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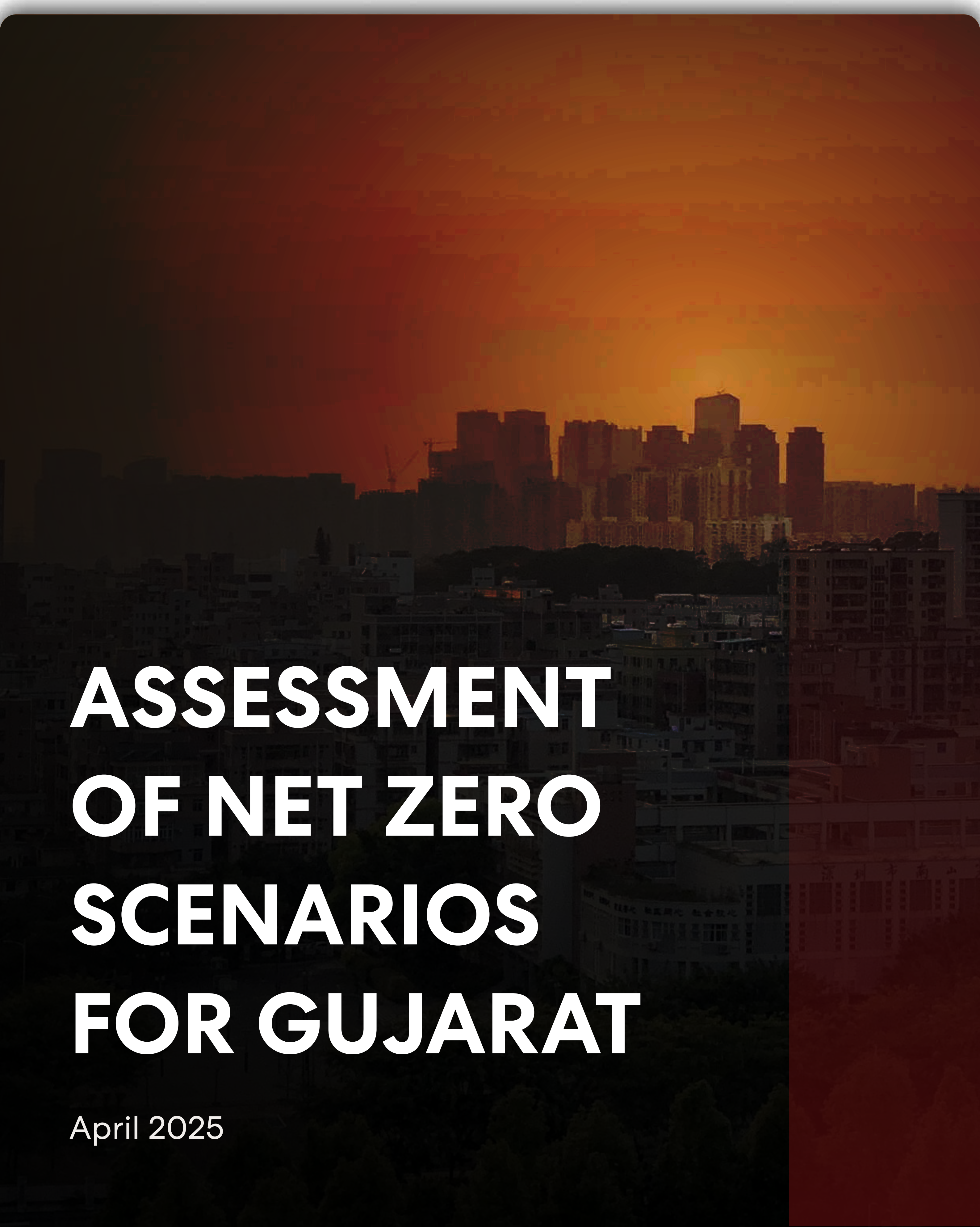

# ASSESSMENT OF NET ZERO SCENARIOS FOR GUJARAT

April 2025

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# ASSESSMENT OF NET ZERO SCENARIOS FOR GUJARAT

April 2025


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# FOREWORD

Government of Gujarat has a firm commitment to address the concerns of climate change through concerted actions. Gujarat is the first state in Asia to establish a separate and dedicated Department of Climate Change at subnational level in 2009, under the visionary leadership of the then Chief Minister and presently Prime Minister of India, Shri Narendra Modi. Some of the globally noteworthy climate change adaptation or mitigation initiatives of Gujarat include the Sardar Sarovar Project, the State-Wide Drinking Water Grid, innovative micro water harvesting strategies, world's first Solar Park, first Canal Top Solar and massive rooftop solar program. With the ambitious policies in renewable energy, Gujarat has turned climate challenges into opportunities for sustainable and inclusive growth.

I would like to take this opportunity to acknowledge efforts of the Ahmadabad University, CEEW and Copenhagen Climate Change Centre for bringing the comprehensive Assessment of Net Zero Scenarios for Gujarat. The report builds upon this legacy, offering a detailed roadmap to align the state's climate ambitions with India's national net-zero targets.

In this research study, it is proficiently attempted to analyze current and future growth and emissions from the key sectors based on the current data and robust modeling tools, which propose how Gujarat can embark on a pathway to achieve net-zero emissions by 2070, through sectoral transformations in energy, industry, transport, and urban development. The report recommends actionable strategies for meeting end use demands at lower emissions including enhanced energy efficiency, electrification of end-use sectors, and expansion of renewable energy. The pathways project Gujarat's ability to balance rapid economic growth with environmental sustainability, ensuring that the benefits of development are equitably distributed across all communities.

The report also highlights the broader co-benefits of a net-zero transition, such as improved air quality, health benefits, green job creation, and enhanced economic resilience. However, it underscores the need to carefully navigate trade-offs, including land-use challenges, energy affordability, and ensuring a just transition for communities reliant on fossil fuel industries. By addressing these complexities, Gujarat aims to provide a replicable model of inclusive and equitable climate action for other regions to follow.

The study on Net Zero Strategy for Gujarat will certainly contribute towards climate resilience while serving India's Nationally Determined Contributions. With the support of scientists and researchers, we aspire to come up with policies and programs for Sustainable Development to unlock Gujarat's potential in driving India's climate actions at the sub-national level.

Rahul Gupta

Dr. Rahul Gupta, IAS

**Secretary, Climate Change Department, Government of Gujarat**

# FOREWORD

Gujarat has consistently demonstrated its leadership in clean energy transitions through key initiatives like the development of India's first Solar village at Modhera integrated with battery energy storage, green hydrogen pilot projects, and Asia's largest multi-developer solar park at Khavda. These efforts underline thee state's commitment to innovation and sustainability, positioning it as a frontrunner in India's journey toward net-zero emissions. The Assessment of Net Zero Scenarios for Gujarat report builds upon these initiatives, offering a comprehensive analysis of the opportunities and challenges in transitioning to a low-carbon economy.

The report highlights the critical role of electrification, renewable energy, and green hydrogen in decarbonizing key sectors such as industry, transport, and urban development. It underscores Gujarat's leadership in integrating advanced technologies into its energy ecosystem while addressing challenges like variable renewable energy integration, demand-side management, and infrastructure scaling. By focusing on pragmatic and actionable strategies, the report demonstrates how Gujarat can align its energy transitions with its ambitious growth targets.

GETRI plays a pivotal role in advancing Gujarat's clean energy vision through research, capacity building, and stakeholder collaboration. This report reflects our commitment to fostering innovation and resilience in energy systems, ensuring that Gujarat's climate actions are grounded in evidence and inclusive decision-making. By addressing the synergies and trade-offs of a net-zero transition, the report emphasizes the importance of balancing sustainability with economic and social priorities.

The Assessment of Net Zero Scenarios for Gujarat provides valuable insights for policymakers, researchers, and industry leaders, highlighting Gujarat's ability to lead by example. As the state embarks on this transformative journey, this report serves as a roadmap for achieving net-zero emissions while driving sustainable development. Together, we can ensure a future that is resilient, inclusive, and environmentally responsible.

Smt. Alka Yadav
**Director, Green Energy Transition Research Institute (GETRI), Gujarat Urja Vikas Nigam Limited**

# ACKNOWLEDGEMENT

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This is a research report prepared for the Project "Net Zero Strategies for Gujarat State" funded by Ministry of Foreign Affairs, Denmark. It does not purport to be comprehensive and exhaustive. While every effort has been made to ensure accuracy of facts and figures. No liability shall accrue under any circumstances on any grounds, whatsoever, to publishers or any individuals or agencies associated with the preparation of this report. Any discrepancy, error, or misinterpretation, factual or otherwise, or any unintended or unintentional infringement of copyright or propriety, as and when pointed out, will be gratefully acknowledged, and suitably acted upon.

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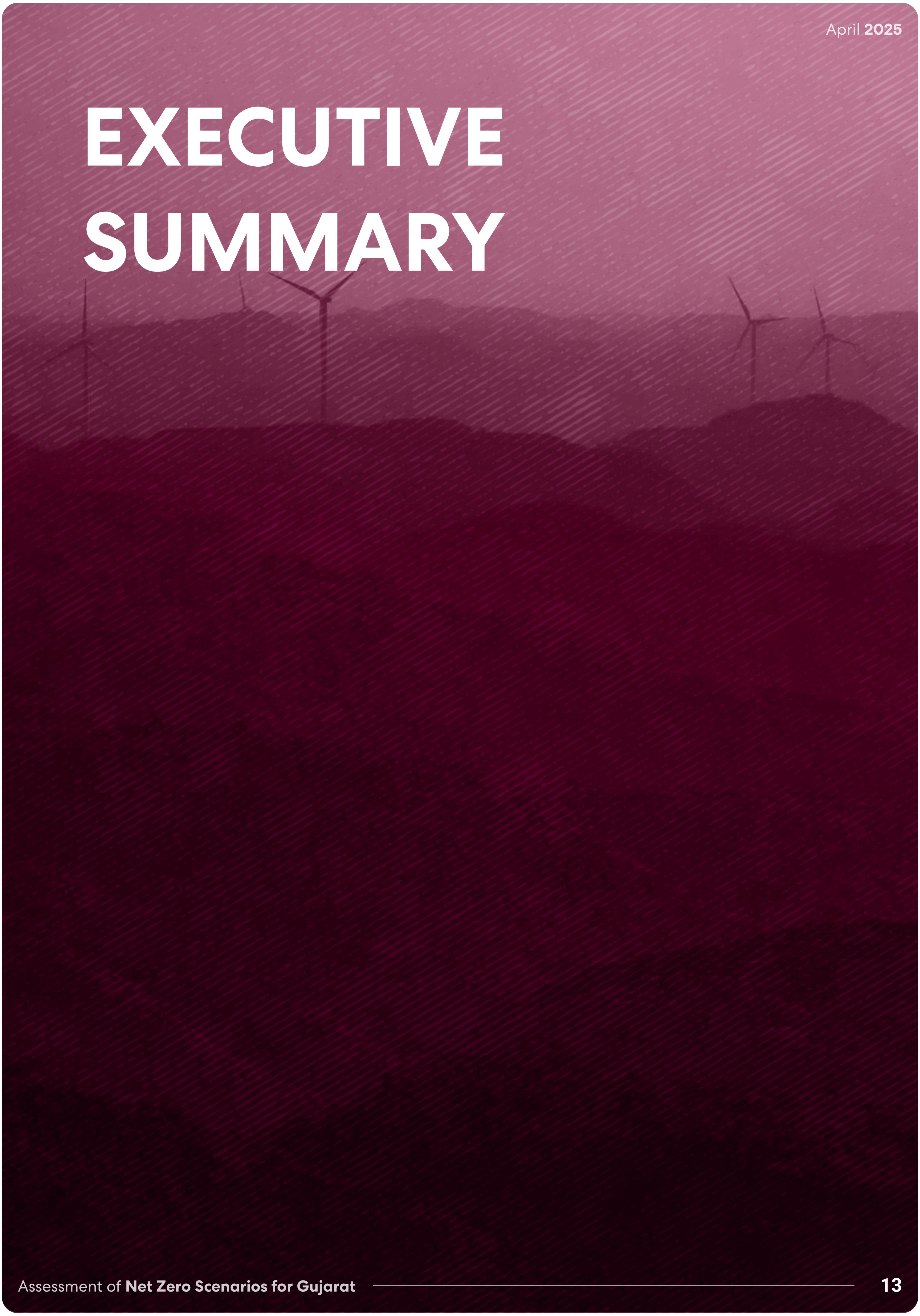
# EXECUTIVE SUMMARY



The urgency of climate action is growing as the severity of climate impacts—such as extreme weather, rising sea levels, and resource scarcity continues to escalate. Simultaneously, a rising number of countries, cities, and businesses have set ambitious net zero targets. Since the release of the IPCC 1.5°C report, support for a net-zero narrative of climate leadership has been constantly growing. According to Climate Action Tracker, as of 20 September 2022, around 140 countries had announced or are considering net zero targets, covering close to 90% of global emissions. The willingness at the political level, backed by robust analysis is expected to move the aspiration towards faster actions to meet this ambitious yet achievable target. At the 26th session of the Conference of the Parties (COP26) in 2021, India demonstrated its climate leadership by announcing that it would achieve net-zero carbon emissions by 2070. With this national target, states must develop their own strategies to align with and contribute to the national goal. Gujarat's effort to formulate a net-zero transition pathway demonstrates its initiative to align the state's climate ambition to the country's climate targets.

Achieving net-zero emissions requires significant transformation across key sectors that produce and consume energy. These include sectors such as industry, power, transport, buildings and agriculture. According to the Viksit Gujarat vision document, Gujarat aims to become a $3.5 trillion economy in 2047 (nominal terms). This will mean a per-capita income growth of more than 8 times between 2020 and 2050 in Gujarat, with more people living in urban areas - as urbanisation levels increase from 48% in 2020 to 73% in 2050. These developments will further increase energy demand and emissions across sectors that contribute to the economy. The challenge for Gujarat, then, is to identify and chart out low-carbon pathways for the aforementioned sectors while not compromising on the state's growth and developmental prospects. Achieving net zero emissions alongside economic growth and development will be challenging. A commitment to net zero, therefore, requires consistent efforts to adapt low-carbon pathways across various sectors in the near, medium, and long term.

A net zero pathway, offers the opportunity to transition to clean energy technologies that can support new industries, create green jobs, reduce oil import bills, and boost economic resilience. Actions toward shifting to energy-efficient technologies, higher electrification, and renewables will also provide co-benefits by way of reduced air pollution, leading to significant health benefits. Gujarat's net zero ambition and actions can serve as a model for other states, showcasing leadership while driving sustainable economic growth with lower emissions.

The analysis in this report is based on the development of two alternate policy scenarios for achieving Net Zero emissions: i) Net Zero Conventional Scenario and ii) Net Zero Structural Shift Scenario for Gujarat, spanning through 2070. The Net Zero Scenarios are compared to a reference scenario. The latest greenhouse gas emissions inventory for Gujarat state and a careful study of past trends and ongoing policies and actions at the state level form the basis for existing conditions. The report involves model-based assessments that are carried out using two different models: i) Global Change Analysis Model (GCAM) and ii) Low Emissions Analysis Platform (LEAP).

The key insights are presented below, and these are elaborated in the last chapter:

Gujarat witnessed a 62 per cent rise in energy sector GHG emissions between 2010 and 2022. From around 143 Million tons of Carbon dioxide Equivalent ($MtCO_2eq$) in 2010, GJ's overall GHG emissions rose to 232 $MtCO_2eq$ in 2022. In this year, the industry sector was the largest contributor, accounting for 49% of the total emissions. Total electricity generation contributed 36%, transport contributed 13% to total emissions. The impact of COVID is clearly visible in the trends with the emissions dropping to 222 $MtCO_2eq$ in 2021 against the estimated high of 242 $MtCO_2eq$ in 2019 just before the pandemic.

With continuation of current trends, emissions in Gujarat are going to increase by 5-6 times in 2070 compared to 2020, and will continue to be dominated by the industry sector.

Between 2020 and 2070, total energy demand increases nearly sevenfold. The industrial sector, dominated by manufacturing, remains the largest contributor to energy consumption (72%) and emissions (54%) by 2070, up from 68% and 48% in 2020.

This growth is driven by rising per capita incomes, which will boost demand for commodities such as chemicals, plastics, paints, cosmetics, metals, and cement.

## Decarbonisation requires a significant shift towards the low-emissions industry sector

In the next decade, enhanced energy efficiency and electrification of low- and medium-temperature applications will be crucial for decarbonization. Over the long term, as hydrogen production costs decline and high-temperature heat applications remain challenging to electrify, alternative fuels like green hydrogen will play a key role in reducing $CO_2$ emissions. Electrification's share is projected to rise from 18% in 2020 to 83% by 2070. Stringent energy efficiency measures could cut industry emissions by 3.6 $MtCO_2$ in the peak year, 2040, compared to the reference scenario. Structural economic shifts, such as a higher GDP share from services or transitioning to less energy-intensive industries like automobiles and semiconductors, can further mitigate supply and demand challenges.

## A significant shift and expansion of renewable energy

The net-zero transition require significant electrification across industry, transport, and building sectors. In the industry sector, green hydrogen will also be essential for high-temperature heat applications, with its production relying on renewable energy. By 2070, electricity consumption in Gujarat under the net-zero (NZ) scenario is 1.5 – 2 times higher than the reference scenario and nearly 25 times that of 2020. Electricity generation in the NZ scenario increases 14-fold between 2020 and 2070. However, after 2050, the state's renewable energy potential, primarily solar, becomes insufficient to meet the rapid rise in electricity demand. By 2070, approximately 40% of Gujarat's electricity demand will need to be met through imports from other states.

## Solar and wind installations dominate total power sector investments in the future

To align with net-zero goals, Gujarat will need approximately 100 GW of solar and 43 GW of wind capacity by 2030, increasing to 275 GW of solar and 93 GW of wind by 2040. This exceeds Gujarat's current target of 100 GW of renewable energy by 2030. Cumulative investment in electricity capacity additions from 2020 to 2070 is estimated at ₹55 lakh crore in the reference scenario, rising to ₹74 lakh crore in the net-zero scenario - a 35% increase. However, integrating variable renewable energy poses significant challenges and additional costs, requiring solutions like battery storage, demand-side management, energy efficiency, and behavioral changes.

## Green hydrogen could be a clean fuel alternative

Green hydrogen will be a clean fuel alternative for industry sub-sector areas that are not easy to shift to electricity as well as for shipping, aviation, The demand for green hydrogen within the state could also be an economic opportunity for Gujarat to become a manufacturing hub that caters to hydrogen needs within and outside the state. However, scaling up green hydrogen will require investments in R&D, pilot projects, and the creation of infrastructure for the transportation and storage of green hydrogen.

## Role of CCS in power sector will be limited for net-zero

Assuming that coal capacity additions in the power sector continue until 2035 and new additions beyond it have the option of being equipped with CCS, it is still economical to build solar and wind plants. In fact, in the future, costs of solar and wind power would become much lower and it could be cheaper to retire some older, more expensive coal plants and replace them with solar and wind.

## Modal shift strategies can play a more significant role in freight as well as passenger transport.

The energy demand for transport increases rapidly for both freight and passenger transport. A modal shift in freight will require improved intermodal integration, especially increasing connectivity of rail with smaller ports. In the case of urban passenger transport, sustainable urban planning that prioritizes compact, mixed-use development, increasing supply of affordable public transport and strategies to promote walkability can support a shift to sustainable travel modes and simultaneously deliver multiple benefits for Gujarat.

## The future of transport is electric

As charging infrastructure improves, transport decarbonization will primarily occur through vehicle electrification, especially as electricity becomes cleaner. In the near term, e2Ws and e3Ws drive this shift, with e4Ws and e-buses playing a smaller role. Over time, as technical and infrastructure challenges are resolved, e4Ws and e-buses gain market share. However, electric heavy-duty vehicles like trucks may face limitations due to charging time, battery size, and highway infrastructure. Based on the two modelling exercises in this study, by 2070, a significant share of transport will be electric (between 50 to nearly 100 %).

Coupled with low-carbon electricity, this transition would reduce $CO_2$ emissions as well as PM2.5 emissions.

## Commercial and Public Services Sector is the fastest growing demand sector

An increase in building energy demand is witnessed in both the residential and commercial sector, with the latter being higher owing to a faster rate of floorspace. Energy use for residential cooking is expected to decline significantly by 2070 due to more efficient stoves and fuels and a complete phase out of biomass before mid-century. However, cooling energy demand will rise sharply, by almost 52 times, due to increasing incomes, floor space and air conditioner use. Building energy efficiency improves; however, these improvements are outpaced by the growth in demand for floorspace, services and appliance ownership and use.

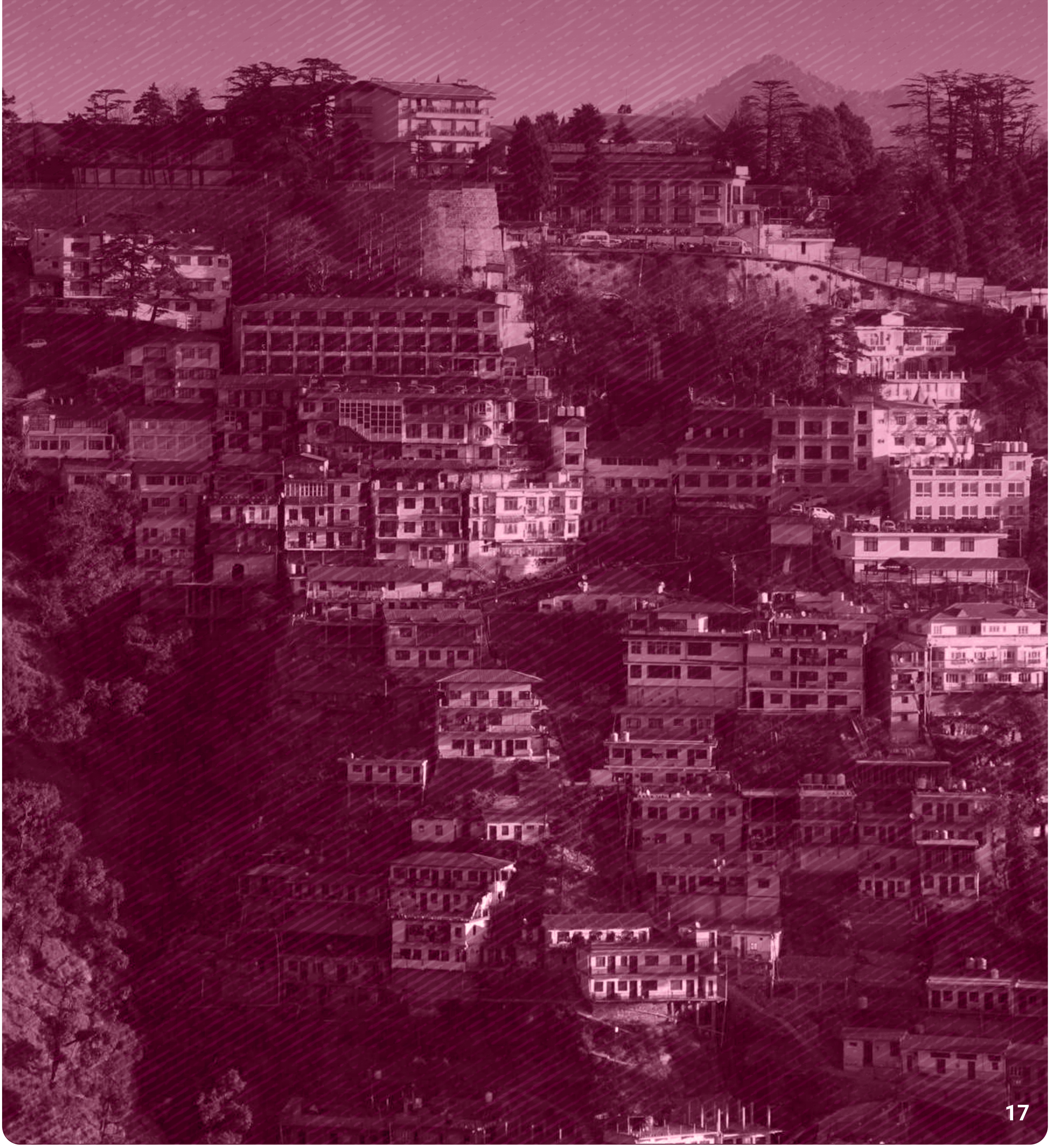
## Technology and efficiency improvements still leave some residual $CO_2$ Emissions.

A small quantity of $CO_2$ emissions will remain unmitigated despite deploying CCS in the power sector and increasing forested areas (may require more than double the current area). In 2070, residual emissions are around 98-112 $MTCO_2$. These unmitigated $CO_2$ emissions may have to be offset in other states or through the state's own measures beyond the interventions considered in this study. This could include adoption of CCS in industry and IPPU sectors, shifting from energy-intensive to less energy-intensive industries with high value added, as well as behavioural changes and demand-side management.

**A net zero transition in Gujarat would deliver synergies with multiple SDGs, however there could be trade-offs.** Sizeable benefits can be achieved through higher electrification and renewables directly through reduced $CO_2$ emissions, increasing share of clean energy, reduced PM2.5 emissions and potential indirect benefits such as improved health (from air quality improvement), technology development and green jobs. However, there could be trade-offs for example, loss of employment in fossil-related sectors like petroleum refining and increasing demands for land and water. In the near-term, potential adverse impacts such as displacement of communities, unequal access to energy benefits, and loss of carefully considering these synergies and trade-offs, Gujarat can develop integrated policies that maximize the benefits of its net zero transition while minimizing potential conflicts between different sustainable development goals. This approach will help ensure a more balanced and equitable path towards a sustainable future for the state.

While the current study is limited to assessment of net zero pathways, adaptation will be an important issue that must be simultaneously prioritised. Strategies such as sustainable water management, increase in forest cover and sustainable urban planning can also support resilience of human settlements.

# 1.
# BACKGROUND



UNEP Copenhagen Climate Centre (UNEP-CCC) initiated a project for "Net Zero Strategy" in one state of India, and through a competitive process, the state and national implementation partners were identified in 2023. The project is funded by DANIDA and is jointly delivered by the Global Centre for Environment and Energy (GCEE), Ahmedabad University and the Council for Energy, Environment and Water (CEEW). The project approach creates an evidence base through detailed scientific assessments and stakeholder consultations (Figure 1-1). This report is an output of the exercise to create the evidence base.

***Figure 1-1 Project Approach for Net Zero Strategy***

## EVIDENCE BASE

1. Net Zero scenario-based assessment covering key mitigation sectors using energy system models
   - Updation of state-level $CO_2$ inventory
   - Desk review of scenario-based assessment for of low carbon and Net Zero Scenarios
   - Analysis of Net Zero $CO_2$ emission pathways at state-level till 2070 using LEAP & GCAM model
2. Sustainable Development Impact assessment of Net Zero pathway

## ROADMAPS

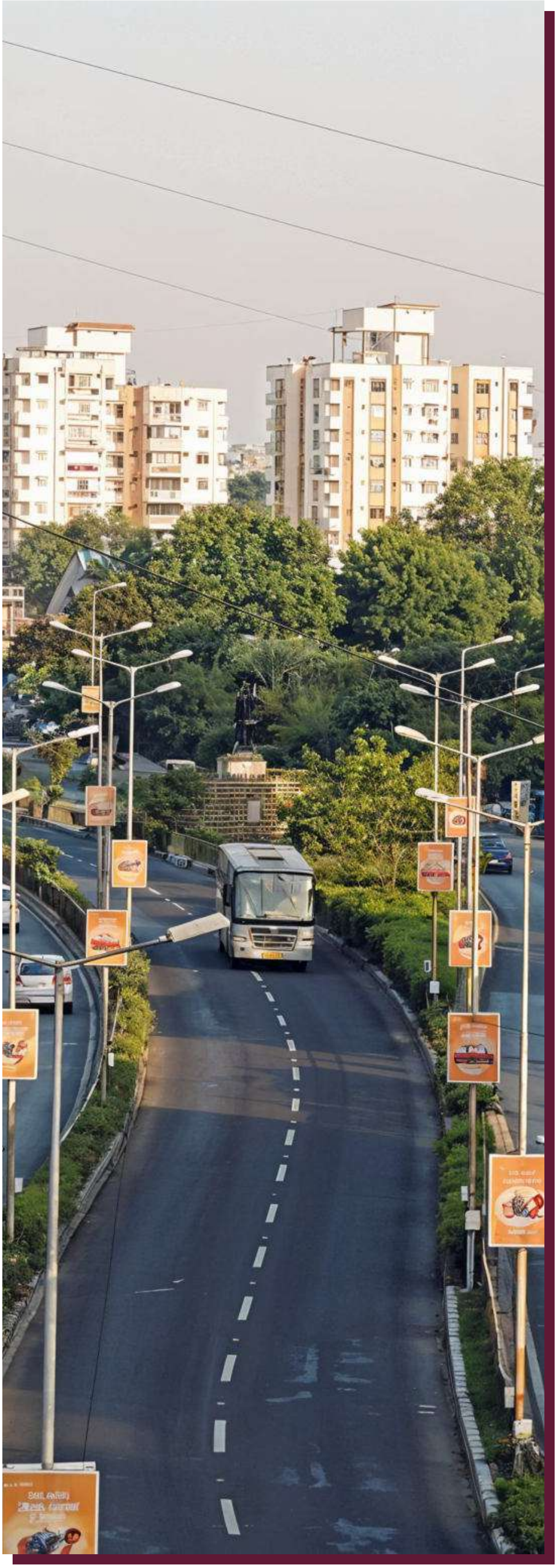
3. Prepare a technology roadmap to guide the implementation of the Net Zero strategy, including
   - Prioritise the technologies relevant to the state based on Net Zero assessment and SD impact assessment
   - Barrier analysis and measures to address barriers for the technologies
   - Prepare a draft roadmap with actions needed in the short term (until 2030) and thereafter Net Zero by the target year
   - Organise a a final workshop

Stakeholder consultations and capacity building within line ministries on net-zero pathways

The report involves model-based assessments that are carried out using two different models: i) Global Change Analysis Model (GCAM) and ii) Low Emissions Analysis Platform (LEAP). The CEEW team carried out the modelling analysis using GCAM, whereas the UNEP-CCC and Ahmedabad University team carried out the modelling analysis using LEAP. GCAM is an energy sector–focused model used extensively for energy and climate policy analyses. This model was chosen because it can project beyond mid-century into the future, providing an opportunity to explore the net zero scenario and understand the implications of its target to achieve economy-wide net zero emissions by 2070. LEAP is an energy system model that has also been used extensively for the modelling of climate policies and supported several countries in formulating their nationally determined contributions (NDCs).

With a well-defined economic vision to cater to a stabilising population, Gujarat is poised for rapid economic growth, leading to higher per-capita income and urbanisation levels – slated to be among the highest in the country. The rapid economic growth will eventually result in higher energy demand across major sectors such as transport, industry, and buildings, leading to higher carbon emissions.

An important question pertinent to many sub-national entities in India, including Gujarat, is the feasibility of achieving net-zero in line with India's net-zero vision for 2070.



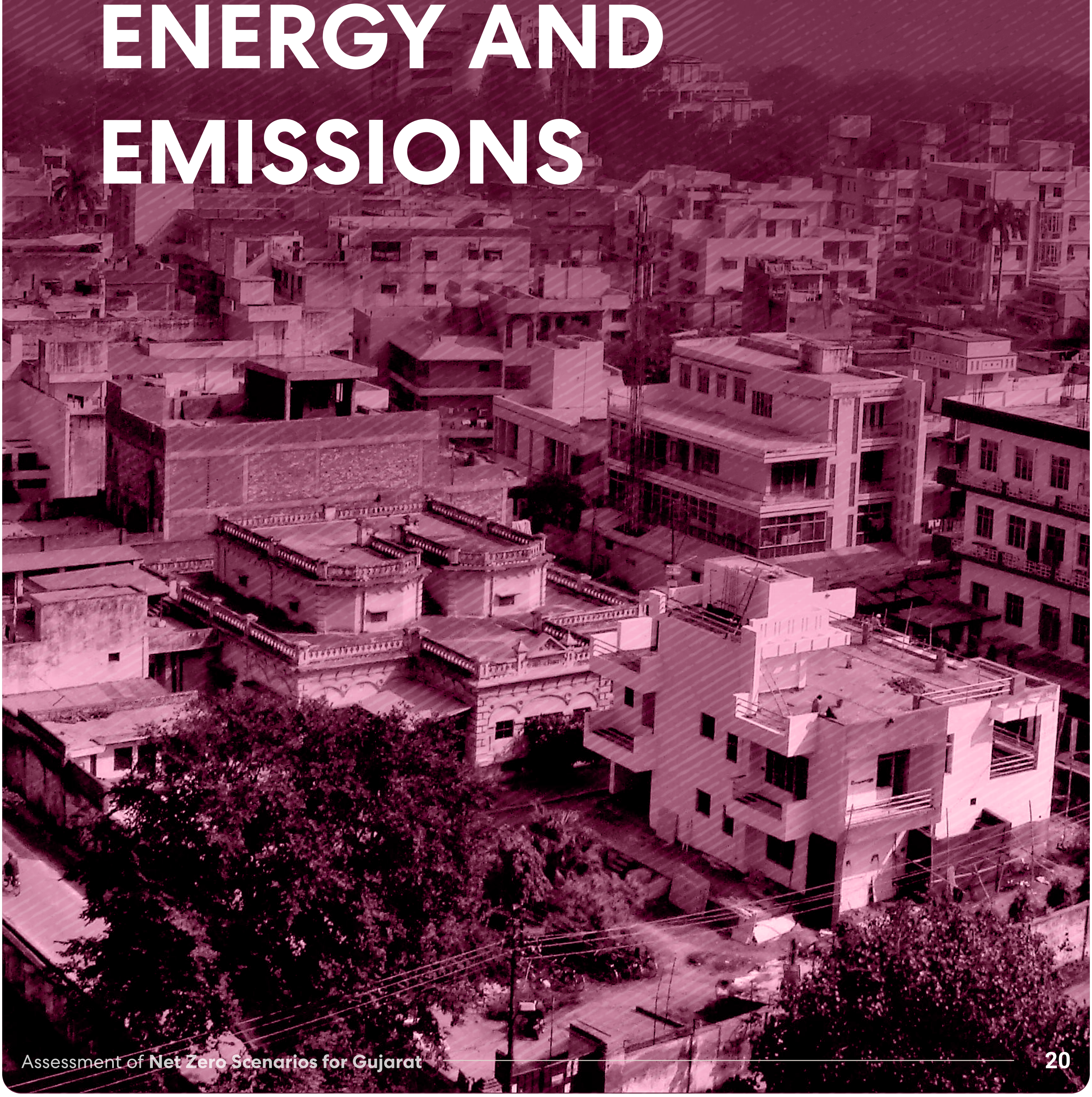
The project report presents two alternate policy scenarios for achieving Net Zero emissions: i) Net Zero Conventional Scenario and ii) Net Zero Structural Shift Scenario. Both scenarios span a time frame from the current period (2020) up to 2070, In line with the Government of India's announcement to achieve NetZero Emissions by 2070. The Net Zero Scenarios ere compared to a reference scenario. The Net Zero Conventional Scenario is analysed using the GCAM model, which has been used earlier for analysis in the states of Bihar end Tamil Nadu and is well designed for analysing changes that happen due to energy prices and technology costs. The Net Zero Structural Shift Scenario was analysed using LEAP, which has a bottom up and detailed representation of demand sectors.

Chapter 2 provides an overview of energy sector GHG emissions from 2018 to 2022 (pre-COVID to post-COVID). This chapter Is useful for setting the context end for calibration of the base years In the models. The following chapter 3 then provides a review of energy and climate policies at the national and state levels which then leads us to key elements of the scenario storylines for reference end two net zero scenarios. This is followed by a section on the modelling approach and methodology. Detailed quantitative assumptions and key dote sources ere also described in the Appendix. The model results section discusses the future energy mix and emissions for both scenarios and other key elements of the economy and environment. An assessment of sustainable development implications of the transition is next undertaken to represent what net zero scenarios mean In terms of resources and development priorities such as water consumption, employment, air quality end health. The report concludes with a summery of key findings end implications for state level policy.

## Scope of the study

In terms of GHGs, the study covers $C0_2$ emissions from both energy end non-energy sources. The energy sector Includes $C0_2$ emissions associated with the burning of fossil fuels in power generation, industry, residential, commercial, transport, agriculture, coal mines, oil refineries and power generation. Non-energy emissions include $C0_2$ emissions and sequestration in Agriculture, Forestry, and Other Land Use (AFOLU) and process related $C0_2$ emissions In industry (IPPU). At the state level, Gujarat can import/export any shortfall or surplus In fuels or electricity from the other states.

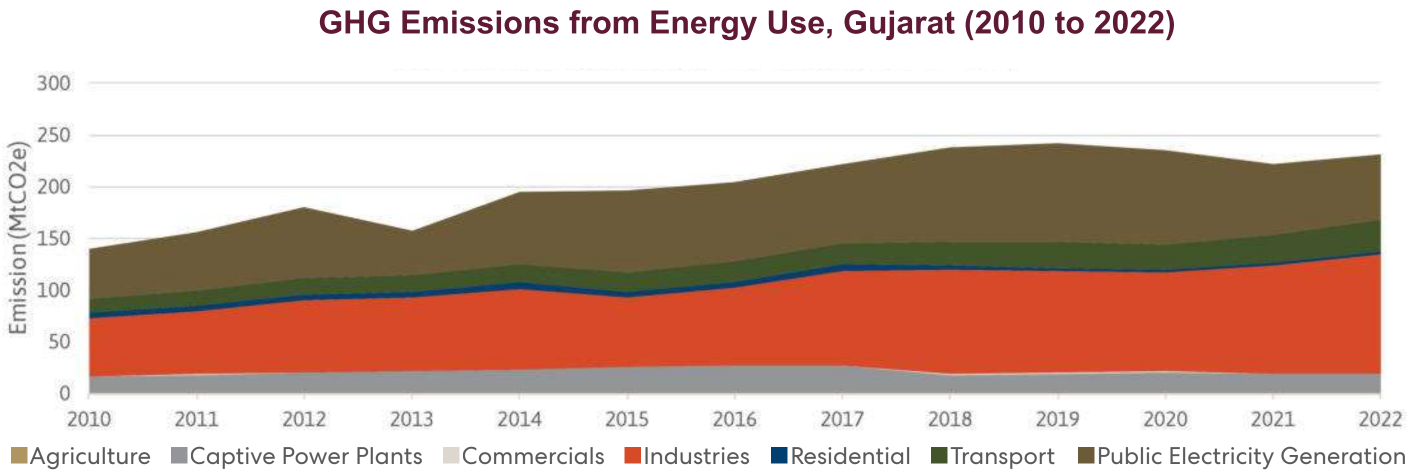
# 2.
# CURRENT PROFILE OF GUJARAT: ENERGY AND EMISSIONS



Gujarat is in the western part of India and is among the most developed sub-national region in the country. With a contribution of over 8% to the country's GDP, the state has witnessed rapid growth in the past few decades (Government of Gujarat, 2024c). Manufacturing contributes nearly a third of the state's GDP. Including energy & transport sector the share of the industry sector goes up to nearly 48%.

Given its advantages in terms of geographic location, economic structure and a thriving industry, the state aims to become a USD 500 billion economy by 2026-27 in nominal terms while increasing its share from 8.3 to 10% of the country's GDP (Government of Gujarat, 2024c). Gujarat's population is around 70 million (2020) and is relatively highly urbanized at 56%.

***Figure 2-1 GHG Emissions from Energy Use in Gujarat***




**Source**: GHG Platform-India*

* **Note**: The emission estimate till 2018 is available on GHG Platform India. Emission estimate for 2019 onwards has been prepared by the authors following the methodology described in Appendix number (10.3).

The greenhouse gas inventory for the energy sector of Gujarat until 2018 was prepared by the "GHG Platform-India" and is available in the public domain. The inventory has been updated for the years 2019 to 2022. In 2022, The emissions have been calculated using the state-wise fuel consumption data published by the Ministry of Petroleum and Natural Gas, coal consumption published by the Annual Survey of Industries and the coal consumption reported by the Central Electricity Authority in certain cases. A detailed methodology is included in the "Appendix 10.3" Gujarat emitted 231.6 million tons of greenhouse gases.

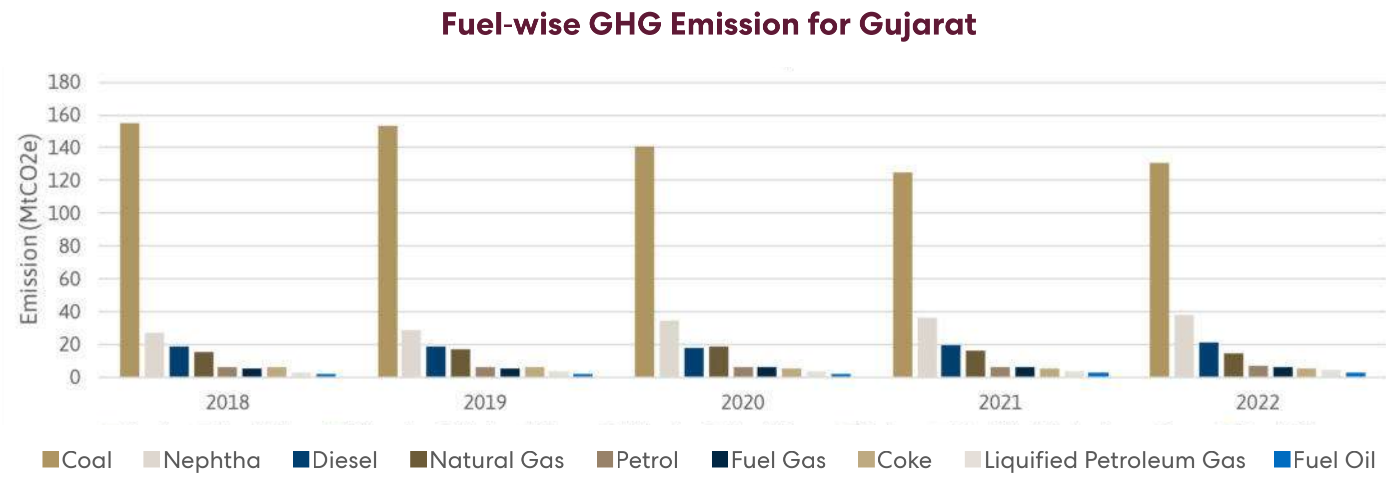
In 2022, the industry sector was the largest contributor, accounting for 49% of the total emissions. Utility electricity generation contributed 28%, transport contributed 13%. Captive electricity generation contributed 8% to the total emissions. The impact of COVID is clearly visible in the emission trends with the emissions dropping to 222 million tons (see Figure 2-1) $CO_2e$ in 2021 against the estimated high of 242 million tons $CO_2e$ in 2019 just before the pandemic. The sectoral emissions for 2018 to 2022 are presented in table 2.1[1].

According to Climate Trace, Gujarat's greenhouse gas emissions in 2023, including CO2, CH4, and N2O, are estimated at 272.79 MtCO2e, based on a 100-year climate impact horizon. For 2022, the estimate stands at 266.98 MtCO2e. These estimates are derived from 684 sources, excluding emissions from land use and forestry[2]. While Climate Trace provides an economy-wide GHG inventory, analysis in this study focuses specifically on emissions from the energy sector.

[1] Author's emission estimate for 2018 varies by approximately 6% compared to the estimate available on GHG Platform India. Lower disaggregation of the fuel consumption (Fuel categorization as followed in the IPNG Statistics report have been followed by the authors; GHG Platform India disaggregates fuel consumption into more categories than that) is expected to be the cause, as the difference is uniform accross sub-sectors. 19

[2] Climate Trace https://climatetrace.org/data

***Figure 2-2 Fuel-wise GHG Emissions***

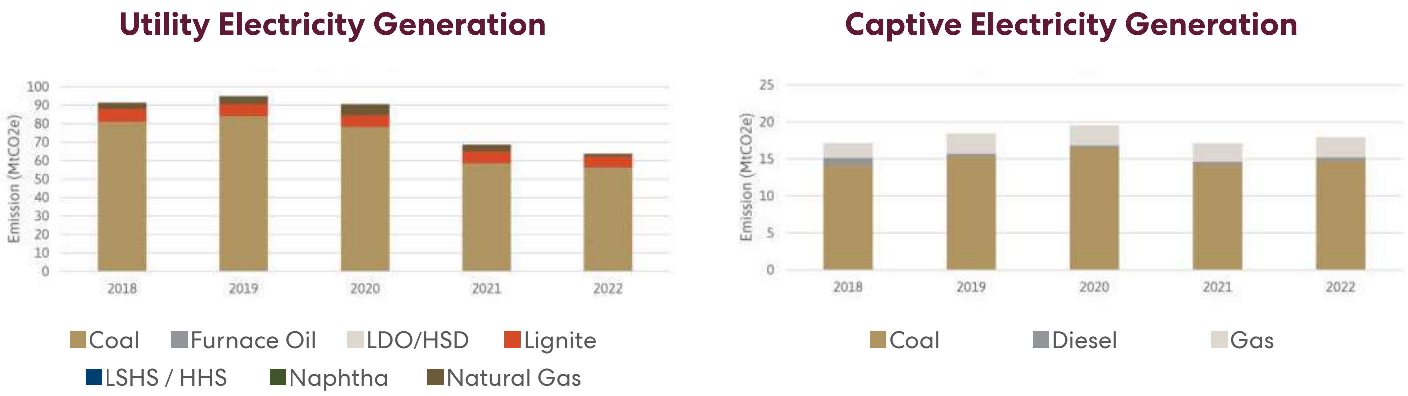



Coal, naphtha, diesel, natural gas, and petrol account for 91% of the total emission with the other fuels making up the rest. Coal is the largest contributor to total emissions having a 56% share in emission, followed by naphtha as a distant second at 16% (See Figure 2-2).

***Table 2-1 GHG Emissions for Gujarat, 2018-22, Million tons of $CO_2e$***

| SECTOR | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Agriculture | 1.13 | 1.22 | 1.27 | 1.32 | 1.32 |
| Captive Electricity Generation | 17.18 | 18.46 | 19.54 | 17.11 | 17.96 |
| Commercial | 0.40 | 0.35 | 0.38 | 0.40 | 0.42 |
| Industry | 101.06 | 97.87 | 95.91 | 104.43 | 114.53 |
| Residential | 3.47 | 3.38 | 3.40 | 3.53 | 3.70 |
| Transport | 24.06 | 25.82 | 23.93 | 26.22 | 29.91 |
| Utility Electricity Generation | 91.42 | 94.92 | 90.67 | 68.86 | 63.73 |
| **Grand Total** | **238.74** | **242.02** | **235.10** | **221.68** | **231.59** |

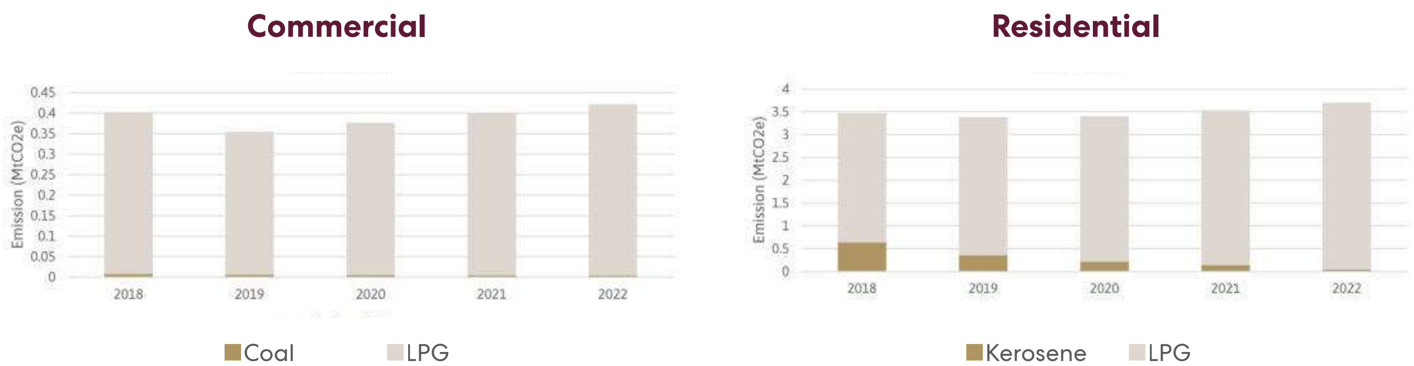
***Figure 2-3 GHG Emissions from Electricity Generation***




GHG emissions from utility electricity generation decreased from 94.92 Mt-$CO_2$e in 2019 to 63.73 Mt-$CO_2$e in 2022 reflecting a decrease in coal consumption and natural gas for electricity generation (Figure 2-3). There is visible decrease in the diesel and coal consumption in the captive electricity generation during COVID.

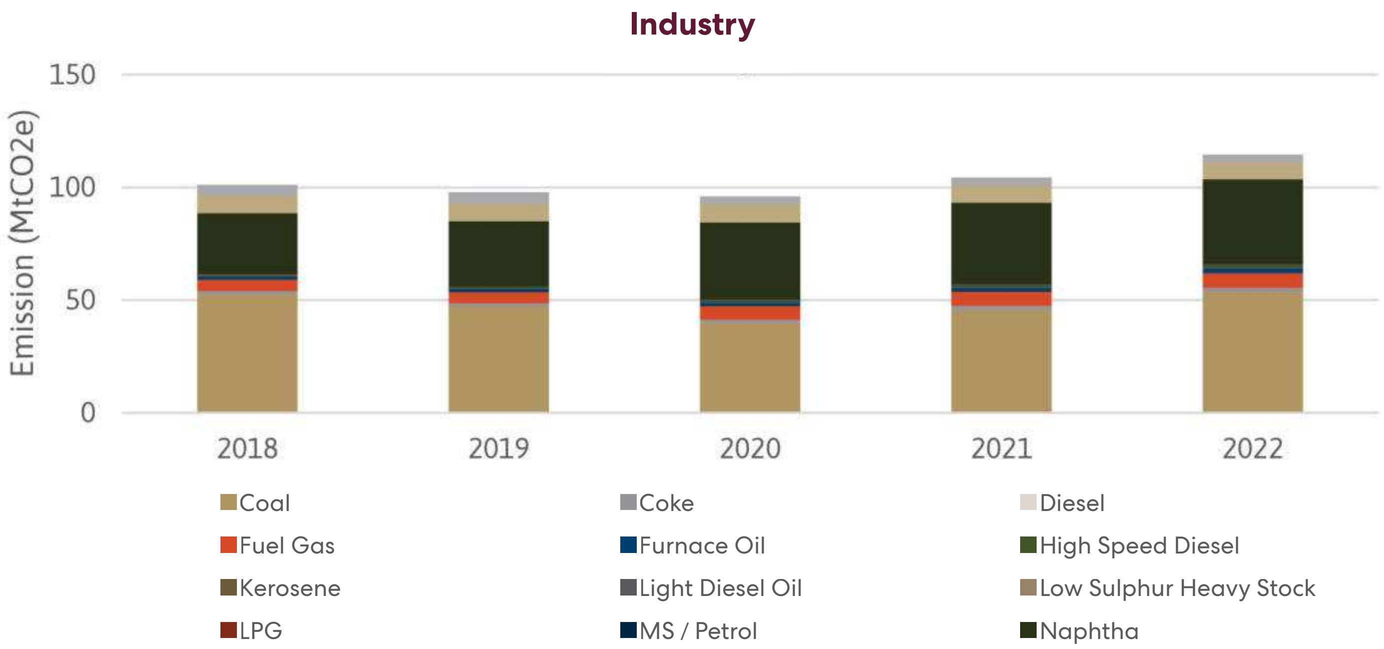
The decreases here are attributed to the overall decrease in industrial and other commercial electricity demand owing to preventive measures enforced during the period. The renewable production during this period increased by approximately 3.3 times from 14.6 thousand GWh to 47.7 thousand GWh.

***Figure 2-4 GHG Emissions from Commercial and Residential Sector***




The commercial and residential sectors show a growth of 5% and 7% growth in emissions compared to 2018 levels (Figure 2-4). Emissions in the residential sector are dominated by liquefied petroleum gas (LPG) as the share of kerosene has rapidly declined. Decrease in commercial sector energy consumption is observed in 2019 as compared to 2018, but subsequently a continued upward trend is observed. This may be due to increase in e-commerce activity during the pandemic. The residential sector too shows a small decrease in 2019 but starts increasing from 2021 indicating a rebound from COVID. Industry sector emissions grew by 13% from 2018 levels. The sector is currently heavily dependent on fossil fuels with coal use contributing the highest share of emissions. As witnessed in other sectors, the decrease in the emission in 2020 can be attributed to the decline in coal use during the two years of the pandemic (See Figure 2-5)

*Figure 2-5 GHG Emissions from Industry Sector*




Industry sector emissions grow by 13% from 2018 levels. The sector is currently heavily dependent on fossil fuels with coal use contributing the highest share of emissions. As witnessed in other sectors, the decrease in the emission in 2020 can be attributed to the decline in coal use during the two years of the pandemic (See Figure 2-5).

In 2022, the transport sector contributed 29.91 $MtCO_2e$. The 2022 emissions have grown by 24% compared to 2018 levels. It is the fastest growing sector contributing to energy use emissions. The transport sector also shows the impact of the COVID pandemic with declining emission in 2020 before showing a rebound in 2021 when the emission comes closer to 2019 levels (See Figure 2-6).

*Figure 2-6 GHG Emissions from Transport Sector*

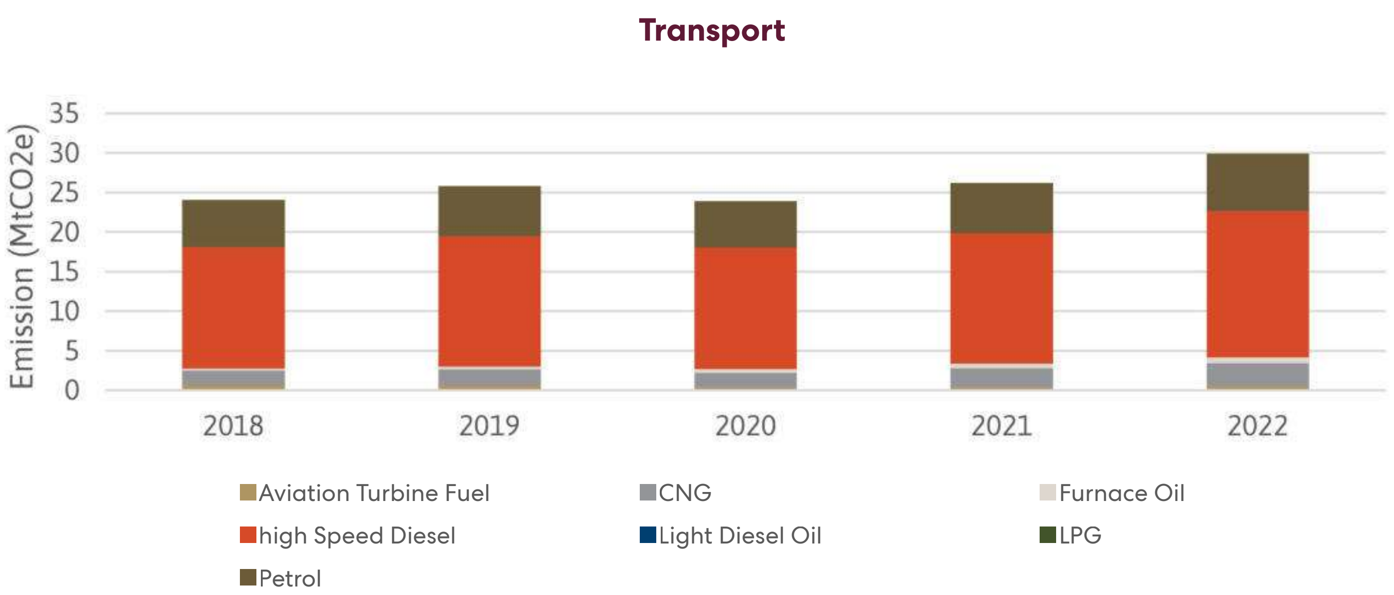
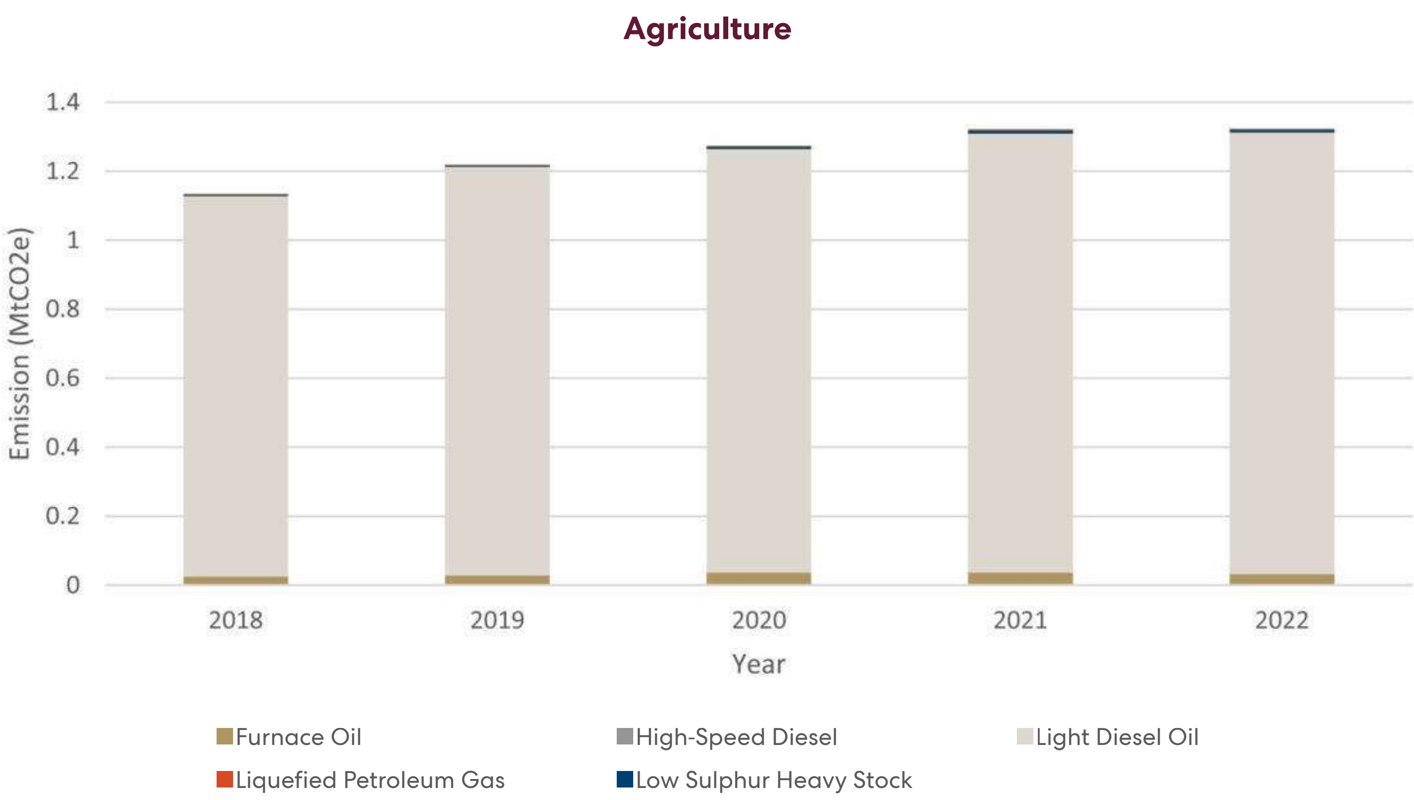
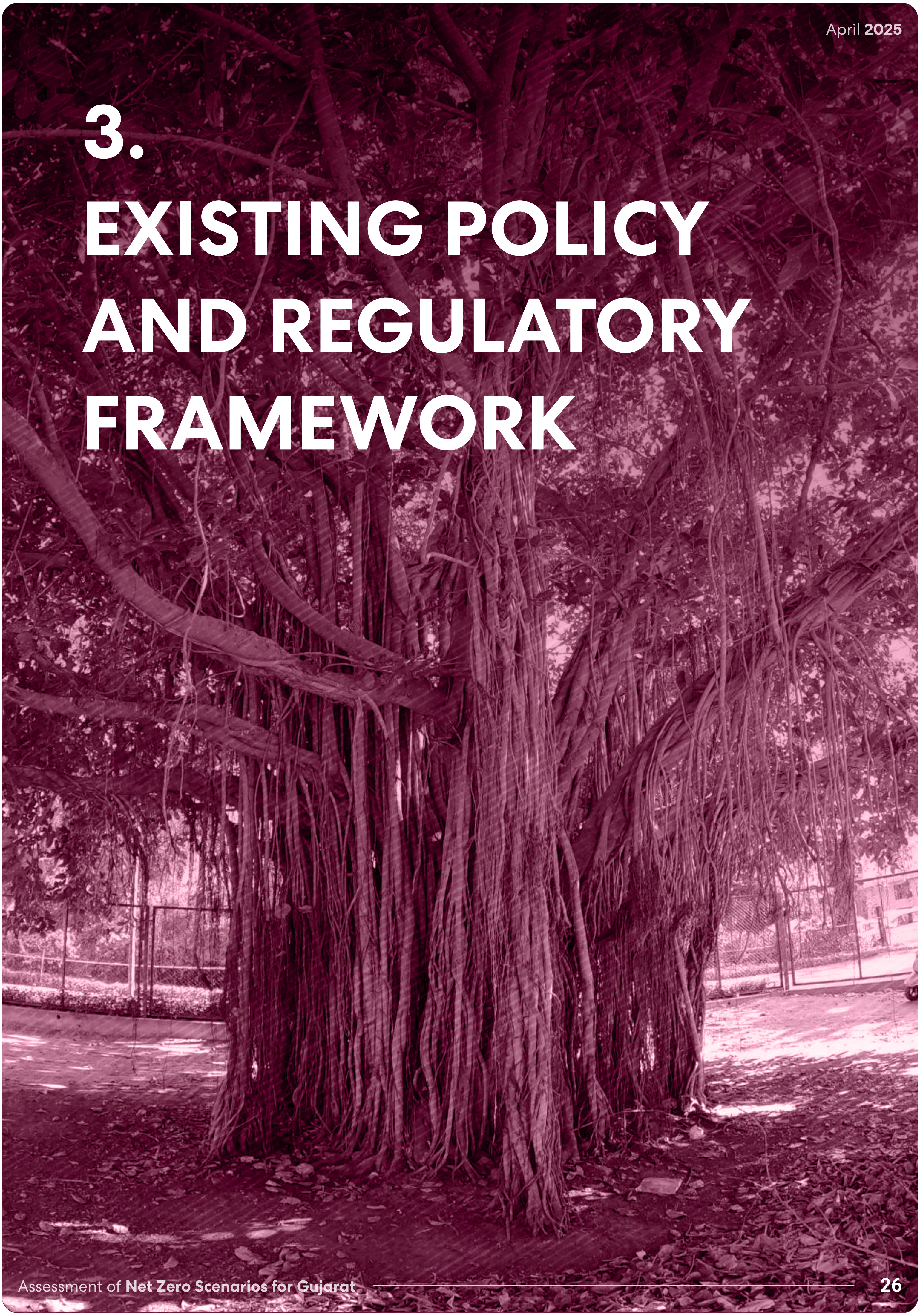


***Figure 2-7 GHG Emissions from Agriculture Sector** (**Million Tonnes $CO_2$e**)*




The energy related emissions from the agriculture sector come from diesel pump sets and energy used for farm equipment. Emissions from the agriculture sector were not impacted during the pandemic period and increased from 1.13Mt-$CO_2$e to 1.32Mt-$CO_2$e (See Figure 2-7).

# 3.
# EXISTING POLICY AND REGULATORY FRAMEWORK



## 3.1 India's National Policy Framework

India's climate action framework has undergone significant evolution keeping pace with international developments. As a rapidly growing economy with a vast population and diverse ecosystems, India's Nationally Determined Contributions (NDCs) (Government of India, 2022) and Long-Term Low Emission Development Strategy (LT-LEDS) (MoEFCC, 2022) underscore its efforts to balance economic development with climate action. The country's national policies for climate change mitigation are comprehensive, demonstrating a strong commitment to reducing greenhouse gas (GHG) emissions while promoting sustainable development. Central to these efforts is the National Action Plan on Climate Change (NAPCC), launched in 2008, which serves as the backbone of India's climate strategy. The NAPCC consists of eight National Missions focusing on renewable energy, energy efficiency, and climate resilience, including the National Solar Mission and the National Mission for Enhanced Energy Efficiency (NMEEE) (Government of India, 2008).

India's Nationally Determined Contributions (NDCs), first submitted in 2015 included a commitment to reducing the emissions intensity of its GDP by 33–35% by 2030 from 2005 levels and achieving 40% cumulative installed electric power capacity from non-fossil fuel sources (Government of India, 2015). In 2021, India updated these targets, raising the emissions intensity reduction goal to 45% and aiming for 50% non-fossil fuel capacity by 2030, demonstrating increased ambition (Government of India, 2022). These targets underscore India's intention to align its development trajectory with global climate goals, particularly through enhanced renewable energy adoption and improved energy efficiency.

Complementing the NDCs, the LT-LEDS, submitted in 2022, identifies key actions to achieving net-zero emissions by 2070. The strategy prioritizes sectors such as energy, industry, urban development, and transportation, with a strong focus on expanding renewable energy capacity, promoting green hydrogen, and advancing electric mobility. This strategy underscores the importance of both technological innovation and behavioural change, notably through the 'Lifestyle for Environment' (LiFE) movement, which advocates for sustainable consumption to reduce carbon footprints (MoEFCC, 2022).

The National Solar Mission aims to achieve 100 GW of solar power capacity by 2022, while the National Biofuel Policy (2018) targets 20% ethanol blending by 2025 (MoP&NG, 2018; Press Information Bureau, 2018, 2024b). The Green Energy Corridor Project further synchronizes renewable energy with conventional power grids, ensuring a smoother transition to a cleaner energy mix (Press Information Bureau, 2023). Additionally, the NMEEE, through the Perform Achieve and Trade (PAT) scheme, incentivizes large industries to reduce specific energy consumption by allowing the trading of energy savings certificates, thus promoting energy efficiency across various sectors (Press Information Bureau, 2022).

India's forestry programs include targets to increase carbon sequestration while also delivering development benefits. The National Mission for a Green India (GIM) aims to increase forest/tree cover by 5 million hectares while enhancing ecosystem services. This mission aligns with the NDC target of creating an additional carbon sink of 2.5 to 3 billion tonnes of $CO_2$ equivalent by 2030 (Government of India, 2022). Other initiatives like the National Afforestation Programme and the REDD+ strategy support these goals by promoting afforestation, reforestation, and sustainable forest-based livelihoods (Press Information Bureau, 2019).

India's transition to cleaner energy is bolstered by the National Green Hydrogen Mission (2023), which promotes green hydrogen production as a sustainable energy source (MoN&RE, 2023). This initiative, alongside the expansion of renewable energy infrastructure and improved energy efficiency measures, positions India as a leader in clean energy development.

India's national policies addressing climate change mitigation are comprehensive, spanning multiple sectors and aligning with both domestic development objectives and international climate commitments (Table 3-1). These policies reflect a balanced approach to reducing emissions, promoting renewable energy, and fostering sustainable growth, while positioning India as a significant player in global climate action.

***Table 3-1 Key National-level policies, milestones, and targets***

| Policy/Strategy | Year | Objective | Target |
|---|---|---|---|
| India's Long Term Low Carbon Development Strategy | 2022 | Outlining India's approach to achieving net-zero emissions by 2070. The strategy is designed to align with India's developmental aspirations, emphasizing equity, climate justice, and sustainable growth. | Net-Zero by 2070 |
| India's Updated Nationally Determined Contributions | 2022 | The updated NDC in line with the Paris Agreement aims to support India's transition to net-zero emissions by 2070. | Achieve a 45% reduction in emissions intensity compared to 2005 levels.<br>Achieve 50% umulative electric power installed capacity from non-fossil fuel sources.<br>Create an additional 2.5–3 billion tonnes of $CO_2$ equivalent carbon sink. |
| Roadmap for Ethanol Blending in India 2020-25 | 2020 | Scale up ethanol blending with petrol to achieve 20% ethanol blending by 2025 | Achieve 20% ethanol blending in petrol by 2025. |
| Solar Energy Programme | 2022 | Deploy 100 GW solar power capacity across the country. | Achieve 100 GW solar power capacity by 2022. |
| Wind Energy Programme | 2022-2030 | Deploy 60 GW wind energy capacity and maintain the same level until 2030. | Achieve 60 GW wind power capacity by 2022. |
| Small Hydro and Biomass Programme | 2022 | Deploy 15 GW capacity from small hydro and biomass-based power generation. | Achieve 15 GW small hydro and biomass capacity by 2022. |
| Green Hydrogen Policy | 2022 | Promote the production, use, and export of green hydrogen and ammonia to reduce dependence on fossil fuels. | Achieve 5 million tonnes of green hydrogen production capacity annually by 2030.<br>Developing a renewable energy capacity of about 125 GW<br>Attracting investments of over 100 billion USD<br>Reducing carbon emissions by nearly 50 Million tons per year<br>Reducing the cost of green hydrogen production to $1.5 per kg by 2030 |

## 3.2 Key Energy and Climate Policies in Gujarat

Gujarat's climate policies are designed in alignment with national and international commitments, such as India's Nationally Determined Contributions (NDCs) under the Paris Agreement, which target a reduction in emissions intensity and a significant shift toward renewable energy sources (Climate Change Department, 2021). For example, the state's ambitious renewable energy targets, energy efficiency measures, and sectoral mitigation strategies collectively support India's long-term vision of achieving net-zero emissions by 2070.

***Table 3-2 Key State-level policies, milestones, and targets***

| Policy/Strategy | Year | Objective | Target |
|---|---|---|---|
| Gujarat Renewable Energy Policy | 2023 | Scale up solar, wind and hydro energy and reduce dependence on fossil fuels. | Achieve 50% target of RE capacity by 2030. |
| Rooftop Solar Policy and Subsidy | 2024 | Promote rooftop solar installations with subsidies, focusing on accessibility for residential and small-scale users. | Achieve 100 GW RE capacity by 2030. Present RE capacity around 30 GW |
| Gujarat Small Hydel Policy* | 2016-2023 | Promote renewable energy via small hydropower projects on canals and rivers. | Old Policy Target - 100 kW and 25 MW.<br>*New Policy under formulation. |
| Gujarat Waste to Energy Policy | 2016 | Utilize municipal solid waste (MSW) for energy generation to support clean energy and urban hygiene. | Develop 100 MW capacity from MSW |
| Policy for Reuse of Treated Wastewater | 2018 | Maximize wastewater treatment and reuse, reducing dependency on fresh water. | Reuse 100% of treated wastewater by 2030. |
| UJALA and Street Lighting Programmes | 2016-2020 | Promotes energy-efficient appliances (LEDs, fans) and upgrades street lighting in urban municipalities to reduce energy use. | Saved 1.4 $MtCO_2$ through installations and energy-efficient lighting systems. |
| UJALA and Street Lighting Programmes | 2022 | Enhances coastal resilience and carbon sequestration through mangrove restoration aligned with the MISHTI initiative. | Expand mangrove cover and link with the voluntary carbon market for offsets. |
| Comprehensive General Development Control Guidelines (CGDCG) | 2024 | Standardised regulations that appropriate development authorities use and impose on all kinds of urban and town planning ventures. | |

| Policy/Strategy | Year | Objective | Target |
|---|---|---|---|
| Energy Conservation Building Codes | 2016 | Enhance energy efficiency in new and retrofitted buildings to reduce urban energy consumption. | |
| Gujarat State Electric Vehicle Policy | 2021 | Aims to promote electric vehicles in the state to reduce air pollution, decrease dependence on fossil fuels, and enhance energy security. | |
| Suryashakti Kisan Yojana (SKY) | 2024 | Enables farmers in Gujarat to generate solar power for self-consumption and sell surplus electricity to the government, providing income support through a subsidy-backed scheme designed to double farmers'income and ensure daytime power supply. | |
| Second State Action Plan on Climate Change | 2021 | Comprehensive roadmap addressing climate mitigation, adaptation, and resilience, with sector-specific strategies for energy, water, agriculture, coastal zones, and urban development. | Aligns with India's NDCs and targets GHG reduction through cross-sectoral interventions. |
| State Vision Document Gujarat @2047 | 2023 | Outlines the state's industrial, economic, and social development aligned with SDGs, focusing on sustainability and resilience. | Envisions long-term growth aligning economic prosperity with environmental stewardship. |
| Gujarat State Energy Efficiency Action Plan (GSEEAP) | 2031 | The Gujarat Energy Efficiency Action Plan (GEEAP) is a strategic initiative to enhance energy efficiency across key sectors, reduce emissions, and achieve Gujarat's climate and energy targets by 2030 and 2031. | Reduce emissions intensity by 45% of GDP by 2030 and increase renewable energy capacity to 100 GW by 2030 through sector-specific efficiency strategies and policy interventions |

Gujarat has placed significant emphasis on renewable energy as a central component of its GHG mitigation strategy (Table 3-2). It was among the first states to announce ambitious targets for renewable energy. These included policies and the investments for research and innovation including funding for R&D projects; pilot initiatives and finally policies and initiatives to enhance diffusion. Table 3-2 summarises key state level policies that have been referred to in this study.

The state's Solar Power and Wind Power Policies, alongside its Solar-Wind Hybrid Policy, have been instrumental in driving renewable energy adoption.

Gujarat has become a leader in solar energy, with initiatives such as the Gujarat Solar Power Policy and Solar Roof Top Scheme contributing to a sharp rise in installed solar capacity, from just 5 MW in 2011 to over 2,400 MW by 2019 (IIMA & IIT-G, 2024). Additionally, the state has made strides in wind energy, with installed capacity rising from 249.5 MW in 2005-06 to over 7,500 MW by 2020. As on November 2024 the total installed renewable energy capacity in Gujarat is 30,502.83 MW (See Table 3-3 for details). These policies align with India's NDC commitment to derive 50% of its installed power capacity from non-fossil sources by 2030.

***Table 3-3 Total Installed Renewable Energy Capacity in Gujarat***

| Category | Renewable Energy Installed Capacity (MW) in Gujarat as on 30.11.24 |
|---|---|
| Small Hydro Power | 91.6 |
| Wind Power | 12,368.5 |
| Biomass Power/Bagasse Cogeneration | 65.3 |
| Biomass Cogeneration (Non-Bagasse) | 12 |
| Waste to Energy | 7.5 |
| Waste to Energy (Off-grid) | 31.8 |
| Bio Power Total | 116.6 |
| Ground Mounted Solar | 10,416.6 |
| PM-Surya Ghar Yojna (Solar Rooftop) | 4,646.9 |
| Hybrid Solar | 783.5 |
| Off-grid Solar/KUSUM | 89.1 |
| Solar Power Total | 15,936.1 |
| **Total Installed Renewable Energy Capacity** | **30,502.8** |

**Source**: MN&RE (2024)

Energy efficiency in Gujarat's industrial sector is promoted through the Perform, Achieve and Trade (PAT) scheme, which incentivizes energy efficiency improvements in high-energy-consuming industries like thermal power, iron and steel, and cement (Government of Gujarat, 2024a). The scheme led to substantial emissions reductions in its first two phases, with a reduction of 10.53 Mt$CO_2$ during PAT-I (2012-15) and a projected reduction of 11.85 Mt$CO_2$ during PAT-II (2016-19) (IIMA & IIT-G, 2024). Additionally, the UJALA and Street Lighting National Programmes have significantly reduced energy consumption in the residential and municipal sectors by distributing millions of energy-efficient LED bulbs and upgrading street lighting systems across the state (Government of Gujarat, 2024a). The Gujarat State Energy Efficiency Action Plan (SEEAP) aims to identify and implement energy efficiency measures across key sectors—industry, transportation, buildings, agriculture, and fisheries—to achieve significant energy savings, reduce emissions, and align with the state's climate and energy goals. The plan focuses on a two-tier approach: a short-term 5-year strategy and a long-term roadmap to 2031 (Confederation Of Indian Industry, 2023).

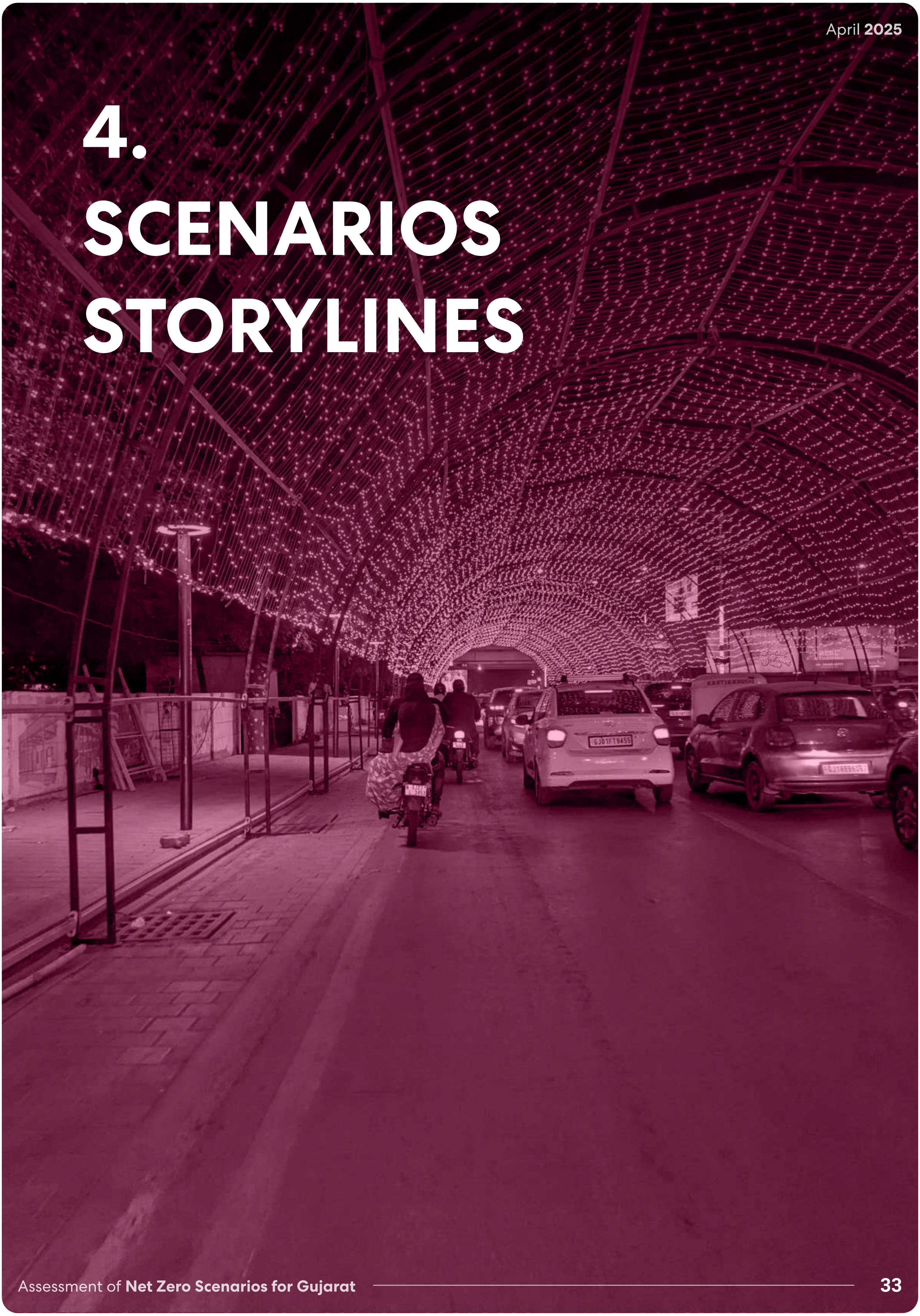
The state has introduced policies to promote electric vehicles (EVs) and expand EV charging infrastructure (Government of Gujarat, 2024a). These efforts are in line with India's national target to make Indian Railways net-zero by 2030 and reduce transport emissions overall. The state is focusing on enhancing public transportation efficiency, with projects like the Bus Rapid Transit System (BRTS) and plans to increase the share of electric buses in urban fleets. Gujarat's EV policies complement national initiatives, such as the Faster Adoption and Manufacturing of Electric Vehicles (FAME) scheme.

Recognizing the vulnerability of its large agricultural sector to climate change, Gujarat has introduced measures to improve energy efficiency in agriculture, such as promoting the adoption of energy-efficient irrigation pumps and encouraging solar-powered solutions under schemes like Government of India's PM-KUSUM scheme (GUVNL, 2024). The promotion of drip and sprinkler irrigation systems under agricultural schemes further aligns with the broader objectives of improving water use efficiency and reducing emissions. Additionally, the state's afforestation and reforestation initiatives contribute to carbon sequestration (Forests and Environment Department, 2024).

The state has adopted energy conservation building codes (ECBC) to improve energy efficiency in new and retrofitted buildings (NRDC, 2022). Gujarat has also implemented waste-to-energy projects to reduce methane emissions from landfills and has promoted the use of biofuels, such as compressed biogas (CBG), through the SATAT scheme, which supports the production of CBG from organic waste (Energy and Petrochemicals Department, 2024).

These initiatives are complemented by efforts to enhance waste segregation and recycling in urban areas, thus contributing to the reduction of GHG emissions in line with national strategies for sustainable urbanization. The state has also implemented several strategies for protecting biodiversity hotspots, mangrove restoration, coastal ecosystem protection. Gujarat's State Action Plan on Climate Change (SAPCC) highlights infrastructure resilience, coastal protection, and the development of early warning systems as integral components of its adaptation strategies. The state's disaster management policies are designed to enhance the ability of both urban and rural populations to respond to the increasing frequency of extreme weather events, thereby fulfilling international commitments to safeguard human lives and livelihoods in the face of climate change (Climate Change Department, 2021).

# 4. SCENARIOS STORYLINES



This section briefly describes the storylines and assumptions for the Reference and Net zero scenarios for modelling exercises undertaken using the Global Change Analysis Model (GCAM) and Low Emissions Analysis Platform (LEAP). The two models and the model assumptions are described in Section 5.

## 4.1 Reference Scenarios (GCAM and LEAP)

Both models include a Reference Scenario which is used to compare against the Net Zero Scenario. The socio-economic drivers are the same for both the Reference Scenarios however there are some differences related to the assumptions.

The Reference scenario in GCAM assesses the state's emission trajectory within the existing policy framework. It considers currently implemented policies (example dedicated freight corridors), current technology developments (for example near 100% electrification of railways), macroeconomic vision (example to decrease the share of manufacturing in GDP), and announced targets (example RE target of 100 GW by 2030) in the state. It also includes autonomous energy efficiency improvements in all end-use sectors (except for the industry sector, where targets from the "Base scenario" in the Gujarat Energy Efficiency Plan until 2030 are adopted and extrapolated into the future), a reduction in the costs of variable renewable energy technologies as they mature and reach economies of scale, and a reduction in the cost of hydrogen production (in line with India's and the state's ambition). A key input to scenarios are socio-economic drivers, including population, GDP, urbanisation, and future evolution of the structure of the economy. These factors drive sectoral demands for the building sector (residential and commercial), transportation (passenger and freight), industry, and agriculture.

In the LEAP model in the reference scenario, the socio-economic drivers are the same as GCAM. The Reference scenario in the LEAP-Gujarat model, however, does not assume major structural changes in fuels and technologies. In the power sector, the Reference scenario assumes some growth in renewable energy capacities in line with recent developments but at the same time it does not impose limitations on new coal and natural gas power plants. The reference scenario assumes some level electrification in the transport sector, transition in cooking fuels, etc. However, it assumes no significant advancements in energy efficiency of respective technologies since there are two opposite effects. Efficiency of vehicles and appliances improve in response to regulations however, there is a change in demand due to increasing incomes for e.g. the increasing preference for larger cars (IEA, 2023a). Fuel shares in industry sectors remain largely unchanged; however, fuel shares in passenger transport and household sectors have changed in line with historical trends.

## 4.2 Net Zero Scenario - Conventional Net Zero Scenario (GCAM)

The Conventional Net Zero scenario is aligned with the Government of India's target to achieve net zero emissions by 2070 and imposes an emission constraint on the reference scenario. The model disaggregates India into 29 states. It is assumed that energy sector emissions for the country peak in 2040 and then decline linearly to achieve net zero by 2070. Compared to the reference scenario (where measures to reduce energy demand and emissions are already included), two additional policy measures are implemented before 2040, specifically for Gujarat - accelerated industrial efficiency improvements and no new coal plants beyond 2030. As mentioned before, after 2040, emissions decline significantly after 2040 to reach net-zero in 2070. This reduction takes place through an endogenously determined carbon price, in accordance with an exogenously defined emission trajectory.

As part of its updated Nationally Determined Contribution (NDC) submitted to the United Nations Framework Convention on Climate Change (UNFCCC), India has officially committed to achieving net-zero emissions by 2070. However, a critical policy choice revolves around determining the peaking year for emissions. The peaking year marks the point when absolute economy-wide emissions reach their maximum, followed by a sustained decline.

This study assumes a peaking year of 2040. This assumption is based on announcements by government representatives regarding the national peaking year (Singh & Lacqua, 2021) and (Chaturvedi, 2021) of historic peaking years and future net-zero target years of advanced economies and China. Additionally, India's projected GDP growth trajectory suggests that an earlier peaking year would be highly challenging owing to issues around just transition of coal workers, loss of fiscal resources for fossil-dependent states, elimination of cross subsidies in India’s electricity pricing structure, political economy challenges from coal-interest groups etc. (Chaturvedi & Malyan, 2022; Nandi, 2021).

At the state level, emission trajectories would need to align with or follow a similar trend. Ultimately, the timing of peaking and subsequent emissions decline will depend on multiple factors, including political ambition at national and state levels, the pace of technological adoption, and broader socio-economic considerations. While this study does not prescribe a specific year, it assumes that, at the national level, emissions will peak in 2040 and decline steadily to reach net-zero by 2070, and Gujarat too follows a similar pattern.

## 4.3 Net Zero Scenario - Structural Shift Scenario (LEAP)

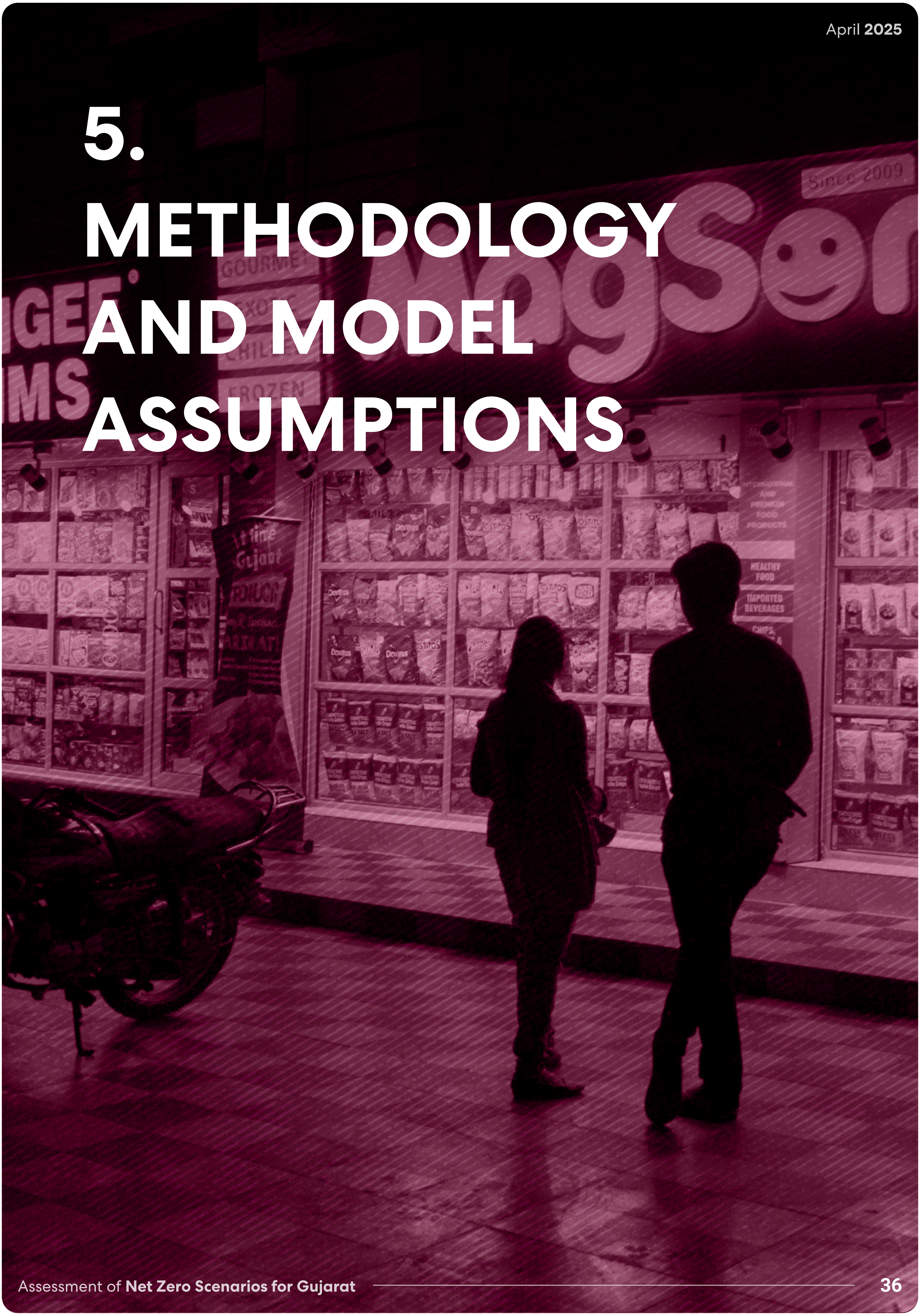
Similar to the conventional Net Zero Structural Shift scenario (Net Zero SS scenario) seeks to achieve net zero by 2070. However, the scenario assumes that the emission reductions will happen through a much broader set of measures. At the macro level, the scenario assumes a more rapid transition towards an economy where the service sector grows faster than in the reference scenario, and as a result, its share in the economy reaches more than 57% by 2070 in the Net Zero SS scenario in comparison to 52% in the reference scenario. On the other, the manufacturing share of the GDP in 2070 will be 5% lower than 34 % in the reference scenario (See Section 5.2.3. for structural shifts in economy).

The structural shift scenario also envisages a more sustainable approach to development. For example, the transport sector follows the avoid-shift improve paradigm that is achieved through improved urban planning, more investment in public and shared mobility for passenger transport and greater reliance on rails and shipping for freight transportation. In the building sector, though the per capita floor space is maintained the same as in the reference scenario, energy efficiency improvements (cooling, appliances, lighting) will lead to the reduction of energy consumption.

In power generation, renewable energy sources hold the highest merit order in the dispatch and the highest priority in the capacity expansion list. While new supercritical coal power plants can still be constructed in the Net Zero Scenario, it was assumed that they will include carbon capture and storage (CCS) technology after 2050 and in line with India's Long-Term Low-Carbon Development Strategy (MoEFCC, 2022)[3]. For renewable energy sources, several variables were described in the LEAP-Gujarat model, including its maximum availability by time slices, capacity credit, and resource availability for solar and wind. A detailed description of sectoral assumptions on mitigation options is presented in Table 5-4 and Appendix 10.2.

[3] It is important to note that in the LEAP-Gujarat model, coal with CCS is not a model's output, but a user assumption. This assumption aligns with India's Long-Term Low-Carbon Development Strategy, which indicates that to achieve net-zero emissions by 2070, India will rely on CCS and negative emissions technologies, particularly to offset emissions from challenging and hard-to-abate sectors. In the LEAP-Gujarat model, the economic feasibility of coal-fired power plant with CCS was not considered; economic feasibility of coal-fired power plant with CCS was conducted using the GCAM model in the Section 6.1.8. The Sustainable Development Impacts of Net Zero Scenarios, specifically the impact on PM2.5 emissions in the scenario involving Coal with CCS, are analyzed in Section 7.1. Further studies may be required to explore the economic and environmental implications of coal with CCS in the Net Zero scenario.

# 5. METHODOLOGY AND MODEL ASSUMPTIONS



## 5.1 Analytical tools and techniques used for scenario analysis

The scenario analysis was conducted using two models: the Global Change Analysis Model (GCAM) and the Low Emission Analysis Platform (LEAP). GCAM is an Integrated Assessment model that has been used at global and national levels in the analysis of mitigation scenarios (Chaturvedi et al., 2014, 2021; TNGCC & CEEW, 2024). LEAP is a bottom-up Energy System model that has been used extensively at the national and local levels. While both models undertake a comprehensive assessment, both these models focus only on Gujarat and do not consider interactions with other states or nations.

### 5.1.1 GCAM Model:

The modelling exercise was conducted using the Global Change Analysis Model (GCAM), a global integrated assessment model widely applied for energy and climate policy analysis at both national and global levels, including in India (Chaturvedi et al., 2018, 2021; Chaturvedi & Malyan, 2022). Originally developed in the 1980s, GCAM has undergone continuous updates to incorporate the latest advancements in energy, land, water, economic, and climate systems. The model is housed at the Joint Global Change Research Institute (JGCRI), USA, and represents 32 global regions, with India as one of them. The model is open-source, and its latest code is available on GitHub (Joint Global Change Research Institute, 2024).

A state-level version of GCAM was developed by CEEW in collaboration with the Center for Global Sustainability, University of Maryland (CGS, UMD), USA, over the last three years and has been used for this study. GCAM-CEEW is based on GCAM 5.2, with several India-specific modifications and assumptions. It includes a detailed representation of the energy systems in all Indian states and union territories. For each state, energy demand is modelled across the following sectors: i) Buildings (commercial, urban residential, and rural residential), ii) Transport (passenger and freight), iii) Industry (aggregate), and iv) Agriculture. The energy demands of these end-use sectors are met by the energy supply sector, which includes power generation, energy transformation industries such as oil refining, coal mining, and gas extraction. The model's granular representation of Indian states, its diverse use cases, and its capability to project scenarios up to 2100—critical for exploring emission targets beyond mid-century—were the primary reasons for its selection. GCAM-CEEW has already been used to examine long-term decarbonisation strategies in Tamil Nadu and Bihar, as well as energy policy scenarios for Rajasthan.

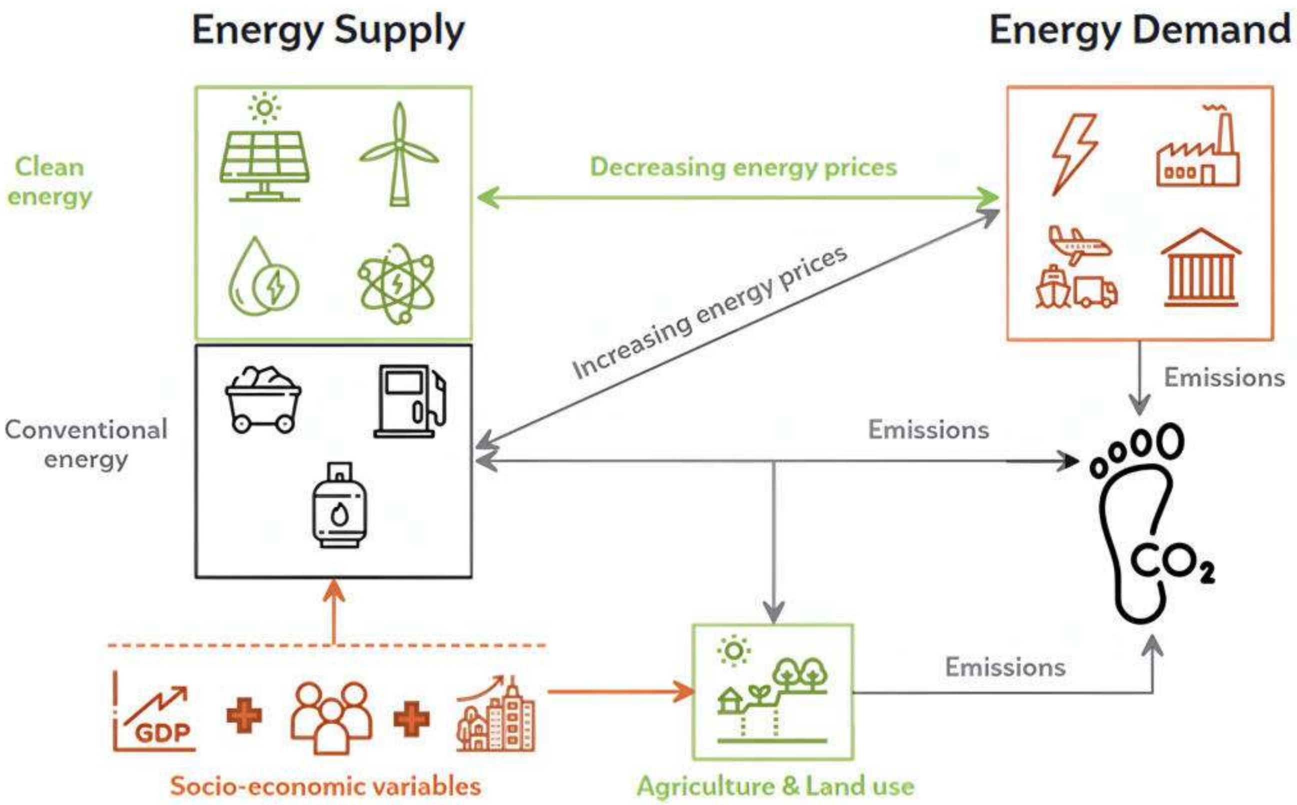
#### 5.1.1.1 Modelling Approach in GCAM

Energy service demand for different end-use sectors is calculated endogenously in the model, responding dynamically to changes in income levels and service prices. Technologies compete based on cost and efficiency to meet service demand at any given time (see Section 10.3.1 for how demand is calculated across the different end-use sectors). For instance, electric and petrol vehicles compete on factors such as capital costs, fuel expenses, and efficiency to satisfy transportation demand. Similarly, LEDs and fluorescent light bulbs compete to provide lighting services in the building sector. In the electricity sector, technologies like coal, solar, wind, and others (excluding hydro) compete based on generation costs. In GCAM, agents are assumed to act in their own self-interest, but the model itself does not perform an overall optimization calculation. The capital costs and efficiencies of all technologies are exogenous to the model and represent key assumptions. Energy prices, on the other hand, are endogenous and serve as signals through which multiple sectors communicate scarcity, demands, and responses. These dynamic interactions enable the model to reflect realistic market and system behavior. Figure 5-1 illustrates the schematic of the model.

GCAM is highly versatile and capable of building and exploring a wide range of policy scenarios. These scenarios include changes in economic growth and urbanisation rates, cost trajectories for solar and wind electricity generation, Adoption rates of electric vehicles (EVs), Efficiency improvements in end-use sectors, Renewable purchase obligations and emission constraints. Additionally, GCAM can investigate alternative deep decarbonisation policies and the potential impacts of emerging technologies, such as hydrogen power and carbon capture and storage (CCS).

Users can either directly specify the price of carbon or GHGs. Given a carbon price, the resulting emissions will vary depending on other scenario drivers, such as population, GDP, resources, and technology, or users can specify the total amount of emissions ($CO_2$ or GHG) into the model. GCAM will then calculate the price of carbon needed to reach the constraint in each period of the constraint.

***Figure 5-1 Schematic Structure of GCAM model***




The carbon price influences which fuels are used in existing technologies, while the carbon price along with technology and fuel costs influence technology choice for new investments.

The model is calibrated to historical energy consumption and supply values in 2020 (See section 10.3.1 for detail).

### 5.1.2 LEAP Model:

The Low Emissions Analysis Platform (LEAP), developed by the Stockholm Environment Institute (SEI), is a software tool for planning energy policies, mitigating climate change, and reducing air pollution (Stockholm Environment Institute, 2024). LEAP is an integrated modelling tool that monitors energy consumption, production, and resource extraction across all economic sectors. It can account for energy sector and non-energy sector GHG emissions as well as local and regional air pollutant emissions. LEAP models the entire energy transformation and transportation process, starting from the extraction of primary resources and imported fuels and extending to the point where these fuels are finally consumed. In the LEAP model, transformation calculations (energy industries) are demand driven. Each transformation module is operated to satisfy the energy demands arising from domestic requirements (considering user-defined import or export constraints, if any). On the demand side, LEAP applies bottom-up, end-use accounting techniques. On the supply side, LEAP offers several options for modelling: accounting, simulation, and optimization methodologies. LEAP applies the concept of scenario analysis: user can create and evaluate different scenarios by comparing their energy needs, social costs and benefits, and environmental impacts.

*Figure 5.2 presents the schematic structure of the Gujarat-LEAP model and has the following characteristics.*

- Demand sectors (industry, commercial and public services, transport, and households)
- Demand sectors are further disaggregated into sub-sectors and end-uses
- Transformation sectors comprise energy industries (transmission and distribution, electricity generation, oil refinery, hydrogen production, energy production)
- Supply side includes resources of primary and secondary fuels

Historical energy balance (based on the International Energy Agency's Energy Balance methodology) was introduced for the base year 2018, and the model was calibrated for 2020 (IEA, 2020a). 2021 is the first scenario year in the LEAP model: this setup was used to calibrate the power sector for 2020. The Sankey diagram for Gujarat in the Base Year (2018) is presented in Figure 5-3 to show energy flows in the base year.

See the Appendix (Section 10.1) for the energy balance table, data sources, and detailed methodologies and assumptions at the sectoral level. The energy balances are further used for estimating $CO_2$ emissions for which default $CO_2$ emission factors from the LEAP database (based on Tier 1, 2006 IPCC Guidelines for National GHG Inventories) were used in LEAP Gujarat.

***Figure 5 2 Schematic Structure of Gujarat LEAP model***

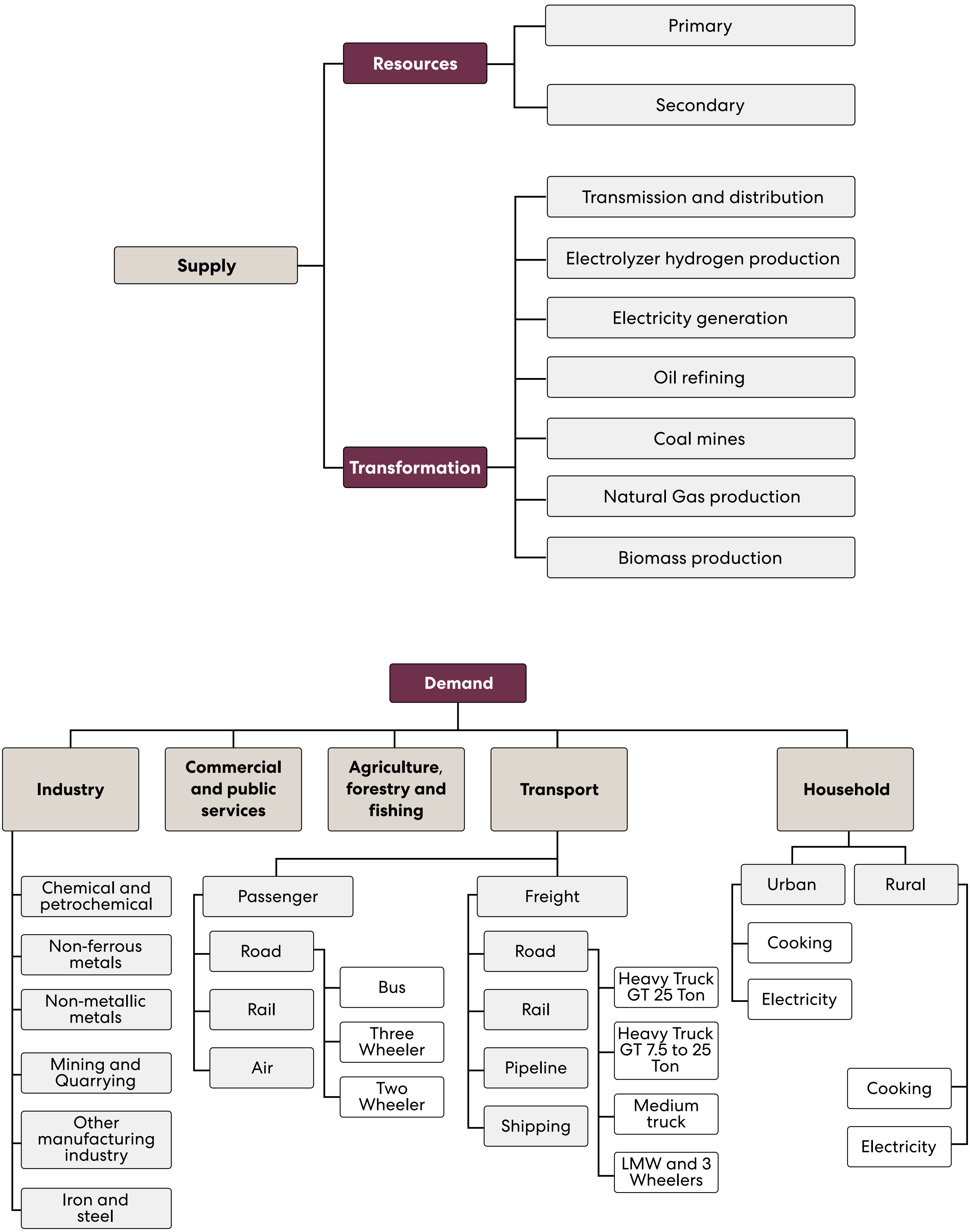
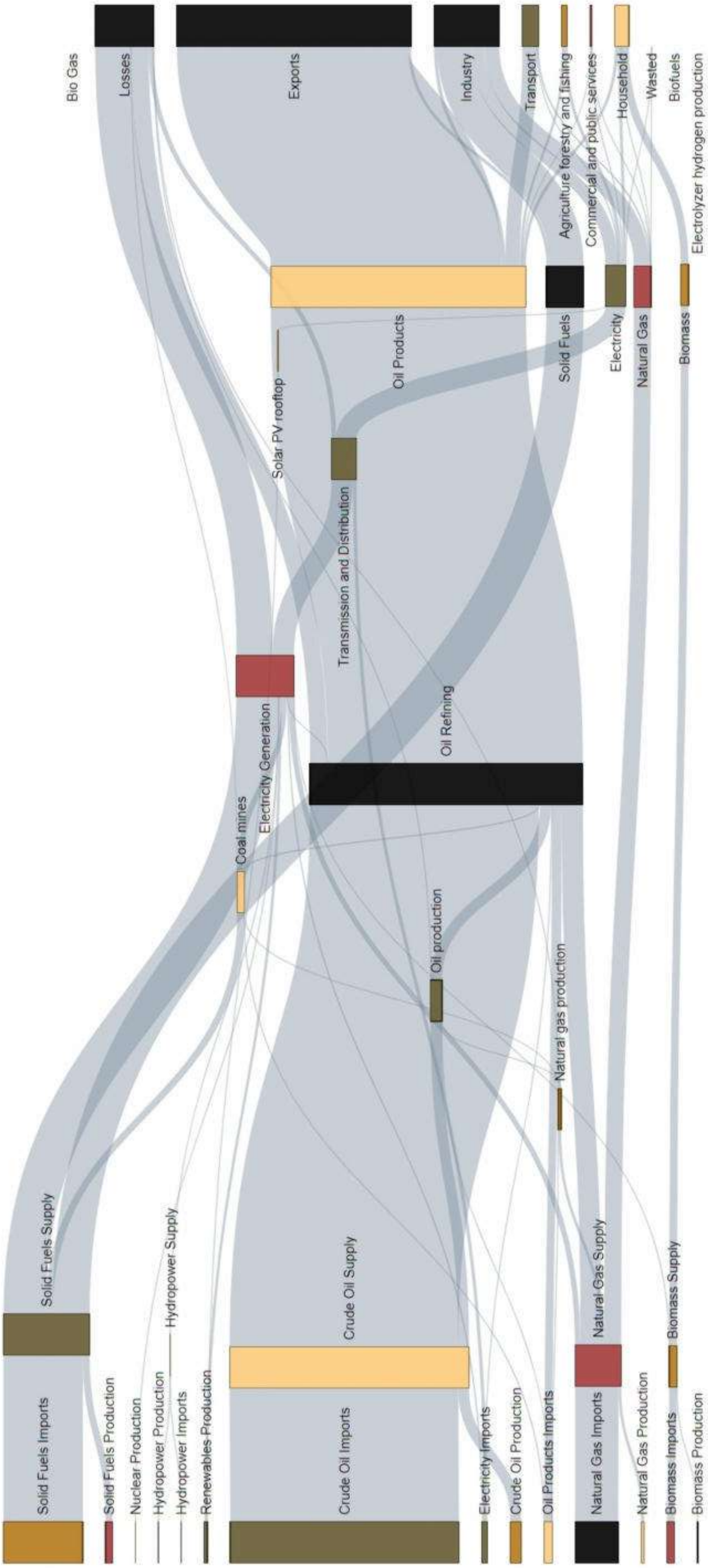


***Figure 5-3 Sankey Diagram with the Energy Balance of Gujarat in 2018***



## 5.2 Socio-Economic Assumptions

For a reasonable estimation of long-term energy demand and emissions, it is important to understand the long-term trends associated with the following key socio-economic variables The GCAM and LEAP models follow similar socio-economic assumptions however the scenario assumptions differ for the economic structure.

Both Reference Scenarios and the Conventional Net zero scenario assumes a decline in share of manufacturing sector. However, the Structural Shift Scenario assumes a more pronounced structural change where the share of services increases to 57% in 2070 (Table 5-1) (See section 5.2.4).

***Table 5-1 Socio-economic assumptions for the four scenarios***

| | GCAM | | LEAP | |
|---|---|---|---|---|
| **Assumptions** | **Reference Scenario** | **Conventional NZ Scenario** | **Reference Scenario** | **Structural Shift Net Zero** |
| **Population** | Population increases until 2035 in line with the projections from Ministry of Health and Family Welfare. After 2035, similar growth rates as before. GJ population peaks in 2055. | | | |
| **GDP growth** | The state's GDP will grow at a CAGR of 7.2% from 2020-2070, reaching 137.2 trillion INR (constant 2011-2012) in 2050 and 361.1 trillion INR (constant 2011-2012) in 2070. | | | |
| **Structural changes in the economy** | Share of manufacturing decreases from 37% in 2020 to 34% in 2070. Share of services increases from 32.9% in 2020 to 52% in 2070. | | | Share of services in GDP increases to 57% in 2070, and manufacturing reduces to 29% in 2070 |

### 5.2.1 Population

Population is an important variable influencing different sectors' material and energy demand. It is assumed that Gujarat's population will peak in 2055. Population projections until 2036 are based on state-level population projections from the Ministry of Health and Family Welfare (MoHFW). The total fertility rate of Gujarat is reported to be 1.9 according to the NHFS report 2019-2021 (1.7 in urban and 2.0 in rural), already below the replacement level of 2.1 and below India's fertility rate of 2.0 in 2022 (MoHFW, 2021). This is expected to decline to 1.8 between 2031-35 (MoHFW, 2023). Our assumptions on population and urbanisation are aligned with the key assumptions in the Viksit Gujarat report, which estimates Gujarat's population will reach between 80 and 90 million in 2047, with an urbanisation rate of 70% (Government of Gujarat, 2024c).

### 5.2.2 GSDP:

Gujarat has set a target of becoming a $500 billion economy by 2026-27 (in nominal terms) and $3.5 trillion in 2047 (nominal terms), from the current level of $259 billion in 2021-22 (Government of Gujarat, 2024c; Task Force Committee, 2022). Thus, the state's economy will need to grow at a CAGR of 14-15% from 2022-2030 and a further 12-13% from 2030-2047 to achieve these targets (Government of Gujarat, 2024c). In the past decade, the average nominal GSDP growth rate was 12 per cent (Virmani, 2024), the growth rate needs to increase even more in the next decade. Beyond 2047, it is assumed that the GSDP increases in absolute terms while the growth rate declines (see Table 5-2 for the assumed growth rate trajectory), reflecting patterns observed in developed countries where growth rates stabilize beyond a specific GDP per capita.

### 5.2.3 Rate of Urbanisation:

In 2023, almost 49% of GJ's population is estimated to live in urban areas (Government of Gujarat, 2024c), ahead of India's figure of 36% (Data for 2020, IEA, 2021). Over time, more of the population is expected to move to urban areas, increasing the share of the population living in urban areas to almost 79% in 2070.

*Table 5-2 Socio-Economic assumptions used in the model assessments*

| Growth Rates | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2015-20 | 2020-25 | 2025-30 | 2030-35 | 2035-40 | 2040-45 | 2045-50 | 2050-55 | 2055-60 | 2060-65 | 2065-70 |
| **GDP (real growth)** | 7.4% | 10.0% | 9.3% | 8.7% | 8.0% | 7.3% | 6.7% | 6.0% | 5.3% | 4.7% | 4.0% |
| **Per Capita GDP** | 1.1% | 8.2% | 7.7% | 7.2% | 6.7% | 5.9% | 5.1% | 4.5% | 4.0% | 3.6% | 3.2% |
| **Population** | 1.4% | 1.2% | 1.0% | 0.9% | 0.5% | 0.4% | 0.3% | 0.1% | 0.0% | -0.1% | -0.2% |

| Per capita GDP (US$, 2020 prices), Urbanization, Population (in Millions) and GDP (Billion US$, 2020 prices) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 | 2060 | 2065 | 2070 |
| **Per Capita GDP** | 2414 | 3674 | 5456 | 7925 | 11345 | 15682 | 21635 | 28753 | 37491 | 47373 | 58386 |
| **Urbanization** | 48% | 50% | 53% | 55% | 59% | 65% | 71% | 73% | 75% | 77% | 79% |
| **Population** | 69.8 | 74.1 | 77.9 | 81.3 | 83.5 | 85.0 | 86.1 | 86.7 | 86.4 | 85.7 | 84.6 |
| **GDP** | 168 | 190 | 297 | 451 | 662 | 944 | 1304 | 1745 | 2262 | 2842 | 3458 |

#### 5.2.4 Structure of Economy:

The secondary sector is the highest contributor to the state's GDP (40%), followed by the tertiary sector (37%). The primary sector contributes to the remaining 23%. Gujarat's dominance as an industrial hub is visible from the fact that not only was manufacturing the fastest growing sector (in terms of Gross Value Added (GVA) among all other sectors in Gujarat) but had the fastest growth among all other manufacturing GVAs in the country (Government of Gujarat, 2024c). The current manufacturing share of the GDP in the state is 37 per cent against the Indian average of 14 per cent, and the share will decrease to 34 per cent in the future by 2070, which is in line with the expectations in the Viksit Gujarat report. As of 2020, although Gujarat has a diversified industry, three types of industries contribute to almost 50% of GJ's Industry GVA. These are oil, gas, chemicals, iron, and steel (Government of Gujarat, 2024c).

## 5.3 Techno-Economic Assumptions (GCAM Model)

The current and future costs of both energy supply and energy demand technologies and their efficiencies are important assumptions for the model. The assumptions related to the cost of power-generating technologies are presented here. These cost assumptions were determined in consultation with the Gujarat Energy Transition Research Institute (GETRI) (Table 5-3).

***Table 5-3 Techno-economic assumptions in the GCAM model. Values in 2020 USD/KWh are in the appendix section 10.1.2***

| Technology | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 | 2060 | 2065 | 2070 | Unit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Coal Super Critical** | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | 2020 INR/kWh |
| **Solar PV** (**without integration cost**) | 2.8 | 2.4 | 2.0 | 1.8 | 1.6 | 1.6 | 1.6 | 1.6 | 1.5 | 1.5 | 1.5 | 2020 INR/kWh |
| **Wind On shore** (**without integration cost**) | 3.5 | 3.4 | 3.2 | 3.1 | 3.0 | 3.0 | 2.9 | 2.9 | 2.8 | 2.8 | 2.8 | 2020 INR/kWh |
| **Wind Off Shore** (**without integration cost**) | 17.4 | 12.9 | 9.5 | 9.3 | 9.0 | 6.6 | 6.5 | 6.4 | 6.3 | 4.6 | 3.4 | 2020 INR/kWh |
| **Nuclear** | 4.6 | 4.6 | 4.6 | 4.6 | 4.7 | 4.7 | 4.8 | 4.8 | 4.9 | 5.0 | 5.0 | 2020 INR/kWh |
| **Gas** (**Domestic**) | 5.1 | 5.2 | 5.9 | 6.2 | 6.6 | 6.9 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 2020 INR/kWh |
| **Gas** (**Imported**) | 8.4 | 8.5 | 9.7 | 10.2 | 10.8 | 11.3 | 11.9 | 12.0 | 12.2 | 12.4 | 12.6 | 2020 INR/kWh |
| **Solar CSP** | 11.7 | 11.1 | 9.8 | 8.8 | 8.5 | 8.3 | 8.2 | 8.0 | 7.9 | 7.7 | 7.7 | 2020 INR/kWh |
| **Hydrogen** | 8.2 | 3.1 | 3.0 | 2.9 | 2.8 | 2.7 | 2.6 | 2.5 | 2.5 | 2.4 | 2.3 | 2020 INR/kWh |
| **Solar integration cost** | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.7 | 2020 INR/kWh |
| **Wind integration cost** | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.7 | 2020 INR/kWh |

For addressing intermittency-related issues, technical interventions, either in the form of storage technologies or backup systems like gas-based turbines, will be required. These technical interventions will have a cost attached to them. A nominal cost is levied on top of the base solar and wind electricity cost to account for the cost of integration. The integration costs for 2020 are based on the Central Electricity Authority (CEA, 2017). These costs are assumed to increase in the future as the share of VRE increases in the grid (Chaturvedi et al., 2018).

In the reference scenario, industrial energy efficiency is assumed to increase at an average CAGR of 0.46% per year until 2070, based on the Moderate Scenario of the Gujarat Energy Efficiency Plan, which outlines targets for different industrial sectors until 2030. In the NZ scenario, efficiency improvements are assumed to be more rapid at 0.9% per annum between 2020 and 2050, with no further efficiency improvements beyond 2050.

## 5.4 Sectoral assumptions (LEAP)

Mitigation measures for the Net Zero Scenario in LEAP are defined by user, based on policy analysis, review of academic literature, stakeholder consultations and expert judgments.

Main assumptions for the Net Zero Scenario is summarised in the Table 5-4 below. Further details on the sectoral assumptions and demand drivers were provided in the Appendix (Chapter 10.2).

***Table 5-4 Sectoral assumption in LEAP model***

| Assumptions | Reference Scenario | Net Zero SS Scenario |
|---|---|---|
| **Power Generation** | | |
| Retirement profile | New supercritical coal power plants allowed (capacity expansion based on electricity demand). | New supercritical coal power plants can be built, but after 2050 they must incorporate carbon capture and storage (CCS) technology. |
| Khavda Renewable energy park | No | 30GW installed capacity of solar and wind by 2040 |
| New Capacity Additions | Capacity addition depends on electricity demand and new capacity addition size defined by the user. | |
| **Industry** | | |
| Energy efficiency | No | Decline of useful energy intensity due to fuel switch. |
| Hydrogen | No | Hydrogen has 0% share before 2050, and starts to play greater role in 2050, reaching 20- 70% of energy consumption of the industry sector (depending on the sector) |
| Phase out of Coal | Existing shares of coal in industry sectors do not change | Gradual phase out of coal in industry by 2070 |
| Electrification | Existing shares of electricity do not change | 25-75% share of electricity (depending on the industry sector) |
| Reduction of $CO_2$ emission factor from glass production | No | From 0.2 tonne $CO_2$/tonne of glass to 0.1 tonne $CO_2$/tonne of glass by 2070 |
| Reduction of $CO_2$ intensity of cement production (IPPU) | No | Reduction of emission factor from 0.537 ton $CO_2$/ ton of clinker to 0.239 ton $CO_2$/ ton of clinker |

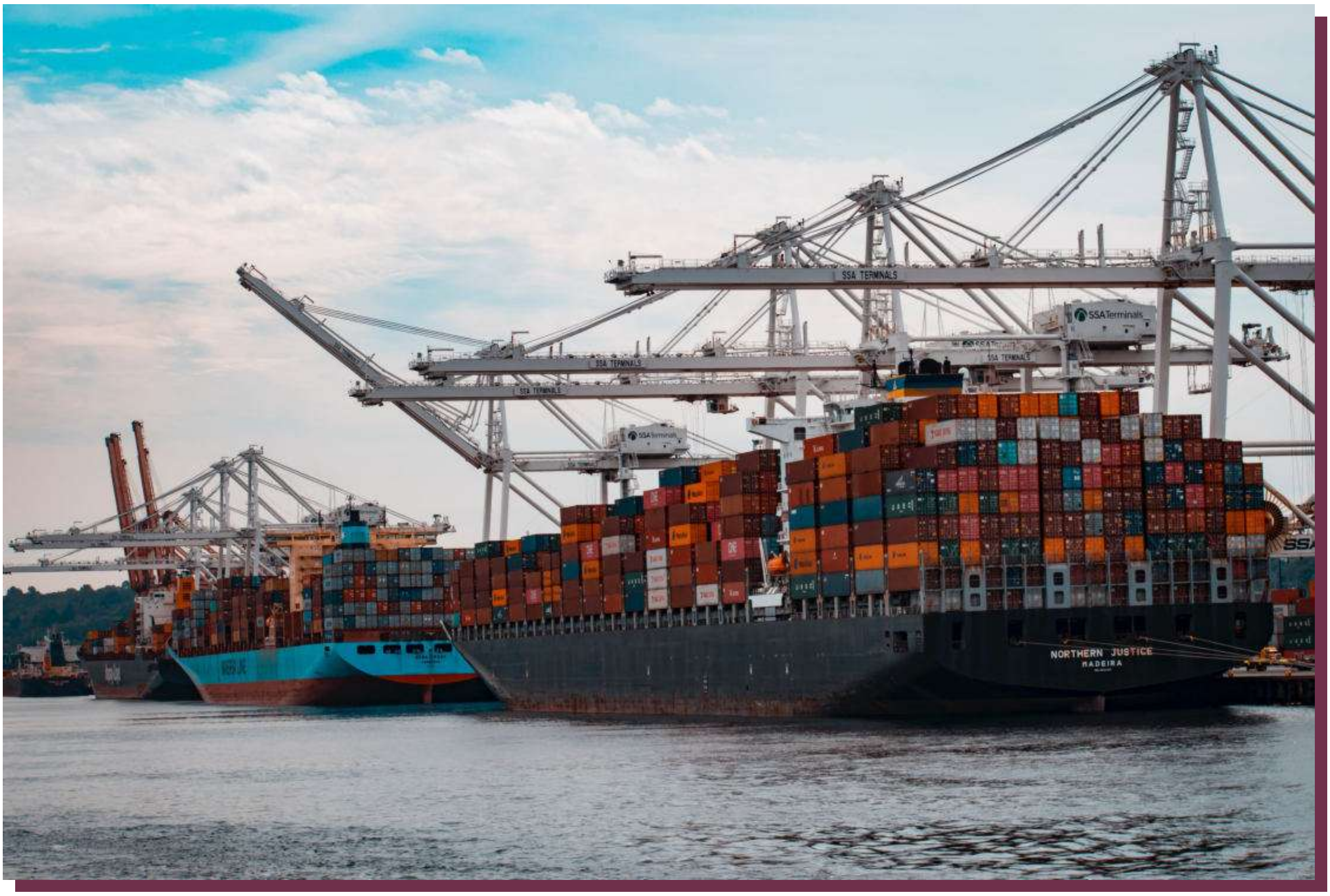
| Assumptions | Reference Scenario | Net Zero SS Scenario |
|---|---|---|
| | **Buildings** | |
| Phase out of wood and kerosene in the households cooking | Phase out by 2040 | |
| Phase of out of CFLs and incandescent lamps | No | Phase out of CFL by 2040 in urban households and by 2050 in rural households.<br>Phase out of incandescent light bulbs by 2040 in rural households. |
| Energy efficiency | No | 1% p.a. energy intensity reduction in the appliances and air conditioning |
| Solar roof top systems | No new installations | Provide 30% of end-use demands in the commercial and agriculture sectors by 2070, 4% in the residential sector by 2070. |
| | **Transport** | |
| Electrification of rail | 100% of rail is electric by 2070 | Increase from 51.2% in 2018 to 100% by 2050 |
| Phase out of oil products in the transport sector | No | Phase out by 2050 in cars, by 2070 in buses, by 2070 in three wheelers. |
| Passenger demand | Passenger demand per capita (PKM) will increase from 8060 to 20000 between 2018 and 2070 | Passenger demand per capita (PKM) will increase from 8060 to 12000 between 2018 and 2070 |
| Freight demand | Freight demand per capita will increase to 12800 TKM in 2070 | Freight demand per capita will increase to 11300 TKM in 2070 |
| Increasing share of biofuel and bio CNG in the transport sector | No | Bio-CNG reach 13% in cars, 30% in buses, 10% in three wheelers in 2070 |
| Electrification of road transport | No | Share of electric vehicles reaches 100% in 2035-2045 (cars, three-wheelers, buses) in line with targets set in GFEI |
| H2 Fuel Cell in freight transport | No | 5-10% in 2070 in heavy trucks and in medium trucks |
| | **AFOLU** | |
| Increased forest cover area | In the reference scenario, following the past trend, forest area increases to 1645 thousand hectares, approximately 8% of the total area. | In the Net Zero SS scenario, ambitious growth of the forest area and about 23% share of forests in the state in 2070 has been assumed. |

## 5.5 Stakeholder Consultations and Expert Interviews

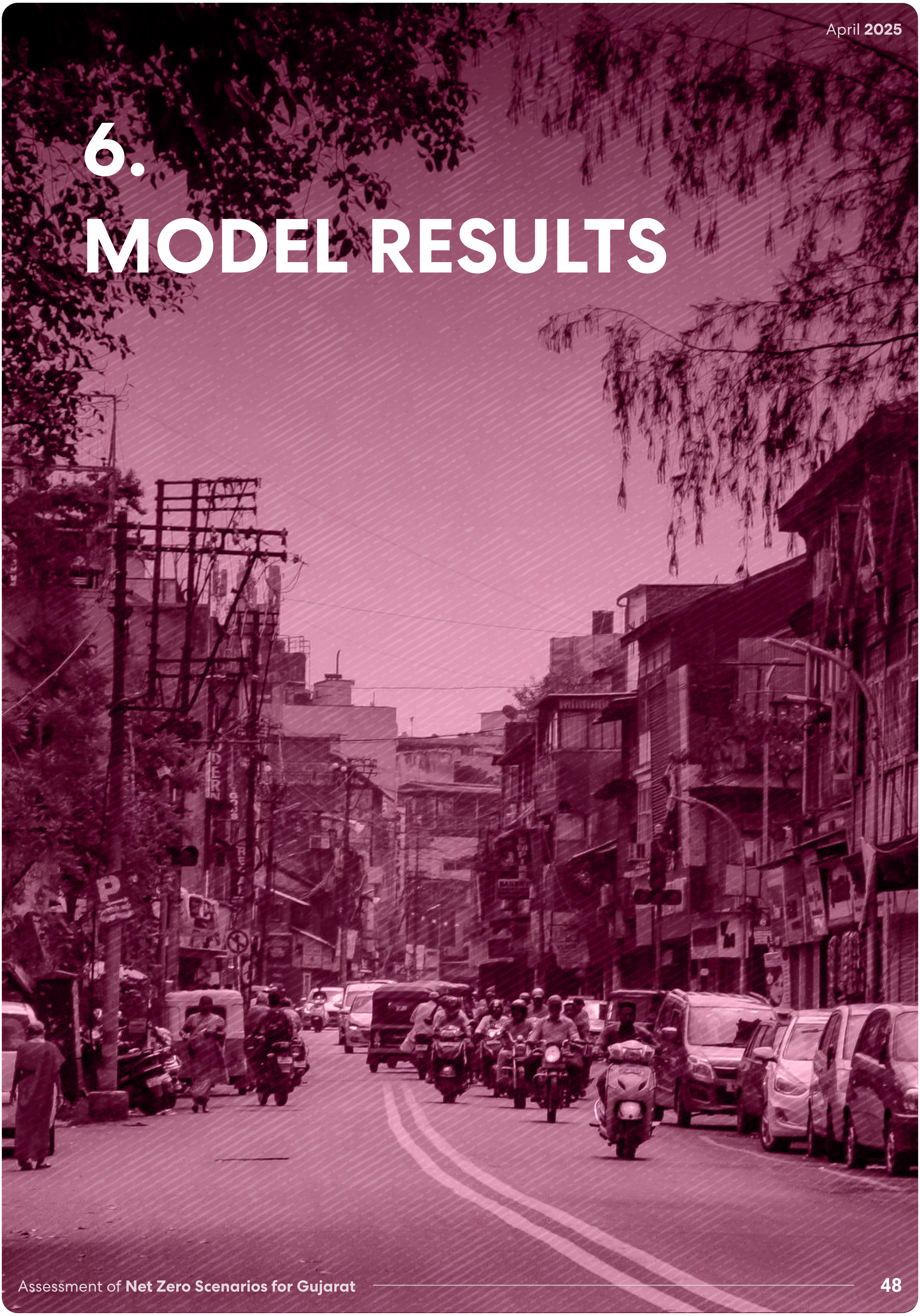
During the analysis, stakeholder consultations were organised to seek feedback on the storyline and key assumptions. The first meeting was organised in April 2024, during which the results from the emissions inventory, key assumptions, and initial results of the BAU scenario were presented. It was attended by stakeholders from various organizations, including the Government of India (NITI Aayog), Government of Gujarat (GUVNL, GEDA, GETRI), and academic and research institutions like Ahmedabad University, CEEW, CEPT University, EMBER, TERI, IIM-Ahmedabad, IIT Gandhinagar, UNEP CCC, and WRI India (See Appendix 10.5 for complete list). Their inputs included key considerations around the urbanization rate, the structure of the economy, discussions on the demand side and sustainable development. This feedback was considered for further work.

The second stakeholder meeting was organised in October 2024, during which the teams presented the overall results to the stakeholders. The stakeholders from the first meeting were invited to ensure continuity and allow them to assess whether their inputs were considered. A key input from the stakeholder meeting was considering the role of CCS and energy storage in the scenario storyline.

In addition, the study team consulted the Gujarat State Climate Change Department, Energy and Petrochemicals Department, GEDA and GETRI on two separate occasions to discuss the project results. The inputs from government agencies were also considered before finalising the results. Finally, the draft report was shared in November with experts in India and international experts.



# 6. MODEL RESULTS



## 6.1 Conventional Net Zero Scenario (GCAM)

The results of the conventional NZ scenario are based on the assessment carried out using the GCAM model. The scenario is termed "conventional" because it assumes that the energy demand behaviours or economic structure does not change much compared to what is observed historically in the state or other developed economies.

### 6.1.1: Industry Sector:

In 2020, the industrial sector accounted for the largest share of total energy demand, at 72%. Assuming the sector's composition remains constant[4], industrial energy demand is projected to increase 7.6-fold, rising from 1.56 EJ in 2020 to 11.8 EJ by 2070, with an average compound annual growth rate (CAGR) of 4% under the Reference scenario.

This significant increase in industrial energy demand is primarily driven by rising per capita income, projected to grow 24-fold between 2020 and 2070 (See Section 10.3.1 on how industrial demand is calculated in GCAM). Higher incomes, coupled with increasing urbanization, are expected to boost demand for commodities such as chemical products, plastics, paints, cosmetics, metals, and cement.

***Figure 6-1 (a) Industrial Final Energy Demand by fuel***

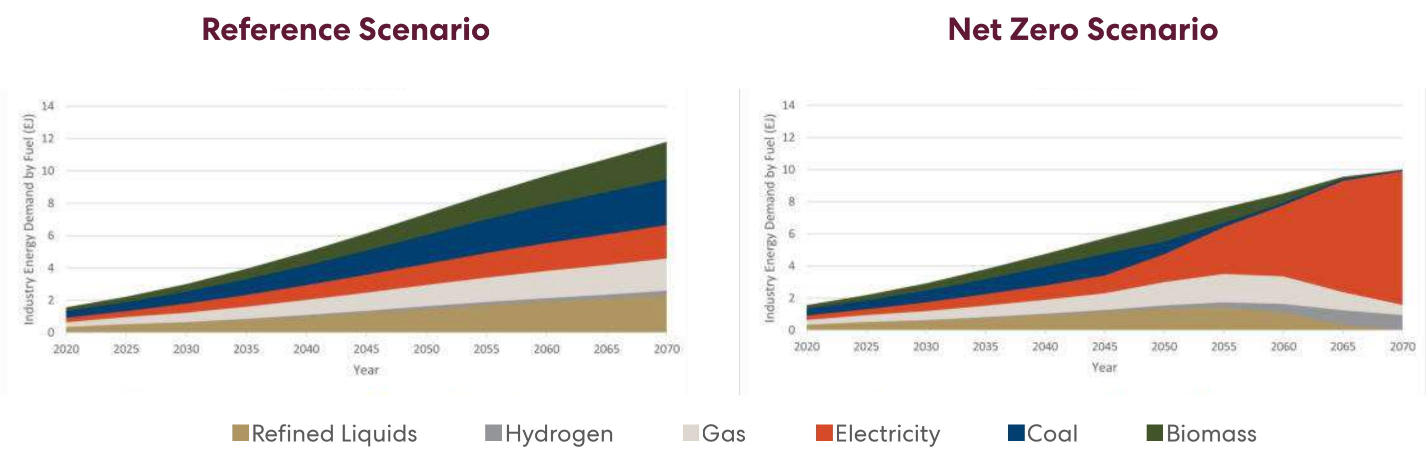
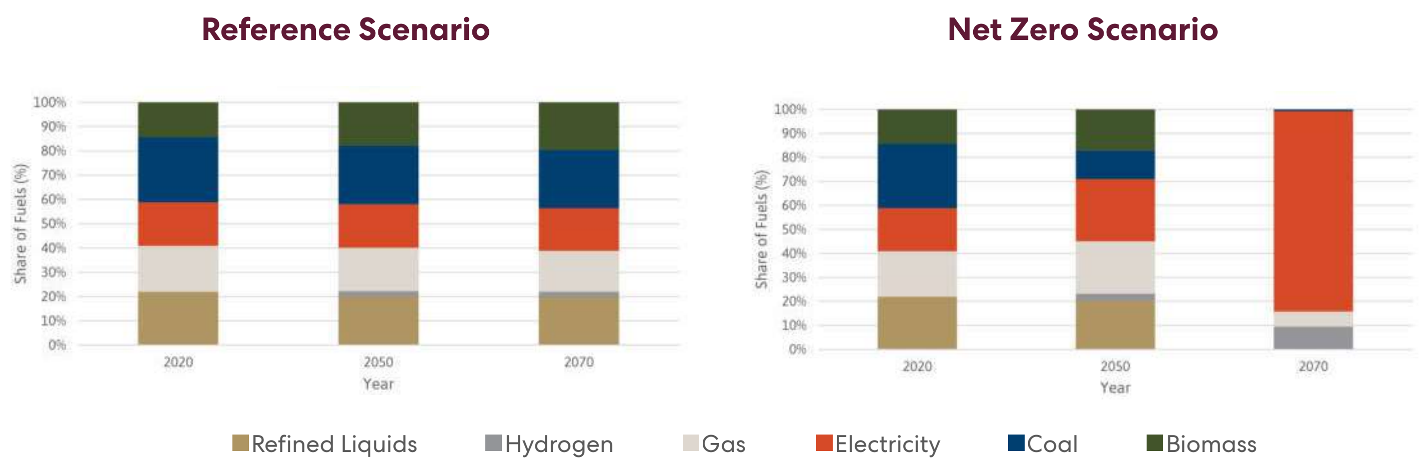



***Figure 6-1 (b) Share of different fuels (GCAM)***




[4] We assume that the share of GVA of industry declines from 37% in 2020 to 34% in 2070. This is true for both reference and NZ scenarios. We assume that the composition of the industry does not change - for example if it is dominated by iron and steel today, it continues to be dominated by iron and steel in the future.

In terms of share of fuel consumption, in 2020, the industry sector has a diversified fuel share, dominated by coal at 27%, refined liquids at 22%, electricity and gas at 18% each and biomass at 14% (Figure 6-1). In the reference scenario, the share of biomass gradually increases to 20% in 2070, while the shares of the remaining fuels remain the same or decrease marginally (Figure 6-1(a)). The reference scenario also assumes energy efficiency improvements in the industry – in line with the "moderate scenario" of the Gujarat Energy Efficiency Plan. It is important to note that these results are only for energy use and not non-energy use in industries.

In the NZ scenario, energy demand from the industry sector is 5% lower in 2040 compared to the reference scenario, mainly due to accelerated energy efficiency improvements assumed in the NZ scenario. Figure 6-1(b) shows that the major shift in the sector will occur after 2050 when there is rapid electrification of the industrial sector. This happens because using fossil fuels in boilers and furnaces becomes much more expensive[5] than similar processes driven by electricity. By 2070, 83% of all industry end-use energy demand is electrified, while the remaining is serviced from natural gas and hydrogen.

Studies analysing the global industrial sector have shown that even with presently available technologies, 50% of the total fuel use in industry could be electrified and that electrification of these processes does not require a change in the industrial process setup but rather replacing a device, such as a boiler or furnace, running on conventional fuel with electric equipment[6]. Looking at the industry sector in Europe, Madeddu et al. (2020) conclude that 78% of the industrial processes could be electrified with technologies already available, and 99% of electrification can be achieved with technologies under development.

Low-temperature processes (<100°C) and medium-temperature processes (100–400°C), such as drying, washing, rinsing, food preparation, and evaporation, are the easiest to electrify. These processes are primarily used in less $CO_2$-intensive sectors, including paper, wood, and textiles. High-temperature processes (400–1000°C), such as steam reforming and cracking in petrochemical industries, are technologically feasible for electrification but not yet commercially viable for all applications. Very high-temperature processes (>1000°C) used in steel, cement, and ceramics production face greater challenges, as electrification technologies for these applications are not yet technologically mature.

Coal consumption in the industrial sector is projected to peak in 2045. As emission constraints tighten, hydrogen becomes increasingly cost-competitive, resulting in a higher share compared to the Reference scenario. However, hydrogen still accounts for only 9% of the industrial energy mix in the NZ scenario.

Hydrogen use in industry is primarily concentrated in the iron and steel sector. In contrast, its applications in the fertiliser and chemical industries are largely limited to use as feedstock.

### 6.1.2: Transport Sector:

In 2020, the transport sector accounted for 13.6% of total energy consumption[7]. Most of this demand came from freight transport (58%), primarily involving trucks. The remaining demand was attributed to passenger transport, dominated by four-wheelers (16%), buses (10%), and two-wheelers (10%), and the remainder from three-wheelers.

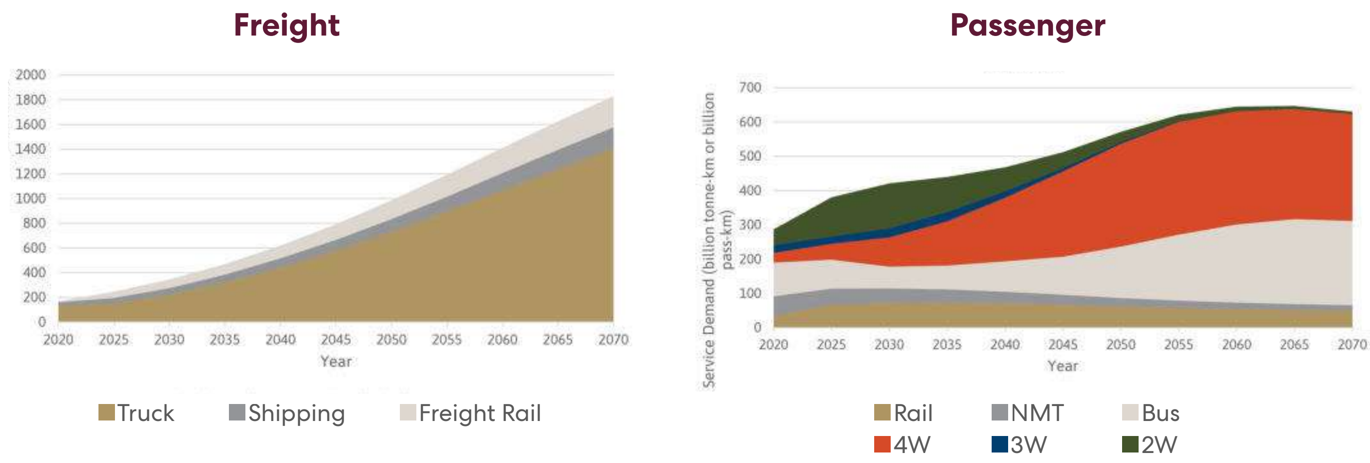
The total demand in passenger-kilometres (pass-km) and tonne-kilometres (tonne-km) for freight is similar in both the Reference and NZ scenarios. In both scenarios, total passenger-km is projected to increase 2.5 times, rising from 288 billion pass-km in 2020 to 723 billion pass-km by 2070. Freight demand is expected to grow more significantly, increasing 11-fold from 169 billion tonne-km in 2020 to 1,829 billion tonne-km in 2070 (Figure 6-2).

[5] Fossil fuels become more expensive because of a carbon price on them. The carbon price is determined endogenously in the model based on emission constraints). Note that we assume that the current structure of the power tariffs – where residential consumers are subsidised through higher power tariffs to the commercial and industrial sector does not change in the future.

[6] https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/plugging-in-what-electrification-can-do-for-industry

[7] Data on energy consumption by transport mode is not shown here but only calculated.

***Figure 6-2 Transport Service Demand*** (***GCAM***)




In 2020, buses fulfilled approximately 34% of total passenger demand (in billion pass-km), followed by non-motorized travel modes—such as bicycles, walking, and rickshaws—at 20%. Passenger rail contributed 12%, while the remaining demand was met by two-wheelers, three-wheelers, and four-wheelers.

In the passenger segment, growth in population and income is accompanied by higher private vehicle ownership and an increase in the number of kilometres travelled. As witnessed globally, higher incomes will result in an increase in the share of cars and a decline in the share of two-wheelers in overall passenger transport. Figure 6-2 shows that between 2020 and 2050, the share of 4W increases from 10% to 53%, whereas the share of 2W decreases from 16% to 5%. However, physical constraints on the size of cities and the issues of congestion - as already witnessed in major cities of India, lead to a stagnation in the growth of private ownership[8]. A similar pattern has been observed in Mumbai, for example, where even high-income individuals prefer public transport over private vehicles to save time (Cropper & Bhattacharya, 2012). The reference scenario already assumes that the response to increased congestion will be higher investments in public transport – particularly buses.

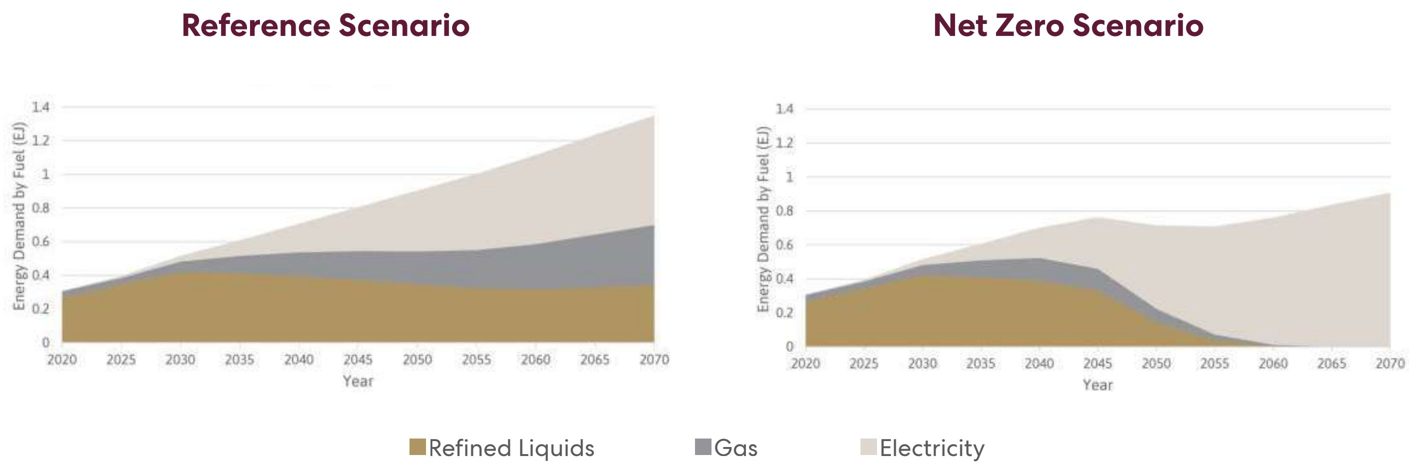
In summary, in the reference scenario, although private ownership increases in response to higher incomes, and the mode share of public transport decreases, the trend reverses in later decades due to higher congestion on roads (leading to lower private transport) and higher investment in public transport. Compared to an ownership in 2020 of 70 and 16 per 1000 people for two-wheelers (2W) and four-wheelers (4W), respectively, the ownership levels in 2070 are projected to reach 119–159 for 2W and 27–35 for 4W, depending on the survival curve assumed. No additional demand-reduction policies are assumed in the NZ scenario.

In the freight segment, higher incomes, and a high share of manufacturing in GSDP lead to a significant increase in freight demand. However, unlike passenger transport in cities, most of the freight movement is expected to take place through highways, where issues of congestion will not hamper movement. In Gujarat, almost 96 per cent of the railway network is electrified. The electrification of railways leads to reduced cost of transport, thereby increasing the share of freight moved by rail from 5% in 2020 to 13% in 2070.

[8] For passenger transport, two-wheelers, three-wheelers, cars, buses, railways, and aviation compete with each other for providing passenger service. Changes in modal shares in future periods depend on the relative costs of the different options, modelled using a logit choice formulation. Costs in the passenger sector include time value of transportation which tends to drive a shift towards faster modes of transport (light duty vehicles, aviation) as incomes increase. We model congestion by reducing the speed of the transport mode, which in return reduces the time value of private vehicles. During this time, there is also a higher policy push towards buses.

[9] Several studies have shown that vehicle ownership saturates with increasing income levels. However, the ownership number, even at similar GDP per capita, can be very different.


***Figure 6-3 Transport Energy Demand (GCAM): Reference & Net Zero Scenario***



With an 87 per cent share, the present fuel mix of GJ's transport sector is dominated by oil (petrol and diesel), followed by natural gas at 12.6 per cent (Figure 6-3). In the reference scenario, significant electrification of the transport sector is expected on the back of favourable policies encouraging EV adoption - through subsidies on EVs, the creation of charging infrastructure, technological improvements, and reduced battery costs. By 2050, it is assumed that all non-economic barriers to electric vehicle adoption will be eliminated, with charging infrastructure availability and charging times comparable to the convenience of today's petrol stations. An exception is made for long-haul heavy freight trucks, where some barriers related to highway charging infrastructure, range, and charging times for EV trucks are expected to persist until 2070. In the rail sector, complete electrification of the inter-city passenger and freight network is anticipated by 2030, replacing refined liquid fuels due to significant advancements in the railway network over the past decade (Press Information Bureau, 2024a). Among trucks, two-wheelers, four-wheelers, three-wheelers, and buses, electric vehicles are expected to achieve cost parity with their diesel or petrol counterparts between 2025 and 2035 in terms of passenger-km or ton-km. This is driven by the declining cost of batteries, which constitute a significant portion of the total vehicle cost. The result is that by 2070, the transport sector is 48% electrified in the reference scenario. The remaining fossil-fuel consumption is mainly from shipping and freight trucks.

In the NZ scenario, there are no major modal shifts compared to the reference scenario in the passenger sector, as the latter already incorporates an increase in public modes of transport on account of congestion in cities. In the freight sector, however, since shipping is very expensive to electrify, there is a shift to trucks, where electrification is less expensive.

In terms of fuel shift, the NZ leads to a significant increase in electrification. In the years 2060-65, both the passenger and freight sectors are almost entirely electrified. This leads to a significantly lower energy demand, as electric motors typically convert 85-90% of the electrical energy from the battery into mechanical energy compared to 20-30% of chemical energy for the internal combustion engines. Thus, the total energy demand in NZ is 32% lower than the reference scenario.

### 6.1.3 Building Sector

In 2020, the building sector - which comprises the commercial and residential sectors consumed a total of 0.33 EJ of energy, with a share of 16% and 84%, respectively. Of the total energy, 64% was used for cooking, 5% for cooling, and 26 % for other uses (Figure 6-4).

Unlike the transport sector, the building sector consumed diverse fuels in 2020 - 42% traditional biomass (fuelwood), 16% refined liquids (LPG, kerosene, and similar liquid fuels), 23% electricity, 14 % natural gas (mainly piped natural gas), and 6 % biomass (commercially available biomass) (Figure 6-5).

***Figure 6-4 Building Energy Demand by end-use** (**GCAM**): **Reference** & **Net Zero Scenario***

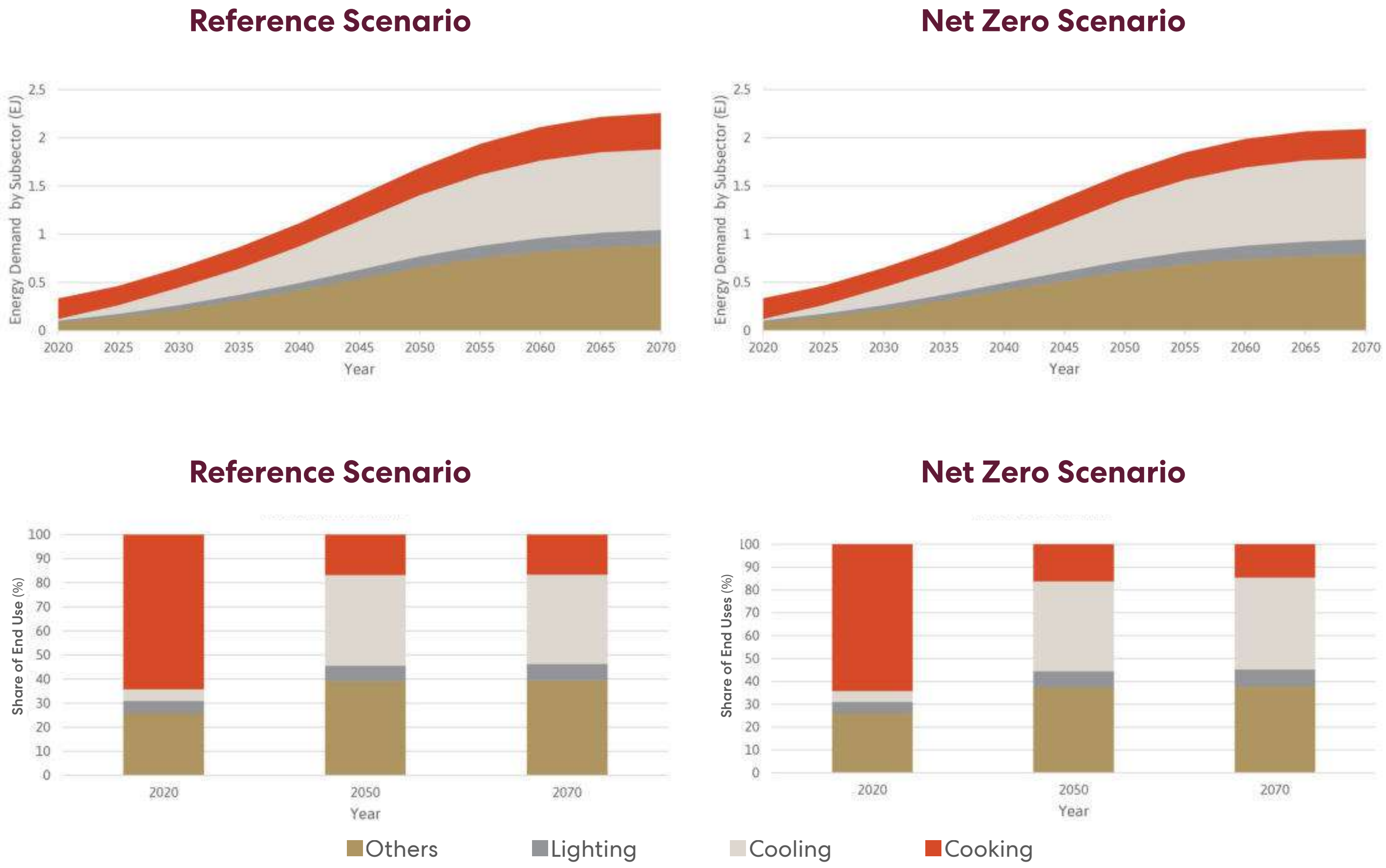
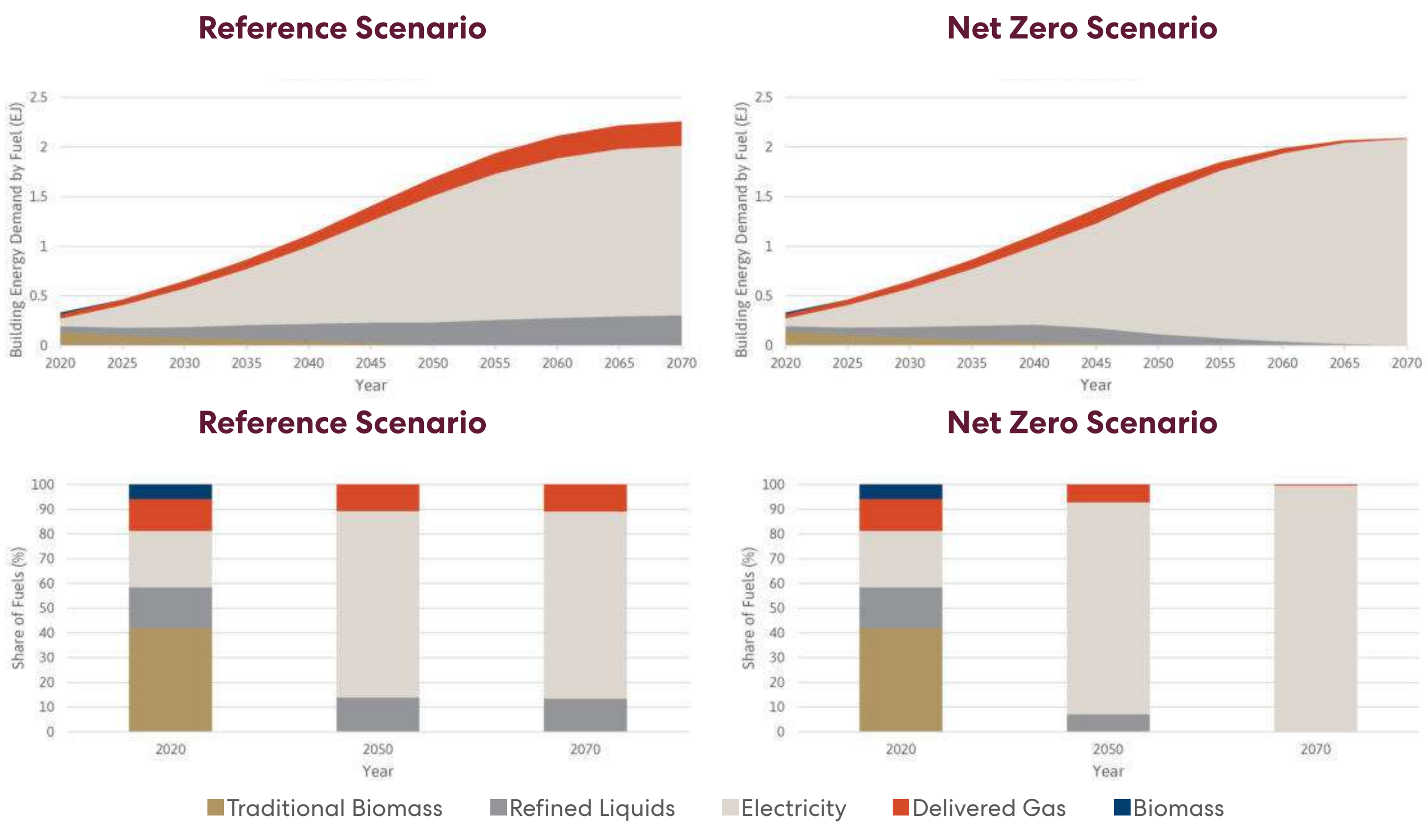



***Figure 6-5 Building Energy Demand by fuel** (**GCAM**): **Reference** & **Net Zero Scenario***



The residential sector comprises both urban and rural areas and services such as cooling, heating, cooking, lighting, etc. The future evolution of building energy use is shaped by changes in (i) floorspace, (ii) the level of building service per unit of floor space, and (iii) fuel and technology choices by consumers. The primary driver for increasing floorspace is the per capita income; however, floorspace starts saturating at a particular income level. The level of building service demands per unit of floor space depends on the climate, building shell conductivity, affordability, and satiation levels.

In 2070, the total energy demand in buildings in the reference scenario increases by 6.8X, from 0.33 EJ in 2020 to 2.25 EJ in 2070, with the fastest increase in cooling service demand, which grows by 52 times, followed by lighting and others, which increase by around ten times. A higher demand for cooling is also due to a warmer climate with more cooling-degree days in the future (see appendix Section 10.1.4. for details). Building energy efficiency improves; however, these improvements are outpaced by the growth in demand for floorspace, services and appliance ownership and use.

It is assumed that traditional biomass will be replaced by alternative cooking fuels by 2045 due to the achievement of universal electricity access and the widespread adoption of LPG. This fuel shift initially leads to a reduction in total energy demand as alternate forms of cooking are more energy efficient. In the second half of the century, more efficient electric cooking replaces fossil fuels. For the same reason, the cooking energy demand increases only two times between 2020 and 2070. In the NZ scenario, near-complete electrification of all services in the building sector is observed, as illustrated in Figure 6-4. Total energy demand in this scenario is 7% lower in 2070 compared to the reference scenario.

### 6.1.4 Agriculture Sector:

In 2022, there were an estimated 31.8 million agricultural irrigation pumps in India, of which 20.3 million were grid-connected (64%), 2.7 million were solar pumps (8.4%), and the remaining 8.8 million (27.6%) were diesel pumps (IEA, 2020b). Thus, around 72% of all agricultural pumps (by number) in India are electrified. At a state-level, most of India's western, central, and southern states have achieved near-100% electrification, whereas states in north-eastern and eastern parts of India particularly Bihar, Jharkhand only have 15-20% electrification (Shah et al., 2018). Given the push from the PM-Kusum scheme for solarisation of agricultural pumps, the number of solar pumps has increased by almost 14 times in the last four years, from 0.4 million in 2018 to 2.7 Million (IEA, 2020b).

***Figure 6-6 Agricultural energy demand (GCAM)***

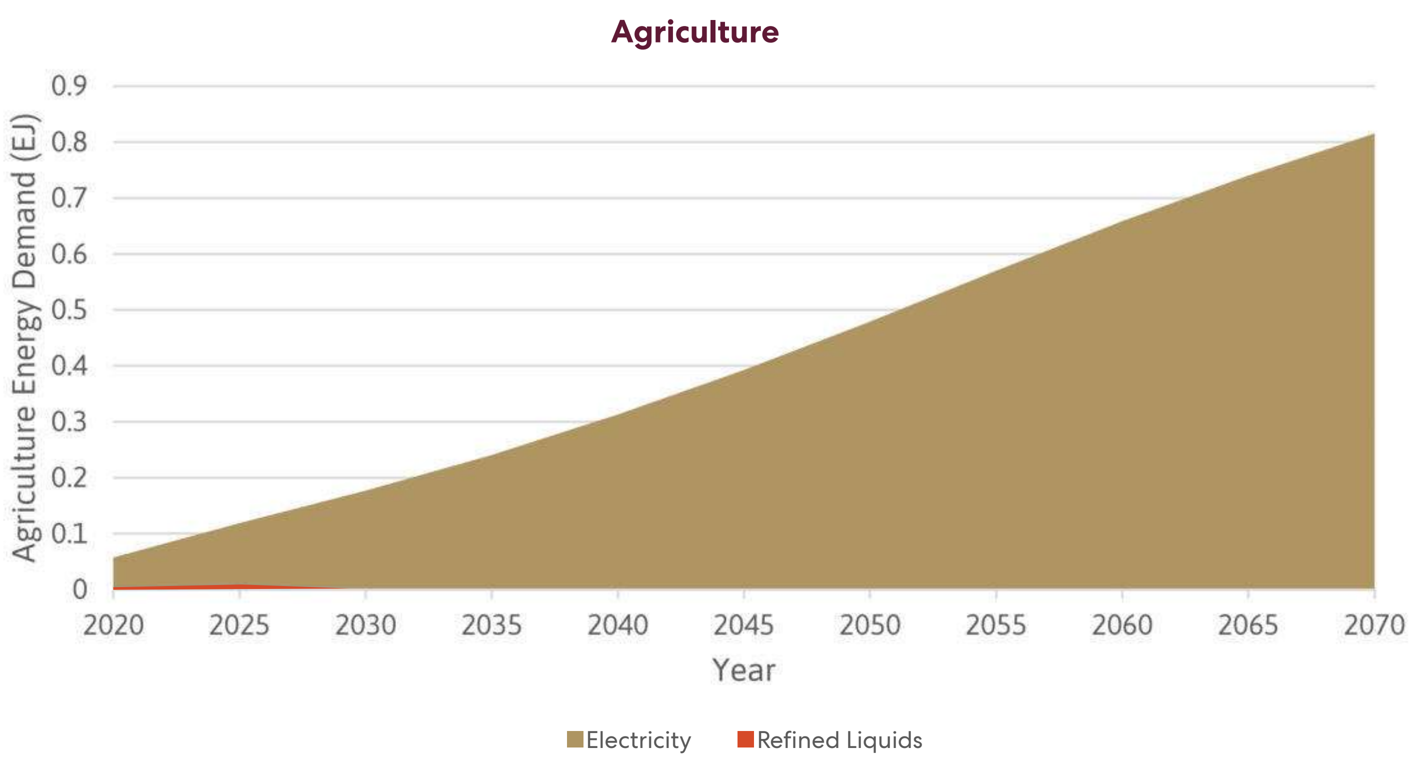


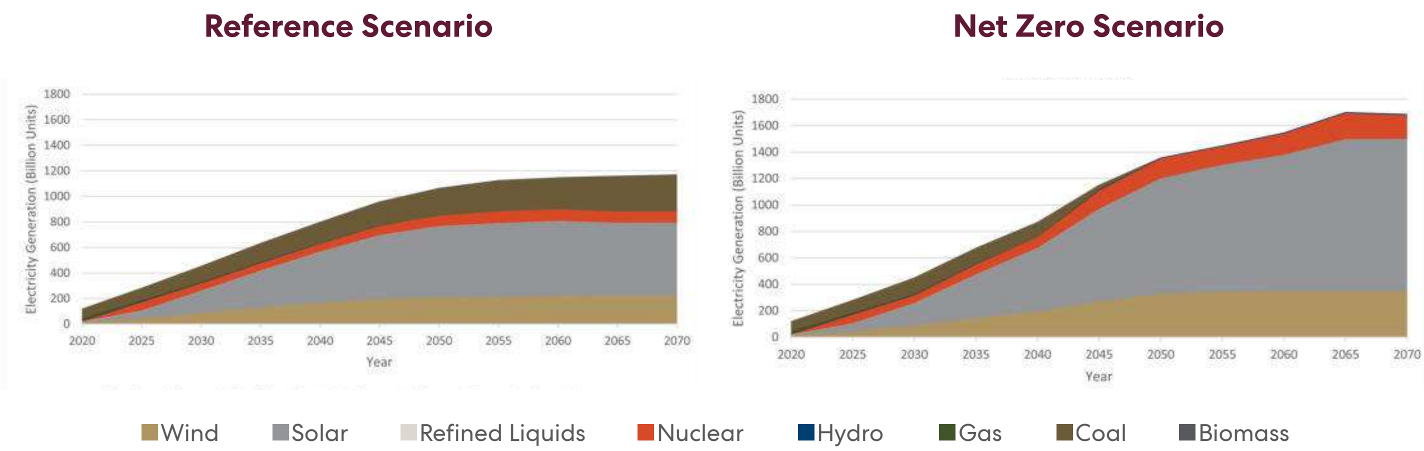
Figure 6-6 shows that in 2020, nearly 92 percent of the energy consumed by Gujarat's agricultural sector was through electricity, the rest through refined liquids. Under the reference scenario, agricultural energy demand increases by 11 times, from 0.07 EJ in 2020 to 0.8 EJ in 2070, driven from increase in area under irrigation. The state has set itself a target of greater than 70% of the Net Irrigated Area to the Net Sown Area by 2047, from 59.6 % in 2023 (Government of Gujarat, 2024c). In the absence of dedicated targets for agricultural pump electrification, it is assumed that with sustained policy efforts toward solarization and electrification of pumps, all agricultural energy use will be electrified by 2030 (Figure 6-6).

### 6.1.5 Power Sector

#### 6.1.5.1 Total electricity generation and share of different fuels

In 2020, the total generation from the power sector amounted to 0.43 EJ or 121 billion Units, while consumption was 99.6 billion Units[10] . 62% of the total generation was from coal, followed by gas (16%) wind (9.5%); solar, hydro, and nuclear were all around 2.4%-3.7% each (Figure 6-7).

***Figure 6-7 Electricity generation across scenarios*** (***GCAM***)




In the reference scenario, electricity generation in the state increases by 3.8 times between 2020 and 2030 and nearly 2.6 times between 2030 and 2070, as noted in Figure 6-6. Thus, a significant capacity addition occurs in the next ten years. The overall electricity generation is approximately 455 BUs (billion units[11]) in 2030 and 1171 BUs in 2070, from about 121 BUs in 2020 (Figure 6-7).

While there is already higher end-use electrification in the reference scenario, especially in the transport and buildings sector, electrification is the primary solution to decarbonisation in the NZ scenario. In 2070, the total generation is 1.4 times higher than in the reference scenario at 1690 billion units. However, the increase in generation cannot meet the future electricity demand. From 2050 to 2070, the electricity demand is higher than generation—with the 2070 being ~ 3000 BUs—in other words, 40% of the total electricity in Gujarat needs to be imported in 2070.

[10] While Gujarat produces more electricity than it consumes on an annual basis, it does import electricity during specific demand peaks or operational conditions to ensure reliability and maintain grid stability.

[11] 1 Unit = 1 KWh of electricity

***Figure 6-8 Share of power generation (Table given in appendix 10.1) by source. RE is Renewable energy and includes solar, wind, biomass, and hydro***

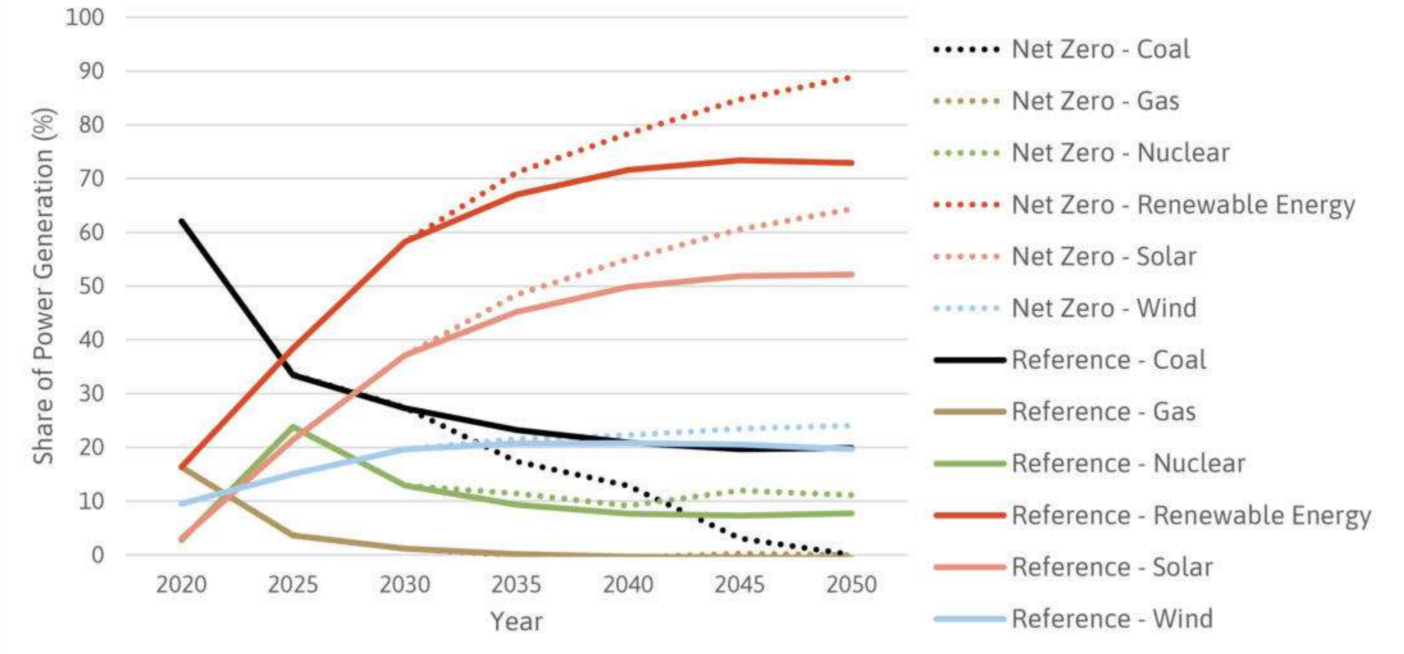



Figure 6-8 shows the share of power generation for different technologies in the two scenarios. In the reference scenario, the share of coal generation decreases from 62 per cent in 2020 to around 24 per cent in 2040 and stays the same until 2070, as other sources of electricity generation, particularly solar and wind, become more cost competitive[12]. The share of solar-based power generation increases from 3% in 2020 to just over 50% in 2040 and continues its dominance until 2070. It is assumed that no new gas generation capacity is added beyond 2020[13] in the reference scenario, resulting in its share becoming negligible by 2040 (Figure 6-8). By 2030, the share of solar generation is expected to overtake coal generation.

In the reference scenario, more than 50% of the power generation comes from renewable sources, higher than the RPO target of 43% in 2030[14]. By 2070, almost 75% of the electricity comes from renewable sources.

In the net-zero scenario, coal is phased out much faster (in 2050), as no new coal power plants are constructed beyond 2030 (Figure 6-7 and Table 6-1). Policy and institutional support for such a phase-out becomes necessary to avoid stranded coal assets in the future. In addition, the constraint to reach NZ implies accelerated addition of solar generation. In 2050, about 88% of the electricity is generated from renewable sources (with the share of solar being almost 74%), the rest being from nuclear (Table 6-1).

[12] For intermittent technologies like solar and wind, we assume certain integration costs which are added to the generation costs of these technologies. Refer to Appendix 10.1.2 for values and rationale behind these costs.

[13] According to a report from the Centre for Net-Zero Energy Transition (CNET), Gujarat aims to decommission four gas power plants before 2030 and no new plants are planned (Center for Net-zero Energy Transition 2023).

[14] The RPO targets are specified in terms of electricity consumption rather than generation. However, assuming that all power is both generated and consumed within the state, it is projected that the RPO targets will be exceeded.

***Table 6-1 Summary of relevant variables for the Reference and NZ scenarios for 2020 and 2050.***

| Variable | Reference | | | NZ | |
|---|---|---|---|---|---|
| | 2020 | 2050 | 2070 | 2050 | 2070 |
| **Total electricity generation** (**BU**) | 121 | 1066 | 1171 | 1358 | 1688 |
| **Total electricity consumption** (**BU**) | 99 | 818 | 1228 | 1005 | 3147 |
| **Total coal capacity** (**GW**) | 17 | 55 | 74 | 0.1 | 0 |
| **Total solar capacity** (**GW**) | 3 | 288 | 270 | 453 | 550 |
| **Total wind capacity** (**GW**) | 5.5 | 99 | 107 | 155 | 163 |
| **Total nuclear capacity** (**GW**) | 0.4 | 10 | 11 | 17 | 22 |
| **Share of RE in total power generation** (%) | 16 | 72 | 68 | 88 | 89 |

[15] Palchak et al. (2017) demonstrated that India could integrate 160 GW of wind and solar energy, achieving an annual renewable penetration of 22% of the system load, without requiring additional storage resources. Similarly, studies by Hirth et al. (2015) and Sholz et al. (2017) for Germany indicate that storage costs remain a minor component of the total cost of integrating variable renewable energy (VRE) up to VRE shares of approximately 50%.

***Table 6-2 Annual Variable Renewable Capacity (solar + wind) addition in the power sector***

| in GW | 2020-25 | 2025-30 | 2030-35 | 2035-40 |
|---|---|---|---|---|
| **This study (NZ scenario)** | 50 GW | 86 GW | 122 GW | 112 GW |
| **C-NET (15% GDP Scenario)** | 19 GW | 18 GW | NA | NA |
| **C-NET (50% RE Scenario)** | 21 GW[20] | 22 GW | NA | NA |
| **GJ 500 billion study** | 16 GW[21] | 30 GW | NA | NA |

Figure 6-9(a) and Figure 6-9(b) shows the capacity addition for three fuels - coal, solar PV, and wind onshore for five-year periods starting in 2020. Reported annually, in the reference scenario, 1 GW of coal is installed on average, ~12 GW of solar, and ~4 GW of wind[22]. In comparison, no new coal plants are installed in the NZ scenario after 2030, which, combined with higher electrification requirements, leads to annual additions of ~ 22 GW for solar and ~ 5 GW for wind. Thus, an NZ scenario implies almost 1.5-2x of the solar and wind capacity additions.

[16] Based on calculations from installed capacity from https://iced.niti.gov.in/energy/electricity/generation/capacity

[17] Based on the sum of under-construction and under-development projects from https://iced.niti.gov.in/energy/electricity/generation/ pipeline-capacity/solar and based on average construction time of 1.5 years.

[18] Sources of numbers and calculations similar to that for solar.

[19] includes solar, wind, hydro, and biomass

[20] Data only available for FY23-FY25, for the remaining years the average addition of available data was taken.

[21] Data only available for FY26-FY27, for the remaining years the average addition of available data was taken.

[22] Number implies capacity addition every year for the next 50 years.

***Figure 6-9(a) Electricity Capacity Addition***

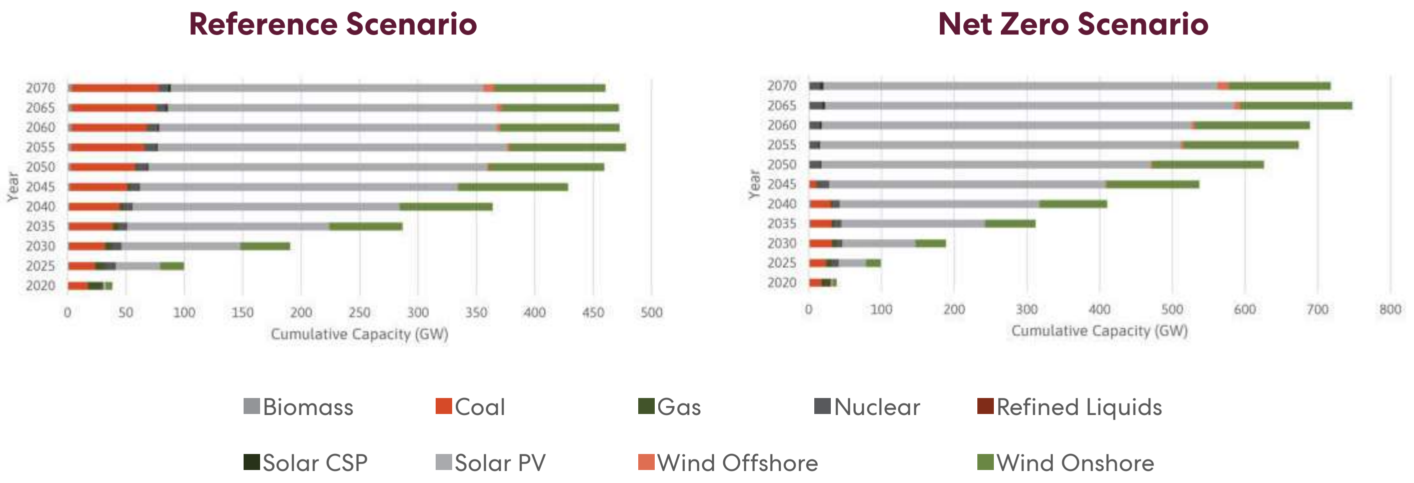


***Figure 6-9(b) Electricity Capacity Addition***

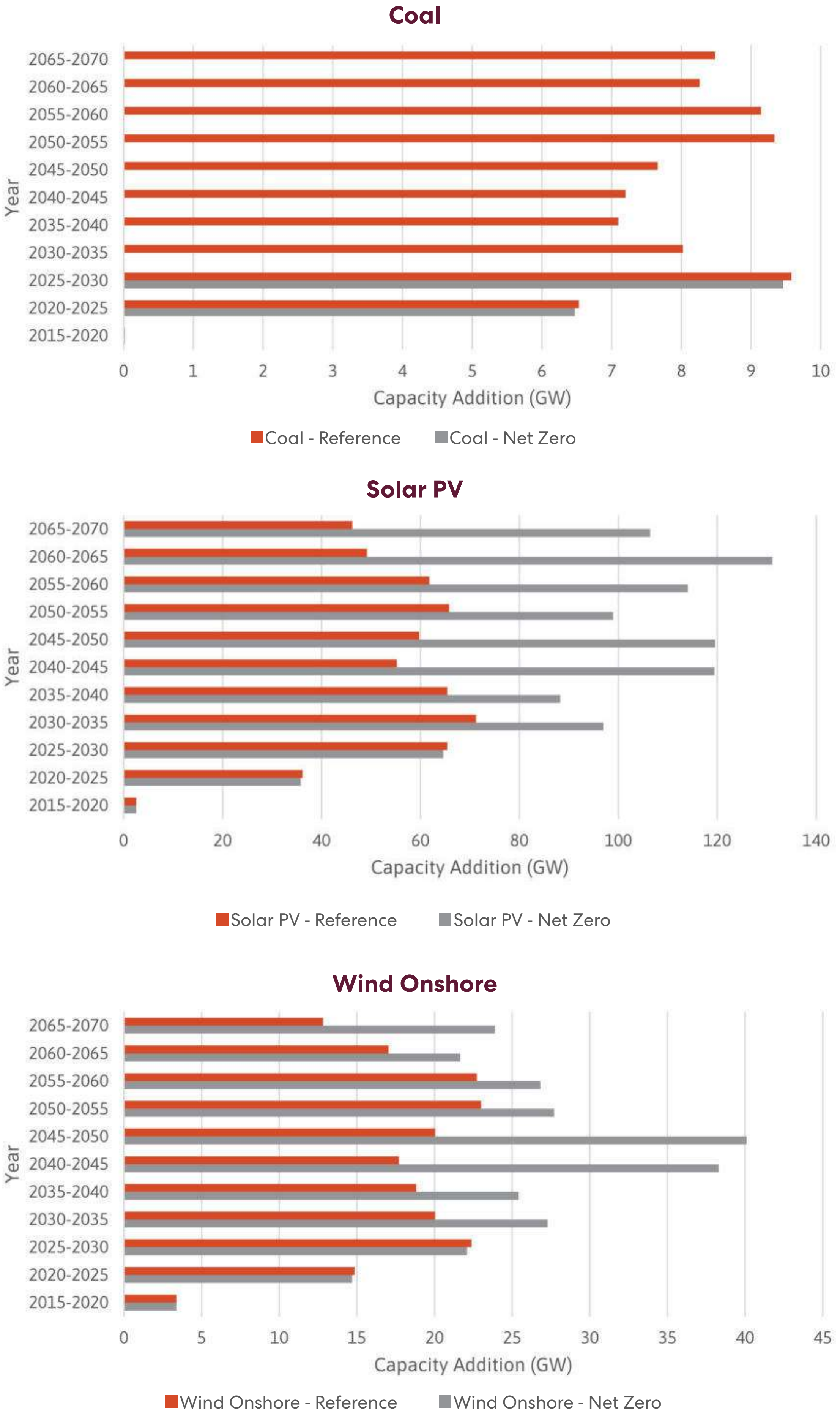
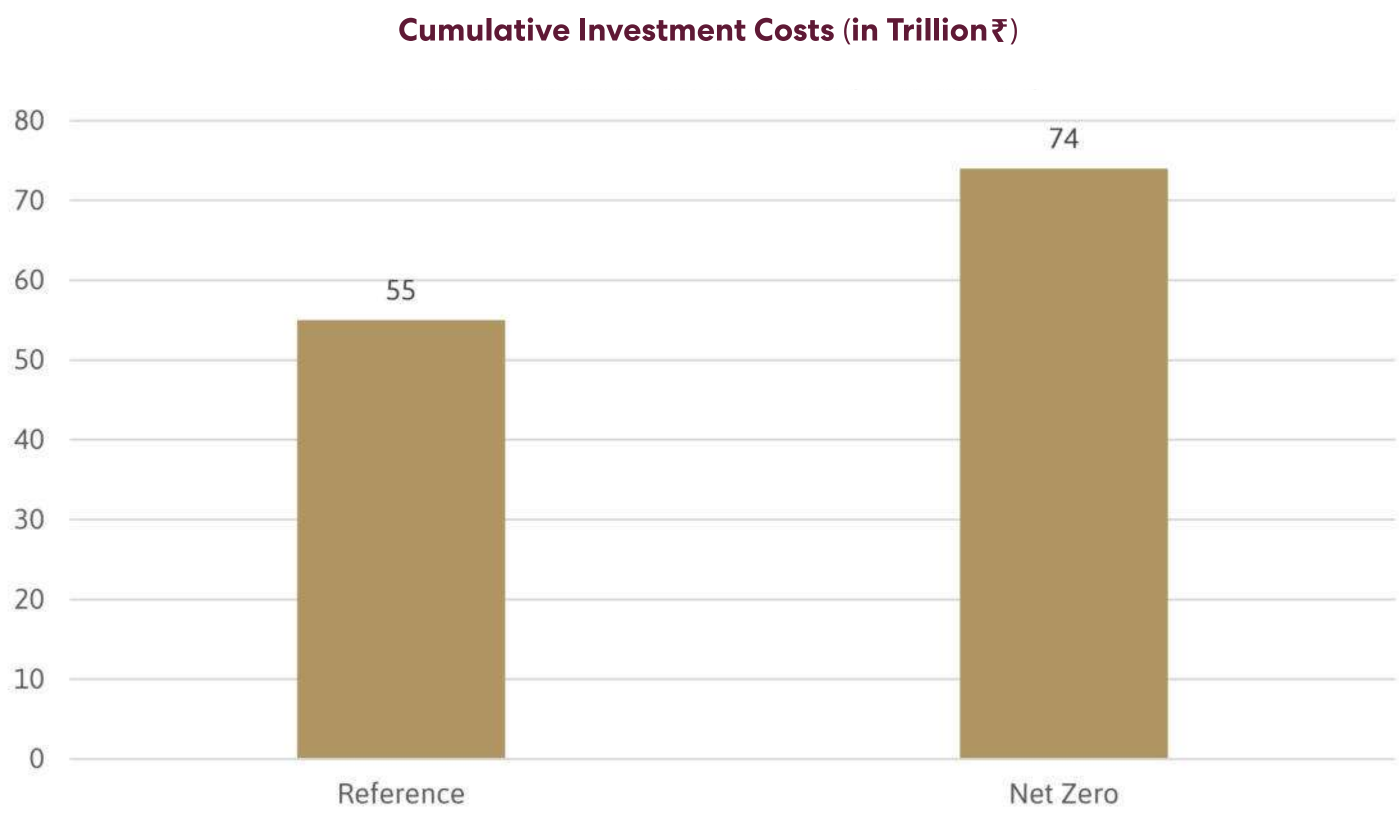


Figure 6-10 shows the cumulative investment in the power sector from 2020-2070. The investment number only includes the cost of new installations and excludes storage and transmission and distribution costs.

For the reference scenario, the total investment is INR 55 lakh crore (USD 65 billion[23]) while for the NZ scenario, this is 35 per cent higher at 74 lakh cr (USD ~ 88 billion). See section 10.2.2 for assumptions used in the calculation.

***Figure 6-10 Cumulative Investment Cost** (**in INR lakh crores**)*

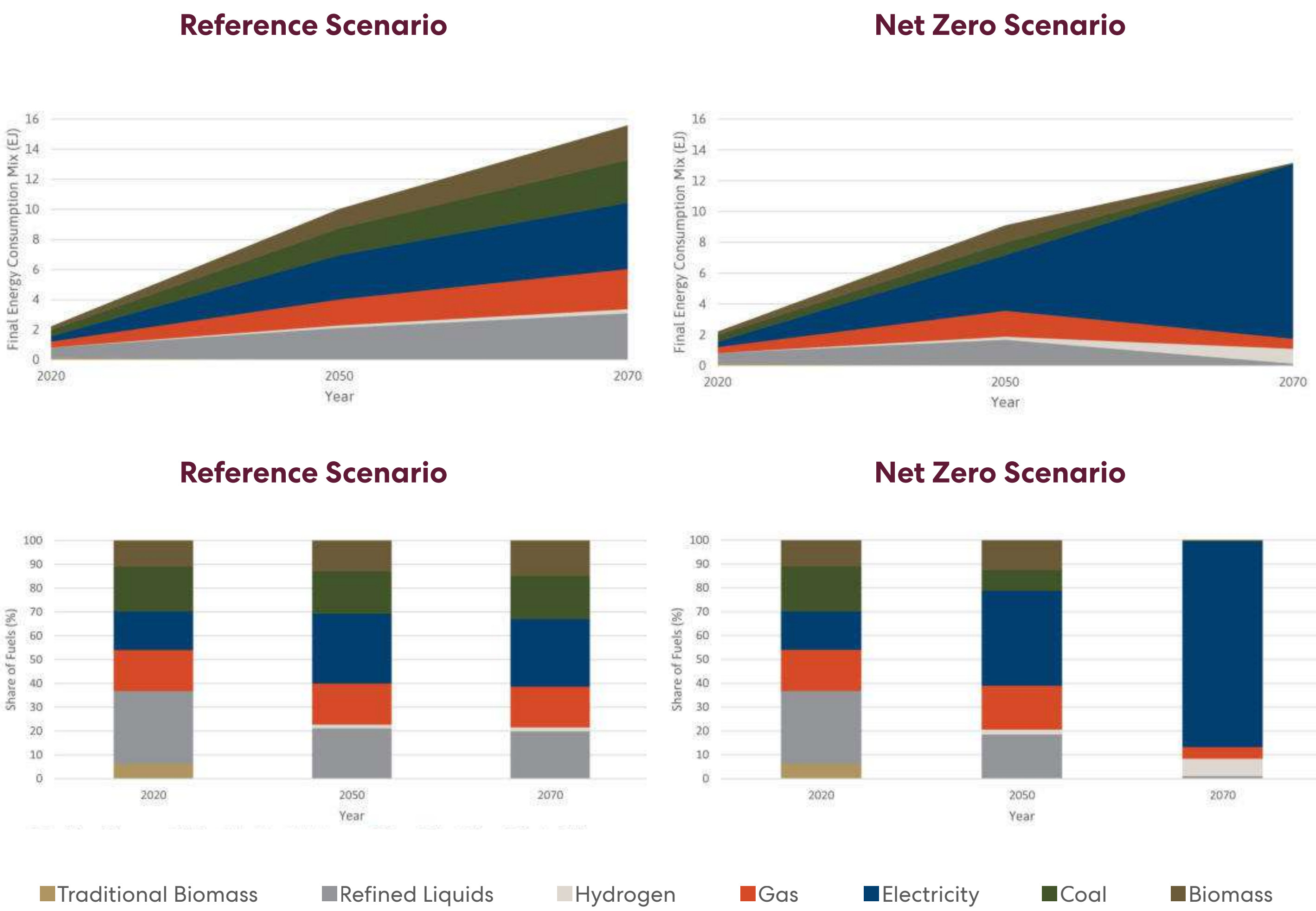



[23] Using conversion factor of INR 84 = 1 USD as of November 2024

## 6.1.6 Energy Demand:

The total final energy demand represents the combined energy demand across all sectors. In 2020, the total energy demand was 2.2 EJ, with industry occupying the largest share at 68%, followed by Buildings (15%), Transport (14%), and Agriculture (3%). In terms of fuel, the share of refined liquids was the highest (30%), followed by coal (19%), gas (17%), and electricity (16%) (Figure 6-11). In the reference scenario, in 2070, the total final energy demand increases 7 times, from 2.2 in 2020 to 15.5 EJ in 2070. Industry continues to dominate the share of final energy at 72%. In the NZ scenario, however, owing to large scale electrification of the end-use sectors (which is more energy efficient), the energy demand is 15% lower at 13.1 EJ. The share of electricity increased from 16% in 2020 to 86% in 2070, with the remaining shares from hydrogen and refined liquids.

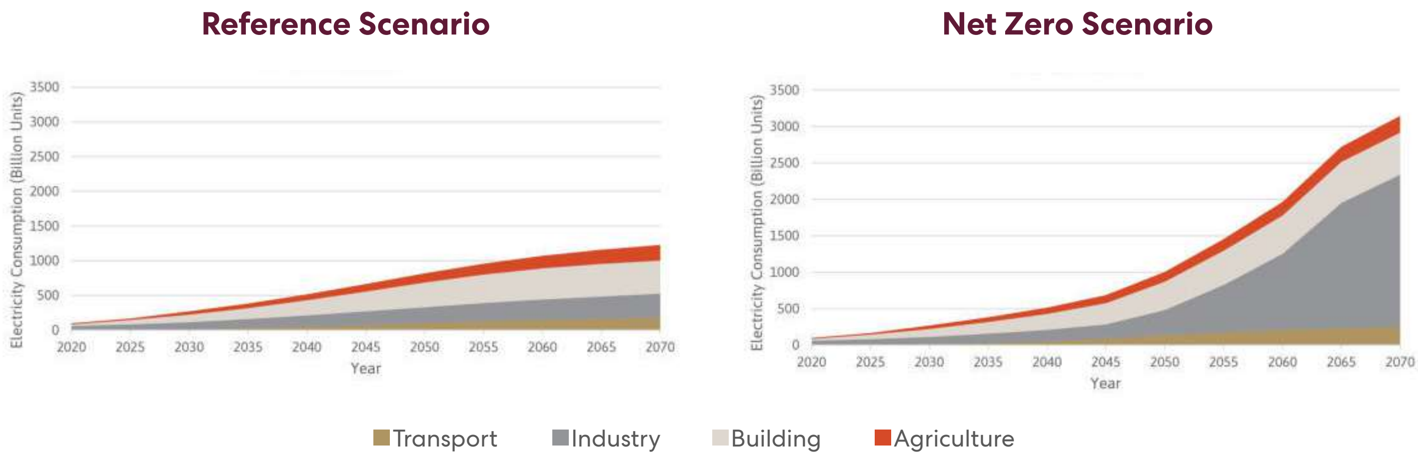
***Figure 6-11 Final Energy Demand (EJ) GCAM***




### 6.1.6.1 Electricity Demand:

Electricity demand is particularly important within the context of net-zero transition, as it is one of the principal routes of decarbonisation among the end-use sectors. This, in turn, also challenges electricity generation and grid management, as most of the additional generation is met through intermittent solar and wind and energy storage systems. Gujarat's per capita electricity consumption in FY 2021-22 was 2378 kWh, compared to the national average of 1181 kWh (C-NET, 2023).

*Figure 6-12 Electricity demand from different end-use sectors*




In 2020, around 64% of the electricity demand was from the industry sector, followed by agriculture and building at around 18% each (Figure 6-12). In the reference scenario, the electricity demand climbs from 99.6 billion units (BU) in 2020 to 272 BU in 2030 – at a CAGR of 10.6%. In comparison, C-NET's demand projections for Gujarat in the same period correspond to a CAGR of about 5.3%, CEA's 20th Electricity Power Survey estimates a CAGR of 7.1%, and Resource Adequacy Plan a CAGR of 5.3% (Table 6-3). The higher growth rate of electricity in this study is due to higher GDP growth rates which are in line with Gujarat's ambition to become a $500 billion economy by 2026-27 and $3.5 trillion by 2047 and possibly from higher autonomous electrification assumed in the transport sector.

*Table 6-3 Comparison of power demand growth rates across multiple studies*

| Study | Time period | CAGR Growth (in %) | Historic growth rate (FY16-FY20)[24] |
|---|---|---|---|
| C-NET (2023)[24] | FY20-FY30 | 5.30% | 4.40% |
| CEA, 20th EPS | FY21-FY31 | 7.10% [25] | 4.40% |
| Resource Adequacy Plan[26] | FY24-FY32 | 5.3% | 4.40% |
| Strategy for GJ govt to enable India become $5 trillion economy[27] | FY22-FY27 | 7.4% | 4.40% |
| **Present study** | 2020-2030 | 10.6% | 4.40% |

[24] C-NET (2023)

[25] CEA (2022)

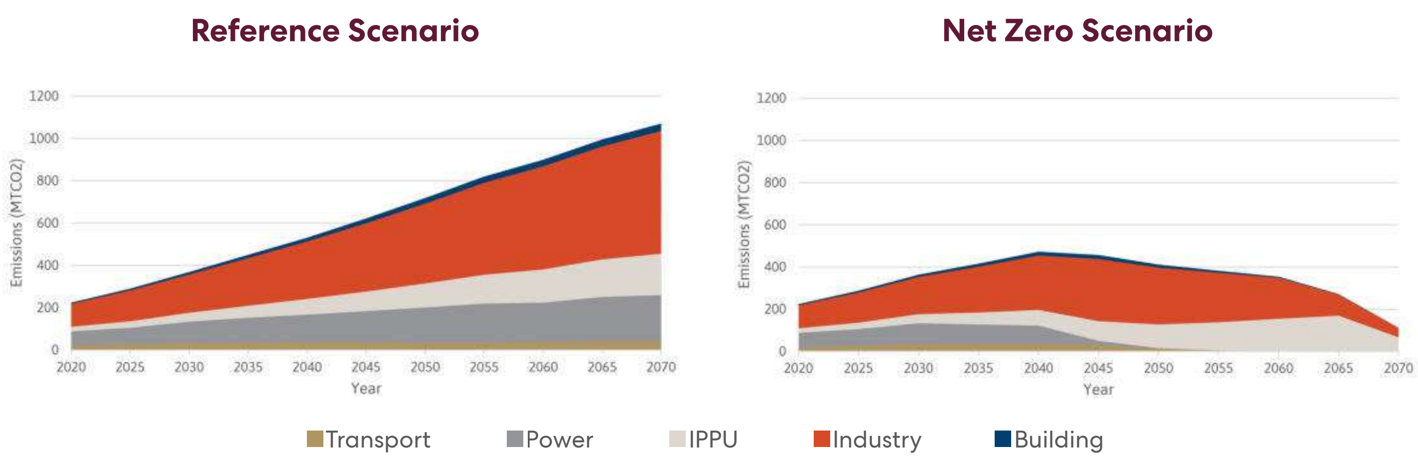
[26] Task Force Committee (2022)

In the reference scenario, between 2020 and 2070, total electricity demand increases ~ 10 times, while in the NZ scenario, it increases by 25 times, particularly beyond 2050 when the industrial sector undergoes significant electrification. By 2070, the electricity demand is almost 3000 BU (Figure 6-12). Until 2050, Gujarat is a net-exporter of electricity, however, beyond 2055, Gujarat becomes a net-importer of electricity, as the industry sector gets significantly electrified.

### 6.1.7 $CO_2$ Emissions:

In 2020, the total energy sector emissions (including IPPU) amounted to 225 $MtCO_2$, with the industry sector accounting for 48%, power for 27%, IPPU 10%, followed by transport (6%) and buildings (2%). In the reference scenario, the total emissions increased by 4.8 times to 1069 $MtCO_2$ in 2070, with the industry still contributing a significant share (54%).

***Figure 6-13 a) Overall $CO_2$ emissions***

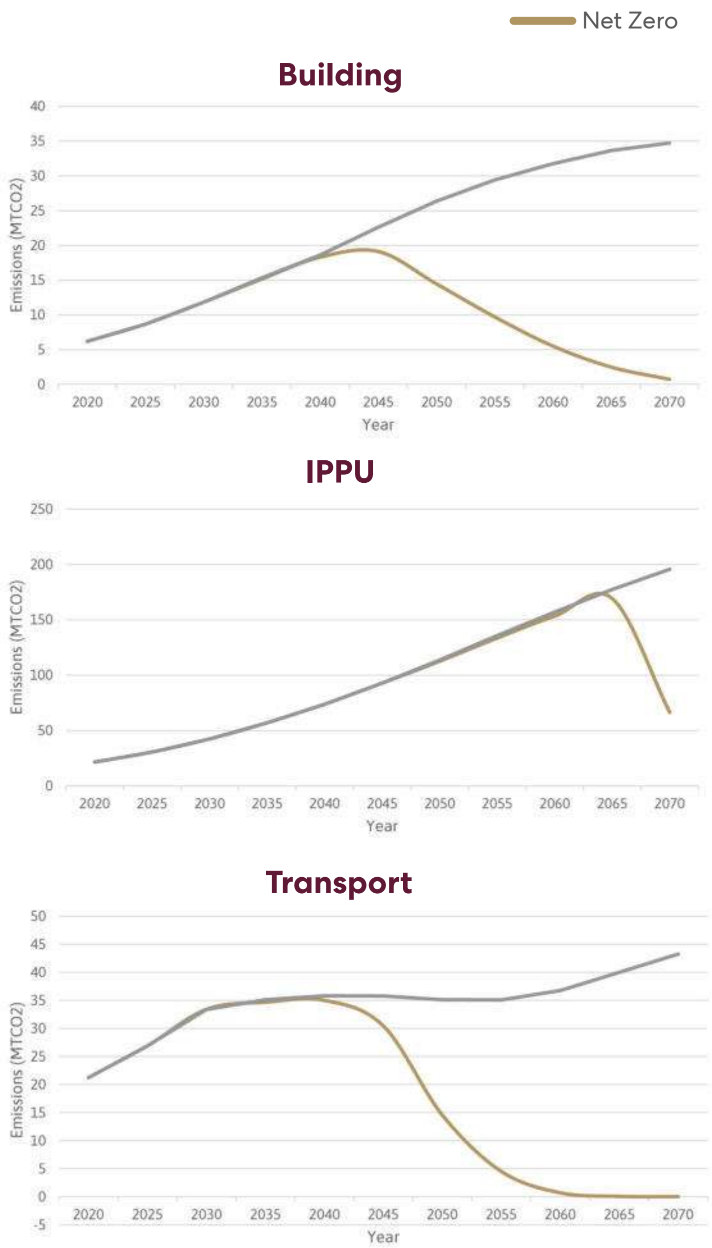



In both the reference and NZ scenarios, emissions increase until 2040, despite policies encouraging renewable energy deployment, energy efficiency in industry as well as other end-use sectors, and higher penetration of electric vehicles. However, because the NZ scenario has additional policy measures before 2040, namely no new coal plant addition beyond 2030 and accelerated energy efficiency improvements in the industry sector, the 2040 emissions are 12% lower (531 vs 472 $MtCO_2$) (See Figure 6-13 for the break-up of emissions by sector). Beyond 2040, in the absence of dedicated emission reduction policies, overall emissions keep on increasing.

In comparison, emissions in the NZ scenario drop steeply as the power sector becomes completely decarbonised by 2050, the transport sector by 2060, and buildings by 2070 (Figure 6-13). Total residual emissions of 112 $MtCO_2$ exist in 2070 – with 66 $MtCO_2$ from process emissions[27] (mainly from limestone in cement production) and 45 $MtCO_2$ from industrial energy use will have to be compensated by sequestration in the land-use sector. Other technology options like Carbon Capture Storage (CCS) have been explored in this study.

[27] Process emissions refer to greenhouse gases (GHGs) released during industrial processes or chemical reactions that are integral to the production of a material, product, or service, rather than from energy combustion

***Figure 6-13 b) $CO_2$ emissions by sector***



### 6.1.8 Net Zero scenario with delayed coal policies and CCS availability:

Net Zero scenario with delayed coal policies and CCS availability. The Conventional NZ scenario assumes, among other factors, that CCS technology is unavailable in the power sector, no new coal-fired power plants are built beyond 2030, and freight transport is predominantly reliant on trucks, followed by rail, with minor contributions from aviation and shipping (the latter assumption is consistent across both the NZ and Reference scenarios).

To explore variations in key outcomes under different assumptions, model runs were conducted under the following conditions: (i) CCS technology is available for coal and gas power generation, with costs (or markup) approximately 50% higher than conventional technologies; (ii) no new unabated coal or gas plants are built after 2035; and (iii) a significant policy push for inland shipping redirects a portion of freight transport from trucks and rail to waterways.

The results are presented for a set of important indicators across the two scenarios: i) Electricity generation by technology, ii) Stranded assets, and iii) Final energy in the transport sector.

Figure 6-14(a) illustrates the share of key technologies and Figure 6-14(b) shows the total coal generation in the Conventional NZ and NZ-CCS scenarios. The following observations can be made:

- Coal Generation: By 2035, the NZ-CCS scenario exhibits a higher share of coal generation (21%) compared to the NZ scenario (16%), as new coal plants are permitted in the NZ-CCS scenario until 2035, whereas no new coal plants are allowed in the NZ scenario beyond 2030 (as shown in Figure 6-14 a). Since total electricity generation is comparable in both scenarios, this results in a lower near-term share of solar, wind, and nuclear energy in the NZ-CCS scenario.

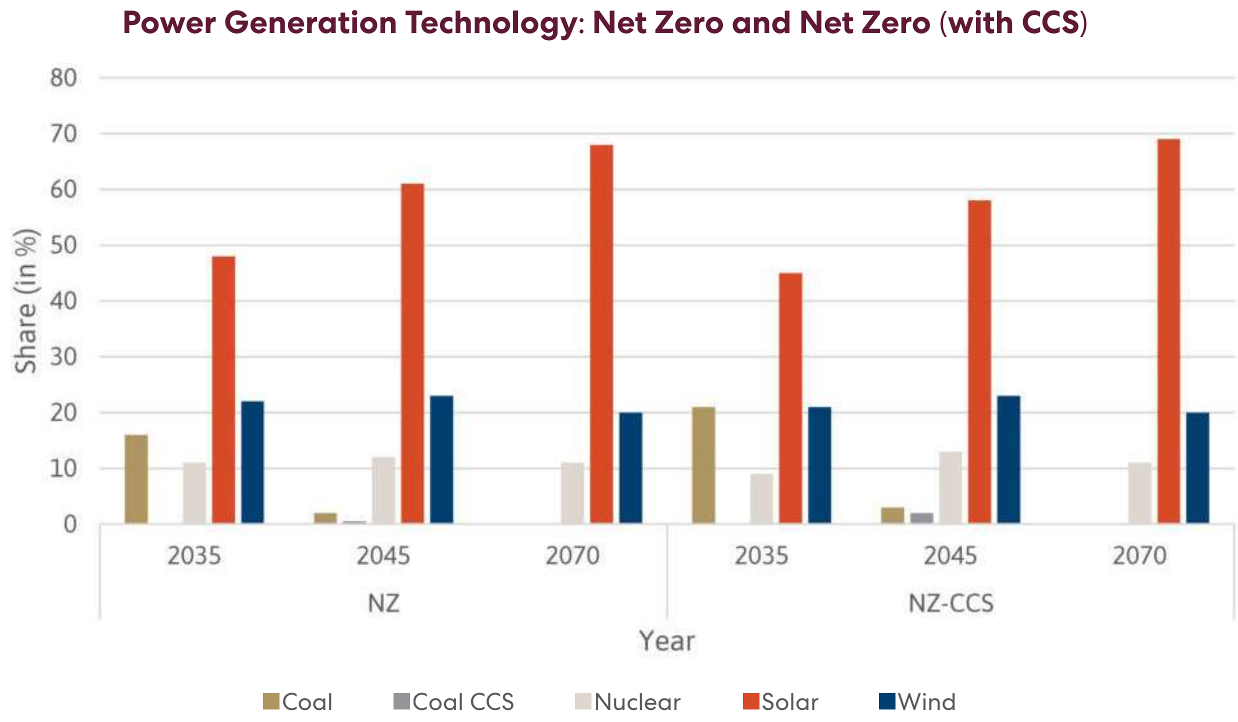
- Emissions: In both scenarios, emissions peak in 2040 and decline significantly thereafter due to a high carbon price. In the NZ-CC, by 2045, carbon capture and storage (CCS) begins to contribute to the electricity mix, albeit with a modest share (~2%). This limited adoption is primarily due to the lower levelized cost of electricity (LCOE) for solar and wind compared to coal CCS.

- Long-Term Convergence: In the longer term, the results between the two scenarios converge. CCS plays a negligible role in the power sector, underscoring its limited competitiveness against cheaper renewable technologies.

It is important to note that the model does not account for the retrofitting of existing power plants; competition occurs exclusively for new capacity additions. However, existing assets may retire prematurely if operational costs exceed revenue over an extended period. Consequently, while coal with CCS appears in the electricity mix in 2035, it is phased out by 2070—before reaching its assumed technical lifespan of 40 years—due to the availability of lower-cost solar and wind generation. In both scenarios, the power sector achieves complete decarbonization by 2050 (Figure 6-14 (b)).

Stranded assets are defined as the total generation or capacity that becomes under-utilized after deployment due to the emergence of cheaper alternative technologies. Comparing stranded generation between the two scenarios, the NZ-CCS scenario exhibits 33% higher stranded generation than the NZ scenario (Figure 6-15). This difference arises from the NZ-CCS scenario allowing the construction of unabated coal plants until 2035. Assuming a capacity factor of 0.6 and averaging over 15 years (2020–2035), the annual average stranded capacity is calculated to be 6 GW/year in the NZ-CCS scenario compared to 4.6 GW/year in the NZ scenario. For information on how stranded generation is calculated, refer to Section 10.1.5.

***Figure 6-14 a) Power generation technology in Net Zero and Net Zero (with CCS) b) Total coal-based generation in the two scenarios***



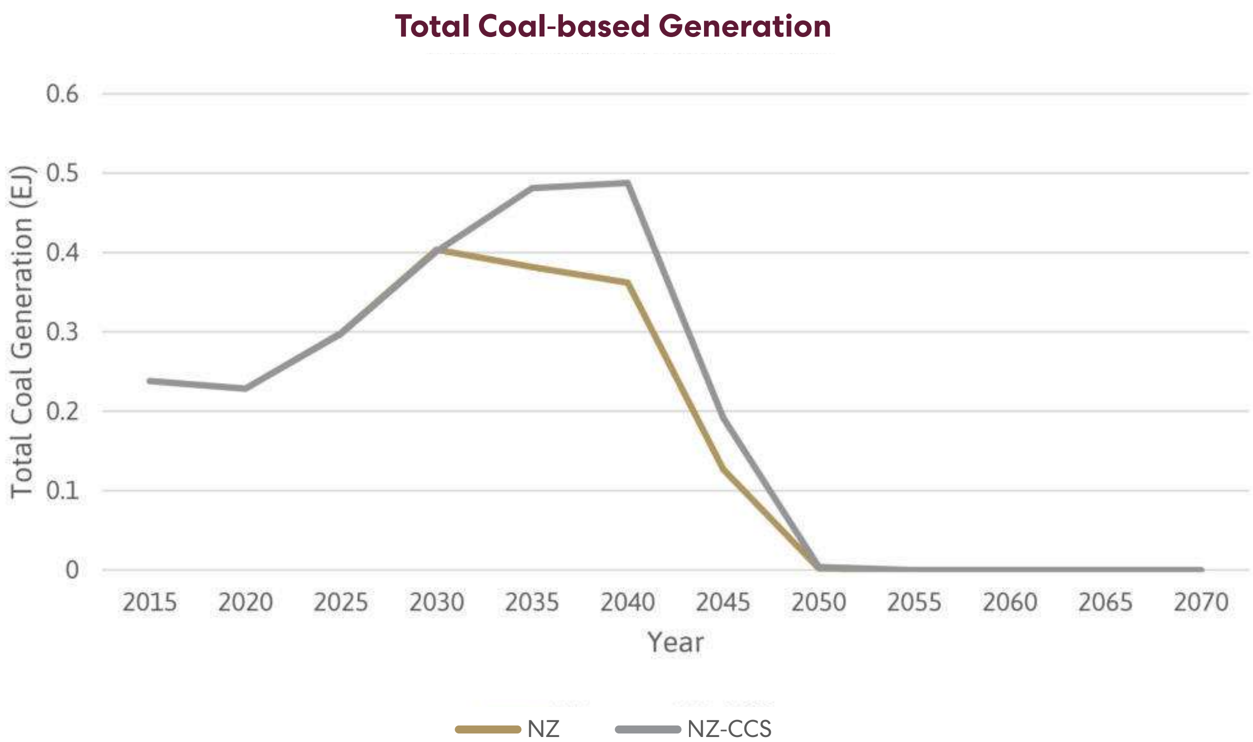
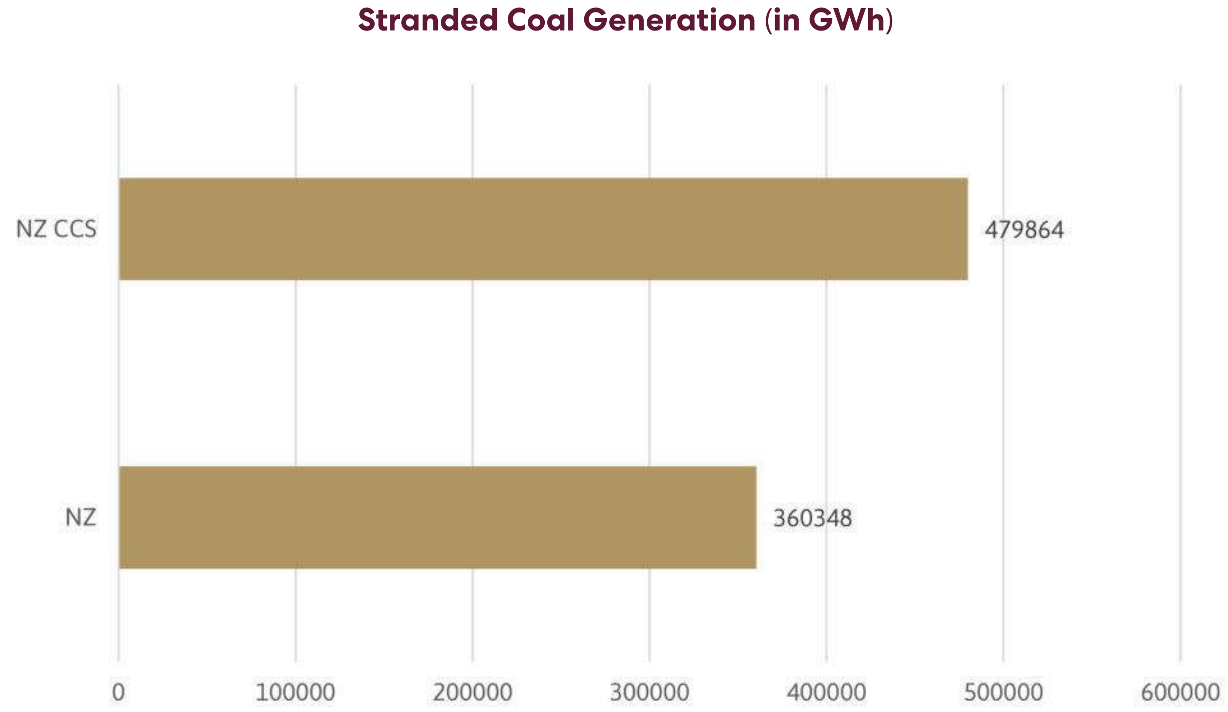
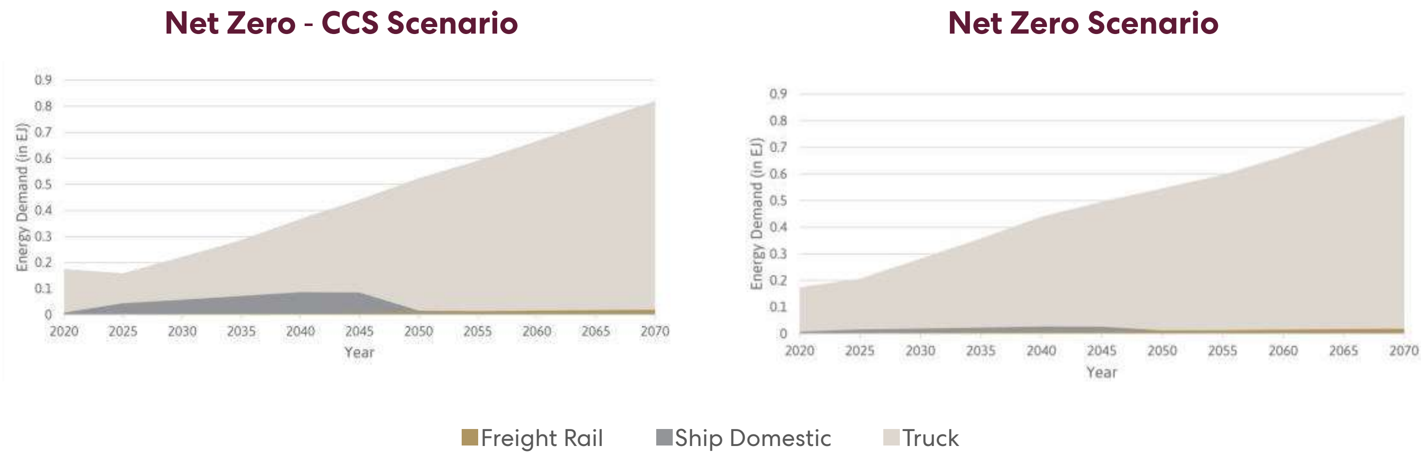



*Figure 6-15 Stranded Coal Generation*




The third main change in the NZ-CCS scenario is that there is a stronger policy push towards inland shipping. This results in a greater share of freight movement from shipping, mainly replacing trucks (Figure 6-16). Since ships have lower cost per tonne-km and lower emissions per tonne-km, this leads to lower emissions in the time period 2020-2045 from freight. After 2045, the share of shipping decreases as alternatives to fossil-powered ships are more expensive than electric trucks. Thus, over the longer term, trucks continue to be the main carrier for freight.

*Figure 6-16 Freight Energy Demand – Net Zero and Net Zero CCS Scenario*



## 6.2 Structural Shift Net Zero Scenario (LEAP)

The results will be based on the analysis done using the LEAP model for Gujarat and cover the Reference and the Net Zero Structural Shift Scenario or Net Zero SS Scenario.

### 6.2.1: Industry Sector:

Energy consumption contributes to over 73% of the emissions from the industry sector (2020 emissions from the LEAP model), with the rest arising from industrial processes and product use (covered under IPPU). In the LEAP model, the industry sectors are further divided into five subsectors, and the growth in energy from these sectors is either based on historical trends or economic growth (See appendix 10.2.1 for the methodology). The industry sector is currently reliant on fossil fuels and is considered to remain reliant on fossil fuels in the reference scenario. Transitioning away from carbon-based energy sources is a requirement of any net-zero emission pathway. The alternative energy sources for the net-zero SS scenario are renewable electricity, hydrogen, biomass, and biogas. Renewable electricity is taken at par with fossil fuel-based electricity in terms of cost and is further discussed in the power sector. Green hydrogen is not economical but is projected to become commercially viable by 2050 in the ambitious scenarios (GEDA, 2024; Government of Gujarat, 2024b).

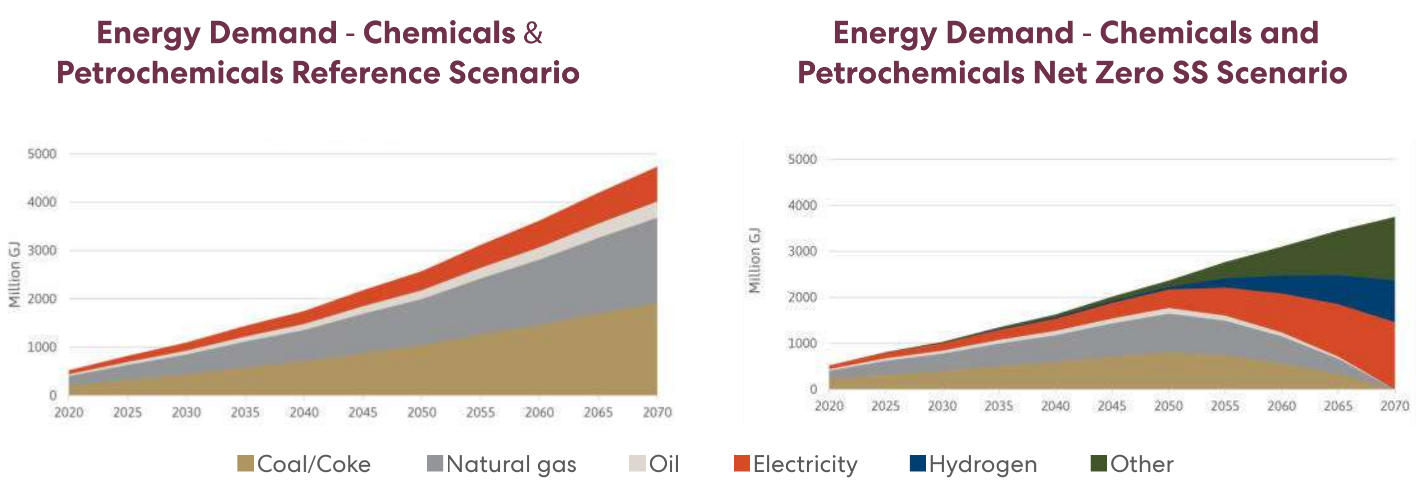
#### 6.2.1.1 Chemicals and petrochemicals:

The manufacturing of chemicals and chemical products contributed 43.5%of the total industrial sector energy consumption in 2020, projected to increase to 47.8% by 2070, which is in line with growth in the manufacturing sector. In the reference scenario, most of this energy demand will bemet by fossil fuels (coal and gas). The energy consumption in the sector is projected to grow 9 times from 519 million GJ in 2020 to 4734 million GJ in 2070 in the reference scenario (Figure 6-17). In the net-zero SS scenario, the demand decreases by 21% to 3748 million GJ due to energy efficiency improvements and a relatively lower share (5% lower) of manufacturing than in the reference scenario.

In terms of fuels, a transition to electricity-powered crackers and a complete phase-out of fossil fuel by 2070 is assumed to achieve net zero emissions. India will require at least 14 cracker units by 2040 to meet its petrochemical demand (CSTEP, 2023), and hence, it is possible to introduce electric crackers without stranding existing capital assets by ensuring that new units are mandatorily electrical. 50% of the available cracking capacity by 2070 is assumed to be electrically powered. 25% is assumed to be powered through hydrogen, 25% using other fuels (biomass and biogas) (Figure 6-17). Natural gas-fuelled cracking units can be operated using green hydrogen and biogas by modifying some components.

As the sector produces multiple final products within Gujarat (such as fertilizers, plastics, synthetic rubber, pesticides, paints, soaps, etc.), having a common approach to mitigate the process and product use emissions completely is not feasible. Ammonia and ethylene oxide production, which are significant processes in the chemical industry, result in flue gas streams with high $CO_2$ concentrations (CII, 2022). This stream can be tapped into for a carbon capture and utilization project. The captured $CO_2$ can be used to manufacture synthetic mineral aggregates, consumer chemicals and fuels, various polymers, etc (Krungsri Research, 2024).

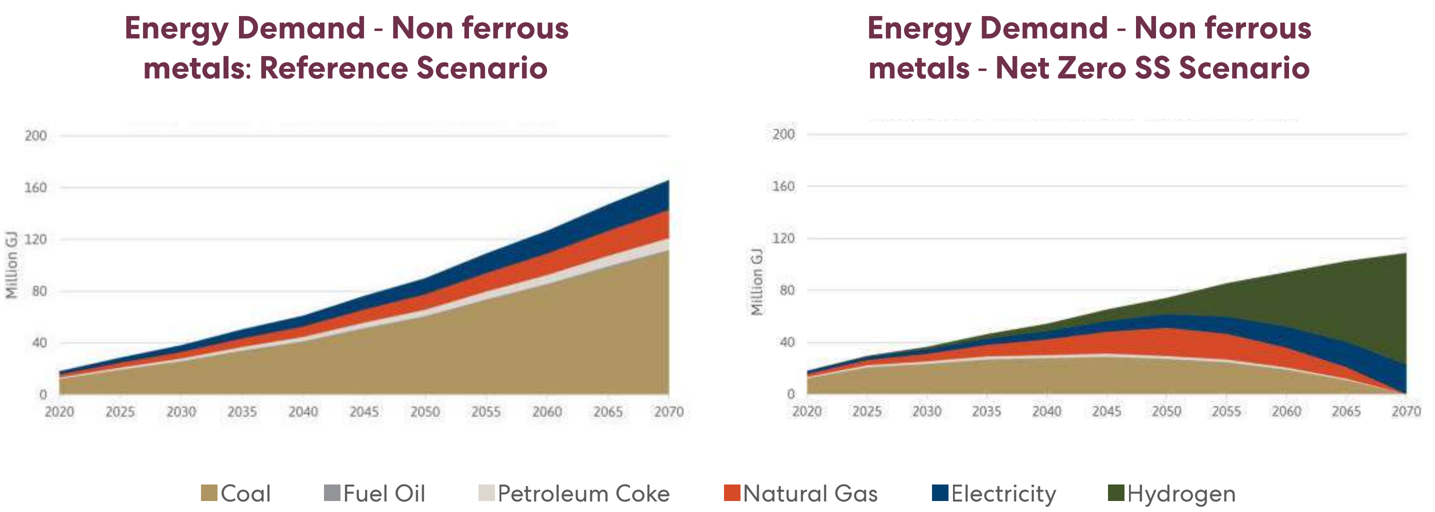
***Figure 6-17 Energy demand – Chemicals and Petrochemicals (LEAP)***



**6.2.1.2 Non-ferrous metals**:

Gujarat has no production facility for aluminium, copper and zinc and therefore non-ferrous metals is a relatively small industry sub-sector. In the reference scenario, the energy demand is projected to rise 9 times from 18.2 million GJ in 2020 to 166 million GJ (Figure 6-18) in line with the growth in the manufacturing sector (See Section 4.3 for growth assumptions and Appendix 10.2.1 for the methodology for energy demand projections). In the reference scenario, most of this energy demand will be met by fossil fuels (coal and gas). In the net-zero SS scenario, energy demand in 2070 can be reduced by 35% to 109 million GJ through efficiency improvements and structural shifts in the economy due to which the share of manufacturing will be 5% lower than reference scenario. Since in the reference a lot of energy demand is met by coal and natural gas in future these are expected to be substituted with green hydrogen. Accordingly, by 2070, 75% of the heating is provided by green hydrogen assuming high temperature heat requirement. The rest is assumed to come from renewable electricity.

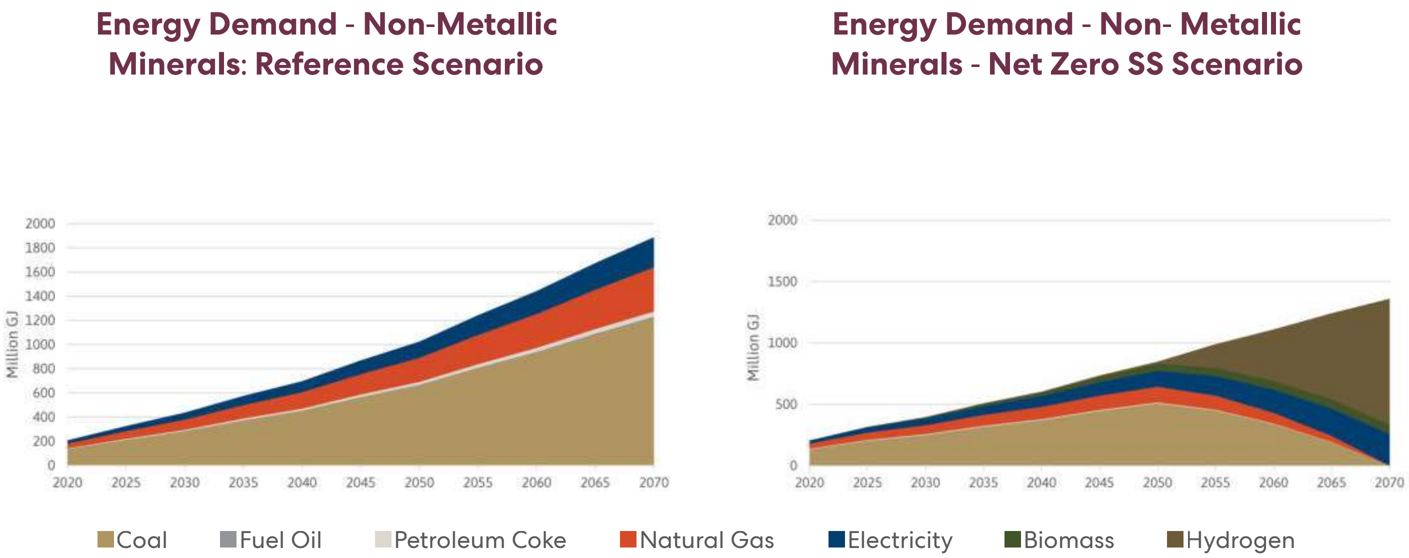
***Figure 6-18 Energy demand – Non-ferrous metals** (**LEAP**)*




**6.2.1.3 Non-metallic minerals**:

In the reference scenario, the energy demand is projected to rise 9 times from 207 million GJ in 2020 to 1890 million GJ in line with the growth of the manufacturing sector (See Section 4.3 for growth assumptions and Appendix 10.2.1 for the methodology for energy demand projections). In the reference scenario, most of this energy demand is met by coal and natural gas. In the net-zero scenario, energy efficiency improvements and structural shifts in the economy bring the energy demand down by 28% to 1360 million GJ (Figure 6-19). Non-metallic minerals are only slightly amenable to induction heating. This limits the use of electricity and therefore share of electricity heating is assumed only 25% in 2070. Hydrogen is assumed to cater to the 70% share of the heating and remaining 5% is considered to be met by sustainable biomass (crop waste, oil cakes, etc) Systems that use natural gas can be modified to use hydrogen with some component modifications (Martin et al., 2024).

***Figure 6-19 Energy demand – Non-metallic minerals (LEAP)***




**6.2.1.4 Mining and Quarrying**:

Mining and Quarrying is a relatively small activity in Gujarat, with an energy consumption of 1.5 million GJ in 2020, i.e., 0.1% of industry sector energy consumption. Hence, no mitigation analysis was done for the same in this report.

**6.2.1.5 Iron and Steel**:

Gujarat's crude steel production in 2020-21 stood at 8.4 million tonnes[28] and accounted for around 8% of national steel output. Crude steel output grew at a CAGR of 3.12% between 1998 and 2018. In the reference scenario, steel production is projected to grow at the same rate, leading to an increase in steel output by 4.7 times, reaching 39.9 million tonnes by 2070.

The steel-making process depends on whether the input raw material is iron ore or scrap steel. If the input raw material is iron ore, a reduction of iron ore to iron must be done in a blast furnace or through a direct reduction process. However, these processes are energy intensive (Options 1-2, Table 6-4) and use fossil fuels such as coke, coal, and natural gas; hence, $CO_2$ emissions are also high (Table 6-5). $CO_2$ emissions can be mitigated by using carbon capture and storage (CCS) technologies. However, CCS has an energy penalty, i.e., results in higher energy intensity due to additional processes such as $CO_2$ separation, transportation, and storage. Another alternative to mitigate $CO_2$ emissions is to use green hydrogen (Option 3). In contrast, if the input raw material is scrap steel, it can be directly melted in an Electric Arc furnace (Option 4). The energy intensity is much lower, and there are no $CO_2$ emissions at the point of use.

[28] Press Release: Press Information Bureau (pib.gov.in)

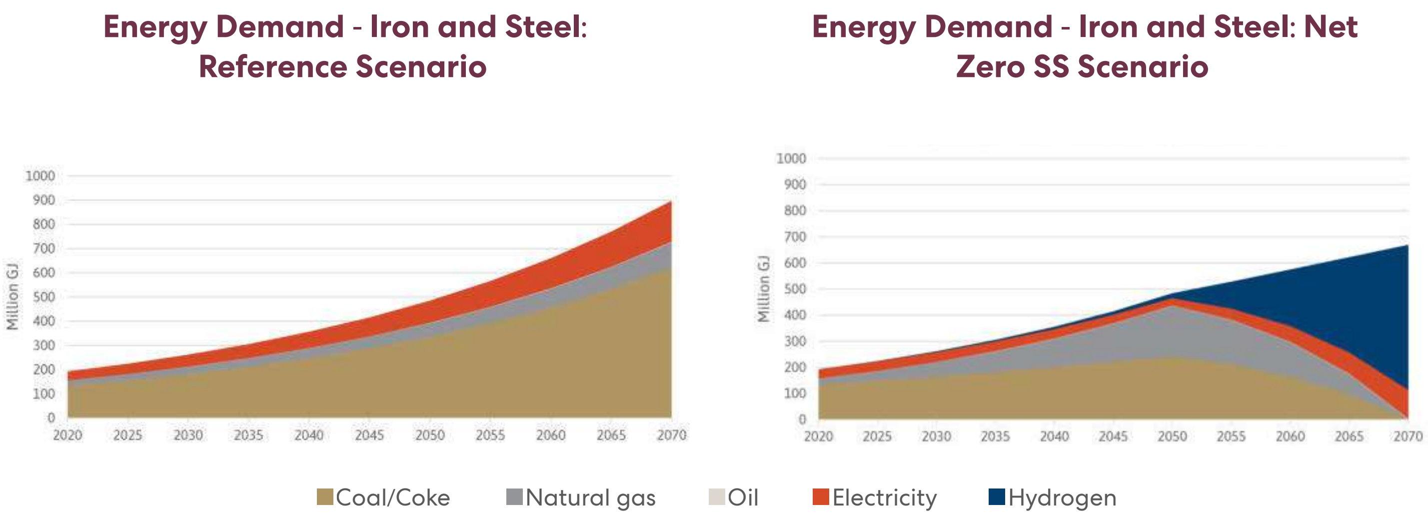
***Table 6-4 Technologies for Steel Production*** (*)

| | Technology | Fuel | Energy Intensity (GJ/t) | $CO_2$ Intensity Scope 1'($tCO_2$/t) |
|---|---|---|---|---|
| 1 | **Blast Furnace - Basic Oxygen Furnace (BOF)** | Coal & Coke | 21.40 | 2.2 |
| 2 | **Natural Gas Direct Reduced Iron - Electric Arc Furnace (DRI-EAF)** | Natural Gas & Electricity | 17.10 | 0.6 |
| 3 | **H2 DRI - EAF** | H2 & Electricity | 17.10 | 0.1 |
| 4 | **EAF Scrap** | Electricity | 8.37 | 0 |

* **Note**: (*) The Energy Intensity and $CO_2$ Intensity values reflect the current best practice based on IEEFA [29]

For the base year, the average energy intensity of steelmaking was 22.5 GJ/ton for the different steel making processes in Gujarat, much higher than the best practice values for different technologies (Table 6-4). This is consistent with other findings (Dhar et al., 2020; Mallett & Pal, 2022) which show the energy efficiency of steel plants in India is much lower than best practice plants and high reliance on coal for DRI instead of natural gas (Mallett & Pal, 2022). In the reference scenario, continued reliance on coal and natural gas for iron ore reduction and electricity for the EAF is assumed. Consequently, energy demand is projected to increase 4.66 times, from 192 million GJ in 2020 to 897 million GJ in 2070, with coal and gas combined providing the largest share of energy (Figure 6-20).

***Figure 6-20 Energy demand – Steel*** (***LEAP***)




[29] Institute for Energy Economics and Financial Analysis https://ieefa.org/resources/facts-about-steelmaking-steelmakers-seeking-green-steel

In the SS Scenario, it is assumed that the share of scrap generated will increase over time, allowing for greater utilization of EAF scrap processes. The BF-BOF technology will be phased down, and DRI-EAF will be used to reduce iron ore. This technology transition, combined with the achievement of industry best practices, will result in the overall energy intensity of steelmaking declining from 22.0 GJ/ton in 2018 to 15.35 GJ/ton in 2070 (Table 6-5). However, fuel switching will also be needed to reduce the $CO_2$ emissions from 1.56 $tCO_2$/ton of steel in 2020 to near zero by 2070. In the DRI-EAF process, natural gas will need to be substituted by green H2.

***Table 6-5 Technologies Assumption for Steel Production Net Zero SS Scenario** (**LEAP**)*

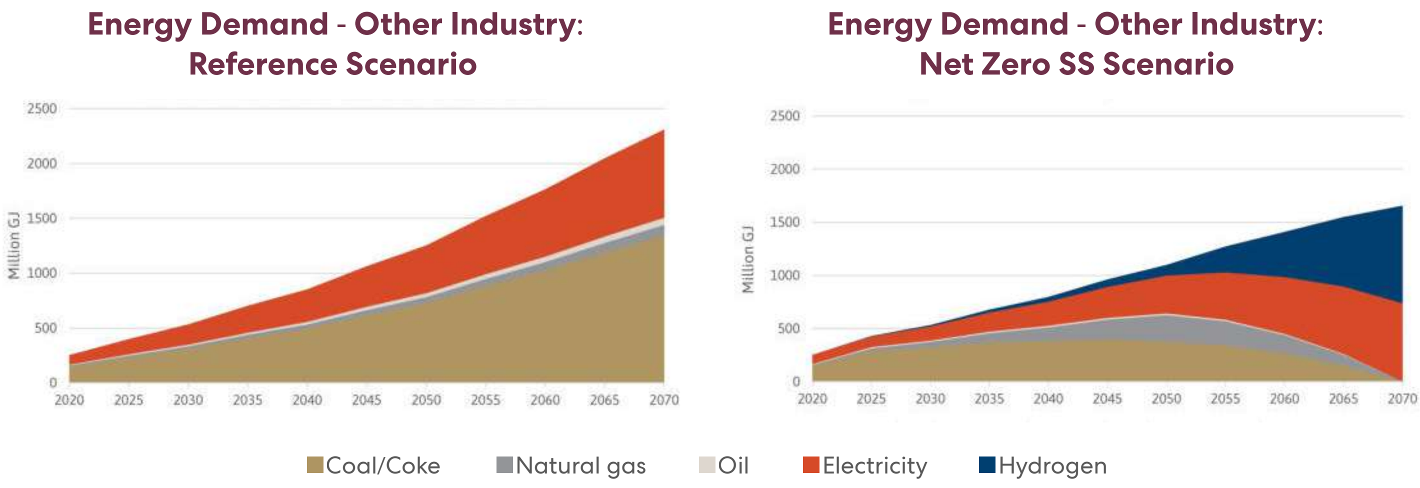
| Technology | 2050 | 2070 |
|---|---|---|
| BF-BOF | 40% | 0 |
| NG DRI-EAF | 45% | |
| H2 DRI - EAF | 5% | 80% |
| EAF Scrap | 10% | 20% |
| Overall $CO_2$ Intensity | 1.163 | 0.08 |
| Overall Energy Intensity | 17.95 | 15.35 |

**6.2.1.6 Other industry**:

It is a heterogeneous grouping of industries that do not fall under the four large energy-intensive industry categories described separately. In the reference scenario, energy demand is projected to grow 9 times from 254 million GJ in 2020 to 2311 million GJ in 2070 (Figure 6-21) in line with the growth of the manufacturing sector (See Section 4.3 for growth assumptions and Appendix 10.2.1 for the methodology for energy demand projections). In the net-zero SS scenario, energy demand decreases by 28% to 1657 million GJ in 2070 through efficiency improvements and structural shifts in economy.

The main energy-consuming industries in Gujarat within this category are textiles, pharma, and paper, where medium-temperature heat (100-400 C) is used. These processes are quite amenable to electrification. Glass making is currently a small part of this group, where high-temperature heat is needed, which is less amenable to electrification. Textiles, which is currently the largest contributor in the group, is considered a sunset sector. Therefore for 2070, an equal share of electricity and hydrogen is assumed for sector decarbonization.

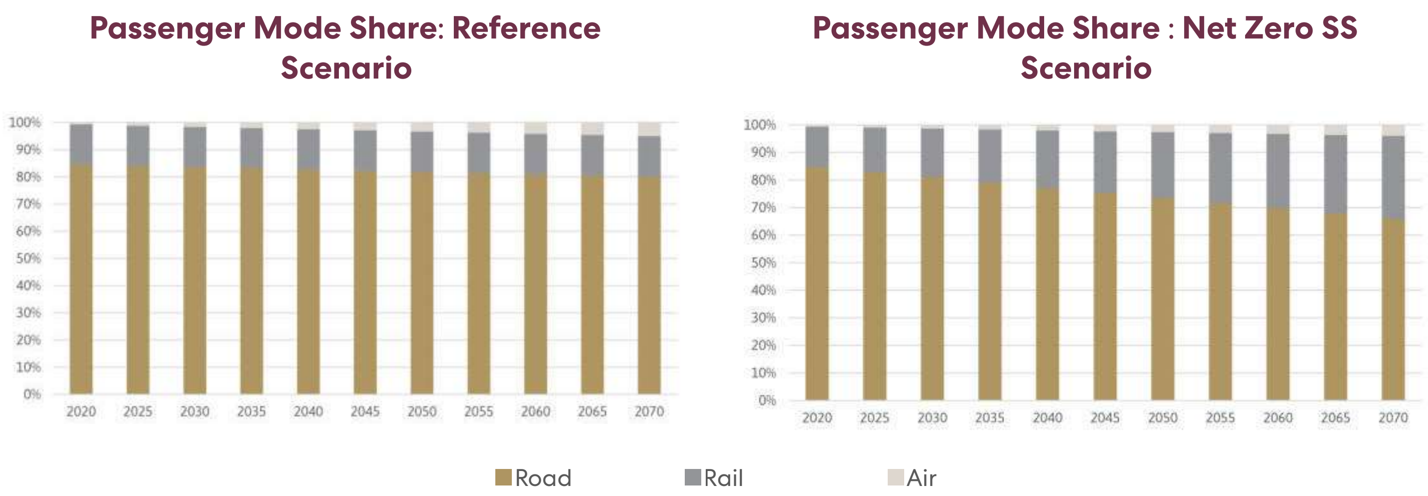
***Figure 6-21 Energy demand – Other Industry** (**LEAP**)*




### 6.2.2. Transport Sector

The overall demand for passenger transportation increases by 3.1 times in 2070 from 2020 (See Appendix 10.2.2) for details on demand estimation) driven by an increase in per capita mobility and population growth. In the Net Zero SS scenario, the passenger transport demand increases by only 2.1 times as the per capita mobility is expected to grow relatively slowly due to various factors such as sustainable city design (which includes design, diversity, and density), which helps reduce trip lengths. The modal mix also has a greater share of rail and, as a result, lower shares of road and air-based transport.

***Figure 6-22 Passenger transport demand** (**LEAP**)*



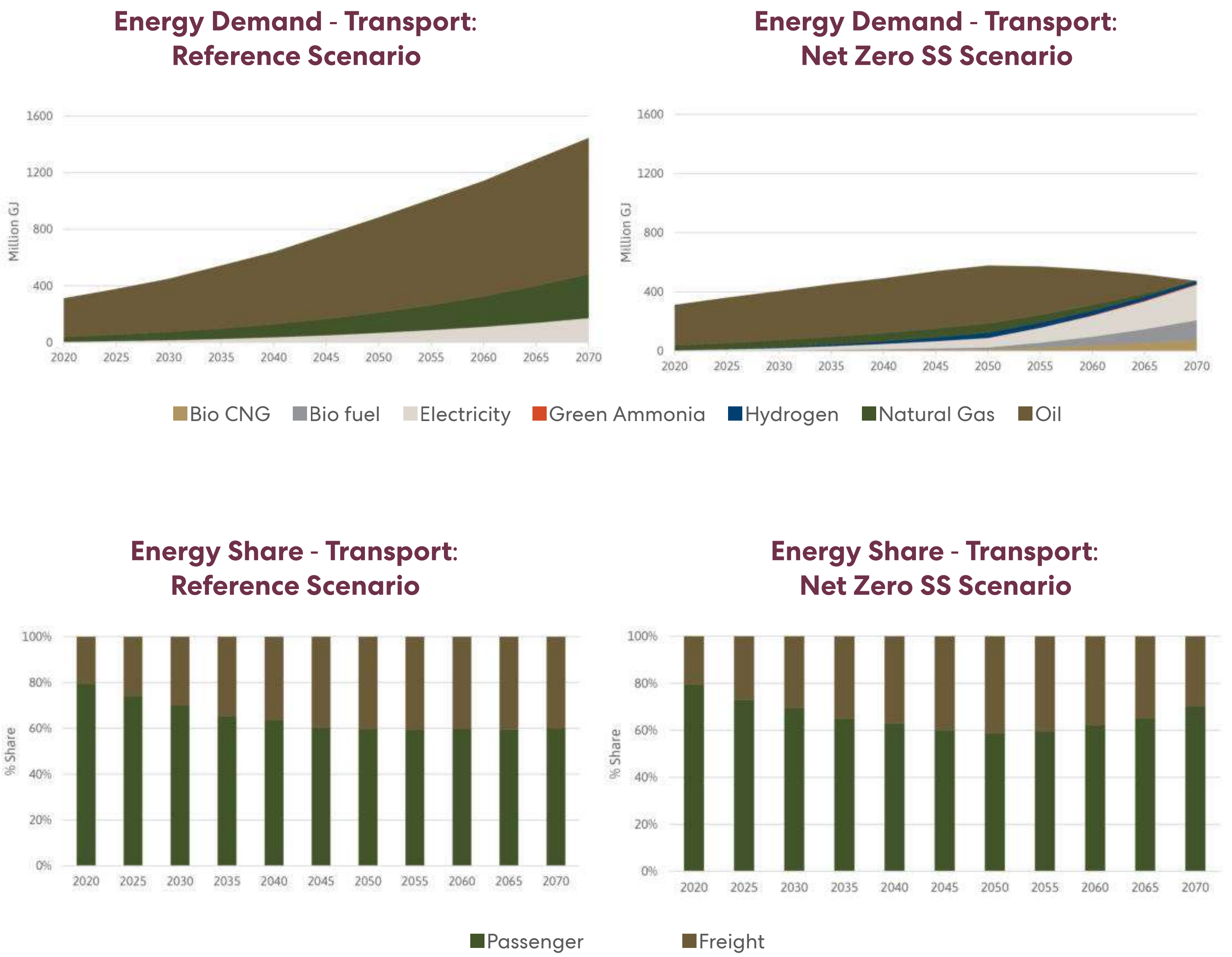
In the reference scenario, freight demand increases by 9.8 times between 2020 and 2070 (See Appendix 10.2.2 for details on demand estimation), driven by rapid growth in manufacturing activities. In the Net Zero SS scenario, however, due to slower growth in the manufacturing sector (See Section 4.3 for growth assumptions), the demand for the transportation of goods and commodities will be lower. As a result, the freight demand will grow by only 8.5 times between 2020 and 2070.

In addition to the lower overall freight demand, the Net Zero SS scenario considers a transformation in how freight is transported. A shift away from the road towards rails and shipping is envisaged. The shift towards rail is quite well formulated and entrenched in Indian policy-making and advocated by the expert community. The National Transport Development Policy Committee aimed for an equal share of rail and road for freight transported on land (NTDPC, 2014) which is also reflected in scenarios for freight transport (Gupta & Dhar, 2022). Gujarat is a coastal state with 41 ports, of which Kandla is a major port. Out of the remaining 40 ports, 11 are intermediate ports, and 29 are minor ports under the control of the Gujarat Maritime Board. Gujarat's minor and intermediate ports handle about 8.5% of national shipping cargo. If railways improve connectivity to the ports, there will be an increase in the share of both rail and shipping. It, however, takes time to change the modal shares, and therefore, instead of a 50% share for rail as envisaged in NTDPC, a 35% share for rail in 2070 is considered in the Net Zero SS scenario. Shipping (including inland waterways) share is expected to increase from 4% in 2020 to 14% in 2070, as the road share comes down to 50% modal share by 2070. In the reference scenario, no changes to the modal shares are assumed. The results are given in Figure 6-23.

***Figure 6-23 Freight transport demand** (**LEAP**)*


The transport sector has historically depended heavily on oil, and in 2020, the share of oil was 88.2%. Indian cities have high levels of air pollution, and to address that, since 2000, CNG has been used in the transport sector in many vehicles, and CNG stations have been established in cities as well as along highways. In 2020, CNG accounted for 10.5% of energy demand, while electric vehicles, particularly three-wheelers, gained momentum, with electricity use in vehicles comprising 1.3% of energy demand. In the reference scenario, these trends are assumed to continue, resulting in an overall increase in energy demand by 4.6 times, from 313 million GJ in 2020 to 1445 million GJ in 2070 (Figure 6-24). In the reference scenario, in 2070, the share of oil will reduce to 66.6%, whereas the share of CNG will increase to 21.5%, and the share of electricity will increase to 11.9%. In the reference scenario, the share of freight in energy will increase and stabilise around 40%, the rest accounting for passenger transport.

***Figure 6-24 Energy demand – Transport (LEAP)***




The Net Zero SS scenario has a different modal structure for passenger and freight (Figures 6-23 and Figures 6-24), strong energy efficiency improvements, and a shift towards EVs and a greater role of alternative fuels (bio CNG, biofuels, green ammonia, and green hydrogen) to eliminate fossil fuel use in transport by 2070 completely. Due to these multiple changes, the overall demand for energy increases slowly and declines from 2050 onwards, and in 2070, it will reach 475 million GJ (only 1.3 times that of 2020; Figure 6-24). The energy mix is completely fossil-free, with electricity meeting 50% of the final energy demand, followed by biofuels and bio-CNG. Green ammonia and hydrogen also take a small share, mainly for use in shipping and heavy trucks. In the Net Zero SS scenario, the modal transitions in freight are more significant, and as a result, the share of freight in energy use, which increases till 2050, starts declining and reaches around 30%, compared to 40% in the reference scenario.

### 6.2.3 Building Sector:

In 2020, buildings contributed a small share of $CO_2$ emissions in Gujarat, accounting for only 2% of the total emissions. Within the LEAP framework, buildings are categorized into households and the commercial and public services sectors. In 2020, $CO_2$ emissions from the buildings sector were 4.2 Mt from households and 0.6 Mt from the commercial and public services sector.

#### 6.2.3.1 Households

Energy consumption in households (Figure 6-25) within LEAP is further divided by urban/rural classification and by end-use (cooking, lighting, cooling, and other). For cooking, the number of households drives energy demand, while for non-cooking end-uses, floor space per household is the driver. In 2018, most household energy consumption (79%) was for cooking, using LPG, PNG, firewood, and kerosene. The share of cooking in household energy consumption is projected to decline to 16% by 2070 in the Reference scenario and 14% in the Net Zero SS Scenario. This shift is partly due to the phase-out of inefficient cooking stoves using firewood and kerosene by 2040, replaced by more efficient LPG and PNG in the reference scenario and electricity in the Net Zero SS Scenario.

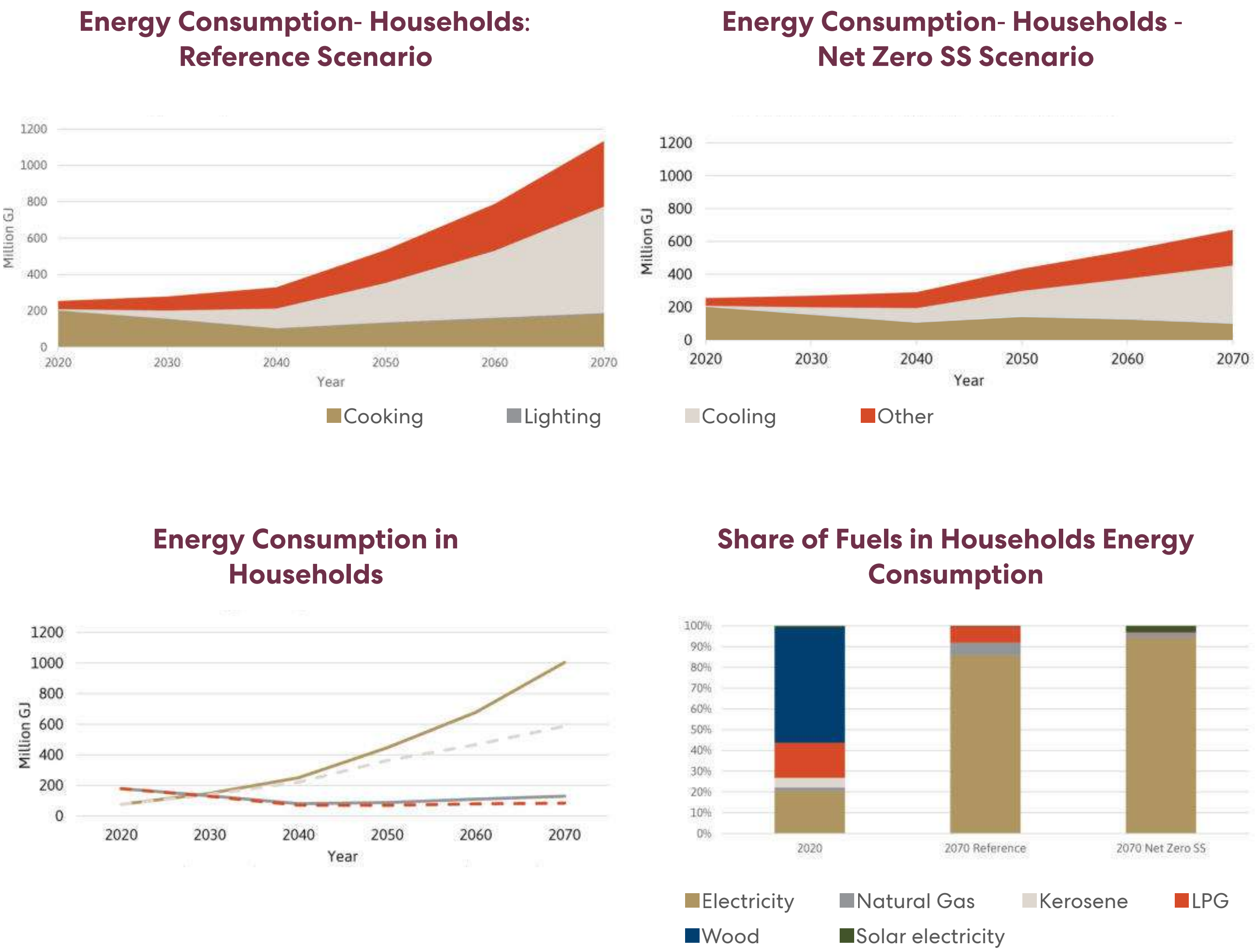
Beyond efficiency improvements from fuel switching, the decline in the share of cooking in household energy consumption is also attributed to significantly higher growth rates in demand by cooling and electric appliances. According to the IEA (2021) study, air-conditioning units are expected to grow faster than any other household appliance up to 2040, becoming the largest single driver of energy demand growth in buildings.

The “Multiple Indicator Survey in India” conducted by NSSO in 2020-2021 (MoSPI, 2023) reported that 1.8% of rural and 18% of urban households in Gujarat owned air conditioners. Among these households, the average number of air conditioners per household was 1 in rural areas and 1.4 in urban areas. It was assumed that by 2070, all households will have air conditioners, with an average of 1.5 units per rural household and 2 units per urban household. Consequently, modelling results show that energy consumption for cooling is projected to rise significantly from 6.2 million GJ in 2020 to 585.8 million GJ in 2070 in the Reference Scenario (CAGR 9.5%) and 354 million GJ in the Net Zero SS Scenario (CAGR 8,4%) (Figure 6-25). The lower energy consumption for cooling in the Net Zero SS Scenario (1,7 times less than the Reference Scenario in 2070) is due to assumed annual energy efficiency improvements of 1% for cooling appliances. This assumption aligns with the India Cooling Action Plan (ICAP) launched in 2019, which aims to reduce cooling energy requirements by 25-40% by 2037-38.

According to National Energy End-Use Monitoring (Bureau of Energy Efficiency, 2019), ownership of CFLs, tubelight, LEDs and bulbs were 78%, 68%, 22% and 15%, respectively (based on Residential Energy End Use Study 2019). In recent years, India has implemented policies to push energy-efficient lighting with LEDs: The Unnat Jyoti by Affordable LEDs for All (UJALA) scheme and the LED Street Lighting National Programme (IEA, 2021). According to the IEA World Energy Outlook, (IEA, 2023), LEDs are expected to make up 100% of lighting sales by 2030 in the NZE Scenario. It is assumed that India will follow this global trend, phasing out CFLs and incandescent lighting by 2050 and 2040, respectively, in favour of LEDs. In the NZE scenario it was assumed that the incandescent lighting will phase out faster (2040), than CFLs (2050). The Reference Scenario assumes no technological improvements in lighting. Modeling results suggest that energy consumption for lighting is expected to grow from 1.9 million GJ in 2018 to 8 million GJ in 2070 in the Reference Scenario and 4.4 million GJ in the Net Zero SS Scenario (Figure 6-25). Technological shift results in a 1.8 times reduction in energy consumption for lighting in the Net Zero SS Scenario compared to the Reference Scenario by 2070.

“Other” end-uses include various household appliances such as washing machines, refrigerators, TVs, and computers. Energy consumption for these end-uses is projected to grow from 46 million GJ in 2018 to 360.3 million GJ in 2070 in the Reference Scenario and 218 million GJ in the Net Zero SS Scenario. The lower energy consumption in the Net Zero SS Scenario is due to improved energy efficiency of appliances, assumed at 1% per annum.

***Figure 6-25 Energy demand – Households (LEAP)*** [30]




In the LEAP model increase in urbanization from the current 46% to 79% by 2070 was assumed. Additionally, the floor area which serves as a driver of household energy demand for cooling and by appliances in urban households is expected to grow at a faster rate than that of rural households (see methodology described in Appendix 10.2.3). As a result of these urbanisation levels, energy consumption in rural households is expected to decline in future compared to current levels in both scenarios, while urban energy consumption is anticipated to grow rapidly in both scenarios.

[30] In the LEAP model, solar PV rooftop installations were presented as a separate process from the large-scale on-grid PV plants. In the commercial, household, and agriculture sectors, an additional fuel called "solar electricity" was introduced to represent electricity from these solar rooftop PV installations. Electricity from the grid was referred to as "electricity".

**6.2.3.2 Commercial and public services sector**:

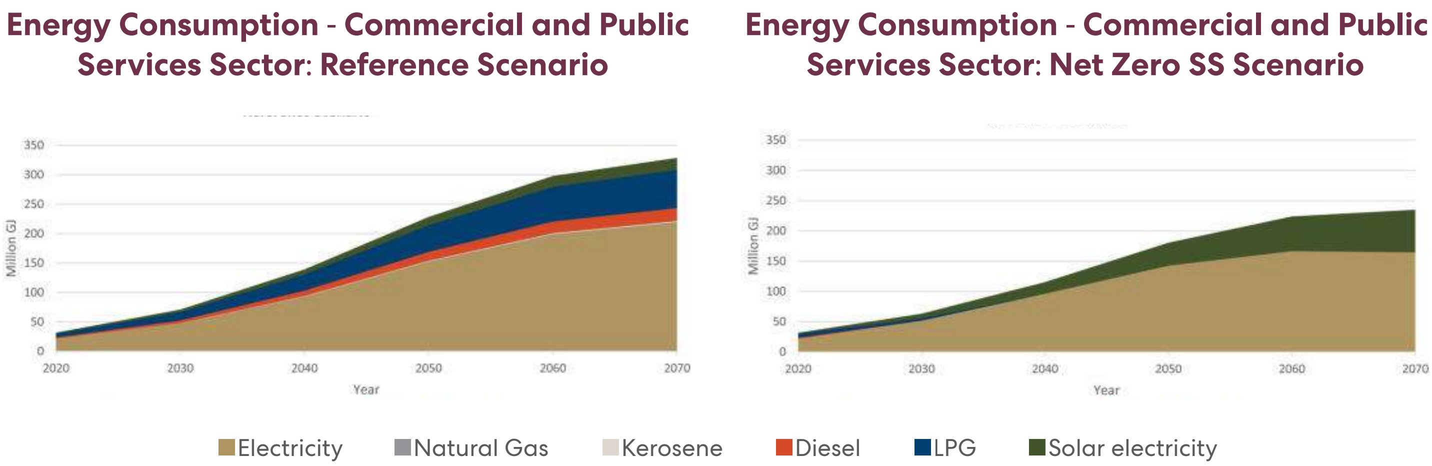
In the Reference scenario, between 2020 and 2070, energy consumption in Gujarat's commercial and public services sector is projected toto grow at a compound annual growth rate (CAGR) of 4.8% (Figure 6-26). The driver for energy demand in this sector is the commercial floor area, which is expected to rise from 99.7 million square meters in 2020 to 1035.4 million square meters by 2070 (Appendix 10.2.3). In the Net Zero Scenario, the sector's energy consumption grows at a slightly lower CAGR (compared to the Reference scenario) of 4.1% due to improvements in energy efficiency.

Currently, electricity accounts for about 67% of the total final energy consumption in this sector. In the Reference Scenario, this share remains stable, while in the Net Zero Scenario, it slightly increases to 70% by 2070 (with rooftop solar PV installations providing remaining demand for the energy services).

In 2020, fossil fuels (diesel and LPG) met 27% of the energy demand in the sector. According to the Net Zero Scenario, it is expected that diesel and LPG use in the commercial and public services sector will gradually decline, and eventually completely phased out by 2070.

Gujarat is currently a leader in rooftop solar installations, holding 82% of the country's total. According to MoN&RE (2024), the state's rooftop solar PV capacity increased from 326 MW in 2019 to 3455 MW in 2024. In the Net Zero Scenario, rooftop solar is assumed to contribute 30% of the sector's total energy consumption by 2070.

***Figure 6-26 Energy demand – Commercial (LEAP)*** [31]



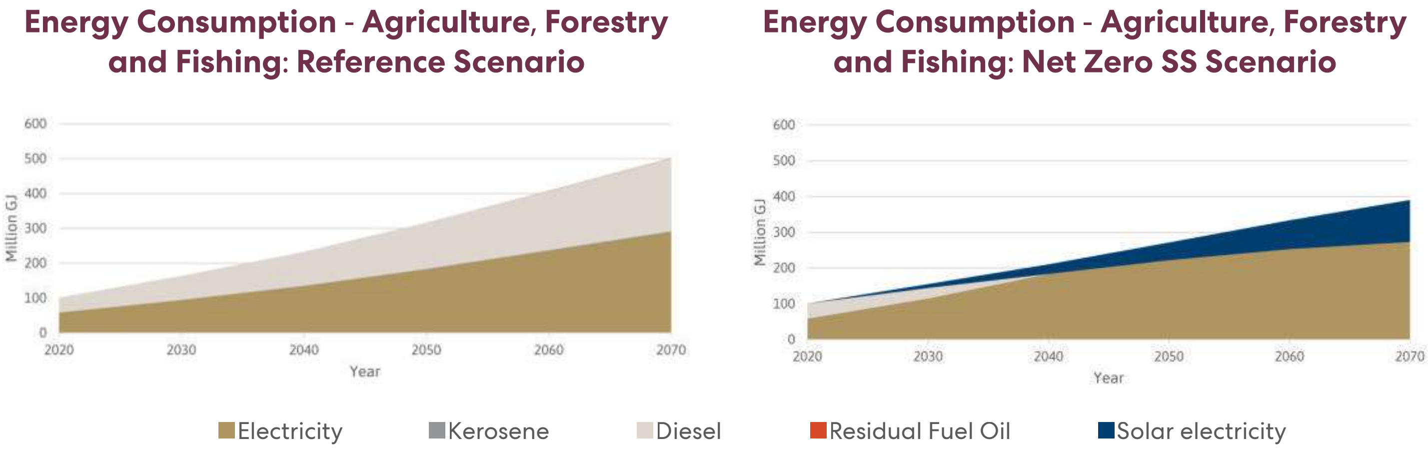

[31] "Solar electricity" represents electricity from solar rooftop PV installations. Electricity from the grid was referred to as "electricity"

### 6.2.4 Agriculture Sector:

Fuel combustion in the agriculture, forestry, and fishing sectors contributes a relatively small portion to the state's total $CO_2$ emissions, accounting for just 1.3%. This sector is projected to maintain a low share of total $CO_2$ emissions, decreasing slightly to 1.1% by 2070 in the reference scenario.

Electricity, which currently makes up 58% of energy consumption, is expected to maintain this share in the reference scenario (Figure 6-27). Oil products, primarily diesel, currently account for 42% of energy consumption but are projected to be completely phased out by 2040 in the Net Zero SS Scenario. In this scenario, the share of electricity is expected to increase to 70% by 2070, with the remaining share covered by solar rooftop PV installations.

***Figure 6-27 Energy demand – Agriculture (LEAP)***




### 6.2.5 Power Sector:

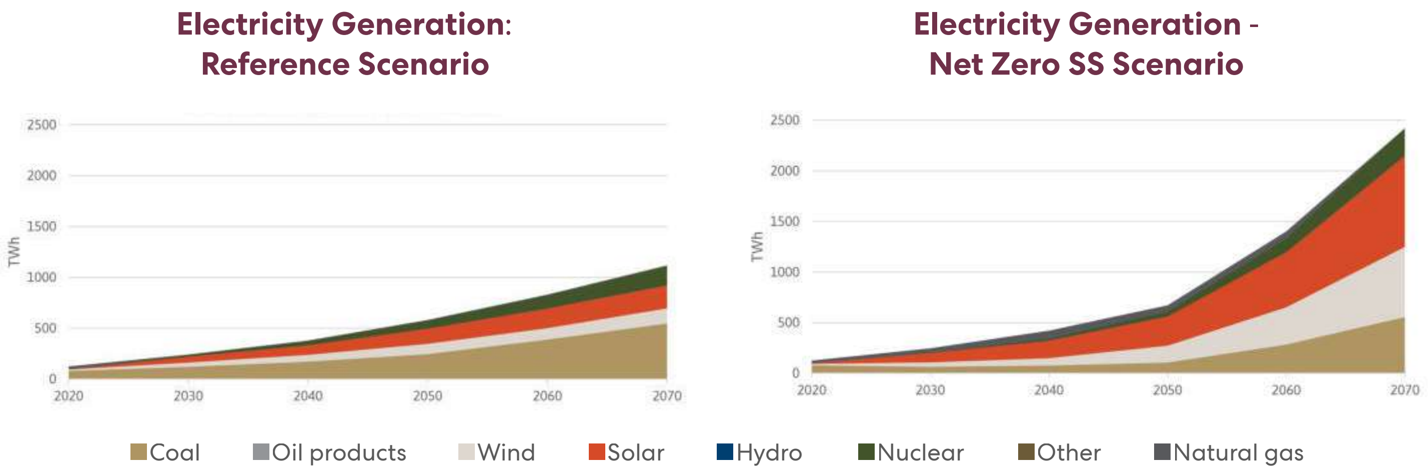
Electricity generation is currently the largest source of $CO_2$ emissions in Gujarat, accounting for 38% of the total emissions, primarily due to the significant use of coal (63% in 2020) for power generation. Details on structure of the power sector in the LEAP-Gujarat model are provided in the Appendix 10.2.4).

(In the Net Zero SS scenario, the primary assumption is that coal power will be significantly reduced, though not entirely phased out. It is expected that new coal power plants will be equipped with Carbon Capture and Storage (CCS) technology after 2050. Coal power plants with CCS are assumed to have significantly reduced $CO_2$ emission factor, with just 10%[32] of the emissions compared to coal power plants without CCS (from 2050 onwards).

Modelling results indicate that in the Reference scenario, the share of coal for power generation decreases from 63% in 2020 to 49% in 2070, with coal remaining a major energy source for power generation (Figure 6-28). In the Net Zero SS Scenario, coal's share declines substantially reaching 23% in 2070. Renewable power generation (solar and wind) increases from 15% in 2020 to 33% in 2070 in the Reference Scenario, and to 66% in the Net Zero SS Scenario.

[32] CO2 capture efficiency was obtained from the study by Rogieri Pelissari et al. (2023)

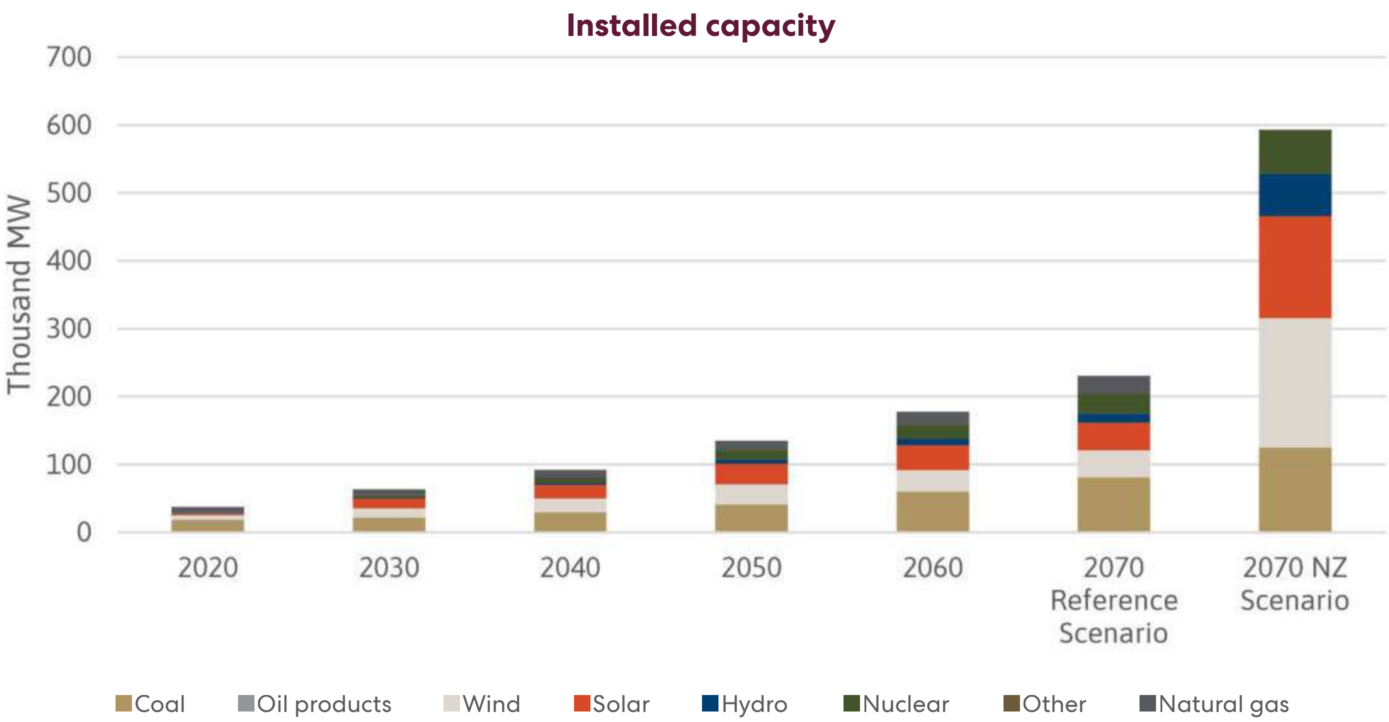
***Figure 6-28 Electricity Generation (LEAP)***



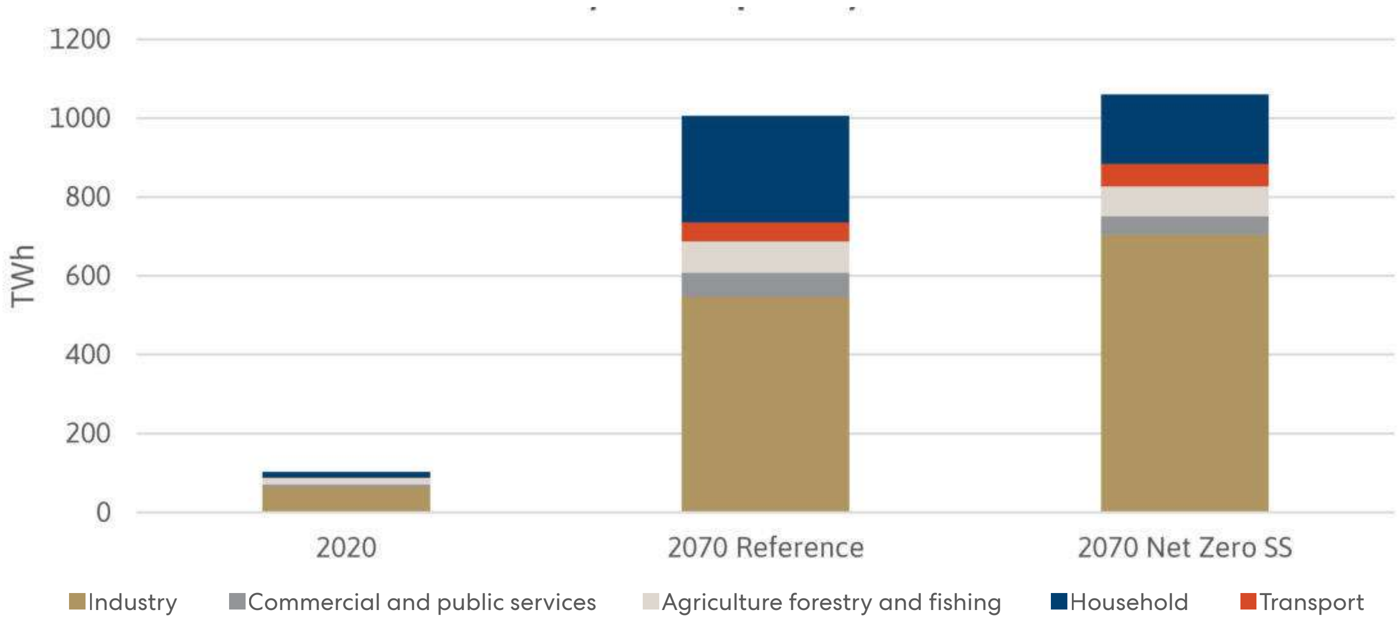

Installed capacity increases from 37.5 thousand MW in 2020 to 231 thousand MW in 2070 in the Reference scenario, while in the Net Zero SS Scenario, it rises to 593 thousand MW. Thus, achieving the net zero goal requires 2.6 times more installed capacity in 2070 compared to the Reference Scenario. In the Reference Scenario, the share of non-fossil fuel capacity (solar, wind, hydro, nuclear) in total installed capacity is projected to reach 50% by 2030 and 53% in 2070. Conversely, in the Net Zero SS Scenario, this share is expected to rise to 52% by 2030 and further increase to 79% by 2070.

Although total electricity consumption by end-use sectors is similar in both scenarios, sectoral differences are significant. Electricity consumption in industry grows from 65 TWh in 2020 to 546.6 TWh in the Reference Scenario and 705.1 TWh in 2070 in the Net Zero SS Scenario, a higher consumption due to the partial replacement of fossil fuels by electricity in industry sectors. In contrast, the commercial and services sector, households, and agriculture sectors see lower electricity demand in the Net Zero SS Scenario due to efficiency improvements in appliances, cooling, etc.

***Figure 6-29 Installed Capacity and Electricity Consumption by end-use sectors (LEAP)***



**Electricity Consumption by Sectors**




In the Net Zero SS Scenario, the LEAP model results indicate that 275.1 TWh and 644.6 TWh of solar energy were classified as "Unmet requirements[33]" for the years 2060 and 2070, respectively. Thus, these unmet electricity requirements, which are 20% of the total electricity generation in 2060 and 27% in 2070, will need to be either imported or generated from other technologies. Unmet requirements from solar resources 33 mean that solar electricity generation requirements exceed the maximum potential from solar resources available in Gujarat. In the model, the values for the maximum available potential for solar and wind were obtained from the Energy Statistics India 2023, published by the Ministry of Statistics and Programme Implementation (MoSPI, 2024) .

Based on the Central Electricity Authority's "General Review" Report (CEA, 2022) (CEA, 2022a), Gujarat experienced transmission and distribution (T&D) losses of 17.9% in 2017-2018, 20.3% in 2018-2019, and 21.6% in 2019-2020. In both scenarios, it was assumed that T&D losses would gradually decrease from current levels, reaching 10% by 2040 and remaining stable between 2040 and 2070.

[33] In LEAP, "unmet requirements" in the results indicate any unserved demands for fuels/energy types that remain after all transformation modules have been processed.

### 6.2.6 Agriculture, Forestry and Land Use:

The total land area of Gujarat is 19,602 thousand hectares and the same is divided across different land cover classes (Table 6.6).

***Table 6-6 Gujarat land area by land cover classes***

| | 2011-12 (000 Ha) | 2015-16 | 2070 (Reference) | 2070 (Net Zero SS) | Remarks |
|---|---|---|---|---|---|
| **Land** | | | | | |
| Agricultural Land | 12,447.60 | 12,843.20 | 12,843.20 | 12,843.20 | |
| Forest Land | 1,275.20 | 1,489.10* | 1,645.00 | 4420 | *The forest area is for 2018 and not 2015-16 |
| Grassland | 1,291.30 | 499.62 | - | - | |
| Other land | 4,229.50 | 4225.5 | 3,494.67 | 719.67 | |
| Settlements | 358.8 | 544.979 | 1,619.53 | 1,619.53 | |
| Total | **19,602.40** | **19,602.40** | **19,602.40** | **19,602.40** | |

**Source**: (1) Envistats India 2018, Statement 1.24: State-wise area by land cover class (MoSPI, 2018)
(2) GHG platform (except for grassland)

The $CO_2$ emission estimation follows the methodology and emission coefficients defined in the GHG platform for India and is explained further in Appendix 10.2.7.

#### 6.2.6.1 Agriculture:

The $CO_2$ emissions from agriculture arise due to changes in $CO_2$ sequestered by biomass and the changes in soil organic carbon. The methodology for the same is explained in Appendix 10.2.7 In both scenarios, we consider no changes in land cover under agriculture in future.

#### 6.2.6.2 Forestry:

The carbon sequestration in forests happens due to two effects i) change in forest cover and ii) change in carbon stock density. The methodology for the same is explained in Appendix 10.2.7

In the reference scenario, following the past trend, forest area increases to 1645 thousand hectares, approximately 8% of the total area (SDG 15.1).

In the Net Zero SS scenario, ambitious growth of the forest area and a 23% share of forests in the state in 2070 has been assumed.

#### 6.2.6.3 Grassland and Other Land:

In both scenarios, grassland and other lands are considered the land pool that will provide increasing land requirements for forestry and settlements. Grassland, as a result, disappears completely in both scenarios. Other lands also reduce; however, the reductions are steeper in the Net Zero SS scenario.

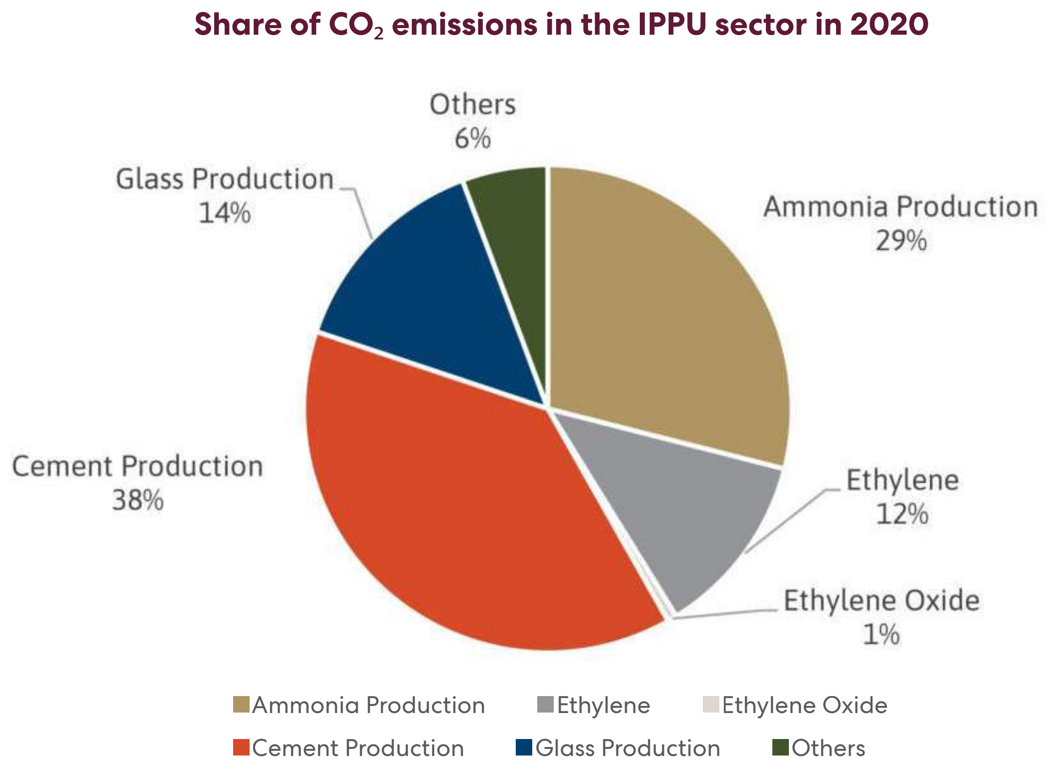
#### 6.2.6.4 Settlement:

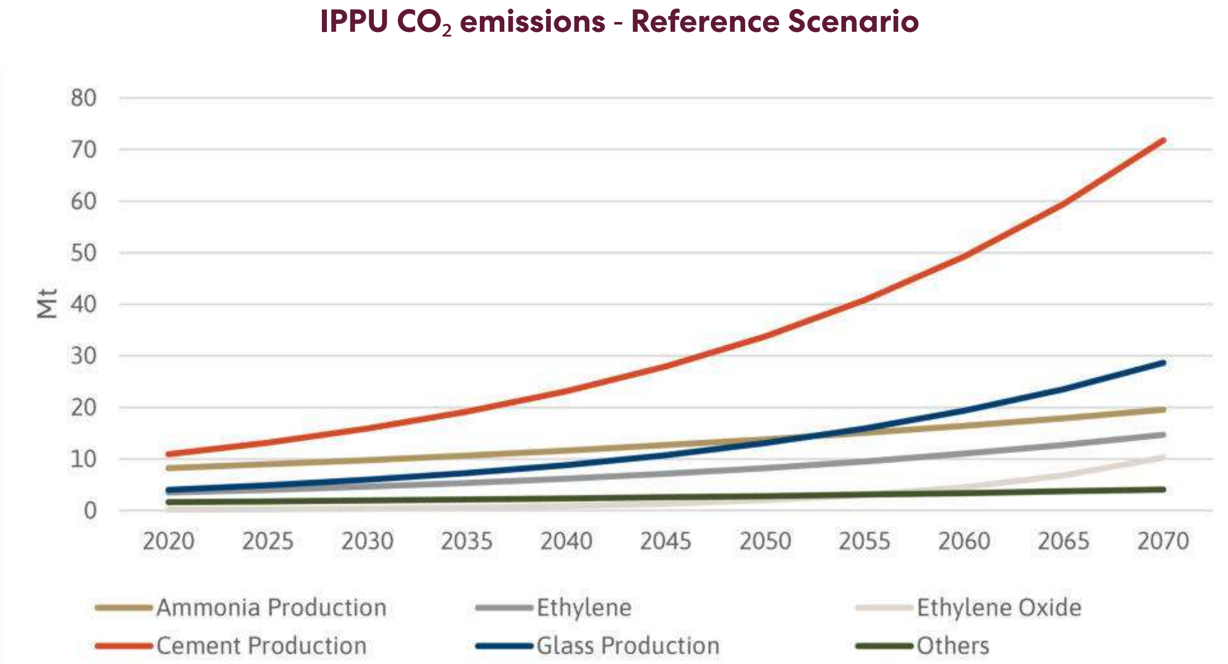
The area under settlements will grow with increased population, urbanisation, infrastructure growth, and industrial development. Therefore, in both scenarios, the land under settlements is considered to increase from less than 2% to around 8% by 2070.

### 6.2.7 IPPU:

Six different sectors are considered for IPPU emissions. The base year emissions are based on GHG platform data, and future growth in the reference scenario is related to the historical growth witnessed in these sectors. The top three contributors to IPPU emissions are Cement, Ammonia, and Glass production, and these sectors are expected to remain the top three contributors in the future as well (Figure 6-30).

***Figure 6-30 IPPU Emissions by Sectors*** (***LEAP***)




Since more than 80% of $CO_2$ emissions from IPPU are from cement, glass and ammonia, the mitigation strategies from these three sectors were analysed in the SS Scenario.

**6.2.7.1 Cement Sector (IPPU):**

The cement production in 2018 in Gujarat was 27.3 million tonnes and accounted for around 8% of the national cement output. Process-related $CO_2$ emissions from cement occur during the production of clinker.

According to GHG platform data, one ton of clinker results in the production of 0.537 $tCO_2$.There are different types of cement used, and each has a different share of clinker (Table 6-7).

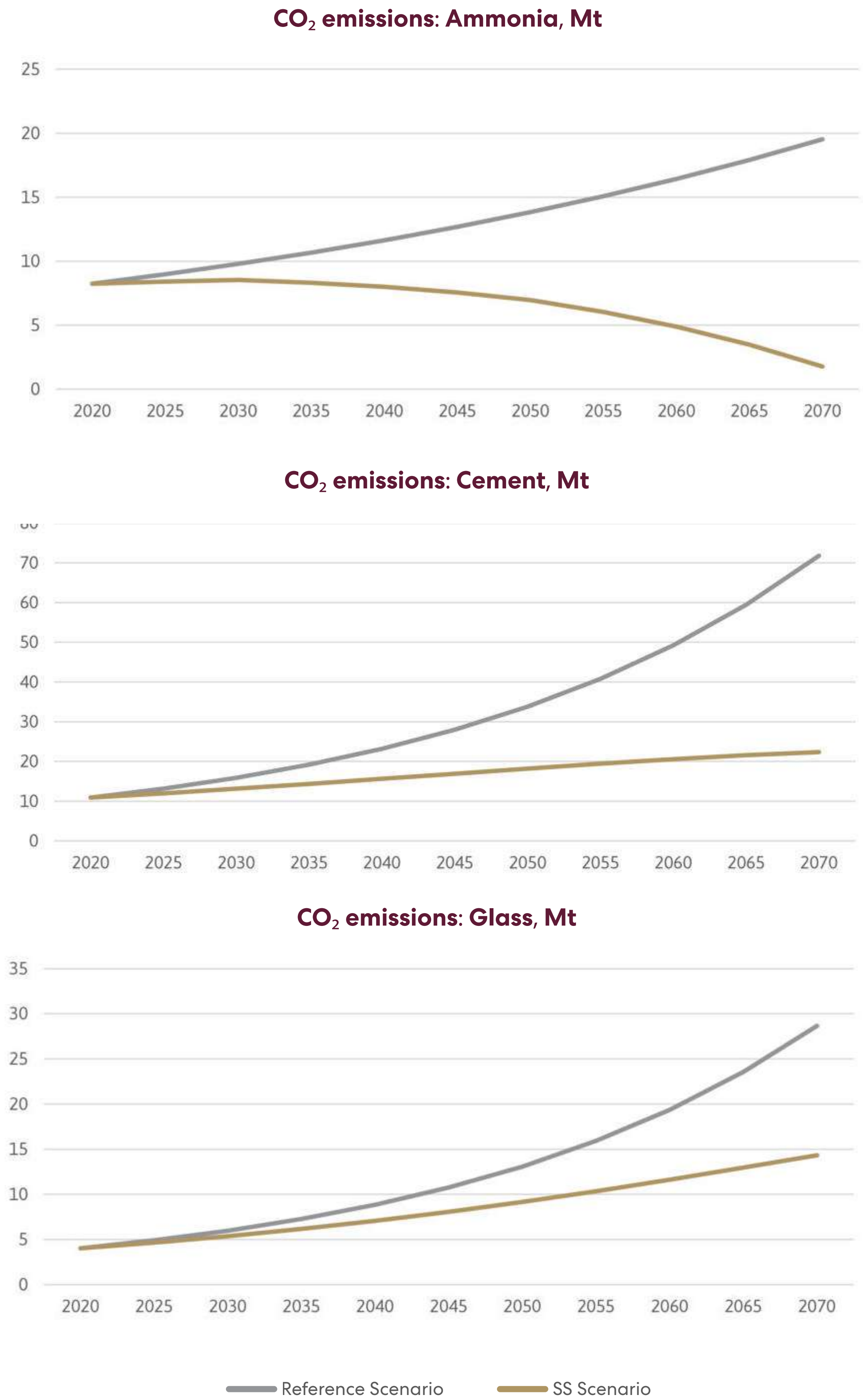
***Table 6-7 Gujarat Status of Cement Production in 2018***

| | Type of Cement | | | | | | |
|---|---|---|---|---|---|---|---|
| | O.P.C | P.P.C | P.B.F.S | S.R.C | IRST 40 | Others | Total Cement |
| Cement production, tons | 6,951,501 | 18,045,667 | 2,200,335 | 6,491 | 94,115 | 12,981 | **27,311,090** |
| % Share | 25.5% | 66.1% | 8.1% | 0.0% | 0.3% | 0.0% | |
| Share of Clinker | 0.95 | 0.68 | 0.60 | 0.95 | 0.95 | 0.95 | |
| $CO_2$ emissions, tons | 3,546,308 | 6,589,556 | 708,948 | 3,311 | 48,013 | 6,622 | 10,902,758 |

The $CO_2$ emissions in the reference scenario assume that the shares of different cement types and the share of clinker in these different cement forms will remain the same. Between 2008 and 2018, the cement emissions have grown annually by 3.84%. In the reference scenario, the same growth rate is assumed; therefore, the emissions increase by 6.5 times from 10.9 million $tCO_2$ in 2020 to 71.8 million $tCO_2$ in 2070 (Figure 6-31). The bulk of the emissions are from OPC and PPC types of cement (Table 6-7).

In the net zero SS Scenario, there are two levers for the decarbonisation of the cement sector. First, the demand for cement is 30% lower due to improved efficiency in design and better construction practices that reduce the wastage of cement (GCCA, 2023). Second, the $CO_2$ intensity of clinker production is expected to decline from 0.537 $tCO_2$ per ton of cement to 0.239 $tCO_2$ per ton of cement (See Appendix 10.2.8) due to changes in the calcination process (Ashfaq & Hempel, n.d.). Overall, it would mean that $CO_2$ emissions will increase only 2 times to 22.3 million $tCO_2$ in 2070.

***Figure 6-31 $CO_2$ emissions from IPPU***



**6.2.7.2 Ammonia (IPPU)**

The ammonia production in 2018 in Gujarat stood at 4.7 million tonnes. The $CO_2$ emissions (Scope 1) from ammonia production typically occur within the steam methane reformer, where natural gas is broken down to produce hydrogen and $CO_2$. In the case of Gujarat, as per the GHG platform, the $CO_2$ emissions for producing one tonne of ammonia are 1.77 $tCO_2$. In the reference scenario, we assume no change in the ammonia production process. As a result, the $CO_2$ emissions grow in line with ammonia output and increase from 8.2 million $tCO_2$ in 2020 to 19.5 million $tCO_2$ in 2070 (Figure 6-31).

In the Net Zero SS scenario, the effort will be to move away from the conventional process of producing ammonia, which is very $CO_2$ intensive, towards blue and green pathways. Blue pathway relies on producing ammonia using natural gas; however, $CO_2$ can then be used in the production of urea, and the remainder can be captured and either stored or used for other productive uses. The cost of capturing in the steam reformer process is quite low, and there is also the possibility of utilising it within the plant itself; therefore, a high share of 70% has been considered for the blue pathway in 2070. In addition, two green pathways relying on biomethane and green hydrogen are also considered. Overall, these interventions can help bring down the $CO_2$ intensity of ammonia production from 1.77 $tCO_2$/ton ammonia in 2020 to only 0.16 $tCO_2$/ton ammonia in 2070.

**6.2.7.3 Glass (IPPU):**

The glass production in 2018 in Gujarat stood at 20.2 million tonnes. The $CO_2$ emissions (Scope 1) from glass production occur when sand, feldspar, dolomite, soda ash and limestone are fused to produce glass and $CO_2$ In the case of Gujarat, as per the GHG platform, the amount of $CO_2$ emissions for producing one tonne of glass is 0.2 $tCO_2$. In the reference scenario, we assume no change in the glass production process. Glass is an essential raw material for other industrial products such as solar panels, wind turbines, electronics, automobiles, construction, etc. and therefore growth in $CO_2$ emissions is kept same as the historical growth (2005-2018) in $CO_2$ emissions from industry growth of around 4% in $CO_2$ emissions.

As a result, the $CO_2$ emissions will grow from 4.0 million $tCO_2$ to 28.7 million $tCO_2$ in 2070 (Figure 6-31). The growth of glass will be driven by four different markets i) flat glass, which is used in buildings and automobiles ii) container glass, which is used in packaging iii) fibreglass, which is used in windmills, electronics and construction iv) specially glass, which is used in electronics and telecommunications (Furszyfer Del Rio et al., 2022).

In the Net Zero SS scenario, the effort will be to improve the recycling of glass and increase the share of cullets (recycled glass) in glass manufacturing. Due to this, the amount of $CO_2$ produced per ton of glass will decrease to 0.1 $tCO_2$ per ton of glass in 2070.

## 6.2.8 Total Final Consumption (TFC)

In the Reference Scenario, total final energy consumption (TFC) increases 7.1 times, from 1,893 million GJ in 2020 to 13,415 million GJ in 2070. However, in the Net Zero SS Scenario, due to fuel switching, reduced share of manufacturing and improvements in energy efficiency, this consumption is reduced by 31% compared to the Reference Scenario in 2070 (Figure 6-32).

In terms of sectors, the share of the industry sector in total final consumption increases in both scenarios (Table 6-9 below). Although absolute energy consumption in households and transport increases, the shares of these sectors in TFC decline by 2070 in both scenarios compared to 2020. This is due to a combination of several factors: industrial demand grows faster than that of transport and households, more efficient energy use due to phase-out of inefficient cooking methods in households, increased electrification, and changes that occur in transportation modes within the transport sector.

In the reference scenario, coal continues to dominate the TFC in 2070 (38% share of TFC). To achieve the net zero target, the fuel shares in total final energy consumption change significantly (Table 6-8 below). Shares of coal, natural gas, and oil products will be gradually reduced to 0% by 2070. While electricity's share increases to 42% in 2070 and the share of "other" fuels rapidly rises to 58% in 2070. These "other" fuels include hydrogen, biomass[34], biogas, and methanol.

[34] Biomass includes sustainably produced biomass "modern biomass," it does not include traditional biomass uses such as fuelwood. In LEAP-Gujarat model, wood is categorized as a distinct fuel, predominantly used in rural households in 2020, with an expected phase-out by 2040 in both scenarios.

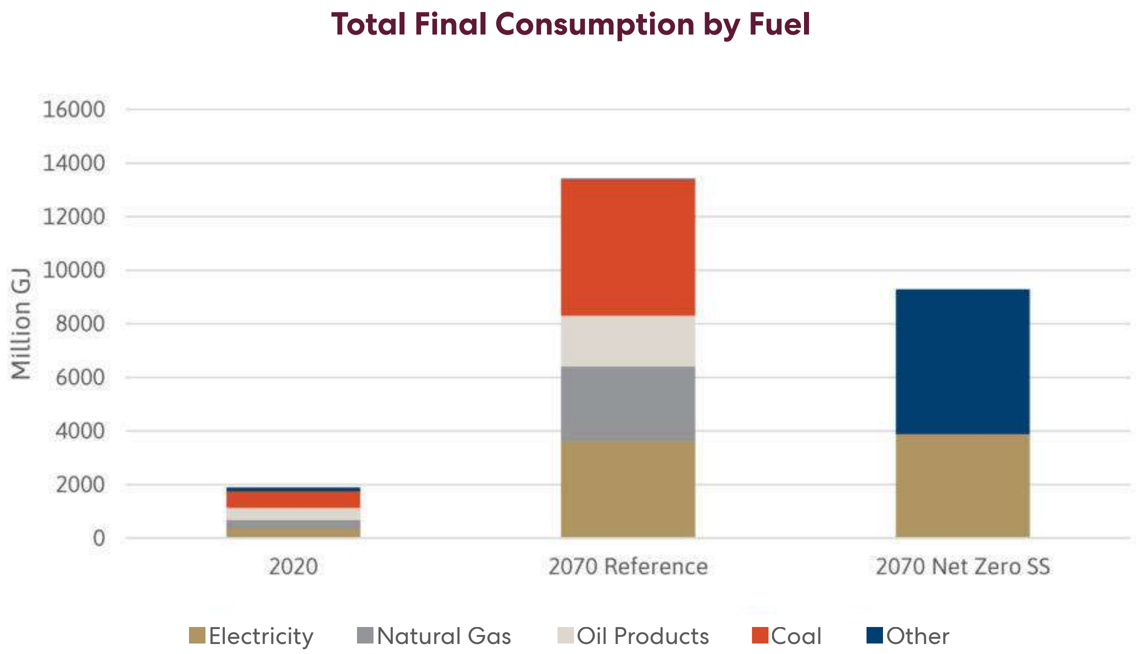
***Table 6-8 Shares of TFC by sectors and by fuels***

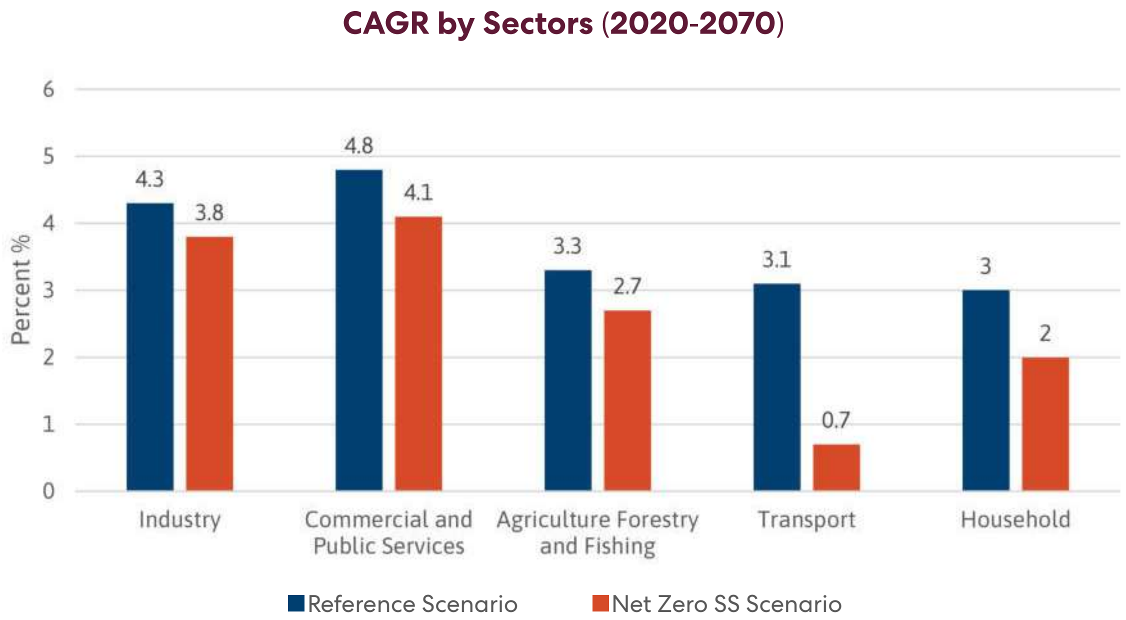
| Fuels | 2020 | 2070 Reference | 2070 Net Zero SS |
|---|---|---|---|
| **Coal** | 33% | 38% | 0% |
| Oil | 23% | 14% | 0% |
| Gas | 16% | 21% | 0% |
| Electricity | 20% | 27% | 42% |
| Hydrogen | 8% | 0% | 58% |
| **Sectors** | | | |
| Commercial and Public Services | 2% | 2% | 3% |
| Industry | 63% | 75% | 81% |
| Transport | 17% | 11% | 5% |
| Household | 13% | 8% | 7% |
| Agriculture Forestry and Fishing | 5% | 4% | 4% |

The annual growth rate of energy demand varies across different sectors. The commercial and public services sector experiences the fastest CAGR in final energy consumption in the period 2020-2070, with a CAGR of 4.8% in the Reference Scenario (Figure 6-32). This significant increase in the commercial and public services sector is driven by the assumed expansion of commercial floor area, which boosts energy consumption. The rise in industrial energy use is attributed to the projected gross value added by industry sectors, which aligns with Gujarat's expected total GDP projections (CAGR 4.3% in the Reference Scenario).

In the Net Zero SS scenario, the growth in final energy consumption from 2020 to 2070 is less pronounced than in the reference scenario. This relatively moderate growth rate (compared to the Reference scenario) can be explained by the transition to different fuels, increased electrification, improvements in appliance energy efficiency, and changes in behaviour within the transport sector.

***Figure 6-32 Total final consumption by fuel and CAGR by sectors***



### 6.2.9 $CO_2$ Emissions:

In the LEAP assessment, all $CO_2$-emitting categories were considered, including emissions from both fuel combustion and non-fuel combustion sectors (AFOLU and IPPU). The reference scenario assumes some growth in renewable energy capacities in line with recent developments but, at the same time, does not impose limitations on new coal and natural gas power plants.

$CO_2$ emissions are projected to rise from 241 Mt in 2020 to 1391 Mt by 2070, with a CAGR of 3.6% (Figure 6-33). The share of industry emissions in the state's total $CO_2$ emissions increases from the current level of 32% to 46% in 2070, owing to significant growth of energy demand. The share of emissions from the transformation processes (mostly power generation) declines from 45% in 2020 to 35% in 2070 due to the gradual retirement of existing power plants at the end of their lifetime and new, more efficient power plants (including renewable energy sources). The sectors with the highest $CO_2$ emissions CAGR (2020-2070) are industry (4.3%), commercial and public services (4%), followed by electricity generation (3.3%), IPPU (3.4%), transport (2.8%), and households (1.8%).

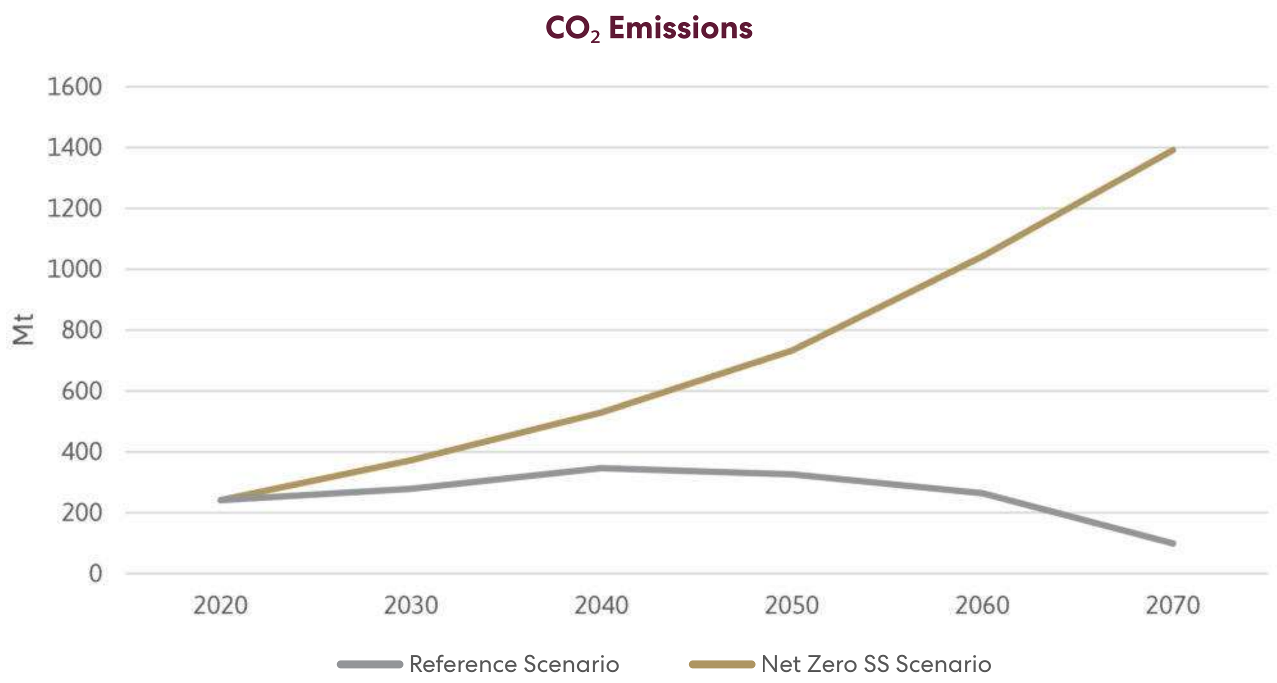
In the Net Zero SS Scenario, $CO_2$ emissions peak around 2040, then gradually decline to 98 Mt by 2070 (Figure 6-33). Despite a significant reduction in emissions in the Net Zero SS Scenario compared to the Reference Scenario in 2070 (a 14-fold decrease), there will still be 98 Mt of $CO_2$ emissions remaining unmitigated in 2070, originating from the power sector and IPPU. CCS was assumed to capture 90% of $CO_2$ emissions, meaning it does not eliminate $CO_2$ emissions from power generation. The industry's share in total emissions rises from 32% in 2020 to 54% by 2060 before dropping to 0.2% in 2070 as hydrogen adoption in industry sectors increases. Different sectors reach their peak emissions at different times: electricity generation in 2040, the industry and household sector peaks in 2050, and IPPU in 2070, indicating a slightly faster energy transition in electricity generation and always growing emissions in IPPU (peaking at the last year of projection period). By 2070, nearly all sectors achieve close to zero emissions, except for electricity generation (due to coal with CCS) and IPPU. The IPPU sector, one of the hardest to decarbonize, emits 68 Mt $CO_2$ in 2070 under the Net Zero SS Scenario, alongside 58 Mt $CO_2$ from power generation (coal with CCS). These emissions are partially offset by increased removals from the AFOLU sector, which accounts for -28.2 Mt in 2070.

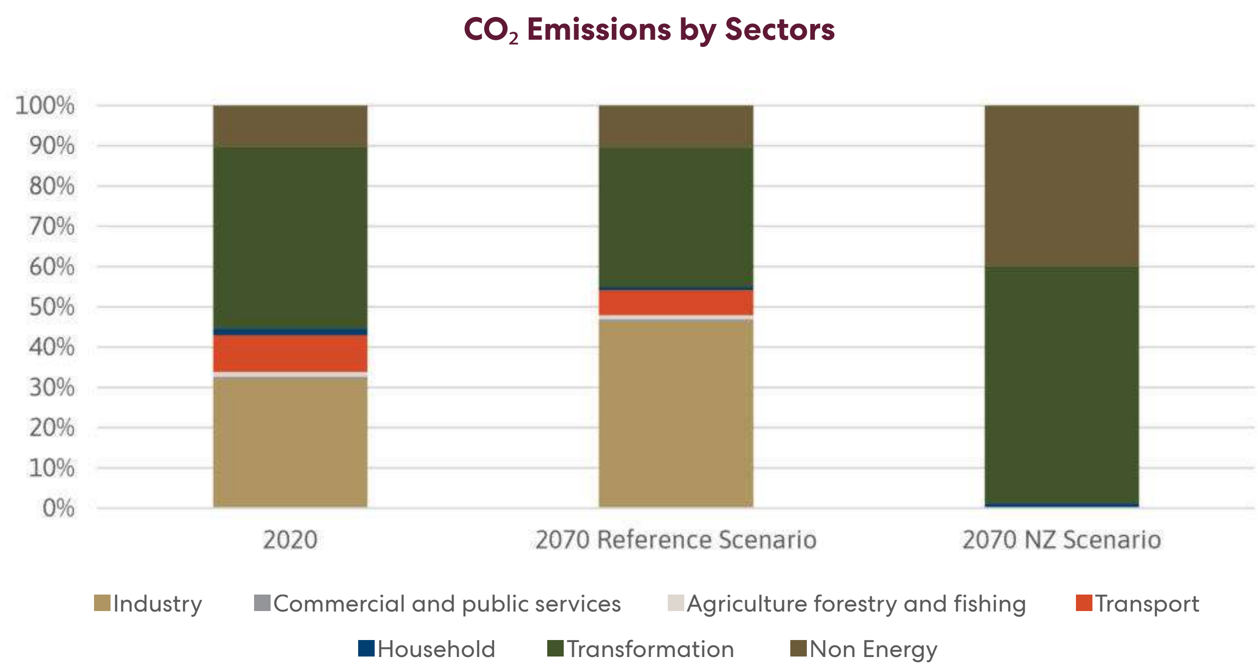
Currently, coal combustion is the primary source of emissions in Gujarat, accounting for 59% of total $CO_2$ emissions. In the Reference scenario, coal remains the main source, increasing to 67% by 2070. In the Net Zero SS Scenario, coal remains the major source with a 59% share of total $CO_2$ emissions in 2070 (coal power plants with CCS).

Emissions from natural gas increase in absolute terms, but its share of total $CO_2$ emissions is relatively stable in the Reference scenario: 13% in 2020 and 12% in 2070. In the Net Zero SS Scenario, $CO_2$ emissions from natural gas combustion rise from the current 31 Mt to a peak of 111 Mt in 2050, then gradually decline to nearly 1 Mt by 2070. This trend reflects the role of natural gas as a "transitional fuel" in the Net Zero scenario.

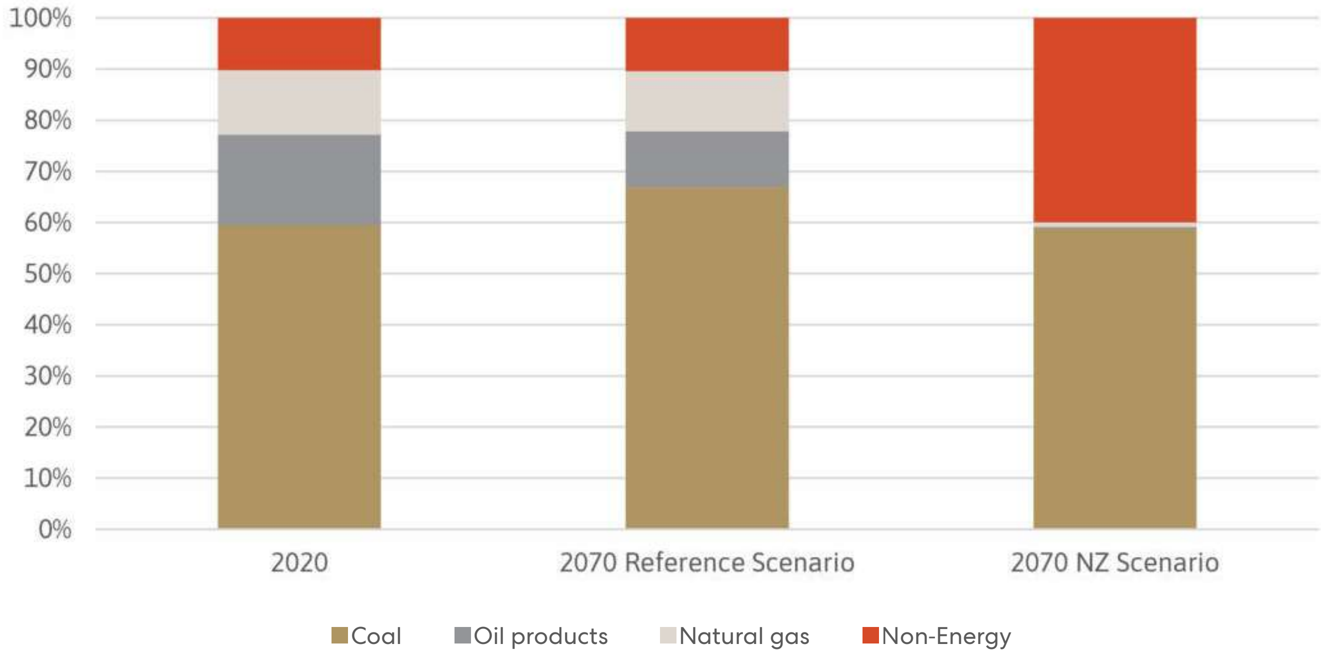
Emission reductions by sector were calculated by comparing the Reference and Net Zero Scenarios in 2070 (Figure 6-33). The industry and transformation (mainly power generation) sectors are the primary contributors, accounting for 83% of the total emission reductions.

***Figure 6-33 $CO_2$ emissions by fuels and by sectors***

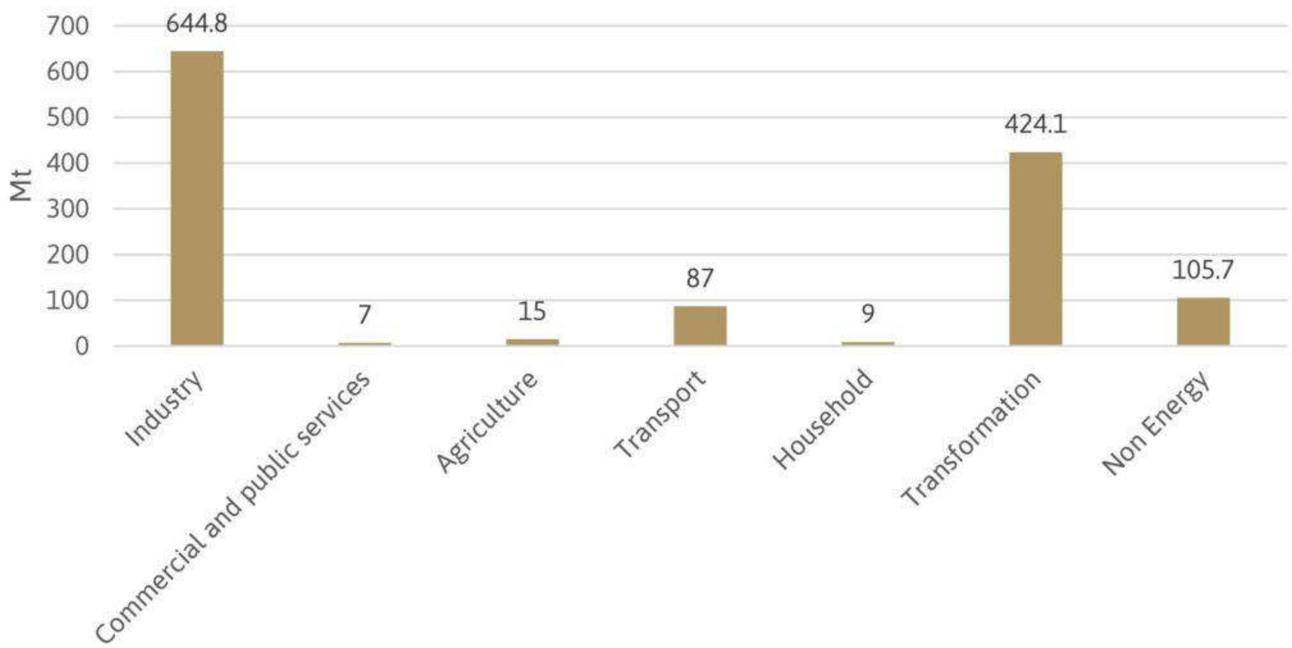


## Share of $CO_2$ Emissions by Fuels




## Emission Reduction by Sectors in 2070



# 7.
# SUSTAINABLE DEVELOPMENT IMPACTS OF NET ZERO SCENARIOS

Ambitious mitigation pathways have implications for sustainable development (IPCC, 2022). In addition to the change in drivers such as population, urbanization and GDP, pathways may entail structural changes (for e.g. shift away from manufacturing), sectoral changes (for e.g. change in technologies or energy mix) or change in activity levels (for e.g., lower or higher end-use demand).

Such changes or interventions could have positive or adverse implications. For instance, generation of green jobs may be a benefit if the state chooses a particular pathway. On the other hand, this could imply adverse distributional impacts for some sectors. For example, declining shares of a certain sector may affect employment and competitiveness at the state level. Similarly, different pathways may have different investment needs or resource requirements and environmental impacts (such as impacts on air quality or land). Evaluating the sustainable development impacts of Net Zero scenarios in Gujarat is essential for a balanced and fair transition to a low-carbon economy. As Gujarat advances toward ambitious climate targets, understanding the environmental, social, and economic benefits and challenges associated with the transition offers valuable guidance for policymakers. However, assessing such synergies and trade-offs with SDGs is challenging (Halsnæs et al., 2024; IPCC, 2022; Pathak et al., 2024), specifically quantifying them. Also, the interactions with SDGs can be assessed as potential synergies or trade-offs while the actual impacts may differ.

In the present study, sustainable development implications were assessed across three dimensions: environmental, economic, and societal/distributional.

Using the broad framework outlined in the Transitions Impact Framework - The Climate Transition Impact Framework (McKinsey, 2023), key results from the scenario assessments in Sections 6 were mapped onto relevant SDG targets and indicators to highlight synergies and trade-offs (Figure 7-1). The analysis focuses on assessing the broader impacts on sustainable development dimensions, and where possible, looking at specific SDG targets. While such a transition can have interactions across a range of dimensions, the assessment here focuses on the most relevant dimensions and indicators for Gujarat. For instance, the deep dive into impacts on water, land, employment impacts and air quality are particularly relevant to Gujarat's development context, considering its industrial base, geographical features, resources, and socio-economic priorities.

The assessment includes the key indicators where quantification was possible through the modelling exercises discussed in previous sections. These include energy and emissions indicators as well as sectoral actions. For some indicators, calculations were made outside the modelling exercise for e.g. forest cover, PM2.5 emissions, water consumption and employment. In some cases, it was challenging to quantify trade-offs due to data availability or the choice of methodology, and some impacts or distributional consequences were out of scope. For example, impacts on biodiversity were not assessed. While the SDG targets have a 2030 horizon, this analysis extends the framework beyond SDGs as Gujarat’s net zero transition will occur over a longer time frame. A brief overview of the indicators and assumptions is provided below.

***Figure 7-1 Indicators assessed***

## DIMENSIONS MEASURED

**Environmental**

- Biodiversity
- $CO_2$ Emissions
- Electricity in Transport (%)
- Emission Intensity of
- Economy
- Energy Efficiency
- Floor Area Change
- Land-use Change
- Mode-share in Transport
- PM 2.5
- RE in Electricity and TFEC (%)
- Water Consumption for Electricity
- Biodiversity

**Economic**

- MVA as proportion of GDP
- Manufacturing employment as proportion of total employment
- Mode-Share in Transport

**Societal / Distributional**

- Total Jobs Generated
- Fossil
- Non-Fossil
- Total Jobs Gained
- Non-Fossil Jobs Gained
- Share of Public Transport

## 7.1 Interactions with SDGs

### 7.1.1: Energy and Emissions:

Clean energy, reduced energy and emissions intensity, and reduction in overall emissions can be mapped to targets mainly under SDGs 7, 9 and 13. Target 7.2 aims to "increase substantially the share of renewable energy in the global energy mix by 2030". Assumptions for $CO_2$ emissions, renewable energy capacity, and electricity generation from renewables were obtained from the scenario assessment discussed in Section 5 and 6.

Net zero scenarios will lead to a significant increase in renewable energy share in the total energy mix thereby delivering synergies with targets under SDG 7 as well as SDG 13. The share of renewables exceeds 50% in electricity generation in the GCAM NZ scenario as well as the LEAP structural Shift NZ scenario. Reduction in the share of biomass for the residential sector is significant due to its known impacts on reduction in indoor air pollution and associated health impacts. (See sections 6.1.3 & 6.2.3.1).

Target 9.4 emphasizes the need to upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies, including renewable energy. Energy intensity was calculated as the energy per GDP.

### 7.1.2 Transport and Residential Sector:

Increasing the share of public transport delivers synergies with several SDGs. Accessible and affordable transport can reduce GHG emissions while improving the urban environment through improved air quality and health and enhancing social equity. A modal shift to public transport can deliver synergies with SDG 3.9 (reduce death or illness from air pollution), 7.3 (energy efficiency), 9.1 (resilient infrastructure development), 12.2 (Efficient resource use) and 13.2 (reduced emissions). Assumptions regarding the share of public transport and electrification of transport were included as part of the storyline for both models.

### 7.1.3 Residential and Commercial floor area:

Targets under SDG 11 aim to ensure safe and affordable housing while also promoting sustainable urbanization. Given the rapid growth in Gujarat, floor space for both residential sector and commercial sector will increase in future. Looking at the land cover classes for Gujarat, future projections show that the area under settlements would increase from 358 to nearly 1620 ha. This additional land would likely come from the area currently under grassland. While future housing and transport infrastructure necessary for the state would contribute positively to SDG11.2, there are trade-offs with SDG 12 and 15.

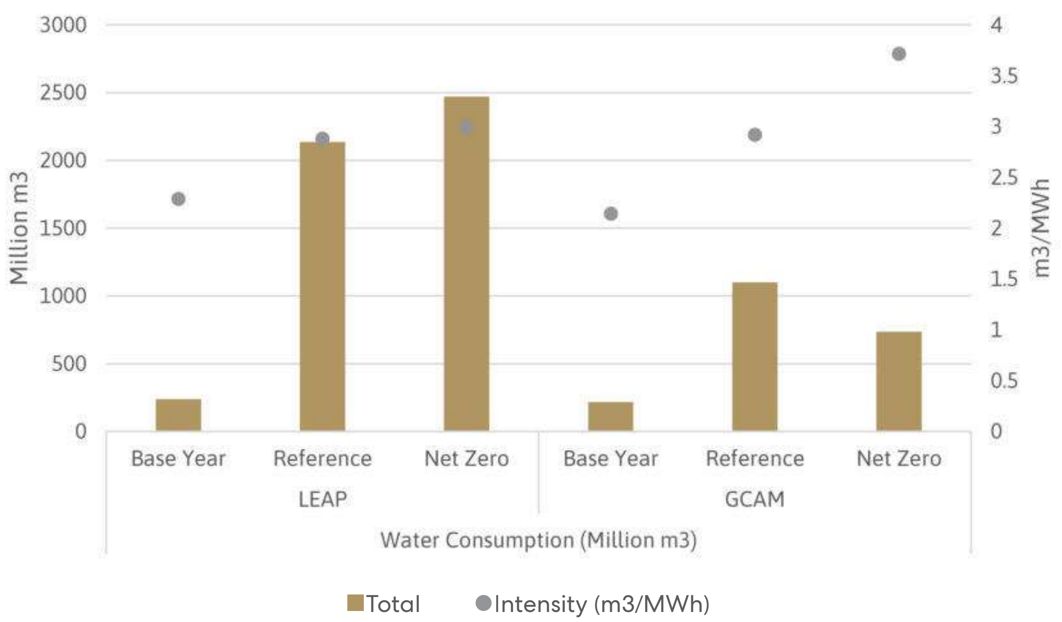
Increase in floor area along with other drivers such as GDP could increase demand for cooling in residential and commercial buildings. The present study compares the residential and commercial floor area for Reference and the Net zero scenarios. For both sectors, floor space increases substantially with the commercial sector witnessing a 10-fold increase in floor area. This has significant implications for material demand. See section 6.1.2 and 6.2.3 for details regarding floor space demand estimation.

### 7.1.4 Water:

Gujarat faces significant water scarcity due to increasing variability in rainfall patterns across the state, climate change, its dependence on inter-state rivers, and depleting groundwater levels from over-extraction. This makes water management a critical challenge for the state's sustainable future. A complex interaction exists between water consumption and clean energy production. Given that water is a vital resource for electricity generation—particularly for cooling systems—the state's future energy mix will have a substantial impact on water consumption. Transitioning to renewable energy reduces overall water consumption compared to thermal power plants. However, certain clean energy technologies like concentrated solar power or bioenergy crops may have significant water requirements.

The analysis compares water use in both the Net Zero (NZ) and Reference scenarios (Figure 7-2). Calculations for water consumption are based on assumptions from Chaturvedi et al. (2020). Overall water consumption increases in future for all scenarios due to the increase in electricity generation. The water consumption intensities (m3/MWh) are projected to increase in both the modelling exercises, compared to their reference scenarios. The structural shift scenario projects a lower intensity but a higher total water consumption as it considers a significantly larger share of nuclear energy compared to the GCAM NZ. Managing the increased water demand will be essential for balancing Gujarat's energy needs with its limited water resources.

***Figure 7-2 Water consumption and water use intensity for electricity generation***



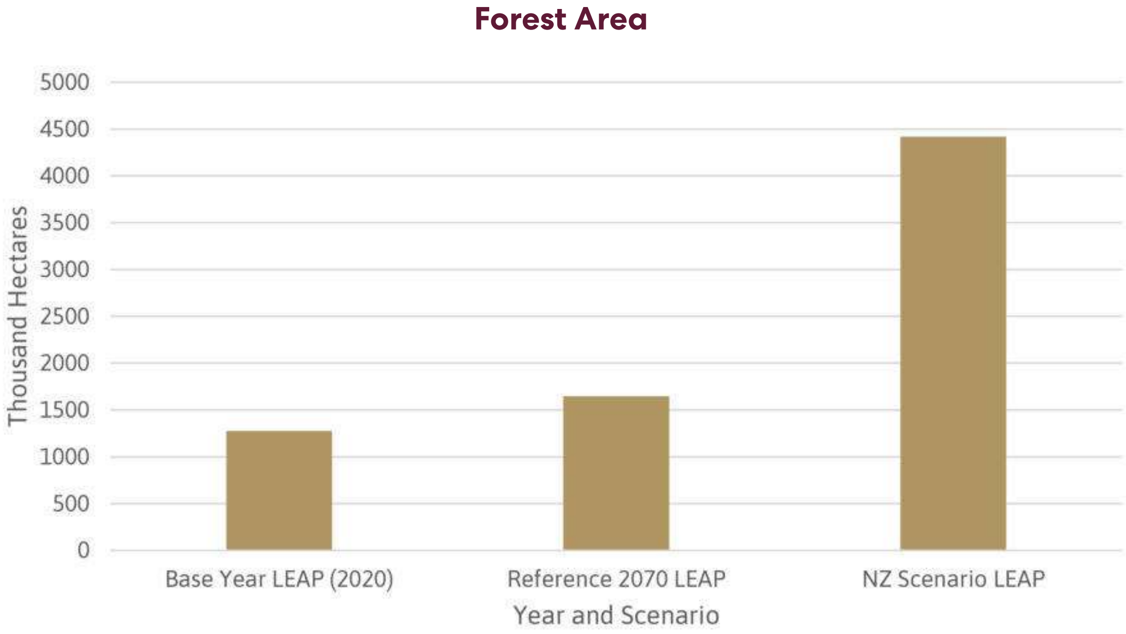
### 7.1.5 Area under forest cover:

In 2021, Gujarat's forest cover was around 1490 hectares (Forest Survey of India, 2021). This includes areas under very dense forests, moderately dense forests, and open forests. The state's afforestation and reforestation initiatives contribute to carbon sequestration. The total carbon stock in Gujarat was 107.7 million tonnes in 2021 (Forest Survey of India, 2021).

Between 1990 and 2021, the forest area in Gujarat increased (GEC, 2021).

The Reference scenario assumes continuation of this trend. In the reference scenario, forest area increases from 1489 ha in 2021 to 1645 ha in 2070. The NZ2070 assumes a much more ambitious increase where the share of area under forest cover increases by nearly 2.5 times from the present share to occupy 23% of the state's total area (GEC, 2021) (See section 6.2.6 and Figure 7-3).

***Figure 7-3 Forest area in Gujarat in thousand hectares***



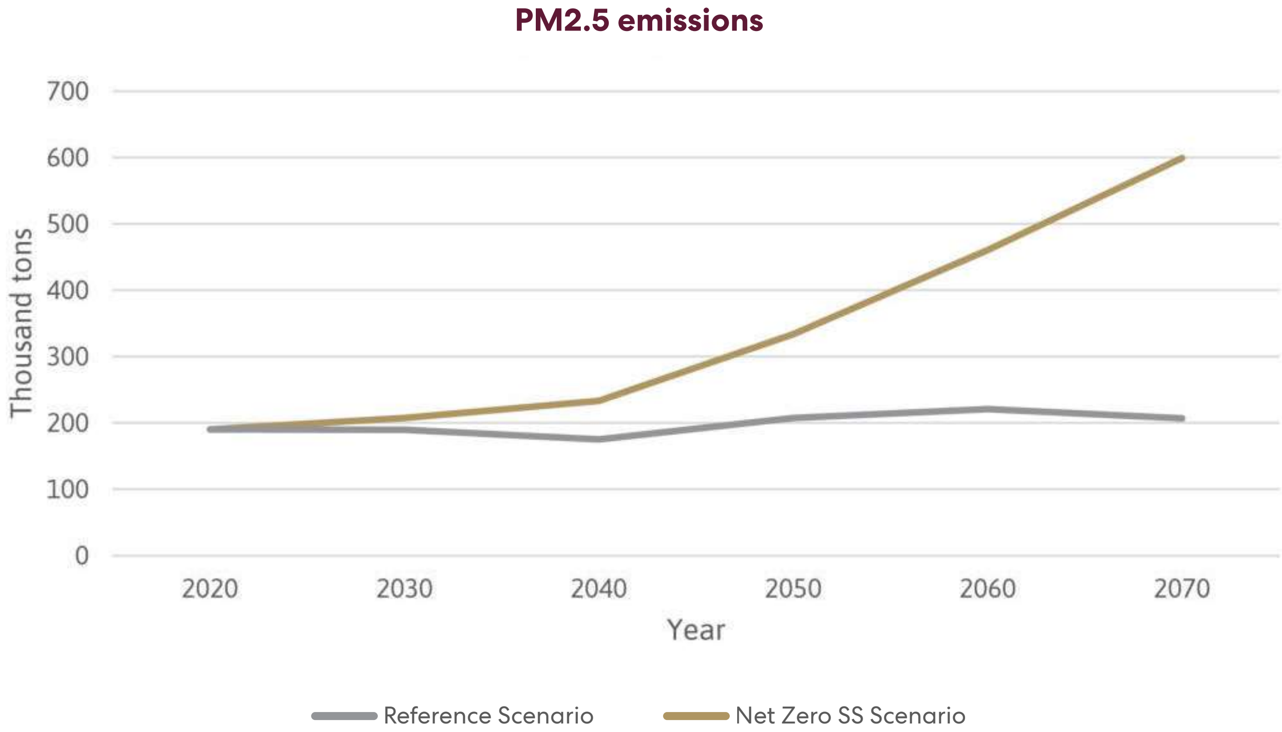

### 7.1.6 Air Pollution:

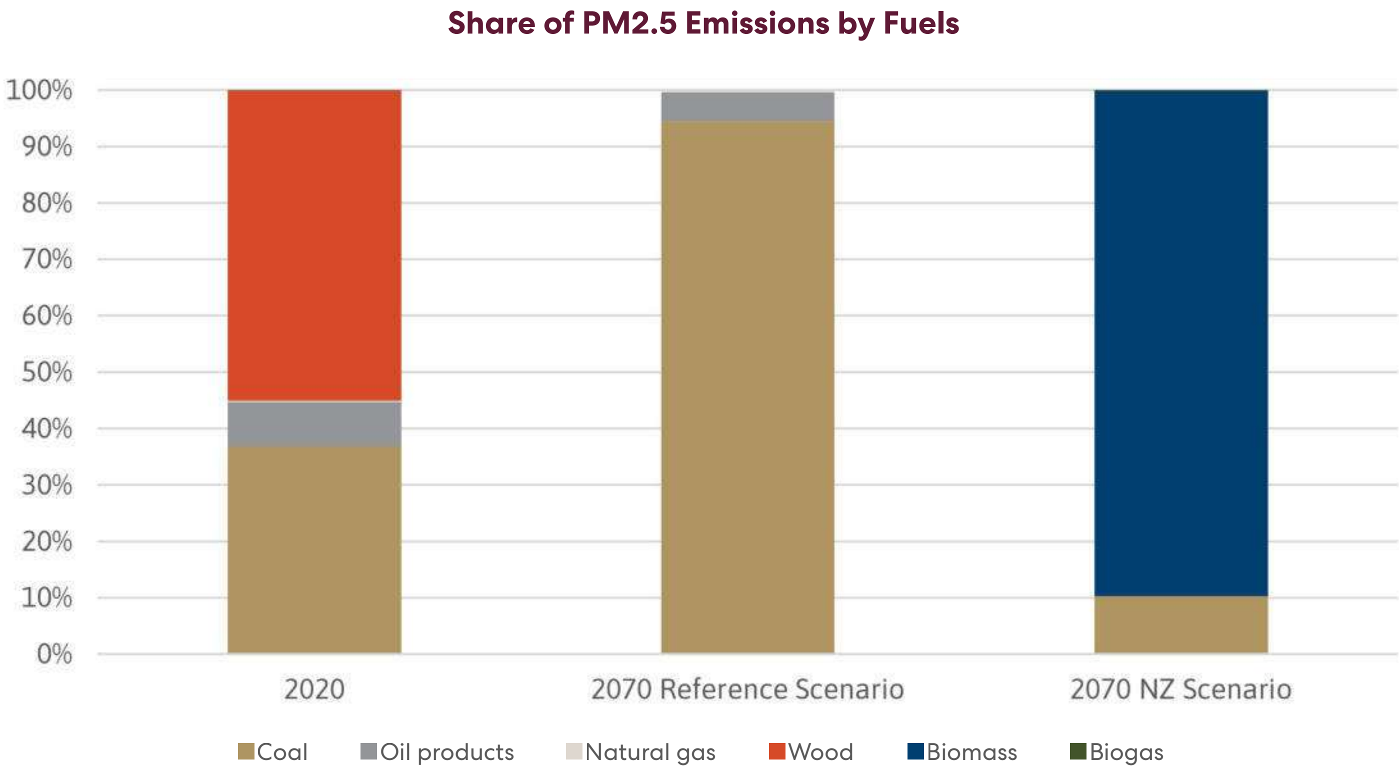
PM2.5 was used as a proxy for the particulate matter load. PM2.5 emissions were calculated for both scenarios (2070 Reference and 2070 NZ scenarios using LEAP). For PM2.5 emissions, Tier 1 emission factors from EMEP/EEA air pollutant emission inventory guidebook 2019 was used (EEA, 2019).

Currently, wood is responsible for 55% of PM2.5 emissions, followed by coal at 37% and oil products at 8%. In both scenarios, it is assumed that wood will be phased out in the household sector by 2040 (MoPNG, n.d.). Consequently, the share of wood in PM2.5 emissions is projected to be 0% after 2040 in both scenarios (See Figure 7-4).

In the reference scenario, PM2.5 emissions are anticipated to rise 3.2 times, from 190 thousand tons in 2020 to 600 thousand tons in 2070, with coal combustion contributing 94% of these emissions by 2070. Conversely, in the Net Zero SS Scenario, PM2.5 emissions are projected to decrease by 3 times in 2070 compared to 2070 in the reference scenario. However, this still represents an increase from current levels, rising from 190 thousand tons in 2020 to 207 thousand tons in 2070, with the majority (90%) of 2070 emissions coming from biomass combustion. The decrease in PM2.5 emissions in the Net Zero SS Scenario, compared to the Reference Scenario, is largely due to the phasing out of coal and oil products. However, despite achieving nearly zero $CO_2$ emissions by 2070, PM2.5 emissions are not completely eradicated because of biomass use in industry and coal use in the power generation.

***Figure 7-4 PM2.5 emissions projections by scenarios***

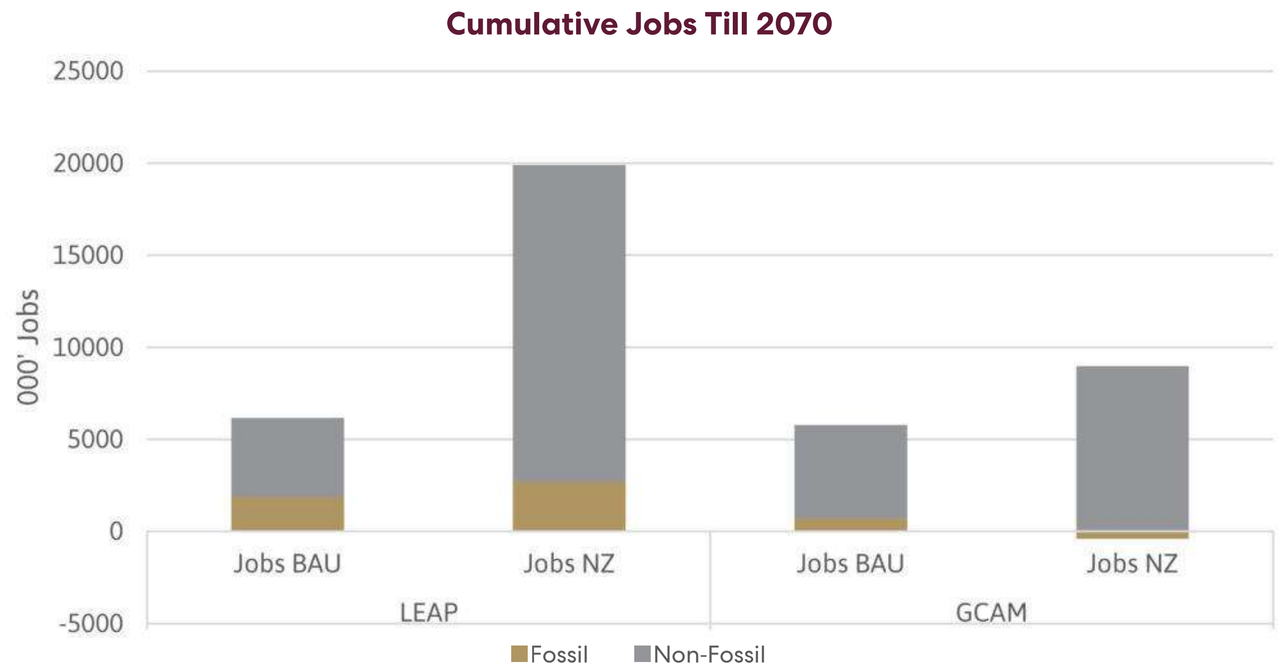


### 7.1.7 Annual GDP growth and global manufacturing value added (MVA) per capita :

Both the overall growth in the state's GDP, per capita income, and the increase in GVA can create employment opportunities, raise incomes, and reduce poverty by providing stable and often higher-paying jobs (See Section 5.2, 5.3 and 5.4 for more details). Sustainable industrialization is essential for inclusive growth and decent work. This could also potentially result from and lead to innovations and investments in technologies, new infrastructure and contribute to sustainable industrialization. However, growth does not necessarily result in greater equality and requires careful policies to ensure this enhances opportunities for all. For example, efforts towards skill development and infrastructure, particularly the districts that are lagging can deliver equitable growth and benefits.

***Figure 7-5 Employment in the Power sector*** (***Cumulative jobs disaggregated by fossil and non-fossil jobs***)




### 7.1.8 Employment:

The shift towards a low-carbon economy presents both opportunities and challenges for employment. New jobs will be created in renewable energy, energy efficiency, and green technologies (See Figure 7-5). However, traditional fossil fuel-based industries may face job losses. Studies focusing on the workforce transition, have carried out macroeconomic analyses of the employment impact of switching to more renewable energy (RE) and have found net job creation (Carley & Konisky, 2020). Studies for India have shown employment impacts from the energy transition (Agrawal et al., 2024; Malik et al., 2021). The study compares employment change across scenarios. Employment coefficients were taken from Malik et al. (2021). These included employment coefficients for different electricity sources and for five future time periods (2020, 2030, 2040, 2050). Employment coefficients for2050 were assumed to continue in future through to 2070. Results show a significant generation of jobs in the NZ scenarios compared to BAU with the LEAP model showing slightly higher numbers due to a different electricity mix. However, there is a loss of jobs in the fossil fuel sectors. In particular, the GCAM Net zero scenario shows a net loss of nearly 300,000 jobs until 2070.

While the current categorization by fossil and non-fossil sectors provides valuable insights, gender-disaggregated data would add a crucial layer of understanding to the distributional impacts of the net-zero transition. It would help identify potential gender disparities in job creation and loss. Targeted interventions and support systems can be put in place to ensure a just transition for all.

### 7.1.9 Other Distributional Impacts:

While the study is limited to assessing major impacts of the transition, several actions could have distributional consequences for regions, cities or communities within the state. For instance, the shift in water consumption patterns due to the net zero transition could have varying impacts across Gujarat's regions and user groups. For instance, changes in water demand for power and industry could have implications for the following communities:

Agricultural communities: Changes in water availability for irrigation, particularly in drought-prone areas of Gujarat, could significantly affect small-scale farmers who may lack resources to adapt to new water management practices.

Urban-rural divide: The transition might exacerbate existing disparities in water access between urban and rural areas, potentially leading to increased migration if rural water security is compromised. Industrial clusters: As industries transition to cleaner technologies, changes in water consumption could impact nearby communities, especially in areas where water resources are already strained.

Changes in forest cover as part of the net zero strategy could have significant implications for the following populations:

- Tribal communities: This could potentially increase the availability of forest products, thereby improving income and food security. This could also provide other opportunities for development. for example, community-managed sustainable forest-based enterprises or sustainable ecotourism projects through involvement of local communities.

- Land use conflicts: Expansion of forest areas could lead to conflicts with other land uses, such as agriculture or renewable energy installations, potentially affecting rural communities and smallholder farmers.

The reduction in PM2.5 emissions could have differential benefits across Gujarat's population:

- Urban poor: Improvements in air quality would benefit all citizens, however, there would be higher benefits in densely populated cities where the air quality index ranges from poor to severe levels. This could also reduce the burden on lower-income populations, especially slum and pavement dwellers residing near major traffic prone areas.

- Industrial zones: Communities living near industrial areas could see significant health improvements, potentially reducing the burden of respiratory diseases and associated healthcare costs.

## 7.2 Summary of Sustainable Development Assessment

Gujarat’s net zero transition entails reductions in greenhouse gas emissions, delivered through increased electrification and clean energy. This transition would imply job creation, reduced air pollution, and an increase in forest area. The adoption of new technologies for example green hydrogen can generate new employment opportunities from manufacturing.

However, ambitious growth can also imply trade-offs in the near term; for example, housing or new infrastructure development can increase demands for materials and energy and conflict with energy efficiency goals. These criteria underscore the potential advantages of renewable energy projects and the critical areas to consider within Gujarat's unique socio-economic context. Similarly, a higher share of public transport can deliver multiple benefits. However, urban areas often have greater access to energy-efficient public transport or smart energy systems. At the same time, rural or poorer regions may lack the infrastructure or funds to implement such improvements, widening the energy gap.

Gujarat’s expected level of urbanization would entail significant demand for additional land. As the land under settlements increases, this would involve taking up other lands- in this case possibly the loss of grassland. In 2070, area under grasslands would get close to zero. Given that grassland is an important ecosystem, this may have significant impacts on local ecosystems and biodiversity and potential secondary impacts on communities dependent on these ecosystems (Das & Das, 2019; Nagendra et al., 2013; Seto et al., 2012; Simkin et al., 2022).

The Table 7-1 below shows how scenarios impact selected SDG targets and indicators. Results show both models showing potentially higher synergies with SDGs. Fewer trade-offs were identified.

***Table 7-1 Summary of indicators and their synergies and trade-offs with SDGs***

| Action | Potential Synergy | Potential Trade-off | Remarks |
|---|---|---|---|
| **Environmental** | | | |
| $CO_2$ Emissions (in Million Tonnes) [Sections 6.1.7 & 6.2.9] |   | | Both Net zero scenarios result in emissions reductions, however emissions continue to increase in the near term |
| Share of renewables in electricity % [Sections 6.1.5 & 6.2.5] Share of renewables in TFEC [Sections 6.1.6 &6.2.8] |   | | This could create local employment<br><br>Potential trade-offs to communities or biodiversity depending on the scale and location of the projects |
| Share of traditional biomass in the residential sector [Sections 6.1.3, 6.1.6, 6.2.3 & 6.2.8] |   | | Poorer households reliant on biomass would require affordable supply of alternate sources |
| Energy efficiency (Primary energy in Million GJ/Billion USD GDP) [Sections 6.1.6 & 6.2.8] |   | | Higher energy efficiency may require increased investments in the near-term |
| Increased electrification of the transport sector [Sections 6.1.2 & 6.2.2] |   |   | Higher electrification may need careful consideration of infrastructure needs and increased demand for electricity and materials |
| Water consumption for electricity [Sections 6.1.5 & 6.2.5; and Kholod et al. (2021)] | |   | The GCAM scenario shows a decrease in water consumption however the intensity is higher. The overall water consumption increases for the LEAP analysis |
| Increase in forest area [See Section 6.2.6.2] |   |   | An ambitious increase in forest cover in the Net zero scenario can deliver a host of ecosystem services and support biodiversity conservation. However, this may entail trade-offs with other land uses |

| Action | Potential Synergy | Potential Trade-off | Remarks |
|---|---|---|---|
| | | **Economic** | |
| Annual GDP growth and global manufacturing value added (MVA) per capita [Sections 4.2 & 4.3] | TARGET 9·B SUPPORT DOMESTIC TECHNOLOGY DEVELOPMENT AND INDUSTRIAL DIVERSIFICATION | TARGET 8·4 IMPROVE RESOURCE EFFICIENCY IN CONSUMPTION AND PRODUCTION<br>TARGET 13·2 INTEGRATE CLIMATE CHANGE MEASURES INTO POLICIES AND PLANNING<br>TARGET 12·2 SUSTAINABLE MANAGEMENT AND USE OF NATURAL RESOURCES | Economic growth can lead to higher resource consumption, material consumption and possibly higher emissions<br>High-productivity sectors often demand high levels of skill and capital, which can lead to inequality if benefits are concentrated among larger companies and skilled workers. |
| GHG emission per unit of value added (Million tonnes per Billion USD) [Sections 4.2, 4.3, 6.1.7 & 6.2.9] | TARGET 8·1 SUSTAINABLE ECONOMIC GROWTH<br>TARGET 8·2 DIVERSIFY, INNOVATE AND UPGRADE FOR ECONOMIC PRODUCTIVITY<br>TARGET 8·3 PROMOTE POLICIES TO SUPPORT JOB CREATION AND GROWING ENTERPRISES | | Structural changes and particularly the type of industries in future could reduce the emissions intensity of the state's economy |
| Phase out of coal [Sections 4.2, 4.3 & 6.1.8] | TARGET 7·2 INCREASE GLOBAL PERCENTAGE OF RENEWABLE ENERGY | TARGET 9·B SUPPORT DOMESTIC TECHNOLOGY DEVELOPMENT AND INDUSTRIAL DIVERSIFICATION | In addition to employment impacts, this could also lead to stranded assets, particularly in the NZ-CCS scenario |

| Action | Potential Synergy | Potential Trade-off | Remarks |
|---|---|---|---|
| | | **Societal** | |
| Employment [Sections 6.1.5, 6.1.6, 6.2.5 & 6.2.8; EF from Malik et al. (2021) | TARGET 8·5 FULL EMPLOYMENT AND DECENT WORK WITH EQUAL PAY | TARGET 8·5 FULL EMPLOYMENT AND DECENT WORK WITH EQUAL PAY | This would involve loss of employment in the fossil fuel sector. However, new technologies in the NZ scenario could potentially generate a large number of green jobs. This change could have distributional consequences for workers in fossil fuel sector |
| Increased share of public transport [Sections 4.3, 6.1.2 & 6.2.2] | TARGET 11·2 AFFORDABLE AND SUSTAINABLE TRANSPORT SYSTEMS<br>TARGET 9·1 DEVELOP SUSTAINABLE, RESILIENT AND INCLUSIVE INFRASTRUCTURES | | Achieving a synergy with SDG 11 would require improving access and affordability |
| Increase in residential and commercial floor area [Sections 6.1.3 & 6.2.3] | TARGET 11·2 AFFORDABLE AND SUSTAINABLE TRANSPORT SYSTEMS<br>TARGET 11·1 SAFE AND AFFORDABLE HOUSING | TARGET 12·2 SUSTAINABLE MANAGEMENT AND USE OF NATURAL RESOURCES<br>TARGET 8·4 IMPROVE RESOURCE EFFICIENCY IN CONSUMPTION AND PRODUCTION<br>TARGET 15·1 CONSERVE AND RESTORE TERRESTRIAL AND FRESHWATER ECOSYSTEMS | Future urbanization will involve loss of grasslands potentially impacting biodiversity |

* **Note**: The SDG synergies are shown for indicators where quantitative assessment was possible. Potential trade-offs are not quantified. Square brackets show sections where results are presented

Improving air quality through reduced PM2.5 emissions can have positive impacts on public health for example decreased respiratory illnesses and improved productivity. However, rapid economic growth may lead to increased emissions if not managed properly. To balance these goals, the following actions can be taken.

- Promote clean technologies and stringent emission standards in industry
- Invest in sustainable urban planning and public transportation
- Encourage circular economy practices to reduce industrial emissions

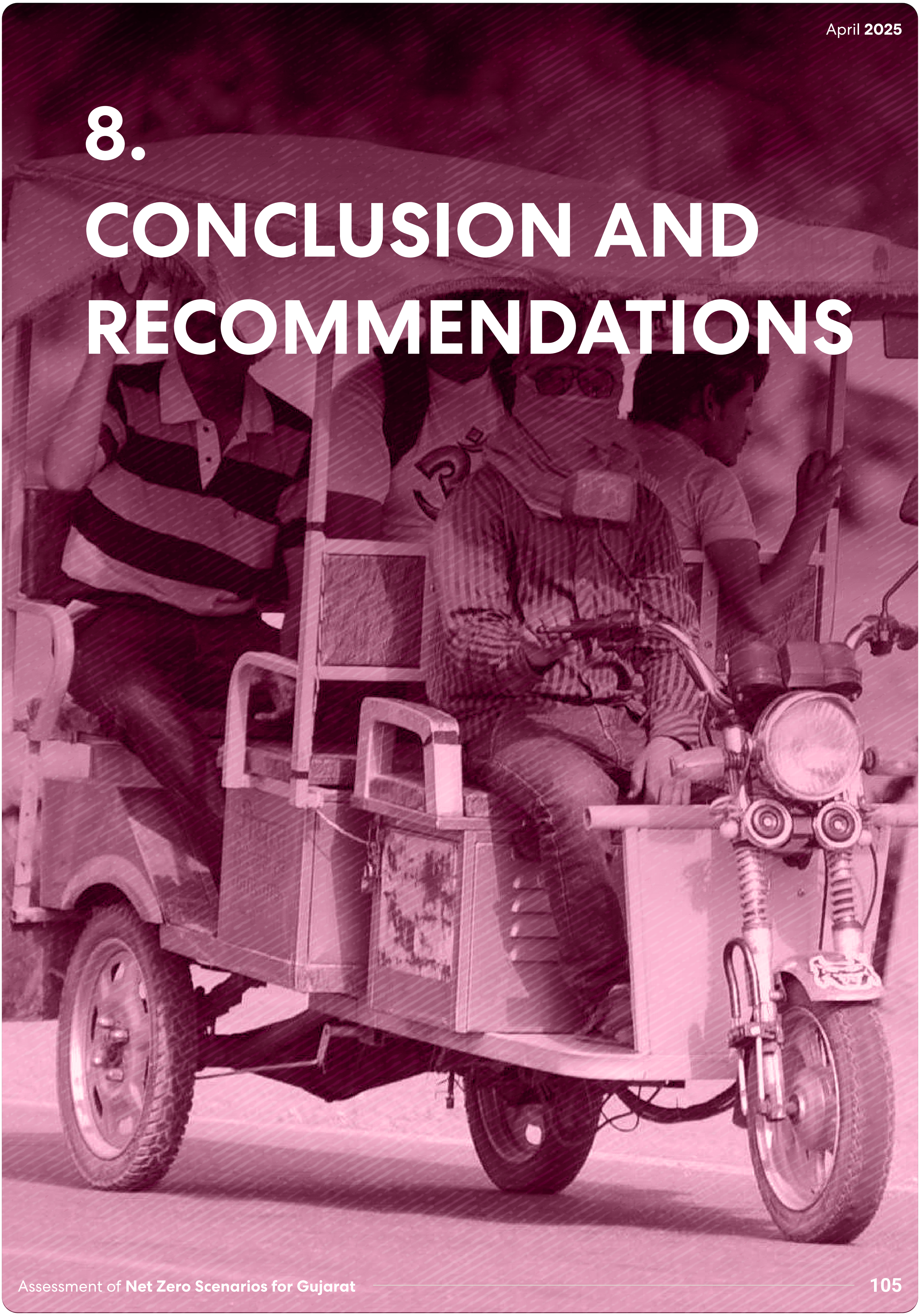
All future scenarios show an increase in water consumption from electricity production. The challenges associated with higher water demand in future would require prioritising water-efficient technologies, implementing water recycling and conservation measures in energy production and targeting research and development of drought-resistant bioenergy crops suitable for Gujarat's climate.

Another significant trade-off may be related to employment impacts due to the change in future energy mix.

Newly created non-fossil jobs need not necessarily be in the same region or area as the lost jobs from the fossil sector. The new employment created from renewable energy may potentially require higher or a different set of skills, resulting in direct employment implications for workers in the fossil power generation. Efforts may be directed to implement targeted skill development programs for workers in transition, providing support for affected communities and regions and encouraging green entrepreneurship and innovation. The transition could offer opportunities to address existing gender imbalances in the workforce. Gender is a key aspect of a development compatible net zero transition and therefore policies must prioritize women's skill development and participation in new green industries.

Such a transition could also lead to secondary impacts for example, migration or displacement in search of employment opportunities. Actions such as energy or infrastructure projects may result in benefits or adverse impacts for different communities however these are not assessed in the current project. Future studies on assessing the distributional consequences could improve our understanding of these differential impacts and support inclusive policy making for the state.

# 8. CONCLUSION AND RECOMMENDATIONS



The analysis in this report is based on the assessment of alternate policy scenarios for achieving Net Zero emissions in Gujarat. The Net Zero Scenarios are compared to a reference scenario. The scenarios span a time frame from the base year (2020) up to 2070, in line with the Government of India's announcement to achieve net zero emissions by 2070. The assessment is carried out using two different models: i) Global Change Analysis Model (GCAM) and ii) Low Emissions Analysis Platform (LEAP). Both models include a reference scenario and a Net Zero Scenario. While some socio-economic assumptions are common for both the models, these differ in their approach to demand estimation and achieving net zero emissions (See section 4). This section presents key insights from the assessment and recommendations for the sectoral transformations.

## $CO_2$ emissions

In 2022, total emissions in Gujarat amounted to 232 $MtCO_2eq$ recording an increase of 62% in energy sector emissions since 2010. The industry sector was the largest contributor, accounting for 49% of the total emissions. Electricity generation contributed 36%, transport contributed 13% to total emissions. The impact of COVID is clearly visible in the trends with the emissions dropping to 222 $MtCO_2eq$ in 2021 against the estimated high of 242 $MtCO_2eq$ in 2019 just before the pandemic.

This trend is expected to continue in future with the industrial sector (of which manufacturing is a major part) emerging as the largest contributor to energy consumption as well as the emissions in the reference scenario. Future emissions rise across all scenarios however these vary across and within sectors.

According to LEAP results, in the Reference Scenario, $CO_2$ emissions are projected to rise from 241 Mt in 2020 to 1391 Mt by 2070, with a CAGR of 3.6%.

Similar trends are observed in the GCAM reference scenario, where emissions increase almost five times between 2020 and 2070. In the NZ scenario, emissions double until the peak year in 2040 after which they decrease steeply. This is significant emissions reduction as it represents a 14-fold decrease in emissions by 2070 compared to the Reference Scenario. In the LEAP reference scenario the primary contributors to this reduction are the industry and transformation sectors (mainly power generation), which account for 83% of the total emission reductions. The power sector is the first to completely decarbonize in 2050, the transport sector by 2060, and buildings sector by 2070.

## Residual emissions

Despite a comprehensive shift in fuels and technology to reduce greenhouse gas emissions in all net zero scenarios, a small amount of residual emissions remain.

Total residual emissions in 2070 amount to 98 $MtCO_2$ for the LEAP NZ scenario and112 $MtCO_2$ for GCAM). Unmitigated emissions mainly include those from the power sector and IPPU. These will have to be compensated by sequestration in the land-use sector.

Given the challenges with land availability and competing demands, unmitigated $CO_2$ emissions may have to be offset in other states or through the state's own measures beyond the interventions considered in this study. This could include adoption of CCS in industry and IPPU sectors, shifting from energy-intensive to less energy-intensive industries with high value added. Though not assessed in the present study, future studies could explore demand side management and lifestyle and behaviour changes to reduce demand and emissions.

## Electricity Supply

Higher end use electrification results in a high energy demand across all scenarios.

In GCAM, electricity demand increases 10 and 25 times in 2070 in the reference and NZ scenario respectively. In net-zero scenario, 86 % of the total energy consumed is from electricity compared to 28% in the reference scenario. In the near-term until 2030, electricity demand from GCAM (~10 % CAGR) is higher than other government estimates (5.3-7.4 % CAGR) mainly due to higher GDP growth rates assumed in line with the state's vision and from higher end-use electrification, particularly in industry.

The backbone of the higher electricity demand is much higher levels of renewable energy generation.

The total electricity generation in the net zero scenario in 2070 is higher than in the reference scenario in LEAP).

The increase in electricity demand outpaces the increase in electricity. After 2050, the increase in generation cannot meet the future electricity demand due to limited renewable generation potentials (mainly solar) within the state, and imports from other states might be needed. Options for demand-side management, enhanced energy efficiency and behavioral change can be explored in future studies. These could reduce electricity demand and potentially avoiding the need for electricity imports.

## RE additions and Investment costs from power generation

There is significant expansion of renewable energy, particularly solar and wind. The LEAP model shows renewable power generation (solar and wind) increases from 15% in 2020 to 66% in the Net Zero SS Scenario. Achieving the net zero goal requires 2.6 times more installed capacity in 2070 compared to the Reference Scenario.

In the GCAM reference scenario, total solar + wind capacity by 2030 is 143 GW. By 2040, the reference and NZ numbers are 318 GW and 374 GW respectively. Only assuming the capital costs of the power plants, electricity capacity additions require a cumulative investment (from 2020-2070) of ₹55 lakh crore in the reference scenario, increasing to ₹74 lakh crore in the net zero scenario.

Gujarat has already set a target of 100 GW of RE capacity by 2030. The study suggests that this needs to be increased and then sustained over the subsequent decades to be aligned to net-zero. Thus, despite ambitious strides in renewable energy penetration, future decarbonization would require further policy pushes for scaling up and integrating renewable energy in the state.

## Energy Storage and Grid Modernization

With increased levels of variable renewable energy in the grid, the need for grid-scale battery storage increases. Large-scale storage solutions (e.g., pump hydro storage, battery energy storage, long-duration energy storage) and a more flexible, resilient grid are essential for handling renewable energy fluctuations. (See section 6.1).

## Role of CCS and Phase out of coal

In the LEAP study, the primary assumption is that coal power will be significantly reduced in the Net zero scenario, though not entirely phased out. It is expected that new coal power plants will be equipped with CCS technology after 2050.

GCAM explores a scenario where coal plant additions continue until 2035 and CCS technology is available. In the NZ-CC, by 2045, coal-CCS has a small share in the electricity mix (~2%). This shows that continuing the use coal with CCS is not economical, and that cheaper renewable energy dominates the power sector.
☒
In the scenario, where coal with CCS additions are also available as the technology, the phase out of coal doesn't change, implying the cost competitiveness of renewable energy technologies.

## Industry Decarbonization

Energy demand from industry will increase significantly in the reference scenario (7.6 times in GCAM and 8.4 times in LEAP) due to increased per capita incomes that will drive demand for commodities like chemicals, plastics, paints, cosmetics, metals, cement, etc.

The growth in energy will, however, vary across different sub-sectors. For example, the energy demand for chemicals will grow 9 times, whereas the steel demand will grow only 4.7 times. Since energy demand in the industry will be largely met by fossil fuels (coal, oil and gas), it will result in an increase in $CO_2$ emissions of 8.3 times in the LEAP model and 6 times in the GCAM model.

## Energy Efficiency

Decarbonisation in industry happens through energy efficiency and electrification in the near term, and higher hydrogen use in the long term. EE measures can deliver significant emissions reductions without substantially increasing the cost of production.

Gujarat has a dedicated Energy Efficiency Plan for the different industrial sub-sectors and has successfully reduced emissions through energy efficiency targets as part of the Perform Achieve Trade (PAT) scheme.

Gujarat could potentially follow more stringent energy efficiency targets and widen the scope of industries including for example by including medium and small manufacturing enterprises (MSMEs). Promoting "Green Rating of Industries" can be further tailored to specific industries. Further developments are expected beyond 2026, with the introduction of India's Carbon Credit and Trading Scheme. Increasing electrification and use of green hydrogen will also accelerate energy efficiency improvements in industry

### Electrification:

Since electricity gets increasingly decarbonised with time, substituting fossil fuels with electricity can help in decarbonising the industry sector. It is easier to electrify processes at low (<100C) and medium (100-400 C) temperatures in industries such as textiles, paper, etc. However, high-temperature processes (400-1000 C) used in petrochemical industries and very high temperatures (> 1000 C) used in steel, cement, and ceramics are not easy to electrify. In such cases, green hydrogen and biomass are more relevant.

The Industry Policy of Gujarat currently provides capital subsidies based on eligible Fixed Capital Investment (FCI) to large industries for setting up manufacturing operations in the state. A higher capital subsidy could be provided to industries with higher electrification components in their manufacturing operations, or subsidies could be removed for manufacturing industries where fossil-fuel-based boilers or furnaces are used.

### Green Hydrogen

Both models show that green hydrogen will be a significant source of final energy by 2070. Green hydrogen will be a clean fuel alternative for industry sub-sectors that are not easy to electrify as well as fine use as raw material for example in the fertiliser sector. Green hydrogen will also be needed in shipping and aviation.

Results from LEAP are more optimistic about hydrogen, and would see the total final consumption of hydrogen increase to 3.5 million GJ (around 30 million ton H2) from almost 1.6 million ton H2 now.

Scaling up green hydrogen will require investments in R&D, pilot projects, and the creation of infrastructure for the transportation of green hydrogen. A large part of green hydrogen production is envisaged through the electrolyzer hydrogen production process, which requires electricity. In the long term (post-2050), the renewable potential will be insufficient to support both electrolyzer hydrogen production and end-use demands. Gujarat may require to import hydrogen or electricity after 2060

### Excess Heat Recovery

Though not modelled a significant amount of energy input could be wasted as heat, and can offers untapped opportunities to capturing and reusing excess heat through industrial microgrids and district energy systems. This can significantly reduce emissions and energy costs.

## Transport

### Modal Shift

In future, the energy demand for transport increases for both freight and passenger transport. In 2020, passenger transport accounted for around 80% of energy demand and freight the rest. However, the share of freight in energy will increase faster in both GCAM and LEAP. Modal shift strategies can play a more significant role in freight transport. Such a shift would require improved intermodal integration, especially increasing rail connectivity with smaller ports.

Growing population and incomes result in a steep increase in the demand for passenger transport grows significantly in all future scenarios. Results from LEAP show an increase of 3.1 times in passenger transport demand between 2020 and 2070. Sustainable urban planning that prioritizes compact, mixed-use development can minimize land consumption, reduce transportation emissions, and promote walkability and public transit, aligning with net zero objectives. Spatial planning and urban land use policies alongside investments in public transport (metros, buses) are required to increase the share of public transport systems.

### Electric Mobility

Electric vehicles (EVs) will play an important role, especially in light-duty vehicles.

In GCAM, significant electrification of the transport sector already takes place in the reference scenario on the back of decreasing cost of batteries, leading to 48 % of the total energy demand from electric vehicles. The remaining fossil share is mainly from freight trucks and shipping. In the NZ scenario, close to 100 % of the transport system is electrified. Expanding the necessary infrastructure, like charging stations and parking policies in cities, is essential for ensuring this. A shift to EVs, particularly when electricity is decarbonised would deliver substantial benefits from reduced PM2.5 emissions.

The Net zero scenario based on the LEAP analysis shows that by 2070, the energy mix is completely fossil-free, with electricity meeting 50% of the final energy demand, followed by biofuels and bio-CNG. Green ammonia and hydrogen also take a small share, mainly for use in shipping and heavy trucks.

## Buildings

Increase in cooling demand and building energy efficiency. Rapid growth in floor space (4times in residential and 10 times in the commercial sector) happens between 2020 and 2070.

GCAM assumes increasing cooling degree-days due to warming from climate change. Together with increasing incomes and urbanization, there is a significant increase in cooling demand. Between 2020 and 2070, cooling demand increases by 52 times.

The LEAP analysis also shows a rapid increase in energy demand- increasing from 6.2 million GJ in 2020 to 586 million GJ in the Reference Scenario . Energy demand from cooling in the Net zero scenario is lower (354 million GJ) mainly due to annual increase in efficiency improvements for cooling appliances.

Building energy efficiency improves significantly in both models however, growth in floorspace and air conditioner use outpaces these improvements. Ambitious building energy efficiency guidelines, mandates and enforcement can reduce building energy demand in future

## Phase out of biomass and electrification

Traditional biomass use for household cooking will be completely phased out before mid-century; however, the role of commercial biomass in the industry sector will increase in the Net Zero scenario.

Results from the LEAP model show that the share of cooking in residential energy consumption declines to 14% by 2070 in the Net Zero SS Scenario. This shift is partly due to the phase-out of inefficient cooking stoves using firewood and kerosene by 2040, replaced by more efficient LPG and PNG in the reference scenario and electricity in the Net Zero SS Scenario. Other end-uses like lighting, cooling, appliances etc. are already electrified in both scenarios.

## Implications for Sustainable Development

Gujarat's net-zero transition faces challenges due to its high energy demand, industrial growth and a fossil intensive economy. However, the transition also brings opportunities for green jobs, improved public health, and energy security. Sizeable benefits can be achieved through higher electrification and renewables directly through reduced $CO_2$ emissions, share of clean energy, reduced PM2.5 emissions and potential indirect benefits such as improved health (from air quality improvement), technology development and manufacturing capacity within the state.

In the near-term, potential adverse impacts such as displacement of communities, unequal access to energy benefits, and loss of agricultural land must be carefully examined. These issues are especially pertinent in Gujarat.

## PM2.5 Emissions

PM2.5 emissions will increase across all scenarios in future. Analysis using LEAP results shows that PM2.5 emissions will increase by 3.2 times between 2020 and 2070, largely dominated by coal and wood combustion. However, a change in energy mix, particularly phasing out coal and oil results in a significant decrease in the Net Zero scenario.

However, even in 2070, PM2.5 emissions are not completely eradicated because of biomass use in industry and coal use in the power generation.

## Water demand

Overall water consumption increases in future for all scenarios due to the increase in electricity generation. In LEAP, the net zero scenario projects a lower intensity but a higher total water consumption as it considers a significantly larger share of nuclear energy compared to the GCAM NZ.

The challenges associated with higher water demand in future would require prioritising water-efficient technologies, implementing water recycling and conservation measures in energy production and targeting research and development of drought-resistant bioenergy crops suitable for Gujarat's climate.

## Implications for Employment

In both the Net zero scenarios, the share of coal power is significantly reduced. In the LEAP Net Zero Scenario, coal's share declines substantially reaching 23% in 2070. This shift away from fossil fuels which can have significant impacts on employment and fossil fuel assets. Net employment is generated, but fossil jobs will be lost. The transition may lead to short-term job losses in conventional energy sectors.

Documenting best practices and lessons learned from similar energy transition efforts in other regions or countries can inform Gujarat's strategy development and implementation. Efforts may be directed to implement targeted skill development programs for workers in transition, providing support for affected communities and regions and encouraging green entrepreneurship and innovation.

Gender is a key aspect of a development compatible net zero transition. Women's participation in the manufacturing sector can lead to a more diverse and inclusive workforce, bringing different perspectives and skill sets to drive innovation and efficiency. Efforts need to be made towards achieving gender equality by enhancing women's participation in the secondary and tertiary sector, ensuring state policies and infrastructures benefit vulnerable populations, including women and involving these communities in decision-making

## Limitations and future work

Both models indicate that a significant share of variable renewable energies is essential to meet the growing energy demand in a Net Zero scenario. Long-term energy system models often face challenges in accurately assessing energy storage and dispatch. Since storage is not supported in simulation-based scenarios in LEAP, storage requirements were not evaluated with LEAP. Future research should focus on dispatch modeling in the power sector to assess storage requirements. Power sector models are designed to manage the operational aspects of the electricity grid, incorporating high temporal resolution and considering start-up performance (including start-up time and related costs) as well as the minimum load level of power generating units.

Future studies could take a more granular approach to assessing sustainability impacts of the net zero transition. For example, how would scaling up renewable energy impact biodiversity or how could women and other marginalised communities benefit from the transition. Future urbanization and growth of the manufacturing and service sectors would entail additional demands on land and water. Future work could look more closely at the land sector including agriculture, land use and forestry and associated impacts on biodiversity and ecosystems.

The current net-zero scenario assessment does not assume major changes in end-use demands compared to the reference scenario. However, lifestyle and behaviour changes can have a significant impact. A variant of the net zero scenario may explore the implications of reduced demand (e.g. through behavioural changes, lifestyle changes, infrastructure and end-use technology adoption); however, this is presently not considered within the scope of this report. Promoting sustainable lifestyle choices and raising public awareness about low-carbon living can deliver additional emission reductions and resource savings. Future studies can assess the potential associated with demand-side changes.

Changing industrial structure and move towards industrial sectors with lower energy intensity (Energy consumed per GVA added). Sectors like automobile manufacturing, machinery, food processing industry, electronics, etc., consume lower energy per GVA compared to steel, cement, and chemicals. According to Gujarat's Industrial Policy and Gujarat's 2047 vision, it already wants to shift its focus on promoting these types of industries. Future studies can assess the mitigation potential associated with changes in industrial structure.

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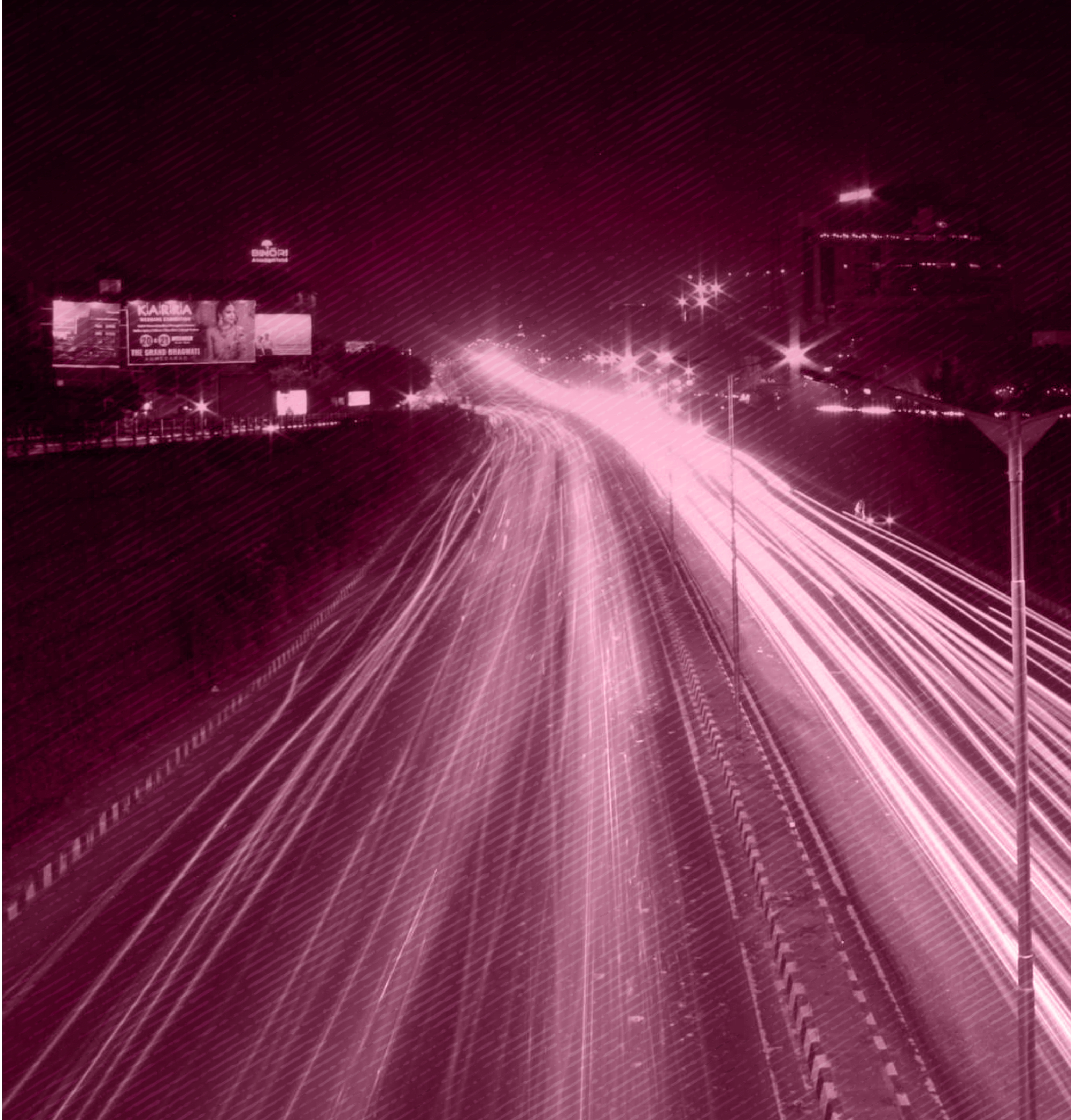
# 10. APPENDIX



## 10.1 Methodology and Assumptions for GCAM Model

### 10.1.1 Modelling end-use energy sectors in GCAM

Generally speaking, demand for each energy service grows in response to income and service prices.

Technologies compete on the basis of cost and efficiency to provide a given service.

GCAM models three end-use energy sectors – **buildings**, **industry**, **and transportation.** In GCAM-CEEW, the buildings sector is disaggregated into commercial buildings, rural residential, and urban residential sectors. Energy service demand is modelled for air-conditioning (high and low efficiency), cooking (biomass, coal, electricity, liquefied petroleum gas (LPG), and natural gas), lighting (fluorescent bulbs, incandescent bulbs, kerosene lamps, and LEDs), refrigeration (high and low efficiency), ventilation (low- and high-efficiency ceiling fans), television, water heaters (electricity, LPG, solar) and 'other appliances' as a category.

The future evolution of **building energy** use is shaped by changes in (1) floorspace, (2) the level of building service per unit of floorspace, and (3) fuel and technology choices by consumers. Residential floorspace depends on population, income, population density, and exogenously estimated parameters. Commercial floorspace depends on population, income, the average price of energy services, and exogenously specified satiation levels. The level of building service demands per unit of floorspace depend on climate, building shell conductivity, affordability, and satiation levels.

The energy demand in the **transportation sector** is modelled for passenger transport (road, rail and aviation), freight transport (road and rail), and international shipping with the demand for each service being driven by per capita GDP and population. Each type of service demand is met by a range of competing modes. For passenger transport, two-wheelers, three-wheelers, cars, buses, railways, and aviation compete with each other for providing passenger service. Changes in modal shares in future periods depend on the relative costs of the different options, modelled using a logit choice formulation.

Costs in the passenger sector include time value of transportation which tends to drive a shift towards faster modes of transport (light duty vehicles, aviation) as incomes increase.

No upper limits of battery electric vehicles (BEV) or fuel cell vehicles (FCV) use are implemented. In GCAM-CEEW, population and income (GDP) are the exogenous drivers of passenger service demand expressed in passenger kilometres travelled (PKT). Further, in GCAM-CEEW the passenger service demands by mode are estimated endogenously based on the total travel costs (monetary cost per passenger kilometre travelled, USD/PKT) by mode, fuel, technology and time cost of travel which itself is a function of the average hourly wage rate of the employed population, mode-specifiic value of travel time (VTT) and travel speed.

**Freight service demand** is based on simple functions of population, GDP, and fuel prices in GCAM-CEEW. Freight trucks and railways compete for servicing freight demand in GCAM-CEEW. The rate of efficiency improvement of each represented vehicle technology is exogenous in GCAM-CEEW. Time value is also not considered in the freight sector, where the future inter-modal competition takes place on the basis of the evolution of the weighted average technology costs alone.

**Industry sector**: The industrial sector in GCAM-CEEW is modelled in an aggregate way, with future industrial output growth driven by GDP, income elasticities, and price elasticities. The current industry representation does not consider global trade. Various fuels (biomass, coal, electricity, natural gas and oil) compete on the basis of relative prices for providing energy service for meeting industrial energy demand. The current model version only tracks the energy mix (for energy use and feedstock use) and emissions from an aggregate industrial sector and includes energy demanded in the agricultural sector.

As GCAM is a detailed energy sector model, fuel use in one sector impacts its use in other sectors through the fuel price. For example, if oil demand in the transport sector reduces due to shifts towards electricity-based vehicles, its price will decline, which will lead to increased usage of oil in other sectors.

### 10.1.2 LCOE of different technologies

***Table 10-1 LCOE of different electricity generation technologies***

| Technology | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 | 2060 | 2065 | 2070 | Units |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coal Super critical | 24.8 | 24.9 | 24.1 | 24.2 | 24.3 | 24.4 | 24.5 | 24.6 | 24.6 | 24.7 | 24.8 | 2020$/GJ |
| Gas | 25.9 | 78.9 | 87.6 | 77.3 | 77 | 77.7 | 78.8 | 79.6 | 79.9 | 80.4 | 80.6 | 2020$/GJ |
| Solar PV | 16.8 | 15.5 | 14.1 | 13.2 | 13.1 | 14 | 14 | 14.4 | 14.4 | 15 | 15.2 | 2020$/GJ |
| Wind Onshore | 19 | 19 | 18.7 | 18.7 | 18.7 | 19 | 19 | 19.3 | 19.3 | 19.6 | 20 | 2020$/GJ |
| Wind Offshore | 70.7 | 54.6 | 41.9 | 41.7 | 42.1 | 32.3 | 32.9 | 31.8 | 31.9 | 26.6 | 22.1 | 2020$/GJ |
| Nuclear | 17 | 17.2 | 17.3 | 17.4 | 17.6 | 17.8 | 18 | 18.2 | 18.4 | 18.6 | 18.8 | 2020$/GJ |

### 10.1.3 Solar and Wind potential

The wind and solar technical potentials for various states in India were assessed using the RE Data Explorer tool[35].

For wind potential, parameters were set to constrain wind speeds between 4 and 15 m/s, with power density values derived from the Global Wind Atlas for the top 10% windiest areas. Slope limits were defined between 0% and 20%, while distance constraints for roads and transmission lines were left unrestricted. Specific land categories, such as barren or sparsely vegetated land, cropland/grassland, and shrubland/grassland, were included by selecting all land types and excluding those not required. The calculated technical potential for wind in Gujarat was 158 GW.

For solar potential, the analysis constrained solar resources to values between 4 and 9 kWh/m$^2$/day, applying a power density of 50 MW/km$^2$. Slope limits were defined between 0% and 5%, and distance constraints for roads and transmission lines remained unrestricted. Similar land type categories were selected as in the wind analysis. The calculated technical potential for solar in Gujarat was 1186 GW.

### 10.1.4 CDD-HDD Methodology

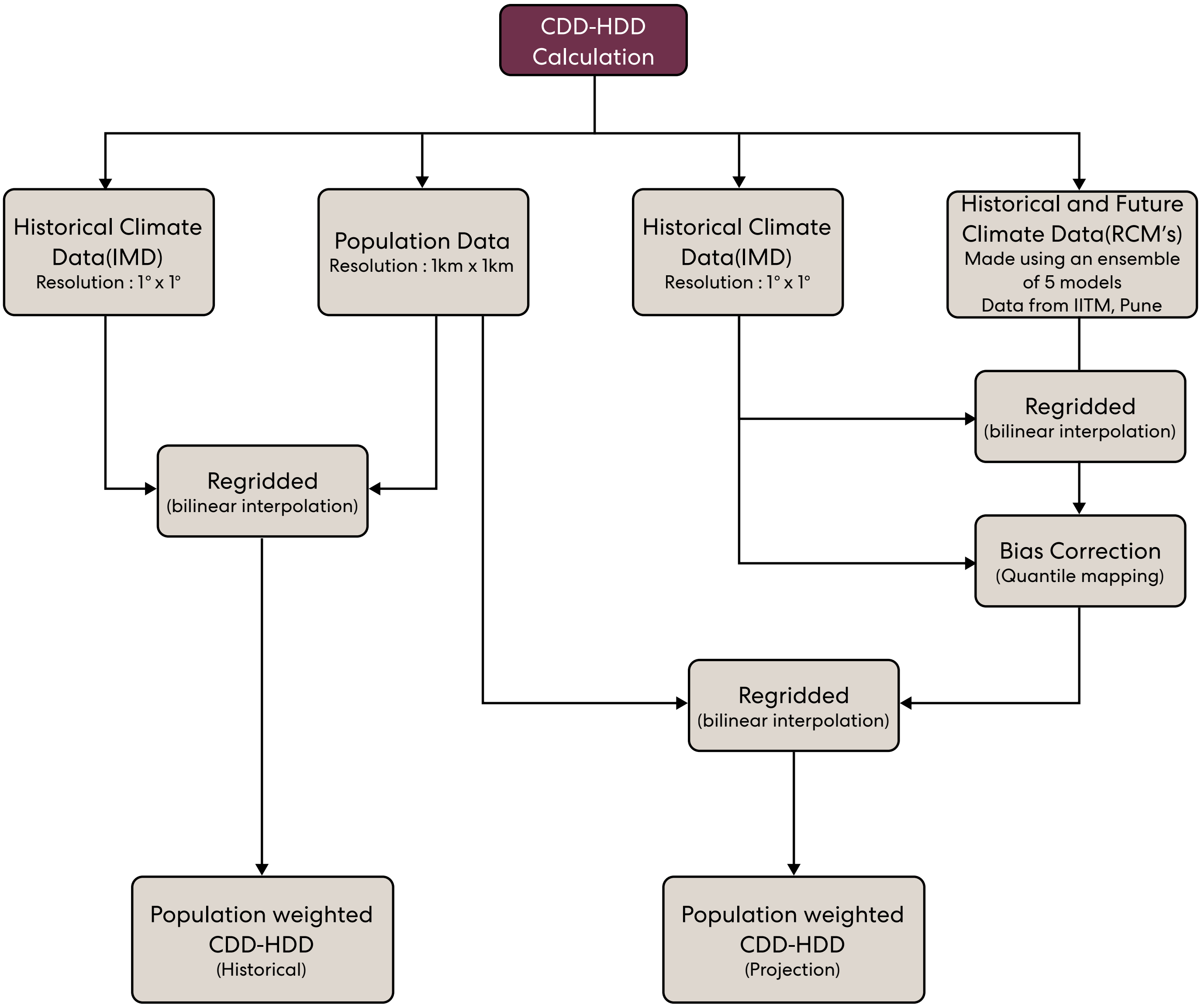
Cooling Degree Days (CDD) and Heating Degree Days (HDD) are critical metrics for estimating future energy demand for heating and cooling. As temperatures rise due to climate change, CDD values are expected to increase, leading to higher cooling energy demand, particularly in warmer regions. Conversely, decreases in HDD will reduce heating requirements in colder climates. These shifts in CDD and HDD will influence energy consumption patterns, potentially posing challenges in meeting peak cooling demands and energy supply, thereby necessitating adaptations in infrastructure and energy planning.

The historical CDD and HDD were calculated using the average temperature derived from IMD gridded data (with a spatial resolution of 1°×1°) (Pai et al., 2014). A threshold value of 26.5°C was used for CDD, and 16.5°C for HDD. For future projections of CDD and HDD, we relied on the CORDEX regional climate models (RCMs), as they provide a better representation of regional climate dynamics compared to global climate models. The RCM data were obtained from IITM Pune (CCCR, n.d.). Given that the RCMs are provided at a ~0.44° spatial resolution, we first re-gridded the RCM grids to match the IMD resolution and corrected for biases using the statistical quantile mapping bias correction method. To minimize the uncertainty associated with using different RCMs, we computed the ensemble mean across these models.

Recognizing that future CDD and HDD values will be influenced by population changes, we also performed population-weighted (Wang et al., 2022) calculations of CDD and HDD, using the same threshold values as in the historical calculations. This ensures that the impact of demographic changes on energy demand for cooling and heating is accounted for in our future projections.

[35] https://data.re-explorer.org/

***Figure 10-1 Visual representation of CDD-HDD Methodology***




**Legend**:

**IMD**: Indian Meteorological Department

**IITM**: Indian Institute of Tropical Meteorology, Pune

After the calculations, we got an increasing CDD trend with respect to years, while the HDD trend was a decreasing one. This is because HDD and CDD are inversely related to each other.

### 10.1.5 Stranded assets

GCAM assumes that the capital cost of existing vintage of stock in any given year is sunk, so these costs do not figure in the future operating decisions. Production from existing vintage is not subject to competition from new technologies. However, existing vintage plants may be temporarily shut down if input fuel cost is higher than the average revenue from the electricity generated. This could be the case in the event of a high carbon price that increases the generation cost from a coal-based power plant even more than the average revenue, in which case generation from this vintage will be temporarily shut down. We essentially use the "shut down of vintage plants" to calculate stranded assets – which we define as the difference in power generation of the coal fleet in the absence of climate policy with generation in the presence of climate policy. The generation is then converted to capacity using an appropriate capacity factor.

### 10.1.6 Investment Costs:

Investment costs by technology and year are calculated as the multiplication product of the capacity addition in that year and the capital cost of technologies. The capital cost of technologies, including their trajectory until 2050 is taken from (CEA, 2023). The values between 2050 and 2070 are assumed to be the same as in 2050.

***Table 10-2 Capital cost of technologies***

| cr rupees /MW | PV | CSP | Wind Offshore | Wind Onshore | Biomass | coal | Gas | Nuclear | RL | Hydro |
|---|---|---|---|---|---|---|---|---|---|---|
| **2015-20** | 5.4 | 3.9 | 23.1 | 6.7 | 5 | 8.3 | 3.5 | 19 | 92.8 | 8.3 |
| **2020-25** | 4.7 | 3.4 | 18.5 | 6.5 | 5 | 8.3 | 3.5 | 18.9 | 92.5 | 8.3 |
| **2025-30** | 3.9 | 2.8 | 13.8 | 6.2 | 5 | 8.3 | 3.5 | 18.8 | 92.2 | 8.3 |
| **2030-35** | 3.3 | 2.4 | 13.3 | 6.1 | 5 | 8.3 | 3.5 | 18.7 | 92.3 | 8.3 |
| **2035-40** | 2.7 | 1.9 | 12.7 | 6 | 4.9 | 8.3 | 3.5 | 18.5 | 92.3 | 8.3 |
| **2040-45** | 2.5 | 1.8 | 12.4 | 6 | 4.9 | 8.3 | 3.4 | 18.3 | 92.4 | 8.2 |
| **2045-50** | 2.3 | 1.6 | 12 | 5.9 | 4.8 | 8.3 | 3.4 | 18.1 | 92.5 | 8.2 |
| **2050-55** | 2.3 | 1.6 | 12 | 5.9 | 4.8 | 8.3 | 3.4 | 18.1 | 92.5 | 8.2 |
| **2055-60** | 2.3 | 1.6 | 12 | 5.9 | 4.8 | 8.3 | 3.4 | 18.1 | 92.5 | 8.2 |
| **2060-65** | 2.3 | 1.6 | 12 | 5.9 | 4.8 | 8.3 | 3.4 | 18.1 | 92.5 | 8.2 |
| **2065-70** | 2.3 | 1.6 | 12 | 5.9 | 4.8 | 8.3 | 3.4 | 18.1 | 92.5 | 8.2 |

## 10.2 Methodology and Assumptions for LEAP Model

Energy Balance for Gujarat for the base year (2018) (See Table 10-3) was estimated using several sources of information:

- GHG Platform India
- Annual Reports of the Central Electricity Authority
- Annual Data from the Ministry of New and Renewable Energy
- Annual Survey of Industries
- Annual report of the Ministry of petroleum and natural gas
- Annual report of the Ministry of coal

Crude oil production and natural gas production in 2018 was taken from the "Indian Petroleum and Natural Gas Statistics" Report. For the demand sectors, energy consumption was estimated using data from the GHG Platform India (database with GHG emissions data at the level of Indian states). $CO_2$ emissions by sector and fuel were divided by their respective emission factors to determine fuel consumption. The total electricity consumption for the industry was sourced from the Central Electricity Authority's Annual Report for 2018-2019. Electricity consumption for residential, commercial, and public services, agriculture and forestry, rail was obtained from the Annual Report of the Central Electricity Authority for 2018-2019.

***Table 10-3 Energy Balance for Gujarat, 2018, Million GJ***

| Category | Solid Fuels | Natural Gas | Crude Oil | Renewables (including biomass and hydro) | Nuclear | Electricity | Gas | Oil Products | Total |
|---|---|---|---|---|---|---|---|---|---|
| Production | 126 | 52 | 197 | 53 | 3 | - | 3.5 | - | 431 |
| Imports | 1,446 | 789 | 4,173 | 144 | - | 106 | 3.5 | 144 | 6,802 |
| Exports | -57 | - | - | - | - | - | 3.5 | -4,217 | -4,274 |
| **Total Primary Supply** | **1,515** | **841** | **4,371** | **197** | **3** | **106** | 3.5 | **-4,073** | **2,960** |
| Bio Gas | - | - | - | - | - | - | 3.5 | - | - |
| Biofuels | - | - | - | - | - | - | 3.4 | - | - |
| Natural Gas Production | - | -3 | - | - | - | - | 3.4 | - | -3 |
| Oil Production | - | - | -12 | - | - | - | 3.4 | - | -12 |
| Coal Mines | 0 | 0 | - | - | - | - | 3.4 | - | 0 |
| Oil Refining | -26 | -420 | -4,371 | - | - | - | 3.4 | 4,517 | -318 |
| Electricity Generation | -867 | -96 | - | -52 | -3 | 369 | 3.4 | -7 | -655 |
| Electrolyzer Hydrogen Prod. | - | - | - | - | - | -87 | | - | -87 |

| Category | Solid Fuels | Natural Gas | Crude Oil | Renewables (including biomass and hydro) | Nuclear | Electricity | Gas | Oil Products | Total |
|---|---|---|---|---|---|---|---|---|---|
| Transmission and Distribution | - | - | - | - | - | -87 | | - | -87 |
| Solar PV Rooftop | - | - | - | -4 | - | 4 | | - | - |
| **Total Transformation** | **-893** | **-530** | **-4,371** | **-56** | **-3** | **267** | | **4,509** | **-1,076** |
| Industry | 622 | 275 | - | - | - | 234 | | 62 | 1,193 |
| Commercial/Public Services | - | - | - | - | - | 23 | | 9 | 32 |
| Agriculture, Forestry, Fishing | - | - | - | 58 | - | 43 | | - | 101 |
| Transport | - | 32 | - | - | - | 4 | | 268 | 304 |
| Household | - | 4 | - | 141 | - | 54 | | 55 | 254 |
| **Total Demand** | **622** | **311** | - | **141** | - | **374** | | **436** | **1,884** |
| Unmet Requirements | - | - | - | - | - | - | | - | - |

Based on the 2018 Energy Balance for Gujarat, oil refineries are a crucial component of the state's energy system. These refinery plants in Gujarat consumed 4,370 million GJ of crude oil and produced 4,517 million GJ of oil products, with over 95% of produced oil products (4,216 million GJ) being exported. The state's internal consumption of oil products was 436 million GJ in 2018. Details on the oil refinery process structure in the LEAP model for Gujarat can be found in Appendix 10.2.5.

Electricity generation processes were categorized as either captive or utilities. Fuel input to power plants, installed capacity and historical energy generation (utilities and captive power) were obtained from the Annual Report of the Central Electricity Authority for 2018-2019. Kakkrapar Nuclear Plant (Surat) production was added to public power plants generation. For renewable energy sources, electricity generation and installed capacity was obtained from the Ministry of New and Renewable Energy. Detailed information on the electricity generation processes described in LEAP, including performance parameters for different electricity generation technology in LEAP were provided in the Appendix. The Electrolyser hydrogen production process was incorporated into the transformation branch of the LEAP model for Gujarat under the Net Zero SS Scenario. This process uses electricity as the input fuel and produces hydrogen, with an assumed efficiency of 79%.

### 10.2.1 Industry Sector

The industry sector is further divided into six sub-sectors

1. Chemicals and petrochemicals
2. Non-ferrous metals
3. Non-metallic minerals
4. Mining and Quarrying¨
5. Other industry
6. Iron and Steel

The first five sectors are wide in definition and encompass multiple processes, technologies, and outputs. Therefore, we use gross value added (GVA) by these sectors to represent demand (activity in the sector).

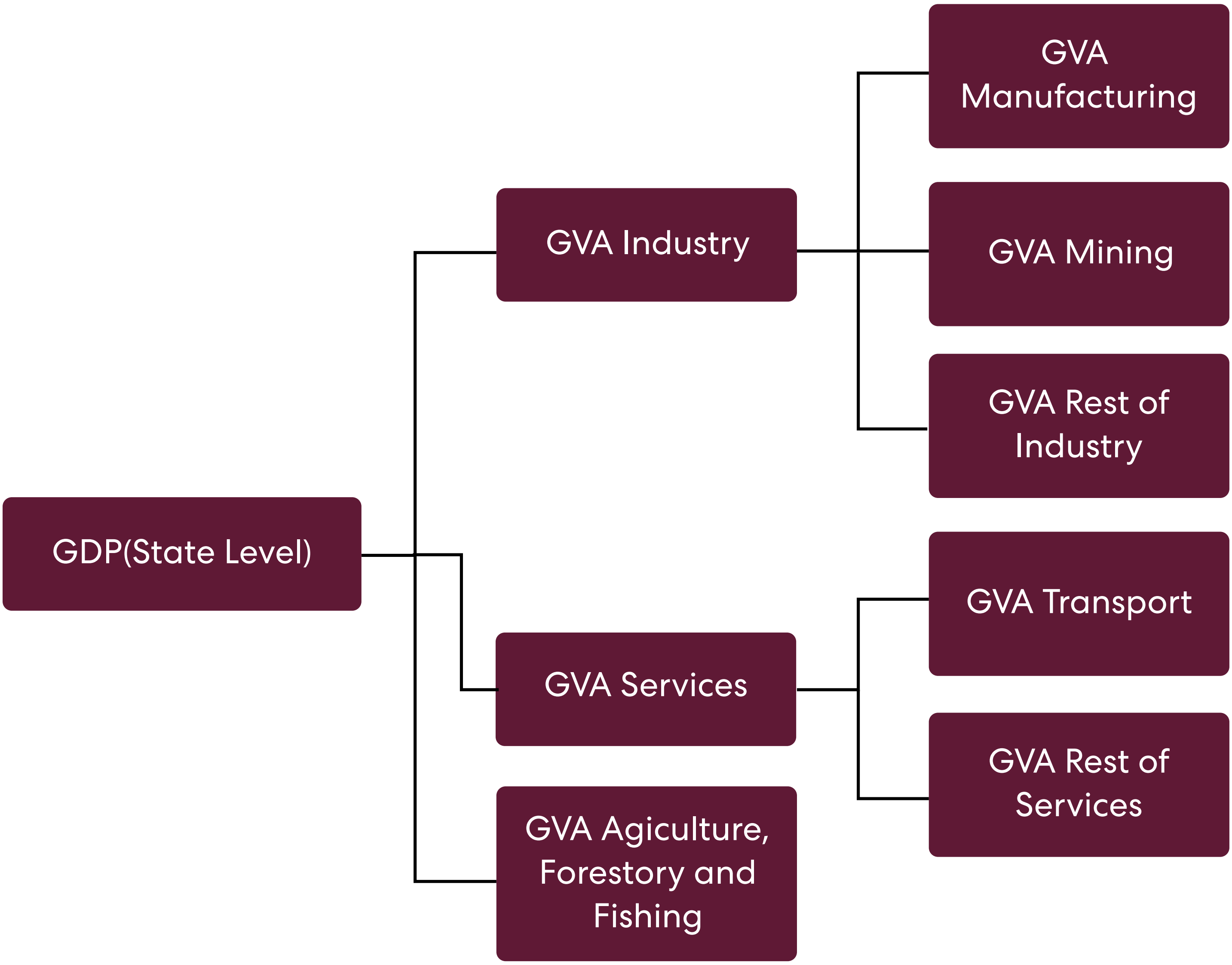
In the case of Iron and Steel, there are well-defined process technologies, and hence, steel output is used instead.

The GVA added by respective sectors for 2018 is then expected to grow at the rate of growth in manufacturing (or mining for mining and quarrying) multiplied with an elasticity value. The rate of growth in manufacturing is consistent with the overall GDP growth (Table 5-2) and sectoral growth rates at level 1 (Table 5-1). GVA Manufacturing and GVA Mining are at level 2 (Figure 10-2). The GVA calculation for chemicals and petrochemicals is shown below

$$GVA_{\text{chemicals petrochemicals "t"}} = GVA_{\text{chemicals petrochemicals " t-1"}} * \%\ Growth_{Mfg} * \varepsilon$$

All five sectors were assigned an elasticity value of 0.65. This elasticity value allows us to account for the improvement in energy intensity of the sector as a whole.

***Figure 10-2 Hierarchy of GVA***




GVA values for the five sectors were taken for the base year 2018 based on the Annual Survey of Industries. Using the energy consumption in these sectors for 2018 (taken from Energy Balance), energy intensity was calculated. The energy intensity values are held constant across the time periods. The overall improvements in energy efficiency are captured within the elasticity assumed.

## 10.2.2 Transport Sector

The passenger and freight demand in the LEAP model are provided exogenously. Here, we provide the methodology for the same.

#### 10.2.2.1 Passenger Demand

The overall demand for passenger transport is calculated using following equation

**Overall Passenger Demand=Per capita mobility x Population**

Per capita mobility tends to increase with per capita incomes (Schafer and Victor,2000); however, growth in per capita mobility also tends to peak around a per capita GDP of USD $25,000 and US$30,000 (Dhar

& Shukla, 2015). The saturation level has varied across countries. The variations can arise due to different factors, such as demographic structure (e.g., Japan has a low value of 10,000 pkm due to a high proportion of old people in population who have limited mobility), investment in infrastructure (e.g., US has a high value of 27,000 pkm due to high investment into road infra-structures), or design, diversity and density of cities (e.g., EU countries have a value of 12,000 pkm due to cities that have a diverse land use, reasonable density and good public transport). In the reference scenario, we assume the asymptotic value is 20,000 pkm for Gujarat, considering a high share of the working-age population and limited progress in terms of transforming cities on a sustainable path. In the SS scenario, however the asymptotic value is lower at 14,000 pkm assuming that cities are designed in a sustainable way (design, diversity, and density) and overall share of service sector is higher. Better city design can help in reducing trip lengths whereas service sector jobs permit more flexibility in terms of working from home.

#### 10.2.2.2 Freight Demand

Freight demand is linked to the demand for commodities within the economy, which is related to economic growth. The following equation was used for estimating the freight demand.

$$\text{Freight Demand}_{t} = \text{Freight Demand}_{t-1} + \text{Freight Demand}_{t-1} \times \varepsilon \times GVA$$

Where

**ε = Elasticity of freight transport demand to growth of GVA transport**

**GVA = % growth in transport gross value added**

In contrast to an elasticity of 1 that was taken in the NTDPC report an elasticity of 0.45 was taken since in the long term the demand for commodities follows a Kuznets curve, i.e., increasing initially with increasing incomes; however, it declines once the incomes cross a certain threshold, e.g., steel demand declines when incomes cross US$24,289 (Wårell,2014). There are variations across developed countries in per capita freight demand, e.g., in the EU, the freight demand is around 8000 tkm, whereas, in the US, it is around 18,000 km (Dhar & Shukla, 2015). The elasticity value was taken so that in no case the per capita freight demand exceeds 18,000 tkm.

## 10.2.3 Building Sector

Floor area is the primary driver of energy consumption in the residential and commercial sectors in LEAP. The model uses the projected compound annual growth rates (CAGR) for residential floor area, divided into urban and rural categories, as provided by (Yu et al., 2017).

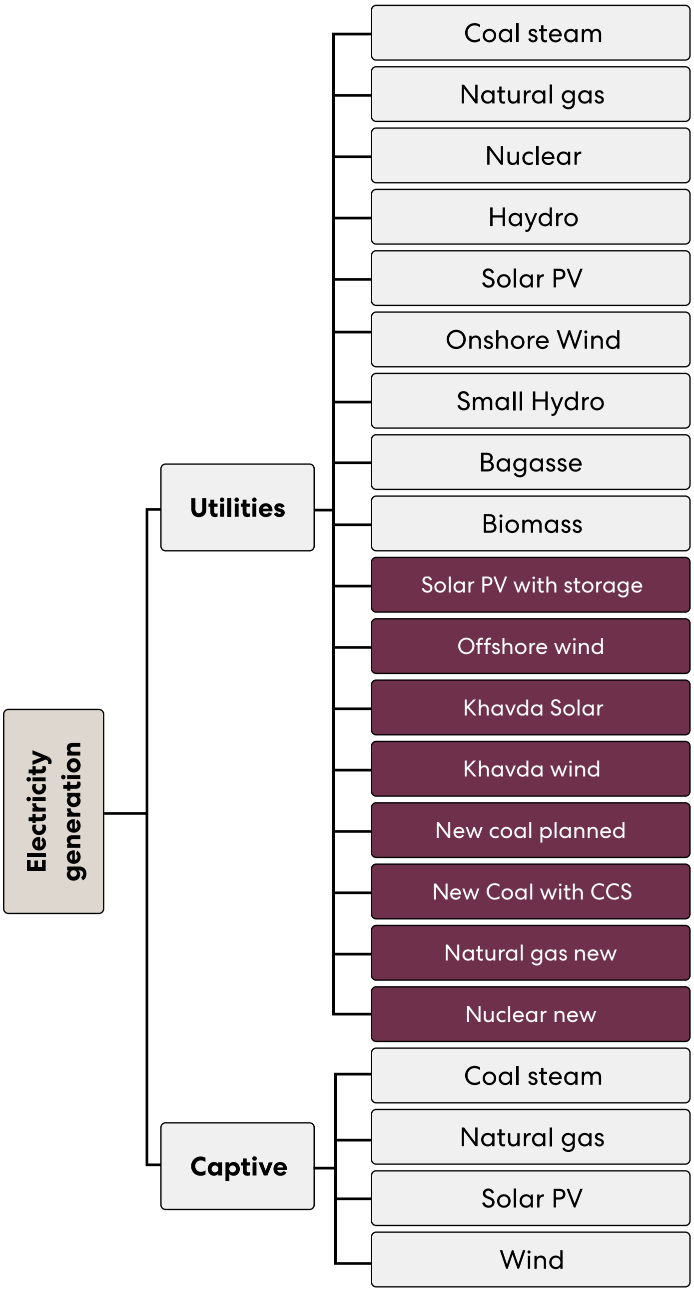
Key assumptions for the buildings sector's drivers in LEAP model for Gujarat include:

- Urban residential floor area is expected to grow from 47 sq.m. per household in 2020 to 104 sq.m. in 2070, with a CAGR of 1.6%.
- Rural residential floor area is projected to increase from 37.6 sq.m. per household in 2020 to 79.2 sq.m. in 2070, with a CAGR of 1.5%.
- Saturation level for air conditioners per household is expected to rise
  - from 18% in 2018 to 200% in urban households in 2070;
  - from 1.8% in 2018 to 150% in rural households in 2070.
- Commercial floor area is projected to expand from 99.7 million sq.m. in 2020 to 1035.4 million sq.m. in 2070.

### 10.2.4 Power Sector

Figure 10-3 below shows the existing electricity generation processes and new processes (marked with orange) described in LEAP Gujarat. These new processes are not present in the base year; they were assumed to be implemented in future years.

***Figure 10-3 Electricity generation processes in LEAP***




In the LEAP (Low Emissions Analysis Platform) model, exogenous and endogenous capacities represent different methods of defining power generation capacity:

- **Exogenous Capacity**: This is the capacity explicitly specified by the user, including existing capacity, and planned or committed additions and retirements. Essentially, it is predetermined and manually input into the model.
- **Endogenous Capacity**: This capacity is determined by the model based on factors such as projected demand, reserve margins, and other user-defined parameters. The model calculates this capacity to meet future needs.

Existing power plants retire at the end of their lifespan, and LEAP builds new capacities based on projected electricity demand, planning reserve margins, and user-defined capacity additions (size and order). The performance parameters for various generation technologies such as plants efficiency, plants availability, and their capacity credit in Table 10-4. These input data were applied in the LEAP model for the existing and new technologies.

***Table 10-4 Performance parameters for different electricity generation technology in LEAP-Gujarat***

| Technology | Installed Capacity in 2018 (Thousand MW) | Historical Production in 2018 (Thousand GWh) | Process Efficiency (%) | Maximum Availability (%) | Capacity Credit (%) | Merit Order Dispatch |
|---|---|---|---|---|---|---|
| Coal Steam | 13.4 | 67.5 | 32.9 | 90 | 100 | 2 |
| Natural Gas | 6.2 | 8.6 | 52.5 | 100 | 50 | 3 |
| Nuclear | 0.4 | 0.8 | 100 | 85 | 100 | 2 |
| Hydro | 0.8 | 0.6 | 100 | 55 | 100 | 3 |
| Solar PV | 2.1 | 2.2 | 100 | 30 | 30 | 1 |
| Wind | 6.1 | 10.5 | 100 | 38 | 30 | 1 |
| Small Hydro | 0.1 | 0.1 | 100 | 100 | 100 | 1 |
| Bagasse | 0 | 0.1 | 32.2 | 100 | 100 | 1 |
| Biomass | 0.1 | 0.1 | 100 | 100 | 100 | 1 |
| Solar PV with Storage | - | - | 100 | 100 | 100 | 1 |
| Offshore Wind | - | - | 100 | 43 | 30 | 1 |
| Diesel Captive | 1.3 | 0.6 | 40 | 90 | 100 | 3 |
| Coal Steam Captive | 3.7 | 12.7 | 35.6 | 90 | 100 | 2 |
| Natural Gas Captive | 2.7 | 5.4 | 53 | 100 | 50 | 3 |
| Solar Captive | 0.1 | 0 | 100 | 20 | 30 | 1 |
| Wind Captive | 0.5 | 0.7 | 100 | 38 | 30 | 1 |
| Coal Supercritical New | - | - | 40 | 90 | 100 | 2 |
| Nuclear New | - | - | 100 | 85 | 100 | 2 |
| Natural Gas New | - | - | 60 | 100 | 100 | 2 |
| Khavda Solar | - | - | 100 | 30 | 30 | 1 |

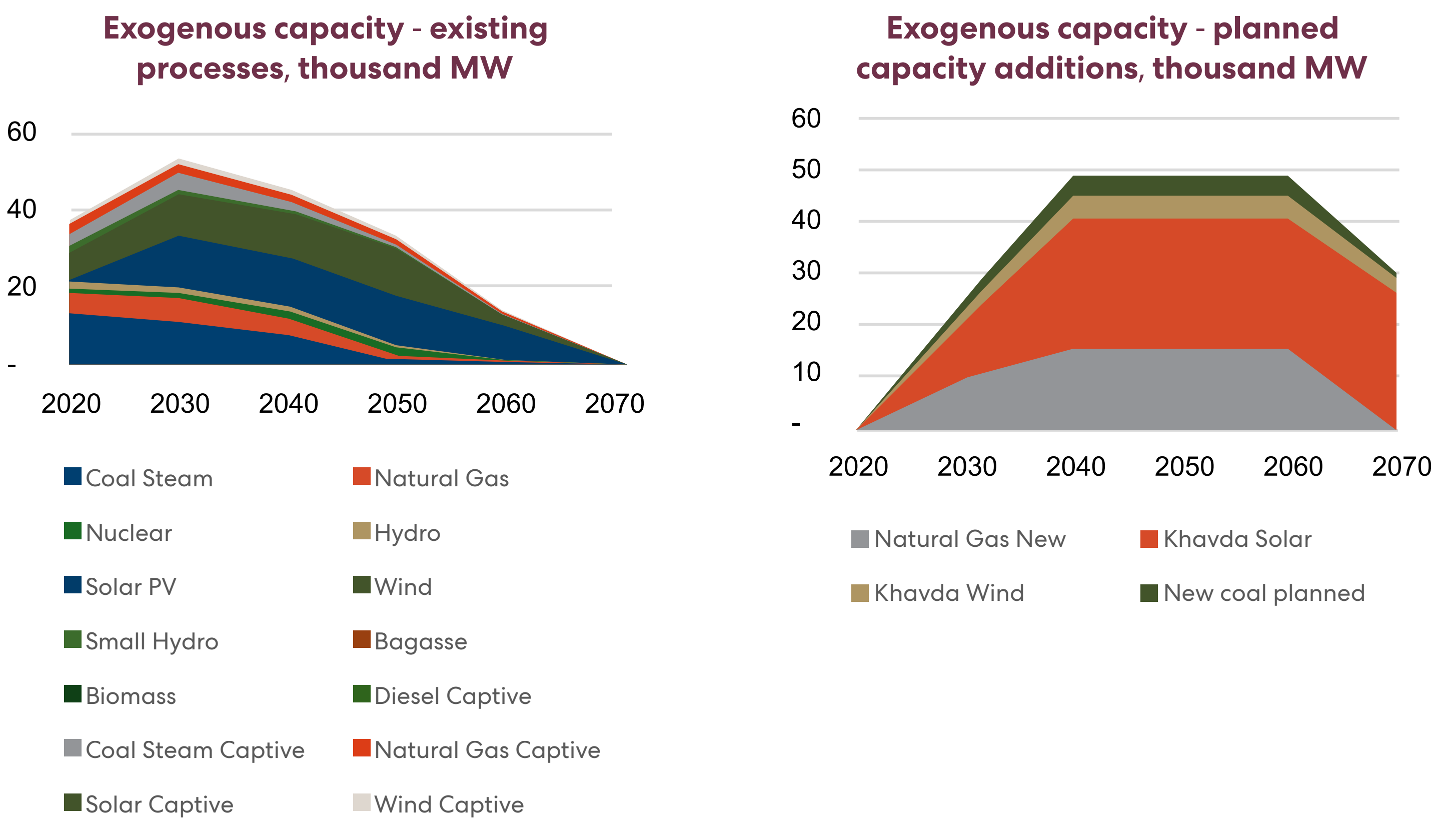
| Technology | Installed Capacity in 2018 (Thousand MW) | Historical Production in 2018 (Thousand GWh) | Process Efficiency (%) | Maximum Availability (%) | Capacity Credit (%) | Merit Order Dispatch |
|---|---|---|---|---|---|---|
| Khavda Wind | - | - | 100 | 38 | 30 | 1 |
| New Coal Planned | - | - | 40 | 90 | 100 | 2 |
| Coal with CCS | - | - | 32 | 90 | 100 | 2 |
| **Total** | **37.5** | **109.8** | - | - | - | - |

**Note**: *Processes shown in italic are not present in the base year; these are assumed new processes to be implemented in future years (defined as exogenous capacity or endogenous capacity).

$CO_2$ capture efficiency for the "Coal-fired supercritical power plant with CCS" process was taken as 10%. The efficiency of coal-fired supercritical power plant with CCS is assumed to decline by 20% compared to coal-fired supercritical power plant without CCS (based on the study by (Rogieri Pelissari et al., 2023)).

Exogenous Capacity values include existing capacity as well as planned/committed capacity additions and retirements. Figure 10-4 below shows the existing processes (considering the retirement of the existing capacity at the end of the lifetime) and new planned/committed capacity additions that were specified in LEAP-Gujarat model. New committed capacity additions also include the Khavda renewable energy park. In the LEAP-Gujarat model, it is assumed that the Khavda project will have a total capacity of 30 GW of solar and wind energy by 2040. Additionally, new planned/committed coal capacity totalling 3720 MW, with start dates ranging from 2024 to 2028, has been included in the exogenous capacity.

***Figure 10-4 Exogenous capacity assumed in LEAP***



Endogenous capacity additions is calculated internally by LEAP in order to maintain a minimum planning reserve margin, and it can occur in addition to the exogenous level of capacity[36]. The list of endogenous capacity that was assumed in the Reference scenario and Net Zero SS scenario is provided below (Table 10-5). It was assumed that the Net Zero SS Scenario emphasizes reducing carbon emissions through technologies mix of renewable energy sources and relatively small coal capacity with CCS. In contrast, the Reference Scenario relies more on traditional fossil fuels and nuclear energy, with a significant addition of coal supercritical new capacity. Although, both scenarios include similar capacities for onshore wind, offshore wind, solar PV, solar PV with storage, and hydro. However, the key difference is that the Net Zero SS Scenario prohibits the construction of conventional fossil fuel plants (without CCS) after 2050 and assumes higher reliance on renewable energy sources.

***Table 10-5 Endogenous capacity in the Net Zero SS and Reference Scenarios***

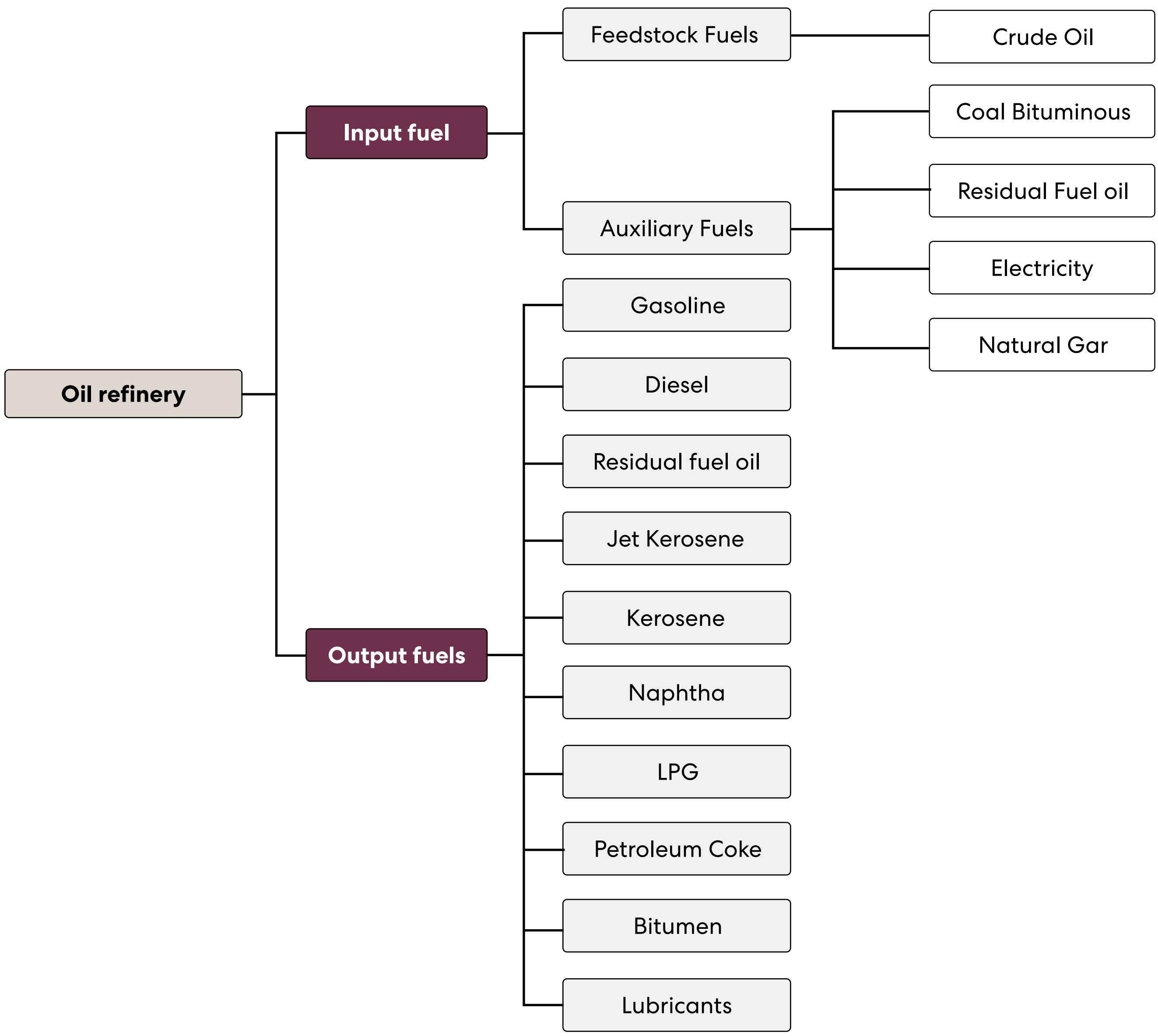
| Net Zero SS Scenario<br>Capacity addition order and size, MW | | Reference Scenario<br>Capacity addition order and size, MW | |
|---|---|---|---|
| Onshore wind | 50 | Solar PV | 100 |
| Offshore wind | 100 | Onshore wind | 50 |
| Solar PV | 50 | Offshore wind | 100 |
| Solar PV with storage | 50 | Solar PV with storage | 50 |
| Nuclear new | 50 | Coal supercritical new | 300 |
| Hydro | 50 | Natural gas new | 100 |
| Coal with CCS | 100 | Nuclear new | 100 |
| | | Hydro | 50 |

[36] The endogenous capacity in LEAP works as follows (according to SEI LEAP tutorial): Every time the LEAP goes through the supply module (transformation branch) it will try to build any of these processes (specified with endogenous capacity) whenever it is required to do so in order to meet demand. User reorders these processes by changing the addition order and specifies the addition size.

### 10.2.5 Oil refinery

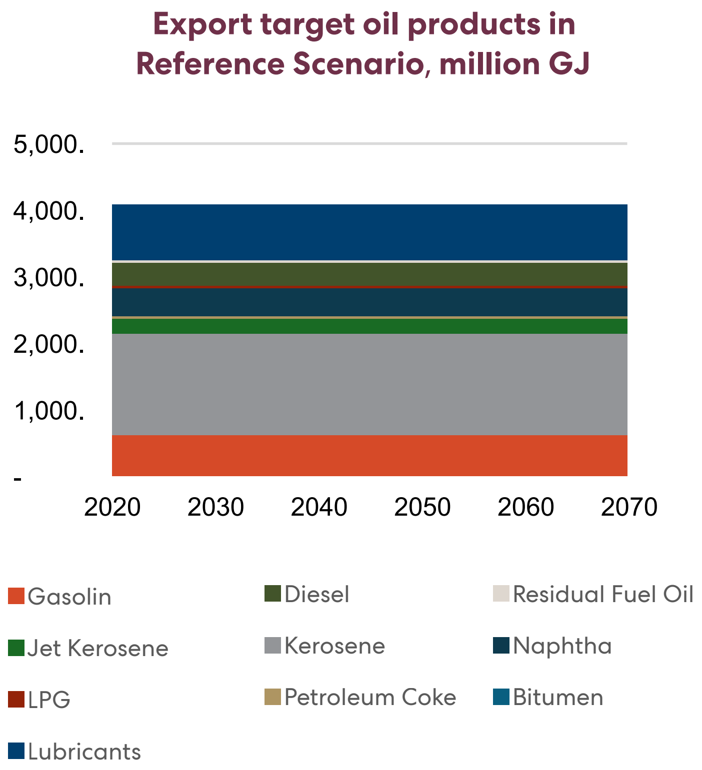
Figure 10-5 below shows the oil refinery process structure in LEAP Gujarat. Inputs of crude oil and outputs of oil products from the refinery processes for the base year were obtained from the Annual report of the Ministry of petroleum and natural gas.

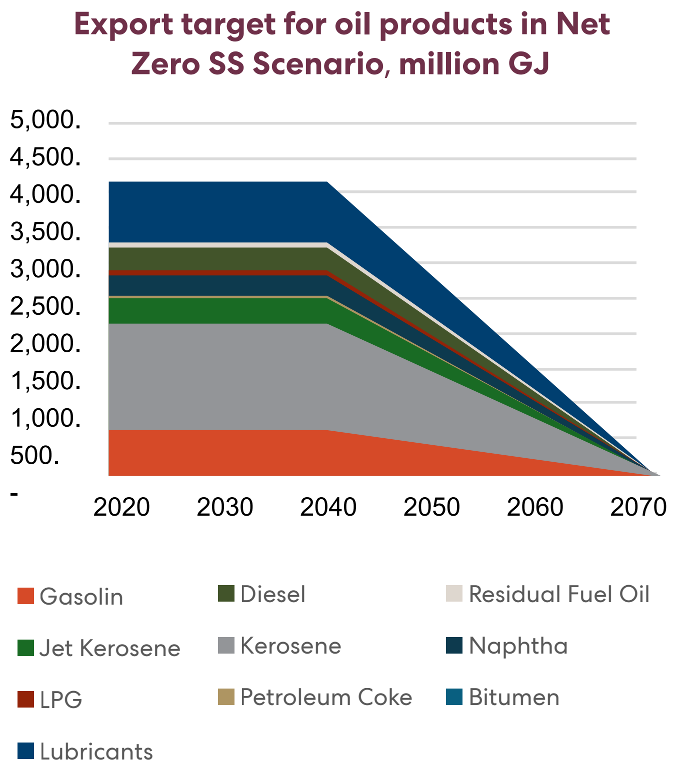
***Figure 10-5 Endogenous capacity in the Net Zero SS and Reference Scenarios***




The state's current demand for oil products is significantly lower than the capacity of its oil refineries as most of the produced oil products are being exported from the state. In the Reference Scenario, it is assumed that the oil refineries will continue to operate and the state will keep exporting oil products. Consequently, the model was set to produce oil refinery products to meet the "export target." In the Net Zero Scenario, it is assumed that oil refineries will continue exporting until 2040, after which their operations will gradually decrease, reaching zero by 2070 due to reduced demand for oil products in the Net Zero India setting, driven by a major fuel switch in the transport sector. Assumed export target for oil products in both scenarios are presented in the Figure 10-6 below.

*Figure 10-6 Assumed export targets for oil products in Reference scenario and in Net Zero SS Scenario, million GJ*




### 10.2.6 Maximum Availability of Resources

In the resources branch of LEAP, the reserves of oil, gas, and coal in Gujarat were specified. The data for oil and gas reserves was sourced from the Annual Report of the Ministry of Petroleum and Natural Gas, while the lignite reserves were derived from the Annual Report of the Ministry of Coal. Solar and wind potential in Gujarat was obtained from the Energy Statistics India 2023 published by the Ministry of Statistics and Programme Implementation (Table 1.3: Source wise and State wise Estimated Potential of Renewable Power in India during 2021-22). These values were specified in the "Resources" branch in LEAP-Gujarat through "Maximum production" variable.

### 10.2.7 Agriculture, Forestry and Land Use

**10.2.7.1 Agriculture**:

The $CO_2$ emissions from agriculture arise due to changes in $CO_2$ sequestered by biomass and the changes in soil organic carbon.

### Biomass carbon

Biomass carbon sequestered is calculated using the equation

**Biomass Carbon stock change = Rate of change in biomass carbon (tC/ha/yr) x Land Area i**

Where

- Rate of change in biomass carbon (tC/ha/yr = 0.045 tC/ha/yr) for agricultural land
- Land Area i at time "i" includes agricultural land the remains agriculture and other land uses that convert to agriculture such as from wet land and other lands to agriculture.

In both scenarios, we consider no changes in land cover in future.

### Soil organic carbon (SOC)

SOC is applicable only when there is a change in the land use. In the GHG platform only

**Change in Soil Organic Carbon = Change in SOC per hectare (tC/ha/yr) x Land Area i**

Where

- Change in SOC (tC/ha/yr = - 1.881 tC/ha/yr for other land to agricultural land
- Change in SOC (tC/ha/yr = 29.31 tC/ha/yr for wet land to agricultural land

#### 10.2.7.2 Forestry

The carbon sequestration in forests happens due to two effects i) change in forest cover and ii) change in carbon stock density and can be represented mathematically as

$$\text{Carbon Sequestered (CS)} = CS_{\text{change in forest cover}} + CS_{\text{change in carbon stock density}}$$

$$CS_{\text{change in forest cover}} = \text{Change in Forest Cover (t1-t0)} \times \text{Carbon stock density at t0}$$

$$CS_{\text{change in carbon stock density}} = \text{Forest land in t1} \times \text{Change in carbon stock density per hectare (t1-t0)}$$

Where

- Forest cover is a variable defined in LEAP, and growth in forest cover is driven by scenario assumptions. Changes in forest cover are calculated endogenously.
- Carbon stock density in t0(2018) was 72.2 tC/hectare.
- Change in carbon stock density per hectare between 2017-2018 as per GHG platform was 0.01 tC and the same is assumed for the entire projection period.

### 10.2.8 IPPU

The IPPU emissions relate to the production process of different materials, chemicals, etc. In the LEAP model, we do not describe the production process but the material, chemical output, etc., and calculate the $CO_2$ emissions based on emission coefficients from the GHG platform (Table 10-6).

***Table 10-6 Emission factors for IPPU emissions***

| Metal/Chemical/Mineral | Emission Factor ($CO_2$) | Emission Factor ($CH_4$) | Emission Factor ($N_2O$) | Unit |
|---|---|---|---|---|
| Cement | 0.537 | - | - | $tCO_2$/tclinker |
| Ammonia | 1.76715 | - | - | $tCO_2$/tproduct |
| Nitric Acid | - | - | 0.01 | $tCO_2$/tproduct |
| Adipic Acid | - | - | 0.3 | $tCO_2$/tproduct |
| Caprolactam | - | - | 0.009 | $tCO_2$/tproduct |

| Metal/Chemical/Mineral | Emission Factor ($CO_2$) | Emission Factor ($CH_4$) | Emission Factor ($N_2O$) | Unit |
|---|---|---|---|---|
| Glyoxal | - | - | 0.0052 | $tCO_2$/tproduct |
| Calcium Carbide | 1.1 | - | - | $tCO_2$/tproduct |
| Titanium Dioxide | 1.385 | - | - | $tCO_2$/tproduct |
| Soda Ash | 0.138 | - | - | $tCO_2$/tproduct |
| Methanol | 0.67 | 0.023 | - | $tCO_2$/tproduct |
| Ethylene | 1.73 | 0.003 | - | $tCO_2$/tproduct |
| Ethylene Dichloride | 0.296 | - | - | $tCO_2$/tproduct |
| Vinyl Chloride | 0.47 | - | 0.00226 | $tCO_2$/tproduct |
| Ethylene Oxide | 0.863 | - | 1.79 | $tCO_2$/tproduct |
| Acrylonitrile | 1 | - | 0.18 | $tCO_2$/tproduct |
| Carbon Black | 2.62 | - | 0.06 | $tCO_2$/tproduct |
| Aluminium | 1.65 | - | - | $tCO_2$/tmetal |
| Lead | 0.52 | - | - | $tCO_2$/tmetal |
| Zinc | 0.53 | - | - | $tCO_2$/tmetal |
| Lubricant Use in Coal Mining | 73 | - | - | $tCO_2$/tonne |

**Source**: GHG Platform - http://www.ghgplatform-india.org/

In the SS Scenario, first, the mitigation options that help reduce $CO_2$ emissions from the sector are identified, and then a revised emission factor is estimated, which is used to estimate the $CO_2$ emissions.

#### 10.2.8.1 Cement

Process-related $CO_2$ emissions in cement production occur in the rotary kiln, where at temperatures exceeding 1450 °C, the raw materials react to form clinker. The chemical reaction during clinker production can be summarised as follows

$$CaCO_3 \text{ (limestone)} \rightarrow CaO \text{ (calcium oxide)} + CO_2 \text{ (carbon dioxide)}$$

The amount of $CO_2$ emissions produced in clinker formation is 0.537 $tCO_2$ per ton of clinker. The amount of clinker used in cement varies depending on the type of cement (Table 6-6), and hence if the share of clinker is used less, the $CO_2$ emissions will be lower. In the LEAP model all the different types of cement (Table 6-6) are included. The $CO_2$ emissions for each cement type can be estimated using the equation.

**$CO_2$ Emissions Cement Type a = Clinker Emission Factor x Clinker Factor a**

There are initiatives to ensure that the clinker emission factor, which is around 0.537 $tCO_2$ per ton of clinker, now can be brought down. According to MSCI, the value can be brought down to 0.239 $tCO_2$ per ton of clinker in the near future.

#### 10.2.8.2 Ammonia

There are three options for reducing $CO_2$ emissions from ammonia production. The first involves the capture, use and storage of CO 2 that is produced in the steam methane reformer unit where natural gas (most common feedstock), along with water and air, is broken down to produce hydrogen and nitrogen Guidehouse Netherlands B.V, (2023). The second option is to replace natural gas (fossil fuel) with bio-methane. The last option is to get rid of the steam methane reformer and directly take green hydrogen that has been produced using renewables.

In the next step, a transition from the conventional steam methane reformer process for ammonia production into these three different pathways is proposed. Table 10-7 provides the percentage shares of the assumed innovative processes till 2070. The overall $CO_2$ intensity of ammonia production is then calculated based on share of different processes and this is then introduced back into the LEAP model.

***Table 10-7 Technology shares for ammonia production in Net Zero SS Scenario (LEAP)***

| Option | Decarbonisation Pathway | $CO_2$ Intensity ($tCO_2$/ton) | 2020 | $CO_2$ Intensity ($tCO_2$/ton) | 2030 | $CO_2$ Intensity ($tCO_2$/ton) | 2050 | $CO_2$ Intensity ($tCO_2$/ton) | 2070 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Steam Methane Reformer (SMR) with CCUS (Blue Ammonia) | 0.27 | 0% | 0.25 | 10% | 0.24 | 40% | 0.23 | 70% |
| 2 | Replacing natural gas with biomethane | - | 0% | - | 0% | | 5% | | 10% |
| 3 | Replacing H2 with green hydrogen (Green Ammonia) | - | 0% | - | | | 5% | | 20% |
| | Ammonia conventional process | 1.77 | 100% | 1.68 | 90% | 1.59 | 50% | 1.52 | 0% |
| | Overall $CO_2$ intensity | | 1.77 | | 1.54 | | 0.89 | | 0.16 |

## 10.3 GHG Emissions Inventory for Gujarat - Method Note for Energy Sector

### 10.3.1.Background

The IPCC laid down the methodology for preparing national greenhouse gas emission inventories in 2006 and refined it in 2019 (IPCC, 2019). It consists of 5 volumes containing general inventory preparation guidelines, as well as focused guidelines for the i) Energy, ii) Industrial Processes and Product Use (IPPU), iii) Agriculture Forestry and Other Land Use (AFOLU), and iv) Waste sectors. This document lays down the methodology followed for estimating the Energy sector emissions for Gujarat.

### 10.3.2 Methodology

**10.3.2.1 Energy Sector**:

The energy sector emissions are classified into two primary categories: a) Fuel Combustion Emissions and b) Fugitive Emissions.

Fuel combustion emissions are estimated by multiplying the fuel consumed (energy-use only that is combusted), termed as "activity data", by the emission factor. The activity data for the exercise has been directly sourced from various publications by the central government, primarily the Central Electricity Agency (CEA) for fuel consumption in the electricity sector, the Annual Survey of Industries reports, Centre for Monitoring Indian Economy database, and the Indian Petroleum and Natural Gas Statistics Reports for the fuel consumption in the industrial sector. The Indian Petroleum and Natural Gas Statistics Reports are also the source for fuel consumption in the transport sector . The IPCC provides three different approaches for estimating emissions based on the available data. Tier 1 requires the amount of fuel consumed in different industrial sectors and relies on the default emission factors provided by the IPCC. The present exercise takes a Tier 1 approach for estimating methane and nitrous oxide emissions, while the carbon dioxide emission has been calculated using an India specific emission factor making it a Tier 2 category estimation. Tier 3 includes a plant level granularity in terms of the activity and emission data, which is not the case here.

**TIER 1 Emission Calculation**

$$\text{Emission}_{(GHG,\ fuel\ type)} = \text{Fuel Consumed}_{(fuel\ type)} \times \text{IPCC Default Emission Factor}_{(GHG,\ fuel)}$$

Tier 2 replaces the emission factors in Tier 1 from the IPCC defaults to country-specific emission factors.

**TIER 2 Emission Calculation**

$$\text{Emission}_{(GHG,\ fuel\ type)} = \text{Fuel Consumed}_{(fuel\ type)} \times \text{Country-Specific Emission Factor}_{(GHG,\ fuel)}$$

### 10.3.3 Fuel Combustion Emissions

**10.3.3.1 Electricity Sector** :

The consumption of fuel in the power sector is reported by the Central Electricity Agency, segregated by states on a regular basis since 2015 (with an exception for 2019) in the "General Review" annual report. It provides data for the previous financial year[37] (example the report published in 2020 will report data for 2018-19). The latest report, published in 2023 provides fuel consumption data for 2021-22. While the data reported in India is for the financial year, the emission inventory is reported for the calendar year. This is achieved in the exercise by arriving at fuel consumption per calendar year by assigning weightage relative to the portion of calendar year that is represented in the financial year1. Since there is no report yet in 2024 (with data from FY 2022-23), the data for the calendar year 2022 for the public electricity production in the state has been sourced from the monthly fuel reports from the CEA for coal, gas, light diesel oil/high speed diesel (LDO/HSD) and naphtha and the furnace oil, low sulphur heavy (LSHS/HHS) stock and lignite consumption is extrapolated based on the previous trend of consumption from the CEA general review report and the categorical consumption reported in the Industrial Consumption Report published by the Petroleum Planning and Analysis Cell. As this data is not available for the captive power stations, the emissions from captive electricity generation have been updated only until the calendar year 2021.

[37] The data for the financial year 2021-22 is reported for the period April 1, 2021 till March 31, 2022, i.e. 3/4th of 2021, and 1/4th of 2022. This weightage, i.e. 75% duration of 2021 and 25% duration of 2022, which is represented in the financial year 2021-22 is the weightage used to arrive at the yearly figures.

- Aluminium
- Cement
- Ceramic and Glass
- Chemicals and Allied Ind.
- Civil Engineering
- Electrical and Electronics Ind
- Engineering Industries
- Fertilizer
- Iron and Steel Production
- Mechanical Industries
- Metallurgical (Iron and Steel)
- Metallurgical (non-ferrous)
- Mining and Quarrying
- Petrochemical
- Textile and Fibre
- Others

**10.3.3.2 Industry Sector**:

Industry sector emission estimate carried out in this exercise excludes the production of electricity as it has been estimated separately (as part of the electricity sector under the captive electricity generation category). Fuel consumption data, including coal used in industries has been sourced from the Annual Survey of Industries (ASI). ASI reports contain fuel consumption data for sub-industries in India but only the consumption of coal is reported in terms of physical mass ('000 tons), and electricity is reported in terms of power ('000 kWh). All other fuels consumed are collectively reported in terms of their cost and are not segregated as per the different fuels consumed either. This is not very helpful for estimating emissions. As such, fuel combustion data for the industry sector, except coal, has been sourced from the India Petroleum and Natural Gas (IPNG) Statistics reports which are also annual publications. As industries contribute to emissions through both fuel combustion and industrial process and product use (IPPU), the former is accounted under the energy sector while the latter forms a separate category of its own. As the latest available IPNG statistics report is the 2021-22 edition, fuel combustion data till 2021 is available. Therefore, 2021 is the cut-off for the industry sector fuel combustion emissions.

**10.3.3.3 Transport Sector**:

The transport sector also contributes to energy emissions from fuel combustion. Using the share of the different fuels consumed for different modes of transport at the national level and the absolute share of Gujarat for each respective fuel from the IPNG Statistics report, the mode-wise total transport fuel consumption for Gujarat for each fuel has been calculated. This fuel consumption is used to estimate the transport emissions for the state. Emissions have been reported at a mode-level, i.e., Road, Rail, Aviation and Shipping. The retail sale of Motor Spirit (Petrol) and High-Speed Diesel (HSD) as reported in the IPNG Statistics Report has been allocated to Road Transport as that consumed for shipping and other sectors is direct sales and not retail.

**10.3.3.4 Other Sectors**:

Agriculture, residential and commercial sector contribution of emissions has been estimated based on the fuel consumption of these categories reported in the IPNG statistics reports for each of the various fuels. For example, a large majority of the LPG is consumed for domestically, being allocated to residential sector. Agriculture and commercial sector consumptions for each applicable fuel have reported separately in the reports. LPG, HSD, LDO, FO and LSHS are consumed in the agriculture sector while LPG and coal are consumed in the commercial sector.

**10.3.3.5 Emission Calculation and Inventory Reporting**:

All the various fuels are either reported in weight ( '000 MT) or volume (KL-Kilo litre). Where the fuel consumption is reported in weight, the same is multiplied first with the calorific value, and then the India specific emission factor when estimating the $CO_2$ emission for coal and lignite (As reported in the BUR-III). For all other fuels reported in weight (except coal and lignite) and all fuels reported in volume, the calorific value and emission factor are the default values provided in the IPCC 2006 guidelines for National Greenhouse Gas Inventories. For the fuel consumption reported in terms of volume, it is multiplied by the density of the fuel, before converting it to total energy by multiplying it with the calorific value. The total energy is then multiplied by the emission factors when estimating the $CO_2$, CH4 and N2O emission.

**10.3.3.6 Fugitive Emissions**:

Fugitive emissions are emissions that occur during non-combustion processes such as distillation and primarily attributed to refinery operations and fuel transport. While the state of Gujarat houses the largest petroleum refinery complex in the world, the same is under estimation and not included in the presented inventory.

**10.3.3.7 Emission Factor and Global Warming Potential**:

The emission factor and the global warming potential used for the emissions estimation have been presented in Tables 10.8 and 10.9 respectively.

***Table 10-8 Fuel wise emission factors for different gases. Highlighted ones are IPCC default calorific values and emission factors providing a tier 1 estimate and the non-highlighted ones are from India's Biennial Update Report - III, providing tier 2 estimate***

| Fuel | NCV | $CO_2$ EF | CH4 EF | N2O EF |
|---|---|---|---|---|
| Coking Coal | (TJ/kt) | (t/TJ) | (kg/TJ) | (kg/TJ) |
| Non-coking Coal | 23.66 | 93.61 | 1 | 1.5 |
| Lignite | 17.09 | 96.76 | 1 | 1.5 |
| LDO/HSD | 9.8 | 105.97 | 1 | 1.5 |
| LSHS/ HHS | 43 | 74.1 | 3 | 0.6 |
| Furnace Oil | 43 | 74.1 | 3 | 0.6 |
| Naptha/Light Distillates | 40.4 | 77.4 | 3 | 0.6 |
| Kerosene | 43 | 74.1 | 3 | 0.6 |
| Natural gas / CNG | 43.8 | 71.9 | 3 | 0.6 |
| LPG | 48 | 56.1 | 1 | 0.1 |
| Motor Spirit / Petrol | 47.3 | 63.1 | 1 | 0.1 |
| ATF | 44.3 | 69.3 | 3 | 0.6 |

***Table 10-9 Global Warming Potential of Different Gases***

| Gas | | Formula | Global Warming Potential (GWP) |
|---|---|---|---|
| | | SAR | AR6[38] |
| Carbon Dioxide | $CO_2$ | 1 | 1 |
| Methane | CH4 | 21 | 1 |
| Nitrous Oxide | N2O | 310 | 272 |

**10.3.3.8 Updated Inventory**

The inventory for the years 2019 to 2021 has been presented separately in the accompanying excel workbook.

## References for GHG Emissions Inventory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[38] Table 7.15, Chapter 7: The Earth's Energy Budget, Climate Feedbacks and Climate Sensitivity, Climate Change 2021, the Physical

## 10.4 Employment Factors used for Calculating Job Gains and Job Losses.

| Employment Factors - NDC | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fuel** | **2020** | | | | **2030** | | | | **2040** | | | | **2050** | | | |
| **Row Labels** | **CI** | **Fuel supply** | **Manf** | **OM** | **CI** | **Fuel supply** | **Manf** | **OM** | **CI** | **Fuel supply** | **Manf** | **OM** | **CI** | **Fuel supply** | **Manf** | **OM** |
| Biomass | 13.92 | 91.34 | 10.60 | 9.28 | 14.51 | 91.34 | 11.04 | 9.67 | 15.09 | 91.34 | 11.49 | 10.06 | 15.68 | 91.34 | 11.93 | 10.45 |
| Coal | 2.76 | 28.50 | 19.73 | 0.63 | 2.81 | 13.79 | 20.09 | 0.64 | 2.86 | 7.50 | 20.44 | 0.65 | 2.91 | 5.53 | 20.80 | 0.66 |
| Gas | 1.84 | 15.10 | 3.40 | 0.31 | 2.05 | 15.10 | 3.79 | 0.35 | 2.26 | 15.10 | 4.18 | 0.38 | 2.48 | 15.10 | 4.57 | 0.42 |
| Hydro-large | 20.80 | 0.00 | 12.79 | 0.57 | 22.61 | 0.00 | 13.90 | 0.62 | 24.42 | 0.00 | 15.01 | 0.67 | 26.23 | 0.00 | 16.13 | 0.72 |
| Hydro-small | 39.00 | 0.00 | 39.82 | 0.84 | 42.40 | 0.00 | 43.29 | 0.91 | 45.79 | 0.00 | 46.76 | 0.99 | 49.19 | 0.00 | 50.23 | 1.06 |
| Nuclear | 13.74 | 0.00 | 4.75 | 1.39 | 16.70 | 0.00 | 5.77 | 1.69 | 19.65 | 0.00 | 6.79 | 1.99 | 22.61 | 0.00 | 7.81 | 2.29 |
| Oil | 4.75 | 15.10 | 3.40 | 0.51 | 4.74 | 15.10 | 3.39 | 0.51 | 4.73 | 15.10 | 3.38 | 0.51 | 4.72 | 15.10 | 3.38 | 0.51 |
| Solar\|CSP | 29.23 | 0.00 | 14.61 | 2.19 | 21.17 | 0.00 | 10.58 | 1.59 | 17.31 | 0.00 | 8.65 | 1.30 | 13.41 | 0.00 | 6.71 | 1.01 |
| Solar\|PV-rooftop | 6.06 | 0.00 | 12.42 | 0.50 | 4.00 | 0.00 | 8.21 | 0.33 | 3.49 | 0.00 | 7.16 | 0.29 | 3.32 | 0.00 | 6.80 | 0.27 |
| Solar\|PV-utility | 2.21 | 0.00 | 12.42 | 0.50 | 1.46 | 0.00 | 8.21 | 0.33 | 1.28 | 0.00 | 7.16 | 0.29 | 1.21 | 0.00 | 6.80 | 0.27 |
| Wind offshore | 29.23 | 0.00 | 57.00 | 0.73 | 28.02 | 0.00 | 54.64 | 0.70 | 27.66 | 0.00 | 53.93 | 0.69 | 27.98 | 0.00 | 54.57 | 0.70 |
| Wind onshore | 0.96 | 0.00 | 6.21 | 0.50 | 0.92 | 0.00 | 5.95 | 0.48 | 0.91 | 0.00 | 5.88 | 0.47 | 0.92 | 0.00 | 5.95 | 0.48 |

**Source**: Malik et al. (2021)

## 10.5 List of Stakeholders Consulted

Below is the list of people who were invited for the stakeholder workshop held in April 2024.

| Name | Organisation |
|---|---|
| Shri Sanjeev Kumar [IAS] | Climate Change Department, Government of Gujarat |
| Shri Ajay Prakash [IAS] | Gujarat Energy Development Agency, Government of Gujarat |
| Mr. Abhigyan Patra | CEPT University |
| Dr. Abhijit Lokre | The Urban Lab, India |
| Dr. Abdul Rasheed | Gujarat Energy Research & Management Institute (GERMI) |
| Ms. Amita Pandya | Gujarat Energy Development Agency |
| Mr. Amitosh Gautam | WRI India |
| Professor Amit Garg | IIM, Ahmedabad |
| Mr. Ankit Makvana | ICLEI, South Asia |
| Mr. Arunava Mandal | Ahmedabad University |
| Ms. Astha Agarwalla | CEPT University |
| Dr. Ashwani Kumar | CEPT University |
| Dr Bhargav Adhvaryu | Ahmedabad University |
| Mr. Bandish Patel | C40 Cities Climate Leadership Group Inc. |
| Dr. Chaitali Trivedi | Ahmedabad University |
| Professor C.N. Pandey | IIT, Gandhinagar |
| Mr. Divyesh Desai | Independent Consultant for Energy Sector |
| Dr. Dipti Gupta | IIM, Ahmedabad |
| Dr. Darshini Mahadevia | Ahmedabad University |
| Dr. Diptiranjan Mahapatra | Indian Institute of Management Sambalpur |
| Dr. Dhvani Sanghvi | CEPT University |
| Ms. Falguni Tailor | Centre for Sustainable Development (KPCSD), IIT Gandhinagar |
| Dr. Hemangi Dalwadi | CEPT University |
| Dr. Jyoti R. Maheshwari | IIM, Ahmedabad |
| Mr. Kandarp Mistry | Centre for Net-zero Energy Transition (C-NET), GUVNL |
| Dr. Kopal Agrawal | Ahmedabad University |
| Ms. Kruti Mihir Upadhyay | IIM, Ahmedabad |
| Ms. Lakshita Lilani | Ahmedabad University |
| Mr. Mehul Patel | WRI India |
| Dr. Neeru Bansal | Adani Group – Cement Business |

| Name | Organisation |
| --- | --- |
| Ms. Neha Bajaj | The Urban Lab, India |
| Mr. Ninaad Desai | Ahmedabad University |
| Dr. Rajan Rawal | Center for Advanced Research in Building Science & Energy (CARBSE) |
| Dr. Ritwika Verma | IIM, Ahmedabad |
| Ms. Rutva Patel | IIM, Ahmedabad |
| Mr. Rakesh Arya | Gujarat Energy Development Agency |
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| Mr. Shwetal Shah | German Society for International Cooperation, India [GIZ India] |
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| Dr. Shivanand Swamy | Centre of Excellence in Urban Transport, CEPT University |
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| Ms. Shrutika Parihar | Ahmedabad University |
| Ms. Srutisri Sundaram | Ahmedabad University |
| Ms. Srutika Parihar | Ahmedabad University |
| Dr. Supratim Das Gupta | Ahmedabad University |
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| Mr. Yash Shukla | Center for Advanced Research in Building Science & Energy (CARBSE) |

Below is the list of people who were invited for the stakeholder workshop held in October, 2024.

| Name | Organisation |
|---|---|
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| Mr Ankit Makvana | ICLEI, South Asia |
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