines, 20,000 bulk milk-chillers, 80,000 solar refrigerators, and up to 4 lakh vertical fodder growing units in Rajasthan, emphasising the vast potential that is yet to be realised.
- The state will also support the replacement of existing post-harvest processing machinery with cleaner and energy-efficient solutions (such as higher-HP AC motors with energy-efficient DC motors).

IV. Transition enablers: The four Ms

The journey to the clean and inclusive energy sector of 2050 will witness the creation of new energy infrastructures across sectors at both centralised and decentralised levels. It will also encompass the development, diffusion, and management of many emerging and innovative technologies for energy production, distribution, consumption, monitoring, and management. Underpinning these sub-transitions will be the timely and adequate availability of the **four Ms: money, manpower, machinery, and materials**. This section describes the importance of each of these enablers and how Energy Policy 2050 proposes to activate and leverage each of these.

1. Money | Mobilising sustainable finance

As per a recent estimate, India will require investments of the order of USD 10 trillion to achieve the net-zero target by 2070. Similarly, in order to realise Energy Vision 2050, Rajasthan will require significant investments to build the new energy infrastructure comprising RE capacity (utility-scale and decentralised) and transmission corridors, charging infrastructure for electric vehicles, energy-efficient technologies for various end-uses, etc. So far, the majority of energy infrastructure in the country and Rajasthan has been financed through bank debt. However, from a broader perspective, access to affordable and adequate investments in clean-energy infrastructure and end-use products continues to remain a challenge, partly due to diverse risks (25–29). It, therefore, becomes imperative for the state to collaborate with all relevant institutions to unlock the flow of capital in a timely manner.

- The state will commission a study to quantify the amount of capital that is required to realise Energy Vision 2050.
- The state will commission a study to assess the different types of capital flows that can meet the capital requirement for Energy Vision 2050.
- The state will explore suitably designed instruments to enhance the flow of low-cost equity and debt capital from domestic and overseas markets into Rajasthan. These may include:
    - Guarantee mechanisms to mitigate a variety of risks (foreign exchange risks, off-taker risks, default risks for end-use applications, etc.).
    - Alternative investment sources such as infrastructure investment trust (InvIT) and bond markets.
    - Green bond issuances by state-supported public-sector undertakings.
- The state will coordinate with relevant departments to address factors that inordinately contribute to risks (e.g., off-take risks associated with power distribution companies) in order to reduce them to the extent possible to generally enhance creditworthiness.

- The state will work with the financing institutions in the state to ensure easy access to innovative financial products for diverse energy technologies and applications (such as rooftop solar, solar pumps, electric rickshaws, green buildings, etc.). This will entail:
    - Development of sound investment appraisal systems for various applications
    - Strengthening the on-field capacity of financial institutions through timely recruitments, capacity building, and technology demonstrations
    - Leveraging digital tools and local community networks (such as self-help groups) to make financing products accessible for all and optimise the processing time.
    - Sensitising consumers to financing options and processes.

2. Manpower | Skilling and training of youth

The availability of skilled and well-trained manpower will be integral to the success of Rajasthan's Energy Vision 2050. At present, Rajasthan has 34 certified training partners under the Suryamitra Skill Development Programme, which has produced nearly 3,000 trainees as of March 2021 (30). Deployment of a total of 90 GW solar and wind capacity by 2030 will employ a workforce of 110,000 people with varying skill requirements for business development, project design, construction and commissioning, and operations and maintenance (12).

However, the clean energy transition encompasses all energy production and consumption sectors and will require manpower trained in diverse aspects of production, dissemination, and management of new energy technologies and equipment with a special focus on digitalised energy systems. The state would need to strengthen its existing skill-development programmes and curate new initiatives to cater to manpower requirements from new sunrise sectors.

The GoR is committed to building a dynamic network of institutions to train and skill the local youth to drive the energy transition and create diverse and meaningful employment opportunities. The Energy Transition Committee will work on 'Skilling for Energy Transition' with the following responsibilities:

- Assessing the manpower and training requirements across sectors. These may include training for technical roles related to:
    - Deployment, grid integration and management of renewable energy–generation technologies (both utility-scale and distributed).
    - Designing green buildings including modern and traditional sustainability features and conducting building energy audits and IoT-based building energy management systems.

    - Service, repair, and management of EVs, batteries, energy-efficient motors and appliances, cooling appliances, and technology installations.
    - Deployment and servicing of efficient and renewable energy-powered end-use applications for farming and agro-processing such as solar-pumps, solar refrigerators, etc.
    - Financing clean and energy-efficient technologies and end-use applications such as rooftop solar, electric vehicles, DRE-powered technologies for agro-processing, etc.
- Overseeing the development of training and certification modules in coordination with relevant agencies such as Rajasthan Knowledge Corporation Limited, Sector Council for Green Jobs, and line departments.
- Expanding and supporting the network of training partners to deliver identified training and skilling programmes in physical as well as hybrid modes (in-person and online classes).
- Coordinating with state universities to develop and introduce clean energy–related courses.
- Organising biannual job fairs to facilitate networking between trainees and clean energy industry players.

3. Machinery | Strengthening clean energy R&D and manufacturing infrastructure

The success of the state's energy transition also rests on the timely availability of transition technologies at affordable costs. Currently, most of the transition technologies such as solar PV modules, wind turbines, batteries, automation technologies, etc. are imported by Rajasthan (from other Indian states or countries). The transition is creating an increasing demand for energy technologies that presents an unprecedented opportunity for the state to become a manufacturing hub for new energy technology and products beyond being a major clean energy producer. For instance, it is estimated that India would need around 40 GW of electrolyser capacity by 2030 to meet its green hydrogen production targets, which presents a market opportunity of INR 1.5 lakh crore (~USD 19.2 billion) for selling electrolysers in the country. Similarly, meeting annual demand of 260 GWh of battery storage by 2030 with domestic supply will require rapid buildout of manufacturing capacity, a market opportunity of INR 1.17 lakh crore (USD 15 billion) (31).

Seizing such opportunities through a local manufacturing base would help reorient the state's economy towards a low-carbon and sustainable future while securing the transition against supply-chain disruptions and price volatility.

The Energy Transition Committee will work on 'Manufacturing for Energy Transition' that will:

- Identify energy technologies, products, and materials of strategic importance for the state's energy transition through a cross-sectoral consultative process.
- Develop a roadmap to support R&D and commercialisation of emerging technologies and at-scale manufacturing of established clean technologies of strategic importance.
- Coordinate with the relevant departments to integrate the roadmap with the state's industrial policy and the iStart Rajasthan initiative.
- The state will augment and leverage the existing Bhamashah Startup Promotion Fund to provide seed funding and mentorship support for start-ups working on innovative and cutting-edge clean-energy technology ideas.
- The state will create a 'Clean Energy Investment Fund' to provide financial incentives in the form of capital grants, interest subsidies, and risk guarantees to attract domestic and international investment into green-field R&D labs and manufacturing units for strategic energy technologies and products in Rajasthan.
- The state will also incentivise public and private enterprises to invest a share of their profits (or revenue) into the R&D of clean technologies related or relevant to their existing businesses or transition plans.
- The state will prioritise the resolution of existing and emerging bottlenecks to at-scale manufacturing and commercialisation (domestic and international) of clean-energy technologies and projects. This may include the identification and development of land parcels for setting up Cleantech manufacturing hubs with the provision of high-quality power supply and the provision of a single-window system for project approvals.
- The state will also collaborate with industries to co-develop and impart courses and training modules related to clean-technology manufacturing and operations. Such courses will be offered through training partners or industrial training institutes to ensure the timely availability of a skilled workforce.

4. Materials | Building a circular economy ecosystem for energy technologies and products

With ambitious decarbonisation goals, Rajasthan would also be a prominent centre of waste originating from these technologies at the end of their useful life. Technologies like solar PV modules and wind turbines have a long useful life of 25 to 30 years, while those like batteries (for EVs or stationary storage) have a short life of 5 to 8 years. This implies that the state will start experiencing a significant quantum of clean energy waste generation by the end of this decade.

Effective management, utilisation/re-purposing, and disposal of clean energy waste will be essential to minimise its environmental impact, besides supplementing the availability of minerals and materials critical to clean energy technologies. Through this policy, Rajasthan commits itself to establishing a circular economy ecosystem for the effective management of energy technologies and materials at the end of their life.

The Energy Transition Committee will facilitate research and action on 'Circular Economy for Energy Transition' with the following objectives:

- Prepare a circular economy roadmap for the energy sector and circularity metrics across the supply chains in consultation with officials and experts from all relevant sectors, particularly for the following priority segments:
    - Power: solar PV modules, wind turbines, batteries, electrolysers, inverters
    - Consumer segment: refrigerants in cooling appliances, smart meters, EVs
    - Building: Construction and demolition waste
- Coordinate with state departments to embed the circularity principles within the state's industrial policy such that new manufacturing units and supply chains are designed to minimise their material consumption, use sustainable and recovered materials in production, design products for easy recycling and reclamation of materials, and promote the reuse of products.
- Incentivise and support industry–academia collaboration for the development, pilot, and demonstration of efficient recycling technologies (high recovery rates, less residual waste, low energy and water footprint), innovation in component manufacturing (design for recycling, eco-design), and reuse of products.
- Devise suitable financial incentives (viability gap funding, tax credits, interest subsidies, etc.) and regulatory frameworks (directives for safe waste management, mandates for recovery rates, reuse of materials, etc.) to support the adoption of circularity practices across sectors.
- Conduct a need assessment and establish a network of certified collection centres, refurbishers, dismantlers, and recyclers of waste.
- Support uptake of refurbished equipment and products by developing performance standards, stimulating demand, and promoting innovative business models to collect, segregate, and refurbish waste products.
- Develop a framework for monitoring the social, economic, and environmental impact of recycling technologies to identify successful solutions and approaches for deployment at scale.
- Track the progress and compliance of manufacturing industries against the circularity metrics for their products and supply chains to identify the barriers to the adoption and implementation of a circular ecosystem.

Annexure I – Modelling Rajasthan's sectoral energy transition towards net zero

With a steadily rising population and growing economy, the energy needs of Rajasthan are expected to significantly increase in the future across the transport, industry, and buildings sectors. A significant share of the state's future energy needs will be met through renewables and other emerging clean energy technologies, given the global crises of climate change, environmental pollution, and increasing risks with fossil fuel supply chains. In this context, the Government of Rajasthan (GoR) must carefully balance the state's growing energy needs commensurate with its developmental aspirations while moving towards a sustainable development paradigm.

With this context, the GoR embarked upon a consultative exercise to develop the state's comprehensive, long-term energy policy. It also undertook a scientific and rigorous energy modelling exercise to inform the state's vision and set the goals under this policy. The primary objectives of this supporting analysis were:

- Assessing long-term energy demand and associated carbon emissions for Rajasthan across various energy-intensive sectors such as power, transport, industries, and buildings.
- Analysing a 'business-as-usual' (BAU) scenario to estimate Rajasthan's energy needs until 2050.
- Analysing an economy-wide net-zero (NZ) emissions pathway through which Rajasthan could potentially achieve NZ emissions by 2070, aligning it with India's NZ emissions targets. [1]
- Understanding the sectoral implications of a BAU scenario until 2050 and sectoral pathways for Rajasthan to achieve NZ emissions by 2070.

This document presents the overall approach/modelling framework, and modelling results from the BAU and NZ emission scenarios.

Overall approach/Modelling framework – Global Change Analysis Model (GCAM)

The modelling exercise was conducted using the Global Change Analysis Model (GCAM) – an energy sector–focused model used extensively for energy and climate policy analyses. This model was chosen as it can project beyond the mid-century into the future, providing an opportunity to explore net zero scenarios for India and understand the implications of its target to achieve economy-wide net zero emissions by 2070. Further, GCAM can present for a representative state of the future energy mix for multiple policy scenarios based on projected prices of various energy fuels and technologies.

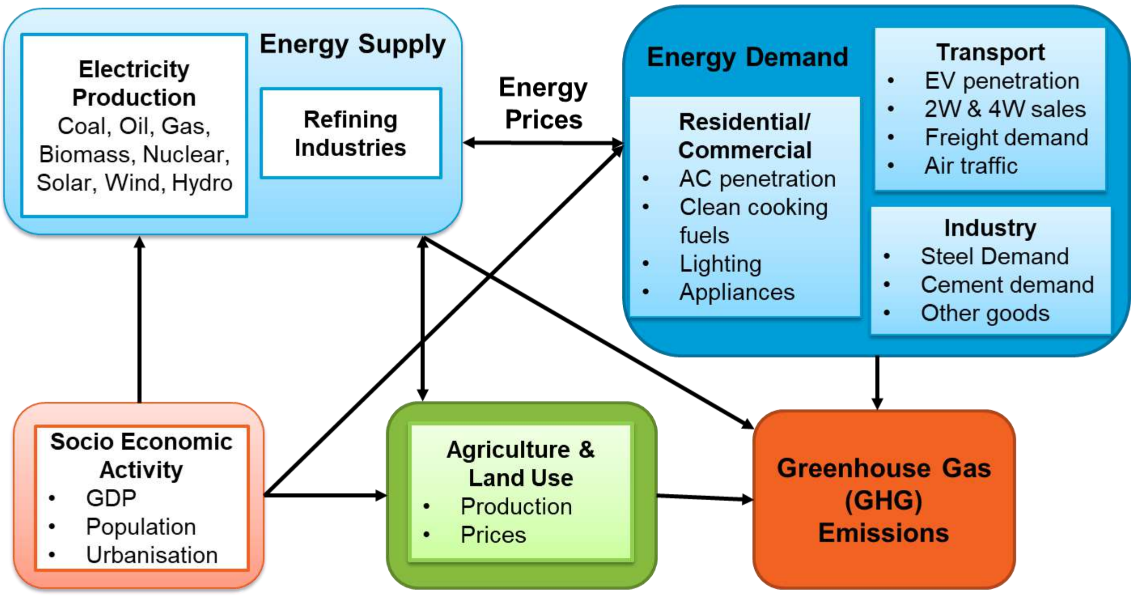
GCAM represents the behaviour of and interactions between energy systems, water, agriculture and land use, the economy, and the climate. The model is housed at the Joint Global Change Research Institute (JGCRI), USA and models 32 regions of the world, with India as a separate region. The GCAM-IIM version was set up at the Indian Institute of Management (IIM), Ahmedabad during 2007–09 and has since been used extensively for India-specific analyses.

The state-level version of GCAM-IIM was developed by the Council on Energy, Environment and Water (CEEW) in collaboration with the Centre for Global Sustainability, University of Maryland, USA (CGS, UMD). This version has a detailed representation of the energy system of all Indian states and union territories. For each state, energy demand is modelled for:

- Household/Buildings sector (urban and rural)
- Transport sector (passenger and freight)
- Industrial sector (aggregate)
- Agricultural sector

Energy demand from these sectors is serviced by the energy-supply sector, which includes the power generation sector and refining industries. Figure A1 depicts the interaction between energy demand and supply and how it is modelled within GCAM.

Figure A1: Schematic representation of the Global Change Analysis Model (GCAM)



Source: Adapted from Joint Global Change Research Institute (JGCRI) and Pacific Northwest National Laboratory (PNNL)

The key drivers of future sectoral energy demands are economic and population growth, urbanisation rate, consumer behaviour, technology costs, energy prices, and government policies. The model can explore various scenarios like the implications of high or low economic growth and urbanisation rates, high or low solar/wind electricity generation cost trajectories, high or low adoption rates of electric vehicles, and high or low rates of efficiency improvements, among other scenarios. The model can also explore alternative deep decarbonisation policies and the availability of breakthrough technologies such as hydrogen and carbon capture and storage (CCS).

What GCAM does not do:

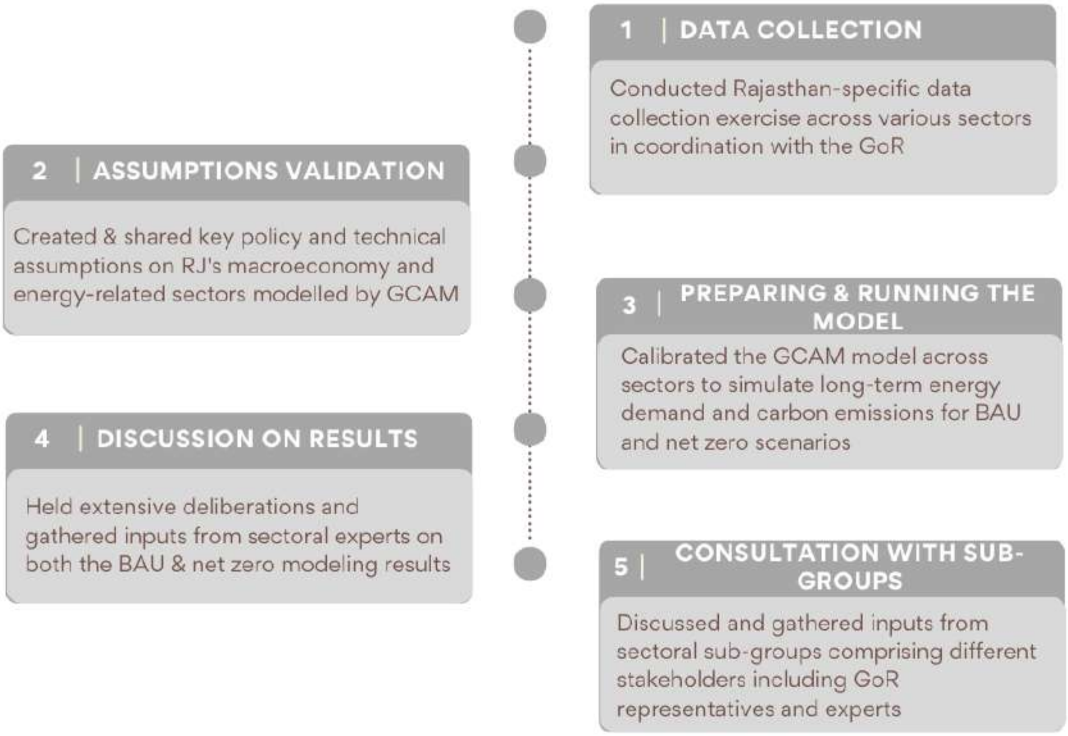
- GCAM does not try to predict the future. It tries to simulate how the energy system could evolve under a set of assumptions about emission limits, available technologies, efficiency growth, and energy costs. Many of these assumptions carry high levels of uncertainty.
- GCAM does not consider certain non-economic factors such as crucial equity and justice considerations with these technologies or the political viability of these approaches but seeks pathways that minimise economic costs.

- Modelling exercises such as these cannot provide a definitive picture of the future, however, can offer insights into key factors and potential policy directions that could enable positive outcomes and mitigate risks.

The process followed for the long-term energy assessment and emissions modelling through GCAM has been outlined here:

Activities conducted

Figure A2: Modelling approach for Rajasthan Energy Policy 2050



V. Inputs and assumptions

This section captures all the key data inputs, sources, and assumptions for designing future scenarios. It is important to note that the BAU scenario includes an inherently defined improvement in energy efficiencies and reduction in costs of technologies, while the NZ is a carbon constraint on the BAU which follows India's ambition of reaching NZ emissions by 2070. For India to reach NZ by 2070, the peak year for emissions is taken as 2040.

VI. Data sources

Sources for historical data and future projections across socio-economic, energy-producing, and energy-consuming sectors are given here.

Socio-economic data

- State-level population and urbanisation projections are based on Census of India projections until 2036. Beyond that, similar growth trajectories are assumed so that the national numbers are aligned with United Nations (UN) population projections. [2]
- Gross domestic product (GDP) projections are based on the theory of conditional economic convergence; meaning that less-developed states will grow faster than more developed ones and converge at similar levels of income. National GDP projections are aligned with NITI Aayog projections.

Energy data

The first step to estimating emissions is to gather the historical, sectoral fuel-consumption data for all fossil fuels including coal, oil products, and gas in the state/region for a given year. Data for current energy consumption across sectors are based on official sources. For future assumptions, market trends are considered.

- **Coal:** Data for coal usage was collected from the Coal Directory, Ministry of Coal, Government of India. [3]
- **Refined liquids:** Includes petrol, diesel, kerosene, liquefied petroleum gas (LPG), aviation turbine fuel (ATF), light diesel oil (LDO), and furnace oil. Data for the consumption of refined liquids was obtained from the Ministry of Petroleum and Natural Gas (MoPNG), Government of India.[4]
- **Gas:** Includes piped natural gas (PNG) and compressed natural gas (CNG). Data on gas consumption was obtained from GHG Platform India. [5]
- **Electricity:** Generation data was collected from the NITI Aayog dashboard [6] and utility and captive electricity–generation data at the state level was collected from the Central Electricity Authority (CEA). [7] Consumption data for all demand sectors were obtained from the CEA dashboard. [8]

Other technology-specific data

- Buildings: Ownership of appliances from the India Human Development Survey (IHDS) [9] and National Survey Sample (NSS) [10] for estimation of service-wise demand in urban, rural, and commercial buildings.
- Transport: Zone-wise route kilometres from the Ministry of Railways; [11] vehicle registration data from the Ministry of Road Transport and Highways (MoRTH);[12] fuel-consumption data from the GHG Platform India.[5]
- Industry: Annual Survey of Industries (ASI) data.[13]
- Cost trajectories for the future: Vehicles and technology costs in the buildings sector from market surveys.
- Technology efficiency in the future: For building appliances, vehicles, etc. from literature and market surveys.
- Costs of electricity-generation technologies trajectories: Costs are determined based on new investments and not current/historical trends in costs. This is based on publications from Indian and international research institutions such as the Lawrence Berkeley National Laboratory (LBNL) [14] and CEEW, [15] consultations with investors, and various government agencies. The future cost trajectories are captured in Table 1.

Table A1: Future cost assumptions for supply-side technologies (INR/kWh)

Costs of Technology	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	Unit
Coal Super Critical	4.7	4.7	4.7	4.7	4.6	4.6	4.6	4.6	4.5	4.5	4.5	2020 INR/kWh
Solar PV	2.4	2.0	1.7	1.7	1.6	1.6	1.6	1.6	1.5	1.5	1.5	
Wind	3.5	3.4	3.2	3.1	3.0	3.0	2.9	2.9	2.8	2.8	2.8	
Nuclear	4.8	4.9	4.9	4.9	5.0	5.0	5.1	5.1	5.2	5.3	5.3	
Gas (Domestic)	5.1	5.2	5.9	6.2	6.6	6.9	7.2	7.3	7.4	7.5	7.6	
Gas (Imported)	8.4	8.5	9.7	10.2	10.8	11.3	11.9	12.0	12.2	12.4	12.6	
Solar CSP	11.7	11.1	9.8	8.8	8.5	8.3	8.2	8.0	7.9	7.7	7.7	
Integration Costs of Wind and Solar	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**	**2060**	**2065**	**2070**	Unit
Solar	0.80	0.84	0.87	0.91	0.95	0.99	1.02	1.06	1.10	1.14	1.17	2020 INR/kWh
Wind	0.80	0.84	0.87	0.91	0.95	0.99	1.02	1.06	1.10	1.14	1.17	

Source: GCAM modelling assumptions

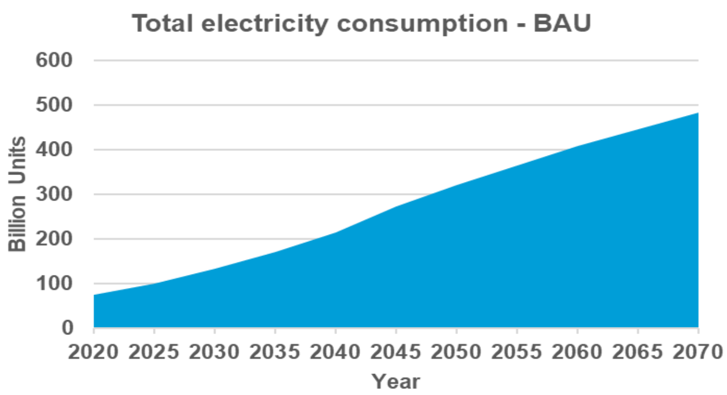
Sector-wise long-term energy modelling results: Business as usual (BAU) & net zero (NZ)

This section showcases key results from the long-term energy modelling exercise for the BAU and NZ scenarios.

Overall trends

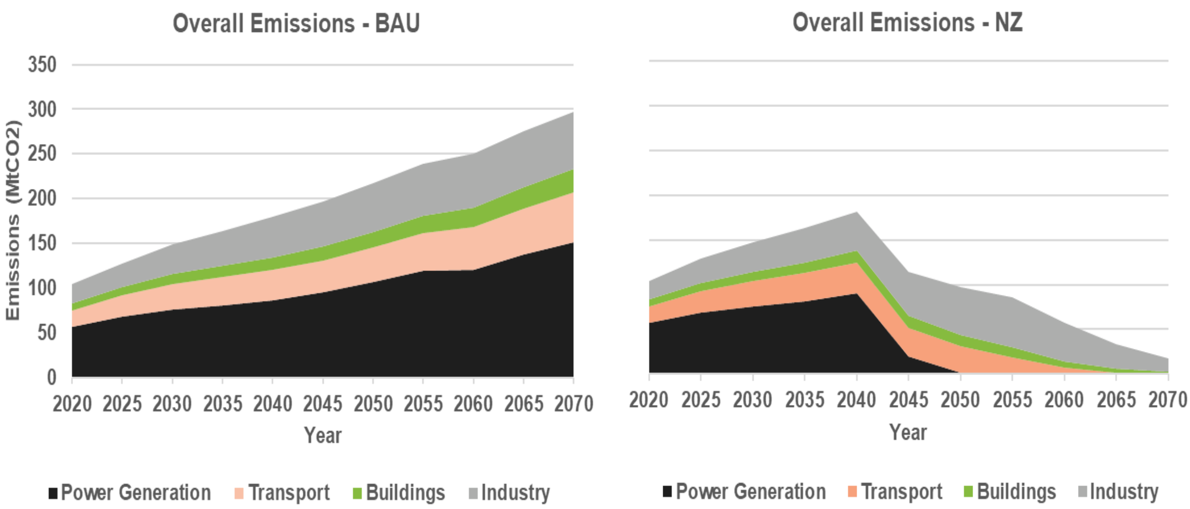
In the BAU scenario, total electricity consumption increases by 6.4 times between 2020 and 2070 as noted in Figure 3. With the increase in electricity consumption, Figure 4 highlights the 2.8-time increase in overall energy emissions between 2020 and 2070. Observing the growth in BAU emissions, it is crucial that possible pathways for sustainable and low-emission development of the energy sector are explored and timely strategies identified. If Rajasthan pursues an NZ development pathway that is aligned with India's 2070 net-zero target, the emissions trajectory would be as observed in Figure 4.

Figure A3: Total electricity consumption in a BAU scenario



Source: GCAM analysis

Figure A4: Overall emissions trajectories for the energy sector under BAU and NZ scenarios



Source: GCAM analysis

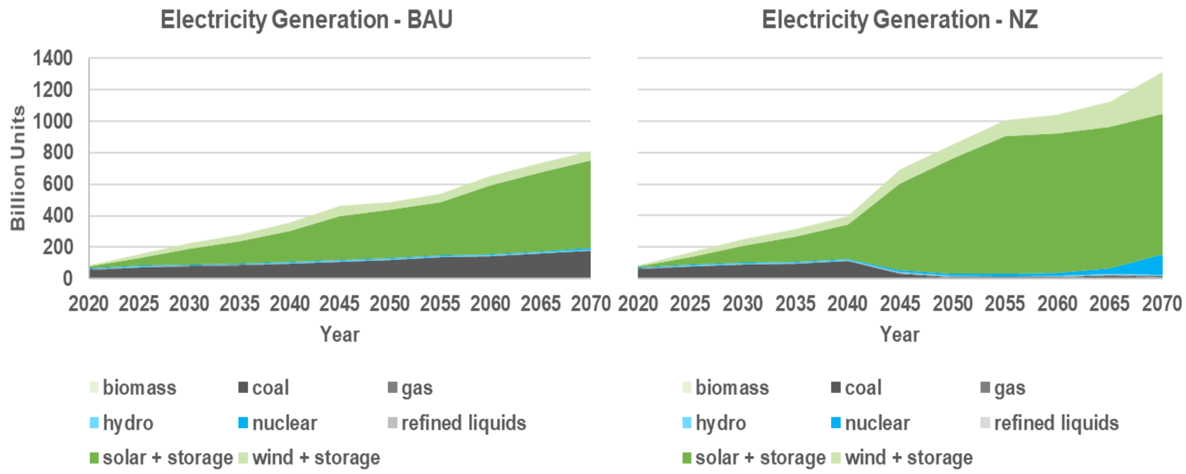
On one hand, in the BAU scenario, overall emissions in 2050 are expected to reach ~220 MTCO_2 (double the 2020 levels). Power generation is the largest contributor to the total emissions, fuelled by coal power generation, which is estimated to increase in the future to cater to Rajasthan's electricity demand. Emissions from all energy-consuming sectors would increase by 1.8–2.5 times that of 2020 levels.

On the other hand, in an NZ scenario, emissions are expected to peak around 2040 at ~180 MtCO_2 and decline thereafter until 2070, which is in line with when India is expected to peak, as pointed out by different studies and experts. [1] It is important to note that there will be residual emissions from Rajasthan's energy sector in 2070 that will be offset by land-use sequestration. Emissions reduction for the energy sector will begin post-2040, resulting in a 1.9-time decrease in emissions by 2050 relative to 2040, reaching approximately ~95 MtCO_2. The power sector represents the biggest decarbonisation opportunity, owing to Rajasthan's massive solar potential, which will translate into rapid and cost-effective decarbonisation post-2040.

Power sector

In the NZ scenario modelled in GCAM, all states collectively achieve net-zero emissions by 2070 and electricity demand will rise across all states. Rajasthan has a high renewable energy potential, due to which it will play a key role in India's energy transition by supplying clean power to other states, besides meeting its own electricity needs. The modelling exercise suggests that Rajasthan could produce more than 220 billion units (BUs) in 2030 in both BAU and NZ scenarios, and around 500 and 850 BUs of electricity in 2050 in BAU and NZ scenarios, respectively, which will be significantly higher than its own electricity needs. However, the state would require only around 320 BUs in the BAU scenario and around 360 BUs in the NZ scenario to meet its own electricity demand in 2050. (*Please refer to Tables 2 and 3 to observe the trends in electricity generation and consumption in a BAU and NZ scenario*). Figure 5 demonstrates the fuel mix required in the power generation sector in a BAU and NZ scenario if the state chooses to capitalise on the opportunity of becoming a clean energy supplier to other states. The major difference between the BAU and NZ scenarios is the phase-down of coal beyond 2040, which would require power generation through solar and wind to be ramped up.

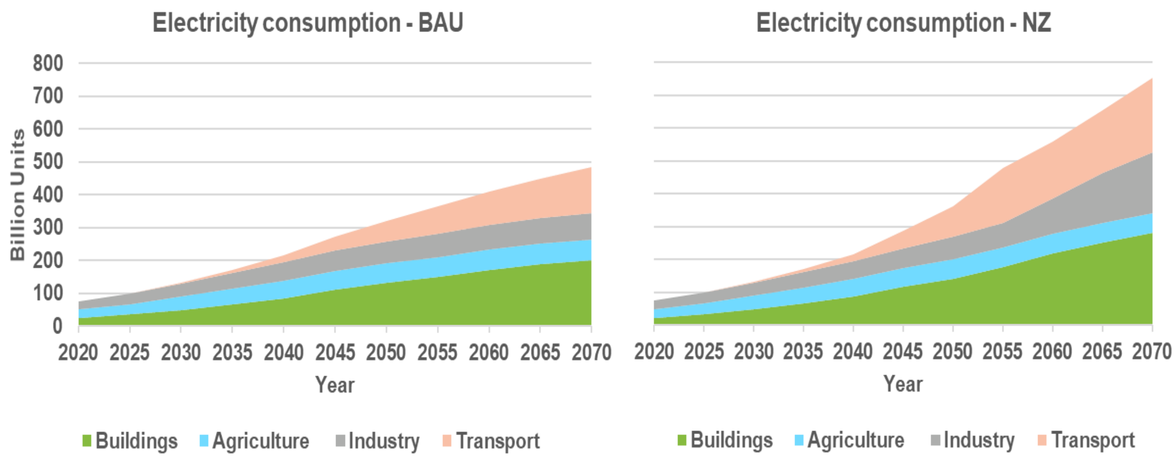
Figure A5: Electricity generation for Rajasthan under BAU and NZ scenarios



Source: GCAM analysis

Electricity consumption across the demand sectors (buildings, agriculture, industry, and transport) follows a similar long-term trajectory in the NZ scenario as the BAU until 2050 (Figure 6). This is mainly due to the inherently defined energy efficiency improvements in the BAU scenario. However, electricity consumption in the state is expected to significantly increase in an NZ scenario beyond 2050. This is because carbon constraints would drive the system away from coal and other fossil fuels and result in aggressive electrification of all end-use sectors. This includes the electrification of vehicles (especially freight trucks), cooking, and industrial processes. However, greater efforts on the energy efficiency front could result in early electrification of the hard-to-abate sectors and end uses.

Figure A6: Electricity consumption across the demand sectors under the BAU and NZ scenarios



Source: GCAM analysis

Tables A2 and A3 showcase the electricity generation and demand across CAMZ scenarios (2020–70)

Electricity Generation	BAU (Billion Units)				NZ (Billion Units)			
	2020	2030	2050	2070	2020	2030	2050	2070
biomass	0	0	0	1	0	0	0	5
coal	55	80	121	176	55	87	8	3
gas	2	2	1	2	2	2	3	10
hydro	1	3	5	6	1	3	5	6
nuclear	6	7	7	9	6	7	13	127
refined liquids	0	0	0	0	0	0	0	0
solar + storage	8	95	302	558	8	107	732	896
wind + storage	9	38	52	61	9	42	94	265
Total	82	226	488	812	82	249	854	1312

Source: GCAM analysis

Table A3: Electricity consumption (including captive electricity consumption) by demand sectors in the BAU and NZ scenarios (2020–70)

Electricity Consumption	BAU (Billion Units)				NZ (Billion Units)			
	2020	2030	2050	2070	2020	2030	2050	2070
Buildings	22.7	48.8	130.3	200.5	22.7	50.1	142.9	280.5
Agriculture	27.5	40.8	59.7	64.0	27.5	40.9	59.7	61.1
Industry	24.7	39.3	67.3	78.7	24.7	38.8	67.0	186.0
Transport	0.4	3.9	62.8	140.2	0.4	4.1	91.7	225.9
Total	75.3	132.7	320.1	483.4	75.3	133.9	361.4	753.6

Source: GCAM analysis

Demand-side sub-sectors

This section assesses long-term trends in energy demand across key end-use sectors viz. transport, industry, buildings, and agriculture under BAU and NZ scenarios. While energy demand continues to rise across sectors in both scenarios, the NZ scenario assumes Rajasthan's emissions will peak in 2040 and progressively decline until it reaches net-zero emissions by 2070, in line with India's net-zero target.

Transport

Given its growing population and economy, the mobility needs of Rajasthan are expected to increase in both passenger and freight segments. The recently introduced electric vehicle (EV) policy of Rajasthan seeks to reduce vehicular emissions by promoting a transition towards clean mobility. This demonstrates the state's commitment to sustainably fulfilling its mobility needs. This section explores how the energy demand of Rajasthan's transport sector could potentially evolve in the future. Under a BAU scenario, the share of the transport sector in the total energy demand rises from 27 per cent in 2020 to 34 per cent in 2050 to 40 per cent in 2070. Under an NZ scenario, the transport sector is expected to contribute 33 per cent of the total energy demand in 2050 and 29 per cent in 2070. Energy demand for the transport sector is further disaggregated into passenger and freight transport. Some insights into how this energy demand is met are explained following.

Passenger transport

Passenger transport in GCAM includes 2W, 3W, 4W, bus, rail, aviation, and non-motorised forms of transport (cycling and walking). Under a BAU scenario, energy demand from the passenger transport segment decreases from approximately 53 per cent of the total transport-sector energy demand in 2020 to 14 per cent in 2050 due to a decrease in dependency on refined liquids, i.e., petrol, diesel, etc. and the subsequent increase in electric vehicles, which are more energy efficient. Consequently, emissions from this segment are projected to reduce from 10 $MtCO_2$ in 2020 to 4 $MtCO_2$ in 2050. It is important to note that aviation projections from the passenger segment have not been included in this analysis due to the complexities of accounting for the fuel consumption and apportioning it to the state for a flight that travels from Jaipur to New Delhi, for example. As Rajasthan urbanises in the future, the long-term modelling results project a modal shift towards 4W in particular, implying that as incomes rise, people prefer faster and more convenient modes of transport. This will result in a drop in the share of non-motorised and public forms of transport. This analysis, therefore, suggests maintaining a healthy modal share of non-motorised and public forms of transport by strengthening their infrastructure.

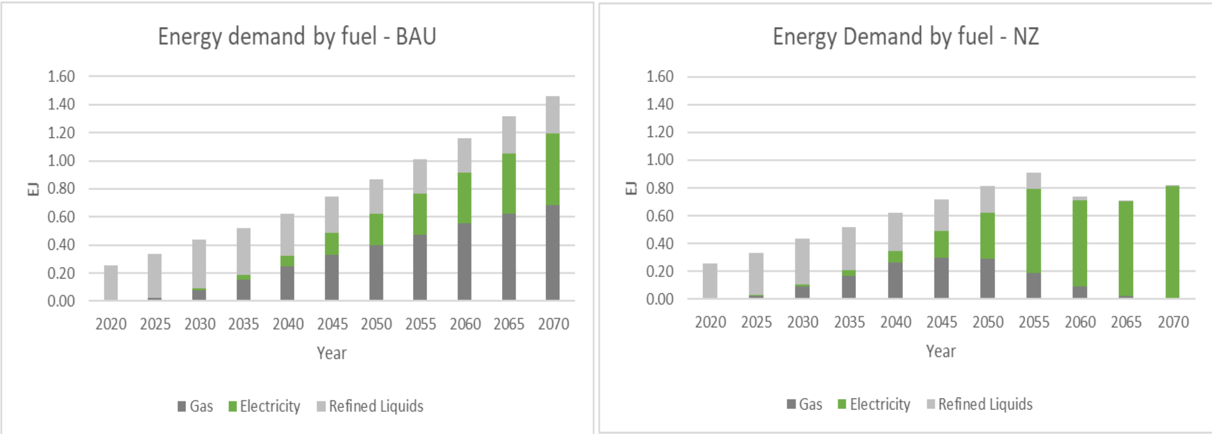
The BAU scenario for energy demand is characterised by the consumption of refined liquids and a significant uptake of electricity. Electricity contributes nearly 52 per cent of the energy demand from passenger transport by 2050 from a negligible share in 2020. It is important to note that electrification of passenger transport takes place even under a BAU scenario, reflecting the long-term impact of sustained policies to increase the adoption of electric vehicles. For modelling purposes, it is assumed that Rajasthan will have 100 per cent access to charging and infrastructure, which will be fully developed by 2050. A shift in electricity generation towards renewable sources could potentially reduce emissions from the passenger transport segment. An NZ scenario leads to the complete electrification of passenger transport by 2070, owing to carbon constraints placed in GCAM to achieve net zero emissions. Usage of refined liquids under the NZ scenario gradually declines from 2035 until it is entirely phased out by 2065.

Freight transport

Freight transport primarily includes rail and trucks. While energy demand from the freight sector constitutes 47 per cent of the total transport sector energy demand in 2020, this increases to 86 per cent by 2050, indicating large-scale movement of goods in Rajasthan owing to higher economic activity. Thus, emissions from this segment are projected to increase from 8 $MtCO_2$ in 2020 to 30 $MtCO_2$ in 2050 in a BAU scenario.

Energy demand in the BAU scenario for the freight segment is characterised by a massive rise in the consumption of natural gas by 2050 (reflective of the low prices of gas on the demand side), along with refined liquids and electricity. Gas contributes nearly 57 per cent of the energy demand from freight transport by 2050 from approximately 4 per cent in 2020 *(Note: Current results showcase a large share of gas in the transport sector, reflecting past low gas price trends. However, with the current geopolitics at play, there is volatility expected in future gas prices. If gas prices increase in the future, the share of gas in* *the transport sector may be lower.)* While emissions from natural gas are comparatively less than refined liquids, [16] it is evident that the usage of fossil fuels to meet the energy demand in the freight sector continues to grow under a BAU scenario. An NZ scenario leads to complete electrification of freight transport by 2070 to achieve zero emissions in the transport sector.

Figure A7: Energy demand by fuel for the transport sector



Source: GCAM analysis

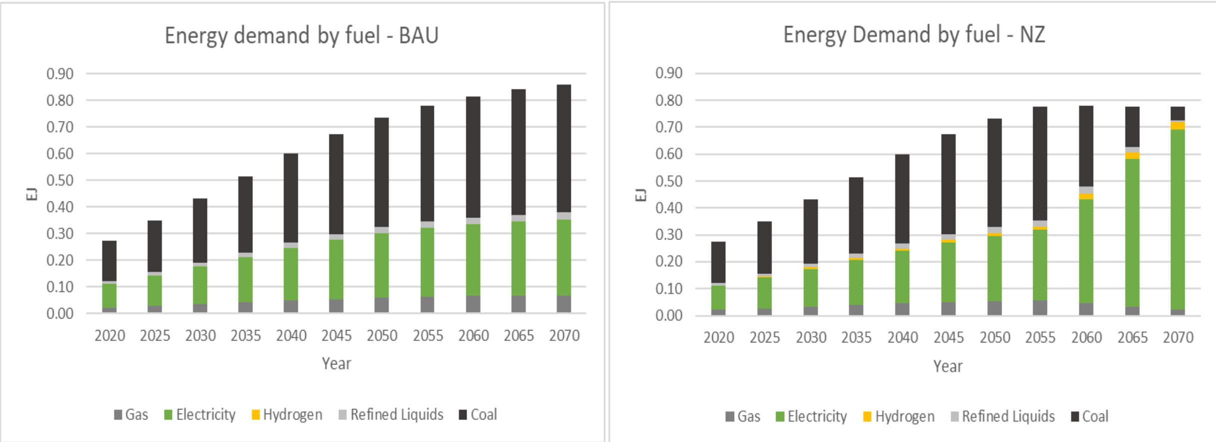
Industry

With a growing economy, Rajasthan is expected to have energy implications for its industrial sector. The cement, chemical, and fertiliser industries being the most energy- and emissions-intensive industries in the state are projected to grow, resulting in increased energy requirements. The energy demand of the industrial sector is projected to grow 2.7 times by 2050 in both the BAU and NZ scenarios. However, this trend changes by 2070. Under a BAU scenario, industrial energy demand increases by 3.1 times, while it increases only by 2.8 times in an NZ scenario. This is due to increased electrification and inherent energy efficiency improvements. The share of electricity in the industrial fuel mix in an NZ scenario stands at around 32 per cent in 2020 and is expected to grow steadily to 34 per cent by 2050. Beyond 2050, an aggressive electrification of the sector will take place and the share of electricity is expected to rise to 86 per cent by 2070.

Modelling results show that the share of hydrogen in Rajasthan's industrial fuel mix does not exceed 3 per cent in an NZ scenario until 2070. While green hydrogen is a potential solution for producing ammonia and to decarbonise the fertiliser industry, it remains uncompetitive for meeting industrial process heat demand through boilers and other equipment as compared to direct electrification. Green hydrogen uptake in Rajasthan is limited given that the state has no refineries and primary steelmaking industry that are anchors for industrial consumption. In 2020, coal use within the sector stood at 56 per cent and is not expected to start declining until 2060 in an NZ scenario. The share of coal in the fuel mix will be at 7 per cent in 2070 as electrification of the sector takes over post-2055. Due to the efforts in decarbonising the sector in an NZ scenario, emissions from this sector will decrease from 21 $MTCO_2$ in 2020 to 16 $MTCO_2$ in 2070, relative to the BAU scenario where emissions from the industrial sector are projected to be 63 $MTCO_2$ in 2070. The 16 $MTCO_2$ residual emissions from the industrial sector will be offset by land-use sequestration.

Overall, as is the trend witnessed in the other demand sectors, electrification will be observed in the industrial demand sector while hydrogen will make up a small percentage of the fuel mix in the sector only after 2060. Natural gas, refined liquids, and coal will progressively be phased down, making up 13 per cent of the fuel mix in 2070 in an NZ scenario, as noted in Figure 8.

Figure A8: Energy demand by fuel for the industrial sector

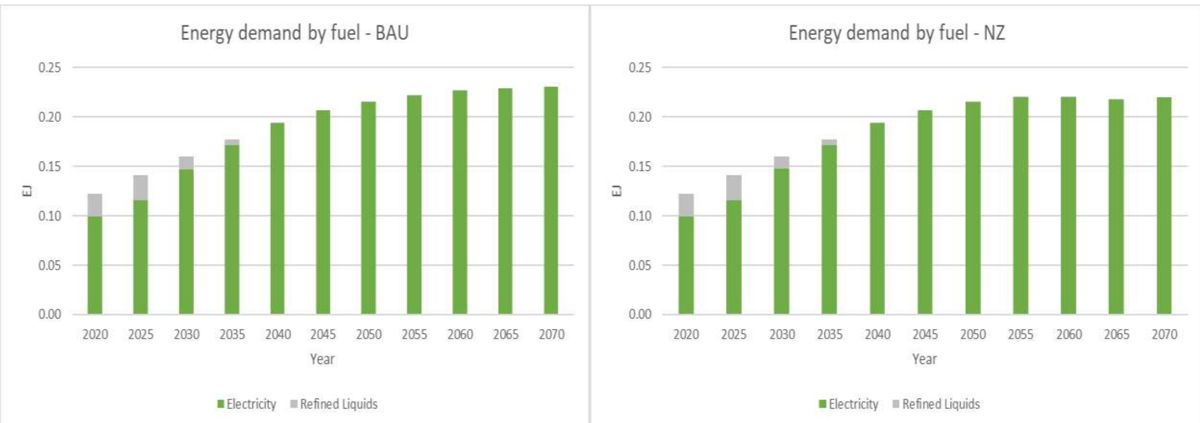


Source: GCAM analysis

Agriculture

Agriculture accounts for ~44 per cent of the total electricity sales by electricity distribution companies in Rajasthan. In 2020, electricity accounted for 81 per cent of the energy demand in the sector, while refined liquids accounted for the rest (19 per cent). The share of electricity consumption within the sector is projected to increase further and likely to phase out refined liquids by 2045. The reason for this shift will be the increased utilisation of electric pumps and electric tractors instead of those powered by diesel. Overall, agriculture accounted for 13 per cent of the total energy demand in 2020, which will reduce to 8 per cent by 2050, mainly on account of increased mechanisation and a shift towards energy-efficient electrification in the future. It is important to note that the decrease does not imply a reduction in absolute terms; rather, it will increase by 1.8 times between 2020 and 2050 in both BAU and NZ scenarios.

Figure A9: Energy demand by fuel for the agriculture sector



Source: GCAM analysis

Buildings

The growing population and economic activity in Rajasthan will imply the need for adequate housing and an increase in commercial buildings. Total built-up area is expected to increase by 2.5 times in the state by 2050 over 2020, while the total energy consumption from buildings also increases concomitantly by 2.5 times in both BAU and NZ scenarios. However, the fuel mix in the two scenarios varies.

Buildings services

Cooking: Electric cooking displaces LPG consumption in the NZ scenario, with the share of electricity in cooking energy use reaching 37 per cent in 2050 and 68 per cent in 2070, as against only 27 per cent in 2050 and 23 per cent in 2070 in the BAU. Driven by the electrification of cooking in the NZ scenario, the share of electricity in building energy demand will grow from 28 per cent in 2020 to 71 per cent in 2050 and 97 per cent in 2070, compared to 63 per cent each in 2050 and 2070 in the BAU. It is assumed that the use of traditional biomass will be completely eliminated by 2050. The share of PNG and LPG also rises until 2050 to meet the cooking energy demand but phases down by 2070 in the NZ scenario.

Cooling and Heating: Despite an increase of 8 times in absolute electricity use for cooling and heating, their share in building electricity use remains at around 15 per cent due to efficiency improvements in the BAU and NZ scenarios. Cooling demand grows by 10 times between 2020 and 2050 in the BAU and NZ scenarios.

Figure A10: Energy demand by fuel for the buildings sector

Source: GCAM analysis

Buildings sectors

Commercial

Commercial floorspace increases nearly 6 times by 2050 over 2020, leading to a rise in total energy demand by 7 times over the same period. Cooking is a major driver of growth in energy use in commercial buildings, with both PNG and electricity use witnessing large increases between 2020 and 2050. HVAC demand increases by 6.3 times between 2020 and 2050 for both the BAU and NZ scenarios. Overall, electricity is the largest energy source in commercial buildings, increasing from 72 per cent in 2020 to nearly 80 per cent of total energy use in 2050.

Residential

Rural residential and urban residential floorspaces grow by 1.7 and 3 times between 2020 and 2050, respectively, reflecting the need for housing to accommodate a larger urban population. Due to increasing heat stress, cooling demand grows by over 9 times between 2020 and 2050 in both the BAU and NZ scenarios. Although the growth in cooling service demand will be slightly lower in the rural residential segment at around 7 times that of 2020 levels, the urban cooling service demand is expected to grow by 8.6 times in the period 2020–50. The share of cooking energy consumption reduces from 69 per cent in 2020 to 40 per cent in 2050 in the NZ scenario, despite a growth of 1.3 times in absolute terms. This indicates massive efficiency improvements due to electrification. LPG and PNG consumption will increase in the BAU scenario due to the absence of a carbon constraint that keeps LPG and PNG cost-competitive with electricity as a fuel. Therefore, LPG and PNG use is expected to grow by 1.8 and 2.2 times in the residential sector until 2050 under a BAU scenario and increase thereafter until 2070. Alternately, in the NZ scenario, LPG and PNG use grows by almost 1.75 and 1.5 times in the residential sector until 2050 but falls precipitously thereafter until 2070 to settle below the current levels in the case of LPG.

Conclusion

In summary, the modelling exercise has provided key insights; particularly in terms of the generation mix and the potential of solar power generation in Rajasthan. The modelling results suggest that Rajasthan would be able to generate almost 2.4 folds' power than what it would consume in 2050 in an NZ scenario. About 86 per cent percent of it could come from solar, further demonstrating that Rajasthan's solar potential is an asset for India to meet India's NZ emissions aim by 2070 and supply the excess power generated to other states. This will not only align Rajasthan's aspirations with the national target but also position it as a clean energy leader. In a national NZ emissions story by 2070, Rajasthan's energy sector's residual emissions will be sequestered through land use. The emissions will peak at ~180 $MtCO_2$ in 2040 and will decrease by 6 times to ~18 $MtCO_2$ by 2070.

References

1. Ministry of Statistics and Programme Implementation. Gross state domestic product of states in India. Government of India; NA. Available from: https://rbidocs.rbi.org.in/rdocs/Publications/PDFs/19T_241121DFA82C44E8B444EAB1C50666FE14406B.PDF.

2. Central Electricity Authority. State wise per capita availability of power. Government of India; NA. Available from: https://rbidocs.rbi.org.in/rdocs/Publications/PDFs/122T_241121A3B9148F92634ECBB28DCC8879FB37EA.PDF.

3. Directorate of Economics and Statistics. Economic review 2021–22 [Internet]. Government of Rajasthan; 2022. Available from: https://www.samyakias.com/wp-content/uploads/2022/05/economic-survey-english.pdf.

4. Department of Energy. Rajasthan solar energy policy 2019. Government of Rajasthan; 2019. Available from: https://rajnivesh.rajasthan.gov.in/Uploads/d64c2541-89cb-44ae-bcd4-a5090c9f59ba.pdf.

5. Department of Energy. Rajasthan wind and hybrid energy policy 2019. Government of Rajasthan; 2019. Available from: https://energy.rajasthan.gov.in/content/dam/raj/energy/rrecl/pdf/Home%20Page/RajasthanWindandHybridEnergyPolicy2019_2.pdf.

6. RRECL. Rajasthan Renewable Energy Corporation Limited: Home. Government of Rajasthan; NA. Available from: https://energy.rajasthan.gov.in/content/raj/energy-department/rrecl/en/home.html#.

7. MNRE. State wise installed capacity of renewable power as on 31.05.2023). Government of India; 2023. Available from: https://mnre.gov.in/img/documents/uploads/file_s-1686304505453.pdf

8. Ministry of Rural Development, Indian Space Research Organisation. Wastelands atlas of India (change analysis based on temporal satellite data of 2008–09 and 2015–16). Government of India; 2019. Available from: https://dolr.gov.in/sites/default/files/Wastelands%20Atlas%20-%20Cover%2C%20Preface%2C%20Contents%2C%20Project%20Team%2C%20Executive%20Summary%2C%20Introduction%20-%20Result.pdf.

9. Ashwin Gambhir, Abhiram Sahasrabudhe, Srihari Dukkipati, Saumendra Aggrawal. Renewable energy data portal. Prayas (Energy Group). 2016. Available from: https://energy.prayaspune.org/our-work/data-model-and-tool/renewable-energy-data-portal#baTab4.

10. Mohanty A, Wadhawan S. Mapping India’s climate vulnerability: A district-level assessment. CEEW. 2021.

11. Central Pollution Control Board. List of 131 non-attainment cities. CPCB; NA. Available from: https://cpcb.nic.in/uploads/Non-Attainment_Cities.pdf.

12. Kuldeep N, Chawla K, Ghosh A, Anjali Jaiswal, Nehmat Kaur, Sameer Kwatra, et al. Greening India’s workforce: Gearing up for expansion of solar and wind power in India. CEEW; National Research Development Corporation (NRDC). 2017.

13. Central Electricity Authority. All India installed capacity of power stations in India (As on 30.09.2022) . Government of India; 2022. Available from: https://cea.nic.in/wp-content/uploads/installed/2022/09/IC_Sep_2022.pdf.

14. Department of Energy. Technical document for Rajasthan's sectoral energy transition towards net zero. Government of Rajasthan; 2022.

15. Chernyakhovskiy I, Joshi M, Gadzanku S, Inskeep S, Rose A. Opportunities for renewable energy, storage, vehicle electrification, and demand response in Rajasthan's power sector. NREL; 2022. Available from: https://www.osti.gov/servlets/purl/1891214/.

16. Ministry of Petroleum and Natural Gas. Exploration and production of crude oil. Government of India; NA. Available from: https://mopng.gov.in/en/exp-and-prod/production.

17. Department of Petroleum. Land mark development in hydrocarbon sector of the state. Government of Rajasthan; 2022. Available from: https://petroleum.rajasthan.gov.in/landmark-development.htm.

18. National Sample Survey Office. Annual survey of industries 2018–19. Government of India; 2021. Available from: http://microdata.gov.in/nada43/index.php/catalog/150.

19. Central Electricity Authority. All India electricity statistics: General review 2021. Government of India; 2021. Available from: https://cea.nic.in/wp-content/uploads/general/2020/General_Review_2021.pdf.

20. Climate Studies, IIT Bombay, Department of Environment and Climate Change. Draft of State Action Plan on Climate Change 2022. Government of Rajasthan; 2022. Available from: https://environment.rajasthan.gov.in/content/dam/environment/Env/Pdf_Files/Draft%20of%20State%20Action%20Plan%20on%20Climate%20Change%202022.pdf.

21. International Energy Agency. India energy outlook 2021. IEA; 2021. Available from: https://www.oecd-ilibrary.org/energy/india-energy-outlook-2021_ec2fd78d-en.

22.Department of Water Resources. Water resources vision 2045. Government of Rajasthan; NA. Available from: https://water.rajasthan.gov.in/content/water/en/waterresourcesdepartment/rulespoliciesandacts/vision2045.html.

23. RERC. Aggregate revenue requirement, tariff petition and investment plan of Jaipur Vidyut Vitran Nigam Ltd (JVVNL), Ajmer Vidyut Vitran Nigam Ltd (AVVNL) and Jodhpur Vidyut Vitran Nigam Ltd (JdVVNL) for FY 2022–23. Government of Rajasthan; 2022. Available from: https://rerc.rajasthan.gov.in/rerc-user-files/tariff-orders.

24. Ministry of Jal Shakti. National compilation on dynamic ground water resources of India, 2020. Government of India; 2020. Available from: http://cgwb.gov.in/documents/2021-08-02-GWRA_India_2020.pdf.

25. Singh VP, Sidhu G. Investment sizing India's 2070 net-zero target. CEEW. 2021.

26. Dutt A, Soman A, Chawla K, Kumar N, Bhattacharya S, Vaze P. A guide on green bonds for renewable energy and electric transport. CEEW. 2019.

27. Agrawal S, Jain A. Financing solar for irrigation in India. CEEW; Swiss Agency for Development and Cooperation SDC; SHAKTI Sustainable Energy Foundation. 2018.

28. Centre for Budget and Governance Accountability, SHAKTI Sustainable Energy Foundation. Climate mitigation financing framework in Rajasthan. 2020. Available from: https://www.cbgaindia.org/wp-content/uploads/2020/09/Climate-Mitigation-Financing-Framework-in-Rajasthan.pdf.

29. Arjun Dutt, Pablo Gonzalez, Nikhil Sharma, Lucila Arboleya, Ruchita Shah. Clean energy investment trends 2021: Evolving financial performance expectations & power procurement mechanisms In India. CEEW; IEA. 2021.

30. Akanksha Tyagi, Sharayu Shejale, Neeraj Kuldeep. Upgrading Suryamitra Skill Development Programme: Improving uptake and employability of Suryamitras in the solar sector. CEEW. 2022. Available from: https://www.ceew.in/publications/improving-employability-of-suryamitra-skill-development-programme-in-solar-sector.

31. NITI Aayog, RMI, and RMI India, Need for Advanced Chemistry Cell Energy Storage in India (Part I of III), February 2022. Available from: https://www.niti.gov.in/sites/default/files/2022-02/Need-for-ACC-Energy-Storagein-India.pdf.

References for Technical Document

[1]: Chaturvedi V, Malyan A. Implications of a net-zero target for India's sectoral energy transitions and climate policy. CEEW. 2021 October.
Available from: https://www.ceew.in/publications/implications-of-net-zero-target-for-indias-sectoral-energy-transitions-and-climate-policy.

[2]: Census of India 2011. Population projections for India and states 2011–2036. New Delhi: Ministry of Health and Family Welfare; 2019. Available from: https://www.nhm.gov.in/New_Updates_2018/Report_Population_Projection_2019.pdf.

[3]: Ministry of Coal. Official website of Coal Controller's Organization. Government of India. Available from: http://www.coalcontroller.gov.in/pages/display/16-coal-directory.

[4]: Ministry of Petroleum and Natural Gas (MoPNG). Indian PNG Statistics. Government of India. Available from: https://mopng.gov.in/en/petroleum-statistics/indian-png-statistics.

[5]: GHG Platform India. An Indian civil society initiative to understand India's GHG emission estimates. Available from: https://www.ghgplatform-india.org/.

[6]: NITI Aayog. Available from: https://www.niti.gov.in/edm/#electricity.

[7]: Ministry of Power. General Review Report. Central Electricity Authority, Government of India; 2021. Available from: https://cea.nic.in/general-review-report/?lang=en.

[8]: Central Electricity Authority (CEA). Central Electricity Authority Dashboard (2020). Government of India. Available from: https://cea.nic.in/dashboard/?lang=en.

[9]: India Human Development Survey (IHDS). Available from: https://ihds.umd.edu/data/data-download.

[10]: National Sample Survey Office, Ministry of Statistics. National Sample Survey (NSS) data (unit level), Harvard Dataverse. 2017. Harvard Dataverse. Available from: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi%3A10.7910%2FDVN%2FK8BSDU.

[11]: Indian Railways Civil Engineering Portal. About us. Government of India. Available from: https://ircep.gov.in/AboutUs.html.

[12]: Ministry of Road Transport & Highways. Road Transport Year Book (2013–15). Government of India. Available from: https://morth.nic.in/sites/default/files/other_files/Road_Transport_Year_Book_2013_15.pdf.

Ministry of Road Transport & Highways. Road Transport Year Book (2015–16). Government of India. Available from: https://morth.nic.in/sites/default/files/other_files/Road_Transport_Year_Book_2015_16.pdf.

[13]: Ministry of Statistics and Programme Implementation. Annual survey of industries. Available from: http://microdata.gov.in/nada43/index.php/catalog/ASI.

[14]: Abhyankar AN et al. Least-cost pathway for India's power system investments through 2030. 2021. Electricity Markets and Policy Group.
Available from: https://emp.lbl.gov/publications/least-cost-pathway-india-s-power.

[15]: Chaturvedi V, Koti PN, Chordia AR. Sustainable development, uncertainties, and India's climate policy. CEEW. 2018. Available from: https://www.ceew.in/publications/sustainable-development-uncertainties-and-india%E2%80%99s-climate-policy.

[16]: US Energy Information Administration (EIA). US Energy Information Administration - EIA - independent statistics and analysis. Available from: https://www.eia.gov/environment/emissions/co2_vol_mass.php.