AurovilleConsulting

Envisioning Tamil Nadu's Renewable Energy Scenarios for 2030

March 2024

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Acknowledgment

I express my sincere gratitude to Auroville Consulting for supporting the completion of this report. Special thanks to Martin Scherfler for providing access to necessary resources and technical guidance. His contributions have significantly enriched the quality and depth of this report.

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Executive Summary

India's commitment to achieving net zero emissions by 2070 underscores the nation's dedication to combating climate change. A pivotal sector in this pursuit is the power sector, which faces a substantial rise in electricity demand over the next two decades, largely driven by the widespread adoption of air conditioning (AC) and electric vehicles (EVs). Especially Tamil Nadu, known for its industrial prowess, is experiencing robust economic growth, leading to an increased electricity demand. These transformative developments are anticipated to reshape the temporal pattern of electricity consumption, posing significant implications for Tamil Nadu's electricity sector planning. In response, this report forecasts Tamil Nadu's total electricity demand in 2030, integrating the escalating demand for ACs and the accelerating trend toward EVs to facilitate informed decision-making in the strategic planning of the state's power sector.

To effectively meet the rising demand and climate targets of becoming a net zero economy Tamil Nadu must expedite its transition towards a sustainable energy future. Aligned with this vision, Tamil Nadu has set an ambitious target of 50% renewables penetration by 2030 but challenges persist in seamlessly integrating renewable sources into the grid, including managing ramping rates, infrastructure upgrades, and the need for storage solutions. Consequently, the latter part of this report explores the escalating contribution of wind and solar energy to Tamil Nadu's energy mix. It considers three scenarios of solar and wind energy penetration and conducts a detailed load analysis for each, assessing their impact on key grid management parameters.

The forecasted total demand for 2030 indicates a 45% increase compared to 2023, with demand ACs constituting 11% and EV demand 2% respectively of the total demand. Peak load instances are projected to increase by 41.20%, with AC load significantly contributing (~16%)to the top five gross peak-load instances, all occurring during solar generation hours in April. Although solar significantly contributes to meeting the expected top 5 gross peak load instances, integrating a higher share of wind energy appears more favorable, offering fewer instances of high load ranges, especially during evening hours, and lower ramping instances compared to scenarios with higher solar shares. Thus, it's crucial to find an optimal balance between wind and solar energy for Tamil Nadu's power system.

The findings also underscore the importance of increasing the state's energy storage capacity, introducing favorable conditions for compensating renewable energy generators and providing incentives for demand shifting. The higher shares of renewable energy result in negative load instances and a significant increase in high ramping instances compared to gross load. This report aims to provide valuable insights into Tamil Nadu's energy landscape, guiding strategic planning efforts to ensure sustainable and resilient power infrastructure for the future.

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List of Abbreviations

2W – Two-Wheeler

3W – Three-Wheeler

4W – Four-Wheeler

AEEE – Alliance for an Energy Efficient Economy

AC – Air Conditioning

BAU – Business as Usual

CDD – Cooling Degree Days

CUF – Capacity Utilization Factor

EV – Electric Vehicle

FY – Fiscal Year

GDP – Gross Domestic Product

GSDP – Gross State Domestic Product

GW – Gigawatts

GW/h – Gigawatt per Hour

ICAP – Indian Action Cooling Plan

IPCC – Intergovernmental Panel on Climate Change

MNRE – Ministry of New and Renewable Energy

MoRTH – Ministry of Road Transport and Highways

MoEF – Ministry of Environment, Forest & Climate Change

MU – Million Units

NSDP – Net State Domestic Product

RCP – Representative Concentration Pathway

RE – Renewable Energy

RPO – Renewable Purchase Obligation

SLDC – State Load Dispatch Centre

TN –Tamil Nadu

TWh – Terawatt Hour

01 Introduction

India is making significant strides towards achieving its climate goals, committing to net zero emissions by 2070 and prioritizing sustainable living to combat climate change. A crucial sector in this endeavor is the power sector. With projections indicating a substantial increase in electricity demand over the next two decades (IEA 2020), driven primarily by the widespread adoption of air conditioning (AC) and electric vehicles (Evs) (IEA 2020, IEA 2018), it is imperative to manage resources effectively to ensure sustainable economic growth while meeting India's climate commitments.

Tamil Nadu (TN) stands out as one of India's most industrially advanced states, experiencing robust economic growth reflected in its steadily increasing Net State Domestic Product (NSDP) at an average rate of 8.30% per annum (MOSPI, 2024). This economic prosperity has led to an improved per capita income, consequently spurring greater electricity demand. Anticipated to further escalate over the next two to three decades, this demand surge is largely attributed to the burgeoning adoption of air conditioning (AC) technologies in residential and commercial sectors (AEEE 2018), alongside the national agenda to electrify transportation, especially two and three-wheeler (2W, 3W) vehicles, as proposed by NITI Aayog's ambitious target of achieving 30% electrical vehicles (Evs) penetration by 2030 (GIZ 2021).

The total cooling demand across the country is expected to increase approximately eightfold by 2037-38 compared to the baseline recorded in 2017-18. Among various sectors, the demand for cooling in buildings is anticipated to experience the most substantial growth, reaching nearly eleven times the baseline level (MoEF 2019). Moreover, NITI Aayog's vision for 2030 sets targets, aiming for 70% of all commercial cars, 30% of private cars, 40% of buses, and 80% of 2W and 3W sales to be electric, shaping the future landscape of transportation (NITI Aayog-RMI, 2019).

These transformative developments are expected to bring significant shifts in the temporal pattern of electricity consumption, carrying profound implications for Tamil Nadu's electricity sector planning (TERI 2019). In response to these challenges and opportunities, this report endeavors to forecast the total electricity demand for Tamil Nadu in 2030. By integrating the escalating demand for AC and the accelerating trend toward Evs adoption, this analysis aims to offer insights on aggregated consumption estimates and temporally resolved consumption profiles. Through providing these insights, the report seeks to facilitate informed decision-making in the strategic planning of Tamil Nadu's power sector.

To effectively meet climate targets of becoming a net zero economy Tamil Nadu must expedite its transition towards a sustainable energy future. Fortunately, the state boasts abundant wind and solar energy resources and has already made significant progress in harnessing clean energy, studies show that Tamil Nadu has a renewable energy (RE) capacity of 86.40 gigawatts (GW) mainly from wind and solar sources (MNRE, 2020). Aligned with this vision, Tamil Nadu has set an ambitious target of sourcing 50% of its total electricity from RE by 2030, positioning itself as an example among Indian states (Government of Tamil Nadu 2023). As of 2023 about 20% of electricity is sourced from RE. As of February 2024, the state's wind capacity stands at 10.46 GW (MNRE 2023). The state's solar capacity currently stands at 7.51 GW, with plans to augment this to 20 GW by 2030 (MNRE 2023).

However, challenges persist in seamlessly integrating these renewable sources into the grid, including managing ramping up and down rates, infrastructure upgrades, and the need for storage solutions (Auroville Consulting 2023). Against this backdrop, the latter part of this report will delve into the escalating contribution of wind and solar energy to Tamil Nadu's energy mix. It will consider three different scenarios of solar and wind energy penetration and conduct a detailed load analysis for each scenario, assessing their impact on key grid management parameters such as peak load instances, minimum load instances, and ramping up and ramping down requirements.

By examining these factors comprehensively, this report aims to provide actionable insights for Tamil Nadu's electricity sector, facilitating a smoother transition towards a sustainable energy future while meeting the state's

02

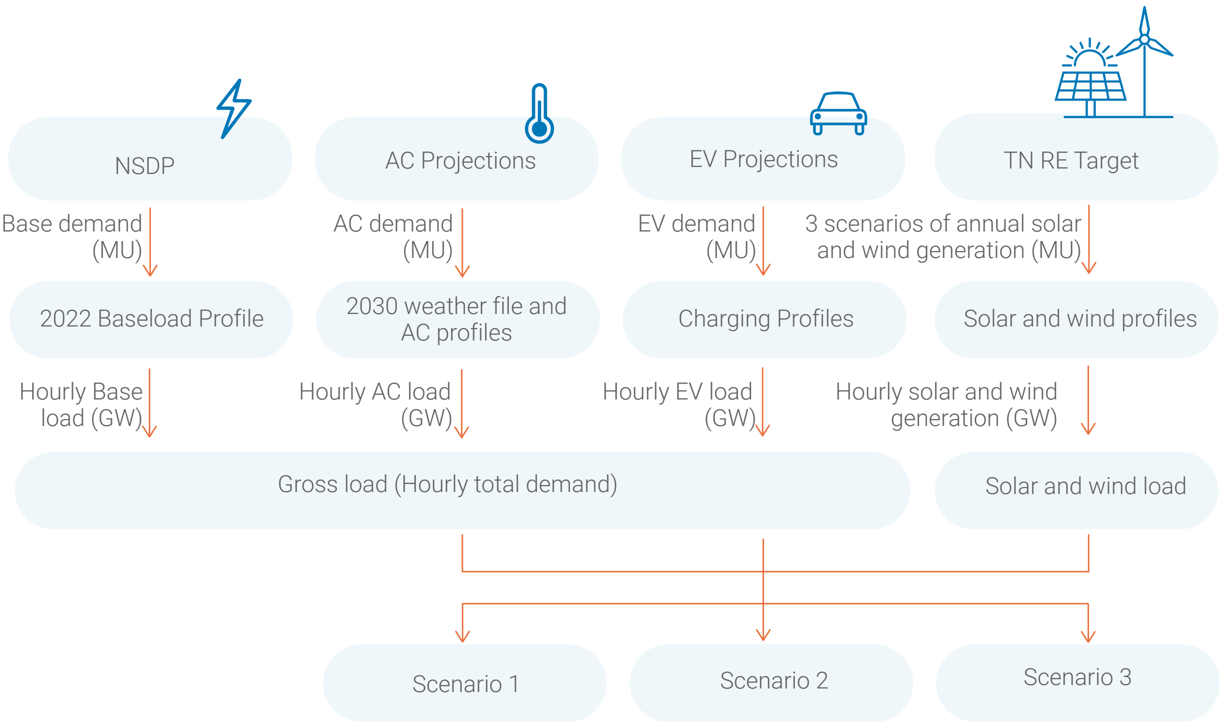
Demand and generation forecasting

2.1 Demand forecast

The methodology for forecasting the 2030 total electricity demand in hourly granularity (Gross load) for Tamil Nadu involves a comprehensive approach divided into three main components:

(i) Forecasting base load which represents gross load - AC load - EV load.
(ii) Forecasting AC load
(iii) Forecasting EV load

Figure 1: Simplified schematic diagram of the methodology



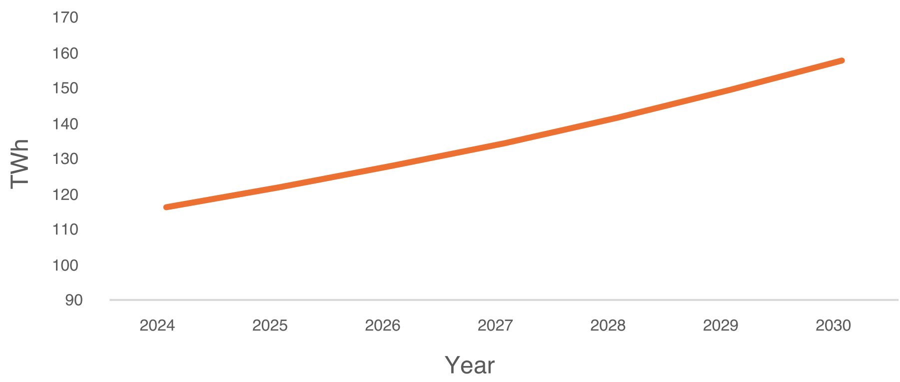
Base load

A strong correlation between economic growth and energy consumption has been established in the Tamil Nadu context in this study based on trends from the past decade (MOSPI, 2024) and has also been observed in other studies (EIA 2013). The primary driver for electricity demand is modelled to be the Net State Domestic Product (NSDP). A simple NSDP regression model is utilized to calculate the total base demand for 2030 as depicted in Figure 2, using data from 2017 to 2023 for training. This approach is preferred over Gross State Domestic Product (GSDP) as NSDP considers depreciation, providing a more accurate indicator of economic performance

[1]The term "total demand" is used under the assumption that the total annual demand is equal to the total annual supply, thus no deficit.
[2]Throughout the report, the hourly resolved total demand is referred to as gross load.

NSDP is assumed to grow at a 9% compound annual growth rate (CAGR), based on past trends for predicting future demand (MOSPI 2024). The forecasted base demand for 2030 is then converted to hourly base load using normalized profiles from 2022 Base load data sourced from the State Load Dispatch Centre (SLDC).

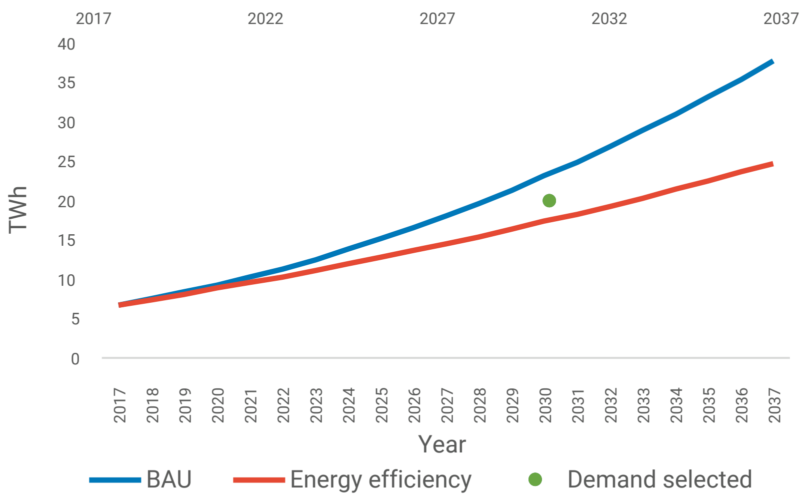
Figure 2: Tamil Nadu forecasted base demand (2024-2030)



Air Conditioning load

Only refrigerant-based air conditioning, including systems like Room Air Conditioners (RAC), chillers, Variable Refrigerant Flow (VRF), and Packaged Direct Expansion (DX), is considered for AC demand estimation. Due to the unavailability of specific AC data for Tamil Nadu, national-level annual energy demand is calculated and scaled down using the ratio of Tamil Nadu's GSDP to national GDP. Two scenarios, Business as Usual (BAU) and Energy efficiency, are considered for estimating 2030 annual AC demand in line with (AEEE 2018) and India Action Cooling Plan (ICAP) by (MoEF 2019) as shown in Figure 3 and the average of these scenarios is taken as annual AC demand. This demand is divided into two categories: residential and commercial, the ratio of residential to commercial consumption is computed from ICAP (MoEF 2019). For daily distribution cooling degree days (CDD's) are used which are derived from the 2030 weather file considering Representative Concentration Pathway 4.5 (RCP 4.5) scenario defined in (IPCC 2014) sourced from (Weather Shift 2024), which is further resolved to hourly AC load using surveyed hourly profiles adapted from residential and commercial AC load studies (IIMA 2010, Miriyala 2024). For a normalized daily average AC load profile by season refer to Figure 13 in the appendix.

Figure 3: Tamil Nadu forecasted AC demand



Electric Vehicles load

The EV demand is estimated using national-level projections from the Council on Energy, Environment, and Water (CEEW 2020) for 2030 total EV adoption. State-level energy consumption is derived by averaging the ratio of total vehicles registered in Tamil Nadu to those registered nationally over five years (MoRTH 2021, Vahan dashboard 2024) as shown in Table 1 below. In Table 1, the base case represents the total EV in Tamil Nadu if the (NITI Aayog-RMI, 2019) target is met, considering this target too aggressive, a medium adoption scenario is chosen, representing a 20% shortfall from the target. Projections for energy consumption across different types of electric vehicles (EVs), including 2W, 3W, and 4W are derived by factoring in their respective energy efficiencies and average distances travelled. These calculations are based on data obtained from various papers, surveys and reports (Bansal 2018, Majumdar 2015, Nayka 2018, and Ather 2024), which provide insights into the average distances covered by various vehicle categories in both urban and rural areas. The total EV consumption is further converted to EV load at hourly resolution using surveyed charging profiles (IRADe 2022). For a normalized daily average charging load profile by EV type refer to Figure 14 in the appendix.

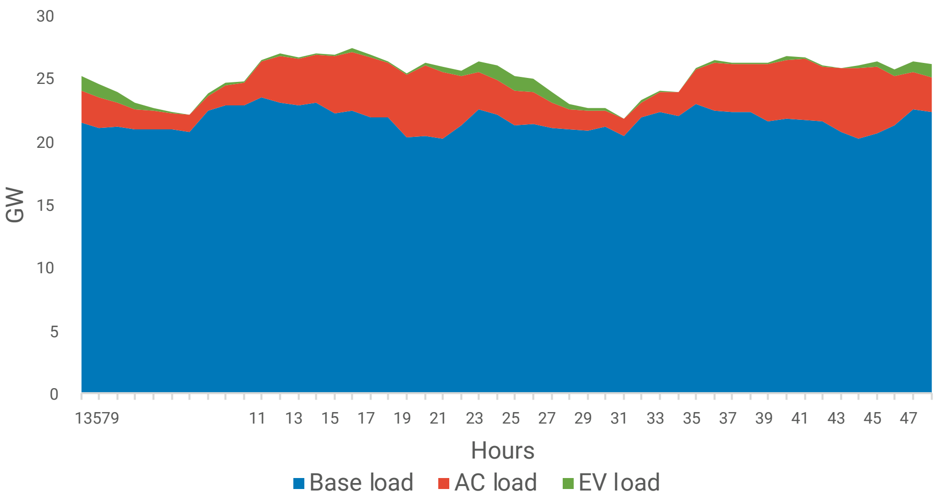
Table 1: Tamil Nadu forecasted total EV sales FY 2021 to FY 2030

	Base case	**Medium adoption**
2W (in millions)	7.43	5.93
3W (in millions)	0.24	0.16
4W-Private (in millions)	0.24	0.16
4W -Commercial (in millions)	0.16	0.16
Total (in millions)	8.06	6.40
Total Energy (TWh)	4.06	3.27

Base case refers to a scenario when NITI Aayog target is met.

From the following methodology, all the loads i.e., base load, AC load and EV load are added to arrive at gross load. The gross load profile for two typical summer days (29th and 30th April) is illustrated in Figure 3.

Figure 4: 2030 load profile across two days in summer



2.2 Solar and Wind Energy Generation forecast

In alignment with Tamil Nadu's 2030 target of sourcing 50% of energy from RE, three solar and wind energy penetration scenarios are simulated. The scenarios vary by percentage shares of solar and wind energy. It is assumed that the Renewable Purchase Obligation (RPO) mandate for hydro energy in 2030 will be 3.25% of the total energy. Therefore, the remaining 46.75% is assumed to come from wind and solar energy. The projected solar and wind generation is distributed to hourly resolution using normalized 2022 solar and wind hourly profiles provided by Tamil Nadu State Load Dispatch Centre (SLDC).

This approach will provide a gross load, alongside three distinct scenarios accounting for variations in solar load, wind load, and resulting net load as shown in Figure 1. After obtaining total and temporally resolved load data for the different scenarios, a comparative detailed analysis is conducted. This analysis assesses the performance of each scenario based on four key parameters relevant to grid operation:

1) Net load in higher load ranges (peaks)
2) Net load in lower load ranges (valleys)
3) Net load ramping up instances[4]
4) Net load ramping down instances

[3]In the context of this report, the Net load refers to the load approximately met by the thermal power stations, i.e., Gross load-solar load-wind load.

[4]An instance means a particular moment when a load reading is noted. So, in this report where load readings are taken and forecasted for every hour, each of these hourly readings is a separate instance. Therefore with 8760 hours in a year, there are 8760 instances.

03

Comparative Analysis

The proportion of wind and solar energy in the renewable energy mix influences both the peak load and the frequency of high ramping instances.

This chapter presents a comparative gross load analysis between the years 2023 and 2030, alongside exploring three different RE scenarios for the year 2030. The impact of these RE scenarios is analysed on key grid management parameters such as net peak load, net valley load, and net ramping requirements. These scenarios are simulated by varying the percentage shares of solar and wind energy, the purpose of scenarios is to better understand the grid impact of solar energy and wind energy. The overall volume of RE assumed for the year 2030 is determined based on the Tamil Nadu 2030 target of sourcing 50% of its total electricity from RE. Based on the total demand forecast, 50% for the year 2030 represents 90,629 MU. Hydro energy is expected to contribute 3.25% of the total RE in 2030. Therefore, to meet the remaining 46.75% or 84,731 MU of energy will need to come from wind and solar energy. A detailed description of each scenario is given in Table 2.
(refer to Table 1).

Table 2: Scenario with varied solar and wind share

	Share on renewables (excluding hydro)		Energy (MU)		Additional capacity requirement (GW)	
	Solar	**Wind**	**Solar**	**Wind**	**Solar**	**Wind**
RE Scenario 1	75%	25%	63,548.4	21,182.8	28.4	0.2
RE Scenario 2	25%	75%	21,182.8	63,548.4	5.3	17.5
RE Scenario 3	50%	50%	42,365.6	42,365.6	16.8	8.9

A CUF of 21% was assumed to determine the additional solar energy capacity requirement. To estimate the additional wind energy requirement a CUF of 28% was used.

3.1 Total demand comparison

By 2030, there will be a 45% rise in overall electricity demand and a 41% increase in peak load compared to 2023, with AC demand contributing 11% and EV demand contributing 2% in total demand.

This section presents a comprehensive analysis of the total demand and gross load for fiscal year (FY) 2023 and 2030 (forecasted). For forecasting 2030 total demand, the primary econometric driver considered for base load modelling is the NSDP growth, while the load from AC and EVs are forecasted separately and added to derive the gross load, as detailed in the preceding section.

As evident from Table 4, there has been a consistent uptrend in the total demand and the single highest recorded peak instance in gross load from FY 2020 to FY 2023. In FY 2023, the total demand stood at 1,25,000 MU, while an anticipated demand for FY 2030 is 181,260 MU. This comprises of base demand of 1,58,000 MU, AC demand of 20,000 MU, and EV demand of 3,260 MU as shown in Table 3. This signifies a substantial 45% increase in total demand from 2023 to 2030.

Table 3: 2030's Total demand composition

	Energy (MU)	Percentage of total demand
Base demand	1,58,000	87%
AC demand	20,000	11%
EV demand	3,260	2%
Total demand	**1,81,260**	**100%**

Furthermore, the highest recorded peak load for FY 2023 was registered at 19.4 GW on the 20th of April. Conversely, the forecasted highest peak load for FY 2030 is expected to reach 27.41 GW, also occurring in April, reflecting a significant 41% increment over the period.

Table 4: Total demand and highest recorded peak for FY

Year	Total demand (MU)	Peak (GW)
2020	1,03,190	15.66
2021	1,10,210	16.85
2022	1,15,650	17.52
2023	1,25,000	19.41
2030*	1,81,260	27.41

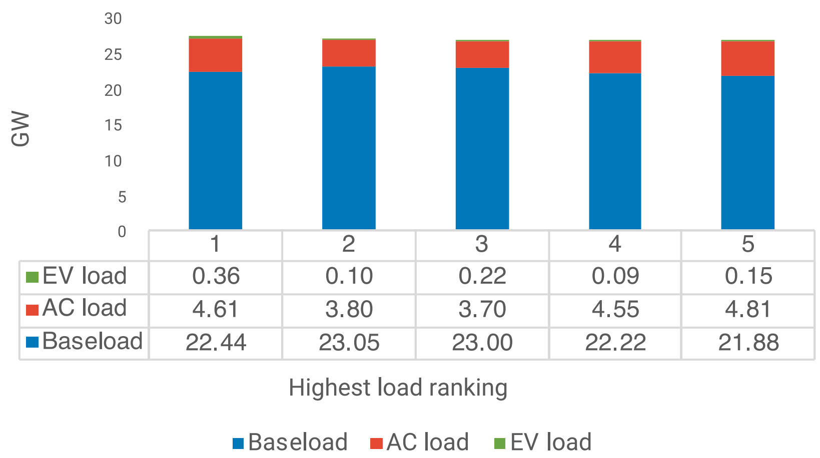
*Forecasted value

3.2 Goss load analysis

The top five gross load peak instances in the year 2030 are expected during solar energy generation hours in April.

Observations for FY 2030 reveal a notable trend wherein the five highest gross load instances all occurred in April in solar generation hours i.e., between 10 am to 5 pm. Among these instances, AC load is a substantial contributor to the peaks, constituting an average of 16%. Conversely, the contribution from EVs remains minimal, with an average of only 1% across the top 5 highest load occurrences as illustrated in Figure 5.

Figure 5: 2030 top five highest load instances in descending order and their composition



	1	2	3	4	5
EV load	0.36	0.10	0.22	0.09	0.15
AC load	4.61	3.80	3.70	4.55	4.81
Baseload	22.44	23.05	23.00	22.22	21.88

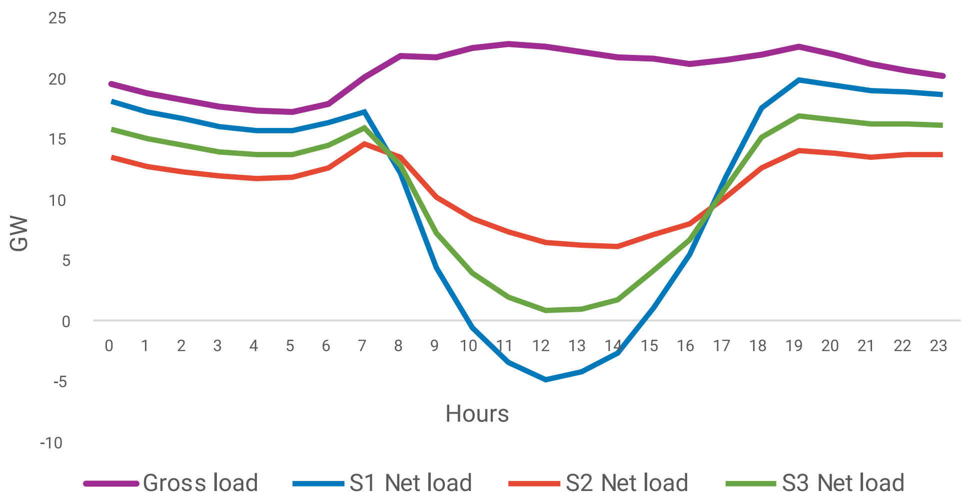
3.3 Net load analysis:

Integrating solar and wind energy into the system aids in mitigating occurrences of high load levels, with the scenario featuring greater wind energy being the most effective, while the scenario with higher solar energy is the least effective one.

In this report, net load is defined as the gross load excluding solar and wind load (calculated as gross load minus solar and wind load). From the perspective of utilities and grid operators, maintaining net load within optimal levels is crucial to avoid strain on the electrical grid, which can lead to voltage fluctuations, frequency deviations, and potential equipment failures. Ensuring optimal net load levels is essential for grid stability, energy efficiency, cost-effectiveness, and environmental sustainability in the electricity sector. This section of the report evaluates the performance of 2030 net load scenarios across higher and lower load ranges.

Figure 6 presents the hourly average gross and net loads for 2030, offering a concise overview of average the load for each hour throughout the year.

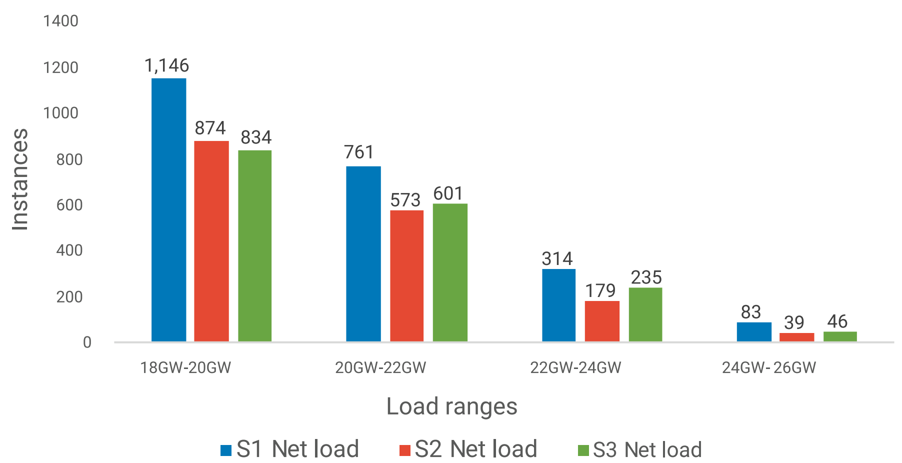
Figure 6: Hourly average gross and net load in 2030



Higher Load Ranges:
This part of the analysis highlights the number of instances of load in four higher load ranges i.e., 24 GW-26 GW, 22 GW-24 GW, 20 GW-22 GW and 18 GW-20 GW as illustrated in Figure 7. Analysis of the higher load range (22 GW - 28 GW) reveals a significant reduction in net load instances compared to gross load, indicating the positive impact of solar and wind load in meeting high load occurrences. For instance, instances of peak load in the range of 26 GW - 28 GW reduced from 60 in gross load to 0 instances in all net load scenarios, representing a 100% reduction and a potential capacity saving of 2 GW.

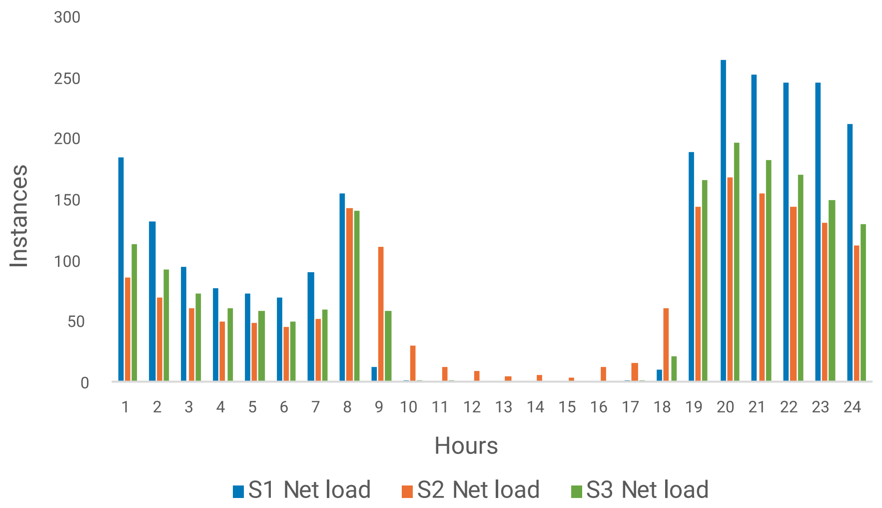
Whereas out of all the net load scenarios, scenario 2 (S2), with a higher share of wind energy, demonstrates the least instances in higher load ranges, while scenario 1 (S1), with a higher solar share, exhibits the most occurrences.

Figure 7: Load instances in higher load ranges



The graphical representation in Figure 8 illustrates the distribution of net load peak instances within the 18 GW-26 GW range across the 24 hours of the day. There are hardly any net peak load instances from 9:00h to 17:00h, in all 3 RE scenarios. This means all 3 simulated solar energy penetration shares meet the daytime peak energy demand in this upper load range of 18-26 GW sufficiently well. Moreover, the scenario with the highest wind penetration (S2) appears to have the least peak load instances during the evening and night hours, indicating the effectiveness of a higher wind energy share in meeting evening and late-night peaks. This finding underscores the considerable potential of wind energy, even during peak demand hours, in meeting net load peak instances.

Figure 8: Net load peak instances in the ranges of 18 GW – 26 GW by hour of the day

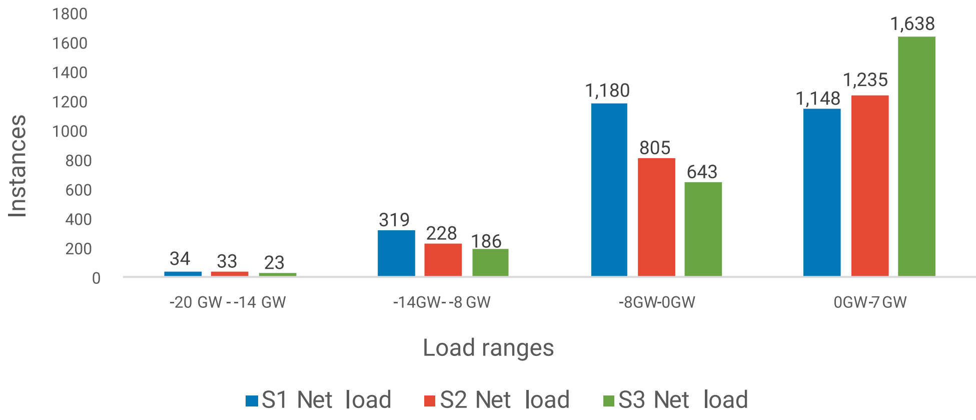


Lower load ranges:

Analysis of the lower load ranges (-20 GW - -14 GW, -14 GW - -8 GW, -8 GW - 0 GW and 0 GW – 7 GW) focuses on extreme net load valley instances and instances of negative net load, both of which may lead to curtailment or RE.

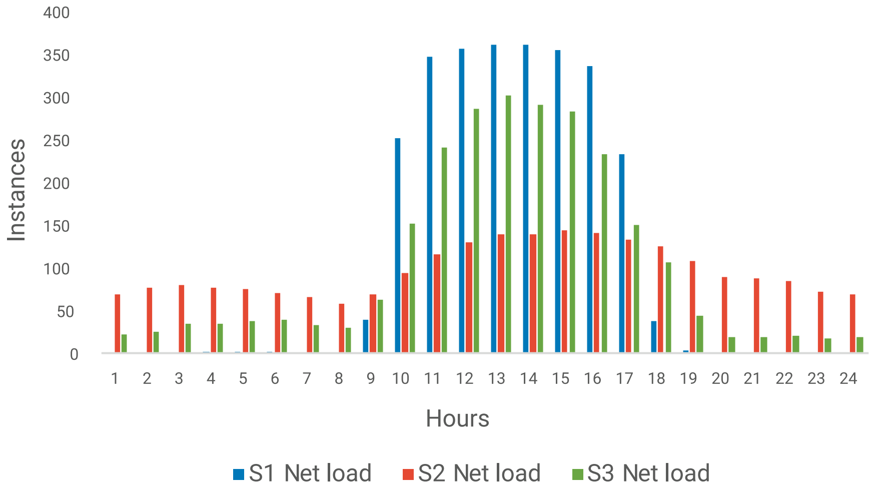
Within the net load scenarios scenario 3 (S3), with an equal share of solar and wind, exhibits the least occurrences in the lower net load ranges, whereas scenario 1 (S1) demonstrates the maximum instances of load in the ranges -20 GW-0 GW, but for the range 0 GW-7 GW the trend completely reverses as illustrated in Figure 9

Figure 9: Net load instances in lower load ranges



The distribution of lower net load instances (all scenarios) across the hours of the day is illustrated in Figure 10. Remarkably, these instances predominantly occur between 10:00h and 17:00h, coinciding with peak solar generation hours suggesting that solar energy is the primary cause for negative and low net load instances. The scenarios with the highest solar penetration (S1) exhibit a corresponding increase in instances during these solar hours. This observation underscores the pressing necessity for effectively balancing generation and demand. One potential solution lies in the introduction of a mechanism such as a "solar sponge," i.e., attracting demand by offering tariff rebates or other incentives during the peak solar generation hours. The aim would be to align demand more closely with generation, thereby achieving a more balanced energy ecosystem. Optimizing the utilization of solar and wind generation is necessary and the demand side can make a substantial optimization contribution (Auroville Consulting 2024).

Figure 10: Instances of the net load occurring in the ranges of -20 GW – 7 GW by hour of the day



3.4 Ramping requirement:

The scenario having a higher solar energy share exhibit the highest instances of high ramping, while the scenario with a greater emphasis on wind energy experiences the least.

In this section, we evaluate all net load scenarios based on ramping , which denotes the rate of load change measured in gigawatts per hour (GW/h), indicating how quickly load or generation levels vary. Managing ramping rates is crucial for grid stability, resource optimization, and efficient electrical system operation. Lower ramping rates are preferable for grid operators (Kaheh 2021).

For the year 2030, we categorized the rate of load changes into three groups: (i) ramping up or ramping down greater than 1.50 GW/h, (ii) ramping up or ramping down greater than 2.50 GW/h, and (iii) ramping up or ramping down greater than 3.50 GW/h. Table 5 below displays the instances of ramping in each category observed in 2030. Notably, the net load of all scenarios exhibits more instances of ramping up and ramping down compared to the gross load. This trend suggests that integrating solar and wind energy into the system may pose technical challenges in managing ramping rates, unlike conventional power plants.

Among the net load scenarios, scenario 2, characterized by a higher share of wind (75% of RE), displays the least instances of ramping up and down across all categories. Conversely, scenario 1, featuring a higher share of solar (75% of RE), exhibits the highest instances of ramping, particularly in categories involving changes of 2.50 GW/h and 3.50 GW/h. This observation underscores that solar energy contributes more to higher ramping rates than wind when integrating renewables into the grid.

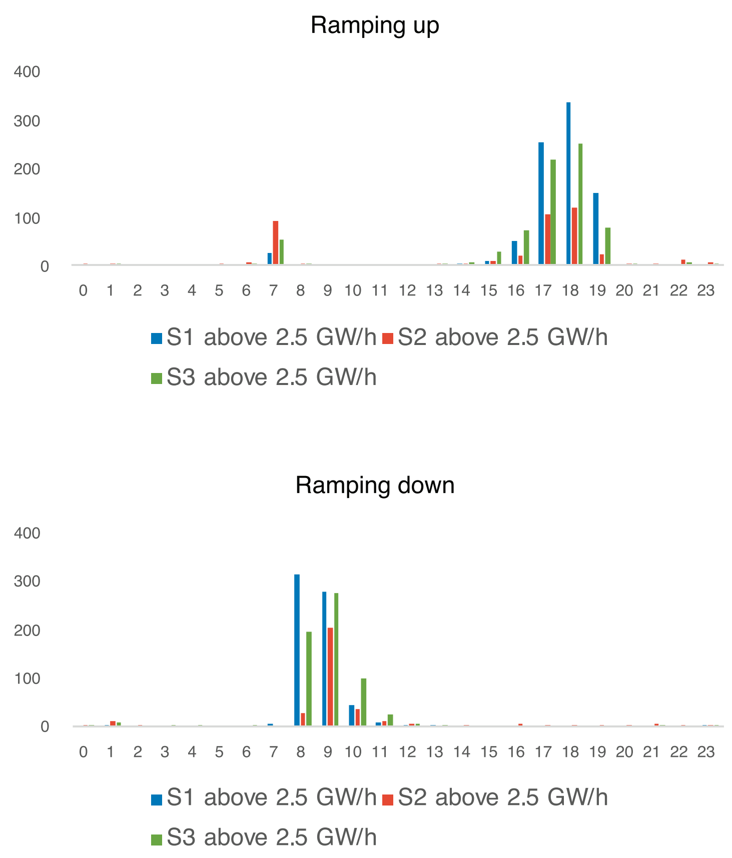
[4]During net load ramping calculations, it is assumed that the load never falls below 7 GW. In instances where the net load approaches or falls below this threshold, excess energy is either stored, banked, or subjected to curtailment. This assumption ensures the continuous operation of thermal power plants to meet demand requirements.

Table 5: Ramping instances in various categories

	Ramping up instances			Ramping down instances		
	Above 1.5 GW/h	**Above 2.5 GW/h**	**Above 3.5 GW/h**	**Above 1.5 GW/h**	**Above 2.5 GW/h**	**Above 3.5 GW/h**
Gross Load	435	125	5	44	3	1
S1 Net load	1,148	823	608	794	644	536
S2 Net load	989	408	103	741	310	111
S3 Net load	1,210	720	440	937	610	394

Figure 11 illustrate instances of ramping up and ramping down exceeding 2.5 GW/h, distributed over the hours of a day. Upon examining the distribution of ramping up instances above 2.5 GW/h, a concentration of high instances is observed from 16:00h to 19:00h. This pattern is attributed to rising demand during these hours and a declining solar energy generation. Notably, scenarios with the highest solar penetration (S1) exhibit particularly pronounced instances during this time, while scenarios with the highest wind penetration (S2) show the fewest instances due to the persistent nature of wind generation, which remains relatively unaffected by diminishing solar output. Similarly, ramping down instances above 2.5 GW/h cluster from 8:00h to 10:00h is explained by a reduction in demand after the morning peak and an increase in solar generation during that time slot. Consequently, scenario 1 (highest solar penetration) experiences the most instances during this period, while scenario 2 (highest wind penetration) shows the least instances.

Figure 11: Net load ramping up and ramping down instances above 2.5 GW/h by hour of the day



This analysis emphasizes the critical need for a balanced integration of solar and wind contributions in renewable energy (RE) systems. It underscores the importance of managing ramping requirements effectively to ensure grid stability. One key aspect highlighted is the necessity for short-term energy storage plans to address these requirements. While wind energy exhibits seasonal variability, solar energy presents daily intermittency challenges. By understanding and addressing these nuances, stakeholders can better navigate the complexities of RE integration and optimize the reliability and resilience of the grid.

04

Conclusion

In conclusion, the forecasted total demand for 2030 stands at 1,81,260 MU, marking a 45% increase compared to the demand in 2023. To fulfil its climate commitments Tamil Nadu must ensure that this surge in energy demand is predominantly met by RE sources. This necessitates a significant increase in RE capacity to keep pace with the escalating demand.

Examining the composition of the total demand in 2030, AC demand makes up a substantial 11%, while EVs demand constitutes 2% of the total demand. The projected peak load for 2030 is estimated at 27.40 GW, compared to 19.41 GW in 2023, marking a 41.20% increase and signalling the need for significant capacity upgrades. Notably, AC load will contribute significantly to peak load instances, accounting for 16% of demand on each of the top 5 gross load instances in 2030. The contribution of EV load to each of the top 5 gross load instances on the other hand is expected to be a 1% only.

It was also observed that higher shares of RE result in low and negative load instances. Moreover, when ramping instances are considered, all scenarios of net load have considerable growth in higher ramping instances when compared to the gross load, addressing this increase in magnitude and frequency of high ramping instances requires both technological and policy interventions. This may include increasing the state's energy storage capacity, introducing favourable conditions that compensate generators for RE requiring curtailment, and providing incentives for consumers to shift demand.

Among the three net load scenarios, S1, which had the highest solar share, exhibited the most instances in both higher load ranges and negative load ranges. It also resulted in the highest occurrences of ramping instances in categories above and below 2.50 GW/h and 3.50 GW/h. Conversely, S2, with the highest wind share, had the fewest occurrences in higher load ranges and exhibited the lowest instances of ramping above and below 2.50 GW/h and 3.50 GW/h. Table 6 summarises the findings as it represents the instances of gross and net load scenarios under various categories.

Table 6: Summary table of instances under various parameters

Parameters	Upper load range 18GW-28GW	Lower load range -20GW-7GW	Ramping up above 2.5 GW/h	Ramping down above 2.5 GW/h
Gross load	7,262	0	125	3
S1 Net load	2,304	2,681	823	644
S2 Net load	1,665	2,301	408	310
S3 Net load	1,716	2,490	720	610

From a utility perspective, integrating a higher share of wind energy appears more be more favorable. However, it also needs to be highlighted that solar is making a significant contribution in meeting the expected top 5 gross peak load instances. Thus, it's crucial to find an optimal balance between wind and solar energy for Tamil Nadu's power system. This report concludes by offering significant insights into Tamil Nadu's future energy landscape. Based on the analytical findings, Table 7 presents summarized recommendations to various stakeholders, aiming to steer strategic planning towards facilitating sustainable integration of RE sources.

Table 7: List of recommendations

	Recommendation	**Agency**
I.	Direct efforts towards defining optimum balance between solar and wind during resource adequacy planning.	SLDC
II.	Plan and deploy energy storage solutions to provide essential grid support services.	TANGEDCO
III.	Redesign the energy banking provisions under the Open Access regulations to reduce the need for curtailment and to promote energy storage.	TNERC
IV.	Gradually apply variable tariffs to all electricity consumer categories.	TNERC
V.	Introduce a solar sponge (e.g., a tariff rebate during peak solar energy generation hours), to better facilitate the integration of a higher solar energy contribution.	TNERC
VI.	Introduce demand response programs for industries and specific consumer appliances such as electric vehicles, air conditioners and hot water heaters.	TANGEDCO

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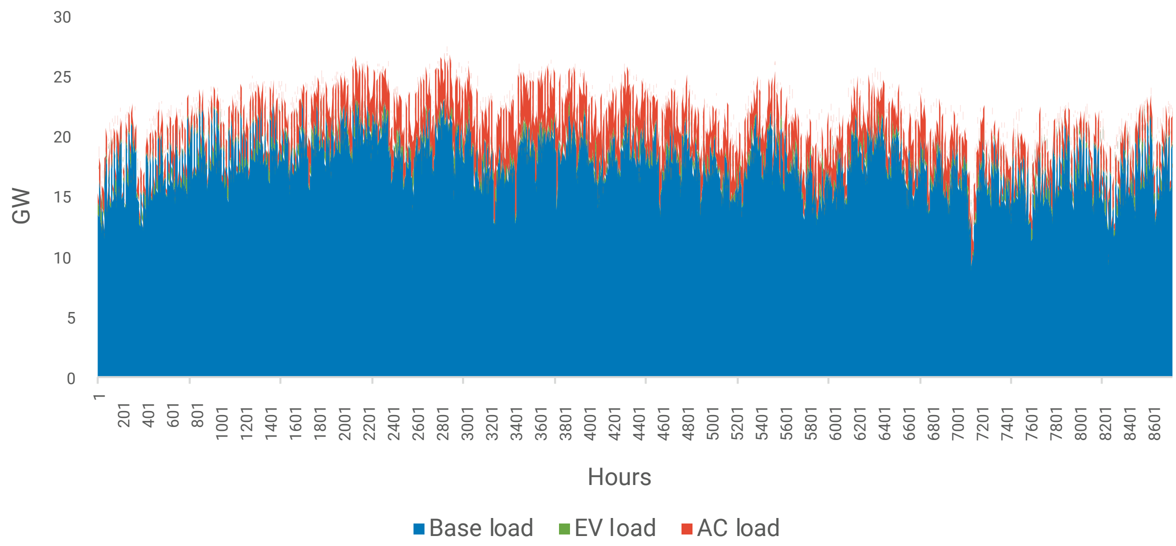
6 Appendix

6.1 Gross and net load

Figure 12 illustrates the spread of 2030 load demand across the 8,760 hours of the year, providing insights into its composition and variations.

Figure 12: Estimated annual gross load of Tamil Nadu and its composition in 2030



6.2 AC load

For calculation of AC load, the annual AC demand is firstly resolved into daily demand using CDDs mentioned next section and then further resolved into hourly load using AC load profiles as shown in Figure 13.

Cooling Degree Days

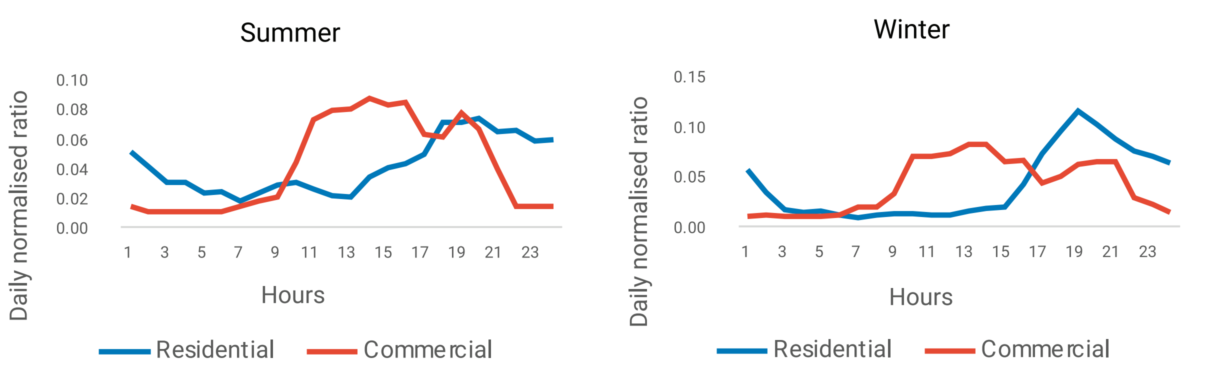
Cooling Degree Days (CDDs) serve as a crucial metric for estimating the energy required for cooling buildings or spaces, particularly during warmer periods. Widely utilized by utility companies, HVAC professionals, and meteorologists, CDD aids in assessing the demand for air conditioning

Calculation of CDDs:

1. Base Temperature Definition: The base temperature signifies the point at which buildings do not necessitate cooling. For this report, we utilize a base temperature of 25°C for residential buildings and 16°C for commercial structures.
2. Daily Mean Dry Bulb Temperature Calculation: We compute the daily mean dry bulb temperature for each day of the year 2030 utilizing the 2030 weather file from (WeatherShift 2024).
3. Degree Day Calculation: Cooling Degree Days are determined by subtracting the base temperature from the daily mean temperature. Any positive difference indicates temperatures surpassing the base temperature, hence contributing to the count of cooling degree days.

By distributing the annual AC demand over 365 days, CDD facilitates a comprehensive understanding of cooling requirements across different building types and climatic conditions.

Figure 13: Normalized AC load profiles for the summer and winter seasons (IIMA 2010, Miriyala 2024)



6.3 EV load

The EV demand is resolved to hourly load using profiles as shown in Figure 14 and the national EV load is converted to state EV load using total registered vehicles ratio as shown in Table 8.

Figure 14: Normalized average daily EV charging profiles by e-vehicle type (IRADe 2022)

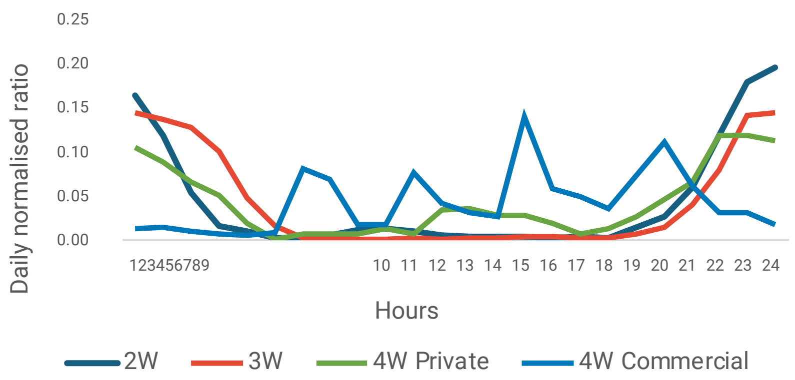


Table 8: Total vehicle registered in India and Tamil Nadu over last 5 years (Vahan dashboard 2024)

Total vehicle registered (millions)			
Year	**India**	**Tamil Nadu**	**Percentage**
2023	23.99	1.83	7.6%
2022	21.57	1.7	7.9%
2021	18.94	1.51	8.0%
2020	18.66	1.49	8.0%
		Average	7.9%

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