# Tamil Nadu's Greenhouse Gas Inventory and Pathways for Net-Zero Transition

Report | February 2024


Technical partner

CEEW

THE COUNCIL

Suggested citation: TNGCC and CEEW. 2024. *Tamil Nadu's Greenhouse Gas Inventory and Pathways for Net-Zero Transition.* Chennai: Tamil Nadu Green Climate Company, Department of Environment, Climate Change and Forest, Government of Tamil Nadu; and Council on Energy, Environment and Water (CEEW).

Acknowledgment: **Government of Tamil Nadu Team**: Tmt. Supriya Sahu I.A.S., Additional Chief Secretary, Environment, Climate Change and Forest Department, and Chairperson and Managing Director, Tamil Nadu Green Climate Company; Dr. Jayanthi Murali I.F.S., Chairperson, Tamil Nadu Pollution Control Board; Thiru. Deepak Srivastava I.F.S., Chief Mission Director, Green Tamil Nadu Mission and Member Secretary, Tamil Nadu Wetland Authority; Thiru. Anurag Mishra I.F.S., Special Secretary – Environment and Climate Change, Environment, Climate Change and Forest Department; Thiru. Deepak Bilgi I.F.S., Chief Mission Director, Tamil Nadu Coastal Restoration Mission; Thiru. Ritto Cyriac I.F.S., Special Secretary - Forest, Environment, Climate Change and Forest Department; Prof. Dr. R. Ramesh, Advisor, Tamil Nadu Green Climate Company; Dr. S. Viswanathan, Chief Executive Officer, Tamil Nadu Green Climate Company; Dr. Prasannavenkatesh Ramachandran, Climate Change Expert, Tamil Nadu Green Climate Company.

**CEEW Team**: Anurag Dey, Research Analyst; Praveen Chandrasekaran, Engagement Lead; Sunita Patra, Research Analyst; Pallavi Das, Programme Lead; Joy Rajbanshi, Programme Associate; Swati Sharma, Research Analyst; Ganesh Dileep, Special Assistant to Director, Research Coordination; Vaibhav Chaturvedi, Fellow; Karthik Ganesan, Fellow and Director - Research Coordination, and Sumit Prasad, Programme Lead.

We acknowledge the contribution of all partners involved in conceptualising the GHG Platform Initiative (GHGPI).

Organisations: The **Tamil Nadu Green Climate Company** (TNGCC) is a Section (8) Not-for-Profit company and a unique platform to respond to Climate Change in Tamil Nadu (TN). TNGCC is a first-of-its-kind ambitious initiative which acts as a Special Purpose Vehicle (SPV) to address climate challenges in the state. TNGCC is committed to creating a climate positive and lasting change in TN, raising the ambition for action against Climate Change and supports sustainable and climate resilient development through detailed research and analysis. To achieve its goal, TNGCC has launched four core climate missions namely Tamil Nadu Climate Change Mission (TNCCM), Green Tamil Nadu Mission (GTNM), Tamil Nadu Wetlands Mission (TNWM) and Tamil Nadu Sustainably Harnessing Ocean Resources and Blue Economy (TN-SHORE).

The **Council on Energy, Environment and Water** (CEEW) is one of Asia's leading not-for-profit policy research institutions and among the world's top climate think tanks. The Council uses data, integrated analysis, and strategic outreach to explain — and change — the use, reuse, and misuse of resources. The Council addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public. CEEW has a footprint in over 20 Indian states and has repeatedly featured among the world's best managed and independent think tanks.
Follow us on X (formerly Twitter) @CEEWIndia for the latest updates.

**Tamil Nadu Green Climate Company**
7th Floor, Secretariat, Namakkal Kavignar Maaligai,
Fort St. George, Chennai - 600009, Tamil Nadu

forsec@tn.gov.in | tngreencompany.com | X@climateactionTN | tnclimateaction | Tamil Nadu Climate Action

**Council on Energy, Environment and Water**
ISID Campus, 4 Vasant Kunj Institutional Area
New Delhi – 110070, India
+91 11 4073 3300

info@ceew.in | ceew.in | X@CEEWIndia | ceewindia

# Tamil Nadu's Greenhouse Gas Inventory and Pathways for Net-Zero Transition

Technical partner

February
2024


**M.K. STALIN**
Chief Minister of Tamil Nadu,
Government of Tamil Nadu,
Secretariat, Chennai - 600 009


## FOREWORD

Climate Change is a subject of international concern and poses a major threat to humanity. With the impact of Climate Change being felt across the world, it has become imperative to integrate climate policies and planning at all levels of government. This enables us to adapt to the warming world and also to put in place mechanisms to mitigate the release of harmful greenhouse gases (GHG). While country-level Nationally Determined Contributions (NDCs) provide the necessary policy direction to mitigate GHG emissions, sub-national governments are at the forefront of formulating State-specific policies to ensure the well-being of its people.

Tamil Nadu is committed to combating the effects of climate change and has been a pioneer in its effort to adapt to and mitigate GHG emissions. It is the first State in India to have conceptualized a Governing Council on Climate Change, comprising of eminent national and international experts, to provide policy directives and guidance on the State's key climate missions. This study is also a first-of-its-kind initiative by the Government of Tamil Nadu to assess the State's emissions profile and identify pathways to achieve Net-Zero emissions while continuing to pursue ambitious economic growth. I congratulate the Department of Environment, Climate Change and Forests for leading this initiative under the guidance of experts from the Governing Council. I also appreciate the efforts put in by all the contributors to ensure Tamil Nadu leads the way for other sub-national governments across India and the world by steering its economy towards Net-Zero emissions.

**(M.K. STALIN)**


**SIVA. V. MEYYANATHAN**
Minister for Environment and Climate Change,
Government of Tamil Nadu,
Secretariat, Chennai - 600 009


## FOREWORD

Tamil Nadu has been one of the most proactive States in India to tackle the effects of Climate Change. We have put in place a robust institutional mechanism that aims to integrate Governance on Climate related issues across various Government Departments that are of relevance to this issue. The Department of Environment and Climate change has set up the Tamil Nadu Green Climate Company (TNGCC), a Section (8) Non-Profit Company, which serves as a unique platform to respond to Climate Change issues in the state. Under the able guidance of the Chief Minister's Governing Council on Climate Change and its own Board of Directors, TNGCC is successfully executing several projects under its four flagship missions designed to create a greener Tamil Nadu. This study facilitates the creation of a repository of Tamil Nadu's Greenhouse Gas (GHG) emissions, and also a much-needed scientific understanding of Tamil Nadu's ambition to become a Net-Zero emissions economy, without compromising on its economic prosperity. I congratulate TNGCC for driving this effort and all contributors for creating a robust body of knowledge for Tamil Nadu to become a green economy.

22/2/2024.

(Siva. V. Meyyanathan)

**SUPRIYA SAHU, IAS**
Additional Chief Secretary to Government, Environment Climate Change and Forest Department, Government of Tamil Nadu,
Secretariat, Chennai - 600 009

## FOREWORD

Tamil Nadu has been a leader in addressing Climate Change related issues, both through an innovative institutional architecture that serves as a model for Climate Change governance, and through multiple projects housed under its four key missions governing climate change, including the Green TN (GTN) Mission, the Climate Change Mission, the Wetlands Mission and the SHORE mission. The wide range of activities under these missions contributes significantly towards climate change adaptation and mitigation in Tamil Nadu.

The concept of Net-Zero has gained prominence across the world, with several State and non-State actors announcing their targets to achieve Net-Zero emissions. In its efforts to combat Climate Change, I am proud to state that the Department of Environment, Climate Change and Forests undertook this unique study supported by the government to create a comprehensive greenhouse gas (GHG) inventory and chart out pathways for Tamil Nadu to achieve Net-Zero emissions, while remaining committed to rapid economic growth in the coming decades. While this study has been customised using Tamil Nadu specific data, the analyses was conducted using international scientific modelling tools and methodologies that have been peer reviewed by global experts. I congratulate and appreciate all authors and editors for bringing out this valuable scientific document for use by all interested stakeholders.

**(SUPRIYA SAHU)**

# Contents


**Executive summary** 1

**1. Introduction** 3

**2. Tamil Nadu's emissions inventory** 5

2.1 Energy sector 5

2.2 Industrial processes and product use 7

2.3 Agriculture, forestry, and other land use (AFOLU) 7

2.4 Waste (wastewater and solid waste) 9

**3. Modelling framework and scenario analysis for the future** 12

3.1 Accounting for emissions 13

3.2 What the GCAM does not do 13

3.3 Drafting TN's long-term NZ transition plan 13

3.4 Key socio-economic assumptions 13

**4. Results: TN's energy sector net-zero transition pathways** 15

4.1 Industry sector 15

4.2 Transport sector 16

4.3 Building sector 20

4.4 Agriculture sector 21

4.5 Final energy demand 22

4.6 Power sector 23

**5. What does TN's NZ transition mean for its emissions?** 25

5.1 Energy sector emissions outlook 25

5.2 Land-use sector sequestration potential 27

**6. Jobs and investment potential** 31

**7. Measurement, reporting and verification** 33

**8. Key insights, recommendations and conclusion** 34

8.1 Key insights 34

8.2 Key recommendations for sectoral targets 36

8.3 Conclusion 37

**Annexures** 38

**Acronyms** 41

**References** 42

# Executive summary

Climate change impacts are increasingly being felt worldwide, and emissions mitigation commitments by countries and companies have picked up the pace. This has been especially true since the release of the Intergovernmental Panel on Climate Change (IPCC) special report on the impacts of global warming of 1.5°C above pre-industrial levels that called for achieving global net-zero (NZ) emissions by the middle of the century (Fischlin et al. 2018). At the 26th session of the Conference of the Parties (COP26) in 2021, India demonstrated its climate leadership by announcing that it would achieve NZ carbon emissions by 2070. This will require significant transformation across key sectors that produce and consume energy, such as agriculture, industry, power, transport, building and waste. Each state in India will have distinct low-carbon transition pathways depending on its current level of economic development, resource availability, and socio-political context. As a developing economy, Tamil Nadu (TN) is bound to witness increased economic growth in the near future, resulting in higher per-capita income and urbanisation levels, which will further lead to increased energy demand and emissions across sectors contributing to the economy. The challenge for TN, then, is to identify and chart out decarbonisation pathways for the aforementioned sectors, while not compromising on the prospects of economic growth. In addition, TN will need to identify and nurture technologies and financing that will enable its NZ transition. A commitment to NZ emissions, therefore, requires consistent efforts to adopt low-carbon pathways across various sectors in the near, medium, and long term. Our analysis based on the latest greenhouse gas (GHG) inventory and long-term projection for emissions in business as usual (BAU) and NZ scenarios reveals important trends and provides the following significant insights:

## A. NZ is as much about economic transformation as it is about climate change

NZ ambition entails reducing GHG emissions across key energy producing and consuming sectors. The face of mobility will change from fossil-based to low-carbon mobility, necessitating a significant change in the automobile industry set up. Industrial energy use will have to be largely electrified, having implications through pass through of electricity prices. Rapid renewable energy penetration will present significant opportunities for investment and job creation. Therefore, it is critical to view NZ transition as a larger economic transformation that has profound implications for the future economy of TN.

## B. Understanding when could the state's emissions peak is as important as the choice of NZ year

Peak year is defined as the year in which absolute economy-wide emissions peak, following which there will be a continuous drop in emissions. Given the diverse economic profiles of various states in India, the shape of emissions pathway for various states, including at what level and which year they will peak, would be different. Understanding this critical milestone is critical for various stakeholders in the state.

## C. The pursuit of NZ emissions results in massive electrification of end-use energy consumption

A net-zero scenario necessitates electrification of the various end use sectors. Total electricity consumption in 2070 Tamil Nadu in the NZ scenario is 75% higher than that in the BAU scenario. In 2020, the building and industry sectors in the state consume about 44 per cent of the total electricity each, while agriculture accounts for 13 per cent, and the transport sector accounts for a negligible 1 per cent. In projections for the future, the electricity demand for NZ emissions is higher for all sectors, and transport sees an exponential growth, accounting for 24 per cent of the share in 2070. Therefore, this key insight pertains to the criticality of the power sector and the imperative to significantly ramp up renewable generation capacity to meet growing consumption needs.

## D. The efficiency of the energy system increases as a result of this massive electrification and dedicated efforts to enhance energy efficiency

Our assessment shows that significant efficiency gains are obtained from the large-scale electrification of end-use sectors. In addition, dedicated interventions to enhance energy efficiency across sectors will have to be undertaken. Compared to 2020, the energy intensity of TN's GSDP has to reduce by 24 per cent in 2030 and 55 per cent in 2050 to achieve NZ emissions. TN's total electricity consumption for 2020–21 stood at around 110

BUs. Electrification and energy efficiency gains imply mean annual energy savings in 2070 could be equivalent to nearly three times that of current electricity consumption.

## E. Power sector decarbonisation paves the way for other sectors to decarbonise

In the NZ scenario, power sector emissions are projected to peak at around 157 $MtCO_2$ in 2040, followed by the building sector at 20 $MtCO_2$ in 2045, and the transport and industry sectors at nearly 62 and 50 $MtCO_2$ in 2050, respectively. This signifies that the power sector holds the highest emissions mitigation potential and is key for other end-use energy consumption sectors to successfully decarbonise, given the extent of electrification observed in the NZ scenario. It is imperative that early focus of decarbonisation efforts is in the power sector, where many technologies are already cost competitive.

## F. TN needs nearly 475 GW of solar and 90 GW of wind power (including offshore) to achieve NZ emissions by 2070, it is imperative to reassess the state's solar and wind potential

Our assessment indicates that TN will need to procure power from outside the state in the future in both the NZ and BAU scenarios. The need for electrification of the end use sectors to achieve the goals of net-zero necessitates the need for significant renewable energy capacity addition over the coming decades. It requires TN to add around 9 GW of solar capacity and 2 GW of wind capacity on average every year, with capacity addition growing at compounded annual growth rates (CAGRs) of 8 and 4 per cent, respectively, for solar and wind. According to TN's energy policy note from 2023–24, one of the targets is to increase the installed capacity of solar to 20 GW over a period of 10 years, indicating that the state is on track in the near term to achieve NZ emissions in the long term. The Ministry of New and Renewable Energy (MNRE) has conservatively estimated that 17 GW of solar capacity can be obtained using 3 per cent of wasteland area (PIB, 2024). However, other estimates indicate that there is much greater potential, which has to be reassessed in the light of the net-zero target.

## G. Nearly 17 GW of offshore wind capacity is required to meet the 2070 NZ target

While it is necessary to increase both solar and onshore wind power capacity in the future, offshore wind power must start contributing to clean energy generation. While India currently does not have any offshore wind power plants, the National Institute of Wind Energy (NIWE) identified that there is potential to harness about 70 GW from offshore wind, spread across 16 offshore zones along the coasts of TN and Gujarat. The MNRE aims to bid out 37 GW worth of capacity by 2030. In 2023, the MNRE published an updated strategy paper and a tender for allocating seabed areas to develop 7 GW of open access–based or captive offshore projects off the TN coast. This could potentially help reduce the emissions footprint of commercial and industrial electricity consumers. Offshore wind, therefore, remains an important untapped source of energy in TN.

## H. Compared to 2005, the overall energy sector emission intensity of TN's GSDP needs to reduce by 46 per cent in 2030 and 87 per cent in 2050 to achieve NZ emissions

Emission intensity measures the amount of GHGs released per unit of economic output. India's NDC aims to reduce the emission intensity of the gross domestic product (GDP) by 45 per cent from the 2005 level (Government of India 2022). In this context, based on the modelling results, TN needs to reduce its emission intensity by 46 per cent in 2030 and by a further 87 per cent by 2050, compared to 2005 levels, to achieve NZ emissions by 2070. For context, in 2020, for every USD 1 million of TN's gross state domestic product (GSDP), the state's energy sector emitted nearly 510,000 $tCO_2$. This has to be reduced to about 410,000 $tCO_2$ in 2030 and 100,000 $tCO_2$ in 2050.

## I. The Green Tamil Nadu (GTN) Mission has the potential to sequester $CO_2$ emissions worth 19–25 $MtCO_2$ per annum

A comprehensive study of one of TN's flagship missions, the GTN Mission, reveals that the GTN Mission is capable of sequestering emissions to the tune of 19–25 $MtCO_2$ per annum. The average annual carbon sequestration potential is 19 $MtCO_2$ for a tree rotational period of 15 years, and this goes up to 25 $MtCO_2$ for a rotational period of 10 years. Carbon sequestration through trees will have to be an important part of the strategy to achieve net-zero for the state.

# 1. Introduction

Since the release of the Intergovernmental Panel on Climate Change (IPCC) special report on the impacts of global warming of 1.5°C above pre-industrial levels, support for NZ emissions has been constantly growing among climate leaders (Fischlin et al. 2018). According to the Climate Action Tracker, as of November 2023, around 145 countries had announced or were considering NZ targets, covering close to 90 per cent of global emissions, compared to 130 countries covering about 70 per cent of emissions in May 2021. Among these are China, the EU, the USA, and India, which jointly account for more than half of global greenhouse gas (GHG) emissions (Climate Action Tracker 2023). The intent to adopt a NZ target demonstrates some level of commitment towards reducing climate-damaging emissions. Political will, backed by robust research and analysis, is expected to inspire faster action to meet these ambitious, yet achievable, targets. At the Conference of the Parties (COP26), India also announced its intention to become a NZ emitter of $CO_2$ by 2070. Since then, sub-national initiatives on climate action have gained prominence. Tamil Nadu's (TN) effort to formulate a NZ transition plan demonstrates its initiative to align the state's climate ambition to the country's climate targets.

Achieving NZ emissions requires significant transformation across key sectors that produce and consume energy. These include sectors such as agriculture, industry, power, transport, building and waste. As a developing economy, TN is bound to witness increased economic growth in the near future, leading to higher per-capita income and urbanisation levels, which will translate to increased energy demand and emissions across sectors contributing to the economy. The challenge for TN, then, is to identify and chart out decarbonisation pathways for the aforementioned sectors without compromising on the state's economic growth prospects. In addition, TN will need to identify and nurture technologies and financing that will enable its NZ transition. A commitment to NZ emissions, therefore, requires consistent efforts to adopt low-carbon pathways across various sectors in the near, medium, and long term.

## 1.1 What to expect from this report

This document presents and evaluates economy-wide energy demand and emissions pathways that exist at present for TN to achieve NZ carbon emissions by 2070. Energy demand has been projected till 2070 for five key sectors – power, transport, building, industry, and agriculture. It is important to note that these future pathways are only indicative and not conclusive. They are based on past trends and present policies that could potentially shape the state's future. As public policies governing the socio-economy and the broader energy and environment sectors of TN continue to evolve, so will these pathways. All assumptions about the future that form the basis of the modelling projections are listed in Annexure 1.

This report presents sectoral pathways for TN to transition to NZ emissions and practical insights that could be gleaned from them. While it also recommends many policy targets across sectors, it does not offer any insights on specific instruments (e.g. feed in tariff, capital subsidies, etc.) to achieve the proposed targets. Sector specific policies and instruments would require an in-depth study of each sector and a thorough assessment of the options available for the same. This document focuses on both TN's energy sector, which accounts for approximately 83 per cent, on average, of its total GHG emissions over the past decade, as well as assesses the carbon sequestration potential of one of the flagship climate missions of TN, the Green Tamil Nadu (GTN) Mission.

## 1.2 How can this report help policymakers?

In a paper titled 'Modeling for Insights, Not Numbers' (Huntington et al. 1982), the authors highlight the importance of modelling tools and their relevance to policymakers. To quote, "With insights as an important product of the modeling process, an assessment of how the models are used is as important as understanding their structures". The key insights derived from modelling TN's energy sector in the long term could potentially be used to shape TN's environmental and economic future. Policymakers play a substantive role in determining this, and the insights presented in this report could assist them in the following areas:

**Visualising the future**: In a rapidly changing world, where the pace of technological evolution is constantly increasing with time, modelling provides foresight to policymakers. It lets them visualise a wide range of 'what if' scenarios pertaining to the state's future. This, in turn, allows them to conceptualise and design public policies that enable the large-scale adoption of such technologies.

For instance, two such scenarios are explored in this document:

- **What if** TN continues to extend its present policy framework to mitigate emissions in a business as usual (BAU) manner?
- **What if** TN wants to achieve NZ emissions by 2070? What are the potential sectoral pathways through which this transition could be achieved?

**Deriving actionable insights**: Modelling the energy system of TN offers unique and valuable insights into how public policies could potentially shape the future. A list of 9 such key insights is presented in the report. These will be of value to policymakers across departments in the Government of Tamil Nadu (GoTN). For instance, while the scale of growth in renewable energy could be of particular interest to the Tamil Nadu Generation and Distribution Corporation Limited/Tamil Nadu Transmission Corporation Limited (TANGEDCO/ TANTRANSCO) and the energy department, the level of reduction required in emissions and energy intensities could be useful to the state's planning department for setting targets in the near, medium, and long term. Similarly, the shift in transport sector service demand might necessitate policy interventions from the transport department, and increasing demand for cooling services in buildings might require similar action from the housing and urban development department.

**Guiding policy decisions**: A combination of the ability to visualise the future and derive insights from it could prove valuable to policy making. Individual departments could use this collective intelligence to draft their own policies to transition to NZ emissions. For example, the TANGEDCO/energy department could utilise the insights of this study to chart out the state's NZ transition plan for its power sector. The guidance cell of the industry department could perform a similar function for the industry department. Finally, the environment and climate change department, under whose guidance this report was prepared, could act as the nodal department facilitating the formulation of sector-wise NZ transition plans.

## 1.3 Overview of the project

With a gross state domestic product (GSDP) of INR 23.64 lakh crore in 2022–23, TN contributes nearly 10 per cent to India's overall gross domestic product (GDP). As a leading industrial state, it has an ambitious target of becoming a USD 1 trillion economy by 2030–31. The state released a vision document to this effect at the recently concluded Global Investors Meet, 2024, which identifies key growth vectors and enablers to achieve this target. According to the document, it aims to attract investments worth INR 23 lakh crore and to create employment for 46 lakh people, in addition to supporting the growth of the manufacturing sector in the state from USD 48.1 billion in 2020 to USD 236 billion in 2030. Given that TN is a growing economy with a stabilising population, its energy needs are also expected to significantly increase in the future, notably in key sectors such as transport, industry and building. A significant share of the state's future energy needs will be met through renewables and other emerging clean energy technologies, primarily to tackle the crisis of climate change and because of the increasing risks associated with fossil fuel supply chains and environmental pollution. In this context, the GoTN must carefully consider whether the state's growing energy needs are commensurate with its developmental aspirations while moving towards sustainable economic growth.

The state's focus on emerging sectors such as electric vehicles (EVs), renewable energy, and fostering an ecosystem for green hydrogen manufacturing, among others, demonstrates its commitment to a sustainable economic transition. In addition, TN's ambition to be a NZ emissions economy will be instrumental to India achieving the updated Nationally Determined Contributions (NDCs) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) and realising the long-term goal of achieving NZ emissions by 2070.

In this context, the GoTN embarked upon an exercise to develop the state's long-term NZ emissions transition plan. TN undertook a scientific and rigorous energy systems modelling exercise to inform the state's vision and sectoral pathways to achieve NZ emissions. The primary objectives of this analysis are given as follows.

- **Updating TN's GHG inventory**: Establishing an emissions inventory for TN is the first step towards identifying areas for intervention in the state. With a representative emissions inventory, the state can prioritise action, even as it looks to expand energy consumption and industrial production. This will involve sector-level interventions – improving the efficiency of the power generation mix; reviewing industrial structure and associated energy choices, transportation services provision, management of waste streams, and resource recovery; and making forestry and land-use changes. These actions are expected to have implications on long-term pathways for energy demand and supply.

- **Assessing long-term energy demand and associated carbon emissions for TN across various energy-intensive sectors such as power, transport, industry and building**: With a well-defined economic vision to cater to the stabilising population, TN is poised for rapid economic growth, leading to higher per-capita income and urbanisation levels slated to be among the highest in the country. This will result in greater energy demand across major sectors, such as electricity, transport, industry and building, eventually leading to more climate-damaging carbon emissions. The Council on Energy, Environment and Water (CEEW) assesses TN's future energy requirements, commensurate with the state's developmental aspirations, while imposing the constraints of a sustainable development paradigm.
- **Analysing a BAU scenario to estimate TN's energy needs until 2070 and economy-wide NZ emissions pathways through which TN could potentially achieve NZ emissions by 2070**: An important question in this assessment of long-term pathways that is pertinent to many sub-national entities is the feasibility of achieving NZ emissions in line with India's own NZ vision for 2070. This analysis will present policy scenarios under which TN could achieve NZ emissions while accommodating the developmental needs of the state and its people. For instance, we explore a BAU scenario, assessing the emissions trajectory of the state within the existing policy framework. This will serve as the reference scenario for the state.
- **Understanding the sectoral implications of a BAU scenario until 2070 and sectoral pathways for TN to achieve NZ emissions by 2070**: A transition towards NZ emissions entails a significant shift in the way energy is produced and consumed across various sectors, such as electricity, transport, industry and building. Sectoral contribution to the economy varies across states. A customised approach to understanding the energy-intensive sectors of TN is essential to determine decarbonisation pathways. This analysis will assess the extent of decarbonisation required for each of these sectors, specific to TN, and outline a clear strategy to achieve sectoral decarbonisation targets.
- **Assessing the carbon sequestration potential of the GTN Mission**: While mitigating emissions from key energy-consuming sectors is one part of the issue, the other is to complement these mitigation efforts through the creation of carbon sinks that will absorb carbon emissions. In the context of TN, this means evaluating the potential of one of the state's flagship missions to sequester carbon emissions – the GTN Mission. To understand TN's potential to net out carbon emissions arising from the energy sector in the long term, the CEEW will assess the carbon sequestration potential of the state's GTN Mission.

This document is organised as follows. It starts with the updated emission inventory for TN. This is followed by a brief on the modelling framework used to determine TN's NZ transition pathways, the process followed over the course of the project, modelling results outlining the NZ transition pathways for TN's key energy-consuming sectors, assessment of the carbon sequestration potential of the GTN Mission. The report concludes with key insights and recommendations drawn from the study.

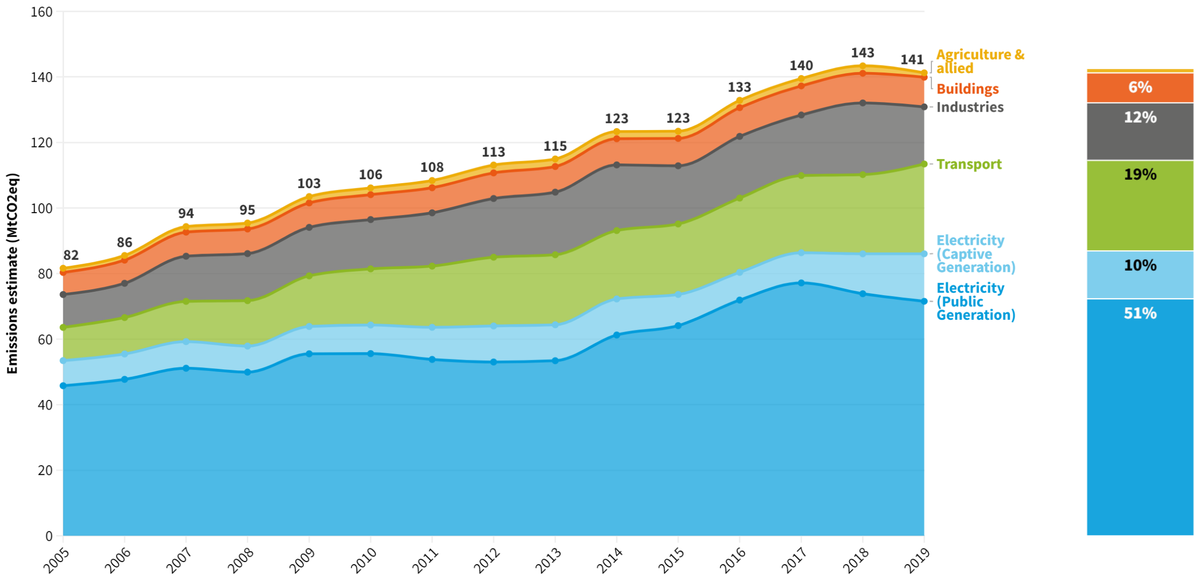
# 2. Tamil Nadu's emissions inventory

## 2.1 Energy sector

TN saw a 75 per cent overall increase in GHG emissions from its energy sector between 2005 and 2019. This corresponds to a 3.7 per cent growth in GHG emissions compounded annually. At a cumulative value of 141 million tonnes of carbon dioxide equivalent (MtCO2Eq), the energy sector is the largest driver of emissions in the state (Figure 1).

Electricity generation is the largest contributor to GHG emissions in the energy sector, as is the case at the national level. Power production contributed 61 per cent of the energy sector emissions in 2019, with the majority share coming from non-captive power plants, at 72 MtCO2Eq. However, notably, the share of emissions from electricity generation in TN's overall energy sector emissions came down from 65 per cent in 2005. Meanwhile, the per-capita electricity consumption

**Figure 1** Energy sector emissions in TN (2005–19)




*Source: Authors' analysis based on GHG Platform India (GHGPI)*

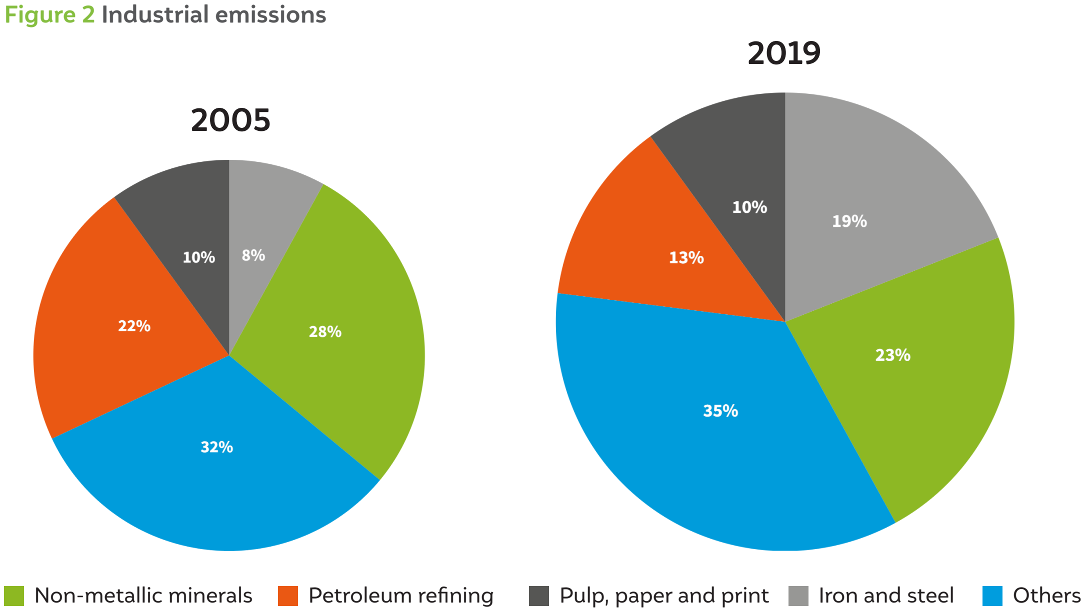
Note: GHGPI must be acknowledged in all the relevant places.

in the state almost doubled, from 977 to 1,844 kWh, between 2005 and 2019 (CEA 2023). The reduction in the emissions share could be attributed in part to the substantial share of Variable Renewable Energy (VRE) power in meeting the state's growing electricity demand, especially from wind power generation – 61 per cent of the state's VRE generation was from wind energy in 2022 (CEA 2023).

Most of the electricity produced is consumed by industry, followed by domestic users. In FY 2019–20, 42 per cent of all power sold in the state was consumed by industry, with domestic consumers accounting for 28 per cent. With increased industrialisation and economic prosperity, the electricity demand in the state is expected to climb further in the short to medium term.

GHG emissions from the transport sector also almost tripled between 2005 and 2019, from 10 to 27 MtCO2Eq. The share of transport sector emissions in the overall energy sector emissions also grew from 12 to 19 per cent in the same period. Of the 19.7 lakh vehicles registered in TN in 2019 (Vahan Dashboard n.d.), 87.7 per cent ran on petrol, followed by 10 per cent on diesel. EVs constituted

**Figure 2** Industrial emissions




*Source: Authors' analysis based on GHG Platform India (GHGPI)*

only 0.17 per cent of the vehicles, with hybrid and CNG vehicles accounting for roughly 0.5 per cent. However, new EV registrations have seen a massive spike in recent years, with 26 times more EVs having been registered in 2023 than 2019. This increased the share of new EV registrations to 5 per cent and reduced the shares of petrol and diesel vehicle registrations to 77 and 8.8 per cent, respectively, in 2023 (Figure 2).

Industrial emissions almost doubled between 2005 and 2019, growing from 10 to 17 MtCO2Eq. Emissions from the cement production, iron and steel, textiles and leather, petroleum refining, chemicals and fertiliser, and pulp, paper, and print industrial categories accounted for 83 per cent of industrial emissions in 2019. Cement production was responsible for almost 23 per cent of the GHG emissions from the industrial sector, followed by iron and steel, at 19 per cent. Notably, emissions from the latter quadrupled between 2005 and 2019, while those from the former increased at a compounded annual growth rate (CAGR) of 2.4 per cent (Figure 3).

About 66 per cent of TN's GHG emissions can be attributed to the use of coal as a primary energy source. Emissions from burning coal increased by 3.6 per cent annually, from 49 to 80 MtCO2Eq between 2005 and 2019. Emissions from liquid and gaseous fuels almost doubled in the reference period, increasing annually by 4 and 6 per cent, respectively.

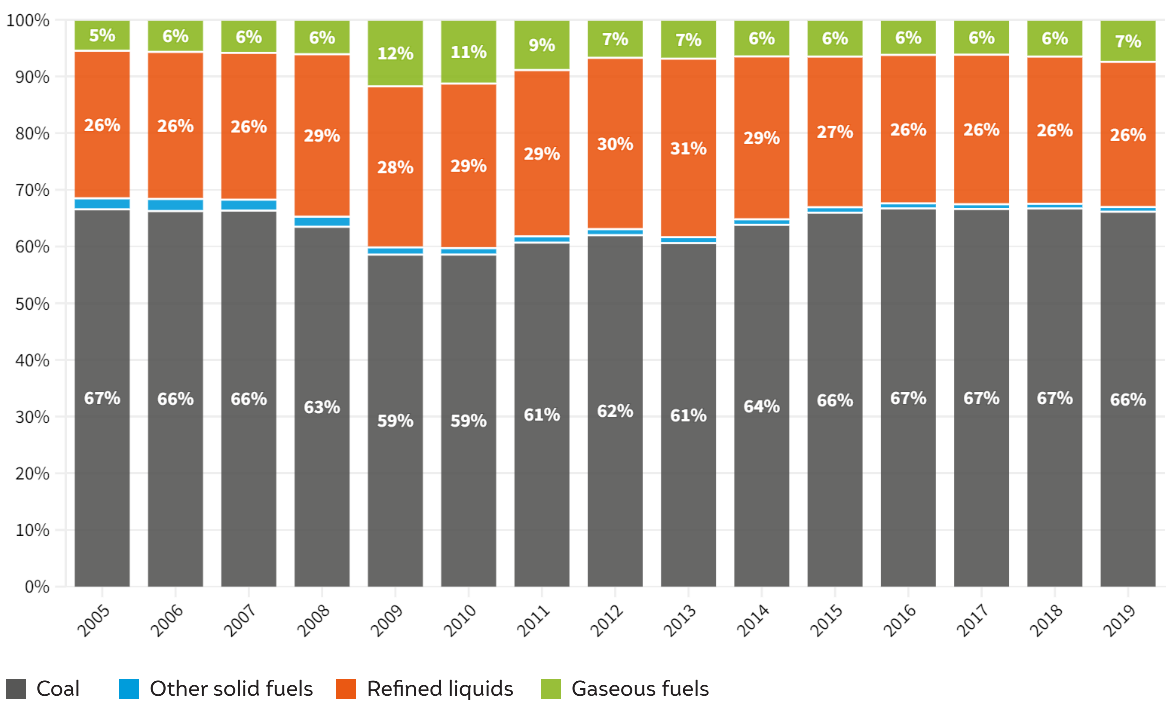
## 2.2 Industrial processes and product use

Industrial processes and product use (IPPU) emissions contributed 6 per cent of TN's overall GHG emissions in 2019 (Figure 4). Being the leading cement producing state in the country, TN's IPPU emissions are understandably heavily driven by cement industries. Cement production alone accounted for almost 98 per cent of IPPU emissions in 2019. Mineral industry emissions grew by 3.8 per cent annually between 2005 and 2019. Overall, IPPU emissions rose by 4 per cent annually during this period.

## 2.3 Agriculture, forestry, and other land use (AFOLU)

Livestock farming, rice, and fertiliser are the three significant sources of GHG emissions in the AFOLU sector (Figure 5). Emissions from livestock farming contributed roughly 50 per cent of the emissions in 2019, of which enteric fermentation was the most significant contributor (91 per cent, with manure management contributing the remainder). However, in the past 15 years, emissions from enteric fermentation have been decreasing steadily (by 1.5 per cent compounded annually) due to the declining bovine population, especially indigenous cattle and buffalo.

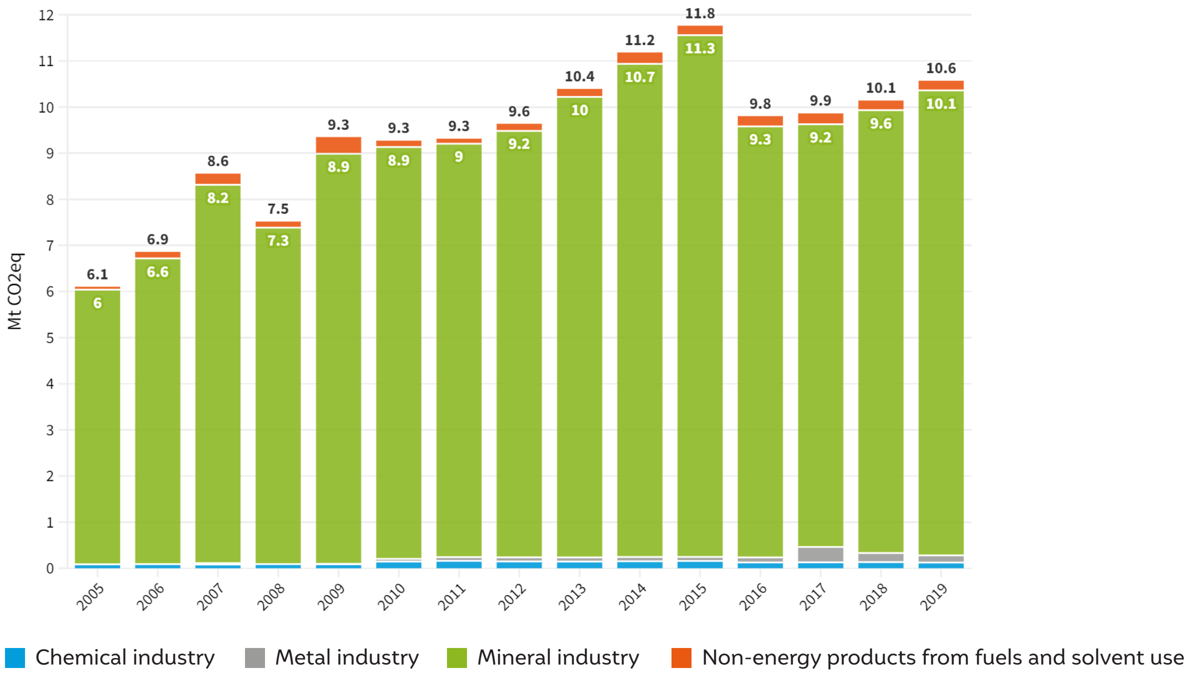
**Figure 3** Percentage share of GHG emissions, by fuel type, due to fuel combustion




*Source: Authors' analysis based on GHG Platform India (GHGPI)*

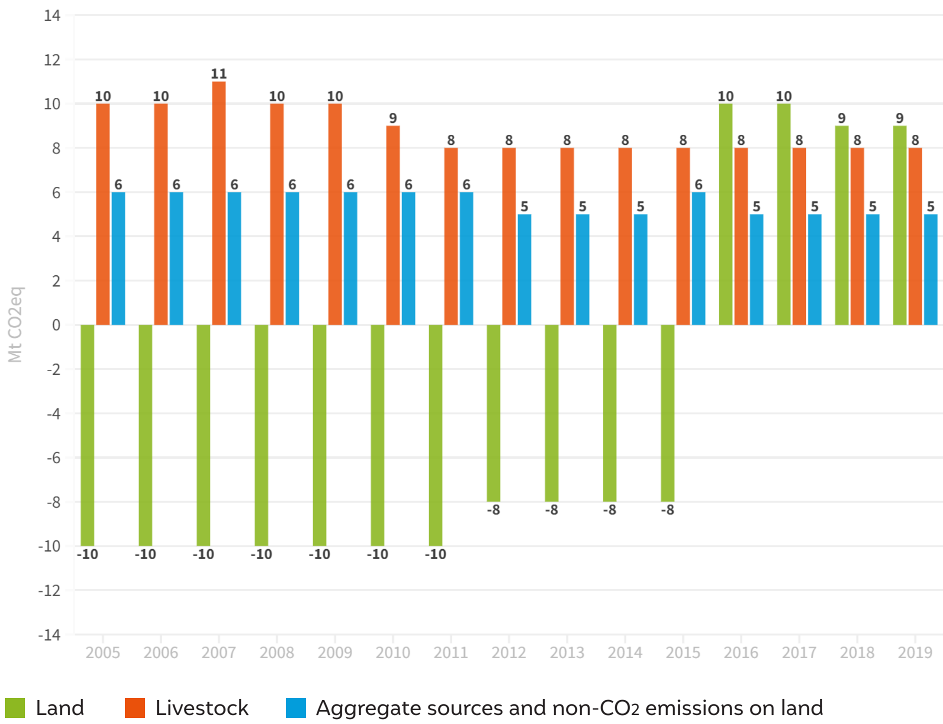
Rice is the second largest contributor to GHG emissions (Figure 6). The area under rice cultivation has fluctuated on a yearly basis, but overall emissions have been declining by 0.9 per cent (compounded annually) from 2005 levels. Consumption of urea and other nitrogen fertilisers by farmers has been increasing for decades, making fertiliser consumption the third most significant GHG emissions contributor. Fertiliser-related emissions have increased by 0.3 per cent annually since 2005. However, emissions from crop residue burning have reduced due to a decrease in the production of crops such as sugarcane.

**Figure 4** GHG emissions estimate for the IPPU sector in TN



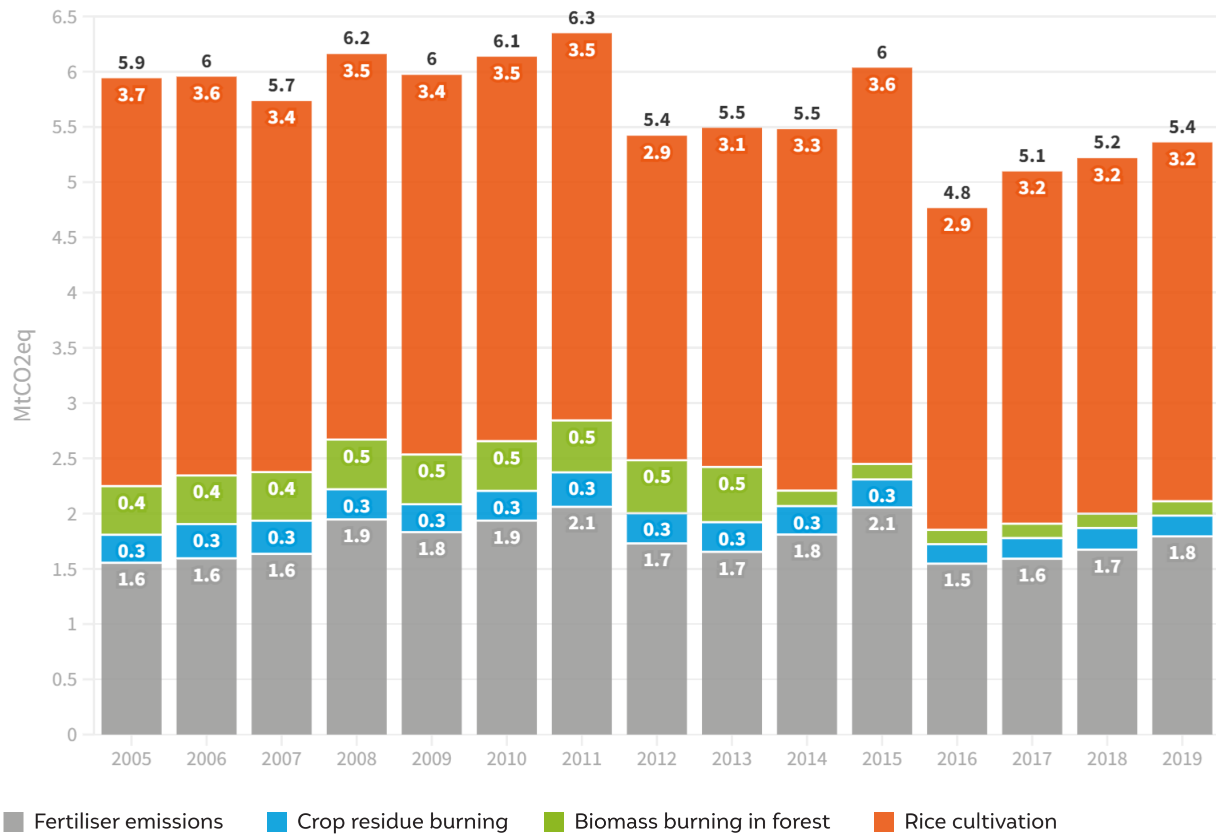

*Source: Authors' analysis based on GHG Platform India (GHGPI)*

**Figure 5** GHG emissions estimate for the AFOLU sector in TN ($MtCO_2Eq$)




*Source: Authors' analysis based on GHG Platform India (GHGPI)*

**Figure 6** Aggregate sources and non-$CO_2$ emissions sources on land




*Source: Authors' analysis based on GHG Platform India (GHGPI)*

Land-use changes, such as converting forests, agricultural land, and wetlands to other land categories, may result in emissions (Figure 7). Between 2005 and 2015, there was a 15 per cent increase in forest area in TN, leading to a rise in carbon sequestration. Therefore, a steady value of sequestration of 9.9 $MtCO_2$ per year was observed from 2005 to 2015. However, this pace declined to a mere 0.5 per cent between 2015 and 2019, leading to reduced carbon sequestration in the years following 2015.

A significant proportion of forest and agricultural lands have been converted to other land categories, increasing emissions in the land-use sector. This shift has transformed the sector from a carbon sink to a source of emissions since 2015, as depicted in Figure 7.

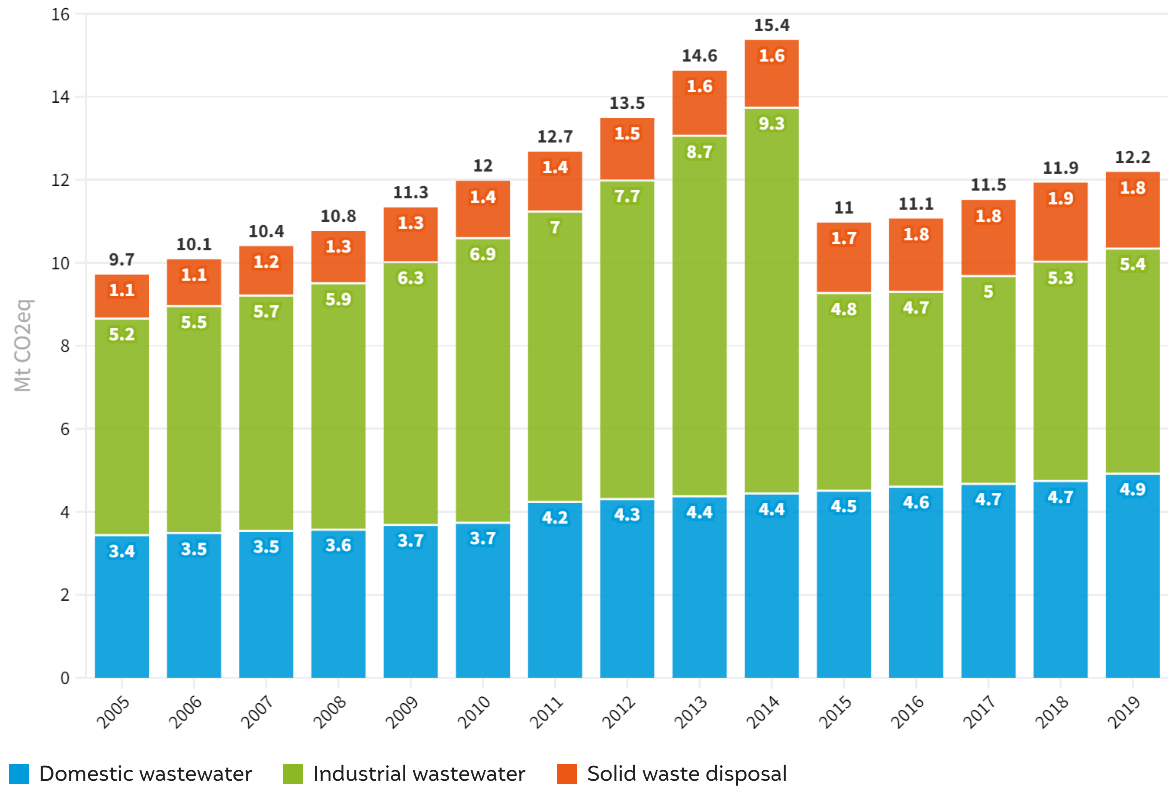
## 2.4 Waste (wastewater and solid waste)

Waste sector emissions accounted for 5 per cent of TN's GHG emissions in 2019, as compared to 4 per cent at the national level in 2018. Key emissions sources in this sector include municipal solid waste, domestic wastewater, and industrial wastewater. Anaerobic decomposition of solid waste, as well as the anaerobic treatment or disposal of domestic wastewater, produces methane ($CH_4$) as a by-product. The breakdown of protein in domestic wastewater also produces nitrous oxide ($N_2O$), which is released into the atmosphere.
In TN, emissions in this sector are greatly driven by the treatment and discharge of industrial wastewater, as well as rural and urban domestic wastewater. Emissions from wastewater treatment and discharge contributed 85 per cent of the total emissions from TN's waste sector in 2019, with industrial fluid effluents accounting for a slightly larger portion (5.4 $MtCO_2Eq$) than domestic wastewater (4.9 $MtCO_2Eq$). Along with emissions from solid waste disposal and decay, the total emissions from this sector reached 12.2 $MtCO_2Eq$ in 2019. GHG emissions from the waste sector in the state had a CAGR of 1.5 per cent between 2005 and 2019 (Figure 8).

**Figure 7** Land-use GHG emissions estimate (MtCO2Eq)


*Source: Authors' analysis based on GHG Platform India (GHGPI)*

**Figure 8** GHG emissions of the waste sector in TN



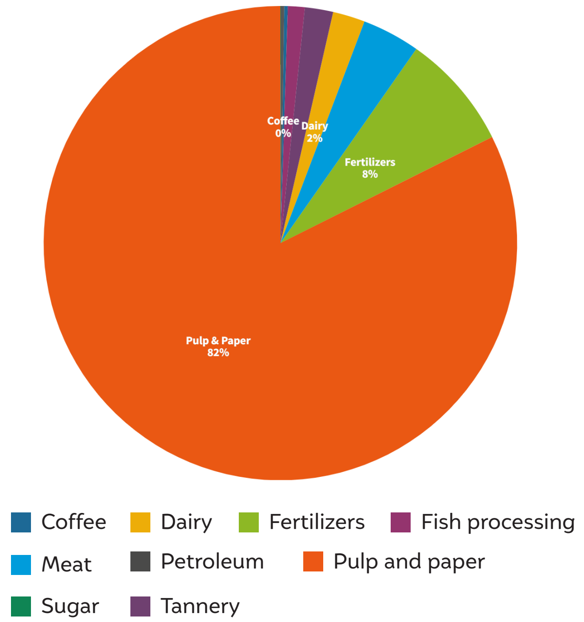

*Source: Authors' analysis based on GHG Platform India (GHGPI)*

Land-use changes, such as converting forests, The increase in emissions from municipal solid waste and domestic wastewater treatment followed a consistent trend between 2005 and 2019. However, a sudden drop in total emissions from the waste sector occurred in 2015. This can be attributed to the sharp decline in emissions from industrial wastewater from 2015 onwards. Notably, emissions from solid waste disposal and decay increased by 2.5 per cent annually in the same reference period.

A closer look at the sources of industrial wastewater in 2019 reveals that the emissions in this sub-sector are greatly driven by the treatment and discharge of effluents from the paper and pulp industries in the state, followed by the fertiliser manufacturing and meat processing industries. Paper and pulp industries contributed 82 per cent of industrial wastewater emissions in 2019, producing 4.5 MtCO2Eq of emissions. Emissions from the treatment of wastewater in this industrial sector alone was only 0.4 MtCO2Eq less than the total emissions from rural and urban domestic wastewater in the same year (Figure 9).

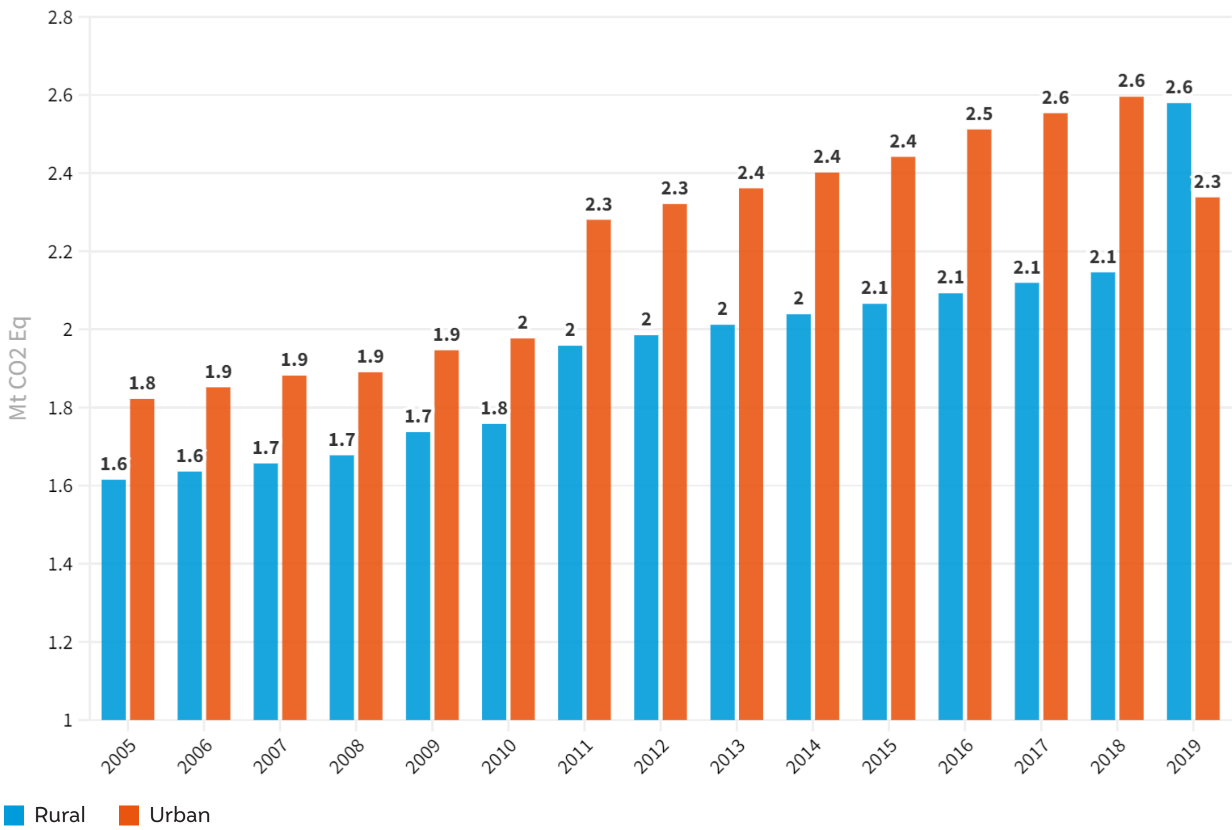
Historically, wastewater from urban households has produced more emissions than wastewater from rural households. However, notably, improvements in urban sewage treatment plant capacities and collections resulted in emissions dropping by 0.3 MtCO2Eq between 2018 and 2019. Rural emissions climbed by 0.5 MtCO2Eq in the same period (Figure 10).

**Figure 9** Industrial wastewater emissions




*Source: Authors' analysis based on GHG Platform India (GHGPI)*

**Figure 10** Area-wise GHG emissions estimates for domestic wastewater




*Source: Authors' analysis based on GHG Platform India (GHGPI)*

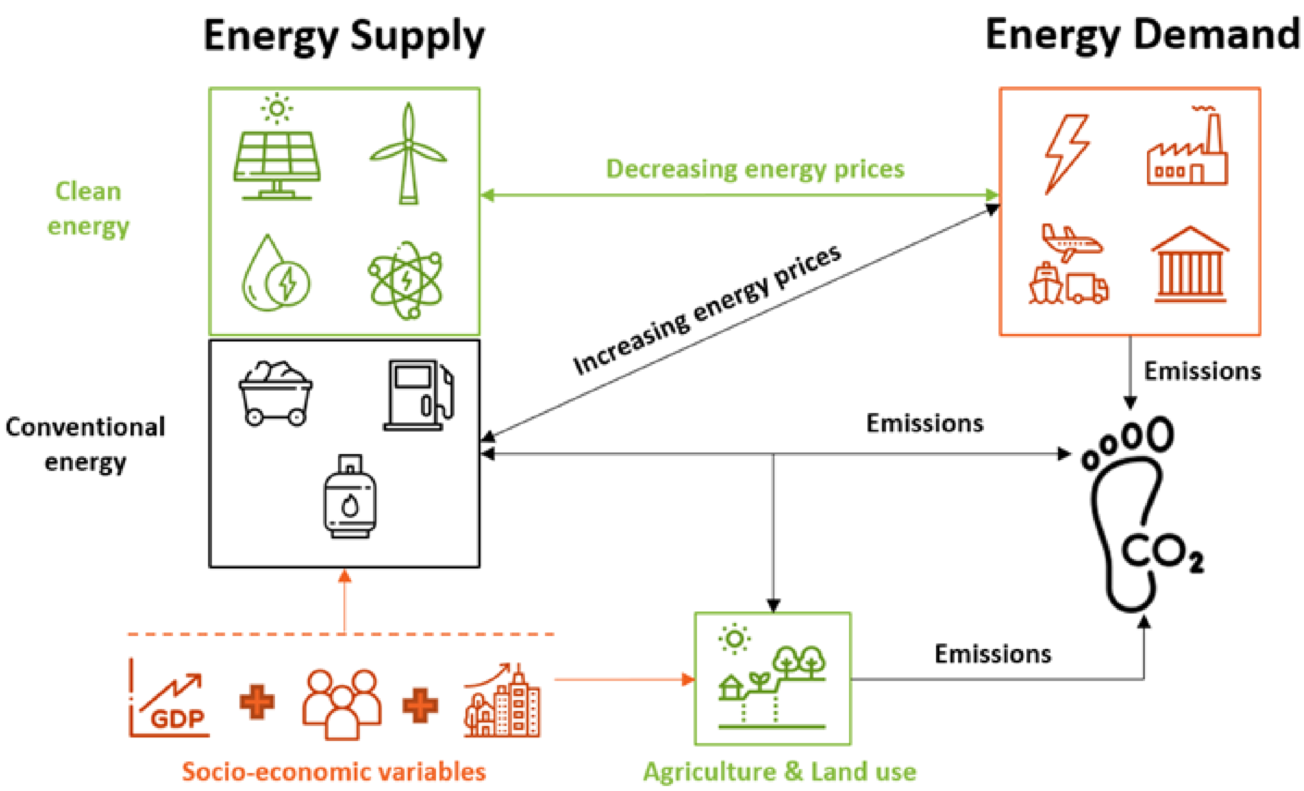
# 3. Modelling framework and scenario analysis for the future

The modelling exercise was conducted using the Global Change Analysis Model (GCAM) – an energy sector–focused model used extensively for energy and climate policy analyses. This model was chosen because it can project beyond the mid-century, and into the future. It facilitates exploring NZ scenarios for India and understanding the implications of the country's target to achieve economy-wide NZ emissions by 2070. Further, the GCAM provides a representative state of the future energy mix for multiple policy scenarios based on the projected prices of various technologies. It captures the behaviour of and interactions between energy systems, water, agriculture and land use, the economy, and the climate. The model is housed at the Joint Global Change Research Institute (JGCRI), USA, and covers 32 regions of the world, with India as a separate one. A state-level version of the GCAM was developed by the CEEW in collaboration with the Center for Global Sustainability, University of Maryland (CGS, UMD), USA. This version has a detailed representation of the energy systems in all Indian states and union territories. For each state, energy demand is modelled for the following sectors:

- Building (commercial, residential urban, and residential rural)
- Transport (passenger and freight)
- Industry (aggregate)
- Agriculture

The energy demands of these sectors are serviced by the energy-supply sector, which includes the power generation sector and refining industries. Figure 11 depicts the interaction between energy demand and supply and how it is modelled within the GCAM. Key drivers of future sectoral energy demands are economic and population growth, urbanisation rate, consumer behaviour, technology costs, energy prices, and government policies. The model can explore various scenarios like the implications of increases and decreases in economic growth and urbanisation rates, solar/wind electricity generation cost trajectories, adoption rates of EVs, and rates of

**Figure 11** Schematic representation of the GCAM




*Source: Adapted from JGCRI and Pacific Northwest National Laboratory (PNNL)* efficiency improvements, among others. It can also investigate alternative deep decarbonisation policies and the availability of breakthrough technologies such as hydrogen power and carbon capture, utilisation, and storage (CCUS).

## 3.1 Accounting for emissions

For this analysis, we followed a production-based accounting procedure, where emissions are accounted for if they occur within the administrative boundary of the state. For example, if TN is procuring electricity from a thermal power plant in Chhattisgarh, emissions associated with that electricity are not accounted for in TN's inventory and vice versa.

## 3.2 What the GCAM does not do

- The GCAM does not try to predict the future. It rather simulates how an energy system could evolve using a set of assumptions about emissions limits, available technologies, efficiency growth, and energy costs.
- The GCAM does not consider certain non-economic factors such as the political viability of these approaches but seeks pathways to minimise economic costs.
- The GCAM is not meant to provide a definitive picture of the future. However, it can offer insights into key factors and potential policy directions that could enable positive outcomes and mitigate risks emanating from an uncertain future.

## 3.3 Drafting TN's long-term NZ transition plan

The drafting process followed for long-term energy assessment and emissions modelling using GCAM is outlined in Figure 12. In the process of drafting the state's NZ transition plan, the CEEW consulted nearly 30 stakeholders in the GoTN across 14 departments as well as nodal agencies within some of these departments. They include the following:

- Department of Environment, Forest and Climate Change and the Tamil Nadu Green Climate Company (TNGCC)
- Planning and development and Sustainable Development Goals (SDG) cell
- Energy
- Industry
- Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO)
- Water resources
- Agriculture engineering, agriculture marketing, and horticulture
- Transport and Metropolitan Transport Corporation (MTC)
- Housing and urban development

## 3.4 Key socio-economic assumptions

The modelling assessment of TN's energy sector is underpinned by various assumptions, key among them being those about the socio-economic realities of the state. 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:

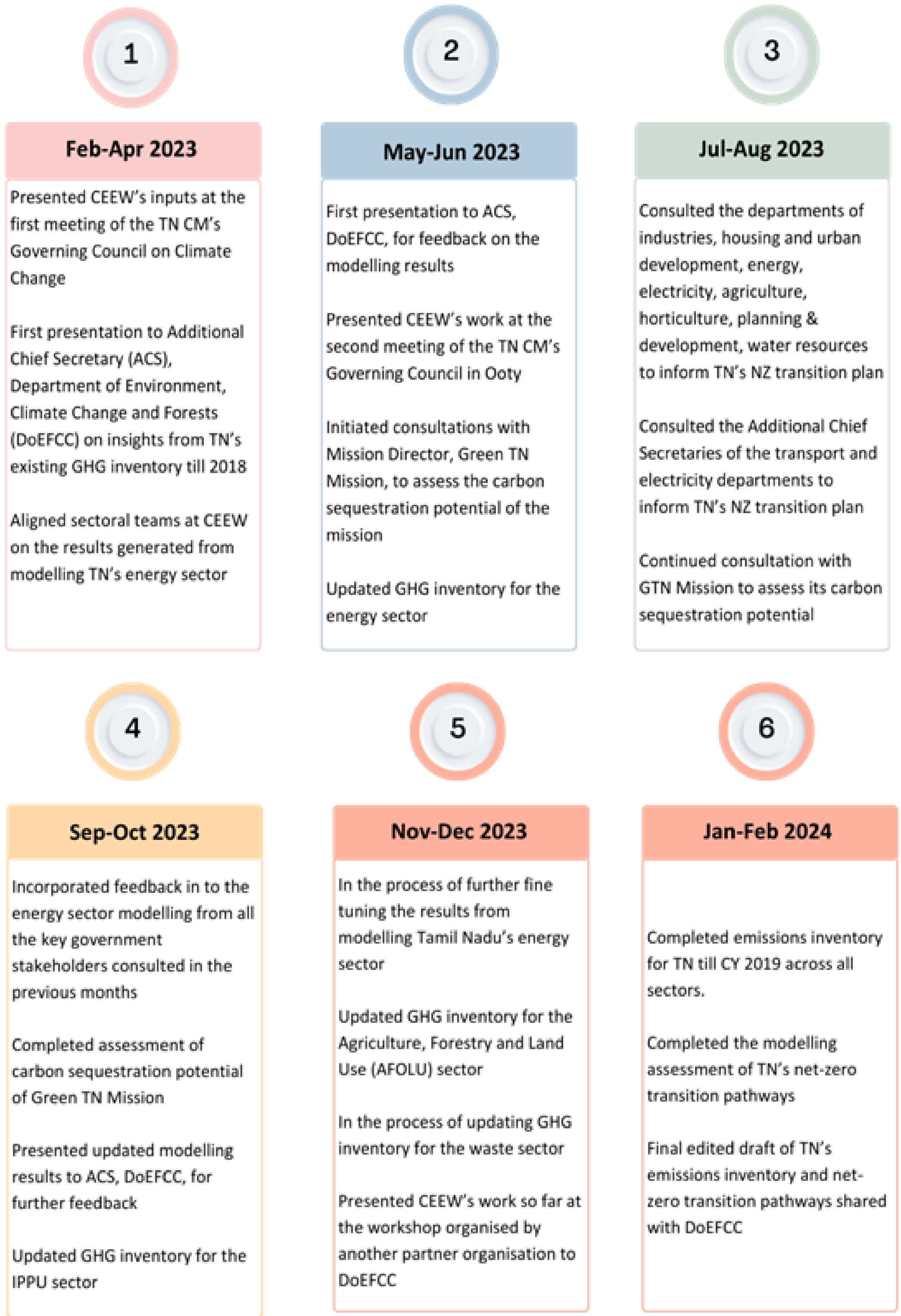
- **Population**: A stabilising population with a growing income could imply higher energy demand, primarily owing to increasing electricity consumption in households, floorspace, and usage of appliances. Also, as the number of households continues to grow, a larger number of vehicles are needed to cater to an increasingly mobile population, and higher industrial output is required to cater to the consumption needs of the population. According to a 2020 report by the Ministry of Health and Family Welfare (MoHFW) on population projections, TN's population is expected to peak in 2032 and should stabilise going forward. This is indeed reflective of social indicators such as the total fertility rate (TFR) in TN. The TFR in TN is 1.8 children per woman, which is well below the replacement level of fertility of 2.1 (IIPS and ICF 2022). The 2020 MoHFW report projects the state's TFR to reduce further, to 1.51, between 2031 and 2035 (MoHFW 2020).
- **GSDP**: TN has set itself an ambitious target of becoming a USD 1 trillion economy by 2030. This implies that the state's economy will rapidly expand in the coming decade. While TN has clocked an average nominal GSDP growth rate of 11 per cent in the past decade, it has to grow at an impressive 18 per cent per annum in the next eight years to achieve the target. The growth rates assumed for this modelling exercise follow a medium-growth trajectory, in line with historical growth rates. This trajectory is outlined in Annexure 1. It is important to note that

while the growth rate might progressively reduce on account of a higher base every year, TN's economy will continue to grow in absolute terms.

- Rate of urbanisation: With 48.4 per cent of its population living in urban areas in 2011, TN is the most urbanised state in India. This is projected to go up to 59.6 per cent by 2036 (Vahan Dashboard n.d.). As the state's economy continues to grow in the coming decades, the share of the urban population could also be expected to grow.

Further details on socio-economic and other assumptions pertaining to the energy sector can be found in Annexure 1.

**Figure 12** Timeline of activities for TN's NZ transition plan



# 4. Results: TN's energy sector net-zero transition pathways

In this section, we present the results from the modelling exercise conducted on TN's energy sector, along with implications on energy demand across sectors and CO2 emissions and the key insights derived. The results are presented for five major energy-consuming sectors – power, building, transport, industry, and agriculture – in BAU and NZ scenarios.

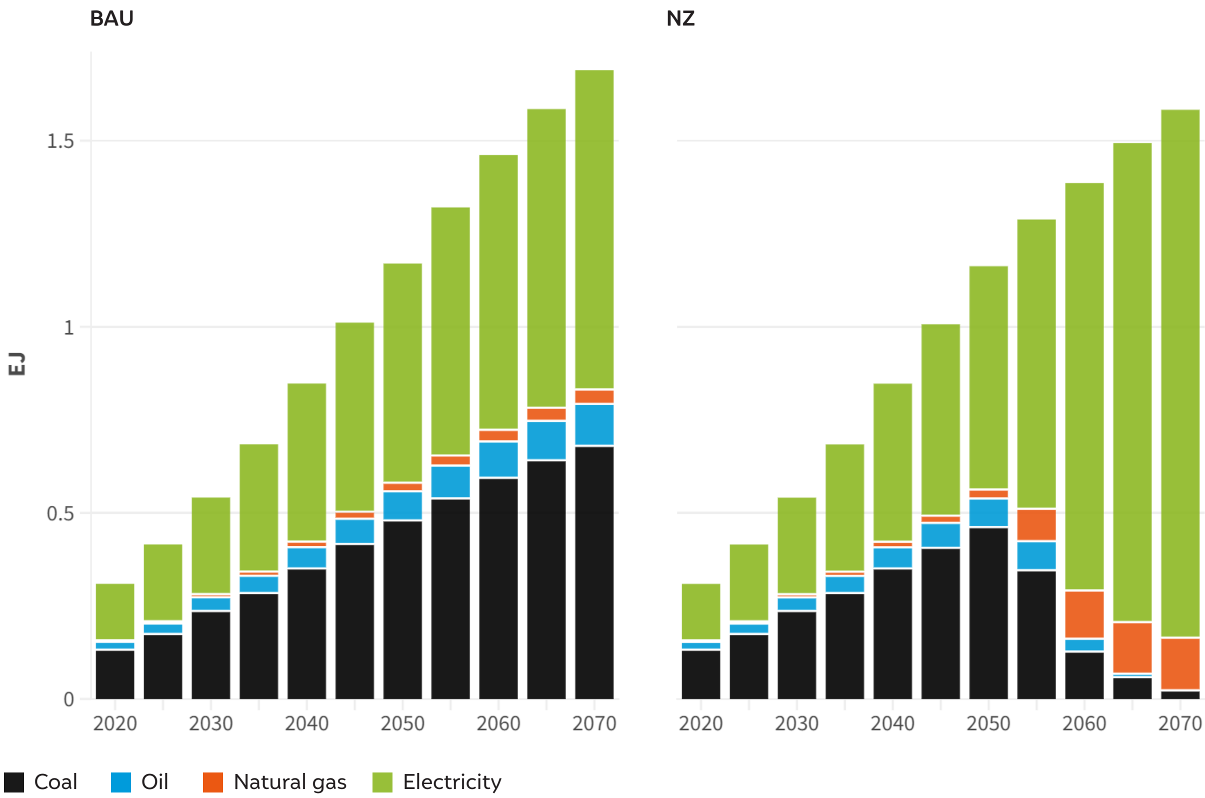
- **BAU scenario**: BAU assumes that existing policies and technologies continue to remain in place. It also includes an inherently defined improvement in energy efficiencies and a reduction in the costs of renewable energy technologies as they mature and reach economies of scale.
- **NZ scenario**: This scenario imposes a carbon constraint on the BAU one, in line with India's ambition of reaching NZ emissions by 2070. For this, the peak year considered for emissions is 2040, and the modelled scenario aligns TN with India's NZ emissions target for 2070. In addition, while TN reaches NZ emissions in 2070, it is also assured that India reaches NZ emissions, so that there is no emissions leakage.

## 4.1 Industry sector

TN aspires to become a USD 1 trillion economy by 2030 on the back of rapid industrialisation. The recently concluded Global Investors Meet in January 2024, at which it drew over INR 6.6 lakh crore in investments, is a testament to this aspiration. These investment commitments are in turn expected to generate nearly 2.7 million jobs, with over 1.45 million in direct employment (BL Chennai Bureau 2024). Further, the state government launched a slew of policies to promote industrial investment, including policies for EVs, semiconductors and advanced electronics, public–private partnerships, footwear and leather products, ethanol blending, city gas distribution and logistics, among various others, positioning the state as highly industry friendly. The current manufacturing share of the GDP in TN is 21 per cent against the Indian average of 14 per cent, and the model assumes that with these policies in place, the share will increase to 24 per cent in the future, by 2070. The contribution of industry to TN's total emissions is a mere 20 per cent compared to that in other highly industrialised states such as Gujarat and Karnataka, where this share stands at 41 and 44 per cent, respectively, due to the presence of emissions-intensive industries such as cement, and iron and steel manufacturing. Even though these industries account for slightly over a third of TN's industrial emissions, emissions are much lower due to comparatively lower production. Other emissions-intensive industries in TN include textile, leather, and petroleum refining industries.

At present, TN's industries primarily consume coal, electricity, and oil for their energy needs. In 2020, electricity consumption accounted for 50 per cent while coal accounted for 42 per cent. Under the BAU scenario, the overall industrial energy demand increases by 5.5 times in 2070, from 0.31 EJ in 2020 to 1.7 EJ in 2070. However, the share of fuels in the energy mix remains the same as in 2020. In the NZ scenario, the industrial energy mix is largely electrified, consuming 1.4 EJ of the total industrial demand of 1.6 EJ. Efficiency gains achieved through large-scale electrification are observed from the overall drop in industrial energy demand to 1.6 EJ in 2070 in the NZ emissions scenario, compared to 1.7 EJ in the BAU scenario as noted in Figure 13. The big trend in the industry sector, hence, is rapid electrification of this sector.

**Figure 13** **Final industrial energy demand in the BAU (a) and NZ (b) scenarios**




*Source: Authors' analysis*

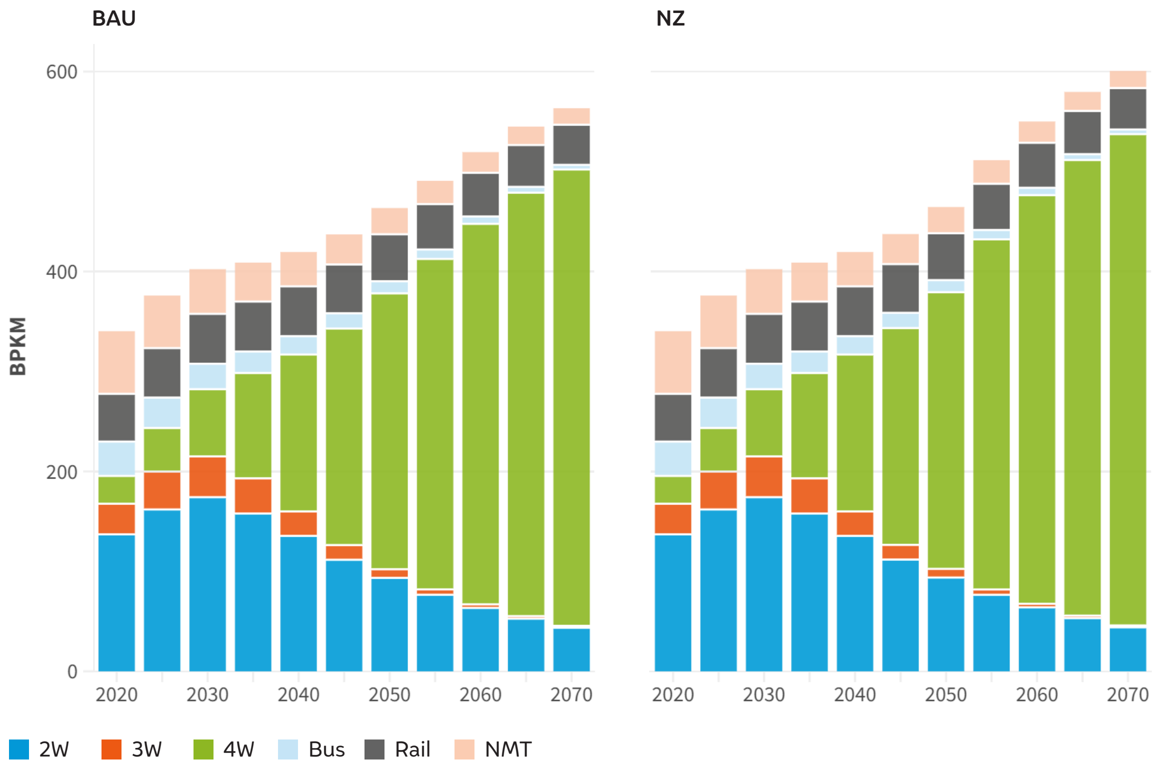
## 4.2 Transport sector

A growing economy will see an increase in demand for transportation services, and consequently, energy demands in this sector will also rise. Given TN's stabilising population in a growing economy, it is essential to understand how transport service demand grows in both the freight and passenger segments. In the passenger segment, as the population stabilises, higher incomes will enable people to aspire to more comfort and luxury while travelling, implying a higher demand for four-wheelers (4W). Concurrently, a growing economy for the freight segment is expected to result in higher demand for trucks and freight rail to transport goods. The passenger segment includes the 2W, 3W, 4W, bus, and rail vehicle types, while the freight segment includes rail and trucks.

In the BAU scenario, from nearly 64 bpkm (billion passenger-kilometres)[1] in 2020, the service demand for NMT (walking and cycling) decreases to 17 bpkm in 2070 as noted in Figure 14. There is a significant drop in the utilisation of buses too, leading to a decrease in service demand for public transport. This fall in service demand is largely taken care of by 4W, which increase from 26 bpkm in 2020 to a massive 457 bpkm in 2070. 4W ownership goes up from 22 cars per 1,000 people to 121 cars by 2070. While 2W ownership grows in the initial years, it drops as the penetration of 4W increases. This necessitates policy interventions to shift service demand to more sustainable forms of transportation and buck the projected market trends. At nearly 50 per cent, much of the energy consumed by the passenger transport sector in 2020 is by 2W. This amount substantially decreases to nearly zero by 2070 in a BAU scenario. 4W replace 2W in the energy consumption mix, as their share grows from 28 to 100 per cent during the same time period, indicating that people prefer the comfort of cars as incomes increase. Overall, the energy consumption in the passenger segment decreases from 0.16 EJ in 2020 to 0.14 EJ in 2070.

1. A passenger-kilometre (pkm) is the unit of measurement representing the transport of one passenger by a defined mode of transport (road, rail, air, sea, inland waterways, etc.) over 1 kilometre.

**Figure 14** Transport service demand, by mode, in the passenger vehicle segment, in the BAU (a) and NZ (b) scenarios




*Source: Authors' analysis*

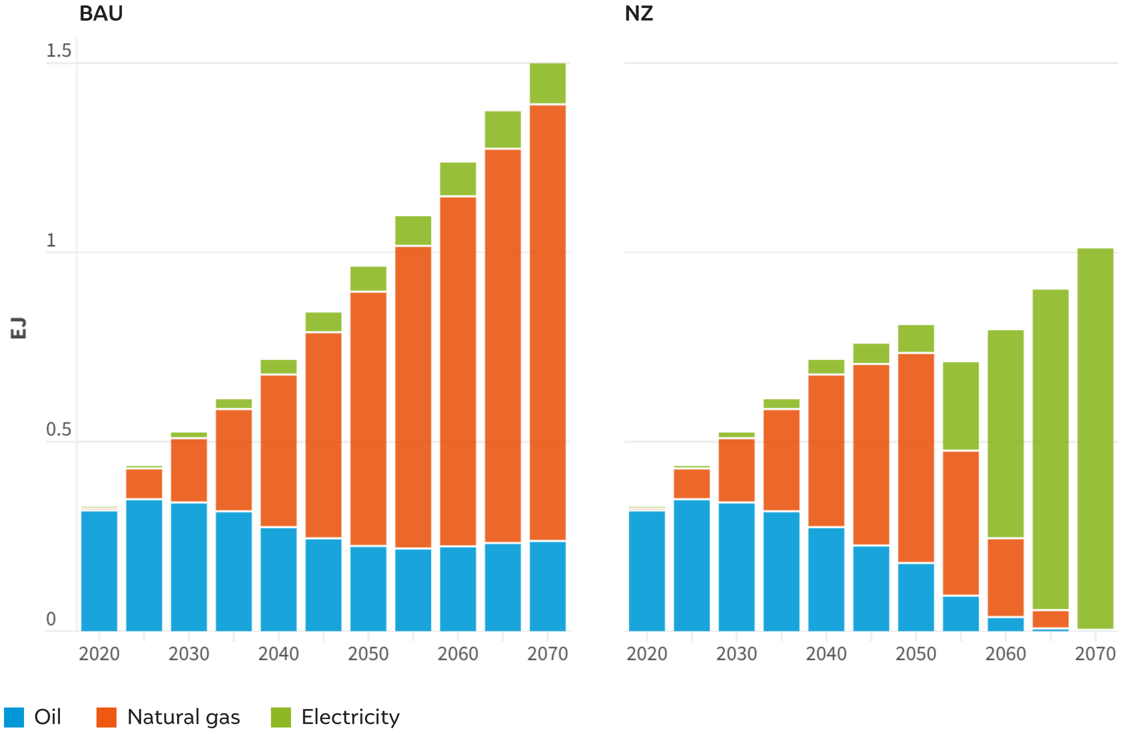
In 2020, the passenger and freight segment equally constituted 50 per cent of the energy demand. This composition undergoes a complete transformation in 2070, with freight constituting nearly 90 per cent of the total transport sector energy demand under the BAU scenario. In absolute terms, the freight energy demand increases from 0.16 EJ in 2020 to 1.36 EJ in 2070. A rapid growth in the energy needs of the freight sector indicates accelerated economic growth spurred by the transport of intermediate/finished goods. In the freight segment, trucks consumed the highest share of energy in 2020 and continue to do so in 2070. In absolute terms, the total energy demand of trucks increases by 8.3 times, from 0.16 EJ in 2020 to 1.34 EJ in 2070, while the freight sector energy demand increased by 8.2 times.

With a 95 per cent share, the present fuel mix of TN's transport sector is dominated by oil (petrol and diesel), while natural gas and electricity have limited shares as noted in Figure 15. However even in the BAU scenario, the dependence on oil in the final energy consumption of the transport sector reduces to 16 per cent by 2070. Both natural gas and electricity increase their shares in final energy to 77 per cent and 7 per cent, respectively, in 2070, as current policies favour them. In absolute terms, the final energy consumption of the transport sector grows by 4.6 times, from 0.33 EJ in 2020 to 1.5 EJ in 2070.

Transport service demand in the NZ scenario reflects trends similar to the BAU scenario, with a significant drop in service demand for NMT and public transport. These are replaced by 4W, the service demand of which rises to nearly 492 bpkm in 2070, from 26 bpkm in 2020. Energy demand across the passenger and freight segments exhibits a trend similar to that in the BAU scenario. However, the total transport sector energy demand in the NZ scenario in 2070 is significantly lower, at 1.01 EJ, in comparison to 1.52 EJ in the BAU scenario. This could be attributed to the efficiency gains achieved through the electrification of the transport sector. The trends observed in the BAU scenario remain consistent in the NZ scenario for energy demand by vehicle type. 4W and trucks continue to be the highest consumers of energy in the passenger and freight segments, respectively.

From near zero in 2020, electricity accounts for 100 per cent of the final energy consumption in the transport sector, reaching 1.01 EJ in 2070. Note that this is much less than the 1.5 EJ consumed in the BAU scenario, highlighting the efficiency gains due to electrification compared to the continued usage of internal combustion engine vehicles.

**Figure 15** **Transport energy demand, by fuel, in the BAU (a) and NZ (b) scenarios**




*Source: Authors' analysis*

## BOX 1 Electric Bus based Public transportation

Our assessment shows that in the absence of a push towards mass transit systems such as buses, people will continue to move towards private ownership of vehicles increasing the emissions intensity of the passenger transport sector. Increasing disposable incomes will induce people to move from buses to two-wheelers to four-wheelers. This will be the case even in the NZ scenario in the absence of any dedicated push towards public transportation, as electric two-wheelers and four-wheelers will replace their petrol and diesel-based counterparts leading to increasing vehicular congestion.

A pivotal policy angle in public transportation should focus on promoting electric buses (e-buses), emphasising the need to transition towards sustainable and eco-friendly mobility solutions. This will address environmental concerns, reduce individual vehicle usage, and promote mass transit systems. Our analysis projects the on-road stock of e-buses in the state in a policy scenario where there is a dedicated push towards increasing adoption of e-buses. If the state government aims to have e-buses as a core element of its NZ strategy, the stock of total buses in the state should increase from around 33,000 (TNSTC 2020) in 2020 to almost 44,000 in 2030 and 52,000 in 2050, with the share of e-buses in the stock increasing from near zero per cent in 2020 to 19 per cent in 2030 and 73 per cent in 2050. According to the Vahan Dashboard, there are currently only 9 e-buses registered in the state. The 2024-25 budget presented by the TN government outlines the state's intent to procure 500 electric buses out of the 3,000 new buses. Our assessment shows that on average, the state government will need to procure 2,000 buses annually between 2025 and 2050 to achieve the 2050 bus target, since many buses in the existing fleet will expire as their technical life ends, and the share of electric buses has to increase significantly with time.

Along with bus procurement, it is critical to also have a streamlined, well connected, reliable, accessible, and safe transport system to motivate the public at large to use it. The procurement of electric buses and policies to motivate the shift towards higher usage of such buses will ensure that public transportation will always cater to at least 10% of Tamil Nadu's long-term passenger transport demand. In absence of such a push, the share could fall to 1% by 2050 owing to market forces pushing in the direction of private transport. The push for public transportation will be critical not only to reduce transport sector emissions, but also to reduce traffic congestion in crowded cities within the state, and reduce air pollution and related health risks for the urban population.

**Table B1** Buses Stocks Target, 2025-2050

| Vehicle Stock | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|
| Electric | 0% | 4% | 19% | 37% | 51% | 64% | 73% |
| Diesel | 100% | 96% | 81% | 63% | 49% | 36% | 27% |
| Total | 33000 | 35290 | 39840 | 43590 | 45660 | 49410 | 51540 |

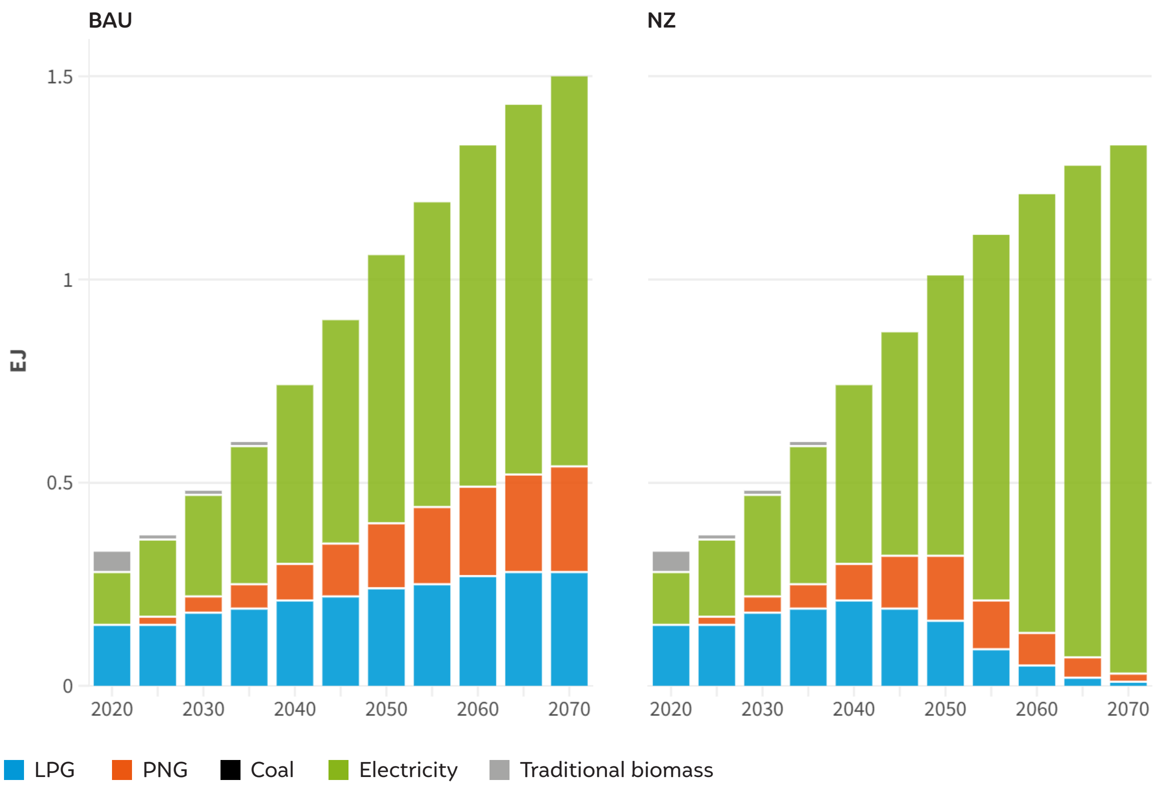
## 4.3 Building sector

According to the National Family Health Survey 5 (NFHS-5) (2019–21), 88 per cent of households in TN are pucca, and almost all households (99 per cent) have electricity (IIPS and ICF 2022). Furthermore, nearly 83 per cent of the households use clean forms of fuel for cooking. As per the NFHS classification, liquified petroleum gas (LPG) and natural gas are considered clean. Given the stabilising population in a growing economy, rising per-capita incomes, and urbanisation, the demand for better-quality goods and services will continue to rise over time in TN. Specifically, in the building sector, people's aspirations could take the shape of bigger houses, better-quality appliances, and increase in demand for cooling, all of which leads to higher energy consumption.

This section explores pathways for the building sector to transition to NZ emissions even while energy consumption continues to increase. According to the most recent emissions inventory for TN, the building sector was responsible for nearly 6 per cent of the total emissions due to the combustion of fuels, primarily for cooking. Note that this does not include the electricity consumed by the sector, which is accounted for under emissions from the power sector. The building sector in the GCAM is disaggregated into four service categories: cooling, cooking, lighting, and other appliances (e.g., computers, fridges and TVs).

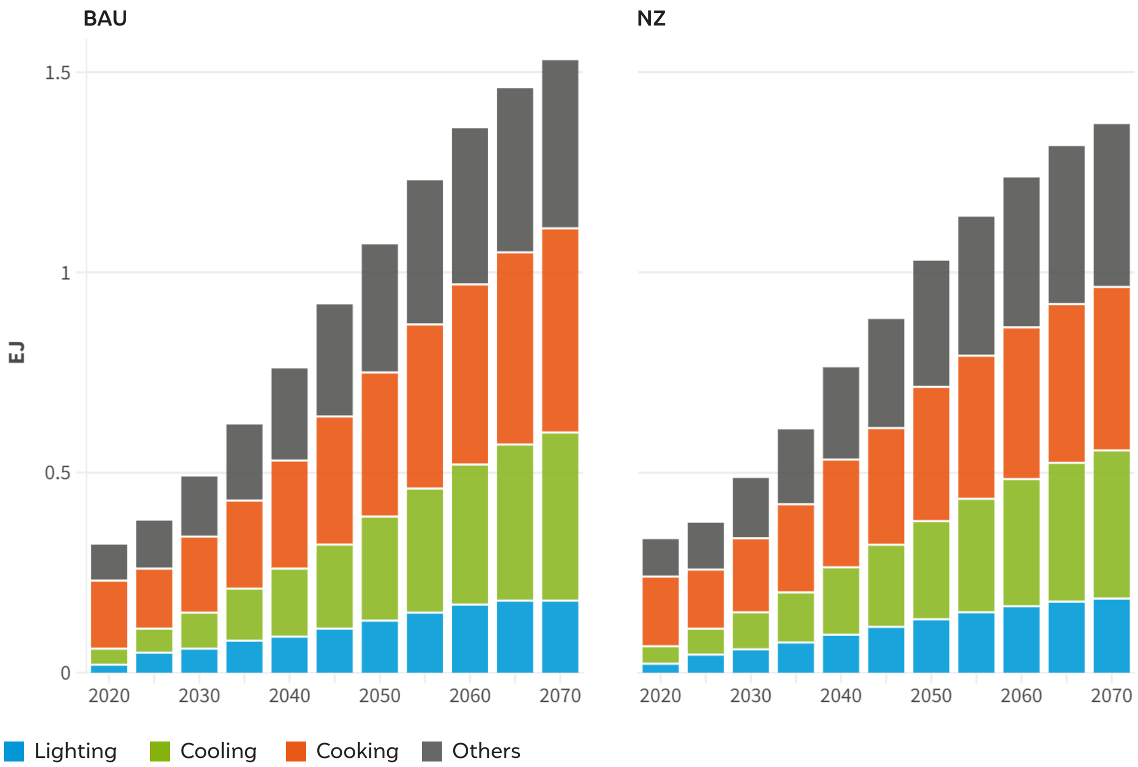
The present energy mix of TN's building sector comprises LPG, piped natural gas (PNG), electricity, and biomass, totalling 0.33 EJ in 2020. However, LPG and electricity together account for nearly 85 per cent of the overall energy demand in the building sector. In the BAU scenario, the total energy demand increases by 4.6 times to 1.5 EJ between 2020 and 2070, with electricity constituting 64 per cent of the energy demand, followed by LPG at 19 per cent, and PNG at 17 per cent as noted in Figure 16. It is noteworthy that the share of PNG in the overall energy mix is increasing, reflecting the present trend across cities in India. Among various services, cooling energy has the highest growth, increasing by 9.5 times between 2020 and 2070, while cooking energy increases by only 2.9 times during the same time period. Another way to analyse the results would be to look at the share of commercial versus residential buildings in the total energy consumption. While commercial buildings were responsible for 26 per cent of the total energy consumed by the building sector in 2020, this rises to 50 per cent in 2070, primarily driven by higher demand for cooling and cooking services.

**Figure 16** **Building energy demand, by fuel, in the BAU (a) and NZ (b) scenarios**




*Source: Authors' analysis*

**Figure 17** Building energy demand, by service, in the BAU (a) and NZ (b) scenarios




*Source: Authors' analysis*

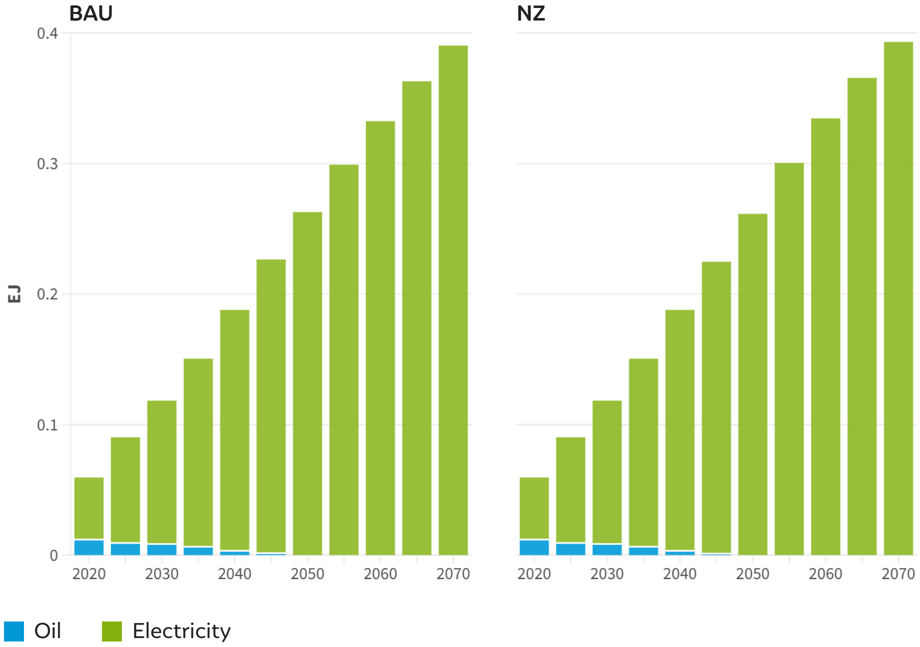
In the NZ scenario, we observe near-complete electrification of all services in the building sector as noted in Figure 17. The total energy demand increases by only 4.1 times under the NZ scenario compared to 4.6 times in the BAU scenario between 2020 and 2070. The energy demand is lower in NZ scenario in 2070 owing to the large-scale use of electric stoves for cooking, which are more efficient than LPG stoves. Moreover, PNG acts as a transition fuel in the NZ scenario, peaking in usage around the middle of the century. Similar to the BAU scenario, cooling energy demand has the highest increase of 8.5 times, from 0.04 EJ in 2020 to 0.37 EJ in 2070. Yet in 2070, cooking still has the highest energy demand compared to other services, at 0.41 EJ as noted in Figure 17. Just like in the BAU scenario, the energy consumption by sector largely holds true for the NZ scenario as well – that is, the share of commercial buildings in the total energy consumption by the building sector rises to approximately 50 per cent in 2070, from 26 per cent in 2020.

## 4.4 Agriculture sector

The agricultural sector's share of TN's GSDP has remained consistent at around 13 per cent over the past decade. Given the relatively low share of the sector in the state's overall economy, agricultural energy demand is also relatively low and responsible for around 1.6 per cent of the total emissions. This is primarily because pumps are used for irrigation purposes. As per the All India Agriculture Input Survey 2016–17, the total number of diesel pumps in TN is only 2,78,600, as compared with states such as Uttar Pradesh, which have over 3.6 million. Through various components of schemes such as the *PM-KUSUM*, the union government is in the process of solarising agricultural pumps to decarbonise the agricultural sector. Under *KUSUM*, till August 2022, TN installed 7,701 stand-alone solar pumps (Ministry of New and Renewable Energy 2022). This is a significant step in moving to cleaner sources of energy to power the state's agricultural sector.

In 2020, nearly 80 per cent of the energy consumed by TN's agricultural sector was through electricity. Under the BAU scenario, agricultural energy demand increases by 6.6 times, from 0.06 EJ in 2020 to 0.39 EJ in 2070. The sector is completely electrified by 2070, even in the BAU scenario as noted in Figure 18. The NZ scenario too follows the same trend as the BAU completely electrifying the sector before 2070. This indicates that NZ emissions could be achieved for the energy consumed by the agricultural sector much ahead of the other sectors driving the state's economy.

**Figure 18** Agriculture energy demand, by fuel, in the BAU (a) and NZ (b) scenarios

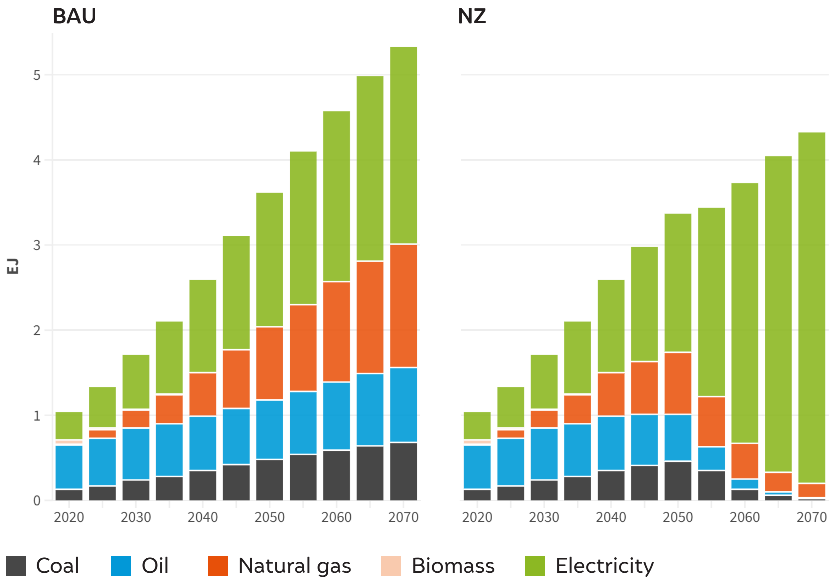



*Source: Authors' analysis*

## 4.5 Final energy demand

The overall energy demand in TN is expected to grow by 5.1 times between 2020 and 2070 in the BAU scenario, as noted in Figure 19. Furthermore, electricity will have the highest share in the final energy, biomass will have the lowest, at 5 per cent, and oil and natural gas will continue to have significant shares. The demand for coal in final energy is limited as it is mostly used for coal generation in primary energy. In the NZ scenario, there is nearly 100 per cent electrification of end-use energy consumption sectors by 2070. Moreover, the final energy consumption of all conventional energy sources – coal, oil, and natural gas – tapers out in the future. While the current use of natural gas is limited in the state, it is projected to be used as a transition fuel, peaking in usage by 2050, following which it is phased out. Furthermore, the final energy consumption is lower in the NZ than the BAU scenario, as more end-use sectors are electrified and electricity-based appliances, vehicles, and technologies become more efficient.

**Figure 19** Final energy demand, by fuel, in the BAU (a) and NZ (b) scenarios




*Source: Authors' analysis*

Moreover, as observed in Figure 20, the industry sector grows 5.5 times during the 2020-70 time period in the BAU scenario which is the highest growth observed amongst all the end-use sectors. This is followed by the transport and building sector, which grows at 5.1 and 4.6 times in the same time period. When compared with the NZ scenario, industry and building sector see an increase in energy demand by 5.1 and 4.1 times in 2020-70. However, transport sector energy demand growth increases only by 3 times in the NZ scenario in comparison to a 5.1 times growth in the BAU scenario. This reflects the energy efficiency gains from electrification of the transport sector as EVs are efficiency than internal combustion engine vehicles.

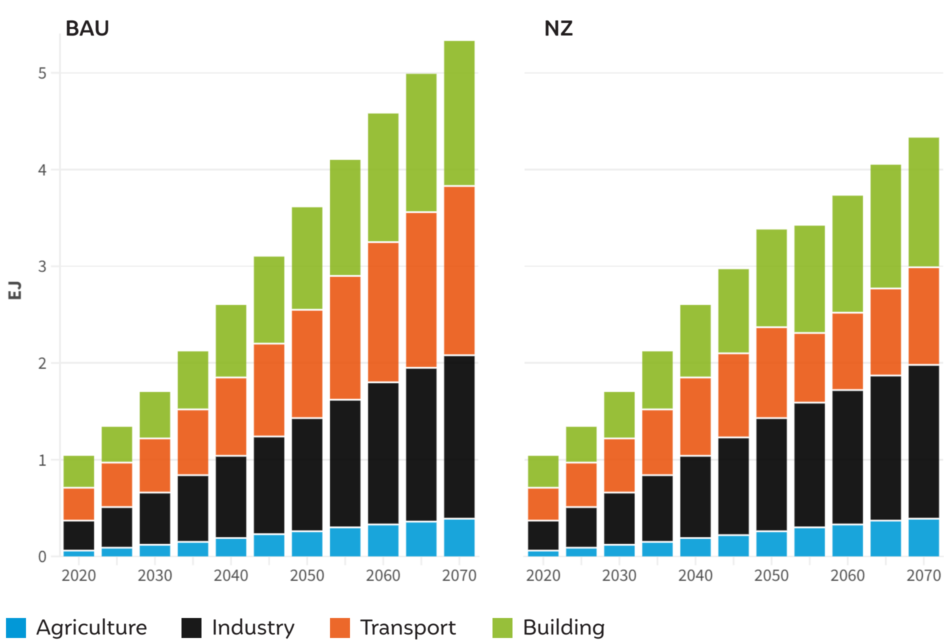
## 4.6 Power sector

TN's mission to become a trillion-dollar economy by 2030 will inevitably lead to an increase in electricity consumption across the state's key energy-consuming sectors – transport, building, and industry. As part of this study, CEEW updated the emissions inventory for TN till Calendar Year (CY) 2019. The updated numbers show that, barring 2020, the power sector, on average, accounts for approximately 60 per cent of the total $CO_2$ emissions in the state. In 2020, this number stood at 67 per cent. It is important to note that the overall emissions were significantly lower in 2020 compared to the previous years, owing to the COVID-19 pandemic. Therefore, it is imperative to prioritise the decarbonisation of the power sector to achieve NZ emissions.

### 4.6.1 Trends in electricity consumption

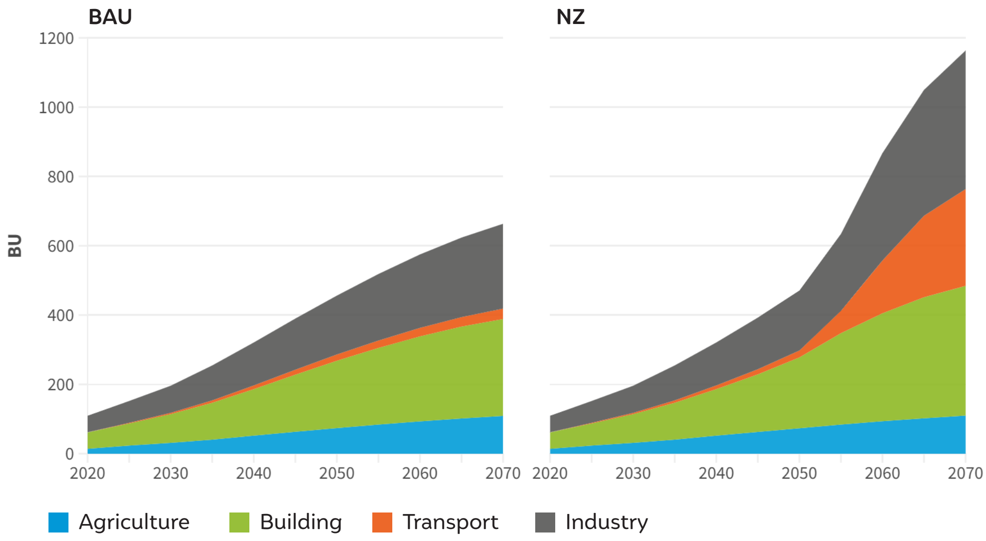
The total electricity consumption in the state increases by 1.8 times between 2020 and 2030 and nearly triples between 2030 and 2070 in the BAU scenario as noted in Figure 21. This results in overall electricity consumption of approximately 195 BUs (billion units) in 2030 and 664 BUs in 2070, from about 110 BUs in 2020. The residential and commercial buildings sector, driven largely by the penetration of air conditioners, expanding new construction of buildings, and switch to electric cooking, accounts for over half of the electricity consumed in 2070. This is reflective of rising incomes at the household level, leading to higher standards of living. Another notable shift is the increase in the share of the transport sector in the final electricity consumption to 4 per cent in 2070, from nearly zero in 2020. This indicates electrification of the new sales and future vehicle stock, particularly of 4W in the passenger transport segment and of trucks in the freight transport segment, owing to state policies that incentivise the manufacturing and purchase of EVs. This creates an enabling ecosystem for a thriving EV charging infrastructure. As regards industry, 50 per cent of TN's industries were powered by electricity in 2020. This remains the same till 2070, even though industrial electricity demand rises in absolute terms between 2020 and 2070. This could be attributed to the rapidly increasing share of buildings in the total electricity consumption.

**Figure 20** Final energy demand, by sector, in the BAU (a) and NZ (b) scenarios




*Source: Authors' analysis*

Figure 21 Electricity consumption, by sector, in the BAU (a) and NZ (b) scenarios




*Source: Authors' analysis*

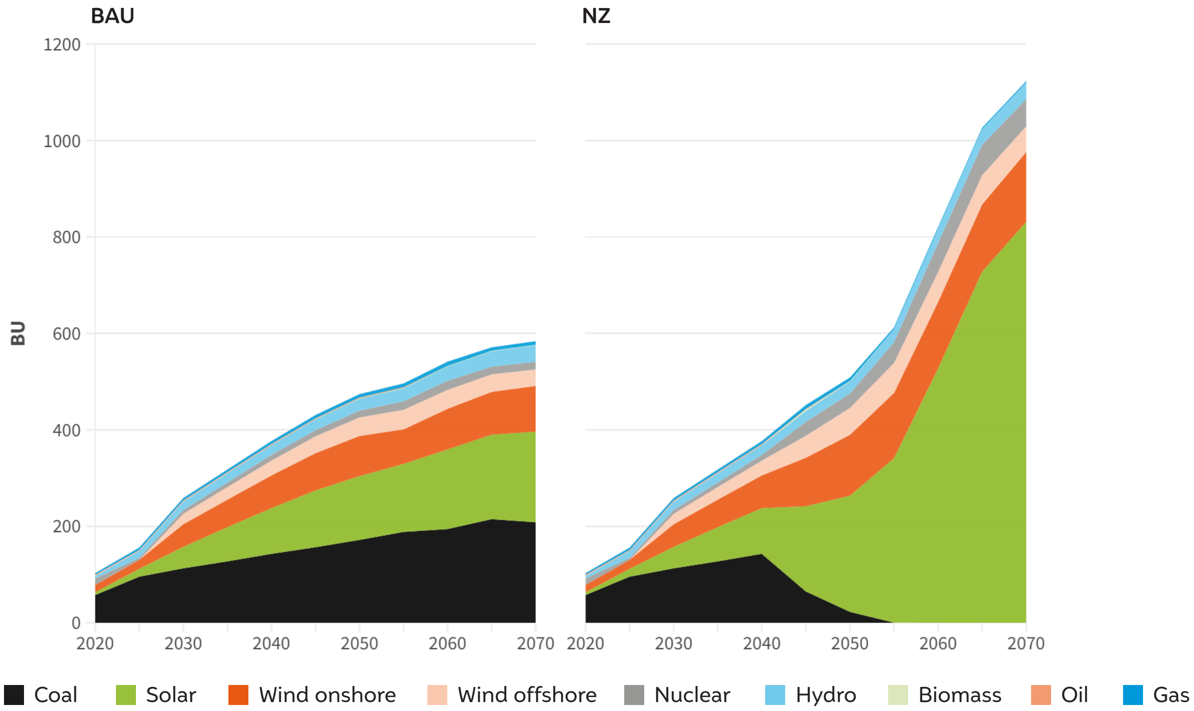
As can be observed from Figures 21, the long-term trends in electricity consumption are similar in the BAU and NZ scenarios till 2045, beyond which the NZ scenario witnesses significant growth in electricity demand. In the NZ scenario, TN's electricity consumption nearly doubles to over 1,163 BUs in 2070 compared to 664 BUs in the same year in the BAU scenario. This could be the result of accelerated efforts to mitigate emissions, leading to rapid electrification of end-use energy consumption. For instance, at 30 BUs, the share of the transport sector in the total electricity consumption is 4 per cent in the BAU scenario in 2070. This increases to 280 BUs, accounting for a 24 per cent share in the NZ scenario. This indicates significant electrification of passenger and freight fleets. Other efforts could include policies to promote electric cooking, which increases the building sector's electricity consumption, and regulatory interventions in the form of green open access rules to encourage clean electricity consumption by industry, among other measures.

## 4.6.2. Trends in electricity generation

Between 2020 and 2070, TN witnesses a 5.7 times increase in electricity generation in the BAU scenario. This translates to about 584 BUs in 2070, from 100 BUs in 2020. Even in the BAU scenario, there is a decline in share of coal-based power generation and an increase in solar-based power generation between 2020 and 2070 as noted in Figure. While 56 per cent of electricity was generated by coal in 2020, this number reduces to 36 per cent in 2070. Furthermore, 6 per cent of electricity was generated through solar in 2020, and this increases to 32 per cent in 2070 due to the falling levelised costs of solar power. According to TN's energy policy note 2023–24, the state has 6,539 MW of installed solar capacity, up from 158 MW in 2015.

In the NZ scenario, as noted in Figure 22, TN witnesses a 11 times growth in electricity generation in 2070 compared to 2020. This translates to about 1123 BUs in 2070, from 100 BUs in 2020. Nearly 74 per cent of the electricity generated in 2070 is by solar, followed by 18 per cent from wind energy. Interestingly, 26 per cent of the electricity generated by wind in 2070 is through offshore wind sources, indicating the future potential of offshore wind energy in TN. A preliminary assessment by the NIWE, reported by MNRE estimates an offshore wind energy potential of 35 GW that can be harnessed off the coast of TN – one of the areas with the highest potential in India. Another significant observation is that power generation through conventional energy sources such as coal peaks in 2040 and declines to nearly zero by 2055. This indicates that the power sector is likely to be the first major sector to achieve NZ emissions. Policies to promote clean energy generation may include, among others, constraints on emissions from power generated using conventional energy sources, possibly in the form of carbon prices. This could potentially reduce their competitiveness compared to cleaner sources of electricity. Mandates in the form of renewable purchase obligations (RPOs) also play a pivotal role in increasing renewable energy penetration in the grid. The TN energy policy note 2023–24 also aims to increase the share of energy generation from renewable energy sources to 50 per cent by 2030, from 20.88 per cent currently.

**Figure 22** Electricity generation, by fuel, in the BAU (a) and NZ (b) scenarios




*Source: Authors' analysis*

# 5. What does TN's NZ transition mean for its emissions?

## 5.1 Energy sector emissions outlook

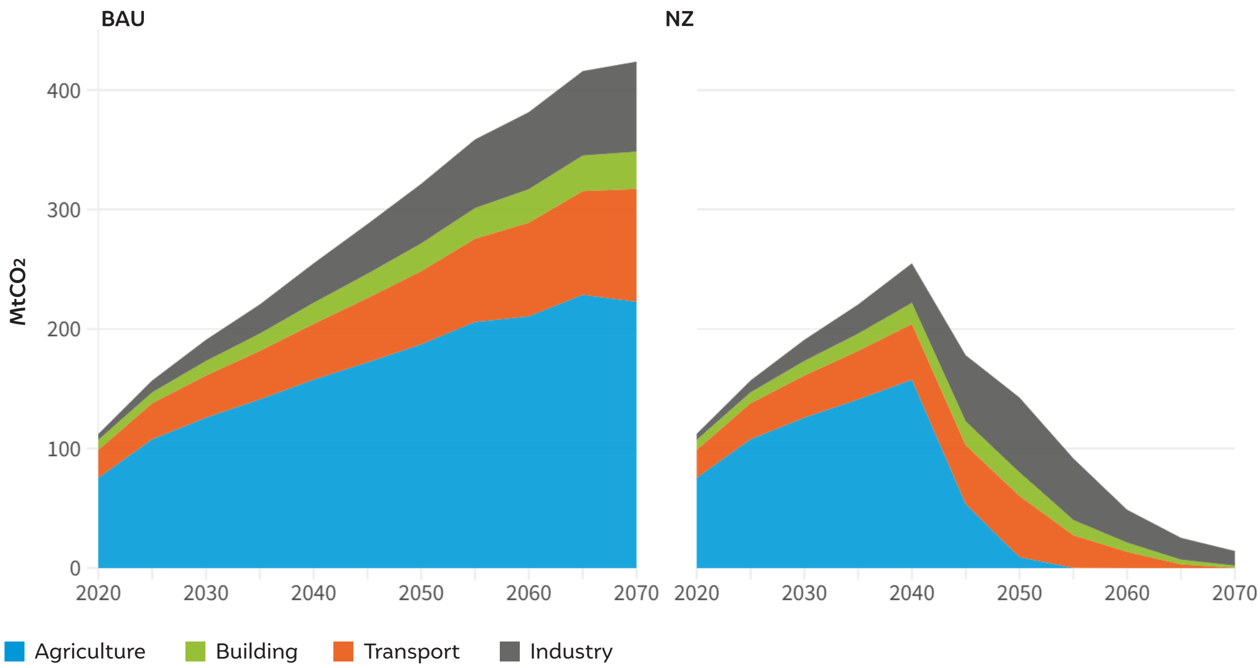
TN's overall GHG emissions in 2019 were around 183 $MtCO_2Eq$, contributing nearly 6 per cent to India's overall emissions. The energy sector accounted for 78 per cent of the state's overall emissions, at around 141 $MtCO_2$. Refer to Figures 23(a) and 23(b) for a breakdown of TN's energy sector emissions. Electricity generation, both from captive sources and state-owned utilities, accounts for 60 per cent of the energy sector emissions. Emissions due to energy consumption by the transport, industry, and building sectors are nearly 19 per cent, 12 per cent, and 6 per cent, respectively. It is evident from the data that the power sector has the highest potential to mitigate climate change. Furthermore, consumption of clean power by the transport, industry, and building sectors will further decarbonise the economy. An interesting feature of TN's emissions profile is that while the state is the third-highest contributor to India's manufacturing gross value addition (GVA), at about 11 per cent in 2021–22 (RBI 2022), in terms of GHG emissions, it is only the ninth. Gujarat and Maharashtra, the two top contributors to the country's manufacturing GVA, at 17 per cent and 13 per cent, respectively, are the second- and third-highest GHG emitters, at around 287 and 290 $MtCO_2$, respectively.

In this section, we analyse TN's emissions trends for key energy-consuming sectors – power, transport, industry, and building – from 2020 to 2070, in the BAU and NZ scenarios (Figure 24).

In the BAU scenario, TN's overall emissions from the energy sector increase by 3.8 times between 2020 and 2070, from 112 to 424 $MtCO_2$. For context, India's overall energy sector emissions in 2070 is projected to be around 8,000 $MtCO_2$, according to a CEEW study (Chaturvedi and Malyan 2022). TN's share in the country's overall emissions remains at around 5.3 per cent in 2070. Emissions from the power sector are anticipated to increase by 2.4 times, from 75 to 222 $MtCO_2$, contributing nearly 53 per cent to the overall energy emissions. Interestingly, the share of the transport sector in the emissions mix rises to 22 per cent, possibly owing to increased demand for oil. Industry and building account for 18 and 7 percent respectively of 2070 emissions. In absolute terms, the transport, industry, and building sectors emit 94 $MtCO_2$, 75$MtCO_2$, and 31 $MtCO_2$, respectively. This consistent rise in emissions is expected in the BAU scenario, owing to the continued use of conventional energy sources.

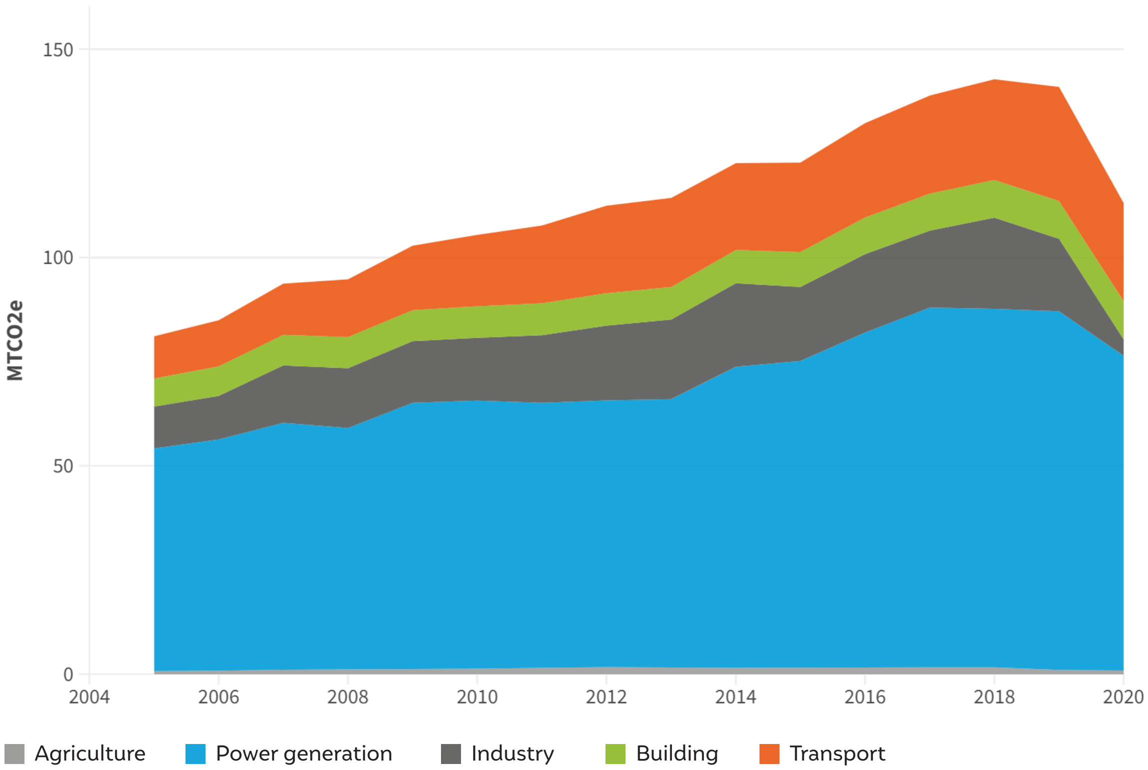
In the NZ scenario, emissions from all sectors have been modelled to peak in 2040, considering that the average lifetime of assets generating thermal power is 25–30 years. Therefore, even if a thermal power plant is constructed in 2040, it could be retired in 2070, assuming a useful life of 25–30 years. After 2040, the model ensures absolute emissions reduction across sectors.

**Figure 23** **Overall $CO_2$ emissions, in the BAU (a) and NZ (b) scenarios**




*Source: Authors' analysis*

**Figure 24** **TN Energy sector emissions profile**




*Source: GHG Platform (2023)*

The overall emissions peak at around 254 $MtCO_2$ in 2040. The power sector's emissions peak the earliest, at 157 $MtCO_2$ and achieve near-zero emissions by 2050. This is important since key end-use energy consumption sectors can successfully decarbonise only if the electricity they consume is generated using non-fossil energy sources. Following the power sector, the building sector peaks in 2045 at 20 $MtCO_2$ and reduces to around 2 $MtCO_2$ in 2070. This is due to residual emissions from cooking. Both the transport and industry sectors peak in 2050, and while transport achieves near-zero emissions by 2070, industry still has residual emissions of around 12 $MtCO_2$. This is due to emissions from cement manufacturing industries, which will continue to emit unless processes such as CCUS become commercially feasible. Overall, in 2070, TN's energy system emits 14 $MtCO_2$. This could potentially be offset through other missions of the state government such as the GTN Mission and Tamil Nadu Wetlands Mission. An analysis of the carbon sequestration potential of the GTN Mission has been conducted, and the results are presented in the following sections.

## 5.2. Land-use sector sequestration potential

As per the India State of Forest Report by the Forest Survey of India (FSI), in 2021, TN's forest and tree cover were 23.7 per cent, approximately 3 million hectares of its total geographical area of about 13 million hectares. As part of the GTN Mission, the state government aims to increase its forest and tree cover to 33 per cent by 2030–31, aligning with the National Forest Policy of 1988. To achieve the additional target of 9.3 per cent (1.2 million hectares), the state plans to enhance forest cover density in the degraded forest area, constituting 3 per cent (3,90,200 hectares) of the state's total land area. This initiative aligns with the Bonn Challenge of 2011, to which India is a signatory and committed to restoring 26 million hectares of degraded forest land by 2030. The remaining 6.3 per cent (8,17,500 hectares) of the target will be addressed by increasing the trees outside forests (ToFs) through agroforestry. In the agroforestry system, some perennial woody plants (such as trees, shrubs, palms and bamboos) are deliberately mixed with agricultural crops and/or animals on the same piece of land. The state recognises these practices as instrumental to achieving the ambitious 33 per cent target. This not only contributes to increased carbon sequestration, aiding the state in reaching its NZ emissions target, but also serves as an instrument of economic empowerment for farmers, offering them a significant avenue to enhance their income through the generation and sale of carbon credits. The state has identified specific tree species for agroforestry practices, along with their allocated areas, to meet the 33 per cent target by 2030–31 (Table 1).

**Table 1 The selected tree species and allocated area for the afforestation programme**

| Species | Local name | Allocated area (%) | Allocated area (ha) |
|---|---|---|---|
| *Tectona grandis* | Teak | 10 | 81,750 |
| *Pterocarpus santalinus* | Red sanders | 15 | 1,22,625 |
| *Santalum album* | Sandalwood | 10 | 81,750 |
| *Azadirachta indica* | Neem | 10 | 81,750 |
| *Swietenia mahogani* | Mahogany (small leaf) | 10 | 81,750 |
| *Dalbergia sissoo* | Sissoo | 5 | 40,875 |
| *Thespesia populnea* | Indian tulip | 10 | 81,750 |
| *Gmelina arborea* | *Gamhar*, white teak | 10 | 81,750 |
| *Melia dubia* | Malabar neem, *maha* neem | 10 | 81,750 |
| *Terminalia arjuna* | Arjuna | 10 | 16,350 |
| *Syzygium cumini* | *Jamun* | | 16,350 |
| *Casuarina equisetifolia* | Casuarina | | 16,350 |
| *Palmyra/Borassus flabellifer* | Palmyra palm | | 16,350 |
| *Tropical dry evergreen forest trees* | | | 16,350 |
| | | **Total Area** | **8,17,500** |

*Source: GTN Mission, GoTN (2022-23)*

### 5.2.1 Methodology and assumptions

To accurately determine the carbon sequestration potential of trees, three critical parameters must be considered. They are as follows:

- Vegetative carbon (VegC), representing the carbon stored in the vegetative biomass;
- Soil carbon (SoilC), representing the carbon stored in the soil; and
- Maturity age, defined as the number of years beyond which the carbon sequestration capacity of trees significantly diminishes or is lost altogether.

In this analysis, the 6.3 per cent of land area required to enhance forest cover density through agroforestry practices has been increased linearly till 2030. In calculating the carbon stock at the maturity of individual tree species, we employed volumetric equations sourced from various FSI reports. The parameters of these equations were extracted from previously published peer-reviewed articles and reports (see Annexure 2). For soil organic carbon (SOC), we utilised the global SOC map from the Food and Agriculture Organization (FAO 2019). The SOC map was masked using the cropland category of the Environmental Systems Research Institute (ESRI) land use/land cover (LULC) data for TN. Since the third quartile (Q3) of all available grid cells of SOC is considered the steady-state value, the mature SOC value of 26.14 tC/ha has been considered here (Figure 25). Finally, the carbon sequestration potential was calculated using the Bertalanffy-Richards function (Richards 1959; Yuancai, Pacheco Marques, and Bento 2001). This function posits that carbon uptake by the trees in their vegetative biomass and soil is rapid during the initial period, but that it declines as the trees and soil reach maturity. Rotational periods of 10 and 15 years were considered in agroforestry practices. This involves harvesting trees at their maturity and planting new trees in the same field. The objective is to sustain the carbon sequestration process even after achieving the 33 per cent area target by 2030. This also helps evaluate the amount of carbon emissions from the energy sector that can be netted out through carbon sequestration by the GTN Mission.

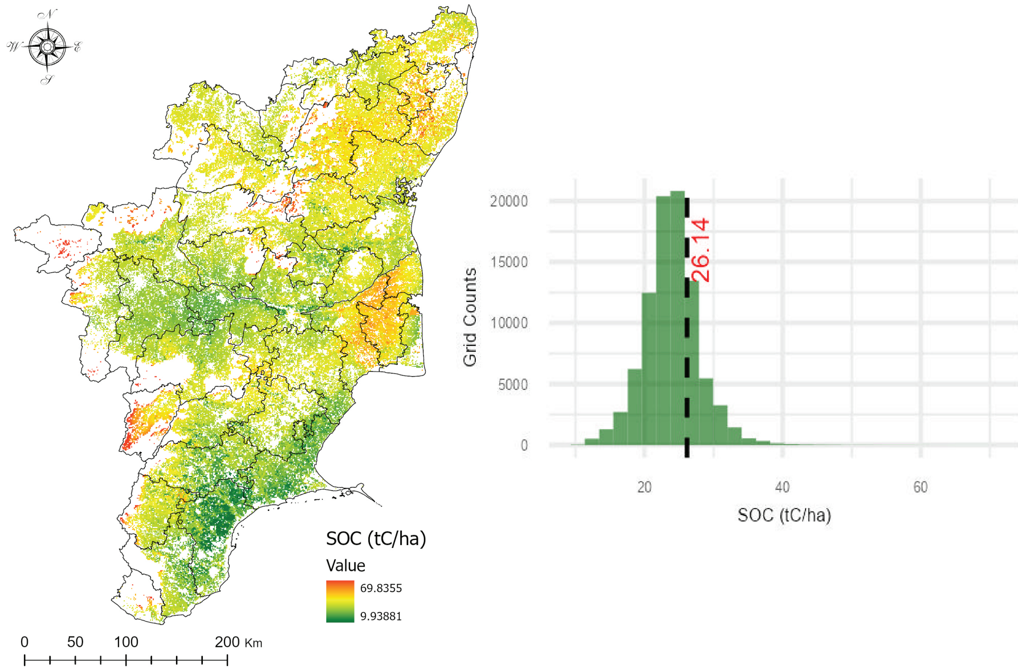
To assess changes in carbon stock during forest regeneration within degraded areas, we considered two distinct scenarios. The first scenario envisions open forest (10–40 per cent canopy cover) transitioning into moderately dense forest (40–70 per cent), while the second involves conversion to very dense forest (>70 per cent canopy cover). Because TN's forests consist of various categories – including southern dry mixed deciduous forest, secondary dry deciduous forest, southern thorn forest, Karnataka umbrella thorn forest, dry deciduous scrub, dry savannah forest, tropical dry evergreen forest and plantation/ToFs, each with different maturity ages – the overall maturity age of TN's forests has been calculated considering the areas covered by these different forest categories along with their individual maturity ages. The overall weighted average maturity age is 37 years. The VegC stock values from FSI reports were utilised, and the potential carbon stock was calculated assuming 3 per cent of the state's total area in this forest regeneration process. It is crucial to note that, within the forest area, SoilC is assumed to have already matured, thus leading to the calculation of carbon sequestration only within the vegetative biomass.

### 5.2.2. Results and Insights

Since the additional area designated for agroforestry is expected to increase linearly until 2030, both rotational periods within agroforestry practices exhibit equal carbon sequestration (i.e., 32 $MtCO_2$) by 2030. Nevertheless, once the expansion of the area ceases, significant variations in carbon sequestration become apparent across different rotational periods (Figure 26). Notably, between 2022 and 2070, the 15-year rotational period demonstrates high variability, with an average carbon sequestration of 19 $MtCO_2$ per year, while the 10-year rotational period exhibits less variability, with an average carbon sequestration of 23 $MtCO_2$ per year.

This variability arises because, during the initial period, trees sequester carbon at a rapid rate; this declines as they mature. Hence, increasing the rotational period allows trees to reach maturity, with a consequently declining rate of carbon sequestration, resulting in higher variability in the process. Conversely, a shorter rotational period captures the high carbon sequestration phase, leading to less variability in the carbon sequestration process. This phenomenon is particularly evident in species with higher carbon content, such as *Tectona grandis, Dalbergia sissoo, Gmelina arborea,* and *Thespesia populnea*, as depicted in Figure 27. However, it is crucial to note that although a shorter rotational period is better for carbon sequestration, sufficient time must be allowed for trees to reach maturity, so that enough biomass is generated for commercial use. This practice significantly impacts the carbon stock, with a projected increase to 2.04 Billion tons of carbon di-oxide

**Figure 25** The spatial distribution of SOC in the cropland area and the Q3 value (steady state) of the SOC from all the grid cells

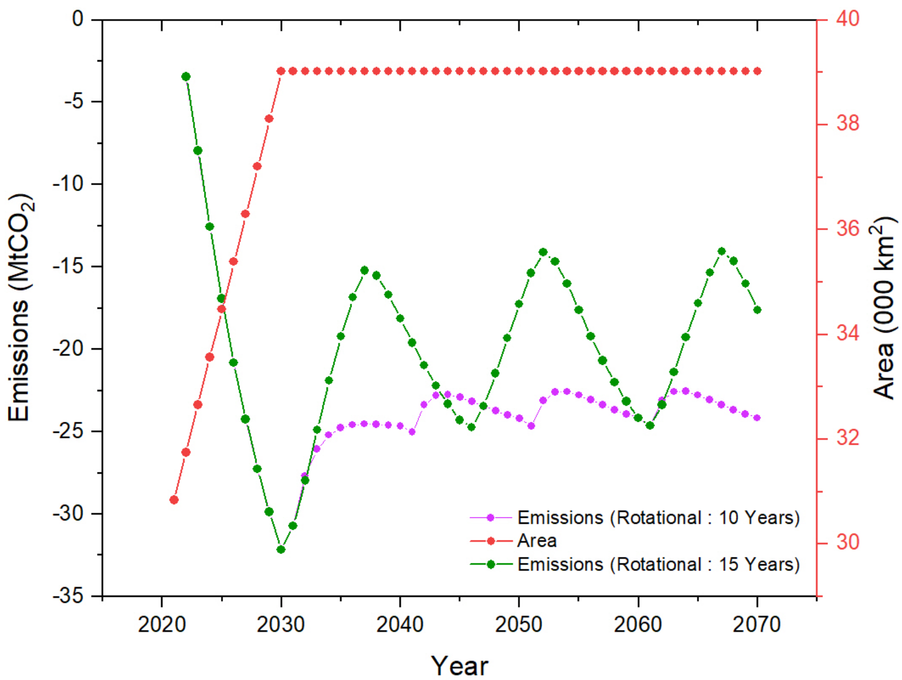



*Source: Authors' analysis*

equivalent (BtCO2Eq) for a 10-year rotational period and 1.9 BtCO2Eq for a 15-year rotational period by 2070, up from 0.9 BtCO2Eq in 2021.

For the forest regeneration of 3,90,200 hectares (3 per cent of the total area of TN), a potential carbon sequestration of 37 MtCO2 is attainable if the transition is from open to moderately dense forest. In contrast, carbon sequestration of 68 MtCO2 is potentially possible if the transition is from open to very dense forest. Achieving this carbon sequestration may take 37 years from 2021, based on the area-weighted maturity age of different forest types in TN calculated in this study.

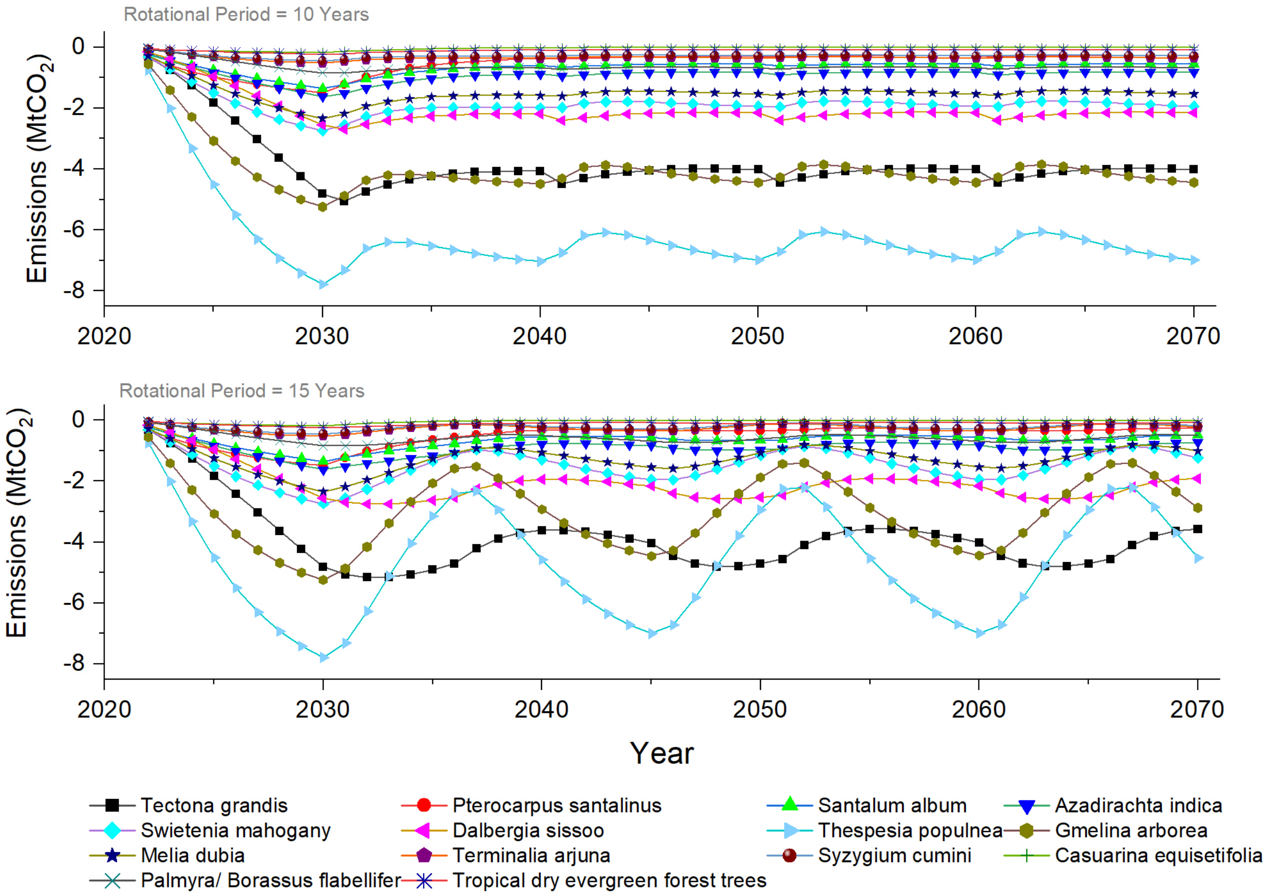
**Figure 26** The expansion of agroforestry area and carbon sequestration for the different rotational periods (10 and 15 years) considered in the study




*Source: Authors' analysis*

The overall carbon sequestration potential of the GTN Mission through agroforestry and the restoration of degraded forest land is highly promising. Agroforestry is expected to sequester a total of 175 MtCO2 by 2030, increasing from 794 to 960 MtCO2 between 2030 and 2070, with a projected increase in carbon stock of 1.9–2.04 BtCO2Eq by 2070, depending on the different rotational periods considered in this study. This results in an average carbon sequestration potential of 19–23 MtCO2 per annum for agroforestry. The restoration of degraded forest lands could sequester an additional 37–68 MtCO2 till 2070, with an annual rate of 1–1.8 MtCO2, varying with the transition to denser forest types. Therefore, a combination of both these efforts could potentially sequester 20–25 MtCO2 per annum. It is important to note that the Government of India's NDC targets require an additional carbon sink of 2.5–3.0 BtCO2Eq by 2030 (FSI 2021; PIB 2022). The GTN Mission could potentially contribute approximately 6.2–6.4 per cent of the country's NDC target by 2030.

**Figure 27 The carbon sequestration of different tree species considered in this study based on different rotational periods (10 and 15 years)**




*Source: Authors' analysis*

# 6. Jobs and investment potential

TN has pioneered renewable energy adoption in India, and its deployment will play a significant role in transitioning the state's economy to achieve its long-term NZ target. Currently, TN has 6.5 GW of solar capacity, contributing to 9 percent of the total installed capacity in India. Similarly, the state's 8.7 GW of wind capacity contributes to 20 percent of the total installed capacity in the country.

The expansion of clean energy generation in the future has the potential to contribute to job creation and economic growth significantly. The expansion of this sector will be able to generate a multitude of employment opportunities, spanning from the manufacturing of renewable energy components to various aspects of project development, installation, and maintenance. CEEW analysis suggests that for every MW of utility-scale solar, there are 2.95 full-time construction jobs created and INR 4.5 crore of investment made. In addition, if modules are manufactured within the state, they will be able to generate 2.6 jobs per MW per year. While construction jobs will be temporary, operations and maintenance (O&M) jobs will be constant once the installations are completed.

While new jobs created between 2020 and 2050 would be around 144,000 (Table 2), some jobs would also decline due to the closing down of solar and wind power plants at the end of their life by 2050. The net total number of people employed in solar and wind-related O&M (for existing as well as new installations) would be 28,000 by 2030 and 113,500 by 2050. Meanwhile, thermal power-based O&M jobs will see a sharp decline after 2040. Between 2020 and 2050, 452,000 temporary jobs for installation of solar modules are expected to be created.

Our analysis finds that investments in the power sector including solar, onshore, and offshore wind energy sources would need to be around INR 1,529 thousand crores between 2020 and 2050 as indicated in Table 3. For these estimations, we assume from the *Optimal Generation Mix Report* by the Ministry of New and Renewable Energy (MNRE), that the capital cost of onshore wind power projects to be INR 6 crore per MW, offshore wind power projects to be INR 10.5 crore per MW, and for solar power projects, it is assumed to be INR 4.5 crore per MW.

**Table 2** Power sector job potential under net-zero scenario

| NZ - O&M Jobs (additional full-time permanent jobs created during respective periods) | | | | | | |
|---|---|---|---|---|---|---|
| Jobs (person) | 2020-25 | 2025-30 | 2030-35 | 2035-40 | 2040-45 | 2045-50 |
| Coal | 2275 | 2001 | 1756 | 1868 | 539 | 42 |
| Solar | 3250 | 8350 | 9000 | 11900 | 18250 | 25850 |
| Onshore | 2000 | 5050 | 4000 | 9650 | 10300 | 13550 |
| Offshore | 0 | 3500 | 1500 | 2000 | 2800 | 4700 |
| **Total** | **8325** | **18101** | **16256** | **25418** | **31889** | **44142** |
| **NZ - Construction Jobs (additional temporary jobs created during respective periods)** | | | | | | |
| | 2020-25 | 2025-30 | 2030-35 | 2035-40 | 2040-45 | 2045-50 |
| Coal | 3322 | 2922 | 2564 | 2727 | 788 | 61 |
| Solar | 19175 | 49265 | 53100 | 70210 | 107675 | 152515 |
| Onshore | 11800 | 29795 | 23600 | 56935 | 60770 | 79945 |
| Offshore | 4720 | 15930 | 8850 | 11800 | 16520 | 27730 |
| **Total** | **39017** | **97912** | **88114** | **141672** | **185753** | **260251** |

*Source: Authors' analysis*

Note: Job potential numbers refer to cumulative jobs created across five-year periods

In Table 3, we compare the investment requirement in the power sector for new additional capacity installed between the time period 2020-2050. We find that solar capacity installations witness the highest investment of INR 223 thousand crore between 2040-2045. Similarly, onshore wind investments will require INR 163 thousand crore during the same time period. Cumulative investment in solar would be INR 689 thousand crores between 2020 and 2050 and INR 839 thousand crores for both onshore and offshore wind. Investments required for the new capacity addition for the respective time periods are given in Table 3.

Tamil Nadu's latest Electric Vehicle (EV) policy 2023 promotes the manufacturing and adoption of EVs, and incentivises the development of a robust charging infrastructure too. This is a crucial step towards achieving NZ emissions in the transport sector.

For smooth electrification, the growth of charging infrastructure (slow and fast chargers) along the length and the breadth of the state is necessary. Based on information from industry experts, the deployment of a one Bharat AC – 001 EV charger will cater to 125 two-wheelers and 30 three-wheelers. Similarly, deploying a single DC charger (Fast Chargers) with a Combined Charging System could cater to 75 private and commercial four-wheelers. The average cost of setting up a public charging station in India could range from INR 30-50 Lakhs per station. The cost of a home charging station would be much lower owing to the difference in output power. Given the high penetration of electric vehicles is imperative in the future, EV charging infrastructure could bring in significant investment in the state.

**Table 3** New Additional Installed Capacity and associated investments potential during respective periods

| Constant 2020 INR | | 2020-25 | 2025-30 | 2030-35 | 2035-40 | 2040-45 | 2045-50 |
|---|---|---|---|---|---|---|---|
| Solar | Additional Installed capacity (GW) | 6.5 | 16.7 | 18 | 23.8 | 36.5 | 51.7 |
| | Investment '000 crores | 29 | 75 | 81 | 107 | 164 | 233 |
| Onshore wind | Additional Installed capacity (GW) | 4 | 10.1 | 8 | 19.3 | 20.6 | 27.1 |
| | Investment '000 crores | 24 | 61 | 48 | 116 | 124 | 163 |
| Offshore wind | Additional Installed capacity (GW) | 1.6 | 5.4 | 3 | 4 | 5.6 | 9.4 |
| | Investment '000 crores | 17 | 57 | 32 | 42 | 59 | 99 |
| **Total Investment '000 crores** | | **70** | **192** | **161** | **265** | **347** | **494** |

*Source: Authors' analysis*

Note: Investment numbers refer to cumulative investment across five year periods

# 7. Measurement, reporting and verification

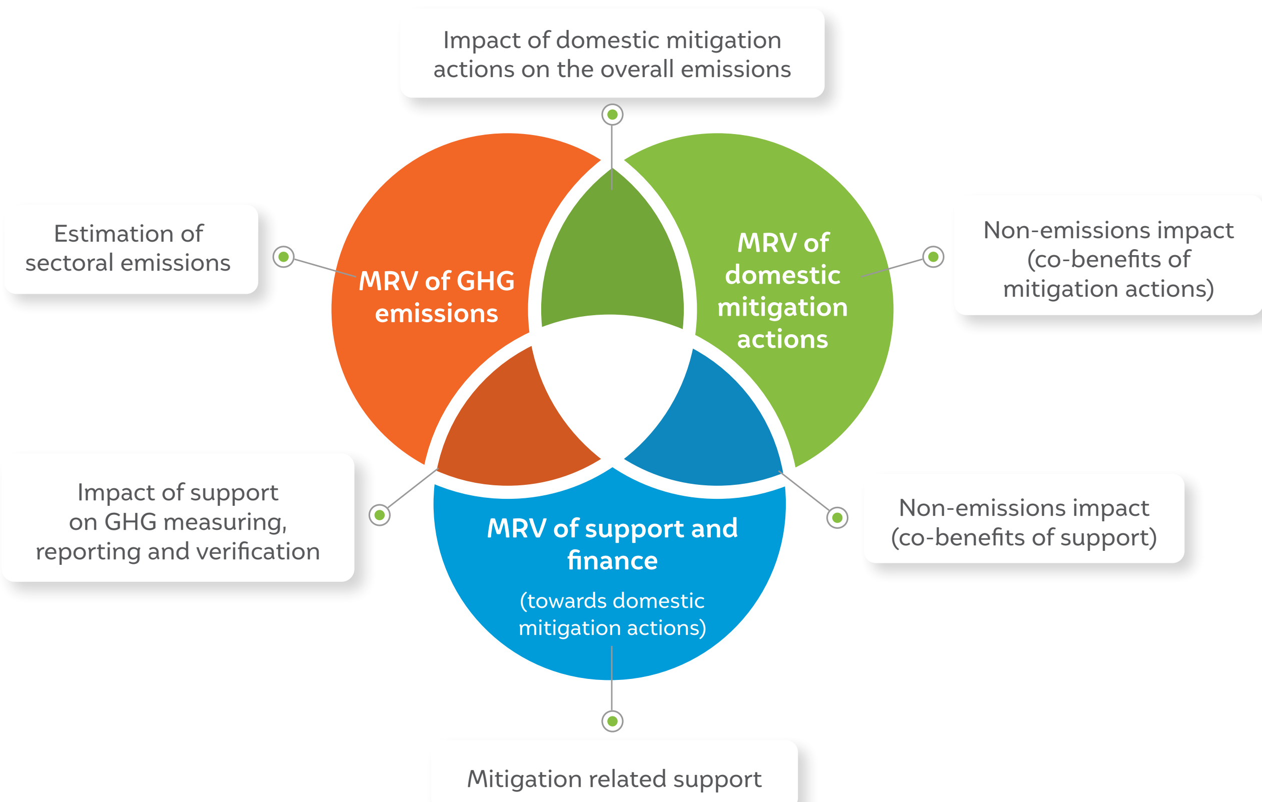
To meet emission reduction targets, measurement, reporting, and verification (MRV) is indispensable. **Measurement** involves the precise description of an activity in a quantifiable manner. Some of the policies/ impacts are easily quantified, whereas some may be difficult to gauge and require indirect indicators. **Reporting** is a fundamental requirement in documenting the measurements in a manner that enables easy analysis and comparison. It is generally based on guidelines available in standard formats, templates or questionnaires. And lastly, **Verification** is the process of reviewing and certifying the factual accuracy and reliability of the reported information. Verification can be done through inspection, observation, enquiry, computation and analytical procedures.

An effective MRV requires an integrated framework and should cover the three crucial elements, regular updates to the GHG inventory, measures on mitigation activities and measure of finance for the mitigation activities.

These elements of an MRV system have significant overlaps with each other. As suggested in Figure 28, a comprehensive understanding of the emission inventory is indispensable in capturing the impact of mitigation actions over a period of time. The impact of mitigation can be measured against a baseline, which should come from periodic GHG inventory assessments. Importantly, MRV of emissions and associated mitigation actions should inform the state government's mitigation strategy. The assessment should tell if state's emissions across sectors are on the targeted pathway or not, and if they are not, required changes in mitigation efforts have to be undertaken. Every few years, the state should relook at its mitigation pathway towards net-zero in light of newly available information and developments related to mitigation technologies. The MRV process seeks to ensure that the state can adjust its plans and policies in a structured and coordinated way.

Similarly, to enhance our mitigation action or to take stock of expenditure made towards it, an MRV of support (including finance) is imperative to justify our climate-related actions appropriately. Some of this financial support could come from the central government, or from the state's own coffers. But some could also come from international routes like carbon markets (voluntary or compliance) or any international climate finance facility.

**Figure 28** MRV framework




*Source: Adapted from UNFCCC (2014) Handbook on Measurement, Reporting and Verification for Developing Country Parties*

It is equally important to monitor and showcase the co-benefits of mitigation actions. For example, promoting renewable energy for cleaner power generation also indirectly reduces the particulate matter in the air, which would have been generated in large quantities from coal-based power plants. Promoting electric vehicles reduces local air pollution from petrol and diesel vehicles.

The MRV arrangement within Tamil Nadu's institutional setup will provide a granular understanding of its emissions sources and pathways across sectors like transportation, industry, agriculture, energy, and waste management. A transparent reporting on all three elements of MRV would help in taking stock of gaps in efforts towards meeting their climate goals. Stakeholders, including government bodies, businesses, civil society, and the public, will have access to reliable and up-to-date information on the progress towards emissions reduction targets. Hence, MRV would not only foster informed decision-making but also encourage active participation and collaboration among stakeholders. The Department of Environment, Climate Change and Forest would be most suited for managing the MRV function.

# 8. Key insights, recommendations and conclusion

Our analysis based on the latest greenhouse gas (GHG) inventory and long-term projection for emissions in business as usual (BAU) and NZ scenarios for Tamil Nadu reveals important trends and provides significant insights. This section presents the key insights (KI) from our assessment.

## 8.1 Key Insights

**KI-1. NZ is as much about economic transformation as it is about climate change**

NZ ambition entails reducing GHG emissions across key energy producing and consuming sectors. The face of mobility will change from fossil-based to low-carbon mobility, necessitating a significant change in the automobile industry set up. Industrial energy use will have to be largely electrified, having implications through pass through of electricity prices. Rapid renewable energy penetration will present significant opportunities for investment and job creation. Therefore, it is critical to view NZ transition as a larger economic transformation that has profound implications for the future economy of TN.

**KI-2. Understanding when could the state's emissions peak is as important as the choice of NZ year**

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 NZ emissions by 2070. While this is highly commendable and provides a much-needed policy direction towards curtailing emissions, it is equally important to reflect on another key policy question: in which year will India (and consequently its states) peak in emissions? Peak year is defined as the year in which absolute economy-wide emissions peak, following which there will be a continuous drop in emissions. Given the diverse economic profiles of various states in India, the shape of emissions pathway for various states, including at what level and which year they will peak, would be different. Understanding this critical milestone is critical for various stakeholders in the state.

**KI-3. The pursuit of NZ emissions results in massive electrification of end-use energy consumption**

In a BAU scenario, the total electricity consumption in 2070 increases by only 6.1 times, from 110 billion units (BUs) in 2020 to around 664 BUs in 2070. Meanwhile in the NZ scenario, electricity consumption increases by 11 times to 1,163 BUs, as noted in Figure ES1. This significant difference in electricity consumption by 2070 is a result of end-use sectors electrifying as they move away from fossils to reduce direct/tail-end emissions. In 2020, the building and industry sectors in the state consume about 44 per cent of the total electricity each, while agriculture accounts for 13 per cent, and the transport sector accounts for a negligible 1 per cent. In projections for the future, the electricity demand for NZ emissions is higher for all sectors, and transport sees an exponential growth to 280 BUs, accounting for 24 per cent of the share. Therefore, this key insight pertains to the criticality of the power sector and the imperative to significantly ramp up generation capacity for renewable electricity to meet growing consumption needs.

**KI-4. The efficiency of the energy system increases as a result of this massive electrification**

The final energy consumption in the BAU scenario increases by 5.3 times, from 1.04 EJ in 2020 to 5.34 in 2070, whereas in the NZ scenario, it increases by 4.2 times to 4.32 EJ in 2070, as noted in Figure ES2. That is, there is a reduction in the final energy consumption of about 1 EJ, implying that significant efficiency gains are obtained from the large-scale electrification of end-use sectors. In addition, dedicated interventions to enhance energy efficiency across sectors will have to be undertaken. Compared to 2020, the energy intensity of TN's GSDP has to reduce by 24 per cent in 2030 and 55 per cent in 2050 to achieve NZ emissions. For context, 1 EJ is about 277.77 BUs of electricity. TN's total electricity consumption for 2020–21 stood at around 110 BUs. Therefore, a reduction of 1 EJ in the final energy consumption would mean annual energy savings of nearly three years' worth of electricity saved.

**KI-5. Power sector decarbonisation paves the way for other sectors to decarbonise**

In the NZ scenario, power sector emissions are projected to peak at around 157 $MtCO_2$ in 2040, followed by the building sector at 20 $MtCO_2$ in 2045, and the transport and industry sectors at nearly 62 and 50 $MtCO_2$ in 2050, respectively. This signifies that the power sector holds the highest emissions mitigation potential and is key for other end-use energy consumption sectors to successfully decarbonise, given the extent of electrification observed in the NZ scenario. This is also evident from the modelling projections, where the total economy-wide emissions also peak in 2040 at around 254 $MtCO_2$, along with the power sector.

**KI-6. TN needs nearly 475 GW of solar and 90 GW of wind power (including offshore) to achieve NZ emissions by 2070, it is imperative to reassess the state's solar and wind potential**

TN is projected to generate about 1123 BUs in 2070 in the NZ scenario to meet its consumption needs of 1,163 BUs in the same year. This is in stark contrast to the BAU scenario, where TN generates around 583 BUs in 2070 to meet its consumption needs of 663 BUs. This indicates that TN will need to procure power from outside the state in the future in both the NZ and BAU scenarios. TN's electricity generation in the NZ scenario must increase by 1.9 times compared to the BAU scenario. This indicates the need for significant renewable energy capacity addition over the coming decades. It requires TN to add around 9 GW of solar capacity and 2 GW of wind capacity on average every year, with capacity addition growing at compounded annual growth rates (CAGRs) of 8 and 4 per cent, respectively, for solar and wind. The capacity utilisation factors (CUFs) assumed for these calculations are listed in Annexure 1. According to TN's energy policy note from 2023–24, one of the targets is to increase the installed capacity of solar to 20 GW over a period of 10 years, indicating that the state is on track in the near term to achieve NZ emissions in the long term. The Ministry of New and Renewable Energy (MNRE) has conservatively estimated that 17 GW of solar capacity can be obtained using 3 per cent of wasteland area (PIB, 2024). However, other estimates indicate that there is much greater potential.

**KI-7. Nearly 17 GW of offshore wind capacity is required to meet the 2070 NZ target**

While it is necessary to increase both solar and onshore wind power capacity in the future, offshore wind power must start contributing to clean energy generation. While India currently does not have any offshore wind power plants, the National Institute of Wind Energy (NIWE) identified that there is potential to harness about 70 GW from offshore wind, spread across 16 offshore zones along the coasts of TN and Gujarat. The MNRE aims to bid out 37 GW worth of capacity by 2030. In 2023, the MNRE published an updated strategy paper and a tender for allocating seabed areas to develop 7 GW of open access–based or captive offshore projects off the TN coast. This could potentially help reduce the emissions footprint of commercial and industrial electricity consumers. Offshore wind, therefore, remains an important untapped source of energy in TN.

**KI-8. Compared to 2005, the overall energy sector emission intensity of TN's GSDP needs to reduce by 46 per cent in 2030 and 87 per cent in 2050 to achieve NZ emissions**

Emission intensity measures the amount of GHGs released per unit of economic output. India's NDC aims to reduce the emission intensity of the gross domestic product (GDP) by 45 per cent from the 2005 level (Government of India 2022). In this context, based on the modelling results, TN needs to reduce its emission intensity by 46 per cent in 2030 and by a further 87 per cent by 2050, compared to 2005 levels, to achieve NZ emissions by 2070. For context, in 2020, for every USD 1 million of TN's gross state domestic product (GSDP), the state's energy sector emitted nearly 510,000 $tCO_2$. This has to be reduced to about 410,000 $tCO_2$ in 2030 and 100,000 $tCO_2$ in 2050.

**KI-9. The Green Tamil Nadu (GTN) Mission has the potential to sequester $CO_2$ emissions worth 19–25 $MtCO_2$ per annum**

A comprehensive study of one of TN's flagship missions, the GTN Mission, was done to understand the role and potential of carbon sequestration in TN's pursuit of NZ emissions. This is important to sequester residual emissions from the energy sector. The analysis reveals

**Table 4 Sectoral targets to align with a net-zero future**

| Sectoral Targets | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|
| **Power sector** | | | | | |
| Solar Installed Capacity (GW) | 27 | 45 | 65 | 95 | 130 |
| Onshore Wind Installed Capacity (GW) | 22 | 30 | 40 | 58 | 75 |
| Offshore Wind Installed Capacity GW) | 7 | 10 | 14 | 18 | 22 |
| **Transport sector** | | | | | |
| Private electric vehicle sales targets (%) | 30 | 40 | 60 | 80 | 100 |
| **Industry sector** | | | | | |
| Energy intensity reduction targets (% reduction relative to 2015) | 21 | 29 | 35 | 41 | 46 |
| **State level economy wide** | | | | | |
| Emissions intensity of GDP reduction targets (% reduction relative to 2005) | 46 | 56 | 63 | 81 | 88 |

*Source: Authors' analysis*

that the GTN Mission is capable of sequestering emissions to the tune of 19–25 MtCO2 per annum. The average annual carbon sequestration potential is 19 MtCO2 for a tree rotational period of 15 years, and this goes up to 25 MtCO2 for a rotational period of 10 years. This is because during the initial period after plantation, trees sequester carbon at a much faster rate; this rate declines as the trees mature.

## 8.2 Key recommendations for sectoral targets

The renewable energy transition requires large-scale participation from the private sector in research and development and the development of projects across the value chains of solar, wind, battery energy storage, EVs, and energy-efficient appliances, among others. But the costs of these technologies remain too high for mass consumer adoption. Government policies and targets (table 2), therefore, will continue to play a key role in the near future to incentivise both the manufacturers and consumers of these clean energy technologies. In addition, government policies are crucial to enable people to adopt a more sustainable lifestyle. TN will need to aggressively increase its use of renewable energy to achieve NZ emissions. To ensure that the increase is in line with the state's NZ trajectory, near- and mid-term targets for renewable energy will be essential.
Our analysis indicates that the service demand for NMTs (walking and cycling) reduces from nearly 64 bpkm in 2020 to 17 bpkm in 2070. There is a significant drop in the utilisation of buses too, leading to a drop in the service demand for public transport. This fall in service demand is replaced by 4W, which witnesses a rise from 26 bpkm in 2020 to a massive 492 bpkm in 2070. This is a market trend that could potentially lead to major congestion on roads and parking space unavailability in urban areas. Government policies incentivising public transport will play a critical role in preventing such situations.

To push private vehicles towards electrification, EV sales targets and charging infrastructure will need to be ramped up. The proposed EV sales target for private vehicles is given in table 4. This target will make sure that by 2050, all private vehicles (4W and 2W) sold will be electric.

Industry is considered to be one of the hard-to-abate sectors. To reach the goal of NZ emissions, it is crucial to enhance the operational efficiency of industries. This means finding ways to use less energy while maintaining productivity. By making industries more efficient, we can ensure that for every billion dollars of economic output, the industry sector produces more without using extra energy. This would not only help the environment, but also contribute to economic growth. The following targets will ensure that NZ emissions are achieved.

The table 4 shows the economy wide target of emission intensity reduction in the respective years compared to 2005 levels. An increase in percentage represents reduction in absolute emission intensity compared to 2005. The increasing target trajectory is a result of the decarbonisation in TN to eventually achieve NZ emissions in 2070. This is aligned with India's NDC target commitments to the UNFCCC.

Since India's announcement to achieve net-zero emissions by 2070 at the COP 26 held in November 2021, the intent to move towards net-zero emissions have started trickling down at a sub-national level too. TN's effort to conduct this study is the first step towards converting this intent into action.

## 8.3 Conclusion

The emissions inventory established for TN, and updated till 2019, as part of this study, serves as the starting point to chart out decarbonisation pathways for the state. The modeling assessment of TN's energy sector, the biggest source of emissions in TN, lays down sector-specific pathways for TN under a BAU and an NZ scenario. This could serve as a potential reference point for each TN government department relevant to the state's net-zero transition to visualise its future, draw insights, and use these to guide policy decisions in the near to mid to long-term future. In addition to modeling the energy sector, the study also assesses the carbon sequestration potential of the GTN mission of the TN government. This is meant to aid the policy maker to understand the scale of carbon sequestration that could potentially net out residual emissions from hard to abate sectors such as industries. While the pace of the net-zero transition could vary based on the ambition set by each sectoral department, this report aligns the larger economy-wide net-zero target to that of India's, that is 2070.

The scale of the transformation required in individual energy producing and consuming sectors reveals an important message that energy transition necessitates a larger economic transition. The speed of the transformation required highlights the urgency with which emissions must be mitigated across these sectors. This report serves to present a broader view of both the scale and the speed at which this transformation has to take place. In committing to this, TN could potentially lead the way among Indian states to enable the country in achieving its targets. This could usher in an era of sustainable economic growth, underpinned by clean energy and green jobs powering the future.

# Annexure 1: Key inputs for and assumptions used in the model

This section captures all the key data inputs and assumptions that were used to model TN's energy sector in both the BAU and NZ scenarios. It is important to note that the BAU scenario includes an inherently defined improvement in energy efficiencies and reduction in costs of technologies, while the NZ scenario is a carbon constraint on the BAU, which follows India's ambition of reaching NZ emissions by 2070. For this, the peak year for emissions is taken as 2040. The following table projects three key socio-economic indicators – population, income, and urbanisation of TN – between 2020 and 2070.

**Table A1 Key socio-economic assumptions**

| Socio-economic assumptions | | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter/Year | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | Unit |
| Population | | | | | | | |
| India | 1,361.34 | 1,475.52 | 1,556.78 | 1,602.98 | 1,615.08 | 1,594.37 | Millions |
| TN | 76.40 | 78.08 | 78.00 | 77.09 | 75.53 | 72.54 | Million people |
| GDP and per-capita income | | | | | | | |
| India's GDP | 2,073.92 | 4,431.20 | 8,510.58 | 14,087.02 | 20,549.66 | 27,286.69 | Billion 2020 USD |
| GDP CAGR of India | 5.0 | 7.9 | 6.7 | 5.2 | 3.8 | 2.9 | Percentage |
| Per-capita GDP India | 1,523 | 3,003 | 5,467 | 8,788 | 12,724 | 17,114 | Billion 2020 USD |
| TN's GSDP | 169.69 | 360.48 | 688.12 | 1,135.15 | 1,648.33 | 2,177.63 | Billion 2020 USD |
| GSDP CAGR of TN | 4.7 | 7.8 | 6.7 | 5.1 | 3.8 | 2.8 | Percentage |
| Per-capita GDP in TN | 2,221 | 4,617 | 8,797 | 14,725 | 21,824 | 30,018 | Billion 2020 USD |
| Urbanisation | | | | | | | |
| Urbanisation | 52.8 | 57.3 | 63.6 | 75.8 | 79.0 | 80.0 | Percentage |
| Urban–rural income divide | 1.42 | 1.40 | 1.38 | 1.36 | 1.33 | 1.31 | NA |
| TN's population growth rate | 0.47 | 0.14 | 0.04 | −0.20 | −0.24 | −0.46 | Percentage |
| India's population growth rate | 1.08 | 0.72 | 0.50 | 0.23 | 0.02 | −0.18 | Percentage |

*Source: Authors' analysis*

The following table projects the cost of various electricity generation technologies from 2020 to 2070.

**Table A2** Assumptions on cost of electricity generation technologies

| Costs of technology | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | Unit |
|---|---|---|---|---|---|---|---|
| Coal supercritical | 3.94 | 3.94 | 3.93 | 3.92 | 3.91 | 3.90 | 2020 INR/kWh |
| Solar PV (without integration cost) | 2.80 | 2 | 1.92 | 1.85 | 1.78 | 1.71 | |
| Wind Onshore (without integration cost) | 3.5 | 3.2 | 3.0 | 2.9 | 2.8 | 2.8 | |
| Wind Offshore (without integration cost) | 10.4 | 5.2 | 4.9 | 4.7 | 4.6 | 4.6 | |
| Nuclear | 4.8 | 4.9 | 5.0 | 5.1 | 5.2 | 5.3 | |
| Gas (domestic) | 5.12 | 5.27 | 5.38 | 5.49 | 5.52 | 5.55 | |
| Gas (imported) | 8.80 | 9.06 | 9.25 | 9.43 | 9.48 | 9.54 | |
| Solar CSP | 11.7 | 9.8 | 8.5 | 8.2 | 7.9 | 7.7 | |
| Hydrogen | 8.2 | 3.0 | 2.8 | 2.6 | 2.5 | 2.3 | 2023 USD/kg |
| **Integration costs** | **2020** | **2030** | **2040** | **2050** | **2060** | **2070** | **Unit** |
| Solar | 0.80 | 0.98 | 1.21 | 1.52 | 1.82 | 2.13 | 2020 INR/kWh |
| Wind | 0.80 | 0.98 | 1.21 | 1.52 | 1.82 | 2.13 | |

*Source: Authors' analysis*

**Table A3** Assumptions on the CUF of electricity generation technologies, 2020

| Electricity generation technology | Assumed CUF |
|---|---|
| Coal | 0.85 |
| Gas Combined Cycle/Steam Combustion Turbine | 0.85/0.3 |
| Oil | 0.35 |
| Hydro | 0.4 |
| Nuclear | 0.85 |
| Solar | 0.18 |
| Onshore wind | 0.18 |
| Offshore wind | 0.30 |

*Source: Authors' analysis*

### Assumptions on solar and wind energy potential in TN

The numbers for solar and wind energy potential for the state have been taken from the National Renewable Energy Laboratory (NREL), USA. We have assumed for our modelling exercise a solar potential of 573 GW and onshore wind potential of 70 GW present within the state.

# Annexure 2: Forestry parameters

**Table A4 Sources of forest parameters for calculating the carbon stock**

| Species | Local name | Volumetric equation source | Specific gravity source | Diameter source |
|---|---|---|---|---|
| *Tectona grandis* | Teak | FSI (2011) | Meena et al. (2018) | Thulasidas and Bhat (2012) |
| *Pterocarpus santalinus* | Red sanders | FSI (2002) | Rajan et al. (2019) | Singh (2020) |
| *Santalum album* | Sandalwood | FSI (2002) | Pullaiah et al. (2021) | Orwa et al. (2009); Vignesh et al. (2022) |
| *Azadirachta indica* | Neem | FSI (2011) | TNAU (n.d.) | Raviperumal et al. (2018) |
| *Swietenia mahogani* | Mahogany (small leaf) | Padmakumar et al. (2021) | Bahnasy (2018) | Dinesha et al. (2022) |
| *Dalbergia sissoo* | Sissoo | FSI (2019) | Kaleeswari et al. (2019) | Tewari and Kumar (2005) |
| *Thespesia populnea* | Indian tulip | FSI (2016) | Warrier (2010) | Friday and Okano (2006) |
| *Gmelina arborea* | Gamhar, white teak | FSI (2011) | Tamang et al. (2019) | Bohre et al. (2013) |
| *Melia dubia* | Malabar neem, maha neem | Padmakumar et al. (2018) | Kumar (2018) | Chavan et al. (2021) |
| *Terminalia arjuna* | Arjuna | FSI (2019) | Jothivel (2016) | Nayak et al. (2009) |
| *Syzygium cumini* | Jamun | FSI (2019) | Tamang et al. (2019) | Nandal, Yadav, and Nath (2023) |
| *Casuarina equisetifolia* | Casuarina | FSI (2019) | Sundarapandian et al. (2014) | Mohan Kumar et al. (1998) |
| *Palmyra/Borassus flabellifer* | Palmyra palm | FSI (2016) | Sharma and Kelkar (2021) | Sarkar et al. (2021) |
| *Tropical dry evergreen forest trees* | – | – | – | – |

*Source: Authors' analysis*

# Acronyms

| | |
|---|---|
| **AFOLU** | Agriculture Forestry and Other Land Use |
| **BAU** | Business-As-Usual |
| **BU** | Billion Units |
| **CAGR** | Compound Annual Growth Rate |
| **CEEW** | Council on Energy, Environment and Water |
| **COP** | Conference of Parties |
| **CUF** | Capacity Utilisation Factor |
| **EJ** | Exa-Joules |
| **GCAM** | Global Change Analysis Model |
| **GHG** | Green House Gases |
| **GoTN** | Government of Tamil Nadu |
| **GSDP** | Gross State Domestic Product |
| **GTN** | Green Tamil Nadu Mission |
| **GW** | Giga-watt |
| **ICE** | Internal Combustion Engine |
| **IIPS** | International Institute for Population Sciences |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **IPPU** | Industrial Processes and Product Use |
| **MoHFW** | Ministry of Health and Family Welfare |
| **MNRE** | Ministry of New and Renewable Energy |
| **$MtCO_2$** | Million Tonnes Carbon Dioxide |
| **MTOE** | Million Tonnes of Oil Equivalent |
| **NIWE** | National Institute for Wind Energy |
| **NZ** | Net-Zero |
| **NDC** | Nationally Determined Contributions |
| **NFHS** | National Family Health Survey |
| **PM-KUSUM** | *Pradhan Mantri - Kisan Urjan Suraksha evam Utthan Mahaabhiyaan* |
| **TFR** | Total Fertility Rate |
| **TANGEDCO** | Tamil Nadu Generation and Distribution Corporation |
| **TANTRANSCO** | Tamil Nadu Transmission Corporation |
| **UNFCCC** | United Nations Framework on Climate Change |

# References


Bahnasy, M. I. 2018. "Growth Study of Some Local and Exotic Timber Tree Species Irrigated with Treated Waste Water." *The Bulletin, Faculty of Agriculture-Cairo University* 69: 201–10.

BL Chennai Bureau. 2024. "TN Global Investors Meet 2024 Attracts Record Investments of ₹6.64-lakh Crore." *The Hindu BusinessLine*, January 8, 2024. https://www.thehindubusinessline.com/news/tn-global-investors-meet-2024-attracts-record-investments-of-664-lakh-crore/article67719459.ece.

Bohre, Priyanka, O. P. Chaubey, and P. K. Singhal. 2013. "Biomass Accumulation and Carbon Sequestration in Tectona Grandis and Gmelina Arborea Roxb." *International Journal of Bio-Science and Bio-Technology* 5 (3): 154–74. https://gvpress.com/journals/IJBSBT/vol5_no3/15.pdf.

CEA. Central Electricity Authority Dashboard.

CEA. 2023. "Report on Optimal Generation Capacity Mix for 2029-30". Last modified 2023. Accessed February 21, 2024. https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/01/2023010910.pdf.

CEEW. 2020. "Financing India's Transition to Electric Vehicles - A USD 206 Billion Market Opportunity (FY21 - FY30) ". Last modified 2020. Accessed February 21, 2024. https://www.ceew.in/cef/solutions-factory/publications/CEEW-CEF-financing-india-transition-to-electric-vehicles.pdf.

CEEW. 2022. "India's Expanding Clean Energy Workforce Opportunities in the Solar and Wind Energy Sectors". Last modified 2022. Accessed February 21, 2024. https://www.ceew.in/sites/default/files/Green-Jobs-Report-Jan27.pdf.

Chaturvedi, Vaibhav, and Ankur Malyan. 2022. "Implications of a Net-zero Target for India's Sectoral Energy Transitions and Climate Policy." *Oxford Open Climate Change* 2 (1): kgac001. https://doi.org/10.1093/oxfclm/kgac001.

Chavan, Sangram, R. Vishnu, Naresh Kumar, and Dhiraj Kumar. 2021. "Melia Dubia: An Indigenous Tree Species for Industrial Agroforestry in India." *Indian Farming* 71 (6): 7–11. https://www.researchgate.net/publication/355110277_Melia_dubia_An_indigenous_tree_species_for_industrial_agroforestry_in_India.

CAT. 2023. "CAT Net Zero Target Evaluations." Last modified December 14, 2023. https://climateactiontracker.org/global/cat-net-zero-target-evaluations/.

Dinesha, S., Mihir Ranjan Panda, Devbratha Pradhan, S. Rakesh, Amarendra Nath Dey, Jahangeer A. Bhat, and Rajiv Pandey. 2022. "Ecosystem Carbon Budgeting under Swietenia Macrophylla King Plantation in Sub Humid Foothills of Eastern Himalayans of India." *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-022-02902-6.

Energy Department, Govt. of Tamil Nadu. 2023. "Policy Note, 2023-24". Last modified 2023. Accessed February 21, 2024. https://cms.tn.gov.in/sites/default/files/documents/energy_e_pn_2023_24.pdf.

FAO. "Global Soil Organic Carbon Map (GSOC)." FAO Global Soil Partnership. Last modified 2019. Accessed October 10, 2023. http://www.fao.org/global-soil-partnership/pillars-action/4-information-and-data/global-soil-organic-carbon-gsocmap/en/.

Fischlin, Andreas, Ismail Elgizouli, and Xuejie Gao. 2018. "Final Report from IPCC Special Report on Global Warming of 1.5°C". Accessed February 3, 2024. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Final_RE_Reports_All.pdf.

FSI. 2002. "Report on Inventory of Forest Resources of Mandya District (Karnataka)." Bangalore: Forest Survey of India, Ministry of Environment & Forests, Government of India.

———. 2011. "India State of Forest Report 2011." Dehradun: Forest Survey of India, Ministry of Environment & Forests, Government of India. https://fsi.nic.in/forest-report-2011.

———. 2016. "Inventory of Trees Outside Forest in Tamil Nadu." Dehradun: Forest Survey of India, Ministry of Environment & Forests, Government of India.

———. 2019. "India State Forest Report 2019." Dehradun: Forest Survey of India, Ministry of Environment & Forests, Government of India.

———. 2021. "India State Forest Report 2021." Dehradun: Forest Survey of India, Ministry of Environment & Forests, Government of India.

Friday, J. B., and Dana Okano. 2006. "Thespesia Populnea (Milo)." In *Species Profiles for Pacific Island Agroforestry*, edited by Craig R. Elevitch. Permanent Agriculture Resources. https://agroforestry.org/images/pdfs/Thespesia-milo.pdf.

GHG Platform Initiative. 2022. "Economy Wide". Last modified September, 2022. https://www.ghgplatform-india.org/economy-wide/

Government of India. 2022. "India's Updated First Nationally Determined Contribution under Paris Agreement."

Accessed February 3, 2024. https://unfccc.int/sites/default/files/NDC/2022-08/India%20Updated%20First%20Nationally%20Determined%20Contrib.pdf.

Huntington, Hillard G., John P. Weyant, and James L. Sweeney. 1982. "Modeling for Insights, Not Numbers: The Experiences of the Energy Modeling Forum." *Omega* 10 (5): 449–62. https://doi.org/10.1016/0305-0483(82)90002-0.

IIPS. 2022. "National Family Health Survey (NFHS-5), India, 2019–21: Tamil Nadu." Mumbai: International Institute for Population Sciences. https://rchiips.org/nfhs/NFHS-5Reports/Tamil%20Nadu.pdf.

Jothivel, Saravanan. 2016. "Diversity of Wood Specific Gravity among Forest Trees, Kolli Hills, Southern Tamilnadu, India." *International Journal of Environmental Biology* 6 (1): 29–33.

Kaleeswari, R. K., A. Balasubramanian, K. Sivakumar, and R. Rajeswari. 2019. "Growth and Physiology of High Density Dalbergia Sissoo Tree Plantations under Micro Fertigation System." *International Journal of Current Microbiology and Applied Sciences* 8 (5): 1528–32. https://doi.org/10.20546/ijcmas.2019.805.176.

Kumar, Ashok. 2018. "Physical and Anatomical Properties: The Case of Two Progenies of Melia Dubia Cav." *Forestry Research and Engineering: International Journal Research* 2 (6): 335–41. https://medcraveonline.com/FREIJ/FREIJ-02-00069.pdf.

Meena, Rajesh Kumar, A. U. Nimakar, and Heena Gupta. 2018. "Variation in Bark Percentage, Specific Gravity of Wood and Fibers Length in Different Provenances of Teak (Tectona Grandis L.) Wood." *Environment & Ecology* 34 (4): 1781–84.

Ministry of Health and Family Welfare, National Commission on Population. 2020. "Population Projections for India and State (2011–2036)." New Delhi: Ministry of Health and Family Welfare, National Commission on Population. https://main.mohfw.gov.in/sites/default/files/Population%20Projection%20Report%2011-2036%20-%20upload_compressed_0.pdf.

Ministry of New and Renewable Energy. 2022. "Installation of Solar Irrigation Pumps." Accessed February 3, 2024. https://sansad.in/getFile/loksabhaquestions/annex/1710/AU397.pdf?source=pqals.

Ministry of Road Transport and Highways. 2024. "Vahan Dashboard". Last modified 2024. Accessed February 21, 2024. https://vahan.parivahan.gov.in/vahan4dashboard/vahan/view/reportview.xhtml.

Ministry of New and Renewable Energy. 2024. "Offshore Wind". Accessed February 12, 2024. https://mnre.gov.in/off-shore-wind/#:~:text=Initial%20assessment%20by%20NIWE%20within,off%20the%20Tamil%20Nadu%20coast.

Mohan Kumar, B., Suman Jacob George, V. Jamaludheen, and T. K. Suresh. 1998. "Comparison of Biomass Production, Tree Allometry and Nutrient Use Efficiency of Multipurpose Trees Grown in Woodlot and Silvopastoral Experiments in Kerala, India." *Forest Ecology and Management* 112 (1–2): 145–63. https://doi.org/10.1016/S0378-1127(98)00325-9.

Nandal, Abhishek, Surender Singh Yadav, and Arun Jyoti Nath. 2023. "Trees Outside Forests as Climate Change Mitigation Champions: Evaluating Their Carbon Sequestration Potential and Monetary Value in Maharshi Dayanand University, Rohtak (Haryana), India." *Environmental Monitoring and Assessment* 195 (8). https://doi.org/10.1007/s10661-023-11597-9.

Nayak, Akshaya K., Ubaid Khan, D. K. Sharma, Vimal Kumar Mishra, Chhedi Lal Verma, Ranbir Singh, and Gurbachan Singh. 2009. "Spatial Variability of Soil Physico-chemical Properties under Prosopis Juliflora and Terminalia Arjun in Sodic Soil of Indo-Gangetic Plains." *Journal of the Indian Society of Soil Science* 57 (1): 31–38.

National Renewable Energy Labrotory, 2024. "RE Data Explorer". Accessed February 3, 2024. https://data.re-explorer.org/technical-potential/analysis.

Orwa, C., A. Mutua, R. Kindt, R. Jamnadass, and S. Anthony. 2009. "Santalum Album." In *Agroforestree Database: A Tree Reference and Selection Guide*. World Agroforestry Center. http://www.worldagroforestry.org/treedb/AFTPDFS/Santalum_album.PDF.

Padmakumar, Babu, Naduparambu P. Sreekanth, Viswanathan Shanthiprabha, Joby Paul, Kasau Sreedharan, Toms Augustine, Kazhuthuttil K. Jayasooryan, et al. 2018. "Tree Biomass and Carbon Density Estimation in the Tropical Dry Forest of Southern Western Ghats, India." *iForest 11* (4): 534–41. https://doi.org/10.3832/ifor2190-011.

Padmakumar, Babu, Naduparambu P. Sreekanth, Viswanathan Shanthiprabha, Joby Paul, Kasau Sreedharan, Toms Augustine, Kazhuthuttil K. Jayasooryan, et al. 2021. "Unveiling Tree Diversity and Carbon Density of Homegarden in the Thodupuzha Urban Region of Kerala, India: A Contribution towards Urban Sustainability." *Tropical Ecology* 62 (4): 508–24. https://doi.org/10.1007/s42965-021-00149-2.

PIB. 2022. "Year End Review: Ministry of Environment Forest and Climate Change." December 23, 2022. Press Information Bureau, Ministry of Environment, Forest and Climate Change. https://pib.gov.in/PressReleasePage.aspx?PRID=1886051.

PIB. 2024. "India's Solar Energy Potential Is Estimated to Be 748 GWp: Union Power and New & Renewable Energy Minister." Accessed February 12. https://www.pib.gov.in/www.pib.gov.in/Pressreleaseshare.aspx?PRID=2003561.

Pullaiah, Thammineni, Sudhir Chandra Das, Vishwas A. Bapat, Mallappa Kumara Swamy, Vaddi Damodar Reddy, and Kongdragunta Sri Rama Murthy. 2021. *Sandalwood: Silviculture, Conservation and Applications*. Singapore: Springer. https://doi.org/10.1007/978-981-16-0780-6.

Rajan, Lakshmy J., S. Suresh Ramanan, and E. V. Anoop. 2019. "Physical and Anatomical: Wood Properties Variation among the Provenances of Red Sanders (Pterocarpus Santalinus)." *Indian Journal of Hill Farming* 32 (1): 162–68.

Raviperumal, A., A. Balasubramanian, S. Manivasakan, C. N. Hari Prasath, and M. Suresh Krishnan. 2018. "Yield Model Construction in Neem (Azadirachta Indica) under Western Agro Climatic Zone of Tamil Nadu, Southern India." *Trends in Biosciences* 11 (24): 3237–39.

RBI. 2022. "Table 33: Gross State Value Added by Economic Activity – Manufacturing." In *RBI Handbook of Statistics on Indian States*. Reserve Bank of India. https://rbidocs.rbi.org.in/rdocs/Publications/PDFs/33T_1911202281F35D8DBADA47CFB4D8665931D740FD.PDF.

Richards, F. J. 1959. "A Flexible Growth Function for Empirical Use." *Journal of Experimental Botany* 10 (2): 290–301. https://doi.org/10.1093/jxb/10.2.290.

Sarkar, Pradip Kumar, Pranati Sarkar, Amit Kumar, Nazir A. Pala, and Munesh Kumar. 2021. "Carbon Storage Potential of a Waterlogged Agroforestry System of Tripura, India." *Water, Air, & Soil Pollution* 232 (151). https://doi.org/10.1007/s11270-021-05098-z.

Sharma, S. K., and Bhushan U. Kelkar. 2021. "Effect of Densification on Certain Physical and Mechanical Properties of Inner Soft Wood of Borassus Flabellifer L." *Journal of the Indian Academy of Wood Science* 18 (1): 39–44. https://doi.org/10.1007/s13196-021-00277-1.

Singh, Sewa. 2020. "Carbon Sequestration Potential of Red Sander (Pterocarpus Santalinus) Plantations under Different Ages in Vellore and Thiruvallur Districts of Tamil Nadu." *Life Sciences Leaflets* 123: 1–11. https://petsd.org/ojs/index.php/lifesciencesleaflets/article/view/1473.

Sundarapandian, S. M., K. Mageswaran, D. Sanjay Gandhi, and Javid Ahmad Dar. 2014. "Impact of Thane Cyclone on Tree Damage in Pondicherry University Campus, Puducherry, India." *Current World Environment* 9 (2): 287–300. https://doi.org/10.12944/cwe.9.2.09.

Tamang, Bisleshna, Biplov C. Sarkar, Nazir A. Pala, Gopal Shukla, Vineeta P. A. Sofi, and Sumit Chakravarty. 2019. "Wood Specific Gravity of Some Tree Species in Sub-tropical Humid Climate of India." *Indian Forester* 146 (7): 309–14. https://doi.org/10.36808/if/2019/v145i7/147028.

Tamil Nadu Agricultural University (TNAU). n.d. "Neem – A Versatile Tree." Accessed February 3, 2024. https://agritech.tnau.ac.in/banking/pdf/Forestry Wasteland_Neem.pdf.

Tamil Nadu State Transport Corporation. 2020. "Tamil Nadu State Transport Corporation Document". Last modified 2020. Accessed February 21, 2024. https://www.tnstc.in/innerHtmls/pdf/Tamil%20Nadu%20STUs-pages.pdf.

Tewari, V. P., and V. S. K. Kumar. 2005. "Growth and Yield Functions for Dalbergia Sissoo Plantations in the Hot Desert of India Grown under Irrigated Conditions." *Journal of Tropical Forest Science* 17 (1): 87–103. https://www.jstor.org/stable/23616529?seq=3.

Thulasidas, P. K., and K. M. Bhat. 2012. "Mechanical Properties and Wood Structure Characteristics of 35-Year Old Home-garden Teak from Wet and Dry Localities of Kerala, India in Comparison with Plantation Teak." *Journal of the Indian Academy of Wood Science* 9 (1): 23–32. https://doi.org/10.1007/s13196-012-0062-7.

Vahan Dashboard. n.d. "Vahan Portal Dashboard." Accessed February 9, 2024. https://vahan.parivahan.gov.in/vahan4dashboard/.

Vignesh, M., M. Sivaprakash, A. Balasubramanian, M. Tilak, S. Radhakrishnan, C. N. Hari Prasath, K. S. Anjali, and S. Navaneetha Krishnan. 2022. "Effect of Spacing on the Growth of Sandalwood (Santalum Album L.) Trees under Farm Conditions in Tamil Nadu, India." *The Pharma Innovation* 11 (7): 785–87. https://doi.org/10.22271/tpi.2022.v11.i7j.13784.

Warrier, Kannan C. S. 2010. "Thespesia Populnea (L.) Soland Ex Corrêa." In *Manual of Economically Important Forestry Species in South India*, edited by N. Krishna Kumar, Kiruthika Palanisamy, Maheshwar Hegde, Kannan C. S. Warrier, and M. Krishnamoorthy, 495–505. Coimbatore: Institute of Forest Genetics and Tree Breeding, Indian Council of Forestry Research and Education.

Yuancai, Lei, Carlos Pacheco Marques, and João Manual Bento. 2001. "Features and Applications of Bertalanffy-Richards' and Schnute's Growth Equations." *Natural Resource Modeling* 14 (3): 433–51. https://doi.org/10.1111/j.1939-7445.2001.tb00066.x.

## Notes



**TAMIL NADU GREEN CLIMATE COMPANY (TNGCC)**

7th Floor, Secretariat, Namakkal Kavignar Maaligai,
Fort St. George, Chennai - 600009, Tamil Nadu

forsec@tn.gov.in | tngreencompany.com | @climateactionTN |
tnclimateaction | Tamil Nadu Climate Action

**COUNCIL ON ENERGY, ENVIRONMENT AND WATER (CEEW)**

ISID Campus, 4 Vasant Kunj Institutional Area
New Delhi - 110070, India

T: +91 (0) 11 4073 3300

info@ceew.in | ceew.in | @CEEWIndia | ceewindia