Action Plan for Comprehensive Renewable Energy Development in Tamil Nadu

Final Report

December 2012

Supported by

SHAKTI SUSTAINABLE ENERGY FOUNDATION

CII

TEDA

Prepared by

WISE

WORLD INSTITUTE OF SUSTAINABLE ENERGY

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Report Team

Suhas Tendulkar, DGM, Projects

Rajendra Kharul, Joint Director and Head, Centre for Wind Power

Sudhir Kumar, Joint Director and Head, Centre for Solar Power

Surendra Pimperkhedkar, Fellow and Head, Center for Renewable Regulation and Policy

Sanjeev Ghotge, Joint Director (Research) and Head, Centre for Climate Sustainability and Policy

Praveena Sanjay, Joint Director and Head, Centre for Co-ordination & Communication

Address any enquiry about this document to

Centre for Wind Power

World Institute of Sustainable Energy

Kalyani Nagar

Pune – 411006 / India [Country code +91]

Fax (020) 2661 1438

E-mail stendulkar@wisein.org

Tel. (020) 2661 3832

Web www.wisein.org

Contents

Tables

Figures

Abbreviations

ABT	Availability Based Tariff
ACSR	Aluminum-core-steel-reinforced
AHEC	Alternate Hydro Energy Centre
APPC	Average Power Procurement Cost
ARR	Annual Revenue Requirement
CBIP	Central Board of Irrigation and Power
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CFA	Central Financial Assistance
CUF	Capacity Utilization Factor
CWET	Centre for Wind Energy Technology
DISCOMS	Distribution Companies
DNI	Direct Normal Irradiation
EPA	Energy Purchase Agreement
EPS	Electric Power Survey
EWA	Energy Wheeling Agreement
FIT	Feed-in tariff
GBI	Generation Based Incentive
GDP	Gross Domestic Product
GHI	Global Horizontal Irradiance
GIS	Geographical Information System
GOI	Government of India
HTLS	High tension, low sag
IEGC	Indian Electricity Grid Code
IPP	Independent Power Producer
IRR	Internal Rate of Return
JICA	Japanese Industrial Cooperation Agency
JNNSM	Jawaharlal Nehru National Solar Mission
JV	Joint Venture
LBNL	Lawrence Berkeley National Laboratory
LGBR	Load Generation Balance Report
LULC	Land Use Land Cover
MCA	Multi-criteria Analysis
MEDA	Maharashtra Energy Development Agency
MNRE	Ministry of New and Renewable Energy
MOP	Ministry of Power
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEF	National Clean Energy Fund
NCEP	National Centers for Environmental Prediction
NREL	National Renewable Energy Laboratory
PDC	Phasor Data Concentrator
PGCIL	Power Grid Corporation of India Ltd
PLF	Plant Load Factor
PMU	Phasor Measurement Unit
PPA	Power Purchase Agreement
PPP	Public Private Partnership
RE	Renewable Energy
REC	Renewable Energy Certificate
RPO	Renewable Purchase Obligation
RPS	Renewable Purchase Standard
SCADA	Supervisory Control and Data Acquisition
SERC	State Electricity Regulatory Commission
SHP	Small Hydro Power
SHR	Station Heat Rate
SISMA	South Indian Sugar Mills Association
SLDC	State Load Dispatch Centre
SNA	State Nodal Agency
SRLDC	Southern Regional Load Dispatch Centre
SSE	Surface Solar Energy
STU	State Transmission Utility
SVC	Static Var Compensator
TANGEDCO	Tamil Nadu Generation and Distribution Corporation Limited
TANTRANSCO	Tamil Nadu Transmission Corporation Limited
TCD	Tonnes Crushed per Day
TEDA	Tamil Nadu Energy Development Agency
TNEB	Tamil Nadu Electricity Board
TNERC	Tamil Nadu Electricity Regulatory Commission
TRADECO	Trading Company
UI	Unscheduled Interchange
UMPP	Ultra Megawatt Power Project
WAMS	Wide Area Management System
WEG	Wind Energy Generator
WEMS	Wind Energy Management System
WPD	Wind Power Density

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Executive Summary

The state of Tamil Nadu is rich in renewable energy (RE) sources, especially wind and solar. Currently, approximately one-third of the country's installed RE capacity exists in Tamil Nadu alone. The *Action Plan for Comprehensive Renewable Energy Development in Tamil Nadu*, aims to tap this abundant source of energy and make Tamil Nadu an energy-sufficient and energy secure state. The action plan is the result of a comprehensive analysis of renewable energy choices and their relevance to the present and future energy plans and energy security of Tamil Nadu for the next two five-year plans (2012–22).

On a broad level, the project findings are striking and indicate that while the existing coal-based power sector planning of the state is exposed to huge risks, the re-assessed renewable energy potential is in multiples of the official estimated potential. The study also sheds light on important aspects related to technical integration and commercial acceptance of renewables and develops a renewable energy action plan and implementation roadmap for the state.

A Key Findings

Coal-Dependent Energy Sector Planning Entails Huge Risks

There are major risks involved in the 'business-as-usual' approach associated with coal dependent power planning in the state. About 9,460 MW of new coal-based thermal power projects expected to be commissioned by 2015–16 are still at very preliminary stages (with a majority at the pre-environmental impact assessment stage). Of this, about 2,400 MW capacity is not expected to have any domestic coal linkage and the state is assessing plans to use 100% imported coal for these new capacities. But with issues related to availability of domestic coal, import dependence, and price volatility of imported coal, it is imperative for the state to factor-in the long-term risks of coal-dependent power planning. On the one hand, large sums of government investment will be locked in capital costs and debt repayments for projects that may not deliver low-cost power, while on the other hand, rising power costs would have an inflationary effect on prices, affecting business growth and economic development.

Against this background, the focus of energy planning has to essentially shift from a mere matching of supply-demand, to an approach guided by long-term energy security. This is where renewables can add value and contribute to long-term energy security for the state.

Need for Re-assessment of RE Potential: Implementation not a Constraint

While the official wind potential estimate for Tamil Nadu is 5,374 MW, the state had already reached 6000 MW in August 2011. This gave rise for the need to reassess the total RE potential in the state. As compared to past potential reassessment studies, the current study uses the Geographic Information System (GIS), with the base data sourced from government and other commercial authorities, thus striving to remove ambiguities or differences (if any), to provide a reliable RE potential estimate. Further, the study also makes use of current market information and literature review for obtaining more accuracy in the reassessment exercise. The use of these methodologies has shown that the total (reassessed) RE potential for Tamil Nadu is over 720,000 MW (including grid-connected and off-grid power). Table A reproduces the results of the total grid-connected RE potential, while Table B shows the off-grid potential.

Table A Summary of grid-connected RE potential in Tamil Nadu

Technology	Independent potential (MW)
Solar PV (NREL data)	259700
CSP (NREL data)	78505
Wind 80 m (no farmland)	36344
Wind 80 m (farmland)	160510
Repowering	1370
Wind 80 m (offshore)	127428
Wind-solar hybrid	7913
Bagasse-based co-gen	1073
Energy plantations**	10800
Total	**683643**
** Energy plantation potential figure is calculated assuming Beema Bamboo plantation for 2% of agricultural land and 100% of wasteland and scrubland	

Table B Off-grid potential in Tamil Nadu

Off-grid		
Rooftop PV	MW	29642
Solar water heating	million sq m	16.15
Solar pumping	MW	7041

Onshore wind potential, together with grid-tied solar PV and CSP, contributes to approximately 535,059 MW as against a total estimated potential of 683,643 MW. In addition, offshore potential is about 127,428 MW, a majority of which is high quality resource. On the off-grid side, the potential of rooftop PV and substitution potential for solar pumping together account for about 37,000 MW, more than twice the existing installed capacity in the state.

Understandably, in the case of grid-tied RE potential, the above figures denote independent potential and in many cases, the potential areas for wind and solar technologies utilize the same land area. To factor in the constraints of common land, WISE has also estimated the constrained potential for the state by prioritizing technologies on the basis of their desirability and location-specificity. The results of the exercise suggest that the constrained potential is about 530,149 MW, which is less than the independent potential. Even after discounting various factors like actual land availability, constraints in offshore development, and extent of non-irrigated farmland allocation to wind from the constrained potential area, it is clear that considerable potential will still be available for the state to power its economy well beyond 2021–22, and upto 2050.

The Capacity Addition Scenarios

The study has developed two capacity-addition scenarios – business as usual (BAU) and aggressive (AGG) – which provide a comparative analysis of the quantitative and qualitative implications of business-as-usual growth versus a state-supported high-acceleration growth.

According to the detailed load-flow study carried out as part of this project, a total capacity addition of 17,570 MW was estimated over the 12th and 13th plan periods (2012-22) in the BAU scenario. Of this, wind is expected to contribute 13,500 MW, solar 3,500 MW, Biomass 440 MW, and other RE

130 MW. In the AGG scenario, total capacity addition of 36,470 MW was estimated over the 12th and 13th plan periods (2012-22). Of this, wind is expected to contribute 28,400 MW, solar 7,500 MW, Biomass 440 MW, and other RE 130 MW. As the BAU scenario is an extrapolation of current RE development in the state, the AGG scenario was taken as the basis of the Action Plan, as the main objective was accelerated development and deployment of renewables in Tamil Nadu.

Integration of Aggressive RE Capacity Addition in the Grid is Technically Feasible

The study shows that an aggressive RE integration scenario is technically feasible, provided operational philosophies are modified and evacuation infrastructure is built to integrate RE.

The biggest technical challenge to renewable integration is managing generation variability and ensuring power quality with system security. For managing variability, major changes in operational philosophy will be needed to ensure that renewables are accommodated optimally at all times. These changes would not only include dynamic demand-side measures but also incorporate strong supply-side measures such as backing down thermal load to its technical limit and complete backing down of hydro for the whole of the southern region when required. However, future developments like the establishment of a national grid in 2014 (the commissioning of a 765 kV Raichur-Solapur line), establishment of an RE Management Centre, and early adoption of forecasting and new technologies like pumped storage and smart grids can help the state to manage its operations even more optimally, allowing it to export surplus power across regional borders.

Under the AGG scenario, RE evacuation studies for the 12th plan showed that in order to evacuate 23,613 MW of RE, (Proposed 16660 + Existing 6953 MW) additional 51 substations of 230 kV and 60 substations of 110 kV are required. In order to evacuate 43,423 MW of RE (Proposed 36470 + Existing 6953 MW) in the 13th plan, additional 74 substations of 230 kV and 61 substations of 110 kV are required. However, for both the plan periods, large increases in power flows are expected due to injection of solar power into the grid.

Funds for Supporting AGG Capacity Addition can be generated from within the state

As estimated in the study, the estimated cost for the total evacuation infrastructure over the 12th and 13th five-year plans to support aggressive RE capacity addition is Rs.11,025 crore (Rs.110.25 billion). This estimate is a very small portion of the total funds planned for transmission and distribution capacity augmentation under the Vision 2023 document (Rs.200,000 crore). In addition, there are various ways in which additional funds can be generated. The state can, if it wants, develop a corpus fund of about Rs.17,000 crore (Rs.170 billion) by using options like diverting funds from value-added tax (VAT) receipts of new RE capacity, allocating dedicated funds for state-owned wind power projects in line with allocations made for imported-coal-based thermal power projects, and creating a state clean energy fund. These options, in addition to central financial assistance for RE development, would allow the state not only to develop the necessary evacuation backbone but also meet other obligations and expenses like payment of wind dues to owners, pilot projects, short-term capacity additions, and capacity building.

Significant Monetary Benefits Accruing from the AGG Scenario

- The state can ensure an investment inflow of Rs.2,26,976 crore (Rs.2,269 billion) upto 2021-22.
- On the revenue side, VAT receipts of Rs.8,171 crore (Rs.81.7 Billion) can be expected during the same period.
- The total estimated central financial assistance (the thirteenth finance commission's RE corpus) is estimated at Rs.1,326 crore (Rs. 13.26 billion) for the period 2010-2015.

Other Benefits Accruing from the AGG Scenario

- As per the Renewable Energy Certificate (REC) registry data, about 2,251.83 MW capacity is registered under RECs (as on 31.01.12), out of which Tamil Nadu accounts for 528.3 MW, amounting to around 23.46%. Cumulative notional savings from surplus RECs in the 12th and 13th plan periods (non-solar) is estimated at Rs.14,838 crore.
- The aggressive RE development plan would create over 3,91,830 jobs upto 2021-22.
- Savings of CO_2 emissions would be to the tune of 2,987,000 tonnes upto 2021-22.

Renewables would provide more Commercial Benefits than Conventional Technologies

The study suggests that contrary to general perceptions, commercial implications of RE are not very high as compared to risks involved in other purchase options such as that of conventional power projects, whose price is variable and increases due to delays, cancellations, etc. The main bottlenecks for commercial acceptance of RE are related to tariff levels, infrastructure funding, and balancing costs. In the case of wind power in Tamil Nadu, there is a generally held notion that high wind penetration has resulted in significant losses to TNEB, on account of balancing costs, due to generation variability of wind. The analysis in the report suggests that commercial impacts of wind may not be as high as thought to be.

From the future perspective, it is also important to understand that the year-on-year increasing trend of average power procurement costs (APPC) indicates a steady increase in conventional power prices. Additionally, the costs of fossil-fuel-based generation are bound to increase with time because of supply constraints and price variability. In this scenario, when we invest in conventional generation capacities, we are effectively locking ourselves for 30-40 years. As the effective cost of generation would be dependent on the fuel price, we need to look at above-normal increase in cost of generation, which is ultimately borne by the consumers or the state. In the worst case, we may have a scenario where non-availability or very high operating costs would force these capacities to be shut down, as has happened in the case of gas or that of plants designed to run on liquid fuels.

In contrast, renewable sources keep on delivering energy at low or no variable costs, with their prices either increasing moderately or sometimes, even decreasing, eg. in the case of solar. The only other cost implication would be the capital investment, bulk of which is anyway expected to come from the private sector. The commencement of forecasting for RE coupled with the development of an ancillary market for power after the establishment of a national grid would effectively translate into huge trading opportunities for the Tamil Nadu Electricity Board (TNEB), allowing it to recoup past losses and cover expenses more effectively.

B RE Action Plan for Tamil Nadu: Interventions and Recommendations

The message from the project's findings is very clear: given the present situation and the emerging scenario in terms of resource ownership and our choice of the development path, renewables seem to be the most optimal option for the state from a long-term perspective. The following summary of interventions/recommendations tries to capture the essence of the changes that are required.

Interventions in Governance and Resource Development

(i) Leadership and advocacy initiatives by

- ensuring that regional RE capacity additions are factored into the power planning process at the national level,
- conducting a detailed grid study to assess power system stability and load flow at inter-state and inter-regional levels to critically identify inter-regional evacuation capacity augmentation,
- ensuring early commissioning of inter-regional link to facilitate operationalization of the national grid, and
- advocating creation of an ancillary market to enable intra-day and spot trading of power.

(ii) Capacity building of state-based agencies to support renewable deployment

The study recommends developing technical, administrative, and communication capacities in identified government agencies such as the Energy Department, TNEB, Tamil Nadu Energy Development Agency (TEDA), State Planning Commission, and the Tamil Nadu Electricity Regulatory Commission (TNERC). The capacity building plan should include aspects related to organizational restructuring, planning, procedures, rules, laws, a management information system, human resource development, financial management, financial autonomy, communication and outreach strategy, and most importantly, training needs identification for RE-specific aspects related to policy, regulation, technology, grid impact, finance, etc.

(iii) Renewable Resource Development

The renewable resource assessment exercise indicates an RE potential significantly greater than the existing estimates. The GIS-based assessment for grid-tied wind and solar power has provided significant data in spatial terms and important takeaways for energy sector planning and policy design. Based on the analysis of RE potential in the study, the key focus areas for field-based renewable resource assessment are identified as CSP, biomass, and offshore wind. In addition, it is also recommended to develop pilot projects of appropriate size for CSP, offshore wind, and energy plantations.

Policy and Regulatory Interventions

(i) Policy Interventions

At present, Tamil Nadu has a solar policy but no notified RE policy. In the absence of a notified RE policy, the following interventions are suggested:

- Creation of a state clean energy fund.
- Land policy for renewable projects that lays down clear guidelines for land allocation, land acquisition, mixed land use, right of way, and title transfer.
- Early approval of pending wind project applications of 13,400 MW.
- Streamlining approval processes for offshore wind.

- Policy on public-private partnership (PPP) for development of RE pilot projects.
- Strengthening of policy and approval process for biomass projects.
- Relaxation of micrositing criteria (5D × 7D) for wind power projects.
- Mandating appropriate clearances for repowering.
- Creation of a state RE law.
- Creation of single window clearance mechanisms for all RE sources.
- Specific interventions for supporting off-grids.
- Preferential payment disbursement to RE generators.

(ii) Regulatory Interventions

The Tamil Nadu Electricity Regulatory Commission will have to act proactively by addressing not only the existing bottlenecks, but also formulating regulation, considering the futuristic needs of the state if renewables have to be promoted aggressively. Some of the proposed interventions are suggested below.

- Revision of tariff determination methodology by considering the time value of money.
- Revision of methodology to determine APPC based on CERC methodology.
- Revision of solar RPO targets for utility and RPO compliance mechanism.
- Tariff orders for large state-based off-grid solar.
- Regulation on RE-dictated inter-state power transfer.
- Establishment of a payment security mechanism as was done in other states like Karnataka.

Grid Planning and Operational Management

The implementation plan for RE has to essentially address a multitude of technical and non-technical issues. From the perspective of high RE integration under the AGG scenario, it is obvious that integration can happen only at the regional and national levels. In this context, integration of the southern grid with the NEW (North-East-West) grid and enactment of a commercial mechanism for inter-state trade of power are the two most important requirements for RE integration. The following specific action points highlight the requirements from the perspective of transmission planning and operational management practices.

- Incorporation of RE capacity-addition in long-term transmission planning.
- Short-term measures like the use of HTLS (high tension low sag) lines and conversion of single circuit lines to double circuit lines for strengthening evacuation infrastructure in congested pockets.
- Modification of the operational philosophy of grid management to include strong supply-side measures to enable participation of storage-based hydro and thermal power plants in variability management.
- Creation of a trading company to manage all interstate power exchanges.
- Activation of advanced wind energy management systems (WEMS), Static VAR controllers (SVCs), and new technologies for better operational control.

Financial Interventions (Sources and Uses)

Funding is the most critical bottleneck in the implementation of any action plan. The study has also assessed the capital requirements for an aggressive RE capacity addition scenario, in addition to exploring the possible sources for raising the funds. Some of the suggested heads for sources and uses of funds are as follows.

- Possible sources or avenues:
  - Central Finance Assistance (CFA) from the 13th Finance Commission,
  - Diversion of value-added tax (VAT) receipts from RE,
  - Allocation of funds in line with allocations made to imported-coal-based projects,
  - Creation of a state clean energy fund.
- Proposed uses:
  - Capacity-building of state agencies,
  - Short-term augmentation of overloaded lines,
  - Pilot projects (CSP, energy plantations, offshore wind),
  - Field-level resource assessment for offshore, CSP, and biomass through field studies,
  - Integrating Wind Energy Management Systems (WEMS) in the existing infrastructure,
  - New grid infrastructure and SVCs.

These recommendations are not exhaustive but they represent a set of suggestions that have the potential to make the highest impact in integrating renewables. The overall conclusion of the study is that renewables are abundant and can provide most of the power for Tamil Nadu upto 2050. The main problem with RE integration is not technical; it is our mindset. We are so tuned to the comforts of a predictable centralized conventional-machine model and associated network that renewables seem like an unwieldy change, bringing us out of our ‘comfort zones’. This aspect also implies that RE integration requires only our willingness to understand renewables and our resolve to choose them.

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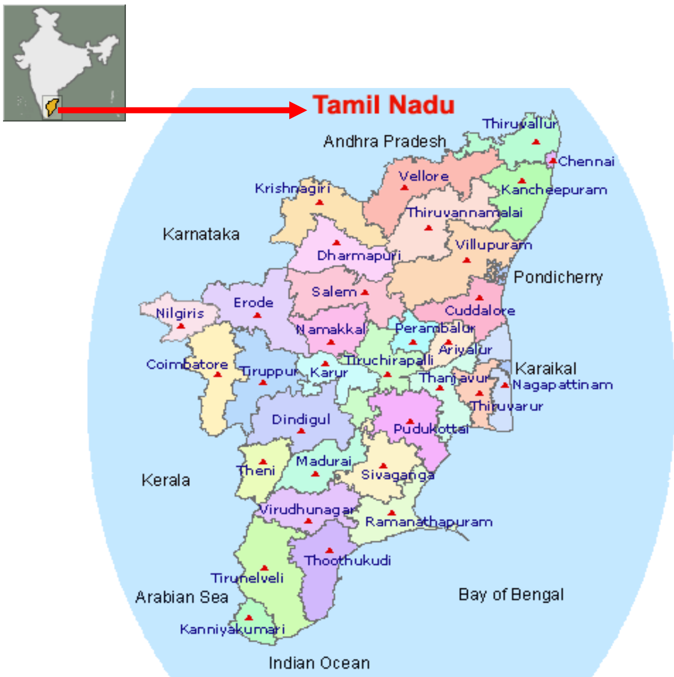
PART – I

INTRODUCTION

1. Tamil Nadu: Introduction & Overview of the Power Sector

Tamil Nadu, the eleventh largest state in India, covers 130,058 square kilometers (50,216 sq miles), and has a coastline of about 910 kilometers (600 miles). In terms of population, it is the seventh most populous state with a population of about 72 million, nearly 6% of India's population (census 2011). At 43.86%, the state has the highest level of urbanization in India and accounts for 9.6% of India's urban population.

Tamil Nadu is divided into 32 districts and 220 talukas for the purposes of administration. Geographically, it is classified into seven agro-climatic zones: north-eastern, north-western, western, southern, high rainfall, high altitude hilly, and the Cauvery delta (the most fertile agricultural zone). However, the state can be broadly divided into two main natural regions, the hilly western area and the coastal plains. The Western Ghats dominate the entire western border with Kerala, whereas the central and the south-central regions are arid plains and receive less rainfall than the other regions. The climate of the state ranges from dry sub-humid to semi-arid, but the state has the distinction of having two monsoon seasons: south-west monsoon from June to September and the north-east monsoon from October to December. This distinctive feature has helped Tamil Nadu to become a favoured wind power destination because the monsoon winds contribute to the bulk of the annual wind power generation. **Figures 1.1** and **1.2** show the political and physical maps of Tamil Nadu respectively.



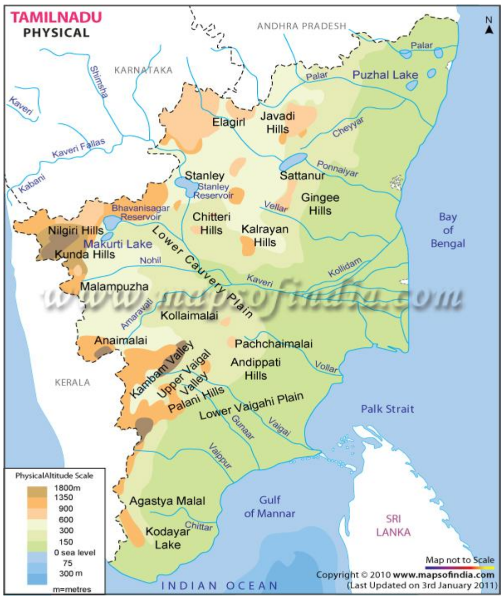


Figure 1.1 Political Map of Tamil Nadu **Figure 1.2** Physical Map of Tamil Nadu

Tamil Nadu is especially rich in renewable energy (RE) resources, especially wind and solar, and can potentially contribute a great deal to green energy generation, thereby reducing the carbon footprint of the state and the country. At present, about one-third of the installed capacity from renewable sources in India exists in Tamil Nadu alone.

1.1 Overview of Energy Scenario in Tamil Nadu

1.1.1 Generation capacity

The total installed generation capacity of Tamil Nadu as on August 2012, was 17,686.37 MW (source: Central Electricity Authority [CEA]) in August 2012 [Ref 1]. **Table 1.1** shows technology- and ownership-wise status of the existing installed capacity.

Table 1.1 Installed generation capacity (MW) in Tamil Nadu by fuel (August 2012)

Ownership sector	Thermal			Total thermal	Nuclear	Hydro	Renewable	Grand total
	Coal	Gas	Diesel					
State	2970.00	523.20	0	3493.20	0	2122.20	118.55	**5733.95**
Private	250.00	503.10	411.66	1164.76	0	0	7304.29	**8469.05**
Central	2959.37	0.00	0	2959.37	524	0	0	**3483.37**
Total	**6179.37**	**1026.30**	**411.66**	**7617.33**	**524**	**2122.20**	**7422.84**	**17686.37**

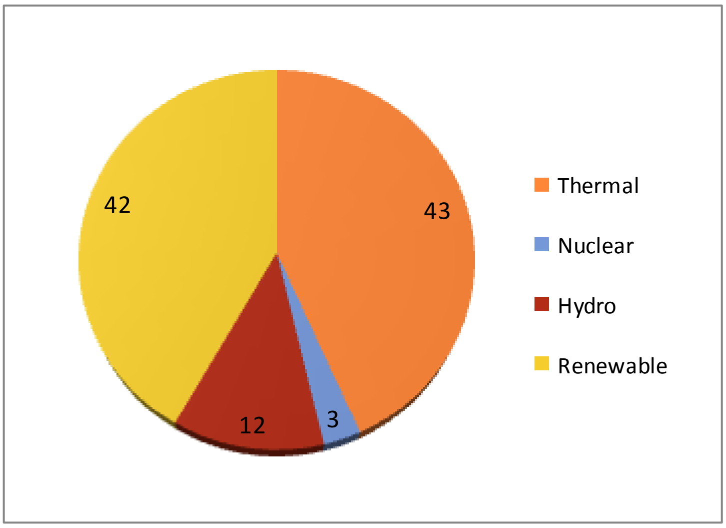


Figure 1.3 State energy break-up in percentage form, as on 30 August 2012

As can be seen, the present installed capacity of 17,868.37 MW mostly consists of coal (35%), hydro (12%) and renewable energy (42%), mostly comprising installed wind power base of about 6,984 MW as on 31 March 2012 (source: Indian Wind Turbine Manufacturers Associations [IWTMA]). This makes wind the single largest power generation technology in Tamil Nadu in terms of installed base.

1.1.2 Energy projections compared with present scenario

The state suffers from severe power shortages and has to resort to load-shedding even for select industrial loads. According to the 2011-12 policy note of the Tamil Nadu Electricity Board (TNEB), for financial year (FY) 2010-11, the deficit during peak hours (1800 hrs to 2200 hrs) ranged from 1400 MW to 3400 MW, while that during the day from 1700 MW to 3700 MW.

According to policy note 2011-12, gross energy consumption for the year was 77,218 million units (MU). Of this, state-owned generating stations contributed to 27,941 MU, while 49,277 MU was purchased from central generating stations, wind, open market, exchanges, etc. The state saw an all-time maximum demand of 10,859 MW on 19 July 2011 and a maximum daily energy consumption of 237 MU on 20 June 2011. State load dispatch centre (SLDC) reports for March and April suggest load shedding to the tune of 2000-2800 MW during lighting peak and evening peak hours. Despite load shedding, the state remains largely dependent on independent power producers (IPPs) and purchases power through power exchanges on a daily basis.

To address the present shortfall of about 1700–3700 MW at different times during the day, the state government is trying to manage the grid by using strong measures in load curtailment and demand side management. Some of the measures are highlighted below (source: *Policy Note 2012-13*) [Ref 2]:

- 40% cut on base demand and energy for high tension (HT) industrial and commercial services.
- Daily two-hour load shedding in Chennai and its suburbs, and four hours in urban and rural feeders in other areas.
- A nine-hour (six hours during day time and three hours at night) three-phase supply for agricultural services.
- HT industrial and commercial consumers are not allowed to draw more than 10% power from the grid during evening peak hours (1800 hrs to 2200 hrs), for lighting and security purposes.
- Introduction of power holiday to all HT, low tension (LT) and low-tension current transformer (LTCT) industries for one day between Monday and Saturday on a staggered basis. In addition to the above, all HT industries are required to declare Sunday as a weekly holiday.
- All HT industries are permitted to procure power through both inter-state and intra-state open access.

In terms of future energy requirements, energy projections for Tamil Nadu based on the 18th Draft Electric Power Survey suggest an increase in annual energy requirement from 80.69 billion units (BU) presently to 110.25 BU by 2016-17 and 154.59 BU by 2021-22. The corresponding increase in peak load is expected to be 18,994 MW by 2016-17 and 26,330 MW by 2021-22 from the projected 2011-12 demand of 11,971 MW. The long-term energy projections based on this document are captured in **Table 1.2.**

Table 1.2 Electrical energy requirement projections for Tamil Nadu by 2022

Source	Electrical energy requirement (GWh)			Peak electric load (MW)		
	2011/12	2016/2017	2021/2022	2011/12	2016/2017	2021/2022
18th EPS draft	80 690	110 251	154591	11971	18994	26330

In view of the present power situation and the future requirements of energy, power planning for the state has to critically address both short- and long-term requirements. On the supply side, the major strategy is to fast-track capacity addition in the short- to medium-term. In this context, the *Vision Tamil Nadu 2023* document released by the state Chief Minister on 22 March 2012, envisages a massive investment of Rs. 4,50,000 crore (Rs. 4500 billion) in the state energy sector, comprising an allocation of Rs. 2,80,000 crore (Rs. 2800 billion) to augment the state's power-generation capacity by 20,000 MW, and an allocation of Rs. 2,00,000 crore (Rs. 2000 billion) for the development of the transmission and distribution sector to create evacuation capacity with adequate buffers. The detailed sectoral plan and project profile are to be evolved and finalized in consultation with all stakeholders. (Source: *Policy Note 2012-13*, Energy Department, Government of Tamil Nadu).

According to the data on the website of Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO) as on 25 May 2012, the expected addition over FY 2012-13 is to the tune of 1,876 MW, with a further 1500 MW conventional thermal under the joint venture (JV) mode, where the capacity available to the state will depend on the power sharing agreement with the JV partners. Most of the planned additions expected to be commissioned in FY 2012-13 were actually slated to come earlier but were beset with huge delays and setbacks, worsening the present power situation considerably. The Kudankulam nuclear power plant's first unit of 1,000 MW is expected to start generating within months and the other unit is expected to become operational by 2013. These additions will ease the power situation by end-FY 2012-13 but will not compensate for the whole deficit.

The second tranche of new projects – mostly from new coal-based plants, amounting to about 11,060 MW – are expected to come into operation only towards the end of the 12th five-year plan and early part of the 13th plan period. However, most of these projects are at a very preliminary stage (most still at the pre-tendering stage) and materialization of all the capacity seems questionable in the present scenario of coal shortages and Engineering, Procurement and Construction (EPC) bottlenecks. These aspects are covered in more detail in section 1.6.

1.2 Renewable Energy in Tamil Nadu Power Sector

Tamil Nadu has maintained its position as the renewable energy leader in India right from the early 1990s. The two monsoons, with the accompanying additional wind power, allow major sites in Tamil Nadu to have much higher capacity-utilization factors as compared to other states. Tamil Nadu has also made considerable efforts in tapping other renewable energy (RE) resources like small hydro and biomass. Installed RE power generation capacity in the state has now reached over 40% of total installed power. RE contribution is expected to increase over the years as the RE market leapfrogs in Tamil Nadu, primarily driven by the new government's thrust to add 5,000 MW of wind and 3,000 MW of solar power over the next five years.

The installed capacity of RE as on 31 March 2012 is tabulated below in Table 1.3.

Table 1.3 RE installed base in Tamil Nadu

Renewable energy	Cumulative achievement up to 31.03.2012 (MW)
Wind power	6970.62
Bagasse co-generation	610
Biomass power	161.15
Small hydro power	90.05
Solar power (SPV)	10
Waste-to-energy	4.25
Total	7846.07

(Source: TEDA website)

Wind power

With a total installed capacity of 7,846 MW of renewable based power projects, Tamil Nadu is way above all other states in tapping renewable power sources. Wind power has the maximum installed capacity with 6,970 MW installed as of 31 March 2012. This is more than the Centre for Wind Energy Technology's (CWET) official estimate of total wind potential of 5,500 MW at 50 m in the state. Total capacity addition in FY 2011-12 was about 1,084 MW. About 13,400 MW of new project applications are pending with TNEB.

Four mountain passes, namely the Palghat pass (Coimbatore and Dindigul region), Shengottah pass (Tirunelveli and Thottukudi), Aralvoimozhi pass (Kanyakumari, Radhapuram, and Muppandal region) and Cumbum pass (Theni, Cumbum, and Andipatti region) in Tamil Nadu, are endowed with heavy wind flows due to the tunnelling effect during the south-west monsoon.

Solar energy

Tamil Nadu has an installed base of 10 MW of solar power as on 31 March 2012. Under the Rooftop Photovoltaic and Small Solar Power Generation Programme (RPSSGP) scheme, 7 projects of 1 MW each were allotted to the state, out of which 5 projects have been commissioned. An additional 2 MW capacity is under construction. 15 MW of SPV projects have been allotted under the Jawaharlal Nehru National Solar Mission (JNNSM) Batch-I and Batch-II in Tuticorin district. A 5 MW SPV power project has been commissioned under Batch-I by CCCL Infrastructure Limited at village Kombukaranatham, Dist. Tuticorin.

Recently, Tamil Nadu has also announced its State Solar Energy Policy with a target of 3,000 MW up to year 2015 with 1000 MW capacity addition each year starting from 2013. The proposed addition will be achieved through utility scale projects, rooftop and REC mechanism. TANGEDCO has already invited bids for 1,000 MW solar power projects under competitive bidding scheme.

On the off-grid side, the state has supplied 12,000 solar lanterns, 6,378 solar home lights and solar street lights under rural village electrification (RVE) schemes, along with 285 solar pump systems and 4,206 solar thermal systems with a collector area of 25,658 m^2 as on October 2011 (source: TEDA website).

Biomass

Cumulative installed capacity of grid-interactive biomass and bagasse-based co-generation stood at 771.15 MW as of 31 March 2012. Of this, bagasse-based cogeneration accounted for 610 MW. The state government is keen to develop biomass potential even further through the gasification/combustion route.

Small hydro

About 111.69 MW of small hydro-power had already been commissioned and 18 MW was under construction as on 31 December 2011 (source: MNRE). Almost all the capacity, (except one 7 MW SHP plant), was developed and is operated by TANGEDCO.

1.3 RE Policy and Regulation in Tamil Nadu

The nodal agency responsible for renewable energy development in the state, TEDA, has drafted a state renewable energy policy framework, which presently awaits approval.

1.3.1 Renewable Regulation in Tamil Nadu

There have been many developments in the field of RE regulation. Some of the main regulations related to RE are discussed below.

Tariff determination methodology

The main features of the various RE tariff orders issued by the Tamil Nadu Electricity Regularity Commission (TNERC) are summarized below.

- Cost plus tariff.
- Single-part tariff for wind, SHP, and solar, and two-part tariff for biomass, bagasse co-generation, biogas and bio-gasification power plants.
- The Commission has awarded average tariff for wind and SHP, whereas levellized tariff is awarded for small scale solar power projects commissioned under JNNSM.
- Control period specified is two years.

Table 1.4 summarizes the notified tariff for various technologies

Table 1.4 Tariffs for various RE technologies

Resource	Wind	Biomass	Bagasse Co-generation	SHP	Small Solar PV	Small Solar thermal
Order date	31.07.2012	31.07.2012	31.07.2012	March 2010 (Consultative paper)	27.05.10	08.07.10
Applicable for projects	Commissioned on or after	Commissioned on and after	Commissioned on and after	Capacity upto 5 MW	Connected at HT level of distribution network	
	31.07.2012	01.08.2012	01.08.2012		(below 33 kV) with installed capacity of 100 kW and up to 2 MW	
Tariff (Rs/kWh)	3.51	4.694–4.893	4.376–4.49	3.76 (FY2012/13)	18.45 (14.34 if Accelerated Depreciation is availed)	15.51 (12.16 if Accelerated Depreciation is availed)
Present status	Tariff applicable for projects commissioned up to 31.07.2014				Up to 31.05.2012	

Interconnection point

The interconnection point for wind power and solar PV projects is defined at the pooling substation whereas for SHP, biomass and cogeneration projects, the same is defined on HV side of the generator transformer. This is consistent with the CERC's RE tariff regulations of 2009 and 2012.

Infrastructure cost

The State Transmission Utility (STU)/ distribution licensee is being made responsible for bearing the cost of interfacing line and related evacuation infrastructure, in case the RE generator opts for sale of entire energy to the distribution licensee. In case the RE generator opts to sell energy to a third party, or decides to use the energy for captive purposes, then the RE generator has to reimburse the cost of evacuation line.

Under an alternative infrastructure development model called 10(1), the wind developer pays no upfront charges but invests directly in the infrastructure, which is then transferred to the distribution licensee. The distribution licensee reimburses the wind project developer an amount equivalent to the lowest tender quote for the same infrastructure development.

Open access

The regulation allows wheeling and banking to facilitate third party sale and captive use of RE. Renewable energy generators in Tamil Nadu can also sell the electricity to any entity other than the host distribution licensee (TANGEDCO) at a mutually agreed upon tariff, subject to the payment of applicable transmission/ wheeling charges and other open access (OA) charges specified in TNERC's RE tariff orders. A generator of electricity from non-conventional energy sources shall be treated as a long-term intra-state open access customer and shall be eligible for open access irrespective of the generating capacity. As per the Government of Tamil Nadu policy for captive generation (G.O. MS. No.48 Energy dated 22 April 1998), and subsequent amendments (a) a consumer of electricity; (b) a group comprising more than one consumer as joint venture; (c) an actual user of power but not a consumer; (d) a group of actual users of power, but not consumers as joint venture; (e) a group comprising both consumers and users of power as joint venture – are allowed to install captive power plants of any capacity and the power generated by these captive power plants shall be used by the owner or by the sister concern(s) of the owner of the captive power plant(s). More specifically, the generated power can be used by the owner and by the sister concern of the owner. The power that remains can be purchased by distribution licensees. However third party sale is not permissible if the generator installs the plant under captive mode. **Table 1.5** summarizes the OA charges applicable for third party sale/captive use.

Table 1.5 OA charges for third party sale/captive use

Charges	Wind	Biomass	Co-gen	SHP
Banking charges	Rs 0.94/kWh up to 31 March 2013; banking period: one financial year; un-utilised energy may be purchased at 75% of the purchase tariff.	N.A.		As per wind
Wheeling and transmission charges including line losses	40% of charges applicable for conventional power	50% of charges applicable for conventional power	60% of charges applicable for conventional power	As per wind
Cross-subsidy surcharge	50% of existing rate	Do	Do	Do
Reactive power charges	25 paise per kVARh (drawl up to 10% of the net active energy generated); in case drawl is in excess of 10% of the net active energy generated, the charges are doubled.	10 paise /kVARh for 2012-13 and escalated at 0.5 paise / kVARh annually thereafter.	Do	SHP projects (induction generators) reactive charges equivalent to wind energy.
Scheduling and system operation charges	Capacity of 2 MW and above, Rs.600/- per day; if capacity is less than 2 MW, the charges shall be proportionate.	Rs. 2000 per day irrespective of capacity	Do	Same as wind.
In addition to this, the consumer opting for OA has to pay grid availability charges specified by the Commission.				

Renewable Purchase Obligation (RPO)/Renewable Energy Certificate (REC)

TNERC notified the regulation on RPO on 7 October 2010, further amended on 29 July 2011 to incorporate REC related provisions. In order to facilitate REC trading, the minimum percentage of obligation (for all obligated entities) was reduced to 9% for FY 2011-12, from the earlier proposed 14%. For FY 2011-12 the solar obligation was pegged at 0.05%. In a recent draft amendment to RPO regulation, the solar percentage has been proposed to be fixed at 0.1% for FY 2012-13, while the total renewable purchase obligation has been kept at the same level. The regulation defines the 'Pooled cost of power purchase' as the weighted average pooled price at which the distribution licensee has purchased the electricity, including cost of self-generation in the previous year, from all the long-term energy suppliers, but excluding those based on liquid fuel, purchase from traders, short-term purchases and RE sources. Recently, TNERC by a separate order, specified pooled cost of power purchase as Rs. 2.54 per unit for FY 2012-13. The eligibility criteria for RE generators to avail REC benefit is as per the Central Electricity Regulatory Commission's (CERC) REC regulation. The regulation designates the SLDC as 'State Agency'. Furthermore, it specifies that a RE-based grid-connected co-generation plant (CGP) shall be eligible for RECs on the energy generated, excluding auxiliary consumption, that such CGP has not availed or does not propose to avail any benefit in the form of concessional/promotional transmission or wheeling charges, banking facility benefit and waiver of electricity duty/tax. The regulation also obligates captive users and open access consumers but allows phased implementation of the obligation due to implementation constraints.

1.4 Challenges to Integrating RE in Tamil Nadu

The installed capacity of power generation in Tamil Nadu from renewable energy sources has now reached about 33% of the country's installed capacity from renewable sources.

However, wind power development in Tamil Nadu has significantly outpaced grid development, leading to severe problems related to grid integration. The developers cite evacuation bottlenecks and low tariffs as the biggest hurdle while the major issue with grid operators and the utility is the technical management of variable generation and the associated commercial implications.

We briefly highlight the major issues to set the reference. A more detailed coverage of these issues is provided in subsequent chapters.

Evacuation infrastructure

Evacuation arrangement for RE resources is difficult owing to resource locations in remote areas where the distribution grids are typically weak. This is especially problematic for small-capacity plants whose size cannot justify creation of additional HV infrastructure. Even in case of large-capacity clusters, the laying of parallel evacuation infrastructure not only adds to costs but also to construction time.

At present, evacuating wind power during peak wind season, especially in Tirunelveli and Muppandal, requires evacuation to nearby major 230 kV or 400 kV substations, as the downstream demand is already met. This overloads the existing 110 kV lines resulting in backing down of wind even when the system may have unmet demand. The only option is to connect wind power generation directly at 220 or 400 kV level or to strengthen the existing line. Both the options have technical and commercial implications. These implications are discussed in more detail in subsequent chapters.

Power system stability

Today RE has prominent influence on grid security, stability and congestion management. As the majority of grid-connected wind farms in India have asynchronous generators drawing reactive power from the grid, there may be problems related to voltage instability and power quality. The dispersed nature of wind resources and their decentralized locations also mean weak interconnection links that result in local impacts like transmission- /sub-transmission-level system overloading. However, it is worth noting that for many new projects, advanced technologies have been deployed to effectively overcome these problems. Many new technology wind turbines can provide a voltage-ride through (VRT) feature in addition to supporting the grid with reactive power based on system conditions.

Power system operation

It is known that the generation pattern of wind and solar power is variable. Typically, the MW contribution of wind in Tamil Nadu may vary from about 3,000 MW (high-wind season) to about 50 MW (low-wind season). On the other hand, even during the wind season, wind generation may, at times, taper down to 900 MW or less from a high of 2,500 MW within a day. This variability poses significant challenges in balancing generation as system operators have to adjust generation from other stations. This results in operational complexities and associated commercial implications.

Costs of regulatory provisions due to banking

Another related aspect is the co-relation of wind generation with demand. In Tamil Nadu, peak demand season is in early summer months, when wind power generation is low. Wind picks up in late summer and monsoon seasons when the demand drops down. This nature of wind generation coupled with the regulatory provision of banking has also been a major point of contention. Banking facility allows wind generators to bank a part of the energy generated during the wind season and offset it with their consumption in off-wind season. As per provisions, banking customers have to be supplied their banked units on priority. This may necessitate the utility to overdraw or buy power from exchanges/IPPs/traders in a low supply situation, when the power costs may be high.

Costs and impacts of balancing generation

Understandably, this variability in generation also has commercial implications. In extreme cases, wind generation contribution may result in a high-supply situation and the utility finds itself in a position where, in order to integrate wind generation, it may either have to back down low-cost thermal or hydro generation, or will have to inject the excess power in the regional grid, and seek frequency dependent unscheduled interchange (UI) charges. Both the options are not acceptable to the utility, which sees more merit in shutting down excess wind generation. On the other hand, there could be situations when gradual drop in wind generation may force the utility either to overdraw power or to resort to unplanned load shedding.

Commercial implications of infrastructure development

Strengthening of existing network or creation of new dedicated evacuation infrastructure carries significant cost implications for the utility. Issues related to evacuation infrastructure are thus commercial and require a commercial solution. It seems that TNEB has also realized this and under the National Clean Energy Fund (NCEF) proposal submission process of the Ministry of New and Renewable Energy (MNRE), has asked for central assistance of Rs. 17,570 million to develop transmission grid infrastructure to evacuate about 4,000 MW of renewable power. This expansion is aimed at evolving a power grid to facilitate free flow of power across regional boundaries by raising the transmission voltage from 230 kV to 400 kV and, if required, enhancing transmission capability to 765 kV level. (Source: MNRE, TNEB websites). The huge capital investment led TNEB to approach the Japanese Industrial Cooperative Agency (JICA) which will provide financial assistance in certain transmission schemes to be taken up during the next five years. The Official Development Assistance (ODA) loan by JICA will strengthen the transmission network at a cost of Rs. 3,572.93 crore, by establishing five 400 kV substations and fourteen 230 kV substations with associated lines during the next five years. Further, to evacuate power from wind generators, a separate corridor with three new 400 kV substations at Thappagundu, Anaikadavu and Rasipalayam, is to be built, along with the associated 400 kV lines of 336 circuit (ckt) km length. These substations will be connected to the proposed 765 kV substations being executed by Power Grid Corporation of India Ltd (PGCIL) at Salem. (Source: *Policy Note 2012-13*, Energy Department, Government of Tamil Nadu).

1.5 Emerging Perspective on Power Sector

Historically, power generation capacity additions of conventional technologies in India have fallen significantly short of government targets. The opposite has been true for renewables. Even from the perspective of future planning, renewables seem to be a better bet as compared to conventional power generation technologies.

While there are contending views on figures related to the availability of fossil fuel sources (coal, gas, etc), there is no disputing the fact that these sources are going to get depleted. Recent developments related to difficulties in coal allocations, limited coal stocks in running plants and price volatility, point to the fact that a coal-based power system is exposed to serious systemic and financial risks. This has major implications for power sector planning and energy security, especially for a state like Tamil Nadu. On the other hand, renewables are not going to deplete. As for their potential to deliver, recent studies clearly point out that wind potential in Tamil Nadu is significantly higher than the official estimate of 5,400 MW. For other RE technologies too, especially solar, preliminary information indicates a very high potential.

If we look at technical integration issues, it can be said that most of the technical challenges related to power quality like reactive power drawl, harmonics, under voltage trip, etc., have been adequately addressed using new technology configurations, while problems related to load management of renewables are still unresolved. Wind and solar generation patterns typically vary significantly across the seasons and even across the day, and integrating this variable generation with scheduled conventional generation and matching it with demand is a challenge for grid operators. But it is worth noting that these same challenges have been addressed very effectively by European utilities, particularly those in Ireland and Denmark, where the instantaneous wind energy contribution has, at times, gone as high as 100% of total system demand. And it is worth noting that despite the experience of dealing with a large penetration of wind, Denmark is planning to increase its wind energy penetration in its network to 50% [Ref 3]. According to Danish energy planners and technologists, the variability problem is technically manageable.

From the point of view of commercial acceptance of renewables, private sector investments from IPPs suggest that wind is already commercially competitive. The year on year increasing trend of average power procurement cost (APPC) indicates a steady increase in conventional power prices. In contrast, solar power prices have seen a steep fall in recent years with prices falling drastically in each successive round of reverse bidding process under the JNNSM. Wind power tariffs are increasing but are not expected to match the rate of increase in the conventional generation prices as delays, coal shortages, financial situation of distribution companies (DISCOMS) and high imported-coal prices are expected to precipitate a serious supply crunch in the face of increasing demand

In this background, low thermal power-generation costs cannot be taken for granted. It has to be accepted that wind power, and ultimately all renewables are getting competitive and will achieve grid parity in the near future, effectively discounting any need for cost comparison. Even from a global perspective, man-made crises related to environmental sustainability, climate change, water scarcity, etc., seem to suggest that a business-as-usual approach and a narrow definition of growth are not justifiable any more.

1.6 The Case for a Transition to RE Power in Tamil Nadu

The total installed generation capacity in Tamil Nadu including state-owned capacity, centrally owned capacity, and private sector capacity is **17686.37 MW** (as on 31.08.2012, source: Central Electricity Authority [CEA]), comprising 7617.8 MW of thermal (coal, gas and diesel), 524 MW of nuclear, 2,122 MW of hydro, and 7,422.84 MW of renewables.

However, the power deficit situation in the state is so acute that the state is forced to buy high-cost power despite high level of demand curtailment. The state-owned energy generation capacity is also not large, resulting in considerable dependence on power from central generating stations, independent power producers (IPPs), captive power plants, energy exchanges, traders and renewables.

The proposed capacity addition plans comprising mainly coal-based power generation capacities are expected to transform the state from a power-deficit state to a power-surplus state. However, a preliminary analysis of the existing data related to coal-based capacity addition indicates that the state energy planning based on these projects is exposed to huge risks that can have serious implications for the state in the years to come.

To elaborate, the conventional capacity addition plans of the state can be categorized into two distinct phases. The first phase includes short-term capacity additions that are expected to come by the end of FY 2012-13. These comprise 2 × 600 MW units of North Chennai Thermal Power Station (NCTPS) Phase II, one 600 MW unit of Mettur Thermal Power Station (MTPS), one 1,000 MW of Neyveli Lignite Corporation (NLC) Limited and 1,500 MW of National Thermal Power Corporation (NTPC)–Tamil Nadu Electricity Board (TNEB) Limited, in addition to about 56.5 MW of hydro capacity, totaling to 4,356 MW.

Phase II includes long-term capacity addition projects of total size of 5,460 MW to be commissioned by the end of 2015-16, and the Cheyyur 4,000 MW ultra mega power project (UMPP) expected to be commissioned by the end of 2016-17. **Table 1.6** provides details of the new capacity addition plans for Phase II.

Table 1.6 Thermal power projects planned in Tamil Nadu in Phase II

Project	Total (MW)	Commissioning date	Status (16 Apr. 2012)
Udangudi near Tiruchendur	1600	NA	Zero date not fixed.
Ennore Thermal Power Station	660	Dec. 2015	Zero date is June 2012. Pre-tendering stage.
NCTPS ash dyke	1600	Dec. 2015	Zero date not fixed. Pre-bid stage. No coal linkages. Imported coal being

Project	Total (MW)	Commissioning date	Status (16 Apr. 2012)
			considered.
NCTPS complex	800	Dec. 2015	Zero date not fixed. Pre-bid stage. No coal linkages, Imported coal being considered.
Uppur, Thiruvadanai, Ramanathapuram district	1600	Dec. 2015	Zero date not fixed. Early planning stage. Environmental Impact Assessment (EIA) pending.
Tuticorin Thermal Power Station Complex	800	Dec. 2015	Zero date not fixed. Early planning stage. Feasibility study completed.
Cheyyur, Kancheepuram district	4000	2016–17	Zero date not fixed. Early planning stage (UMPP). Approval process ongoing.

It is worth noting that Phase II projects are at a very preliminary stage (most are at environmental impact assessment [EIA] stage) and materialization of all these projects is questionable, considering issues related to coal allocations, coal imports, capital equipment shortage, and financial outlay.

The existing domestic fuel supply agreements (FSAs) guarantee only about 65% of the coal requirement on regular basis. Under-supply cases in coal plants abound, with many of the new coal-based capacities not able to get coal linkages at competitive prices, exposing them to availability and price risks of imported coal. A majority of the existing coal power projects blend domestic coal with 10% to 30% imported coal, because of the domestic supply problems. The recent Central Electricity Authority (CEA) advisory asking all power utilities and equipment manufacturers to ensure that the boiler and auxiliaries for future projects be designed for blending with at least 30% or more imported coal, is a clear indication of the precarious position of domestic coal availability [Ref 4]. The situation for Tamil Nadu seems to be even more critical.

Coal India Limited (CIL) has already conveyed its inability to supply coal to Tamil Nadu for some planned Phase I and Phase II projects, prompting the state to assess plans to import as much as 100% of coal for some new power plants [Ref 5]. This level of dependence on imported coal is risky, not only from the cost perspective but also from the availability perspective. It is learnt that the recent increase in coal prices in Indonesia was effected through a presidential decree and Tata Power, despite owning 30% share in one of the largest Indonesian coal mining companies, could not contest the decree, resulting in significant losses for the company. As coal prices are expected to increase even further, it is worth pondering if the projects evaluated on present cost dynamics will be commercially feasible at the time of their commissioning.

An even more worrying aspect is the possibility of international resource capturing or monopoly behaviour of coal-rich countries, which may even result in drying up of imports, leaving the state without any back-up for the huge loss of capacity. This availability deficit is evident even today as many coal-based plants are running on very short supply of coal.

Already, such risks are being envisaged by profit-oriented corporates. Tata Power has put all imported-coal-based power plants on hold [Ref 6]. Most of the large banks have tightened lending norms to thermal power projects citing overexposure and regulatory uncertainty. According to recent media reports, IDFC Bank has stopped lending to coal-based projects on the grounds of risks of fuel availability and price volatility of imported coal [Ref 7].

In this context, it will be insightful to compare the planned capacity additions of the state with the projected system peak demand. **Figure 1.4** projects two scenarios: the firm line plots the annual peak demand (MW) based on 18th EPS projections, the dashed line represents the non-RE capacity availability assuming materialization of all planned projects including the Cheyyur 4,000 MW UMPP, and the red track line represents the non-RE supply availability assuming materialization of the Phase I projects and non materialization of Phase II projects.

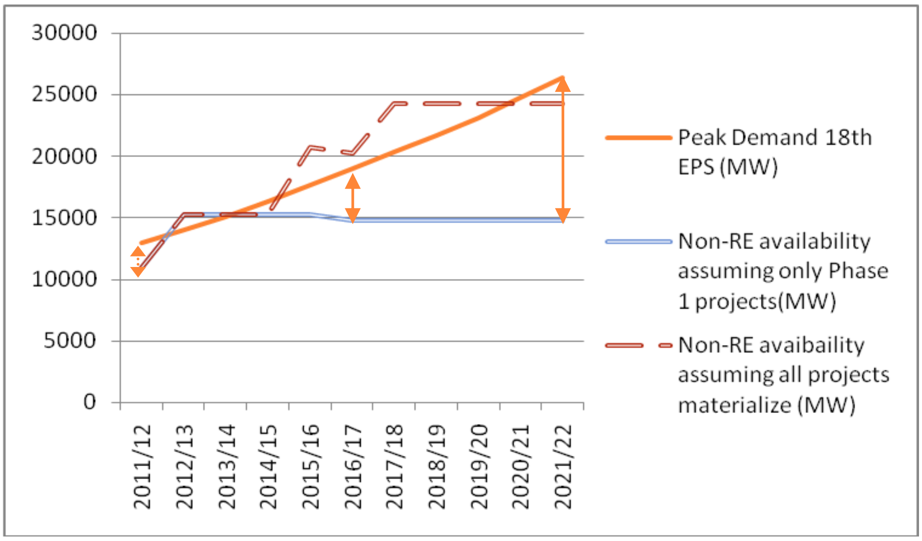


Figure 1.4 Demand–Supply comparison for Tamil Nadu

(Note: The small dip in the graph in 2016-17 indicates de-commissioning of Ennore 450 MW TPS.)

It can be seen from the above figure that if all the proposed coal-based projects (Phase I as well as Phase II) materialize on time, then, except for FY 2013-14 and FY 2020-21, the state will have surplus capacity for all the years even without any injection of RE.

However, if Phase II projects do not materialize, capacity deficit will keep increasing from FY 2014-15, reaching about 5,000 MW in FY 2016-17 and 11,000 MW in FY 2021-22. The effects of a change in the input (capital and variable) costs or a delay in commissioning these capacities will be less pronounced but will still mean power shortages in the state during the 13th five-year plan period.

Considering all the market signals, it is time for the state to at least analyze the possible risks of coal-based power sector planning. In fact, the impact of such contingent risks for the state can be nothing short of disastrous. On the one hand, large state capital will be locked in capital costs and debt repayments for projects that may not deliver low-cost power, while on the other, rising power costs would have an inflationary effect on prices, affecting business growth and economic development.

Against this background, energy planning focus has to essentially shift from mere supply-demand matching, to an approach guided by long-term energy security and greater optimization of available resources. This is where renewables can add value and contribute to long-term power sector planning for the state. And fortunately for Tamil Nadu, renewable energy potential is not a constraint. So it is important to reassess the RE potential in the state to see if renewables can be the mainstay of the state's power generation in the future.

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PART – II

RE-ASSESSMENT OF RE POTENTIAL IN TAMIL NADU

2. The Context, General Objectives and Principles of RE Potential Assessment

The context for re-assessment of renewable energy potential was set after Tamil Nadu reached an installed wind capacity of 6,000 MW in August 2011 as against the official state potential estimate of 5,374 MW. Notwithstanding the fact that an additional 1000+ MW wind capacity was in the pipeline for 2011-12, this mismatch corroborated the long-standing contention of wind power stakeholders, industry leaders and independent experts that the official wind potential estimate was extremely conservative and not representative of the actual achievable potential.

The aim of the present study is to critically re-assess the renewable energy potential of Tamil Nadu and draw up a comprehensive action plan for the development of identified renewable energy capacity in the state. As compared to past potential assessment studies, the present study is different in respect to two aspects.

- The study uses the geographical information system (GIS) platform linked with multi-criteria analysis (MCA) for assessment of wind (onshore and offshore) and grid-tied solar power (solar PV and CSP). In addition, the study also tries to assess potential for other renewable energy technologies like repowering, off-grid solar applications, biomass power and small hydro using standard tabulated calculations.
- The present study uses a mix of market information and literature review to arrive at the methodology and the assumptions for the potential assessment exercise.

Why GIS?

Considering the ambiguities and differences in the assumptions, it is increasingly obvious that a paper-based exercise for potential assessment cannot and will not give a reliable and robust estimate of renewable resource potential. The first step before any real assessment exercise can take place is to understand the assumptions and their underlying rationale. For renewable resources and technology, this assumption set can only be accurately validated with on-site measurements and detailed land surveys. The scope of the project visualised a GIS-based exercise supported by suitable field and spatial data, that not only considers terrain features but also numerical models based on reliable source data for micro-scale assessment. Moreover, such a GIS-based exercise will add tremendous value to the planning process as it will enhance visualization and aid data analysis for varying spatial selections. For the present project, all the GIS-based analysis has been done on the Arc View 10 platform.

GIS-based RE Potential Estimation Plan

WISE has sourced the base GIS data from various commercial and government sources. The emphasis will be on selecting the highest resolution data that meets cost and time targets. WISE has used the following major GIS data layers – wind resource, solar resource, land-use and land cover, terrain elevation, hydrogeology, cropping pattern and irrigated land, administrative and political boundaries, etc. In addition, various thematic layers with features like roads, rivers, railway, transmission lines, etc., have also been included.

The final GIS portal includes a map of Tamil Nadu state with suitable raster and vector layers including land-use, land cover, terrain elevation, administrative boundaries along with gradations and spatial unit-based data values related to wind (onshore), solar (only grid-tied), small hydro and biomass potential.

General Overview of Literature and Methodology

As already discussed, the installed capacity of wind power in Tamil Nadu crossed 6,000 MW in 2011 as against the estimated state power potential of 5,374 MW. This has raised questions about the methodologies of the original resource assessment by government institutions and its relevance in today's context. While new GIS-based studies have been very effective and robust, the methodologies that went into the actual calculations remain the same even in paper-based exercises. To get a good perspective of the differences in methodology and assumptions, we have reviewed both GIS-based and paper-based resource assessment studies from Indian as well as international authors.

The next few chapters (Chapter 3 to 7) give the sector-wise methodology and results of the potential re-assessment study done by WISE. Chapter 8 provides the summary of the total potential of all the sector-wise RE technologies.

Land-Use Considerations

The main consideration before initiating GIS analysis was exclusion of all non-available geographies. Non-available geographies were categorized either as a geographical extent that was not available for development or as a geographical extent that was not recommended for development.

The geographies not available for development included standard geographical features like rivers, other water bodies, protected areas, roads, railroads, cities, settlements, etc. To exclude these features, WISE first created proximity criteria that excluded a certain extent along the perimeter (called buffering) of all the features and then aggregated these buffered extents to create a common layer of 'permanent exclusion'. All natural features like rivers and other water bodies, protected areas, and infrastructure like roads, railroads, settlements, airports were excluded from all analysis after buffering. The buffer values used are as specified in **Table 2.1** and **Figure 2.1,** and depict the areas that were considered as permanent exclusions. Similarly, the geographical features not recommended for development comprised certain land use categories like agricultural land, forest land, etc.

Table 2.1 Buffer values for geographical features

Feature	Buffer (m)
River	300
Water bodies	300
Protected areas	500
Roads	300
Railroads	300
Settlements	500
Airports	2500

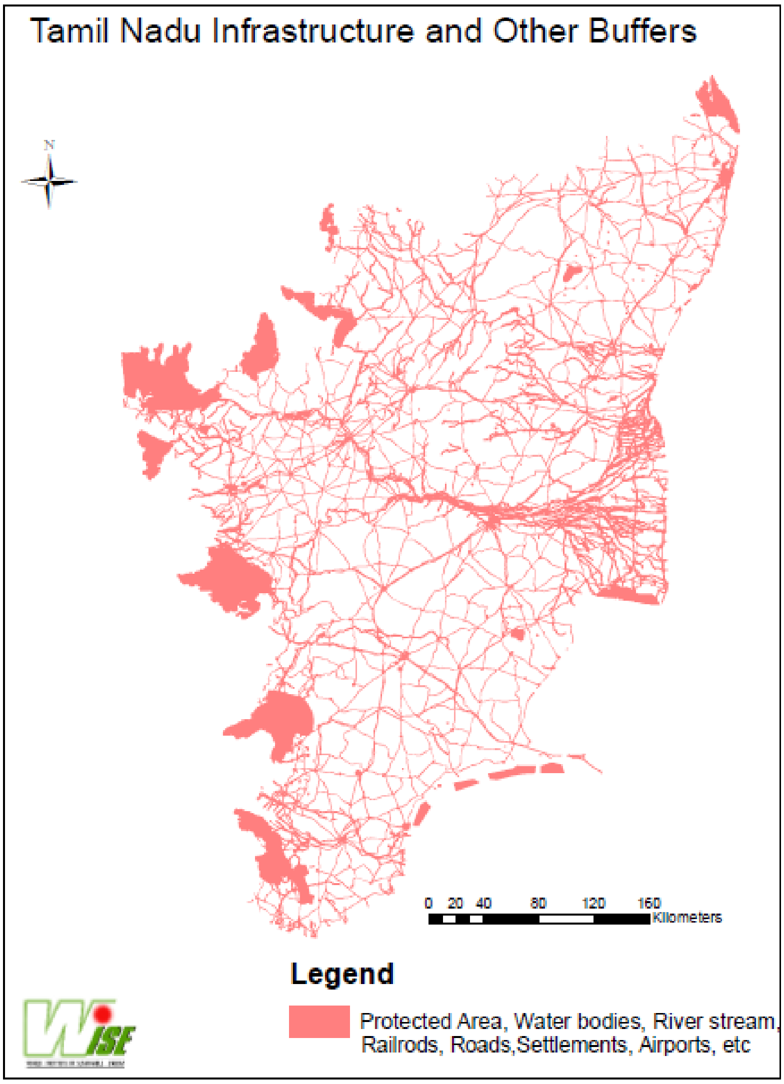

Figure 2.1 Permanent exclusions

Land Use Land Cover Data

WISE evaluated three Land Use Land Cover (LULC) datasets. These were generated by the National Remote Sensing Centre (NRSC)-Indian Space Research Organization (ISRO), Government of India; GlobCover; and ESRI's Digital Chart of the World. **Table 2.2** summarizes the specifications of the datasets.

Table 2.2 Comparison of LULC datasets

No.	Dataset	Spatial resolution	Base data	Date
1	Land-use/land-cover (NRSC ISRO)	~ 62.8 m x 62.8 m	IRS-P6 AWiFS	2010–11
2	GlobCover	300m x 300 m	ENVISAT MERIS SATELLITE	2006
3	Digital Chart of the World	NA (vector data)	Digital aeronautical flight information file, USGS, joint operations graphics and tactical pilotage charge	1992

It was decided to use NRSC-ISRO LULC data for the analysis because it was the latest data (2010-11) and had very high resolution as compared to global datasets. Another important reason for choosing NRSC-ISRO data was that it was government approved and validated by experts attuned to Indian land-use patterns.

WISE retrieved other data including that of administrative areas and geographical features from AWS Truepower. **Table 2.3** provides description and specification of the other datasets used.

Table 2.3 Miscellaneous datasets

No.	Database	Dataset	Base data	Date
1	Shuttle Radar Topography Mission (SRTM) Version 2	90 m × 90 m	NASA satellite	2009
2	Protected area	World Database on Protected Areas	UNEP	Not known
3	Geographic features (rivers, water bodies)	VMAP 0	National Imagery and Mapping Agency	Not known
4	Administrative boundaries	GADM database of Global Administrative Areas v2	Unknown	2012
5	Infrastructure (roads, railroads, cities, settlements, urban areas)	VMAP 0	National Imagery and Mapping Agency	2000
6	Bathymetry map**	Hard copy navigation map INT 754 32	Marine Aids	Not known

**Bathymetry hard copy map was digitized to convert it into a GIS polygon layer

***

3. Solar Power Potential in Tamil Nadu

WISE has assessed solar power potential in Tamil Nadu and its findings are highlighted as part of the literature review. Additionally, to bring the present exercise in context, the emphasis was on reviewing the literature on the use of GIS for solar resource assessment or planning. The brief of the reviewed literature is as below.

Technical parameters keep changing for the solar sector, as new incremental and breakthrough innovations are introduced. Even more important factors like topography, vegetation, land-use considerations and water availability are also crucial factors for identification of areas with solar power potential. GIS-based solar resource assessment goes beyond just providing a figure; it can identify the exact location and the quality of the resources allowing governments and decision-makers to use the results as policy inputs.

3.1 Solar-Resource Data

After evaluating the specifications of freely available datasets (from the American National Renewable Energy Laboratory [NREL] and the National Aeronautics and Space Administration [NASA]) and other modelled datasets on solar resources, WISE procured a modelled dataset of SolarGIS from GeoModel Solar ES, a Slovakia-based resource assessment firm. The main reason for choosing the SolarGIS dataset was the resolution of the dataset (1 sq. km × 1 sq. km), a resolution that was 100 times higher than the NREL dataset, which offered a grid size of 10 sq. km × 10 sq. km. The NASA dataset was at an even lower resolution of 110 sq. km × 110 sq. km.

WISE compared the global horizontal irradiance (GHI) data of GeoModel with other modelled data from NASA, NREL, and Meteonorm, and found that the deviation in correlation coefficient value across the models varied in the range of 0.91 to 0.96, suggesting very good correspondence.

However, comparison of GeoModel's Direct Normal Irradiation (DNI) data with other datasets showed considerable differences in the values, with the GeoModel values being consistently lower by about 10%–50% across all locations. In fact, the GeoModel data indicated a maximum DNI value in Tamil Nadu of 1632 kWh/sq. m, effectively ruling out any attractive CSP potential in Tamil Nadu. In contrast, the next high resolution dataset of NREL (10 km × 10 km) indicated very high values of over 1800 kWh/sq. m for majority of the state.

Interaction with experts indicated that DNI is a derived value and is very sensitive to small deviations in the data inputs, such as aerosol content, water vapour or terrain. Many solar resource assessment studies also suggest that the high deviation in DNI value is mainly due to treatment of aerosols in the model. It is also well known that data variations are common all over the world. WISE's internal research indicates +/– 15% variation in DNI values while comparing the India Meteorological Department data with that obtained from various other software tools from NASA, NREL, Meteonorm etc.

In view of these technicalities and observations, no conclusive comparison could be done for DNI data and it was decided to use both the NREL and GeoModel datasets for solar power potential assessment.

3.2 Land Use for Solar Power

For the final assessment, all other categories except 'Other wasteland' were deemed not suitable for solar power plants and hence excluded from analysis. **Table 3.1** summarizes the land-use categorization used for solar potential assessment for grid-tied solar projects.

Table 3.1 Land-use categorization for grid-tied solar power potential assessment

LULC Code	Code description	Area (Sq km)	% Inclusion	Solar land-use categorization
13	Other wasteland	7549	100%	Solar wasteland (7549 sq km)
1	Built-up	977	0%	Excluded land area
2	Kharif only	9686	0%	
3	Rabi only	21606	0%	
5	Double/triple	32309	0%	
6	Current fallow	23633	0%	
7	Plantation/orchard	3837	0%	
8	Evergreen forest	5632	0%	
9	Deciduous forest	13433	0%	
10	Scrub/degraded forest	1905	0%	
12	Grassland	153	0%	
15	Scrubland	7866	0%	
16	Water bodies	2273	0%	

3.3 Literature Review

In the report, *Solar roadmap for Tamil Nadu: opportunities and roles of government and industry* [Ref 8], by WISE in 2010, the solar power potential in the state was determined on the basis of solar radiation data from the Meteonorm database and the solar radiation data published by the National Aeronautics and Space Administration (NASA). The study considered only seven categories of wasteland for solar power project development and excluded wind power installation areas. The main assumptions for CSP siting were minimum solar resources (annual DNI) of 1800 kWh/m^2, land use of 35 MW/km^2 and water requirement of 4 lit/kWh. For PV plants, a land-use factor of 50 MW/km^2 is assumed. Based on the above assumptions, the study assessed the state-wide potential for PV and CSP at 4,340 MW and 430 MW (assuming 1% land availability), and 21,700 MW and 2,150 MW (assuming 5% land availability), respectively.

The 2010 report, *PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation* [Ref 9], presents a study aimed at developing the first geographical mapping models to locate the most appropriate sites for different PV technologies in Oman using GIS and MCA. The case study and suitability analysis for implementation of large PV farms was carried out for the state of Oman. The most suitable land for solar PV project implementation was evaluated on the basis of solar radiation, areas of constraint and proximity to major roads.

Step 1: The collected geo-referenced database was converted from vector files to a raster format with a pixel of 40 m in order to keep uniformity with the Digital Elevation Model of Oman.

Step 2: The solar radiation analyst module of Arc-GIS was used to map the total solar radiation. The module incorporates slope, hill shade, and the ability to produce an accurate solar radiation map, allowing the coefficient of the atmospheric transmissivity to be modified.

Step 3: A constraint layer regrouping all the unsuitable areas was created. This layer is composed of dams, flood areas, land used, village boundaries, historical monuments, tourist attractions, rivers, sand dunes, roads, and area with slopes of more than 5%. The unsuitable areas were attributed by 0 and the suitable by 1.

Step 4: Land accessibility was recognized as an important criteria for PV farms. As the objective was to minimize distance from roads, the straight-line distance tool of Arc-GIS was used to measure distances from each location to the closest road.

Step 5: Solar radiation, constraint layer and the straight-line distance to roads were used to run the FLOWA module (an optimization application).

The 2011 study *Hotspots of solar potential in India* [Ref 10], sought to identify solar hotspots in a vast and densely inhabited geographical area to help meet the escalating power demand in a decentralized, efficient and sustainable manner. The study collected NASA Surface Solar Energy (SSE) monthly average global insolation data for more than 900 grids, which optimally cover the entire topography of India within 8-38°N latitude and 68-98°E longitude. A geo-statistical bilinear interpolation was employed by the study to produce monthly average global insolation maps for the country detailed with isohels (lines/contours of equal solar radiation) using GIS. Regions receiving favourable annual global insolation for electricity generation with technologies like SPV and CSP and the prospects for successful dissemination of solar devices were demarcated as solar hotspots. Devices based on CSP depend on a direct component of global insolation; hence its intensity in the identified solar hotspots in India was verified based on surface measurements obtained from solar radiation stations.

The result showed that the Gangetic plains plateau region, western dry region, Gujarat plains and hill region as well as the West Coast plains and Ghat region receive annual global insolation above 5 $kWh/m^2/day$. The eastern part of Ladakh region and minor parts of Himachal Pradesh, Uttarakhand, and Sikkim located in the Himalayan belt also receive similar average global insolation annually. These regions constitute solar hotspots and cover nearly 1.89 million km^2 (~58%) of land in India and offer favourable prospects for solar-based renewable energy technologies.

The objective of another 2010 project conducted by Clean Energy Associates in the city of Austin in Texas, USA – *A solar rooftop assessment for Austin* [Ref 11] – was to create a model for assessing the extent of rooftop area on commercial, industrial, institutional, and government buildings in Austin energy, the local power utility's service area (suitable for solar electric energy development) and based on this model, determine the potential installed capacity and annual energy production from solar electric installations on the rooftops of these buildings. In this study, Clean Energy Associates created a model to assess the rooftop solar potential available in Austin. The model employed a step-by-step analytical approach to determine the rooftop area available on buildings in Austin Energy. Once the extent was known, Clean Energy Associates applied appropriate factors to calculate the available MW power and annual energy in MW hours (MWh).

The present study also reviewed two other studies: *Potential and prospects of solar energy in Uttara Kannada, district of Karnataka state, India* [Ref 12], and *Implications of renewable energy technologies in Bangladesh power sector: Long-term planning strategies* [Ref 13].

3.4 Summary of Assumptions and Findings from the Literature Review

The majority of studies considered base solar insolation data along with constraint data from land-use and technology requirement, to identify critical development areas but not to evaluate actual potential. In all potential assessment exercises related to solar, the net land area available after meeting the technical, geographical, social and legal constraints was directly converted into MW potential by using the corresponding solar technology area density (for different PV as well as CSP technologies). Some of the other findings along with the approach adopted by WISE are as follows.

- The studies utilized a mix of numerically modelled or statistically extrapolated solar insolation data.

  For the present study, WISE used numerically modelled data from commercial as well as academic sources. A sample comparison of the modelled data with other datasets like Meteonorm was also done.

- The majority of studies included considerations based on GIS, slope, shading effect and elevation to establish base-siting requirements.

  WISE assumed the following siting considerations: Slope <3% for CSP and <5% for solar PV, in addition to land-use inclusion of 'only wasteland' category.

- All the studies except that of WISE (which was not GIS-based), considered only one technology.

  As the present study on Tamil Nadu study requires evaluation of both solar PV and solar thermal potential, WISE considered only the following generation technologies under the solar PV and CSP technology family.

  - *Solar PV: crystalline PV and CPV*
  - *CSP: solar tower and solar trough*

  Furthermore, considering technology costs and potential, WISE gave preference to CSP over solar PV as CSP requires water in addition to a high value of solar DNI. CSP siting was done based on availability of surface water within a 10 km radius. Furthermore, for each technology family (PV and CSP), a single average land-use requirement for all technologies was taken as the basis for potential evaluation.

  *The land requirement for CSP was assumed as 35 MW/km^2 based on the report, '*Global Concentrated Solar Power Markets and Strategies, 2007–2020'*, while that for PV was taken as 50 MW/km^2, consistent with the industry norms for crystalline PV plants.*

- Based on literature and standard norms adopted by the industry, the established norm for minimum annual DNI is 1800 kWh/m^2 for CSP to ensure feasibility of currently established technologies.

  WISE used the same cut-off values (annual DNI of 1800 kWh/m^2 for CSP) for evaluating the adequacy of the solar resource. For PV technologies, a minimum annual GHI value of 1600 kWh/m^2 was assumed to reduce data processing efforts.

3.5 Solar PV & CSP Methodology for Potential Assessment of Solar Power

The basic approach for solar potential was to work out the net available area suitable for solar generation after excluding the technical, geographic and social constraint layers. This net area identified for each technology family, namely CSP and solar PV, was then to be converted into potential assuming average land utilization factor for each technology family (50 MW/km^2 for solar PV and 35 MW/km^2 for CSP).

Table 3.2 shows the assumptions used for solar power generation potential assessment for solar PV and CSP technologies.

Table 3.2 Assumptions for GIS and MCA-based solar potential assessment for Tamil Nadu

Parameter	Value	Remarks/sources
Average land requirement (PV)	50 MW/km^2	Based on WISE study/ Industry norm
Minimum GHI (PV)	1600 kWh/m^2	Based on field interactions
Maximum slope (PV)	5%	Based on industry norm
Minimum contiguous land	5 acres (0.02 sq. km)	Assuming minimum scale of 1 MW
Land availability	Only wasteland	
Parameter	**Value**	**Remarks/sources**
Average land requirement (CSP)	35 MW/km^2	Based on EEA report [Ref 14]
Minimum DNI (CSP)	1800 kWh/m^2	Based on CEA study (report of sub group II and III)
Water availability distance (CSP)	<10 km	Based on field interactions
Maximum slope (CSP)	3% for CSP	Based on industry norm
Minimum contiguous land (CSP)	38 acres (0.15 sq km)	Assuming 2.5 MW size
Land-use availability (CSP)	Only wasteland	

For off-grid assessment, government data coupled with GIS data was used for evaluation of the potential. Specifically, the potential assessment was done based on the following equations.

For rooftop PV

Potential = households in each district with concrete roofs × concrete roof area per household (assumed at 50 sq. m per household) × solar PV panel density (assumed at 0.05 kW/ sq. m).

For solar water heating

Potential = District-wise, number of non-institutional households with concrete roofs x collectors required to service water-heating requirement (assuming consumption of 100 litres per day [LPD]/per household and 2 sq m collector area for servicing 100 LPD).

For solar water pumping

Potential = net irrigated area of districts having water table <10 m (source: TN statistics and Tamil Nadu Water supply and drainage board [TWAD] × water requirement per area (conservative assumption of water requirement of maize by FAO**) × solar pumping potential (assuming Tata BP solar pump 1.2 kW with a discharge capacity of 17.625 m^3 /day).

For solar process heating

Potential = specific energy requirement of a process suitable for substitution (from industry manuals) × penetration of solar thermal heating in % (market data) × production figures of the product in Tamil Nadu (from industry associations).

Figures 3.1, 3.2, and **3.3** present figurative descriptions of potential assessment methodologies for CSP, solar PV, and off-grid solar respectively.

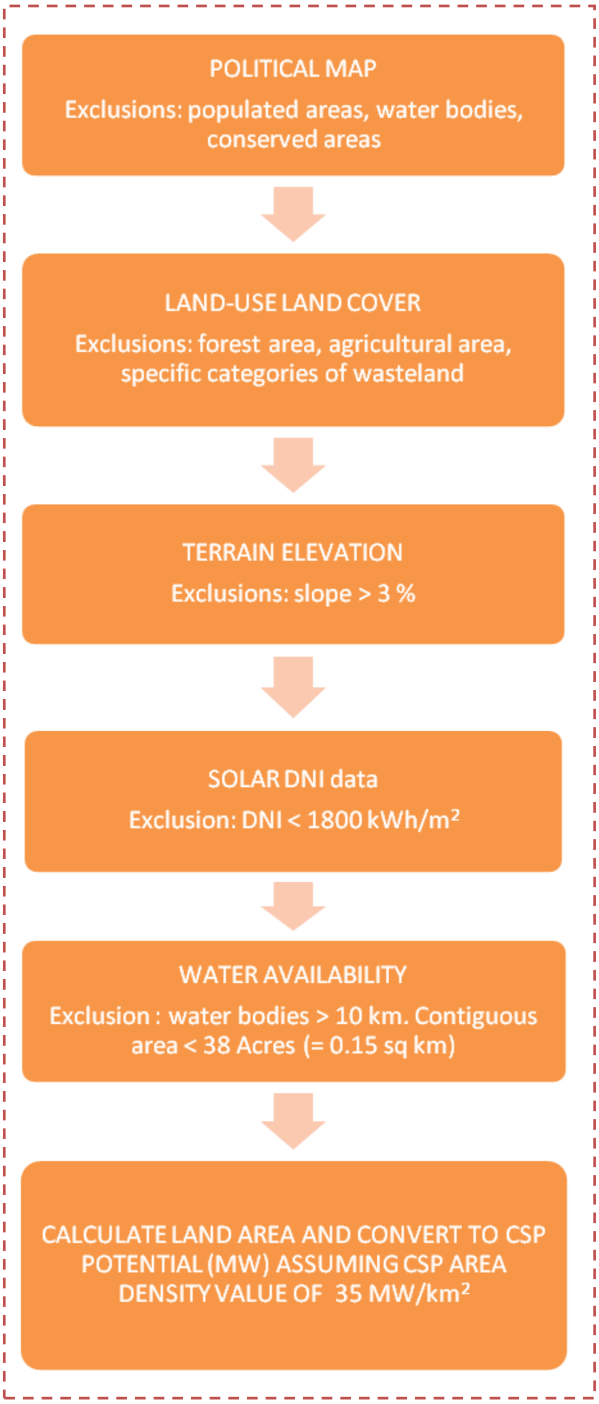

Figure 3.1 Criteria and methodology adopted for CSP potential assessment

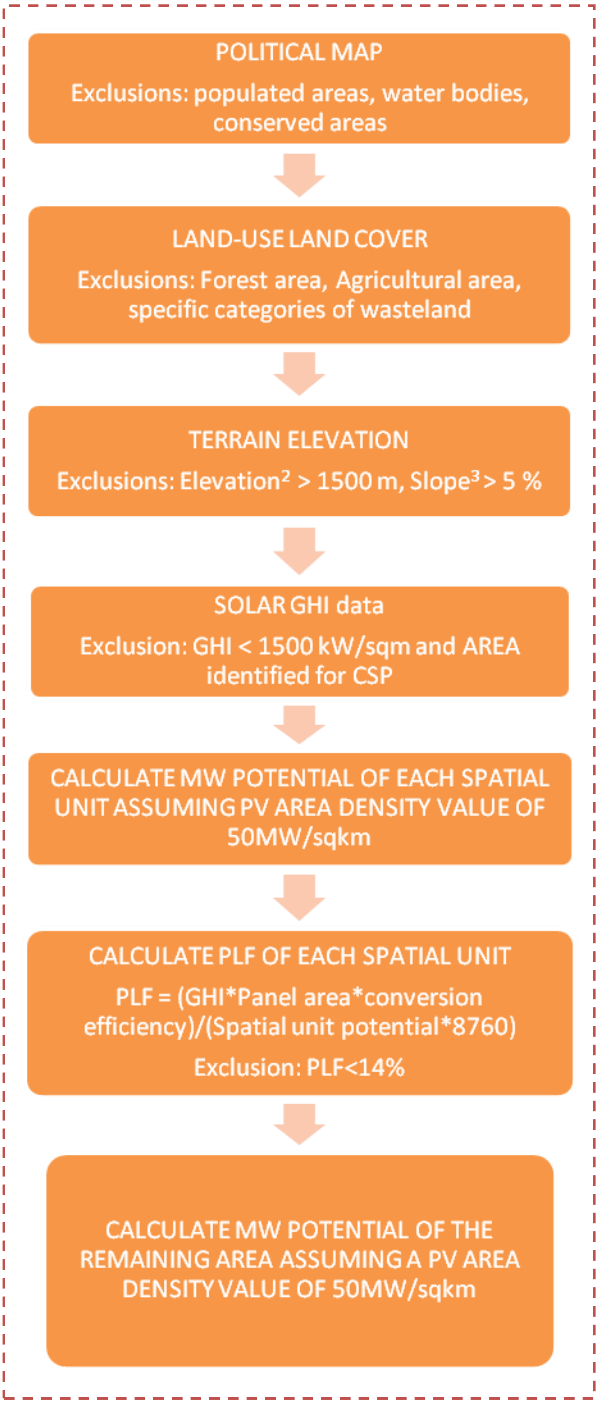

Figure 3.2 Criteria and methodology adopted for solar PV potential assessment

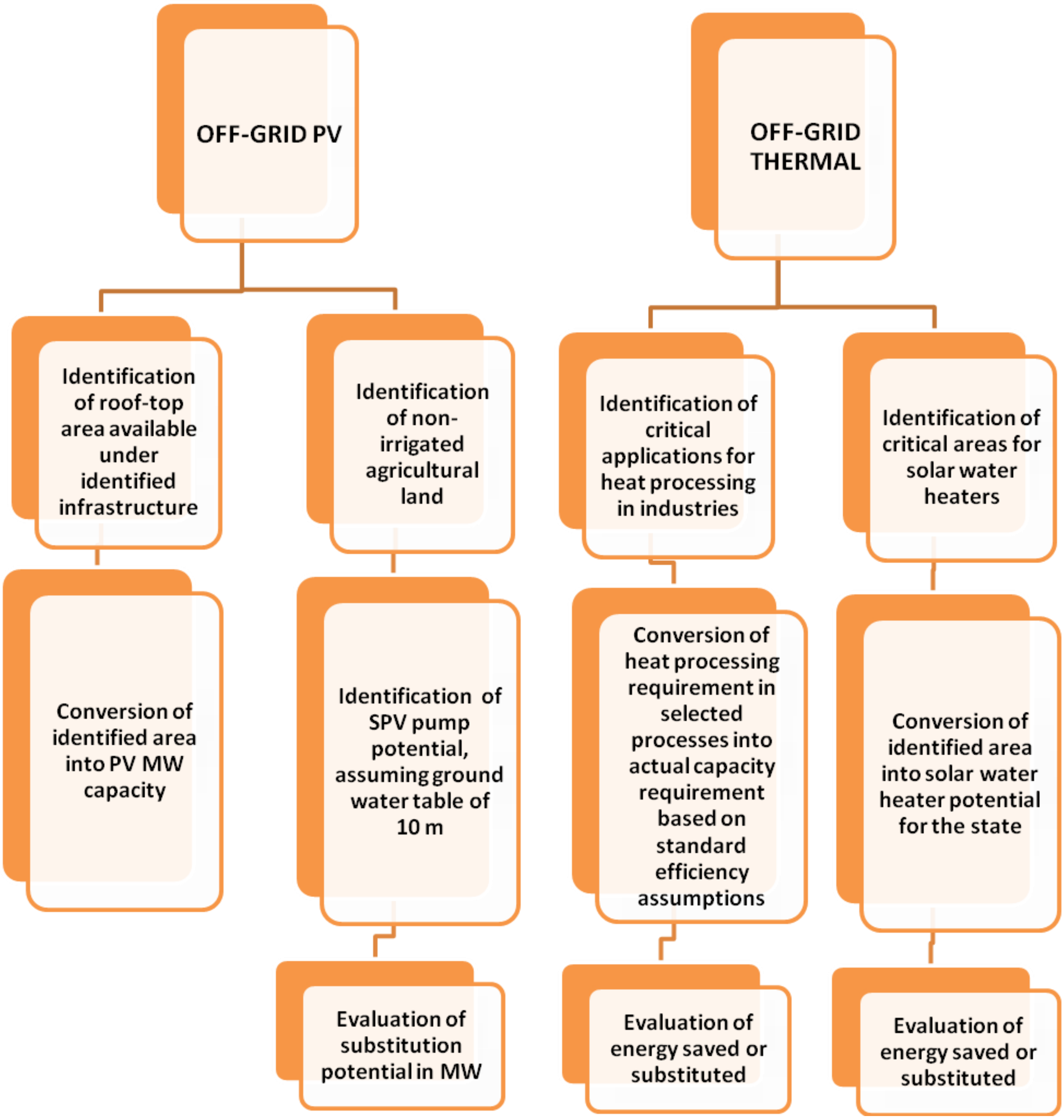

Figure 3.3 Potential assessment methodology for off-grid PV and thermal

Based on the finalized methodology, WISE analysed the potential for large-scale grid-tied solar power for both solar photovoltaic (PV) and solar thermal technologies using the following resource values and technical constraints.

3.6 Potential of Solar PV

Based on the decided methodology, three data layers, namely GHI, terrain slope, and LULC layer, were re-categorized based on the following criteria: land use: wasteland, slope<5% and GHI > 1600 kwh/ sqm. **(see Figure 3.4)**

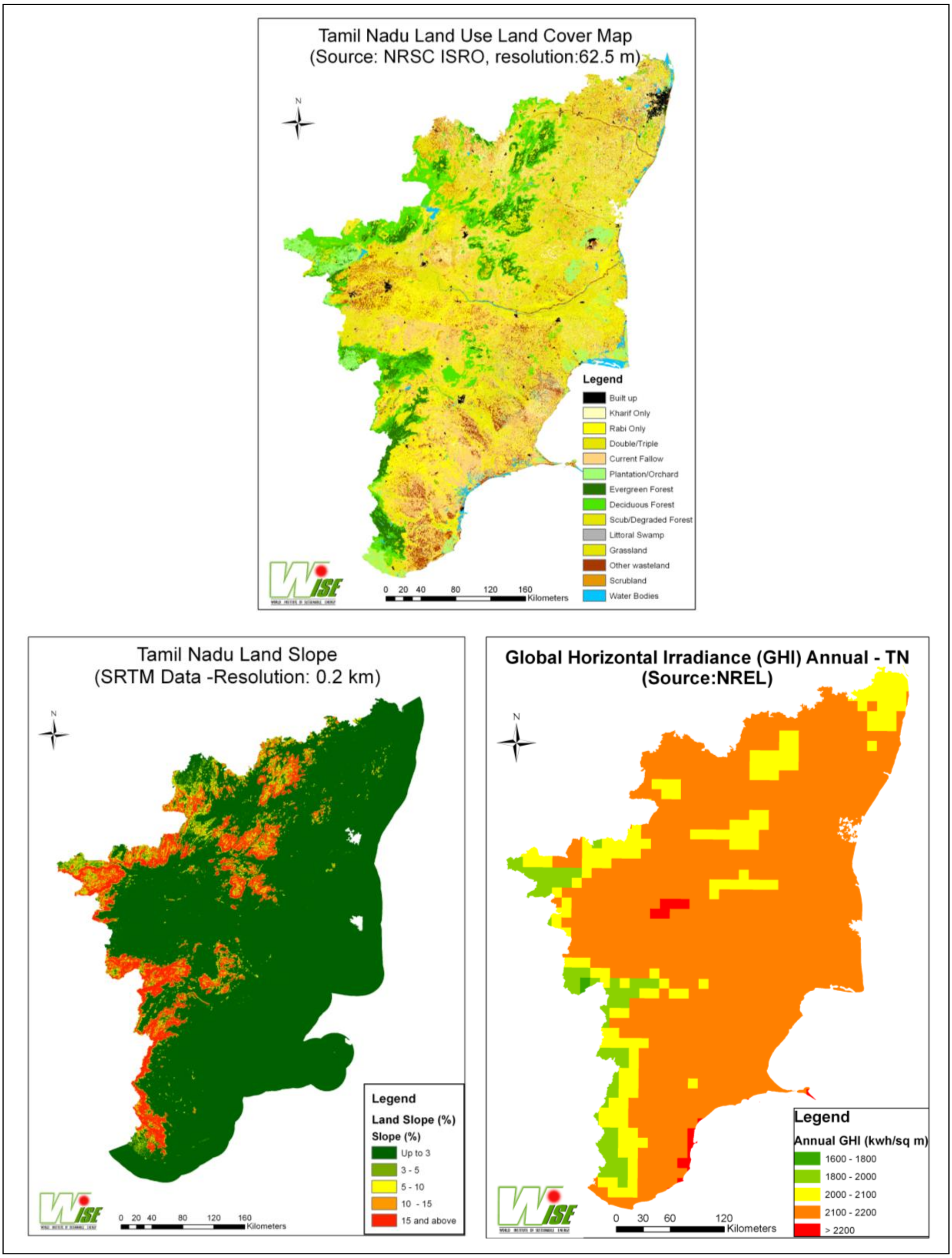

Figure 3.4 GIS base resource layers for solar PV potential analysis

The re-categorized layers were then overlaid to arrive at the common overlapping area, which was thereafter overlaid with permanent exclusions (land not available for development) and all common areas were removed from final consideration. In addition, areas with contiguous land area of less than five acres (0.02 sq. km), representing a minimum of 1 MW solar PV plant capacity were excluded. The remaining area was assumed as area available for solar PV development and was multiplied by the solar PV density function of 50 MW/sq. km to arrive at wasteland-based solar PV potential of Tamil Nadu.

Overlaying a district map on the final area yielded solar PV potential figures for each district. **Figure 3.5** depicts district PV potential area map based on annual GHI value categorization. **Table 3.3** is the stand-alone solar PV potential of each district.

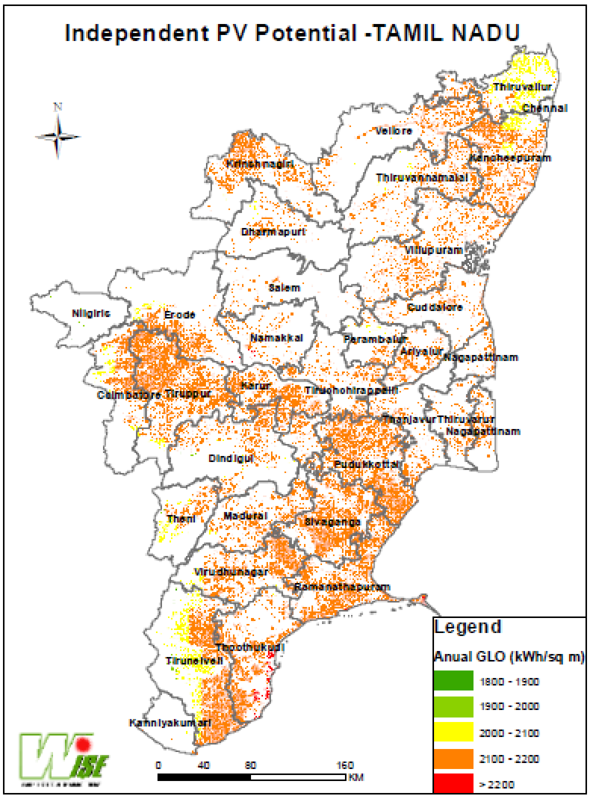

Figure 3.5 Potential of solar PV, by district

No.	District Name	Avg Ann GHI Kwh/sq m	Area Sq km	Potential MW
1	Ariyalur	5.82	73	3650
2	Chennai	5.77	1	70
3	Coimbatore	5.84	172	8576
4	Cuddalore	5.83	61	3047
5	Dharmapuri	5.88	23	1136
6	Dindigul	5.89	73	3647
7	Erode	5.93	127	6354
8	Kancheepuram	5.78	293	14648
9	Kanniyakumari	5.86	1	55
10	Karur	5.97	149	7440
11	Krinshnagiri	5.90	139	6928
12	Madurai	5.88	106	5319
13	Nagapattinam	5.84	37	1828
14	Namakkal	5.96	16	795
15	Nilgiris	5.26	0	16
16	Perambalur	5.78	34	1711
17	Pudukkottai	5.86	465	23226
18	Ramanathapuram	5.88	364	18177
19	Salem	5.92	18	897
20	Sivaganga	5.84	427	21359
21	Thanjavur	5.84	55	2752
22	Theni	5.79	61	3051
23	Thiruvallur	5.73	111	5556
24	Thiruvannamalai	5.79	95	4732
25	Thiruvarur	5.81	23	1167
26	Thoothukudi	5.87	384	19205
27	Tiruchchirappalli	5.88	122	6100
28	Tirunelveli	5.77	746	37310
29	Tiruppur	5.95	491	24554
30	Vellore	5.80	105	5255
31	Villupuram	5.81	111	5571
32	Virudhunagar	5.80	311	15554
		TOTAL	5194	259685

Table 3.3 Solar PV potential of each district (in MW)

3.7 CSP Potential in Tamil Nadu

The most critical data layer for CSP assessment was the DNI resource layer. The DNI data layer procured from GeoModel Solar indicated no CSP potential as the maximum resource value of 1,632 kWh/sq. m was less than the minimum resource requirement of 1800 kWh/sq. m for CSP feasibility. The project team decided to use the NREL database of 100 sq. km resolution. Based on the methodology, three data layers, namely DNI, terrain slope, and LULC layer, were re-categorized based on the following criteria. **(see Figure 3.6)** The criteria adopted for recategorizing CSP potential is given in **Table 3.4**.

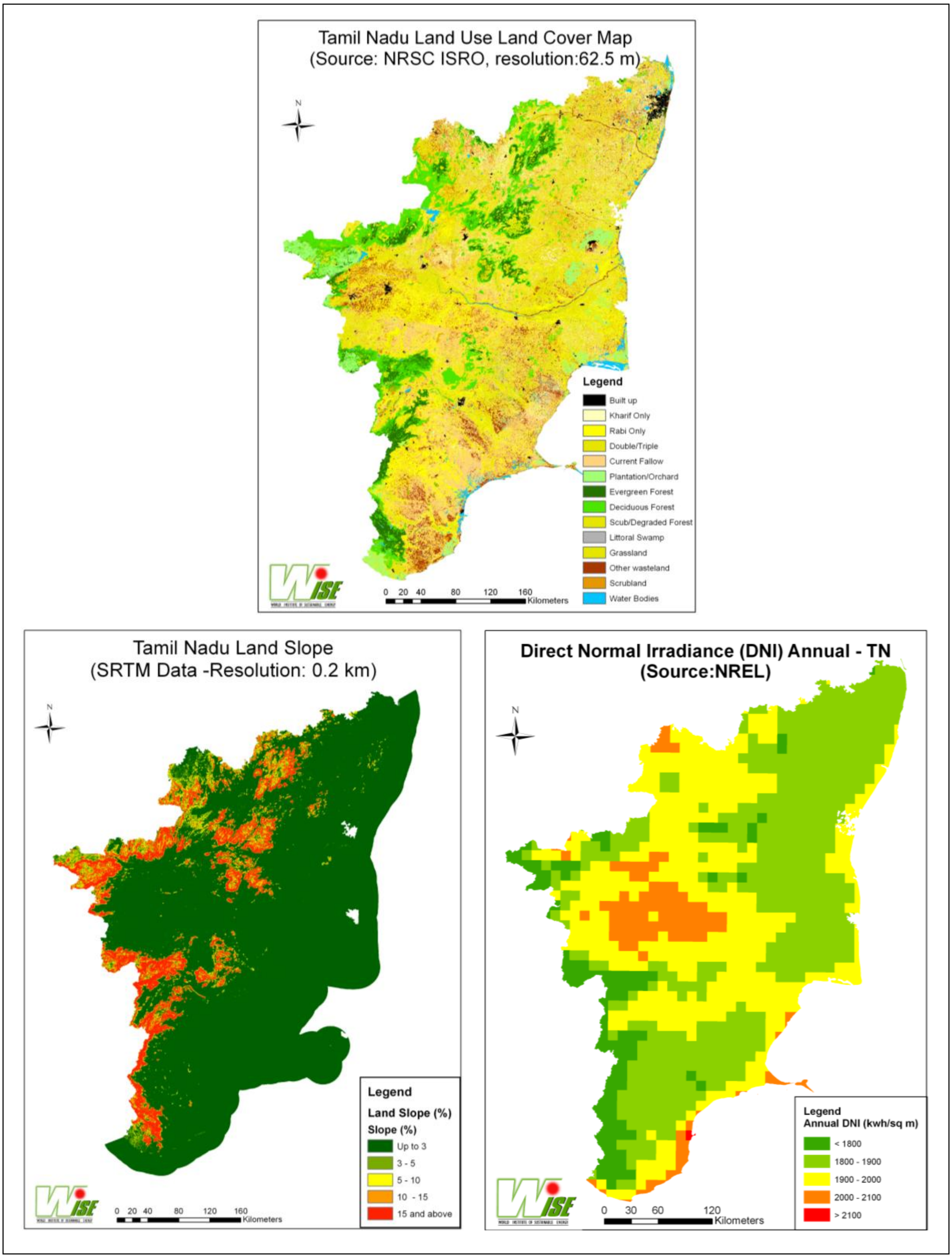

Figure 3.6 GIS-base resource layers for CSP potential analysis

Table 3.4 Basis for re-categorizing CSP Potential

GIS data layer	Re-categorization
Land use land cover (LULC)	Only wasteland
Terrain slope	Area < 3% slope
Direct normal irradiance (DNI)	Area > 1800 kWh/m^2 (mean annual DNI)

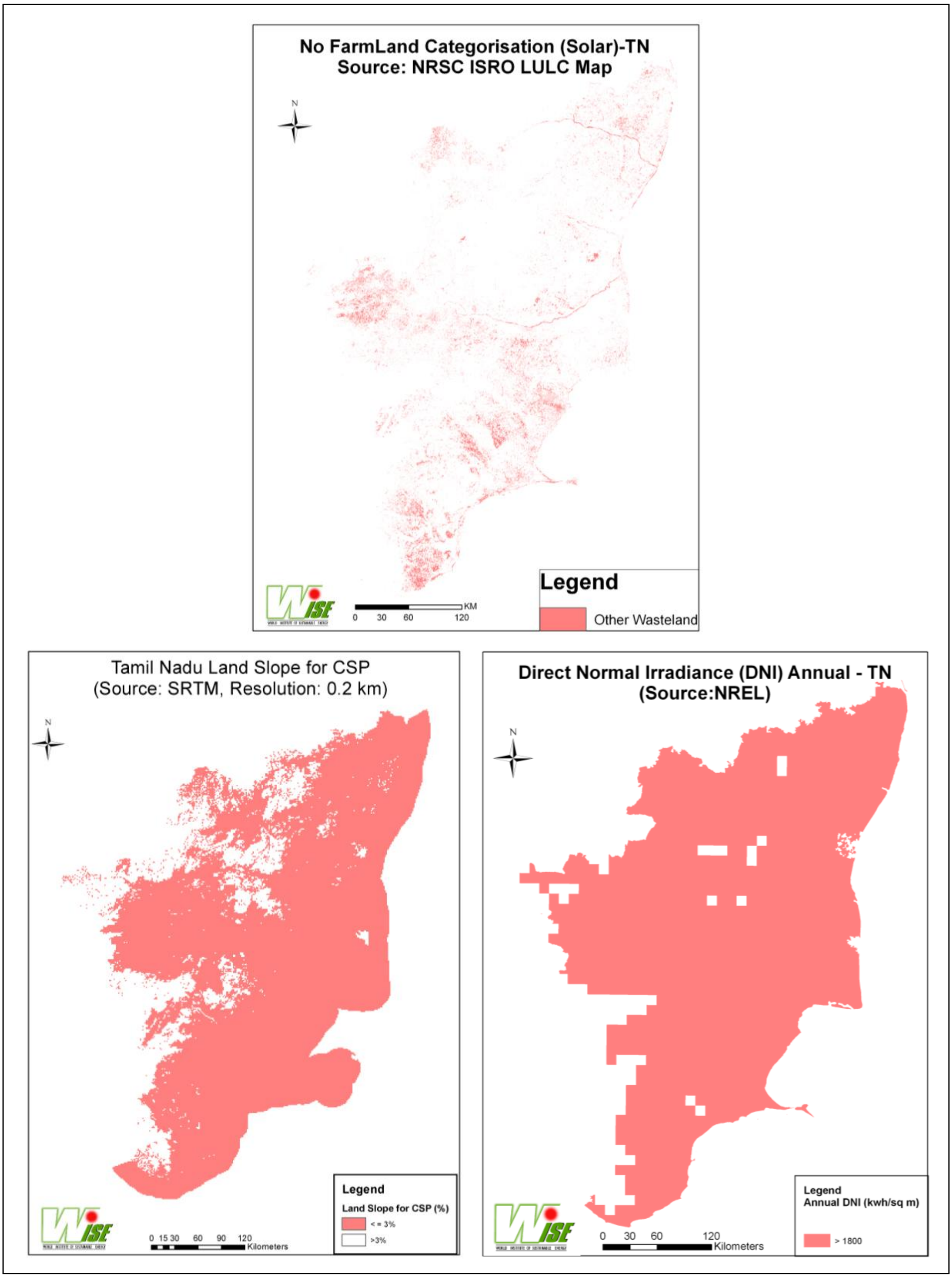

Figure 3.7 Re-categorized layers for CSP potential assessment

The re-categorized layers were then overlaid to arrive at the common overlapping area, which was then overlaid with permanent exclusions (land not available for development) and all common areas were removed from final consideration **(Figure 3.7)**. In addition, all contiguous areas less than 38 acres (0.15 sq km) were removed to limit the minimum single location capacity of CSP plant to 2.5 MW, the present lowest-capacity configuration available commercially. As CSP requires water, the final area map was overlaid with river and water bodies to select CSP potential areas falling within 10 km of a water source. The river stream layer is shown in **Figure 3.8**.

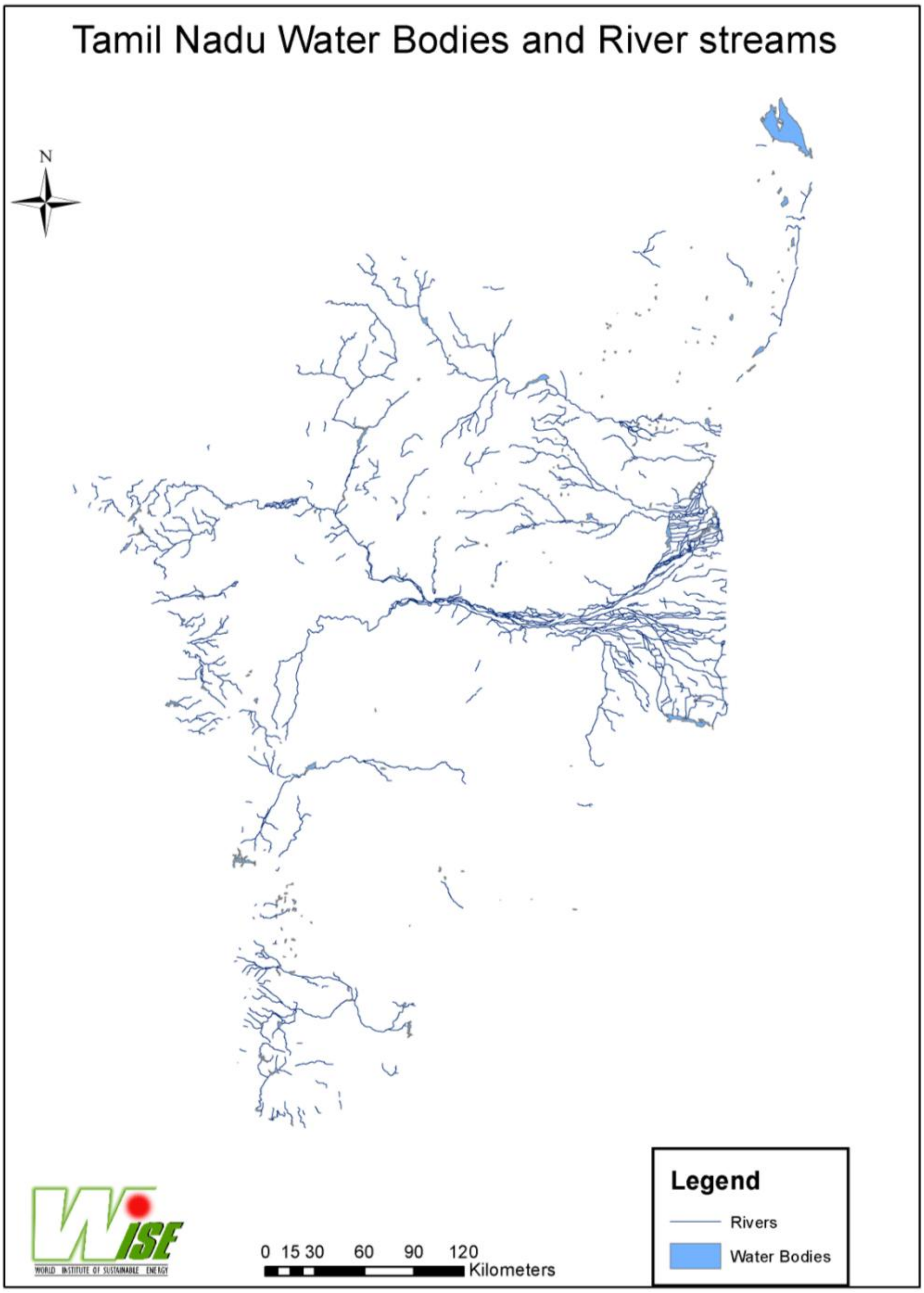

Figure 3.8 River stream layer

The final area within 10 km of a water source was assumed as area available for CSP development and was multiplied by the CSP technology density factor of 35 MW/sq km to arrive at the wasteland-based CSP potential of Tamil Nadu.

Overlaying a district map on the final area yielded CSP potential figures for each district **(see Figure 3.9)** based on annual DNI value categorization. **Table 3.5** gives the stand-alone CSP potential for each district.

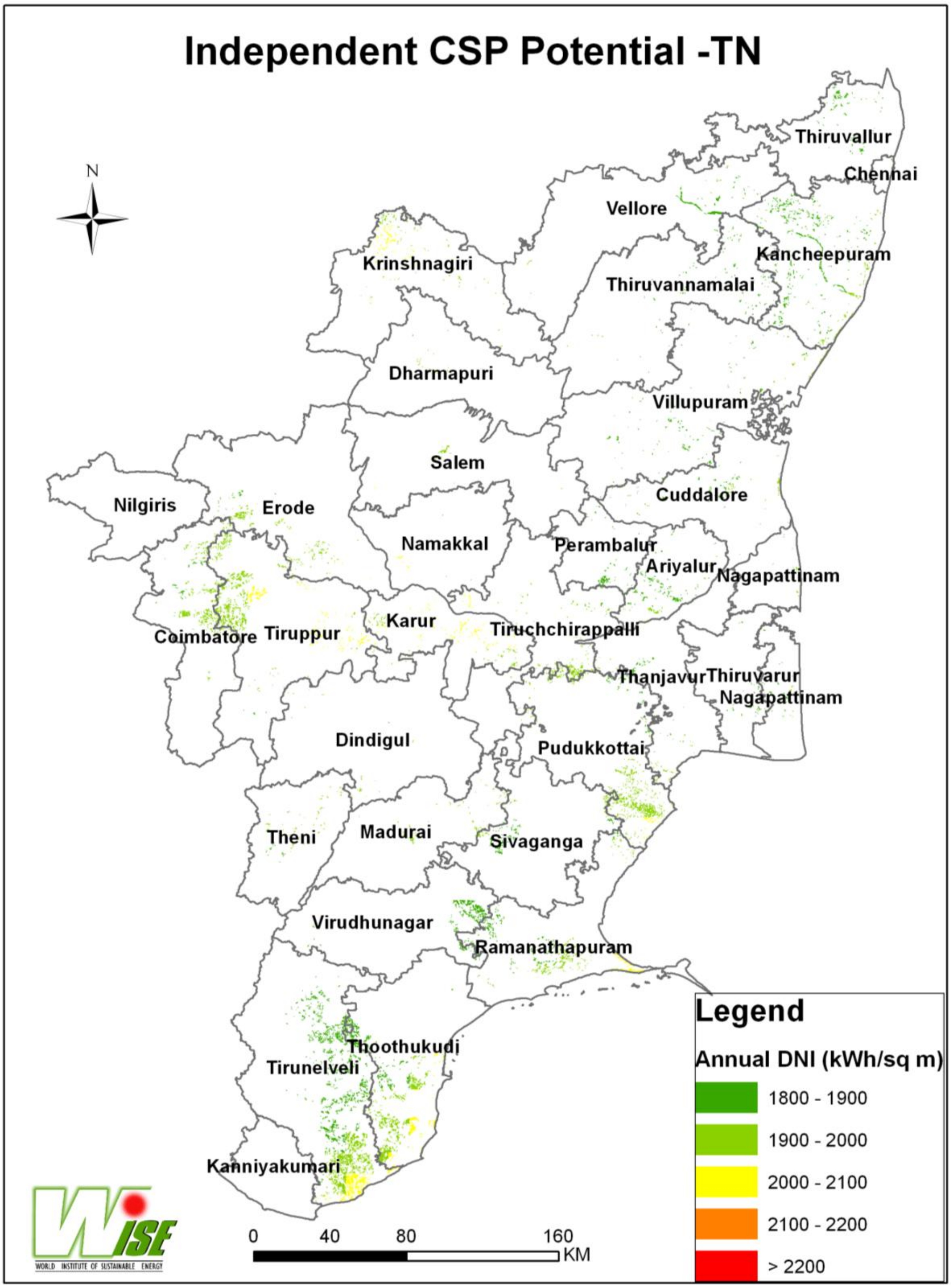

Figure 3.9 District-wise potential of CSP

Table 3.5 District-wise CSP potential (in MW)

Sr	District Name	Avg Ann DNI kWh/sq m	Area Sq Km	Potential MW
1	Ariyalur	5.18	49	1716
2	Chennai	5.06	1	41
3	Coimbatore	5.41	105	3668
4	Cuddalore	5.22	35	1211
5	Dharmapuri	5.40	5	173
6	Dindigul	5.39	6	224
7	Erode	5.42	53	1865
8	Kancheepuram	5.13	159	5555
9	Kanniyakumari	5.01	0	0
10	Karur	5.49	50	1752
11	Krinshnagiri	5.48	48	1670
12	Madurai	5.31	25	858
13	Nagapattinam	5.23	15	512
14	Namakkal	5.46	4	135
15	Perambalur	5.13	21	725
16	Pudukkottai	5.30	172	6036
17	Ramanathapuram	5.40	124	4347
18	Salem	5.23	8	293
19	Sivaganga	5.24	53	1841
20	Thanjavur	5.23	31	1080
21	Theni	5.29	21	719
22	Thiruvallur	5.03	29	1022
23	Thiruvannamalai	5.09	35	1211
24	Thiruvarur	5.15	10	366
25	Thoothukudi	5.38	248	8664
26	Tiruchchirappalli	5.33	63	2208
27	Tirunelveli	5.28	511	17872
28	Tiruppur	5.44	202	7086
29	Vellore	5.14	39	1364
30	Villupuram	5.16	52	1829
31	Virudhunagar	5.04	71	2483
TOTAL			**2244**	**78525**

3.8 Off-grid Solar Potential

Rooftop PV

In order to estimate rooftop solar PV potential in non-institutional households, the data source used by WISE was the Census of Tamil Nadu 2011, published by the Directorate of Census Operations, Tamil Nadu. The methodology followed in arriving at district-wise estimation of rooftop solar PV potential in non institutional households is as follows:

District-wise, the number of non-institutional households with concrete roofs x concrete roof area per household (assumed @ 50 sq.m/per household) × solar PV panel density (assumed @ 0.05 kw/ sq.m)

A similar calculation was done for institutional households with available rooftop area being assumed different for different institutional household categories.

The total potential for rooftop PV was estimated at 29,642 MW.

Solar water heating

In order to estimate solar water heating potential in non-institutional households, the data source used by WISE was once again the Census of Tamil Nadu 2011. The methodology followed in arriving at district-wise estimation of rooftop solar water heating potential in non-institutional households is as follows:

District-wise, number of non-institutional households with concrete roofs x collectors required to service water-heating requirement (assuming consumption of 100 litres per day [LPD]/per household and 2 sq m collector area for servicing 100 LPD).

The estimated potential was assessed as equivalent to a collector area of about 16.15 million sq m.

Solar water pumping

In order to estimate solar water-pumping potential in agriculture, the data for the district-wise net area sown and irrigated during 2009-10 was taken from the Statistical Hand Book – 2011 [Ref 15] (the only available data source). The methodology followed in arriving at district-wise estimation of solar water pump potential in agriculture is as follows.

Net irrigated area of districts having water table <10m (source: TN statistics and Tamil Nadu Water Supply and Drainage Board [TWAD] × water requirement per area (conservative assumption of water requirement of maize by FAO [http://www.fao.org/nr/water/cropinfo_maize.html]) × solar pumping potential (assuming Tata BP solar pump 1.2 kW with a discharge capacity of 17.625m3 /day)

Based on the data available and the methodology, the total substitution potential for solar PV pumping was assessed at 7,041 MW.

Solar process heating

In order to estimate solar industrial process heating applications, the most important consideration was identifying processes and industries suitable for available solar-heating technologies. As solar water heating can supply temperatures up to 100-120° C, there are simply too many processes across major industrial segments that can actually be substituted by solar process heating applications.

However, the actual assessment of solar process heating potential requires authentic data related to process engineering (conventional heat source and specific heat consumption for a particular process) as well as industrial production data for the state. A recent report by PricewaterhouseCoopers (PwC) India titled *Identification of Industrial Sectors Promising for Commercialization of Solar Energy* [Ref 16] details specific heat requirements for some selected processes.

However, WISE also interacted with independent consultants and experts working in the field of solar process heating applications to understand their views on potential estimation. According to them, arriving at a potential output in terms of energy equivalent was difficult because process and product variations within the same industries made generalizations difficult. Detailed state-specific data could only be gleaned from field visits and process analysis, which was beyond the scope of the present study.

In view of the above, WISE decided to do an indicative analysis only for one sector based on the data available in the PWC report. As Tamil Nadu is considered a textile hub of India, the Textile sector (Cotton Cloth Manufacturing) was considered for detailed analysis. The sizing process in Textile (Cotton Cloth Manufacturing) requires hot water at a temperature in the range of 80-85°C. In order to arrive at the potential for replacement of conventional process heating with solar process heating for the sizing process, WISE used some secondary data in addition to the assumption data set from the PWC report. **Table 3.6** summarizes the derivation of the potential for substitution in sizing process.

Table 3.6 Solar process heating substitution potential for sizing process in cotton cloth manufacturing

Parameter	Unit	Equation	Values	Reference
Hot water requirement per kg of cotton fabric for sizing	Litres/kg	A	2	Pwc report[35]
Energy required to heat one litre of water to 90°C	Kilo Joules/Litre	B	293	Pwc report[35]
Specific energy requirement for sizing process	Kilo Joules/Kg	C= A × B	584	Derived
Total production of cotton cloth in India (2011-12)	Million Sq m	D	30592	Refer Note 5.1
Cotton cloth production in Tamil Nadu as percentage of national production	%	E	6.69%	Refer Note 5.2
Area density of textiles	Kg/Sq m	F	0.2	Pwc report[35]
Total cotton cloth production in Tamil Nadu	Million Kg	G= D × E × F	409	Derived
Statel level energy requirement for sizing process	Giga Joules	H =C × G	239043	Derived
Penetration of solar process heating	%	I	25%	Pwc report[35]
Energy saving potential for sizing process	Giga Joules	J= H × I	59761	Derived

Sources of Table 3.7
Textile Ministry, http://www.texmin.nic.in/ermiu/pdata/prod_var_cloth.asp
Article 'Short notes on Localisation of cotton textile industry' by A Raja
http://www.preservearticles.com/2012013022102/short-notes-on-localisation-of-cotton-textile-industry.html

The above mentioned potential (59,761 GJ) is just indicative. Because of the complexities associated with processes, product variations, location-specific practices across the same industries, a generalized analysis (especially in the absence of actual installation performance data) has not been replicated for all other industries and processes. A separate study focusing on single industrial cluster is called for, to accurately assess implementable potential for solar process heating applications

Summary of off-grid potential

WISE covered four off-grid processes: rooftop solar PV, rooftop solar water heating, solar water pumping and solar industrial process heating. Potential assessment for all four technologies was done on tabulated basis without using GIS. The assessed potential for off-grid technologies based on the methodology and set of assumptions is shown in **Table 3.7**.

Table 3.7 Off-grid potential of solar technologies

Off grid		
Rooftop PV	MW	29643
Solar water heating	million sq m	16.15
Solar pumping	MW	7041
Solar process heating*	Gigajoules	59761
*Potential only of sizing process in cotton cloth manufacturing		

Base data taken from Census

Table 3.8 shows the district-wise potential of all off-grid technologies

Table 3.8 Off-grid potential (District-wise) of solar technologies

Sr No.	District	Rooftop PV (MW)	Solar water heating (1000' sq m)	Solar Water Pumping (MW)
1	Thiruvallur	1811	1159	217
2	Chennai	2528	1724	0
3	Kancheepuram	1893	1171	262
4	Vellore	1677	985	220
5	Thiruvannamalai	933	524	351
6	Villupuram	1103	592	581
7	Salem	1392	632	257
8	Namakkal	711	309	175
9	Erode	881	398	325
10	The Nilgiris	224	90	1
11	Dindigul	765	367	261
12	Karur	422	214	140
13	Tiruchirappalli	1178	677	243
14	Perambalur	231	120	67
15	Ariyalur	244	92	79
16	Cuddalore	825	450	351
17	Nagapattinam	544	257	307
18	Thiruvarur	409	188	370
19	Thanjavur	811	398	416
20	Pudukottai	546	238	275
21	Sivaganga	522	249	200
22	Madurai	1595	903	195
23	Theni	483	278	151
24	Virudhunagar	1038	539	134
25	Ramanathapuram	490	248	167
26	Thoothukudi	671	416	101
27	Tirunelveli	1404	714	287
28	Kanyakumari	840	506	69

Sr No.	District	Rooftop PV (MW)	Solar water heating (1000' sq m)	Solar Water Pumping (MW)
29	Dharmapuri	516	233	156
30	Krishnagiri	678	329	119
31	Coimbatore	1393	778	275
32	Tiruppur	884	374	288
	Total	**29643**	**16150.25**	**7040**

3.9 Analysis of Results

Table 3.9 summarizes the results for the two grid-tied technologies using two datasets and also captures the off-grid potential for four main off-grid solar technologies: rooftop PV, solar water heating for institutions and households, solar water pumping for agriculture and solar process heating for industrial applications.

Table 3.9 Results of solar potential assessment

Solar potential assessment			
Solar potential assessment	**Data**	**Area**	**Potential**
Technology type	**Unit**	**Sq km**	**MW**
Grid-tied solar PV			
Solar PV (Source: NREL GHI data)	MW	5194	259700
Solar PV (Source: GeoModel data)	MW	5254	262700
Grid-tied solar thermal			
CSP (Source: NREL DNI data)	MW	2243	78505
CSP (Source: GeoModel data)	MW	0	0
Off-grid			
Rooftop PV	MW	NA	29850
Solar water heating	million sq m	NA	16.15
Solar pumping	MW	NA	7041
Solar process heating*	giga joules	NA	59761
*Potential only of sizing process in cotton cloth manufacturing			

Solar PV

In terms of spatial spread, almost every district in Tamil Nadu has some potential but districts like Tirunelveli (37,310 MW), Tiruppur (24,554 MW), Pudukottai (23,226 MW), Sivaganga (21,359 MW), Virudhnagar (15,554 MW) and Kancheepuram (14,668 MW) hold the bulk of the potential. However, the highest quality sites, in terms of resources (GHI>1900 kWh/sq m), are in Thoothukudi (19,205 MW) and Ramanathapuram (18,177 MW).

CSP

The stark contrast in the results of the two datasets (NREL data indicates a potential of 78 GW while GeoModel data suggests no potential) is reflective of the modelling uncertainties related to solar DNI data. As discussed, there is no conclusive technical proof to validate one dataset over another but inputs from field for established CSP projects indicate DNI values significantly lower than those estimated by NREL. On the other hand, the accuracy of GeoModel data also cannot be ascertained without comparing actual field values in Tamil Nadu with measured data, which is difficult to get.

In view of the same, it is recommended that more rigorous field-level verification, including resource assessment and pilot projects, be carried out.

However, insights can be drawn from the analysis in terms of identifying areas where such pilot studies can be undertaken. Based on the assessment, Thoothukudi, Ottapidaram, Tiruchedur, and Santhakulam talukas of Thoothukudi district; Dharapuram, Tiruppur, Kangeyam, and Palladum talukas of Tiruppur district and some parts of Karur and Krishnagiri districts show good resource potential (annual DNI >2000 kWh/sq m) and can be identified for detailed study.

Off-grid Solar

Tamil Nadu also has a large potential for off-grid solar applications. Based on tabulated analysis, the rooftop PV potential for Tamil Nadu on gross availability of concrete roofs is about 30,000 MW; even availability of 33% concrete roofs implies implementable potential of 10,000 MW. However, the actual implementable target is dependent on policy and regulatory support. New regulatory measures like feed-in tariffs for rooftops or net metering can significantly impact the deployment by reducing the financial viability gap. Policy measures can aim at increasing the reliability of the system starting from supply to servicing, by introducing measures like empanelment, coupled with strong performance monitoring and system performance guarantees to instill confidence in investors and help in building long-term systemic sustainability.

Solar water heating potential for the state assumes the use of around 100 LPD of hot water per household. The potential of about 16.15 million sq m collector area translates into a water heating potential of 33 million LPD. Assuming substitution potential of 1500 electricity units annually (based on MNRE data) [Ref 17] by replacing an electrical 100 LPD water heating unit and assuming 10% substitution potential, the energy-saving potential will be to the tune of 4,950 MU, equivalent to average 15-20 days of consumption for the whole state. While subsidy and incentive mechanisms are in place for these applications, the disbursement model needs improvement.

Solar pumping potential at 7,400 MW implies substantial savings in electricity and grid losses for the Tamil Nadu Electricity Department (TNED). As this figure is based on a number of assumptions related to electrified pumps, water requirement for agriculture, water table, etc., the actual solar pumping potential could be significantly different. There is a need for a taluka-level study to assess actual substitution potential.

Solar process heating for industrial applications is a vast area. Based on data availability, potential assessment was only done for one process in one industry. However, considering the capability of present systems to deliver water temperatures of up to 100°–120° C, many processes across major industries can use solar process heating applications. There are specific processes where the commercial potential of these technologies is high enough to discount the need for any direct fiscal support from the government. However, for other processes, the payback period could be high enough to warrant some basic support in terms of subsidy. More important, there is also a need to create awareness about the potential of solar process heating applications as the knowledge in the industry about these applications is limited. In the absence of a large and dynamic service industry in this sector, it is for the government to increase the knowledge-base and generate an understanding in the industry about the potential benefits of solar process heating applications.

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4. Wind Power Potential in Tamil Nadu

4.1 Literature Review

The study titled *A GIS-based assessment of potential for wind farms in India,* 2011 [Ref 18], assessed the wind power potential in India to be 42,50,000 MW. Deviating from the concept of a ballpark percentage availability of land, this study considered all the available land area (almost 83% of the Indian land mass), other than the Himalayan regions, ecologically sensitive areas and human settlements. The study extrapolated measured CWET and National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) data to derive a wind resource map across a 1 sq km grid resolution at 80 m hub height using the boundary layer technique. The annual energy estimates were calculated for each grid assuming a normalized power curve, an 80 m rotor diameter for a 1 MW turbine, and a turbine density of 3 MW/ km^2. In the final step, all the sites with capacity utilization factor (CUF) less than 15% were masked, and potential was arrived at for each grid element and then added to arrive at the final figure of 42,50,000 MW.

The second study titled, *Reassessing Wind Potential Estimates for India: Economic and Policy Implications*, March 2012 [Ref 19], assesses the all-India potential at 80 m to be 20,06,000 MW. This study uses more advanced modelling and GIS tools for a grid size of 3.6 X 3.6 km to arrive at the potential at three hub heights of 80 m, 100 m and 120 m, and assesses the potential assuming 100% availability of wasteland, farmland, and non-forest scrubland. The wind resource data is a numerical model based data procured from 3 Tier. The study excludes land areas with wind power density less than 200 W/m^2, slope greater than 20%, elevations greater than 1500 m, and assumes a turbine density of 9 MW/km^2. For the state of Tamil Nadu, the expected potential at 80 m was estimated to be about 380,000 MW.

In yet another study titled, *Global potential for wind-generated electricity*, 2009 [Ref 20], numerically modelled wind speed data (GEOSS 5 analysis) extrapolated to 100 m hub height was used along with a 2.5 MW onshore and 3 MW offshore turbine power curve (General Electric [GE] models) and an onshore turbine density of about 9 MW/km^2 for onshore and 5 MW/km^2 for offshore, to evaluate the wind power potential worldwide. The standard exclusions included areas under forest, ice, water and population clusters. The technical exclusion included CUF of less than 20%. The results of the global study, which are in Terra Watt Hours (TWh= 10^6 MWh) generation, are not as relevant in the present context, but the study has been included as the assumptions could form the basis for our analysis.

Other major studies that were referred to during the literature survey included *Europe's Onshore and Offshore Wind Energy Potential* [Ref 21], *Wind Power Project Site-Identification and Land Requirements* [Ref 22], *Evaluation of Renewable Energy Potential using a GIS Decision Support System* [Ref 23], and, *An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States* [Ref 24].

A few of the major insights drawn from these studies are summarized below along with the approach adopted by WISE are as follows:

- In all the studies, one of the two methodologies was used for evaluation of wind resources at micro-scale. The first methodology was based on the extrapolation of measured data, the other was based on numerical modelling. Because of limitations of measured data availability, recent studies have relied more on numerically modelled wind data.

For the present study, WISE used numerically modelled data. Due to time and cost limitations, the verification of such data with respect to actual on site measurements was difficult and could not be included in the study.

- Two main resource assessment methodologies were used, one of which considered wind power density (WPD) as the cornerstone of large-scale wind potential assessment methodologies. This method used the power law equation to calculate potential, by multiplying WPD value, performance coefficient (Cp), rotor area and drive train efficiency. The alternative method of using wind speed data with a standard power curve was employed in some recent studies. This method converts the frequency distribution of speed into frequency distribution of power by correlating each wind speed to the power coordinate in the power curve.

  The first methodology is simpler but the second is more representative of the actual field value as there is little dependence on performance coefficient or drive train efficiency, and the process automatically excludes wind speed distribution less than cut-in and greater than cut-off to simulate actual generated power.

  WISE used the wind speed power curve correlation method using statistical parameters of wind resource for wind power potential assessment.

  In line with the studies referred, WISE evaluated the potential at three hub heights, namely 80 m, 100 m and 120 m.

  *WISE used the standard power curve for these three representative class III machines on offer in the Indian market as the basis for evaluating wind potential for the three hub heights as shown in **Table 4.1**. Class III (IEC classification) machines are specifically designed for low wind regimes and perform better than class II or class I machines in the Indian wind regime.*

Table 4.1 Specifications of representative class III A wind turbines

Wind potential assessment height	**80 m**	**100 m**	**120 m**
Manufacturer/model	Suzlon- (S82)	Vestas V100	Vestas V112
Machine rating (MW)	1.5	1.8	3
Hub height (m)	78	100	120
Rotor diameter (m)	82	100	112
Cut in speed (m/s)	4	3	3
Rated speed (m/s)	14	12	12
Cut-out speed (m/s)	20	20	25
Class	III A	III A	III A

- Turbine density (installable potential per MW per square km) is a function of local land features, turbine rating and directional pattern of wind. At a site where one wind direction is predominant, a closed spacing of 3D/5D can be used. However, in areas having more than one predominant wind direction, the spacing requirement will be considerably more. Again, change in the normative turbine size also affects the turbine density considerably. The general figures assumed for turbine density across the reviewed studies vary from 3 MW/km^2 to 11 MW/km^2.

  However, considering the present mandatory requirement of 5D × 7D criteria for micro-siting of wind turbines in Tamil Nadu, WISE used a turbine density of 7MW/km^2 for all three hub heights, namely 80 m, 100 m and 120 m.

- The recent wind atlas of CWET also categorizes wind zones in terms of WPD after screening out areas with WPD<200 W/m^2 at 50 m hub height. The Lawrence Berkeley National Laboratory (LBNL) study also screened out wind sites with WPD less than 200 W/m^2 at 50 m. However, the recent stipulation by the Ministry of New and Renewable Energy (MNRE) has done away with the criteria leaving no lower limit for WPD value.

  However, to limit data processing and avoiding undue computations, WISE used a lower limit of 150 W/m^2 at all the three hub heights. In addition, a net CUF cut-off value of 15% was chosen to treat wind at par with solar power, the accepted CUF range of which is comparatively low.

- In most of the GIS-based studies, area exclusions included forest land, populated places, elevations greater than 1500 m and slopes of over 15%.

  In line with the above studies, WISE excluded forestland, water bodies, populated areas, conserved areas, and elevations of greater than 1500 m and slopes of over 15%. However, considering the fact that the majority of present installed wind capacity in Tamil Nadu is on farm land, WISE built two land-use scenarios, one representing use of wasteland and the other representing non-irrigated agricultural land.

4.2 Land Use for Wind Power

Established resource-assessment methodologies usually consider only wasteland as land recommended for development. However, it was felt that wind power potential assessment based on such a criteria would not be consistent and true to the actual ground realities in Tamil Nadu: the majority of the wind development in the state has happened on agricultural land, where wind turbines installed on footprint basis on farmland area have co-existed with farming. This model of development has evolved specifically in Tamil Nadu because wind rich regions like Tirunelveli, Tiruppur, Coimbatore, Theni, etc., have a predominance of agricultural land.

The fact that wind power has co-existed with farming in Tamil Nadu makes a strong case for the sustainability of the co-existence model, especially in view of the fact that the actual footprint of even new high-capacity turbines is only about three to five acres and the remaining area surrounding the turbine tower and substation can be used for farming. In view of the same, WISE decided to include farmland in GIS-based assessment of wind. However, in line with standard practices, WISE decided to exclude irrigated farmland areas from any potential assessment consideration.

Furthermore, in line with the actual field practices of land use, WISE decided to club wasteland and non-forest scrubland as 'No Farmland' area for wind development. Based on the above, the three different land-use categorization considered for wind power potential assessment are as shown in **Table 4.2** below.

Table 4.2 Land-use categorization for wind power potential assessment

LULC Code	Code description	Area (Sq km)	% Inclusion	Land-use categorization
2	Kharif only	9686	100%	WIND FARMLAND (54925 Sq Km)
3	Rabi only	21606	100%	
6	Current fallow	23633	100%	
13	Other wasteland	7549	100%	WIND NO FARMLAND (15415 Sq Km)
15	Scrubland	7866	100%	

LULC Code	Code description	Area (Sq km)	% Inclusion	Land-use categorization
1	Built up	977	0%	EXCLUDED LAND
5	Double/triple (irrigated)	32309	0%	
7	Plantation/0rchard	3837	0%	
8	Evergreen forest	5632	0%	
9	Deciduous forest	13433	0%	
10	Scrub/degraded forest	1905	0%	
12	Grassland	153	0%	
16	Water bodies	2273	0%	

4.3 Wind-Resource Data

WISE procured modelled wind resource data from AWS Truepower, USA, a leading resource-assessment firm. Based on the scope of supply, AWS supplied raster and vector datasets of wind-power density and Weibull c and k parameters, respectively. The GIS format data was supplied for three hub heights (80 m, 100 m, and 120 m) and had a resolution of 200 m × 200 m.

The modelled data was compared with CWET mast data at 14 random locations. The correlation between the two datasets for the 14 sample points was found to be **0.845**. Considering the high value of correlation coefficient, the model seemed to have a good correspondence with the measured data.

4.4 Methodology for Wind Power Potential Assessment

WISE used the wind speed-to-power curve correlation using statistical parameters for wind potential assessment. The calculations involved the use of cumulative speed distribution function using Weibull c and k parameters and the corresponding power value from the machine power curve. The average power was calculated based on the following equation:

$$P_{avg} = \int P(V)*p(V)\, dV = \sum P[(Vi+1+ Vi)/2]*[f(Vi+1)- f(Vi)]$$

which can be approximated to

$$P_{avg}= {}^{i= \text{cut in to rated speed}} \sum P[(Vi+1+ Vi)/2]*[f(Vi+1)-f(Vi)] + P_{rated} * [f(V_{cut\text{-}out})-f(V_{rated})]$$

where P (V) is the power curve function representing power at speed V and f(V) is the cumulative distribution function representing probability of speed being less than V.

The function can be represented in terms of Weibull c and k parameters as follows:

$$f(V) = 1- \exp[-(V/c)^k]$$

In addition to onshore wind potential assessment based on GIS and MCA, offshore wind assessment was also done. Under offshore assessment, the exclusion criterion was a seabed depth of over 30 m, a distance to coast of beyond 25 km and CUF of less than 20%. The other assumptions and methodology were similar to that used for onshore wind.

The repowering potential for Tamil Nadu was also estimated by identifying capacity installations of machines with less than 500 kW rating installed before 2002 and assuming their replacement with a repowering ratio of 2. This exercise was drawn from an earlier repowering potential assessment exercise done by WISE.

As value addition, WISE also explored the possibility of arriving at large wind-solar PV integrated potential on wasteland areas. For determination of usable un-shaded area for PV installations within a wind farm, WISE used the assumptions used in The Energy and Resources Institute (TERI) study titled, *Integrated Renewable Energy Resource Assessment for Gujarat.* For a combined large wind PV integrated system, a density factor of 19 MW was taken, assuming wind turbine density of 7MW/ sq km and SPV land density of 12 MW/ sq km (based on 50% utilization of unshaded area).

The assumptions used in re-assessing the wind power potential in the state are summarized in **Table 4.3**.

Table 4.3 Assumptions for GIS and MCA-based wind potential re-assessment for Tamil Nadu

Onshore wind		
Assumed parameter	**Inclusion value**	**Source/Remarks**
Wind-power density	>150 W/m^2	To maximize the potential land area at 80 m, 100 m, and 120 m
Land requirement	7 MW/km^2	Conservative, assuming 5D × 7D criteria
Land elevation	<1500 m	In line with similar studies
Slope	<15%	in line with similar studies
Net CUF (Gross CUF*75%)	>15%	In line with global practices
Land availability percentage (%) in potential region	100% availability	Non-irrigated farmland + wasteland + non-forest scrubland
Contiguous area exclusion	< 5 acres (0.02 sq. km)	All contiguous areas less than a turbine footprint (5 acre /turbine) are excluded
Offshore wind		
Assumed parameter	**Inclusion value**	**Source/Remarks**
Offshore depth (maximum)	<30 m	In line with similar studies
Distance from the coast	<25 km	In line with similar studies
Cut-off CUF	>20%	In line with similar studies and techno-commercial consideration
Repowering		
Assumed parameter	**Inclusion value**	**Source/Remarks**
Wind turbines installed	Before March 2002	Minimum 10-year-old projects to be considered
Wind turbine capacity	< 500 kW	To be replaced with turbines of higher rating
Micro-siting criteria	5D × 7D	As per prevailing practice in the state

Figure 4.1 describes the overall criteria and methodology for wind potential assessment.

Figure 4.1 Criteria and methodology for assessing wind power potential

Wind potential onshore as well as offshore was assessed for three hub heights: 80 m, 100 m, and 120 m. The following narrative and figures summarize the wind potential assessment exercise for onshore and offshore.

Based on literature review and field level interactions, standard exclusion and inclusion criteria related to land-use, wind power density values, land slope, site elevation, etc., were finalized with the objective of arriving at land area available for development. This land area was then multiplied by the turbine density function (7 MW/sq km) to estimate the potential. For estimation of CUF, power curve and wind speed correlation methods were used. Wind speed distribution was derived from Weibull c and k values, while standard power curves of the selected turbines were used for estimation of CUFs. **(Table 4.4)**

Table 4.4 Turbines used for CUF estimation at various hub heights

Hub height (m)	Type	Turbine	Turbine rating (MW)
80	Onshore	Suzlon S82	1.5
100	Onshore	Vestas V100	1.8
120	Onshore	Vestas V112	3
80	Offshore	RE Power MM100	3

Repowering potential was estimated based on identification of turbines of rating below 500 kW installed before 2002 and by multiplying the old capacity with a repowering ratio of 2 (assuming repowered machines to be at least twice the rating of the old machine).

Wind potential assessment has been done for onshore and offshore winds, as well as repowering. To understand the implications of using new high-capacity, low-wind regime machines (Class III and Class IV machines), onshore wind power potential assessment has been done at three hub heights of 80 m, 100 m, and 120 m. Offshore assessment has been done for 80 m hub height. Further, onshore wind power potential assessment has been done using two land-use categories: ‘no farmland’ (including wasteland + non-forest scrubland) and ‘farmland’ (all farmland excluding irrigated farmland).

4.5 Onshore Wind Energy

Based on the methodology, four data layers, namely wind-power density, terrain elevation, terrain slope and land-use, LULC layer, were re-categorized (**Figure 4.2**). Then the preliminary methodology for wind potential at 80 m was decided as in **Figure 4.3**.

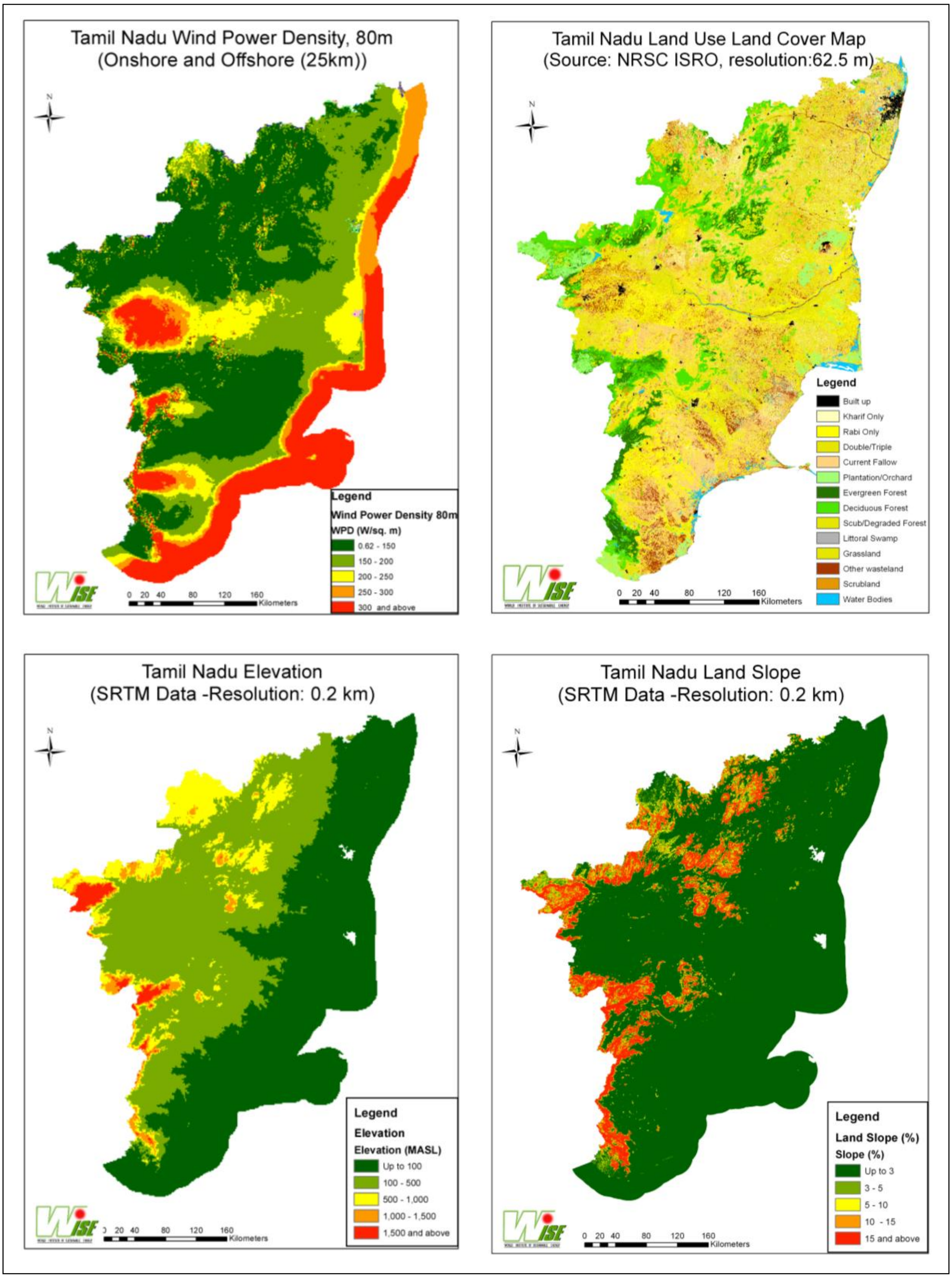

Figure 4.2 Re-categorization criteria for onshore wind

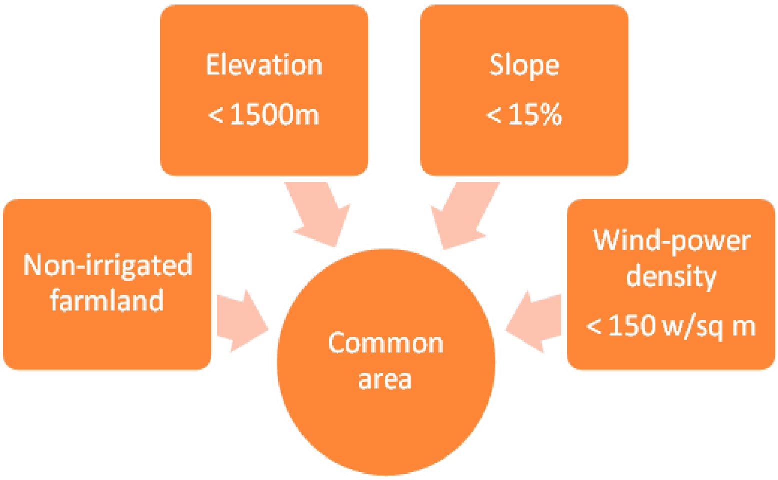

Figure 4.3 Preliminary methodology for wind potential at 80 m (farmland)

The common area was then overlaid with permanent exclusions (land not available for development) and all common areas were removed from final consideration. The remaining area was overlaid with a vector map of Weibull c and k parameters (200 m × 200 m polygon) to calculate the net CUF based on the power curve wind speed correlation method as detailed in the methodology (Suzlon 1.5 MW S82 turbine power curve was used for CUF calculation at 80 m hub height). In the final analysis, all the areas with NET CUF (Net CUF =Gross CUF *0.95^5*0.97) less than 15% were excluded in addition to areas with a contiguous land area of less than five acres (0.02 sq. km), the required land for a turbine footprint. The remaining area was assumed as area available for wind power development and was multiplied by the turbine density factor of 7 MW/sq. km to arrive at the farmland potential of Tamil Nadu.

Overlaying a district map on the final area, yielded wind potential figures for each district. **Figure 4.4** depicts the potential district-wise map of onshore wind based on net CUF value categorization at 80 m and **Table 4.5** shows the wind potential, by district, at 80 m for ‘farmland’ analysis.

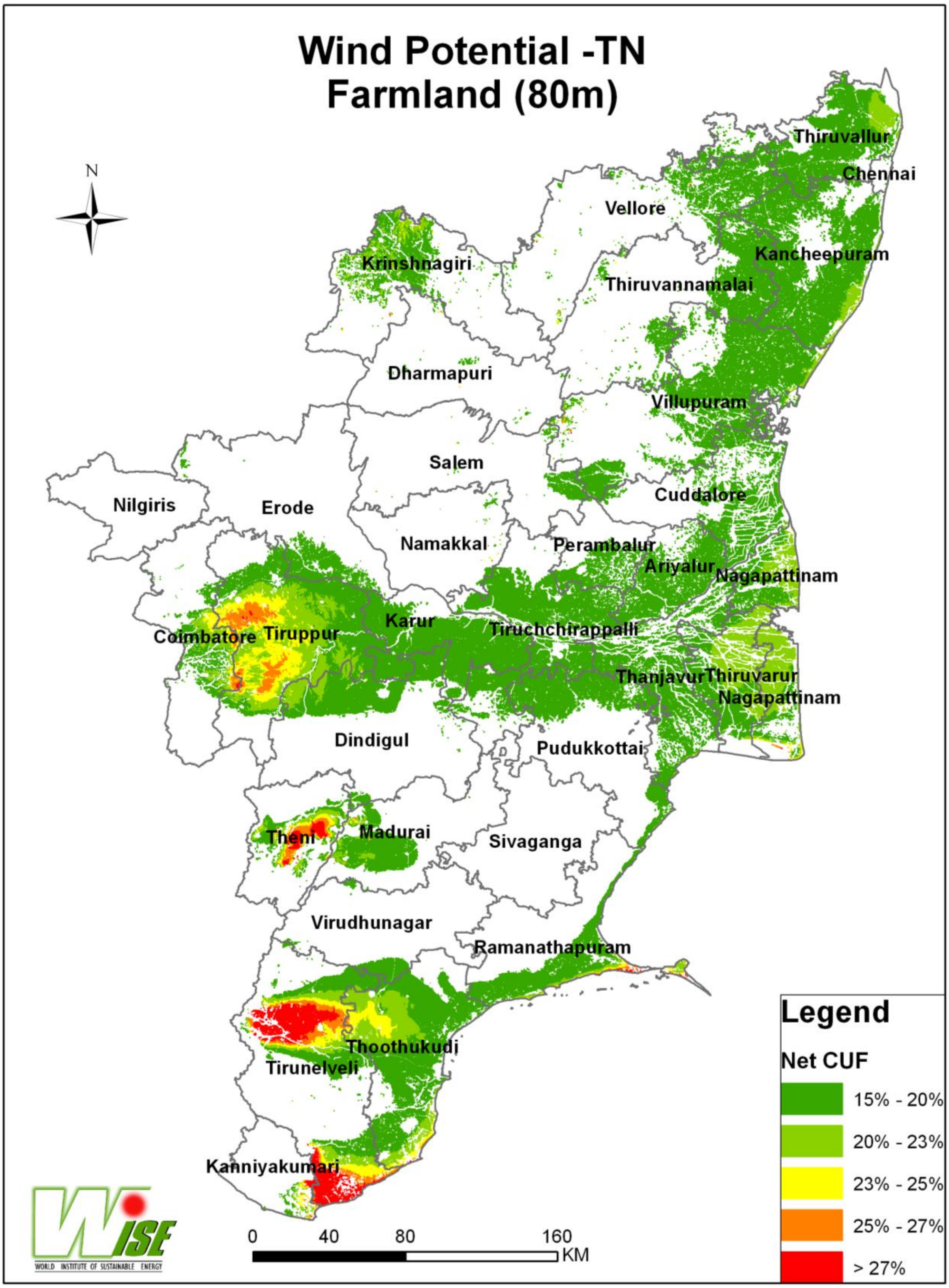

Figure 4.4 Potential of wind at 80 m by district, based on net CUF (Farmland analysis)

Table 4.5 Wind potential, by district, at 80 m (Farmland analysis)

No.	District Name	Avg Net CUF (%)	Area (Sq km)	Potential (MW)
1	Ariyalur	0.17	477	3336
2	Chennai	0.18	2	16
3	Coimbatore	0.20	340	2378
4	Cuddalore	0.17	475	3323
5	Dharmapuri	0.17	15	108
6	Dindigul	0.18	1229	8601
7	Erode	0.16	303	2118
8	Kancheepuram	0.17	1363	9541
9	Kanyakumari	0.23	51	356
10	Karur	0.17	1597	11181
11	Krishnagiri	0.19	390	2728
12	Madurai	0.18	577	4038
13	Nagapattinam	0.20	665	4654
14	Namakkal	0.17	29	202
15	Perambalur	0.17	202	1415
16	Pudukkottai	0.16	715	5002
17	Ramanathapuram	0.17	735	5143
18	Salem	0.17	94	657
19	Thanjavur	0.17	729	5104
20	Theni	0.22	444	3110
21	Thiruvallur	0.17	984	6887
22	Thiruvannamalai	0.16	576	4032
23	Thiruvarur	0.20	677	4741
24	Thoothukudi	0.19	2414	16897
25	Tiruchirappalli	0.17	1312	9181
26	Tirunelveli	0.23	1833	12828
27	Tiruppur	0.21	2870	20093
28	Vellore	0.16	352	2462
29	Villupuram	0.17	1282	8974
30	Virudhunagar	0.16	200	1403
Total			**22930**	**160510**

The same methodology was followed for assessment of 'no farmland' potential at 80 m. The whole exercise was repeated using corresponding data for 100 m and 120 m, the only difference being the data layers used. The complete results are tabulated later in **Table 4.8**.

4.6 Offshore Wind Energy

For offshore wind power assessment, a wind power density map up to 25 km off the Tamil Nadu coastline was provided by AWS Truepower along with an onshore map. All areas with WPD less than 200 W/m^2 were excluded from consideration. **Table 4.6** provides the basis for re-categorising offshore wind potential.

Table 4.6 Basis for re-categorizing offshore wind potential

GIS data layer	Re-categorization
Bathymetry	Sea depth <30 m
Distance to coast	Offshore distance< 25 km
Wind power density	Area >200 w/m^2 (wind power density)

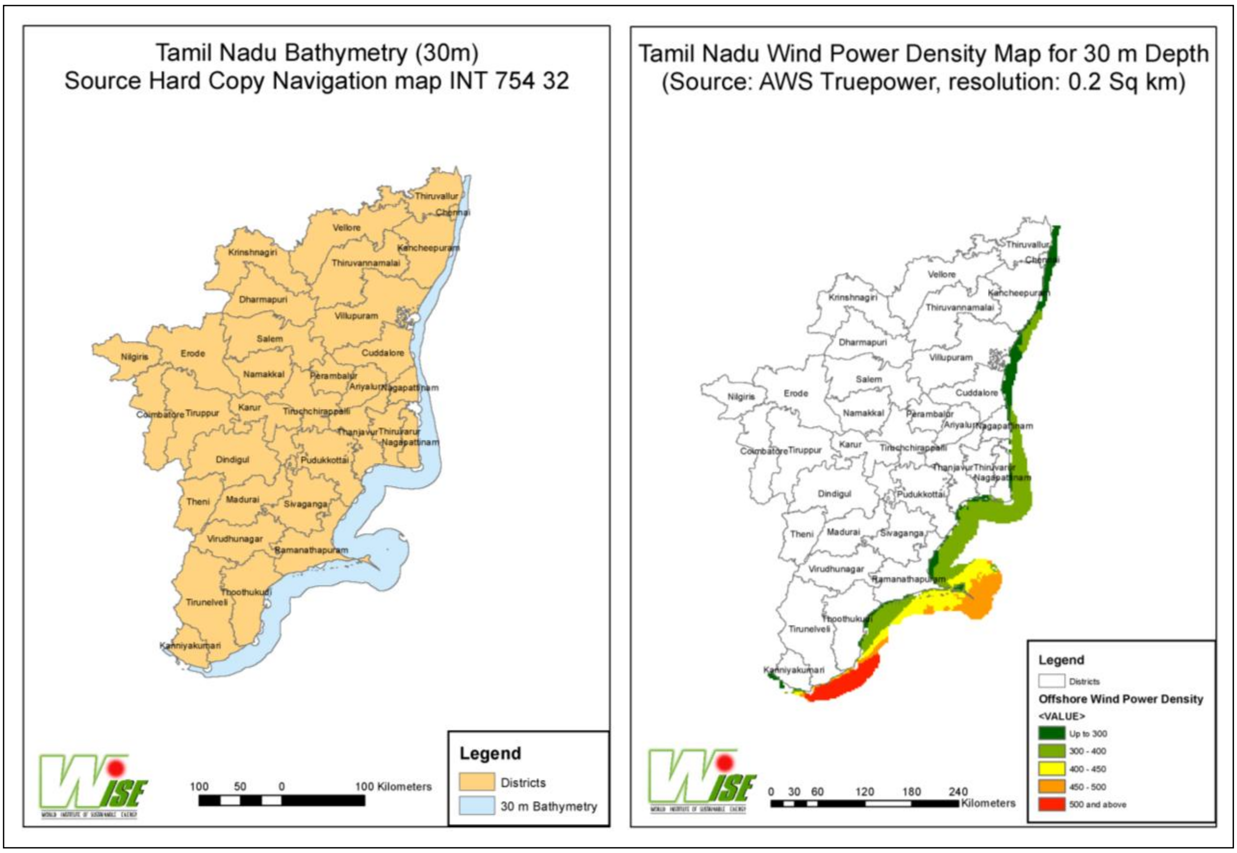

Figure 4.5 GIS-base layers for offshore wind potential analysis

The two GIS-base layers of Bathymentry and WPD were overlaid to filter common area (**Figure 4.5**). The filtered area was overlaid with a vector map of Weibull c and k parameters (200 m × 200 m polygon) to calculate the net CUF based on the power curve wind speed correlation method as detailed in the methodology. (RE Power's MM100 offshore turbine power curve was used for CUF calculation at 80 m hub height). In the final analysis, all areas with net CUF less than 20% were excluded. The final area was assumed as area available for offshore wind power development and was multiplied by the turbine density factor of 7 MW/sq. km to arrive at the offshore wind power potential of Tamil Nadu. **Figure 4.6** represents the net CUF-based categorization of offshore wind potential areas. **Table 4.7** represents a qualitative breakdown of potential by categorizing areas under particular range of net CUFs.

Table 4.7 Offshore wind potential 80 m area break-up based on net CUF

Offshore wind (80m)		
PLF Range	**Area (Sq km)**	**Potential (MW)**
20%–25%	0	0
25%–27%	693	4851
27%–30%	3658	25606
30%–33%	5647	39529
33% and above	8205	57435
Total	**18203**	**127421**

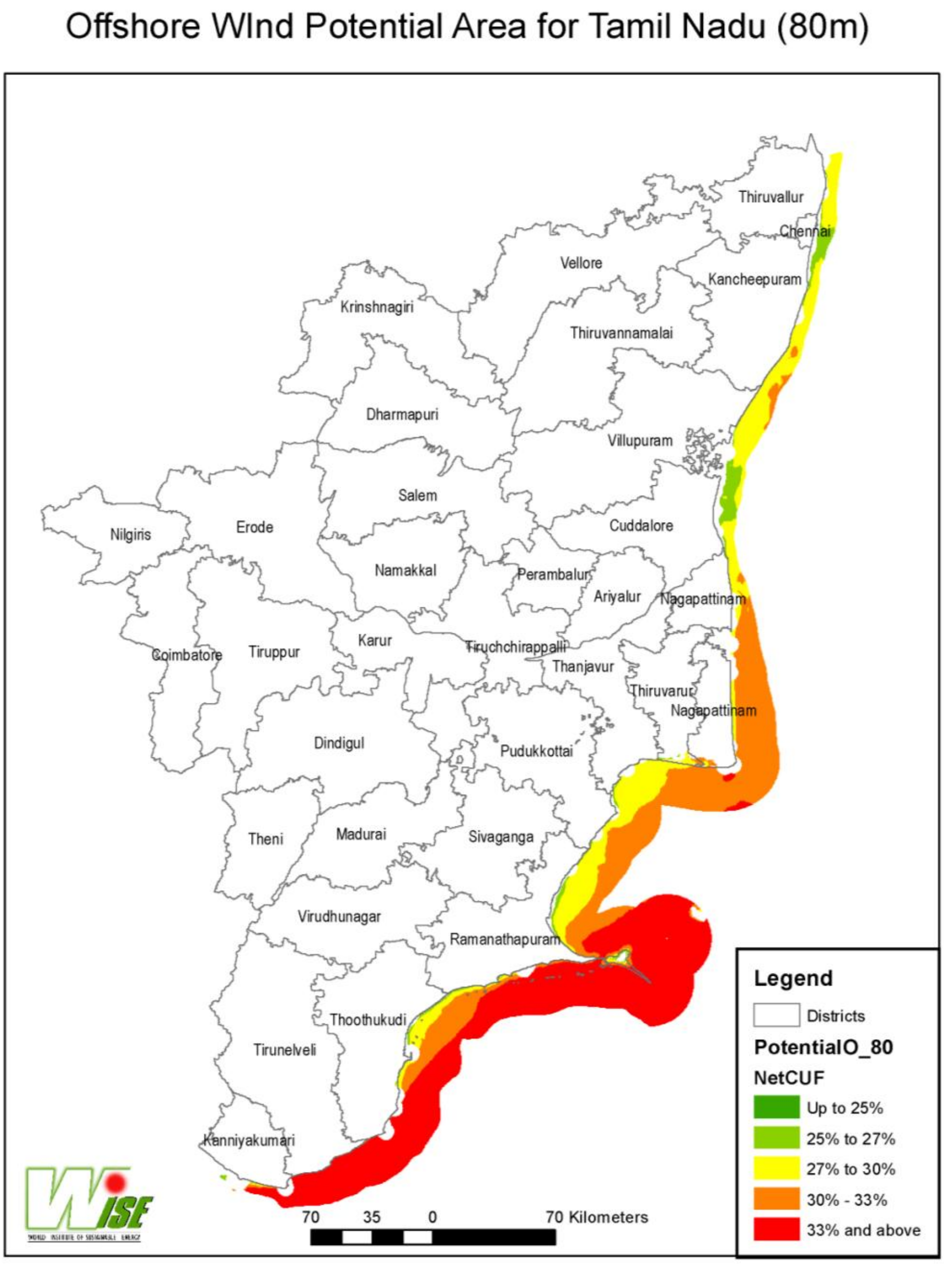

Figure 4.6 Net CUF-based offshore wind potential at 80 m

4.7 Repowering

Repowering deals with the replacement of first-generation wind turbines with modern multi-megawatt wind turbines to improve the extraction efficiency of wind power and to generate more electricity from the same area. GIS was not used for repowering potential estimation as it would have required incorporation of some subjective analysis in addition to raw field data related to turbine locations.

Since Tamil Nadu was one of the earliest markets for wind power in India, there is a substantial number of small-capacity turbines (less than 500 kW rating) still in operation but have lower performance as compared to present-day modern turbines. Taking into account the number of such small-capacity turbines in Tamil Nadu, a capacity of about 685 MW was identified as suitable for repowering. Considering a repowering ratio of 2 (conservative estimate), the repowering potential estimated in Tamil Nadu is about 1370 MW.

4.8 Analysis of Results

The results of the GIS-based wind potential assessment for the three hub heights for onshore wind and at 80 m hub height for offshore wind are shown in **Table 4.8.**

Table 4.8 Results of wind-potential assessment for the three hub heights

ONSHORE WIND POTENTIAL							
Scenario	**Hub Height (M)**	**NET CUF Range**					**TOTAL (MW)**
		15%-20% (MW)	**20%-22% (MW)**	**22%-25% (MW)**	**25%-27% (MW)**	**>27% (MW)**	
Wind Potential (No Farmland)	80	26152	3514	3311	1666	1764	36407
Wind Potential (Farmland)	80	120267	18851	13545	3703	4705	161071
Wind Potential (Total)	**80**	**146419**	**22365**	**16856**	**5369**	**6469**	**197478**
Wind Potential (No Farmland)	100	5445	12578	17086	4535	9198	48842
Wind Potential (Farmland)	100	29258	50599	77852	26842	33055	217606
Wind Potential (Total)	**100**	**34703**	**63177**	**94938**	**31377**	**42253**	**266448**
Wind Potential (No Farmland)	120	14630	14975	12751	4027	8029	54412
Wind Potential (Farmland)	120	72291	56904	65542	23330	27015	245082
Wind Potential (Total)	**120**	**86921**	**71879**	**78293**	**27357**	**35044**	**299494**
OFFSHORE WIND POTENTIAL							
Scenario	**Hub Height (M)**	**NET CUF Range**					**TOTAL (MW)**
		20%-25% (MW)	**25%-27% (MW)**	**27%-30% (MW)**	**30%-33% (MW)**	**>33% (MW)**	
Offshore wind	80	0	4851	25606	39529	57435	127421

(Note: The potential distribution across PLFs is sensitive to the power curve of the machine used for a particular hub height.)

Even at the lowest hub height of 80 m, the 'no farmland' potential is 36,000 MW and farmland-based potential is over 160,000 MW. This is in stark contrast to the official estimate of 5,374 MW.

In terms of spatial spread, the results of the potential assessment correspond very well with the trend of existing wind deployment in the state. Districts like Coimbatore (3,223 MW), Tiruppur (23,380 MW), Theni (3,560 MW), and Tirunelveli (17,785 MW) show the maximum high-quality potential. These districts also presently host the bulk of existing wind installations. These districts are followed by second-tier-resource-quality districts like Kanyakumari (382 MW), Thoothukudi (19,989 MW), Ramanathapuram (6,643 MW), Nagapattinam (5,323 MW) and Dindigul (9,110 MW), where development has already started. Considering the quantum of potential available in the established districts, it could be expected that these districts will continue to witness wind development.

Offshore wind potential has been estimated as 127 GW at 80 m. However, it is to be noted that due to data unavailability, the actual analysis could not include critical exclusions like coastal regulation zones (CRZs), fishing areas, sea routes, international waters, and classified cyclonic zones. If all these constraints are factored in, the exploitable offshore potential can actually be significantly less than the assessed values. However, one major highlight of offshore potential assessment is the quality of offshore resources. The CUF-based distribution of identified area indicates very high potential areas with net CUFs of over 40% and WPDs of over 700 W/m^2 at many locations. These values may mean that offshore wind deployment in Tamil Nadu could become commercially viable despite high costs. These values also make a strong case for developing offshore wind in Tamil Nadu. In terms of spatial spread, the assessment indicates very high quality potential off Tirunelveli and southern Thoothukudi, followed by the coastal region off Rameshwaram. Incidentally, CWET is in the process of setting up a 100 m wind monitoring mast near Dhanushkodi in Rameshwaram to assess offshore resources in the Rameshwaram area.

Repowering is another major area which has been languishing because of policy and regulatory issues. In many cases, repowering of old wind farms requires capacity-augmentation of the grid to evacuate the additional power, which is a real technical constraint. But even in cases where such additional capacity is available, issues related to land ownership, land costing and micro-siting of WTGs are hampering any private activity. TNEB is allowing repowering, subject to the criteria that there will be no change in repowered capacity, tariff and micro-siting criteria. Presently, TNEB insists on a spacing of 5D × 7D even for repowering old machines with new higher-capacity machines. This is not only arbitrary but also not feasible because the new machines have larger rotor diameters and cannot be sited within the constrained private area of existing machines. Furthermore, the insistence on continuing with old tariffs and allotted capacities is further disincentivizing any private efforts in repowering. While there are other commercial and financial issues involved in repowering, the private sector is more than capable of devising ingenious revenue-sharing models to take care of these constraints, only if the technicalities and administrative processes are in place to support the initiative in other areas.

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5. Potential of Wind-Solar PV Hybrid

5.1 Potential Assessment Methodology

Based on the result of the wind and solar PV potential analysis, common areas between wind and solar PV (having no CSP potential) were identified. However, to filter out areas with high potential for both wind and solar generation, only areas with wind CUF of more than 20% and GHI of more than 1800 kWh/sq m were identified as potential areas. A CUF of 20% was used to partially compensate for low land-utilization density of wind and to ensure that high-wind sites in common with PV potential areas were not left out. An area density factor of 19 MW/sq km was used assuming 50% land availability (a conservative estimate) of shadow-free area for solar PV installation. The assumptions are summarised in **Figure 5.1**.

Table 5.1 Assumptions for GIS and MCA-based wind-solar PV potential assessment for Tamil Nadu

Large Wind–Solar PV Integrated Potential		
Assumed parameter	Inclusion value	Source/remarks
Area selection	Wind net CUF >20% and annual GHI > 1800 kWh/sq m	
Technology density	19 MW/sq km	12 MW/sq km of solar PV with 7 MW/sq km of wind (based on TERI study) [Ref 25]

The wind potential layer was overlaid with the solar PV potential layer to identify common area. Standard GIS functionality was used to filter out areas with wind CUF of over 20% and solar GHI of over 1800 kWh/sq. m. **Figure 5.1** depicts wind-solar integrated potential by district and **Table 5.2** provides the breakdown of wind-solar PV potential.

Table 5.2 District-wise break-up of wind-solar PV potential in Tamil Nadu

District	Average Net CUF (%)	Average Annual GHI (kWh/Sq. m)	Potential (MW)
Coimbatore	0.23	5.88	229
Cuddalore	0.21	5.86	28
Dindigul	0.22	5.93	79
Kancheepuram	0.21	5.84	73
Kanniyakumari	0.26	5.87	13
Krishnagiri	0.21	5.90	474
Madurai	0.21	5.76	37
Nagapattinam	0.21	5.83	287
Ramanathapuram	0.23	5.99	446
Thanjavur	0.21	5.89	14
Theni	0.25	5.80	340
Thiruvallur	0.21	5.73	66

District	Average Net CUF (%)	Average Annual GHI (kWh/Sq. m)	Potential (MW)
Thiruvarur	0.20	5.81	121
Thoothukudi	0.22	5.85	658
Tirunelveli	0.27	5.79	2122
Tiruppur	0.23	5.97	2890
Villupuram	0.22	5.87	35
		Total	**7913**

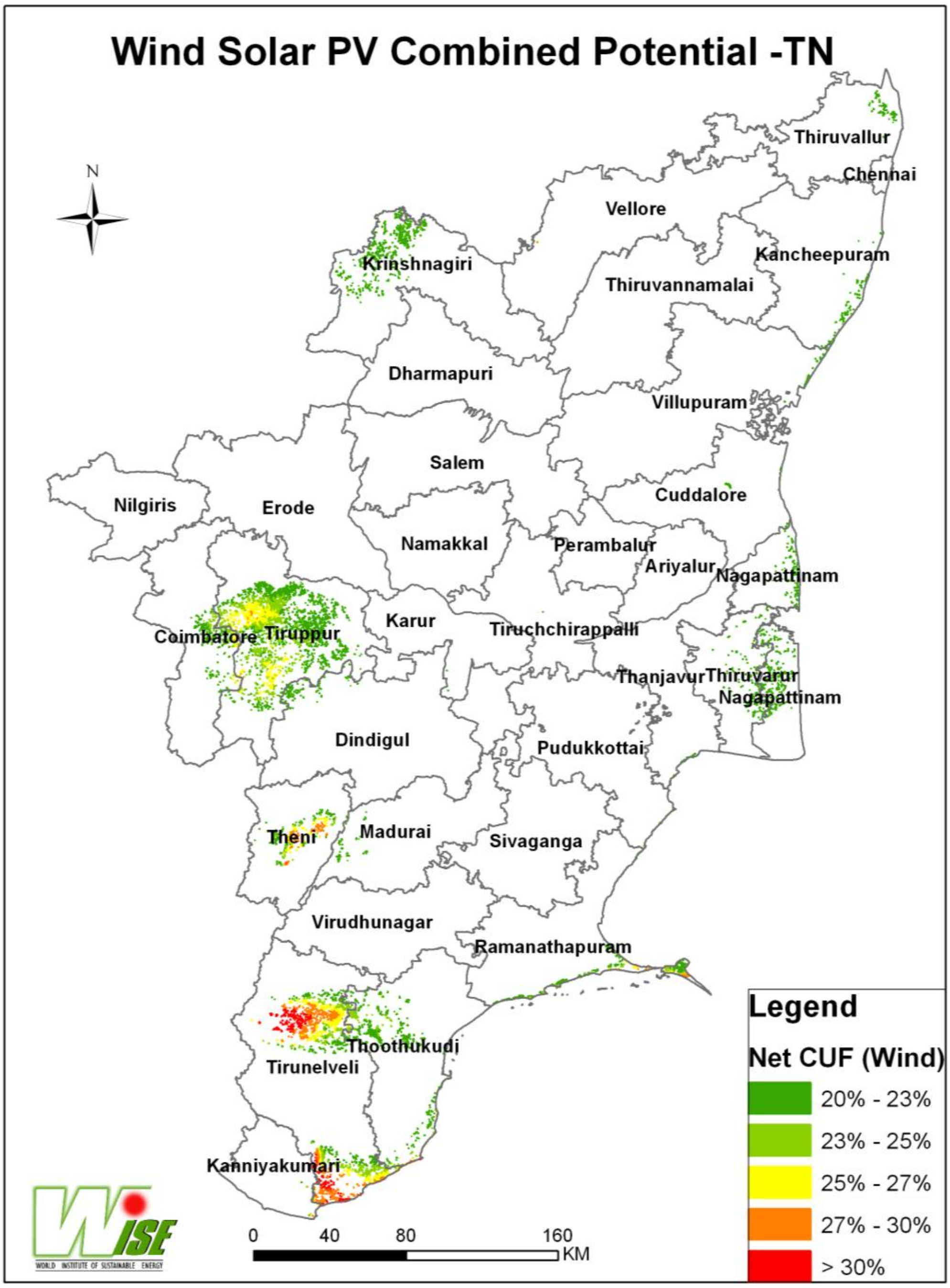

Figure 5.1 District-wise Wind-solar PV integrated potential map of Tamil Nadu

5.2 Analysis of Results

Generation variability of wind and solar are the biggest impediments to grid integration of these two promising technologies.

Presently, the major options being considered to address and manage variability are storage, spinning reserve, forecasting, etc. However, there is very little focus on integrating wind with solar PV to partially address the variability. It is known that wind and solar generation patterns complement each other. On a day-to-day basis, solar PV generation usually peaks near midday, when wind generation is at the lowest and tapers off in the evening when wind generation starts picking up. Even on a seasonal basis, low solar generation during monsoons is compensated by wind generation, which is at its peak. A combined wind and solar PV interface with the grid can be expected to at least reduce the extent of variability of the combined generation as compared to individual generation. It is in this context that the potential assessment for an integrated wind-solar PV project was conducted.

However, large wind-solar PV integration is an area that has not been explored in great detail. Additionally, there are concerns like the possibility of solar PV panel damage in routine wind project/operations activities, lack of a sustainable investment model, and grid interfacing of the combined systems. Any recommendations related to policy, regulation, business models and administrative handling require a great deal of due diligence and consultation. Based on the availability of wind resource quality, Tirunelveli (2,122 MW), Tiruppur (2,890 MW), and Thoothukudi (658 MW) are the major areas with high potential followed by Krishnagiri, Ramanathapuram, Theni, Nagapattinam and Coimbatore. However, the most high-quality potential in terms of wind quality (Net CUF) and GHI is found in Tirunelveli and Theni.

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6. Potential for Power Generation from Biomass

The most critical factor in assessment of biomass power potential is the actual availability of biomass residue that can be used for power generation unlike in the case of other technologies, where assumptions related to technical parameters are crucial. Consequently, biomass potential assessment is very location-specific and depends largely on the pattern of biomass residue generation and consumption at a local level.

A number of studies have been conducted in Tamil Nadu for assessment of biomass potential. In view of the considerations mentioned above, the present literature review covered state-specific studies that focus on assessing biomass power potential based on surplus biomass availability from agricultural, forest and wasteland areas.

6.1 Literature Review

District-wise power potential assessment for Tamil Nadu was completed in the *Biomass Resource Atlas of India* [Ref 26] In this project, the Combustion Gasification and Propulsion Laboratory (CGPL) acted as the national focal point (NFP) that provided information on biomass residue from crops related to energy generation, both in spatial and statistical form.

The residue generation based on agricultural output was used to compute the surplus biomass available for energy production after accounting for societal uses such as fodder, domestic fuel and thatching. While all the use for fodder and thatching was considered unavailable for energy generation, use for domestic fuel was decided based on district-level surveys conducted with MNRE support. Data on agricultural output was obtained from the Ministry of Agriculture, Government of India, whereas the data on residues were obtained from taluka and district surveys. The taluka study was initiated by the Ministry of New and Renewable Energy, Government of India, and conducted during 1999-2001 for about 500 strategically selected talukas across the country. CGPL acting as the NFP had integrated these crop-related data into a database to be used for creating the spatial atlas (Indian Bio-Residue Map, or IBRM). Spatial maps showing land-use were set into GIS by CGPL to use the statistical crop data for spatial distribution at the district-level. GIS-based techniques were adopted for distributing the polygons (with the appropriate crop names) by combining the information on the areas from the land-use data, with statistical data on the crop area. The maps were re-processed to also embed the district- and taluka-level spatial data extracted from the same crop distribution map. However, it is not clear if potential crops like tapioca and other biomass wastes were accurately assessed.

Anna University, Chennai, carried out district-level biomass assessment in 2010 [Ref 27]. The study reports were submitted to the Tamil Nadu Energy Development Agency (TEDA) in 2005 and 2010. According to the 2010 assessment, the net power generation potential based on surplus biomass availability in the state is estimated at 487.41 MW.

TEDA had also conducted a taluka-level biomass power potential assessment study in 2008 [Ref 28], in which 49 out of the 220 talukas were covered. The result of the study indicated a potential of 228 MW for the talukas under consideration. Some other studies were also reviewed.

Most studies assessed biomass potential primarily based on the potential energy content (calorific value) of available feedstock. No specific distinction was made between the combustion and the gasification route in terms of methodologies. Some of the discussion points from the biomass-related literature review are discussed below, along with the approach adopted by *WISE*.

- For crop to residue ratio (CRR), the best measure used was from the *National Biomass Resource Atlas*.
  WISE assumed CRR values as given in the atlas.
- The CUF for each crop residue (factor describing actually available biomass for biomass power after considering alternative use, cattle feed, and industrial use) was found to be highly specific to crop and region.
  WISE used the values as worked out in TEDA's biomass power study report.
- The calorific value of standard feedstock varies from 3000 Kcal/kg – 4700 kcal/kg. All the studies quoted values as accepted by IISc and Tamil Nadu Agricultural University (TNAU).
  WISE used the IISc/TNAU values.
- There are differences in the station heat rate (SHR) and plant CUF assumptions across studies depending on the type of technology and the assumed capacity.
  WISE used CERC assumption (CERC order dated 26 April 2010 for a Tamil Nadu project) for SHR related to biomass combustion/gasification. For bagasse-based generation, WISE assumed a SHR of 3600 kcal/kWh based on a CERC order dated 03 December 2009.

Table 6.1 provides the details of the assumptions and their indicative sources while assessing the bio-energy potential of the state.

Table 6.1 Assumptions for bio-energy power potential assessment for Tamil Nadu

Biomass Power Generation		
Assumed parameter	**Value**	**Basis**
Crop production data (district)	Varying	Season and Crop Report 2005/06
Crop to residue ratio (CRR)	Varying with feedstock	National Biomass Resource Atlas18
Utilization factor (district)	TEDA study[20]	Anna University, TEDA
Calorific value of fuel	3000 – 4700 kcal/kg	IISc Bangalore, TNAU
Station heat rate	3840 kcal/kWh	TNERC Order 2 of 2009 (27.04.09)
Bagasse-based cogeneration		
Assumed parameter	**Value**	**Basis**
Tonnes crushed per day for each mill	Varying for all mills	Sugar Mills Association (SISMA)
Net working days	Varying for all mills	Sugar Mills Association (SISMA)
Bagasse generated per crushed kg of cane	0.29	Sugar Mills Association (SISMA)
Calorific value of fuel	2250 kcal/kg	CERC Order (03.12.09)
Station heat rate	3600 kcal/kWh	CERC Order (03.12.09)
Efficiency	55%	Sugar Mills Association (SISMA)
Energy plantations		
Assumed parameter	**Value**	**Basis**
Land density for Beema bamboo	1.25 MW/sq. km	Growmore Biotech
Total wasteland	7549 sq. km	NRSC ISRO LULC data

6.2 Methodology for Assessment of Biomass Power Potential

WISE used statistical data from various sources covering agriculture, animal husbandry, and agro-based industries in addition to literature review covering state-specific studies that focus on assessing biomass power potential based on surplus biomass availability from agricultural, forest and wasteland areas.

The agro-based power potential for every district was calculated considering all the residues available in that district. For each crop in a particular district, the available agro residue was estimated from the crop production and crop-to-residue ratio. The generated agro residues were then discounted by the known utilization factors to estimate surplus availability, which was finally converted into potential using normative station heat rate (SHR) and plant efficiency values. The following equations depict the methodology.

Equation 1

Crop production (kg) × crop to residue ratio × (1 – Utilization ratio) = surplus availability (kg)

Equation 2

[Surplus (kg) × calorific value (kcal/kg) × station heat rate (kWh/kcal)] / [8760 (h) × efficiency] = kW

For bagasse, the methodology used empirical data related to tonnes (of cane) crushed per day (TCD). The ratio of bagasse generated from crushed cane was used to estimate the value of bagasse generation. Bagasse availability was then converted into potential using similar methodology as that of biomass. The following equations depict the methodology.

Equation 3

Tonnes crushed per day (tonnes/day) × % of bagasse to cane crushed × net working days (days) = bagasse generated (kg)

Equation 4

Bagasse (kg) × calorific value (kcal/kg) × station heat rate (kWh/kcal)] / (8760 (h) × efficiency) = kW

For estimating the potential of energy plantations, Beema bamboo, a high-yielding bamboo species developed by Growmore Biotech was chosen for assessment. Because of limited data availability, the declared land-use density of Beema bamboo (1.25 MW/ sq. km) was multiplied by the available wasteland to estimate the maximum potential of energy plantations in Tamil Nadu.

The biomass power potential was calculated for agro-residue and agro-industrial biomass residue. In addition, assessment was also done for bagasse-based potential and energy plantations.

6.3 Agro Residue-based Potential

In order to estimate the energy potential from agriculture-based residue or agro-residue and agro-industrial residue, WISE used the *Season and Crop Report 2005-06*, published by the Department of Economics and Statistics, Government of Tamil Nadu. This data was used as it was the most comprehensive data covering maximum crops for maximum number of districts.

The agro- and agro-industrial residue list, considered for this resource assessment, are provided in **Table 6.2**.

Table 6.2 Agro- and agro-industrial residues considered in the study

Agro-residue
Paddy straw, maize cobs and stalk, groundnut stalk, sugarcane top and trash, chilli stalk, red gram stalk and husk, green gram stalk and husk, black gram husk, tapioca stalk, jowar cob and husk, ragi stalk, gingelly stalk, and horsegram stalk.
Agro-industrial residue
Groundnut shell and paddy husk

District-wise estimation of biomass power potential was arrived at after calculating the agro- and agro industry-based power potential for every district based on agro and agro-industrial residues available per district. This is shown in the following equations.

$G_i = P \times CRR_i$ (Eq. 1)

Where G is residue generation in tonnes and subscript $_i$ denotes residue like paddy straw, maize cobs etc., P is annual production of crop in tonnes; CRR_i is crop-to-residue ratio

$U_i = G_i \times UR_i$ (Eq. 2)

Where U_i is residue utilization in tonnes; UR_i is utilization ratio

$S_i = G_i – U_i$ (Eq. 3)

Where S_i is surplus residue available for power generation

$Ej = \Sigma S_i \times CV_i \times 1000 / (SHR \times 1000 \times 8760 \times PLF)$ (Eq. 4)

Where Ej is energy potential in MW of j district; CV_i is the calorific value (kcal/kg) of the residue; SHR is the station heat rate (kcal/kwh); PLF is plant load factor

Equation 4 provides the power generation potential in megawatt for every district after summing for all types of residue feedstock.

The final agro-residue based potential assessment figures are produced in **Table 6.3.**

Table 6.3 Agro-residue based potential in Tamil Nadu, by district

No.	District	Agro-residue power potential (MW)	Agro industry-residue power potential (MW)	Total power potential (MW)	Biomass power current installed capacity (MW)	Balance biomass power (MW)
1	Chennai	0	0	0	0	0
2	Kancheepuram	4.91	3.79	8.7	18	-9.3
3	Thiruvallur	5.76	3.13	8.89	4.7	4.19
4	Cuddalore	43.45	2.73	46.18	0	46.18
5	Villupuram	79.34	6.27	85.61	0	85.61
6	Vellore	14.8	3.18	17.98	0	17.98
7	Thiruvannamalai	31.26	5.74	37.00	7.5	29.5
8	Salem	48.34	1.95	50.29	0	50.29

No.	District	Agro-residue power potential (MW)	Agro industry-residue power potential (MW)	Total power potential (MW)	Biomass power current installed capacity (MW)	Balance biomass power (MW)
9	Namakkal	63.92	2.23	66.15	0	66.15
10	Dharmapuri	52.52	1.34	53.86	0	53.86
11	Krishnagiri	3.54	1.04	4.58	10	-5.42
12	Coimbatore	15.88	0.85	16.74	10	6.74
13	Erode	57.64	3.06	60.7	0	60.7
14	Tiruchirappalli	16.95	2.34	19.29	0	19.29
15	Karur	10.06	0.77	10.83	0	10.83
16	Perambalur	28.7	1.76	30.47	0	30.47
17	Pudukottai	12.7	2.72	15.43	17.5	-2.07
18	Thanjavur	15.51	3.13	18.64	7.5	11.14
19	Thiruvarur	4.17	1.76	5.93	0	5.93
20	Nagapattinam	4.44	1.14	5.58	0	5.58
21	Madurai	4.86	1.87	6.73	10	-3.27
22	Theni	12.64	0.55	13.19	4.5	8.69
23	Dindigul	10.44	1.71	12.15	7.5	4.65
24	Ramanathapuram	0.43	1.86	2.3	0	2.3
25	Virudhunagar	4.52	0.95	5.47	14.95	-9.48
26	Sivaganga	3.8	1.58	5.38	24	-18.62
27	Tirunelveli	4.63	2.32	6.95	25	-18.05
28	Thoothukudi	0.92	0.63	1.55	0	1.55
29	The Nilgiris	0.1	0.03	0.13	0	0.13
30	Kanyakumari	10.73	0.56	11.29	0	11.29
Total		**566.99**	**61**	**627.99**	**161.15**	**466.84**

6.4 Bagasse-based Potential

The methodology followed in arriving at the final district-wise power potential from bagasse is as follows.

- The data on sugar mills in Tamil Nadu was obtained from South Indian Sugar Mills Association (SISMA). The data on sugar mills was categorized district-wise. The information from SISMA contained the crushing capacity (TCD) of each sugar mill.
- From TCD data, tonnes crushed per year for each sugar mill was arrived at by multiplying TCD with net working days of that factory.

  Tonnes crushed per year = Tonnes crushed per day × Net working days

  Wherein net working days was taken as an average of last four years (2007-10), this data was available with SISMA.
- Bagasse generated in each factory or mill was calculated by taking the % of bagasse to cane crushed as 29%. This value was available with SISMA. Therefore,

Annual bagasse generated per mill = Tonnes crushed per year of that mill × 0.29

- Next, power potential from each mill was calculated as follows:

  Power potential of a sugar mill (MW) = (Annual bagasse generated × 1000 x 2300) / (3840 × 0.55 × 8760 × 1000)

  Where 1000 is a multiplication factor to convert bagasse generated in tonnes to kg; 2300 is the calorific value of bagasse in kcal/kg; 3840 is the SHR of the plant in kcal/kwh; 0.55 is the CUF; 8760 is the number of hours in a year and 1000 in denominator is the factor to convert kW to MW.

The final bagasse-based potential assessment figures are produced in **Table 6.4.**

Table 6.4 District-wise bagasse-based co-generation power potential in Tamil Nadu

No.	District	Bagasse co-generation power potential (MW)	Bagasse co-generation installed capacity (MW)	Balance capacity (MW)
1	Chennai	0	0	0
2	Thiruvallur	12.08	0.00	12.08
3	Vellore	28.9	0.00	28.9
4	Kancheepuram	45.24	42.3	2.94
5	Thiruvannamalai	69.92	50.5	19.42
6	Krishnagiri	0	0	0
7	Dharmapuri	30.09	5	25.09
8	Villupuram	182.71	89.05	93.66
9	Salem	0	0	0
10	Cuddalore	130.44	90.68	39.76
11	Nagapattinam	17.41	0	17.41
12	Ariyalur	15.68	22	-6.32
13	Perambalur	39.66	23	16.66
14	Namakkal	17.21	0	17.21
15	Erode	176.8	76.5	100.3
16	The Nilgiris	0	0	0
17	Coimbatore	7.57	0	7.57
18	Tiruppur	0	0	0
19	Karur	36.77	22	14.77
20	Tiruchirappalli	44.86	29.02	15.84
21	Thanjavur	60.93	44.52	16.41
22	Thiruvarur	0	0	0
23	Pudukottai	20.28	18.5	1.78
24	Dindigul	0	0	0
25	Theni	19.2	12	7.2
26	Madurai	14.33	0	14.33
27	Sivaganga	33.17	35.1	-1.93
28	Ramanathapuram	0	0	0

No.	District	Bagasse co-generation power potential (MW)	Bagasse co-generation installed capacity (MW)	Balance capacity (MW)
29	Virudhunagar	0	0	0
30	Tirunelveli	70.48	50	20.48
31	Kanyakumari	0	0	0
Total		**1073.72**	**610.17**	**463.55**

6.5 Potential from Energy Plantations

The potential of energy plantations was assessed to understand and assess the role of energy plantations in Tamil Nadu. However, it is to be noted that conventional thinking suggests that energy plantations can be typically considered only as complementary plantations, and hence should only claim wasteland or other land not used for cultivation of crops. However, based on TEDA's request and considering the limited availability of wasteland in Tamil Nadu (unlike the northern and western states in India), it was thought that a basic sensitivity analysis should be conducted assuming farmland inclusion scenarios of 2% and 10%. It was also felt that modelling of energy plantation on farmland should only consider non-irrigated farmland until the commercial and technical potential of energy plantations is established. Moreover, since land that can be used for energy plantations can as well be used for wind or solar PV and solar thermal applications, it was felt that energy density of energy plantations was more critical in determining the preference and desirability of energy plantations.

Generally, the major plantation species considered for energy plantation are *Prosopis juliflora*, *Melia dubia*, jathropha and bamboo. Based on discussions with TEDA, WISE decided to estimate and analyse the energy plantation potential for a new species of bamboo called 'Beema bamboo'.

In the absence of academic literature on 'Beema bamboo', data was derived from the website of Growmore Biotech (source: *www.growmorebiotech.com*). However, it was not possible to ascertain the tentative locations for these plantations in the face of unavailability of data related to soil requirements, soil type, water requirement, irrigation methods, and groundwater availability in wasteland tracts.

Considering the data on intensive cultivation mode and associated calculations as derived by Growmore, an energy density of 1.25 MW/sq. km (200 acres of plantations for a 1 MW power plant) was assumed for analysis.

Based on this value, and assuming 100% (7,549 sq. km) wasteland availability coupled with 2% (1,098 sq km) and 10% (5,492 sq km) of non-irrigated farmland, the total potential of energy plantation was found to be 10,800 MW and 16,300 MW, respectively.

6.6 Analysis of Results

Table 6.5 summarizes the result of biomass potential assessment.

Table 6.5 Biomass potential assessment results in Tamil Nadu

Biomass potential assessment			
Biomass potential assessment	**Data**	**Area**	**Potential**
Technology type	**Unit**	**Sq km**	**MW**
Agro-field and agro-industrial residues based potential			
Biomass Potential Assessment	MW	NA	628
Baggase-based potential (Co-generation)			
Bagasse based co-generation	MW	NA	1073
Energy plantation potential (Beema bamboo)			
Energy Plantation Potential	MW	NA	10800

Agro-based residues

Districts Cuddalore (46.18 MW), Villupuram (85.61 MW), Vellore (17.98 MW), Thiruvannamalai (37 MW), Salem (50.29 MW), Namakkal (66.15 MW), Dharmapuri (53.86 MW), Erode (60.70 MW), Tiruchirappalli (19.29 MW), Karur (10.83 MW), Perambalur (30.47 MW), Thanjavur (18.64 MW), Theni (13.19 MW) and Kanyakumari (11.29 MW) have significant agro-residue-based potential. In our analysis, seven districts, namely Kancheepuram, Krishnagiri, Pudukottai, Madurai, Virudhnagar, Sivaganga, and Tirunelveli, have more installed capacity than the potential. Our preliminary analysis points out that biomass in these districts is sourced from neighbouring districts which have surplus biomass, but such a finding can also imply changes related to crop production or utilization pattern.

The present assessment is based on crop production data of 2005-06 and common utilization ratio values across districts. Utilization ratio (derivation of actual biomass surplus considering all other uses) is the single-most critical parameter of the biomass potential assessment study and the final results are more sensitive to the estimation of surplus availability of biomass residues than to any technical or performance parameter. As the assessment of utilization pattern is a field-based study and requires substantial resources and time, this was not considered as part of the present assessment.

NOTE: However, in order to understand the possible variation in utilization pattern across districts, WISE (on TEDA's request), had commissioned an independent agency to verify the latest utilization pattern for two districts (Erode and Villupuram) in Tamil Nadu. It was found that the utilization ratio values assessed from the studies were at variation with the assumed values for our exercise.

As a detailed field assessment was not in the scope of the existing project, it was decided not to project the biomass potential figures in the final RE potential summary results.

In view of this, the present potential figures are to be used only to gain a broad understanding and it is strongly recommended that detailed field-level biomass utilization pattern assessment be undertaken before actual deployment of any biomass power project. Considering the present market dynamics, even for project-level planning, a great deal of due diligence has to be shown by the investor and the approving authority to address the following concerns.

- An overestimate of the surplus availability may force a 'going concern' to shift to a higher fossil-fuel mix in the case of biomass non-availability, effectively rendering the whole approval and subsidy process obsolete.
- Clustering of biomass power plants within a small region will increase local competition for fuel and will negatively impact the project generation/quality of generation and commercials.
- Despite best efforts in estimating the field utilization of residues, commercial pressures actually divert fodder for biomass generation or affect fodder availability adversely by increasing the price of fodder.

All these concerns can only be addressed by strengthening the policy and approval processes. Another way of partly mitigating adverse impacts can be to promote small-scale plants, initially approving small plants in defined areas and encouraging the plants to expand after a certain period of stipulated technical and successful commercial operation.

Bagasse-based co-generation

The total unexploited power potential from bagasse-based co-generation is estimated to be 1,073 MW, based on the data on crushed sugarcane and without considering any alternative use of bagasse. Though it is known that bagasse is used in the paper industry, the actual availability could not be factored in the present calculation due to unavailability of data related to present bagasse-use in paper mills.

However, considering the power shortage in Tamil Nadu, it is more preferable to use bagasse for power-generation, at least in the short run, until the power situation improves. Suitable policies incentivizing the use of bagasse for power generation can help to ensure the diversion of bagasse for the same.

Interestingly, from a long-term perspective, diversion of bagasse to the paper industry may help in carbon sequestration (as paper is recyclable) as compared to direct combustion of bagasse (in generation) and may be considered as a priority after the power situation improves.

Energy plantations

As for energy plantations, the total potential of 10,800 MW, assuming 100% wasteland and 2% non-irrigated farmland, implies that there may be substantial potential from this technology. However, considering the low land-use density of 1.25 MW/sq. km (even under intensive cultivation), it is difficult to consider energy plantations as a competing technology vying for wasteland availability like solar PV and CSP, which have a land density of 50 MW/sq. km and 35 MW/sq. km respectively.

The only advantage of energy plantations is in terms of employment generation as plantation activity is labour intensive. However, it has to be understood that this employment will be generated only for unskilled labour, with majority of semi-skilled and skilled workforce not finding any employment. The deployment of other technologies would, however, have the potential to generate employment for all categories of workforce, including the highly skilled category.

The best way to assess the impact and viability of energy plantations is to develop a pilot project. Unless the productivity figures, water requirements, pre-processing requirements, technology configuration and lifecycle commercials are known and validated, large-scale promotion of energy plantations may not be recommended as it may lead to disturbances in land use patterns and affect livelihoods and food security in the long-run.

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7. Small Hydro Potential

There have been no state-specific small hydro power (SHP) potential-assessment studies in the public domain in Tamil Nadu. A detailed small hydro potential assessment requires a huge chest of resources including GIS maps, catchment modelling software, and tabulated data. The only large-scale study in small hydro potential assessment was done by Alternate Hydro Energy Centre (AHEC) of the Indian Institute of Technology (IIT) Roorkee. A second study by Central Board of Irrigation and Power (CBIP) recommended the methodology for the assessment of dam-toe based small hydro potential. Considering the scope of the project, these two studies considered for literature review are highlighted in the next section.

7.1 Literature Review

The AHEC study titled, *Optimizing Development of Small Hydel Resources in the Hilly Regions (13 Himalayan and sub-Himalayan states of India*) [Ref 29] assessed the SHP potential of the identified region and assessed the potential on run-of-the-river schemes using the following methodology.

(i) Identification of potential sites.

Information on possible locations of hydro sites was first collected from various state government offices. *Survey of India* (SOI) topographic maps (1:50,000) of the nation's Himalayan region were used to identify potential small hydro sites. Potential sites, earlier identified by state agencies, were also verified during this process.

In order to identify potential catchments for small hydropower generation, the following criteria were adopted:

- catchment area should be at least 10 km^2;
- channel should be perennial (SOI toposheets show perennial channels and streams in blue);
- main channel should be 7-8 km long; and
- availability of head should be at least 20 m.

(ii) Once the above basic criteria were satisfied, all potential catchments in all 13 Himalayan and sub-Himalayan states (Jammu & Kashmir, Himachal Pradesh, Uttar Pradesh, Bihar, West Bengal, Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura) were delineated using SOI toposheets. After delineation of all potential catchments, information related to individual catchments was entered in a spreadsheet programme (Lotus 1-2-3) for presentation and for future use.

(iii) Computation of available head.

One of the major factors in assessing a potential small hydro site is the head available in the catchment. To compute this information, the points on the main channel where the elevation contours cross the channel were marked on the catchment drawing. In each catchment, lower two-third length of the channel was considered for the determination of head (drop), since this part of the channel carries maximum discharge. The information on available head was used to evaluate its hydropower potential.

(iv) Development of regional and sub-regional flow duration curves for un-gauged catchments.

The discharge data for various streams (of varying length and quality) were collected from various sources in the 13 states for the gauged small streams. Discharge data of only 102 catchments could be collected. Based on gauged stream data, flow duration estimates were prepared for un-gauged streams.

(v) Estimation of hydro power potential.

For each catchment, hydropower potential was computed (assuming discharge levels of 50%, 75% and 90%).

The actual electrical power output of the scheme depends on how efficiently the turbine converts water power into electrical power (a maximum efficiency of 80% is possible). Power output is calculated using the standard formula.

P = 9.81 x Q x H x e

where

P = Output power in kW

the value 9.81 represents acceleration due to gravity in m/s^2

Q = Flow rate measured in (m^3/s)

H = gross head in meter (m)

e = conversion efficiency (%)

The study then went a step further and identified small hydro development clusters (many potential sites located near each other) on a GIS map for encouraging private sector investors.

The second publication, *Manual on planning and design of small hydro power* [Ref 30] recommended the following methodology for dam-toe based system, which broadly comprised three main parts.

(i) Dam-toe based small hydro stations

1.1 Field investigations

- Reconnaissance surveys
- Meteorological surveys (rainfall, temperature, wind, etc.)
- Hydrological survey for assessing the design head, design discharge, finalizing installed capacity, daily lake level (daily inflow, daily discharge (10-year data), dam features, downstream water levels, and water-release patterns.
- Topographical survey for setting up an SHP plant at the toe of a dam (general plan and layout of the irrigation dam, details at the intake, contour plan, spillway details, stilling basin details, outlet area of the river/ canal sluice, confluence point of the river sluice discharge with the main river, and site survey furnishing the details of network of roads.

(ii) Analysis

The study considered the inflow, outflow, evaporation losses, reservoir levels at the beginning and at the end of stipulated period and determined the average level in the reservoir. The reservoir level for any capacity is determined from the area capacity curve of the reservoir prepared with the help of a topographical survey. Evaporation losses were computed based on the area of reservoir at average level and the evaporation losses in that month. With the help of a tail water rating curve which indicates the tail water level at various discharges, the gross head is computed by deducting the tail water level from the average water in the reservoir. The output of the turbine varies with the head.

(iii) Evaluation of potential.

The output of the turbine varies with the head. In a reservoir scheme the head varies from a maximum to a minimum. The output of the turbine at lower heads is computed by the following formula or by the performance curve supplied by the manufacturers.

$(P_1/P_2) = (H_1/H_2)^{3/2}$

where,

P_1 = Turbine output in kW at rated head H_1 (m)

P_2 = Turbine output (kW) at the other head H_2 (m).

Similarly, the efficiency of a turbine varies at different heads. The efficiency at various heads is computed as per performance curve supplied by the manufacturers. After ascertaining the efficiency, head, and discharge (limited to requirements of machine output at particular head), the power potential is computed. Such a study is normally carried out for stretches of 10 consecutive days at a time.

The other method of assessing the dependability for small hydroelectric schemes is to plot the following curve to arrive at a decision for economic installation:

- Flow duration curve (discharge vs. percentage exceeded)
- Head duration curve (head vs. percentage exceeded)
- Energy curve (discharge vs. energy in kWh).

Summary of assumptions and findings from the literature review

Like other renewable energy sources, SHP potential cannot be predicted based on mapped resource data and assumptions with regard to land use. Prior meteorological, topographical and hydrological investigations are essential for arriving at the SHP potential. The most important consideration is long-term (10-year) hydrological data. In case of run-of-the-river schemes, most of the time, the potential locations fall within un-gauged catchments, where the determination of dependable flow availability requires time and expert judgment. For un-gauged streams, in case of run-of-the-river schemes, flow duration estimates were found to be extrapolated from available data. For e.g. AHEC has developed flow duration curves for each climatic region in the 13 states, which itself is a comprehensive work that involved three different departments of IIT Roorkee. The regional flow duration exercise is covered in Volume II of the AHEC study report.

Furthermore, the AHEC study calculated the catchment areas using specialized software, hard toposheets, specialized expertise, and some broad-based exclusions for selection of potential catchment areas for run-of-the-river schemes. *It is to be noted that the AHEC study spanned three years, had more than three expert teams, and involved a cost of Rs 60 crore (US $ 18 million).*

Determination of head for dam-toe type schemes is highly dependent on reservoir operations (variation in full supply level and tail race water level) and is thus extremely site-specific, whereas for run-of-the-river schemes, the head is determined based on topographic details along the stream. The AHEC study calculated the head using standard area toposheets.

7.2 Methodology for Potential Assessment of Small Hydro Power

For the present exercise, WISE studied the potential for dam-toe based schemes. The initial scope was to calculate the SHP potential for three common small hydro schemes: run-of-the-river, canal-based and dam-toe based. However, due to unavailability of long-term data related to river flow and canal drop/canal discharge, WISE decided to complete potential assessment only for dams where more than one year flow data was available. The following methodology was used for the present exercise.

- Analysis of daily discharge data (daily discharge data over a 14 month period) for major irrigation dams in Tamil Nadu.
- Using standard technical parameters for high head schemes assuming head and flow duration availability, based on collected data and standard assumptions, identify SHP potential for dam-toe based small hydro schemes.
- Map the existing small hydro schemes and the newly identified potential area on a common GIS platform

For assessing the potential of dam-toe-based potential, WISE was able to access data related to the largest 20 irrigation dams in Tamil Nadu. However, out of these 20 dams, 10 dams were already being used as multi-purpose dams and had existing installed generation capacity.

For the remaining 10 dams, actual discharge data for the period from November 2010 to March 2012 was derived from daily discharge reports provided by the PWD. The report included daily records of full reservoir-level (FRL), capacity at FRL, last-year live storage, current-year live storage, inflow, releases into river, canal, etc.

The flow release data from each of the above dams was analyzed and flow duration curves plotted for computing the dependable design discharge for each of the above schemes. As per the CBIP norms, 50% and 75% dependable discharge was taken as design discharge for computing the power potential at each scheme. In the absence of tail water level and minimum draw-down level data, 2/3rd of the depth of the full reservoir level was taken as average gross head for power potential computation.

Potential was then calculated based on the standard formula:

$P = 9.81 \times Q \times H \times \eta$

where P is power potential (kW), Q is design discharge (m^3/sec), H is gross head (m), and η is conversion efficiency (%). The final potential for dam-toe-based SHP schemes for the listed 10 dams is provided in **Table 7.1**.

Table 7.1 Dam-toe-based small hydro potential for selected 10 irrigation dams in Tamil Nadu

Irrigation Reservoirs							
Name of reservoir	**Depth at FRL (m)**	**Capacity FRL (cum)**	**Gross head (m)**	**Percentage (%) dependable discharge (cum/sec)**		**Power potential at % dependable discharge (kW)**	
				50%	**75%**	**50%**	**75%**
Manimuthar	35.97	156	23.74	1.01	0.7	213	148
Thirumurthy	14.63	126	10	17.29	0	1757	0
Krishnagiri	15.85	47	10.46	4.68	4.18	432	386
Parambikulam	21.95	380	14.49	23.26	3.18	2975	406
Thirumurthy	18.29	49	12	8.73	0.37	925	40
Drinking water-supply reservoirs							
Name of reservoir	**Depth at FRL (m)**	**Capacity FRL (cum)**	**Gross head (m)**	**Percentage (%) dependable discharge (cum/sec)**		**Power potential at % dependable discharge (kW)**	
				50%	**75%**	**50%**	**75%**
Poondi	10.66	91	7.04	6.22	0.56	386	35
Sholavaram	5.44	25	3.59	0.75	0	23	0
Redhills	6.46	93	4.26	5.09	4.61	191	173
Chembarambakkam	7.31	103	4.82	4.24	3.86	180	164
Veeranam	2.59	41.23	1.71	5.16	0.33	77	5
Power potential in (kW)						7159	1357

7.3 Analysis of Results

Small hydro potential assessment was done only for assessing potential of 10 irrigation dams for dam-toe-based potential. Based on a 17-month duration daily discharge data for these dams, an approximate estimation of power potential based on percentage dependable discharge value was estimated at 7.15 MW for 10 unexploited irrigation dams based on 50% dependable discharge.

As per standard practice, dependable discharge is determined on the basis of data on reservoir releases in the past 10 years, the corresponding reservoir level and tail water level. In this particular exercise, the same was worked out using only 17 months data; therefore, the above potential determination exercise provides only an indicative potential. A detailed potential assessment for dam-toe-based installations needs to be undertaken separately to evaluate the possibility of implementation.

Considering the limited scope and the small potential, it was decided to omit the SHP potential figures from the summary results.

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8. Summary of Renewable Potential Assessment

The present GIS-based renewable potential assessment is different from other GIS-based studies mainly on three counts: use of base datasets that have strong data source credentials, transparent methodology assumptions for potential assessment and creation of a GIS interface access portal for wide dissemination. The most important base data considerations for a potential assessment exercise are land use land cover resource data. To recap, the present assessment has used 2010-11 Tamil Nadu LULC data sourced from the National Remote Sensing Centre–Indian Space Research Organization (NRSC–ISRO), which is the latest (2010-11) high resolution (62.88 m) LULC database approved by the Government of India.

8.1 Total Grid-connected RE Potential

The resource data used for wind power assessment has been procured from AWS Truepower, USA, which is a global leader in wind-resource assessment. Comparison of the modelled values with measured data has shown average to good correspondence. The resource data used for grid-tied solar potential assessment (PV and thermal) is sourced from NREL, USA. The NREL data is the official reference source of MNRE.

All the other datasets have been taken from globally known sources. The methodology assumptions as well as procedures have also been transparently described in Chapter 1 in order to dispel any reservations related to the results of the GIS-based assessment methodology.

The potential assessment methodology was based on a detailed literature assessment exercise (as detailed in Chapter 3) and the methodology derivation and assumption sets were validated by field experts and independent reviewers. The methodologies have used well-defined land-use criteria depending on technologies. For example, wind analysis includes five land-use categories: ‘kharif only’, ‘rabi only’, ‘current fallow’, ‘non-forest scrubland’, and ‘wasteland’ and completely excludes ‘irrigated farmland’, ‘forests’ and all other land areas. In the case of solar potential assessment, only ‘wasteland’ is considered for analysis and all other land including ‘non-forest scrubland’ and ‘all categories of farmland’ and ‘forests’ have been excluded. All the other technical assumptions are also based on values derived from well-known sources and validated by technology specialists.

The results of the potential assessment based on the derived methodology assumptions and base data are striking. **Table 8.1** captures the final numbers of the assessed RE potential in the state.

Table 8.1 Summary of grid-connected RE potential in Tamil Nadu

Technology	Independent potential (MW)
Solar PV (NREL data)	259700
CSP (NREL data)	78505
Wind 80 m (no farmland)	36344
Wind 80 m (farmland)	160510
Repowering	1370
Wind 80 m (offshore)	127428
Wind-solar hybrid	7913
Bagasse-based co-gen	1073
Energy plantations**	10800
Total	**683643**
** Energy plantation potential figure is calculated assuming Beema Bamboo plantation for 2% of agricultural land and 100% of wasteland and scrubland	

We find that the figures based on GIS assessment are several hundred times the estimated or imagined potential.

The potential for grid-connected renewable including onshore wind, solar PV and CSP contribute to about 5,35,059 MW. In addition, offshore potential is about 1,27,428 MW, the majority of which is high quality resource.

8.2 Constrained Potential of Grid-connected RE after Land Reconciliation

For GIS-based resource assessment, the values derived in the initial exercise were stand-alone values without considering any kind of competition in terms of land resources. Actually, solar PV-, CSP- and 'no farmland'-based wind power analysis used the same category of land and there was considerable overlap in land areas between the three technologies. To properly model such land constraints, WISE adopted a technology preference methodology under which CSP was given the highest preference for land allotment as it requires solar resource as well as water availability. Wind-solar PV hybrid was given the second preference with the third preference going to solar PV as it is also dependent on wasteland availability unlike wind, which can use footprint area in farmland also. The remaining potential area was then considered as that available for wind. The final constrained potential figure for the RE resources was evaluated based on the above method. **Table 8.2** summarizes the final constrained potential for grid-connected RE in Tamil Nadu as compared to independent potential assessment figures for each technology. The table also shows the final area allocation for various contending technologies.

Table 8.2 Constrained potential and area of grid-connected RE in Tamil Nadu

Source	Density factor	Independent potential		Constrained potential	
Description	**MW/sq. km**	**Area (sq. km)**	**MW**	**Area (sq. km)**	**MW**
Wind 80 m (no farmland)	7	5192	36344	2258	15806
Solar PV (NREL data)	50	5194	259700	2535	126750
CSP (NREL data)	35	2243	78505	2243	78505
Wind-solar PV hybrid	19	0	0	416	7913
Total		**12629**	**374549**	**7452**	**228974**

So after reconciling the factor of overlap of land use for 'no-farmland' wind, solar PV, CSP and wind-solar PV hybrid, the constrained potential for grid-connected RE for these categories together workout to 2,28,974 MW, using an area of 7,452 sq.km. **Figure 8.1** shows the geographic spread of these constrained RE potential.

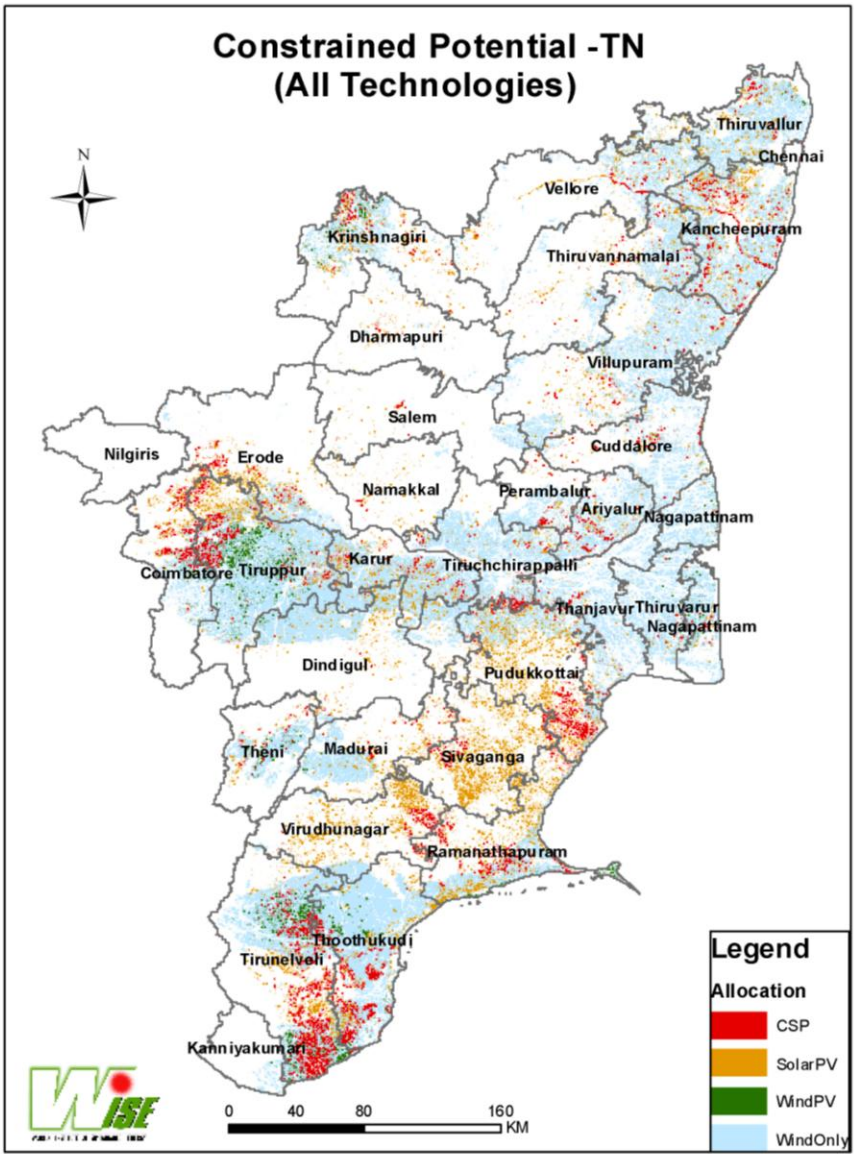

Figure 8.1 Constrained grid-connected RE potential map of Tamil Nadu

8.3 Final Grid-connected RE Potential

After considering all the above factors, especially the constrained potential, the total potential of grid-connected RE in Tamil Nadu is tabulated as below in **Table 8.3**.

Table 8.3 Total potential and area of grid-connected RE in Tamil Nadu

Source	Density factor	Total potential	
Description	**MW/sq. km**	**Area (sq. km)**	**MW**
Wind 80 m (no farmland)	7	2258	15806
Wind 80 m (farmland)	7	22930	160510
Off shore wind	7	–	127421
Wind repowering	–	–	1370
Wind-solar PV hybrid	19	416	7913
Solar PV (NREL data)	50	2535	126750
CSP (NREL data)	35	2243	78505
Bagasse-based cogeneration	–	–	1073
Energy plantations			10800
		Total	**530148**

Note:

- Agro-residue-based biomass power potential not included
- Energy plantation potential is based on assuming Beema Bamboo plantation in 2% of agricultural land and 100% of wasteland and scrubland
- Already utilised potential has not been excluded.

The total potential of grid connected RE in Tamil Nadu, after excluding the overlaps among wind (no farmland), solar PV and CSP potential, thus comes to 5,30,148 MW. However, the realisable potential would be much less than this considering the following factors:

- The wasteland data is not fully correct because it does not reflect the land diversions in the recent past for afforestation, urbanisation, industrialization, other construction purposes, etc. Besides, all wasteland may not be available exclusively for energy production.
- The assessment of wind power potential in farmland considers all farmland with a potential area of 22,930 sq. km. This is 17.63% of the total land area (1,30,058 sq. km) and 56.47% of the total cultivable land area (40,600 sq. km) of Tamil Nadu. Even assuming that wind turbines can co-exist with farming (as is prevalent in Tamil Nadu), or the fact that turbines require only the footprint and the remaining areas could be farmed, it is impossible to utilise the entire farmland area with wind potential for power generation. It would be arbitrary to assume availability of any fixed percentage of the farmland area for power generation. But the advantage is that diversion of even 10% of this land would provide a potential of 16,051 MW wind power from farmland areas.
- The potential of offshore wind power would prima facie not be constrained by area requirements. However, constraints due to existing infrastructural installation of the navy, minor parts or fishing harbours, etc., could limit this potential to some extent. Also, permissions from various maritime authorities could also work as constraints. However, this is a high-CUF resource and should be properly planned and utilized at the appropriate time when it becomes commercially viable.

- Re-powering of old wind power projects is a potential source which can be tapped immediately if a suitable policy is put in place.
- Wind-solar PV hybrid projects are possible in 'no-farmland' areas. But each project should be carefully planned after studying the shading effect of wind turbine blades in each location.
- Considering the recent fall in prices of solar PV, this is a resource available in abundance and could be tapped in an accelerated way, subject to other considerations of grid balancing, etc.
- CSP development should be planned to time it with commercial viability since high prices are still a constraint in developing this technology. Right now we would recommend establishment of a few pilot projects. CSP projects should invariably be planned with thermal storage since in an aggressive RE addition scenario storage would be essential to balancing the grid. Planned development of CSP would be critical for the future from this perspective.
- Agro-residue-based biomass potential has been excluded for reasons of uncertainty of data.
- Bagasse-based power generation potential is realisable.
- The potential of bio-energy plantations have been worked out on the basis of 2% of farmland being made available, as well as the entire wasteland. However, this needs to be studied in more detail because the same wasteland has been considered in working out the potential of wind power, solar PV and CSP. Intercropping in wind project areas is possible, whereas for solar projects the land has to be cleared of vegetation. Besides, the land density of this source is 1.25 MW per sq. km which is very poor compared to 50 MW per sq. km for solar PV, and 35 MW per sq. km for CSP. In addition, Bamboo requires water to give optimal biomass output which may not be forthcoming in Tamil Nadu wastelands. So first, we would recommend few pilot projects which should be studied in detail, before going for any large-scale development.

8.4 Off-grid Potential

The off-grid potential in Tamil Nadu is also substantial. **Table 8.4** shows Tamil Nadu's off-grid potential.

Table 8.4 Off-grid potential in Tamil Nadu

Off-grid		
Rooftop PV	MW	29642
Solar water heating	million sq m	16.15
Solar pumping	MW	7041

It can be seen that the potential of rooftop PV and substitution potential for solar pumping together account for about 37,000 MW, more than twice the existing installed capacity in the state.

To conclude, the implementable RE potential for Tamil Nadu is not a constraint for creating a future energy secure renewable-power-based economy in the state.

8.5 Total Realisable RE Potential

Even after discounting various factors, it is clear that it is possible for Tamil Nadu to power its economy from renewable sources of power. Enough potential is available. Issues of grid balancing, storage, water availability, etc., will have to be tackled. Energy conservation, industrial process heat, decentralised power generation on rooftops and for water pumping, etc., will provide enough RE potential even upto 2050.

8.6 GIS-based Portal for RE Resources in Tamil Nadu

It was further felt that the real benefit of the GIS analysis will only accrue if the findings are made available to potential RE investors, nodal agencies, and other sector stakeholders. In view of this, it was decided to conceptualize and develop a dedicated portal that provides access to the GIS data and allows data download for selected spatial locations. The proposed portal has used Google API as a base layer with Geoserver to provide individual layer visualization and zoom enablers with data download facility. It is expected that the portal will enable the user to see the final potential maps of all the technologies, in addition to allowing the user to visualize and download taluka-level data for grid-tied wind and solar power technology layers. The portal, which will be freely accessible to registered users, will be available through a link on WISE's website *www.wisein.org*.

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PART – III

ACCELERATED RE CAPACITY ADDITION: THE TWO SCENARIOS, CHALLENGES & SOLUTIONS

9. Accelerated RE Capacity-Addition: The Two Scenarios, Challenges & Solutions

Before developing the capacity-addition scenarios, it would be insightful to understand the role of the state in the national context in terms of the capacity-addition figures that can be contributed by Tamil Nadu to meet the National Action Plan on Climate Change (NAPCC) target of 15% RE by 2020 at the national level. As per a recent study conducted by WISE [Ref 31] for achieving 12% RE by 2017 and 15% by 2020 on a national level, Tamil Nadu can, on the basis of its available renewable resources, contribute to the overall capacity-addition as shown in **Table 9.1**.

Table 9.1 RE capacity-addition required in Tamil Nadu to meet 12% by 2017 and 15% by 2020 national-level targets

RE Technology	RE capacity addition (2012-2017)	RE capacity addition (2017-2020)	Total Addition (2012-2020)	RE capacity addition (2012-2017)	RE capacity addition (2017-2020)	Total Addition (2012-2020)
	Wind dominant scenario			**Solar dominant scenario**		
Wind	7038	5829	12867	6805	4992	11797
Solar	265	429	694	1213	1286	2499
Biomass	201	137	338	203	125	328
Small Hydro	45	29	74	45	27	72
Total	**7549**	**6424**	**13973**	**8266**	**6430**	**14696**

It is clear from Table 9.1 that about a minimum RE capacity-addition of 14,000 MW would need to be developed by 2020 in Tamil Nadu to contribute effectively to the NAPCC-set national target. These additions would take its cumulative grid-connected RE installations to more than 20,000 MW by 2020. As per the WISE study, about 80%–90% of the new capacity-addition would have to come from wind power and about 5%–17% from solar power, with the rest coming from other RE technologies like biomass and small hydro power. The above figures represent a capacity-addition of more than three times the current installed renewable capacity. The inputs from the study were taken as a basis for forming a basic understanding of the aspiration level of developing RE.

In formulating the actual RE capacity-addition plan for Tamil Nadu, the most difficult part was to reconcile practicality and aggression. As the scope of the renewable energy action plan covers the 12th five-year plan (2012-2017) and 13th five-year plan (2017-2022), and the focus was on evaluating the direct and indirect benefits (investment inflow, central financial assistance by 13th Finance Commission, notional benefits of RECs, employment generation, etc) from RE development, we developed two capacity-addition scenarios: business-as-usual (BAU), and aggressive (AGG).

The BAU scenario was developed assuming continuation of existing or expected growth of renewables in the state. On the other hand, the AGG scenario was developed assuming RE development that went beyond the basic aspiration level. That meant deployment figures surpassing the figures in Table 9.1 above.

In order to link the capacity-addition plan with detailed grid-planning study, a location-specific capacity-addition plan was required. It was thus felt that the best way to arrive at capacity-addition figures with location details was to use a combination of derived and factual data. In the case of wind power, latest data suggested that Tamil Nadu added about 1,084 MW of new wind capacity in financial year (FY) 2012-13 (Indian Wind Turbine Manufacturers Association[IWTMA]) [Ref 32]even as about 13,400 MW on wind project applications are pending with the TNEB [Ref 33].

As the project application submission implies completion of a preliminary load flow study and an idea on quality of wind resources, the 13,400 MW capacity of wind project applications was assumed as the base capacity (with location) that was available for immediate deployment. For arriving at solar power deployment figures, a combination of scenarios and factual data, including state capacity-addition plan, were used to suggest appropriate capacity additions under each scenario.

It was difficult to model the locations for biomass, and hence its capacity-addition plan was based on exploitation of untapped biomass potential (440 MW) over the two plan periods. Considering the limited potential, capacity-addition projections for both scenarios were kept uniform.

Other RE sources including small hydro, energy plantations, etc., were clubbed together considering the technical complexities and low potential for these technologies. The capacity-addition plan for these technologies was based on a cumulative planned capacity-addition of 60 MW for the 12th plan period and 70 MW for the 13th plan period.

Off-grid capacity-addition targets were based on existing achievements in Tamil Nadu. For the BAU scenario, a year-on-year growth rate of 5% was assumed, whereas a quadrupled growth rate of 20% was used to model capacity-addition targets for the AGG scenario.

As the bulk of capacity-addition for both scenarios came from grid-tied wind, solar PV, and CSP, the grid-planning study was based on capacity-addition figures and deployment locations for these technologies.

9.1 The BAU Scenario

Considering the present annual wind market of 1,000 MW in Tamil Nadu, we assumed a total capacity addition of 13,500 MW (pending project applications with taluka-level break-up) over the next two plan periods in the BAU scenario. This meant a moderate growth rate of about 5% year-on-year on wind capacities over the next two plan periods. Based on the locations of the proposed projects and the actual installed data, an annual capacity-addition plan for wind was developed which translated into new capacity addition of 6,000 MW for the 12th plan and 7,500 MW for the 13th plan periods. But in view of the fall in wind installations in FY 2012-13 in Tamil Nadu on account of existing state level issues, withdrawal of accelerated depreciation (AD) benefit, and lapse of generation based incentive (GBI) scheme, the capacity addition for FY 2012-13 was pegged at 500 MW, at 50% of FY 2011-12 installations. However, considering the strong fundamentals of wind power investments and the expected reinstatement of GBI and resolution of state level issues in future, an accelerated annual capacity-addition figure was projected for the remaining plan period.

In the case of solar, the BAU scenario was developed with the objective of meeting the solar renewable purchase obligation (assuming a Central Electricity Regulatory Commission recommended solar RPO trajectory: 2% in 2016–17 and 3.25% in 2021–22) and demand projections based on the 18th Electric Power Survey (EPS) draft report (80.69 BU in 2016-17 and 110.25 BU in 2021-22). The projected solar capacity requirement, assuming 1.5 MU generation/MW, was found to be 1,470 MW for 2016–17 and 3,300 MW for 2021–22. This meant a capacity-addition plan of about 1,500 MW in the 12th plan period and about 2,000 MW in the 13th plan period. Based on the results of the GIS analysis, best resource sites in Tamil Nadu for solar PV and CSP were chosen and a taluka-level annual capacity-addition plan was developed for the modelled capacities. Also, considering limited installation and solar resource data related to CSP, its capacity contribution in the total power was kept very low to the 12th plan and was subsequently increased in the 13th plan.

For biomass, a uniform annual deployment of 40 MW in the 12th plan and 48 MW in the 13th plan was assumed. For other RE, a cumulative capacity-addition target of 60 MW and 70 MW was assumed for 12th and 13th plans, respectively. **Table 9.2** summarizes the capacity-addition plan for the BAU scenario. The location wise details of proposed wind and solar installations are covered in Chapter 10.

Table 9.2 BAU capacity-addition plan for grid-tied renewables

BAU SCENARIO													
Technology	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**12th Plan**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**13th Plan**	**Total**
Wind Power	500	1290	1340	1400	1470	**6000**	1360	1420	1500	1570	1650	**7500**	**13500**
Solar PV	0	125	250	375	500	**1250**	250	200	300	300	300	**1350**	**2600**
CSP	5	40	50	55	100	**250**	100	100	150	150	150	**650**	**900**
Biomass	39	40	40	40	41	**200**	49	49	49	49	44	**240**	**440**
Other RE	12	12	12	12	12	**60**	14	14	14	14	14	**70**	**130**
TOTAL	**544**	**1495**	**1680**	**1870**	**2111**	**7760**	**1759**	**1769**	**1999**	**2069**	**2144**	**9810**	**17570**

For planning off-grid capacity-addition, an annual target plan has been derived by using a 5% year-on-year growth rate from a base of existing installation data derived from the TEDA website (*www.teda.in*). **Table 9.3** summarizes the off-grid capacity-addition plan.

Table 9.3 BAU capacity-addition plan for off-grid renewables

Technology	**Unit**	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**
Rooftop PV	MW	50	53	55	58	61	64	67	70	74	78
Solar Water Heater	Sq m	36948	38795	40735	42772	44911	47156	49514	51990	54589	57318
Solar Process Heating	Sq m	2183	2292	2407	2527	2653	2786	2925	3071	3225	3386

Note: Figures for current installed capacity of solar pumping are not available; hence targets not worked out based on annual escalations.

9.2 The Aggressive Scenario

Considering the present annual wind market of 1,000 MW in Tamil Nadu, we assumed a capacity-addition of 13,500 MW (all the pending project applications backlog) in the 12th plan period itself. This would actually mean very proactive administrative support from the state machinery and the power centres. For planning capacity-addition for the 13th plan period, the results of GIS-based wind potential assessment (80 m assessment) were modelled to identify potential locations with net CUF of over 22%. After reconciling high-grade potential with respect to installed capacity and pending project locations, a second tier development capacity of 15,000 MW with locations and with a more moderate year-on-year capacity-addition growth was modelled for the 13th plan. But in view of the fall in wind installations in FY 2012-13, on account of existing state level issues, withdrawal of accelerated depreciation (AD) benefit, and lapse of generation based incentive (GBI) scheme, the capacity addition for FY 2012-13 was pegged at 750 MW, at 75% of FY 2011-12 installations. However, considering the strong fundamentals of wind power investments and the expected reinstatement of GBI and resolution of state level issues in future, an accelerated annual capacity addition figures were projected for the remaining plan period.

For the AGG scenario, solar capacity-addition was linked to the government plan of developing solar capacity of 3,000 MW in the first four years of the 12th plan period. For the 13th plan a more moderate or flat yearly growth rate was assumed to model a capacity of 4,500 MW in the 13th plan. Also considering limited installation and solar resource data related to CSP, its capacity contribution to the total power was kept very low in the 12th plan period and was subsequently increased in the 13th plan.

For biomass, a uniform annual deployment of 40 MW in the 12th plan and 48 MW in the 13th plan was assumed. For other RE, a cumulative capacity-addition target of 60 MW and 70 MW was assumed for 12th and 13th plans, respectively. **Table 9.4** summarizes the capacity-addition plan for the AGG scenario. The location wise details of proposed wind and solar installations are covered in Chapter 10.

Table 9.4 AGG capacity-addition plan for grid-tied renewables

AGG SCENARIO													
Technology	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**12th Plan**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**13th Plan**	**Total**
Wind power	750	3000	3100	3250	3300	**13400**	3000	3000	3000	3000	3000	15000	**28400**
Solar PV	70	190	300	425	625	**2600**	625	625	750	750	750	3500	**6100**
CSP	5	20	75	150	150	**400**	150	150	175	225	300	1000	**1400**
Biomass	39	40	40	40	41	**200**	49	49	49	49	44	240	**440**
Other RE	12	12	12	12	12	**60**	14	14	14	14	14	70	**130**
TOTAL	**864**	**3250**	**3515**	**3865**	**4116**	**16660**	**3824**	**3824**	**3974**	**4024**	**4094**	**19810**	**36470**

For planning off-grid capacity addition, the annual target plan is derived by using a 20% year-on-year growth rate from a base of existing installation data derived from TEDA website (*www.teda.in*). **Table 9.5** summarizes the off-grid capacity-addition plan.

Table 9.5 AGG capacity addition-plan for off-grid renewables

Technology	**Unit**	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**
Rooftop PV	MW	50	60	72	86.4	104	124	149	179	215	258
Solar Water Heater	Sq m	36948	44338	53205	63846	76615	91938	110326	132391	158870	190644
Solar Process Heating	Sq m	2182.8	2619	3143	3772	4526	5432	6518	7821	9386	11263

Note: Figures for current installed capacity of solar pumping are not available; hence targets not worked out based on annual escalations.

As the BAU scenario is an extrapolation of current RE development and the action plan aims to expand the limit of renewables by highlighting the extent of possibilities, the AGG capacity-addition plan was taken as the basis for action plan development, as elaborated in Chapters 11 and 12 of this report.

9.3 Challenges and Solutions

The proposed capacity-addition plan is essentially a modelling exercise and therefore, before drawing the development path required for capacity deployment, it is important to see if it can be realistically justified. At the same time, analyzing the proposed plan scenario from the perspective of present capabilities will only be half an exercise. To fully fathom the extent of possibilities, we need to take the expected future developments also into consideration.

The following sections try to assess the technical and commercial challenges and possible solutions for deploying the aggressive capacity addition plan.

9.3.1 RE integration into the grid

The major problems in integration of renewables are more a result of perception gaps than a result of real technical constraints. For a sector that is tuned to a centralized generation model with defined system behaviour, switching to renewables requires a paradigm shift. The following narrative highlights the specific issues that arise from this mindset and tries to look at the problems and possible solutions for aggressive RE integration.

Grid transmission planning process

At present, there is no provision in the present long-term transmission planning process to incorporate transmission and evacuation requirements of renewable energy. This is a major area of concern simply because RE projects (wind, solar and biomass) have significantly low gestation periods and the slow pace of grid infrastructure creation, which is based on large gestation periods of conventional projects, will always mean that new transmission capacities will not be adequate to accommodate the rapidly building RE portfolio.

However, the need for an integrated transmission planning process is being felt at the highest level. The Ministry of Power has constituted a committee to look into aspects related to renewable energy development through legislative and policy changes. The terms of reference (ToR) for the committee acknowledge that planning for conventional transmission has been done keeping conventional sources in mind and seeks that the committee make demand-specific mentions in the Electricity Act, 2003, to factor in likely RE capacity in transmission planning [Ref 34]. This major shift in outlook has very significant implications for Tamil Nadu as it will mean that transmission planning at the state and Central Transmission Utility (CTU) level (inter-state and inter-regional corridors) will factor in the transmission requirements of new renewable capacity additions in the state. In the long-term, this will allow Tamil Nadu to evacuate renewable generation and import/export power from a wider pool.

Generation variability

Typically the contribution of wind during peak demand period in Tamil Nadu varies from about 2500 MW (high-wind season) to about 100 MW (low-wind season). In fact, the contribution of wind during the high-wind season is on many days more than that from state-owned thermal power stations. This poses significant challenges in balancing generation between various technologies and may lead to backing down of wind capacities in high-wind season, when system operators see more merit in running thermal power plants at high plant-load factors (PLFs) instead of allowing wind to meet the demand.

We analyzed Tamil Nadu state load dispatch centre reports for two dates (the 10th and the 20th of each month) of three off-wind months (February, March, April) and three high-wind months (June, July, August) in 2011. The contribution of various generation technologies for the morning peak, evening peak and the minimum load condition was mapped and it was found that wind contribution was consistently low for all system conditions on all the days in the off-season months but varied substantially on all the days in the high-wind months. **Table 9.6** summarizes the load dispatch data as derived for the 12 days (six days each in off-season and high-season).

Table 9.6 Load dispatch daily data for 12 days in 2011

Contribution (MW)	**10 Feb**	**20 Feb**	**10 Mar**	**20 Mar**	**10 Apr**	**20 Apr**	**10 Jun**	**20 Jun**	**10 Jul**	**20 Jul**	**10 Aug**	**20 Aug**
Total morning peak	9710	9373	9547	9191	8999	9519	9777	9208	8811	10167	9693	8858
Total thermal	4714	4360	4768	4369	4116	4199	4196	4218	4210	4759	4659	4464
Hydro	1343	1263	860	869	438	857	918	898	960	831	1081	763
Wind	247	0	0	4	3	60	1232	1818	986	2580	1647	1529
IPP	1130	1125	1126	797	687	778	776	477	535	268	468	497
Purchase	446	720	482	1120	1687	1320	228	330	1027	1166	1175	1135
Load shedding	852	1004	1329	911	1412	1634	1443	1181	871	900	911	0
Contribution (MW)	**10 Feb**	**20 Feb**	**10 Mar**	**20 Mar**	**10 Apr**	**20 Apr**	**10 Jun**	**20 Jun**	**10 Jul**	**20 Jul**	**10 Aug**	**20 Aug**
Total lighting peak	9657	10422	10295	10450	10012	9657	10526	9520	10239	10859	10050	9593
Total thermal	4412	4657	4990	4333	4571	4521	4445	4650	4186	4455	4745	4704
Hydro	1521	1500	1532	1192	750	314	1158	1081	820	1488	745	954
Wind	53	57	85	67	53	537	2224	1621	2204	2608	2380	1450
IPP	1127	1039	1121	874	1001	760	812	469	809	281	494	563
Purchase	636	1222	382	1385	1429	1273	285	330	727	1166	1175	1135
Load shedding	369	265	391	114	652	843	0	0	0	0	0	0
Contribution (MW)	**10 Feb**	**20 Feb**	**10 Mar**	**20 Mar**	**10 Apr**	**20 Apr**	**10 Jun**	**20 Jun**	**10 Jul**	**20 Jul**	**10 Aug**	**20 Aug**
Minimum load	8603	9573	9288	9109	8706	9349	9598	9205	9445	9255	9131	8352
Total thermal	4436	4360	4724	4181	4190	4145	4166	4209	4405	4440	4442	4401
Hydro	209	647	582	715	179	315	330	606	463	495	554	405
Wind	58	3	8	0	21	216	1439	1761	1809	2511	1633	1092
IPP	1126	1124	1126	794	689	768	988	475	482	207	460	491
Purchase	600	1187	518	1280	1619	1218	228	330	1027	1166	1175	1135
Load shedding	0	0	0	0	0	0	0	0	0	0	0	0

From the figures above, it can be surmised that seasonal variation is not a major constraint as the wind contribution in off-season is typically very low and the dispatch will be totally dependent on conventional sources and hydro resources. However, the intra-day and intra-seasonal variation in generation during the high-wind season is substantial. The maximum observed intra-day variation in wind generation for the mapped days in the high-wind months was 1,218 MW (difference between the wind contribution in the morning and evening peaks on 10 July 2011), while the maximum intra-seasonal variation for the mapped days in the high-wind months was to the tune of 1,594 MW (the difference between morning peak contribution on 10 July and 20 July 2011). Considering the present installed state-owned thermal (2,970 MW) and pure storage-based hydro (1,375 MW) capacity of Tamil Nadu and assuming a ramp time of 2% per minute for thermal and 5% per minute for hydro, theoretically, a maximum of 1,900 MW of generation variability can be managed over a 15-minute period assuming a constant load.

In the context of aggressive capacity addition scenario, the expected variance in wind generation will translate to 2,800 MW and 5,200 MW during 2016-17 and 2021-22 respectively.

However, even considering the present level of resources, this variability can be managed by effective control of 10,070 MW hydro power in the southern region provided inter-state cooperation coupled with a suitable commercial incentive is put in place to incentivize storage-based hydro schemes to participate as a spinning reserve for wind in the whole southern region. Taking advantage of the skewed RE generation pattern, the RE peak season can be used by the thermal power plants in the southern region to undertake maintenance and efficiency improvement projects. Considering the precarious situation of coal stocks in some thermal power plants, an increased RE penetration can help in conserving coal stocks, especially in plants having a history of generation back-down due to coal shortage.

But going beyond this, there are multiple opportunities to create new avenues and tap new resources to integrate the variability in the grid. Perhaps the most effective solution is to strengthen inter-regional corridor capacity and allow power transfer from southern region to the northern region. In this context, it is worth noting that the high-wind, low-demand situation in Tamil Nadu coincides with the high-demand, low-supply situation in the northern grid. Thus a strong inter-regional power transfer capability will doubly help Tamil Nadu; by allowing it to sell excess RE generation at profitable prices during peak season and buy deficit power from a larger seller base at a more reasonable price during off-peak season.

In this context, it is expected that a common national grid will be a reality in 2014, after the commissioning of 765 kV Raichur-Solapur line, which will facilitate exchange of surplus power between the southern region and the rest of the country. In addition, it is also expected that a 765 kV main corridor running from Tamil Nadu to Karnataka and Andhra Pradesh will be commissioned in 2015. If the expected grid extensions materialize, they will not only mean a smoothening in load management, but will also mean commercial benefits to host states by sweeping away the existing issues stemming from the limitations of the state grid.

The second major solution to manage grid variability could be implementation of RE forecasting. As per the Indian Electricity Grid Code (IEGC), 2010, the RE developer/operator shall forecast day-ahead power at intervals of 15 minutes with some provision for short time deviation. This forecasting mechanism is also linked to a commercial mechanism that will require the generators to pay charges for forecast deviations above a stipulated limit. Effective implementation of forecasting would allow utilities to plan for wind power in advance and will significantly reduce operational complexities and commercial impacts arising from generation variability.

In addition to the above mentioned alternatives, other options like pumped hydro, utility-scale energy storage, wind-solar PV integration, etc., coupled with smart load-management practices using smart grids and wind energy management systems (WEMS), will help in addressing the problem even at high renewable penetration. It is learnt that the Tamil Nadu Generation and Distribution Corporation (TANGEDCO) Ltd. is proposing to commission a 500 MW pumped storage scheme in Kundah in the 12th plan period, to balance the excess power available during off-peak hours and to tide over the peak hour shortage. A detailed description of the above mentioned options (storage, pumped hydro, smart grids and WEMS is covered in Chapter 10.

In conclusion, it can be said that even for a substantially higher RE penetration, the generation variability can be managed by using operational flexibility, stronger interconnections, forecasting services and storage options.

International experiences in managing RE variability are interesting. The Danish grid sometimes sees an instantaneous wind penetration surpassing total demand but is still able to manage this by making use of its strong interconnection to a larger Nordic system. In contrast, Ireland has a relatively small independent system but is still able to manage an instantaneous wind penetration of 40% by using flexible natural gas plants.

DEDICATED RE MANGEMENT AND CONTROL CENTRE

Another very effective planning initiative for integrating wind and RE as seen by many is to set up a dedicated RE control centre. In this context, Spain is the first country to set up a dedicated RE control centre called Control Centre of Renewable Energies (CECRE) and is responsible for managing all wind farms of over 10 MW. CECRE is integrated into the main power control centre of Spain and acts as an intermediary between the grid operators and the RE generators. The main function of CECRE is to integrate the maximum RE production into the electricity system whilst maintaining quality levels and guaranteeing supply security. CECRE receives real time information (every 12 seconds) from 23 control centers of generating companies and assesses it to determine the possibility of integrating the available wind generation into the system without compromising system security and operational performance. The analysis of CECRE is conveyed to the main national control centre, which modulates the generation from other sources. Doing this for Tamil Nadu would significantly change the way of integrating and managing variability. Understandably, the basic requirement before putting up this system would be to have forecasting in place. This may be challenging in the present scenario as the high dispersion of wind power across location, ownership, voltage, etc., would make aggregation of forecasts very challenging. However, in parallel and independently, many organizations and institutions are exploring the possibility of integrating forecasts. More about this is covered in Chapter 10.

Power system stability

Today, RE has a prominent influence on grid security, stability, and congestion management. As the majority of grid-connected wind farms in India have asynchronous generators which draw reactive power from the grid, there may be problems related to voltage instability and power quality. Furthermore, a weak interconnection link may result in local impacts like transmission- or sub-transmission-level system overloading.

While the Nordic countries of Germany, UK, Ireland, Spain and Canada, among others, have introduced technical regulations for RE integration, the IEGC, 2010, has also introduced some special clauses relating to wind and solar power integration into the grid. Some of the important clauses are:

- Special requirements for wind and solar generators from the system-security approach
- Reactive power and voltage control
- Outage planning.

The IEGC, 2010, also specifies that all necessary information be provided by RE generators and they should not draw/inject reactive power (voltage and reactive power or VAR) when system safety is involved. The new code also specifies that during wind generator start-up, the wind generator shall ensure that the reactive power drawal (in-rush currents in the case of induction generators) shall not affect grid performance. With this guideline on reactive compensation, grid operators can ensure that system voltage (at the grid connection point) remains within the limits set by the IEGC.

The IEGC has also laid down forecasting process for RE generators, which state that the RE developer/operator shall forecast power for the next day, and the next few hours to minimize scheduling errors. Some of the specific provisions of IEGC, 2010, related to forecasting are discussed below.

- Day-ahead forecast: at intervals of 15 minutes for the next 24 hours, for aggregate generation capacity of 10 MW and above.
- The schedule by such RE-generating stations supplying inter-state power under long-term access and medium-term and short-term open access may be revised by giving advance notice to the regional load dispatch centre (RLDC). Such revisions by RE-generating stations shall be effective from the sixth time-block, the first being the time-block in which notice was given. There may be a maximum of eight revisions for each three-hour time slot starting from 00:00 hours during the day.

A commercial mechanism is also detailed in the new code in which the commercial implications of all variations between the RE forecast and actual up to +/-30% are absorbed by the host state and adjusted through renewable regulatory fund (with RE developers paid for all energy supplied at agreed feed-in tariff and host state getting paid at applicable UI rate, which is usually lower than feed-in tariff, as system frequency at peak wind injection period will be generally high) and any variation beyond +/-30% is taken by the RE developer/operator. RE generators will be paid (for over injection) or will have to pay (for under injection) at applicable UI rates beyond +/-30% up to +/- 50% variation. With this standardization, it is easier for grid operators to provide secure and stable grid operation.

9.3.2 Commercial acceptance

The high wind penetration in Tamil Nadu has resulted in significant operational and commercial complexities in integrating wind power. While the need and the importance of wind energy and renewables are not being discounted, there are very grave concerns about the impact of high-wind penetration on finances of TANGEDCO.

Notwithstanding the recent instances of high-wind generation that allowed the utility to meet 100% demand, the emphasis of the utility is on the correlation of wind energy generation with demand and its impact on the operational costs associated with ‘power drawal and purchase’.

On the other hand, wind energy generators (WEGs) say that the losses to TANGEDCO are more a result of sub-optimal planning, system losses and subsidized supply, and that wind power, because of its accounting complexities, is being projected as the reason for major losses and lost recoveries.

In this context, it is important to highlight the direct costs of wind to TANGEDCO and evaluate the desirability and the financial feasibility of wind power for TANGEDCO and for the state as a whole.

The main issues in commercial acceptance of renewables are related to tariff levels, infrastructure funding and balancing costs.

Direct costs of wind generation to utility

It is generally believed that RE technologies are costlier than conventional technologies. As major RE technologies are driven by private investments, the basis for this comparison is the tariff difference between renewables and other technologies, especially coal. The preferential tariffs in many states for RE technologies are usually more than the tariffs for baseload conventional sources, making utilities resistant to paying more for generation that may or may not contribute to their peak requirements.

At present, WEGs in Tamil Nadu have two options to sell or use electricity. The first option is to opt for sale to the utility under an energy purchase agreement (EPA). In this mode, the generators sell the generated power to TANGEDCO at the prevalent preferential tariff for wind power as determined by TNERC. The other option is to use the generated energy for own use under the captive mode. This form of energy accounting comes under an energy wheeling agreement (EWA). In the most basic form, an EWA entitles the generators to set off the generated units against their own consumption in the state. The generators are expected to pay transmission and wheeling charges by way of rent for using the utility infrastructure.

Tamil Nadu has the additional provision of banking for WEGs under the EWA mode. Under this provision, the energy generated by WEGs in excess of consumption is banked with the utility. The banked energy is set off against consumption every month and the balance is carried forward to the next month. The total cycle for carrying forward this balance is over a year (1st April of first year to 31st March of second year). TANGEDCO had been petitioning for removal of this banking provision on account of the high price of supplying banking customers during the summer peak, when power costs are high.

The following narrative tries to estimate the costs under EPA and EWA separately.

According to the figures available in the TNERC document *Determination of tariff for generation and distribution*, dated 30.03.12 [Ref 35], the total units sold to TANGEDCO under EPA for FY 2012-13 are expected to be 5,408 MU at an average cost of about Rs. 3.01/kWh. **Table 9.7** provides the summary of figures available in the document.

Table 9.7 Summary of figures in TNERC document

Description	Unit	FY 2012-13
Total wind energy generation	MU	9549
Energy sales under Energy Purchase Agreement (EPA)	MU	5408
Purchase costs under EPA	Rs Cr	1629
Unit cost of wind under EPA	Rs/kWh	3.01

Further, in Order No. 1 of the TNERC document, the total quantum of energy generation under EWA framework is 4,141 MU for FY 2012-13. Considering past media reports related to the quantum of banked units in Tamil Nadu, it appears that the banked energy in 2011-12 was less than 1,200 MU [Ref 36]. We have assumed a very conservative figure of 1,242 MU (30% of energy under EWA) as banked energy for FY 2012-13. Understandably, this is expected to be a higher estimate of banked units than the actual figures for FY 2012-13. **Table 9.8** is derived to estimate the units under EWA and banking.

Table 9.8 Estimated units under EWA

Description	Unit	FY2012–13
Total wind-energy generation	MU	9549
Energy under wheeling (EWA)	MU	4141
Energy banked in off-wind season (assumed at 30% of wheeled energy)	MU	1242

Under the EWA agreement, the energy generation that is set off against consumption does not cost anything to TANGEDCO as intra-day and inter-day adjustments are already provided for by the provision of slot-to-slot adjustment (peak hour generation is set off against peak hour consumption and vice versa). So, the major cost under EWA, as reiterated by TANGEDCO and TNERC in the latest wind tariff order of August 2012 is the cost of supplying banked energy during supply deficit situations, i.e. off-wind season [Ref 37].

In the cited wind tariff order, TNERC has equated the cost of purchasing banked units to the average cost of bilateral trading prices for a period spanning April 2010 to March 2012. This works out to be Rs. 4.45/kWh. Based on this cost, TNERC has allowed TANGEDCO to levy a charge of Rs. 0.94 /kWh (Rs. 4.45 /kwh – Rs 3.51/kWh[preferential tariff]) on banked units.

Considering that the demand of the banking consumers are known, the average price under bilateral trading seems to indicate the most likely cost of purchase for TANGEDCO. However, just to model the maximum possible exposure on account of banked power purchase, we have also assumed power purchase at weighted APPC of Independent Power Producer (IPP) + Traders +UI. We look at the proposed APPC from non-core sources (IPP + Traders +UI) of purchases as provided in TANGEDCO's revised submission to TNERC in the tariff determination order of March 2012. **Table 9.9** below shows the figures as provided in TANGEDCO's revised submission.

Table 9.9 Figures submitted by TANGEDCO to TNERC (March 2012)

Average power cost from IPPs + Traders + UI	2012-13	
	Average Rate (Rs/Unit)	MU
GMR	13.98	495
Samalpani	12.84	575
PPN	9.49	2395
Madurai	14.45	575
ST-CMS	4.28	1795
ABAN	3.22	810
Penna	3.43	375
Traders	5.7	5365
UI	4.14	145
Weighted Average Purchase cost (Rs/Unit)	7.03	

As can be seen, the weighted average cost of power purchase for FY 2012-13 is about Rs. 7.03/kWh. Even if we assume that TANGEDCO purchases banked power at this rate and recovers banking charges, the total costs to TANGEDCO would not exceed Rs. 760 crore. **Table 9.10** tries to capture the impact of banking under the most likely and maximum scenario.

Table 9.10 Impact of banking under the most likely and maximum scenario

Parameter	Unit	Equation	Most Likely	Maximum	Explanation
Energy under wheeling (EWA)	MU	A	4141	4141	'Determination of Tariff for generation and distribution', Order No. 1 of 2012 dated 30.03.12, TNERC
Banked energy (@30% of wheeled energy)	MU	B (=A*30%)	1242.3	1242.3	Assumption of 30% energy under EWA as banked for use in off-wind season
Purchase cost for supplying banked power	Rs Cr	C (=B* rate of purchase/10)	552.8	873.3	**Rate of purchase** Most likely: Rs 4.45/kWh- Average bilateral trading prices from April 2010 to March 2012 Maximum: Rs 7.03/Unit weighted average cost (for IPP + Traders + UI) FY 12-13
Recoverable banking charges	Rs Cr	D (=B*0.94/10)	116.8	116.8	Banking charge of Rs 0.94/kWh
Total cost to TANGEDCO on account of banked power	Rs Cr	F (=C-D-E)	436.0	756.6	Total cost of banking
Unit cost for banked energy	Rs/kWh	G (=F*10/B)	3.5	6.1	
*Incidentally, this calculation does not include other charges payable to TANGEDCO					

If we now consolidate the total cost of wind power to TANGEDCO, the following tabulated summary emerges **(Table 9.11).**

Table 9.11 Consolidated total cost of wind power to TANGEDCO

Parameter	Unit	Equation	Most Likely	Maximum
Total energy from wind	MU	A	9549	9549
Energy under direct sale mode (EPA)	MU	B	5408	5408
Energy under wheeling (EWA)	MU	C	4141	4141
Energy under banking (@30% of wheeled energy)	MU	D (=C*30%)	1242.3	1242.3
Purchase costs for EPA	Rs Cr	E	1629	1629
Purchase cost for banked power	Rs Cr	F	436.0	756.6
Total cost to TANGEDCO for EPA + banked energy	Rs Cr	G (=E+F)	2065.0	2385.6
Unit Cost of wind (EPA)	Rs/kWh	H (=B/E*10)	3.01	3.01
Unit Cost of banked power	Rs/kWh	I (=D/F*10)	3.51	6.09
Unit Cost of EPA + banked power	Rs/kWh	J (=G/(B+D)*10)	3.11	3.59

Even if we consider the maximum impact and account only for purchased and banked units, the cost of wind is unlikely to exceed Rs. 3.59/kWh. This is comparable to the existing preferential tariff for wind. The 'most likely' scenario indicates an average cost of Rs. 3.11/kWh, which is comparable to purchase prices of thermal generation.

Comparing the maximum cost with total average purchase cost (purchase cost excluding state-based generation) of Rs. 4.04/ kWh as submitted by TANGEDCO in the tariff determination order of March 2012, it would seem that TANGEDCO is still getting wind power at a cost much below its projected APPC for FY 2012-13. Prima facie, this would suggest that wind power, coming from a mix of EPA and EWA with banking is still cost effective for TANGEDCO as compared to other purchase options.

In this context, it is important to understand that the year-on-year increasing trend of APPC indicates a steady increase in conventional power prices. Additionally, trading mechanisms like RECs would allow host utilities to buy RE power even at APPC (prices below the preferential tariff) thus reducing their direct exposure.

9.3.3 Funding evacuation infrastructure development

From the states perspective, a strong grid network would mean an enhanced ability to manage load variability by flexibly transferring the excess energy or drawing deficit energy from across a wider region.

Many studies on large scale renewable energy integration have singled out a strong evacuation backbone as the most important prerequisite for RE integration. Denmark is able to handle an instantaneous penetration of 100% RE (wind) primarily because of the strong interlinks and inter-regional corridor capacity that allows it to export the surplus much easily to a larger Nordic pool. In this context, it would make more sense if Tamil Nadu can focus on developing strong inter-regional links and adopt an open border policy of using or supplying power to the much larger national grid rather than closing its borders to potential co-operative arrangement and a higher level of flexibility.

The biggest constraint for large-scale RE generation in Tamil Nadu is evacuation infrastructure. At present, evacuating wind power during peak wind season, especially in Tirunelveli and Muppandal, requires evacuation to nearby major 230 kV or 400 kV substations, as the downstream demand is already met. This overloads the existing 110 kV lines resulting in backing down of wind even when the system may have unmet demand. The only option is to strengthen the existing line or to connect wind power generation directly at 220 or 400 kV level. Both options carry significant cost implications for the cash-strapped utility. Issues related to evacuation infrastructure are thus commercial, not technical, and therefore require a commercial solution.

In the context of AGG scenario, the new RE capacity-addition requirement is substantially over and above the envisaged new capacity addition. The AGG capacity-addition scenario would imply requirement of about 154 substations and 6,500 km of lines over capacity addition slated for the 12th and 13th five-year plans. Details of grid infrastructure requirements are shown in **Table 9.12**.

Table 9.12 Grid infrastructure requirement for AGG capacity addition scenario (Ref: Chapter 10)

Infrastructure requirement for 2021–22 AGG		
Infrastructure requirement	**2012-17**	**2017-22**
Substation voltage level	**Number**	**Number**
400 kV	11	8
230 kV	51	23
110 kV	60	1
Line voltage level (kV)	**Km**	**Km**
400 kV	1001	891
230 kV	1490	630
110 kV	1260	0

The cost implication of the additional grid infrastructure is estimated at Rs. 11,025 crore, which is very large considering the existing demands and expected funding requirements.

However, it is to be noted that the proposed capacity addition may not mean an immediate fund deployment for the state as the existing infrastructure development model under section 10(1) effectively shifts the cost burden of the infrastructure on the developers, who make up-front investments and are partially reimbursed over time. Additionally, the state can, even without allocating specific funds for the expansion, divert funds from other activities or generate new funds (creation of a state clean energy fund) to finance grid expansion. The next chapter identifies ways in which this can be done.

9.3.4 Balancing costs: commercial implications

There is a generally held notion that high wind penetration has resulted in significant losses to TNEB on account of balancing costs due to generation variability of wind. We analyzed the load generation balance reports and the overdrawal/under-injection reports of Southern Regional Load Dispatch Centre (SRLDC) for FY 2011-12 to map the monthly energy supplied, wind generation, and average frequency profile for Tamil Nadu to understand the implications of UI charges on the state.

Table 9.13 summarizes the values for UI charges for all the months of FY 2011-12.

Table 9.13 Values for UI charges for all the months of FY 2011-12

Parameter	**Unit**	**Apr-11**	**May-11**	**Jun-11**	**Jul-11**	**Aug-11**	**Sep-11**
Energy Requirement Avg/Day	MU	7144	7532	7309	7313	6905	6797
Energy supplied	MU	6519	7018	6887	6974	6703	6490
Schedule	MU	2324	2248	1834	1886	2145	1702
Drawal	MU	2529	2436	1951	1871	2118	1717
Overdrawal(+)/Underdrawal (-)	MU	205	188	117	-15	-27	15
Total Drawal @ frequency <49.7 Hz	MU	116.37	62.61	21.45	15.33	3.01	12.8
Total UI Charges @ frequency <49.7 Hz	Rs Cr	93.97	44.12	12.6	8.3	0.4	10.49
Wind-power generation							
Wind generation	MU	233.69	532.43	1314.85	1833.88	1843.27	1502.79
% of energy supplied through wind	%	3.58	7.59	19.09	26.30	27.50	23.16
Frequency Profile							

Max Frequency	Hz	50.86	50.87	50.84	50.64	50.65	50.74
Min Frequency	Hz	48.81	48.83	48.77	48.97	49.35	48.81
Average Frequency	Hz	49.67	49.82	49.84	48.82	49.9	49.88
Parameter	**Unit**	**Oct-11**	**Nov-11**	**Dec-11**	**Jan-12**	**Feb-12**	**Mar-12**
Energy Requirement Avg/Day	6801	6243	6800	6899	7239	7988	84970.0
Energy supplied	6724	5489	5996	5956	5629	6016	76401.0
Schedule	2037	1899	1928	1939	1776	1881	23599
Drawal	2096	2007	1955	2074	1918	1977	24649
Overdrawal(+)/Underdrawal (-)	59	108	27	135	142	96	1050
Total Drawal @ frequency <49.7 Hz	42.47	50.92	17.77	50.22	74.96	56.13	524.04
Total UI Charges @ frequency <49.7 Hz	28.09	31.1	9.82	28.57	45.07	34.92	347.45
Wind power generation							
Wind generation	1187.02	176.1	329.46	309.63	317.16	275.29	9855.6
% of energy supplied through wind	17.65	3.21	5.49	5.20	5.63	4.58	12.90
Frequency Profile							
Max Frequency	50.52	50.62	50.7	50.79	50.99	50.79	50.75
Min Frequency	48.8	48.81	48.93	48.87	48.81	48.84	48.88
Average Frequency	49.68	49.71	49.74	49.74	49.69	49.64	49.68

In general, it can be seen that the UI charges paid by TNEB for drawal below 49.7Hz is significantly less in the wind season as compared to off-wind season. From 11 June to 11 October, when monthly wind generation was over 1,000 MU, it spent on average about Rs. 12 crore/month. In the remaining period of lower wind generation, the average UI charges (f <49.7) were Rs. 41 crore/month.

In the absence of high resolution data related to wind generation and information on the operational choices made by TANGEDCO, the actual benefit/loss cannot be ascertained with accuracy. However, the correlation of monthly wind generation with the average frequency (weakly negative correlation coefficient of -0.26) seems to suggest that wind power generation in Tamil Nadu may not necessarily have significant effect on the regional grid frequency. The comparison of monthly wind generation with the UI charges paid for frequency below 49.7 Hz (negative correlation coefficient of -0.63) seems to suggest that high wind power generation could imply lower UI charges.

Even if we consider a lower demand in the high-wind season and discount an effective payout of preferential tariff to non-captive customers, the equation would still mean an overall commercial benefit to TNEB. It is to be noted here that as wind generation in the off-wind season is negligible, the high UI charges in that season are on account of supply-side deficit and high demand.

However, it is worth discussing whether renewables will make commercial sense when the state-based conventional capacity is able to meet the summer demand. We expect that given the existing dynamics and market options, renewables can still translate into a benefit to the state. The most cost-effective option for the state for balancing power would be to use storage-based hydro power from the southern region. This would necessitate either a mutually agreeable bilateral understanding between different states or a viable commercial agreement that would incentivize the state owned hydro stations to participate in managing load. The National Load Dispatch Centre (NLDC) has already mooted the idea of using hydro power for balancing the generation-variability of wind, and a regulatory mechanism for effecting the same is being discussed at various levels.

Any unscheduled wind generation can still make commercial sense as the financial exposure of the utility is only to the extent of preferential tariff or APPC (depending on power sale mode) for non-captive wind generators as against spot purchase prices through exchanges. As the REC market develops, the exposure would become even less when the generators opt for RECs and sell the power at APPC rather than at the preferential tariff. Further, considering the weak co-relation of wind with the grid frequency, any additional generation would mean underdrawal that will bring in frequency dependent UI rate, which may range from Rs. 0 /kWh to about Rs. 10 /kWh for frequency in the range of 50.2 Hz to 49.7 Hz, respectively. Conversely, any drop in wind generation would result in the utility incurring charges for overdrawal.

However, the commencement of forecasting for RE coupled with the establishment of a national grid would change the picture completely and translate into huge trading opportunities to TNEB, allowing it to recoup past losses and cover expenses in a more effective manner.

But perhaps the real commercial benefit of the proposed RE integration can only be assessed by comparing the expected commercial implications of RE with the possible commercial implications arising from delay, cancellations, or price escalation of planned conventional power projects. As on today, the possibility for this seems very real.

In conclusion, the single-most important finding from the analysis is that even an aggressive renewable energy deployment scenario (capacity-addition of 36,470 MW of RE in the 12th and 13th five-year plans) is technically feasible, if we are willing to make changes in the way we analyze and value renewables.

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10. Summary Results of a Detailed Grid Study for Large Scale RE Integration and Evacuation

A detailed study of the grid integration issues, infrastructure development, and costs involved were done by WISE with the help of Power Research Development Consultants (PRDC), Bengaluru. The following summary is based on that detailed study. Please note that there may be minor tweaking of the proposed target capacity addition figures in this study.

Power evacuation studies were carried out in-depth to check the ability of the network to absorb large-scale integration of RE into the Tamil Nadu grid. Load flow analysis is the best algorithm available for this purpose. The starting point of any analysis of a power system is the computation of complex voltages at all the buses. The study showed the electrical performance and power flows (real and reactive) for specified conditions when the system is operating under steady state. Load flow analysis of network conditions with the proposed RE sources was carried out for 2016–17 (end of the 12th five-year plan) and 2021–22 (end of the 13th five-year plan). In line with the preliminary recommendations of the RE roadmap, it was decided to study large-scale RE integration for the BAU and Aggressive scenarios.

The methodology followed for the study is as below:

- The entire southern grid database has been modelled for 2011–12, 2016–17 and 2021–22 network conditions covering 765 kV and 400 kV networks (for 2016–17 and 2021–22).
- Since RE sources are concentrated mainly in four regions of Tamil Nadu—Tirunelveli, Udumalpet, Muppandal and Theni—geographical drawings have been prepared for these four regions representing the existing and proposed renewable sources in these regions.
  Capacity utilization factor: From the past data available for the TNEB network, it was found that peak wind generation during windy season could occur simultaneously with solar power generation. Following a worst-case scenario basis to ascertain the ability of the network to absorb large-scale RE integration into the grid, it was clear that the contribution of wind and solar together formed the critical scenario. The study team assumed a capacity utilization factor of 0.6, which is applicable for wind power as well as solar power, although the factor will decrease with large-scale integration of RE sources.
- **Network conditions:** Studies were carried out for the following network conditions.
  - 2011–12 network conditions (the existing case or the base case).
  - 2016–17 network conditions (end of the 12th Plan).
  - 2021–22 network conditions (end of the 13th Plan).
- **Demand details:** The system peak demand details were extracted from the 18th EPS (draft) report. Since the windy season in Tamil Nadu does not coincide with the system peak demand, 80% (of the system peak demand) was considered as the peak demand during high wind season.
- The Raichur to Sholapur inter-regional 765 kV line was considered as the slack bus and equivalent generator is modelled at Raichur 765 kV bus (for 2016-17 and 2021-22 scenarios).
- System studies were carried out considering all the above-mentioned points.
- The cost of strengthening the transmission network to meet the projected demand with different RE integration scenarios was estimated based on the unit cost figures (based on STU/CTU/CERC benchmarking costs) given in **Tables 10.1 and 10.2.**

Table 10.1 Unit cost (Rs Crore) of substation equipments

Voltage level of the S/S in kV	Establishment cost	Bay cost	Transformer cost
400	50	5	12
230	7.5	2	3.91
110	3	1.5	2.83

Table 10.2 Transmission line costs (Rs Crore)

Voltage level of the line	Cost per km
400 kV	1.8
230 kV	0.7
110 kV	0.55

10.1 Proposed Locations for RE Capacity Addition

The proposed locations for the BAU and Aggressive scenarios are provided in **Tables 10.3 and 10.4** respectively

Table 10.3 Business-as-usual scenario – Proposed locations

Wind power capacity (MW)				
Taluka	**District**	**Installed**	**12th Plan**	**13th Plan**
Ariyalur	Ariyalur		44	56
Coimbatore South	Coimbatore	69.6	110	140
Pollachi	Coimbatore	42.125	143	182
Sulur	Coimbatore		88	112
Attur	Salem		44	56
Kodaikanal	Dindigul		88	112
Palani	Dindigul	138.8	241	308
Bhavani	Erode		11	14
Sathyamangalam	Erode		88	112
Aravakurichi	Karur		88	112
Denkanikottai	Krishnagiri		44	56
Peraiyur	Madurai		132	168
Usilampatti	Madurai		44	56
Nagapattinam	Nagapattinam		44	56
Pudukkottai	Pudukkottai		88	112
Kadaladi	Ramanathapuram		88	112
Rameswaram	Ramanathapuram	0.5	88	112
Omalur	Salem		66	84
Andipatti	Theni	123.35	110	140
Bodinayakkanur	Theni	3.6	121	154
Theni	Theni	21	22	28
Uthamapalayam	Theni	146.05	55	70
Ambattur	Thiruvallur		66	84

Tiruvannamalai	Thiruvannamalai		44	56
Kodavasal	Thiruvarur		88	112
Kovilpatti	Thoothukudi	166.495	766	979
Ottapidaram	Thoothukudi		439	560
Sathankulam	Thoothukudi		88	112
Vilathikulam	Thoothukudi	4	44	56
Alangulam	Tirunelveli	334.025	33	42
Ambasamudram	Tirunelveli	10.475	33	42
Nanguneri	Tirunelveli	36.25	175	224
Palayamkottai	Tirunelveli	112.405	88	112
Radhapuram	Tirunelveli	1182.44	526	672
Sankarankoil	Tirunelveli	289.945	526	672
Sivagiri	Tirunelveli		11	14
Tenkasi	Tirunelveli	247.95	252	322
Tirunelveli	Tirunelveli	292.205	110	140
Veerakeralampudur	Tirunelveli	256	11	14
Dharapuram	Tirupur	611.66	274	350
Kangeyam	Tirupur	257.135	66	84
Madathukulam	Tirupur		186	238
Palladam	Tirupur	128.425	11	14
Tirupur	Tirupur		125	0
Udumalaipettai	Tirupur	832.75	197	252
Total		**5307.185**	**6000**	**7500**
Solar PV development plan capacity (MW)				
Taluka	**District**	**Installed**	**12th Plan**	**13th Plan**
Peraiyur	Madurai		250	525
Thirumangalam	Madurai		250	0
Kovilpatti	Thoothukudi		250	825
Ottapidaram	Thoothukudi		250	0
Vilathikulam	Thoothukudi		250	0
			1250	**1350**
CSP development plan capacity (MW)				
Taluka	**District**	**Installed**	**12th Plan**	**13th Plan**
Ramanathapuram	Ramanathapuram		120	325
Srivaikuntam	Thoothukudi		130	325
Thoothukkudi	Thoothukudi		0	0
			250	**650**
Biomass development plan (capacities in megawatts)				
Taluka	**District**	**Installed**	**12th Plan**	**13th Plan**
	Villupuram	0.0	35	40
	Namakkal	0.0	30	35
	Dharmapuri	0.0	25	30

	Salem	0.0	25	30
	Cuddalore		20	25
	Erode		25	25
	Thiruvanmalai		15	20
	Perambalur		16	20
	Tiruchirappalli		10	15
			200	**240**

Table 10.4 Aggressive scenario - Proposed locations

Wind power capacities in MW				
Taluka	**District**	**Existing capacity**	**12th Plan**	**13th Plan**
Ariyalur	Ariyalur		100	344
Coimbatore South	Coimbatore	70	250	174
Pollachi	Coimbatore	42	325	417
Sulur	Coimbatore		200	0
Attur	Salem		100	0
Kodaikanal	Dindigul		200	0
Natham	Dindigul		0	104
Nilakkottai	Dindigul		0	288
Oddanchatram	Dindigul		0	516
Palani	Dindigul	139	550	0
Vedasandur	Dindigul		0	667
Bhavani	Erode		25	0
Sathyamangalam	Erode		200	142
Agastheeswaram	Kanyakumari	7	0	173
Thovala	Kanyakumari	113	0	140
Aravakurichi	Karur		200	0
Denkanikottai	Krishnagiri		100	1196
Hosur	Krishnagiri		0	619
Krishnagiri	Krishnagiri		0	462
Peraiyur	Madurai		300	134
Usilampatti	Madurai		111	241
Kilvelur	Nagapattinam		0	186
Nagapattinam	Nagapattinam		100	105
Sirkali	Nagapattinam		0	304
Tharangambadi	Nagapattinam		0	167
Thirukkuvalai	Nagapattinam		0	85
Pudukkottai	Pudukkottai		200	0
Kadaladi	Ramanathapuram		200	217
Kamuthi	Ramanathapuram		0	46
Mudukulathur	Ramanathapuram		0	61
Paramakudi	Ramanathapuram		0	33
Ramanathapuram	Ramanathapuram		0	494
Rameswaram	Ramanathapuram	1	200	0

Wind power capacities in MW				
Taluka	**District**	**Existing capacity**	**12th Plan**	**13th Plan**
Tiruvadanai	Ramanathapuram		0	416
Omalur	Salem		150	0
Andipatti	Theni	123	250	248
Bodinayakanur	Theni	4	275	0
Periyakulam	Theni		0	79
Theni	Theni	21	50	67
Uthamapalayam	Theni	146	125	308
Ambattur	Thiruvallur		150	58
Ponneri	Thiruvallur		0	436
Tiruttani	Thiruvallur		0	287
Tiruvannamalai	Thiruvannamalai		100	532
Kodavasal	Thiruvarur		200	0
Mannargudi	Thiruvarur		0	356
Nannilam	Thiruvarur		0	157
Needamangalam	Thiruvarur		0	152
Thiruthuraipoondi	Thiruvarur		0	382
Thiruvarur	Thiruvarur		0	96
Valangaiman	Thiruvarur		0	132
Ettayapuram	Thoothukudi		0	322
Kovilpatti	Thoothukudi	166	1749	0
Ottapidaram	Thoothukudi		999	0
Sathankulam	Thoothukudi		200	46
Srivaikuntam	Thoothukudi		0	390
Thoothukudi	Thoothukudi		0	226
Tiruchendur	Thoothukudi		0	308
Vilathikulam	Thoothukudi	4	100	472
Alangulam	Tirunelveli	334	75	0
Ambasamudram	Tirunelveli	10	75	0
Nanguneri	Tirunelveli	36	400	215
Palayamkottai	Tirunelveli	112	200	0
Radhapuram	Tirunelveli	1182	1199	0
Sankarankoil	Tirunelveli	290	1199	0
Sivagiri	Tirunelveli		25	153
Tenkasi	Tirunelveli	248	575	0
Tirunelveli	Tirunelveli	292	250	0
Veerakeralampudur	Tirunelveli	256	25	0
Dharapuram	Tirupur	612	625	0
Kangeyam	Tirupur	257	150	166
Madathukulam	Tirupur		425	0
Palladam	Tirupur	128	25	425
Tirupur	Tirupur		0	412
Udumalaipettai	Tirupur	833	450	0

Wind power capacities in MW				
Taluka	**District**	**Existing capacity**	**12th Plan**	**13th Plan**
Vaniyambadi	Vellore		0	271
Vellore	Vellore	45	0	250
Wallajah	Vellore		0	326
Total		5472	13400	15000

Solar PV development plan (capacities in MW)				
Taluka	**District**	**Installed**	**12th Plan**	**13th Plan**
Peraiyur	Madurai		290	700
Thirumangalam	Madurai		370	700
Kovilpatti	Thoothukudi		370	700
Ottapidaram	Thoothukudi		290	700
Vilathikulam	Thoothukudi		290	700
Paramakudi	Ramanathapuram		285	
Ramanathapuram	Ramanathapuram		285	
Tiruvadanai	Ramanathapuram		420	
			2600	3500
CSP development plan (capacities in MW)				
Taluka	**District**	**Installed**	**12th Plan**	**13th Plan**
Ramanathapuram	Ramanathapuram		140	350
Srivaikuntam	Thoothukudi		130	325
Thoothukudi	Thoothukudi		130	325
			400	1000
Biomass development plan (capacities in MW)				
Taluka	**District**	**Installed**	**12th Plan**	**13th Plan**
	Villupuram	0.0	35	40
	Namakkal	0.0	30	35
	Dharmapuri	0.0	25	30
	Salem	0.0	25	30
	Cuddalore		20	25
	Erode		25	25
	Thiruvanmalai		15	20
	Perambalur		16	20
Biomass development plan (capacities in MW)				
	Tiruchirappalli		10	15
			200	240

10.2 Study for 2011-12 Conditions

A load-flow study was carried out for 2011-12 conditions to form the base case scenario. All the existing wind power generation was considered for this analysis. The existing network has some constraints to wind power evacuation during the peak wind season. Major observations of the study are given below.

- **Tirunelveli region:** A few lines are loaded beyond their thermal loading limit. Necessary augmentation measures are being implemented such as the use of high tension, low sag (HTLS) conductor and network reconfiguration to reduce the overload.
- **Udumalpet region:** All the line loadings (except the Palladam to Kethanur 110 kV S/C line) and voltages in the vicinity of the wind farm are within acceptable limits during normal operating conditions. However, during high wind season, the reactive power drawals from old machines are high, which results in low voltage in certain pockets.
- **Muppandal region:** A few lines are loaded beyond their thermal loading limit. Necessary augmentation measures are being implemented, such as network reconfiguration, to reduce the overload.

General observations: At present, most of the 110 kV substations are connected to one another using S/C lines. Wind farms are connected to these 110 kV substations. During an average windy day, the local loads consume most of the wind power generated. However, during peak wind season, if the local demand is less (which is the worst possible case), the wind power generated will have to be evacuated into nearby major 230 kV or 400 kV S/S. Due to this, 110 kV lines are overloaded during the peak wind season.

At present the split-bus arrangement and network reconfigurations are being implemented to reduce such overloads. However, these are only short-term solutions. To integrate large-scale RE into the TAMIL NADU grid, a reliable transmission network is needed.

10.3 Load-Flow Analysis for BAU Scenario

As explained earlier, load flow was studied for 2016–17 and 2021–22 network conditions considering business-as-usual scenario, which is addressed in this section.

10.3.1 Business-as-usual Scenario for 2016–17 conditions

The proposed action plan for BAU 2016–17 network conditions is given in **Table 10.5**. The 18th EPS (draft) puts Tamil Nadu system peak demand at 18,994 MW. Considering 80% of this demand, the Tamil Nadu system was simulated for 15,195 MW during the peak wind season. Three 765 kV links will become operational during this period. System reinforcements like transmission line and sub-stations already planned by Tamil Nadu under the National Clean Energy Fund (NCEF) were also considered in the study. The 765 kV substations expected are shown in **Figure 10.1**. A consolidated list of existing and proposed RE resources considered for study is given earlier in Section 10.1 of this chapter.

Table 10.5 Proposed action plan for BAU 2016–17 network conditions

Proposed new capacity addition in 12th plan (BAU)	
RE source	**2016–17 scenario (MW)**
Wind	6000
Solar	1500
Biomass	200
Other RE	60
Existing RE (Effective)	6953
Total RE (expected)	**14713**

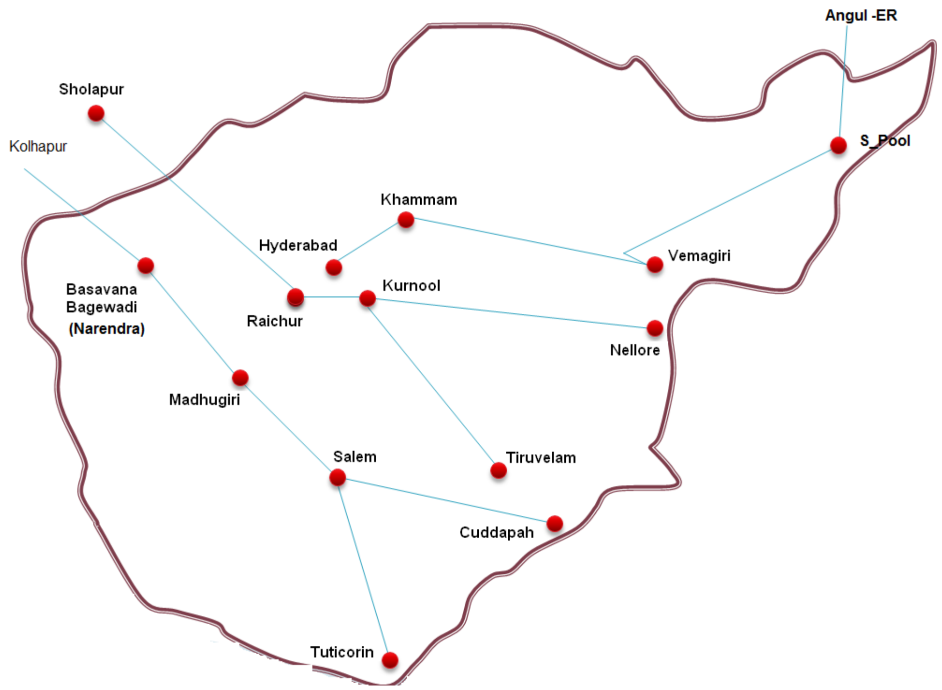

Figure 10.1 The 765 kV link considered for the BAU scenario 2016–17 network conditions

General observations from the 2016–17 BAU system study

- For the purposes of transmission planning existing RE capacity of 6,953 MW and the BAU scenario proposed in this report of 7,760 MW has been considered; together the total of which comes to 14,713 MW.
- Total effective RE sources considered for the study amount to about 8,830 MW (60% of 14,713 MW), which shows that the contribution of wind power to the system is 52% during the peak wind season.
- The transmission system requires additional 400 kV, 230 kV, and 110 kV substations to reliably evacuate the available RE. The additional substations are proposed based on the following criteria.
  - Substations already proposed by STU / CTU / other criteria.
  - Wind power injection at any location exceeds 200 MW (one 230 kV substation).
  - Wind power injection is 100–200 MW (110 kV substations).
  - Based on these criteria, the number of substations required in the 2016–17 scenario are given in **Table 10.6**. Table and transmission line lengths are given in **Table 10.7**.

Table 10.6 No. of substations proposed for 2016–17 BAU scenario

Voltage level of the substation	Number of stations
400 kV	5
230 kV	21
110kV	47

Table 10.7 Proposed line lengths (in circuit km) for 2016–17 BAU scenario

Voltage level of the line	Length (km)
400 kV	874
230 kV	690
110 kV	956

- All 765 kV and 400 kV lines are loaded within their thermal limits.

Export of power from Raichur (S.R.) to Sholapur (W.R.) on 765 kV line is 513 MW.

In a few cases, the 110 kV lines are overloaded, which can be resolved by changing the existing ACSR Panther conductor to equivalent HTLS conductor (which will need additional investments of almost 6–7 times as normal conductors). A few 230 kV lines are also overloaded, which can be resolved by introducing additional lines.

10.3.2 Business-as-usual Scenario for 2021–22 conditions

It is expected that nearly 22,877 MW of RE would be added during this period (**Table 10.8**).

Table 10.8 Proposed action plan for BAU 2021-22 network condition

Proposed new capacity addition in 13th plan (BAU)	
RE source	**2021–22 scenario (in MW)**
Wind	7500
Solar	2000
Biomass	240
Other RE	70
Total RE (proposed)	9810
Total RE at the end of 2016–17	(7760+6953) 14713
Total RE expected	24523

The Tamil Nadu system peak demand will be 26,330 MW in 2021–22. Considering 80% of this demand, the Tamil Nadu system was simulated for 21,064 MW. Three 765 kV links will be operational during this period.

General observations from 2021-22 BAU system study

- Total Tamil Nadu system demand considered for the study is 21,064 MW (80% of peak demand of 26,330 MW).
- Total effective RE sources amount to 14,714 MW (60% of 24,523 MW), which shows that the contribution of RE to the system is about 65% during the peak wind season.
- The transmission system requires additional 400 kV, 230 kV, and 110 kV substations to reliably evacuate the available RE. The additional substations are proposed based on the following criteria.
  - Substations already proposed by STU / CTU / other criteria.
  - Wind power injection at any location exceeds 800-1000 MW (one 400 kV substation).
  - Wind power injection at any location exceeds 200 MW (one 230 kV substation).
  - Wind power injection is 100–200 MW (110 kV substations).

Based on these criteria, the number of substations required for 2021–22 scenario is given in **Table 10.9** and the lengths of transmission lines are given in **Table 10.10**.

Table 10.9 No. of substations proposed for the 2021–22 BAU scenario

Voltage level of the substation	Number of substations
400 kV	11
230 kV	49
110 kV	60

Table 10.10 Proposed line length (circuit km) for 2012–22 BAU scenario

Voltage level of the line	Length (km)
400 kV	1001
230 kV	1490
110 kV	1210

- The 400 kV line between Kannarpatti and Tirunelveli S/S is overloaded and should be strengthened. For this purpose, a twin moose conductor is recommended for this line.

All 765 kV and 400 kV lines are loaded within their thermal limits. There are increased power flows in the Salem–Nagapattinam 765 kV line (from 631 MW to 2142 MW) and also in Raichur–Sholapur 765 kV line (from 513 MW to 1345 MW) in 2021–22 BAU scenario, as compared to the 2016–17 BAU scenario, mainly because of additional RE considered in Salem and Tuticorin and the corresponding re-adjustment of conventional generation in Karnataka.

- In a few cases, the 110 kV lines are overloaded, which can be resolved by changing the existing ACSR Panther conductor to an equivalent HTLS conductor. Overloading of 230 kV lines can be resolved by augmenting with additional lines.

10.4 Load Flow Analysis for Aggressive Scenario

As with the BAU scenario, a load-flow study was carried out for network conditions in 2016–17 and 2021–22, considering the Aggressive scenario.

10.4.1 Aggressive scenario for 2016–17 conditions

It is expected that nearly 16,660 MW of RE would be added during the 12th plan. Considering the existing installed capacity of 6953 MW, the total capacity at the end of 2016–17 would be 23613 MW. A breakdown of different RE sources is given in **Table 10.11**.

Table 10.11 Proposed action plan for AGG 2016–17 network condition

RE source	2016–17 scenario (in MW)
Wind	13400
Solar	3000
Biomass	200
Other RE	60
Total RE (Proposed) for 12th plan period	16660
Existing RE (effective)	6953
Total RE (expected)	23613

A capacity factor of 60% was assumed for this study. Demand details were taken from the 18th EPS draft report. As per the report, Tamil Nadu system peak demand will be 18,994 MW under the 2016–17 network conditions. Considering 80% of this demand, the Tamil Nadu system has been simulated for 15,195 MW. Three 765 kV links will be operational during this period.

General observations from the 2016–17 AGG system study

- Total Tamil Nadu system demand considered for the study is around 15,195 MW (80% of peak demand of 18,994 MW).
- Total effective RE sources considered for the study amount to 14,168 MW (60% of 23,613 MW), which shows that wind power contributes approximately 93% to the system during peak wind season.
- Since the available generation in the southern region is more due to the aggressive addition of RE, nearly 4,500 MW may have to be exported. Otherwise, all the available hydro projects in the southern region (approximately 5,500 MW except irrigation-based), along with conventional power plants, will have to operate at their technical minimum, so that inter-regional export will be less than 3000 MW.
- Tamil Nadu will export bulk of its power to the neighbouring states, for which a suitable contract mechanism needs to be in place.
- The transmission system requires additional 400 kV, 230 kV, and 110 kV substations to reliably evacuate the available RE. The additional substations are proposed based on the following criteria.
  - Substations already proposed by STU / CTU / other criteria.
  - Wind power injection at any location exceeds 800-1000 MW (one 400 kV substation).
  - Wind power injection at any location exceeds 200 MW (one 230 kV substation).
  - Wind power injection is 100–200 MW (110 kV substations).

Based on the above criteria, the number of substations required for the 2016–17 AGG scenario is given in **Table 10.12** and transmission line lengths are given in **Table 10.13**.

Table 10.12 No. of substations proposed for the 2016–17 AGG scenario

Voltage level of the substation	Number of substations
400 kV	11
230 kV	51
110 kV	60

Table 10.13 Required transmission lines for 2016-17 AGG scenario

Voltage level of the line	Length (km)
400 kV	1001
230 kV	1490
110 kV	1260

- All the 765 kV and 400 kV lines are loaded within their thermal limits. Power flows increase in the Salem–Nagapattinam 765 kV line (from 631 MW to 2130 MW) and in the Raichur–Sholapur 765 kV line (from 513 MW to 1345 MW) in 2016–17 aggressive scenario as compared to the 2016–17 BAU scenario, because of large solar power injection in Salem/Tuticorin regions, leading to backing down of hydel generation in Karnataka, etc., to accommodate the increased RE power. The western grid has to accommodate the increased flow from southern grid, a matter that needs to be examined. Overloadings on 110 kV and 230 kV lines could be resolved by augmenting with HTLS conductors or with additional lines. The HTLS conductors cost about 6–7 times as much as the ACSR.

10.4.2 Aggressive scenario for 2021–22 conditions

It is expected that nearly 41,942 MW of RE would be installed by the end of the 13th plan period. The contribution of different RE sources is shown in **Table 10.14**.

Table 10.14 Proposed action plan for AGG 2021-22 network conditions

RE source	2021–22 scenario (in MW)
Wind	28400
Solar	7500
Biomass	440
Other RE	130
Total RE (proposed) for 12th & 13th plans	36470
Total RE at the beginning of 12th plan	6953
Total RE (expected)	43423

A capacity factor of 60% was assumed for this study. Demand details were taken from the 18th EPS draft report. As per the report, Tamil Nadu system peak demand will be 26,330 MW. Considering 80% of this demand, Tamil Nadu system was simulated for 21,064 MW. Three 765 kV links will be operational during this period. The 765 kV substations expected are shown in **Figure 10.1** of Section 10.1. A consolidated list of existing and proposed RE resources considered for the study are given in **Table 10.4**.

General observations from the 2021–22 AGG system study

- Total Tamil Nadu system demand considered for study is 21,064 MW (80% of peak demand of 26,330 MW).
- Total effective RE sources considered for study amount to 26,054 MW (60% of 43,424 MW), which shows that wind power contributes more than 100% to the system during peak wind season.
- Large increases in power flows are seen in the Tuticorin–Salem 765 kV line (from 2,280 MW to 4,719 MW) and in Raichur–Sholapur 765 kV line (from 1,345 MW to 2,864 MW) in this aggressive scenario as compared those in the BAU scenario under 2021–22 conditions, mainly because of large RE power coming into the grid including solar power in Salem and Tuticorin areas.
- Since the available generation in the southern region is more, following the aggressive addition of RE, nearly 8,000 MW of power may have to be exported. Otherwise, all the available hydro projects in the southern region (approximately 5,500 MW except irrigation-based), along with all the conventional power plants, will have to operate at its minimum (almost to zero) at their technical minimum, so that inter-regional export will be around 2,500 MW.
- In this scenario, Tamil Nadu may have to export the bulk of its generation to the neighbouring states, for which suitable contract arrangements must be in place, otherwise, such a high RE penetration would not be possible.
- The transmission system requires additional 400 kV, 230 kV, and 110 kV substations to reliably evacuate the available RE. The additional substations are proposed based on the following criteria.
  - Substations already proposed by STU / CTU / other criteria.
  - Wind power injection at any location exceeds 800-1000 MW (one 400 kV substation).
  - Wind power injection at any location exceeds 200 MW (one 230 kV substation).
  - Wind power injection is 100–200 MW (110 kV substations).

Based on the above criteria, the number of substations required for the 2021–22 AGG scenario are given in **Table 10.15** and transmission line lengths are given in **Table 10.16**.

Table 10.15 No. of substations proposed for 2021-22 AGG scenario

Voltage level of the substation	Number of substations
400 kV	19
230 kV	74
110 kV	61

Table 10.16 Required transmission lines for 2021-22 AGG scenario

Voltage level of the line	Length (km)
400 kV	1890
230 kV	2220
110 kV	1260

- Due to the large-scale integration of RE into the grid under this scenario, static var controllers (SVCs) may be necessary in the selected places of the southern grid to keep bus voltages within permissible limits. The excepted values of the SVCs are given in **Table 10.17**.

Table 10.17 SVC requirement for the 2021–22 AGG scenario

Bus	Voltage (kV)	SVC requirements (MVAr)
Trichy	230	200
Myvady	400	439
Salem	400	200
Chuliyar	400	500
Maddakara	400	200
Villupuram	230	200
Unjanai	230	200
Deivakurichy	230	200
Thudiyalur	230	196
Thiruvarur	230	163
Thanjavoor	230	195
Pudukottai	230	200
Ranganathapuram	230	200
Karambayam	230	107

10.5 Cost Estimation

The study team estimated the cost of developing the grid infrastructure required for large-scale integration of RE into the Tamil Nadu grid. The unit costs are considered as per the practice followed by STU/CTU/ CERC benchmark prices.

In the 2021–22 AGG scenario, for which SVCs may be required, the unit cost is considered as Rs. 2000/kVAr. (Additional cost of Rs. 640 crore is required). The approximate cost of grid infrastructure for the proposed grid augmentation in both the scenarios is given in **Table 10.18**.

Table 10.18 Cost estimates for proposed grid augmentation in BAU and AGG scenarios

Year	Additional cost required (Rs Crore)	Total cost (Rs Crore)
Business-as-usual		
2016/17	4790	4790
2021/22	2480	7270
Aggressive		
2016/17	7270	7270
2021/22	3755	11025

Yearly break-up of the infrastructure cost for the business-as-usual scenario is given in **Table 10.19**.

Table 10.19 Yearly break-up of infrastructure cost for the business-as-usual scenario

Year	2012 /13	2013 /14	2014 /15	2015 /16	2016 /17	12th Plan	2017 /18	2018 /19	2019 /20	2020 /21	2021 /22	13th Plan
Capacity addition (MW)	1141	1357	1550	1740	1972	**7761**	1769	1787	2009	2085	2159	**9809**
Cost (Rs crores)	400	1038	1057	1074	1217	**4790**	447	452	508	527	546	**2479**

Yearly break-up of the infrastructure cost for the aggressive scenario is given in **Table 10.20**.

Table 10.20 Yearly break-up of infrastructure cost for the aggressive scenario

Year	2012 /13	2013 /14	2014 /15	2015 /16	2016 /17	12th Plan	2017 /18	2018 /19	2019 /20	2020 /21	2021 /22	13th Plan
Capacity addition (MW)	2587	2904	3299	3708	4162	**16660**	3552	3688	3981	4181	4410	**19811**
Cost (Rs crores)	800	1467	1570	1618	1816	**7270**	673	699	755	792	836	**3755**

It is learnt that Tamil Nadu has permitted wind developers and private investors to develop the entire 400 kV infrastructure required for wind power evacuation under the public-private partnership (PPP) model with equity contribution by the state's transmission utility and the State Government.

10.6 Integration of RE Sources Generation in the National Grid

Power evacuation studies for conventional power plants are generally carried out as stipulated in the Central Electricity Authority's *Manual on Transmission Planning Criteria* for annual system peak load and system light load conditions for maximum hydro/thermal generation scenarios. Evacuation studies would be analysed for different seasons to examine the ability of different elements of a network to carry the power during peak/off-peak hours without network congestion and voltage violations, including contingency conditions stipulated in the relevant grid codes. System studies also examine whether voltage excursions are within limits, particularly during light load hours, and help to suggest measures to keep the voltage within acceptable limits.

A true national grid with complete synchronous zone across the country is expected to be in place by 2014 with the commissioning of a 765 kV line between Raichur and Sholapur interconnecting the Southern region with the new grid. This will facilitate exchange of surplus power between the southern region and rest of the country. In addition, there is a plan for a 765 kV main corridor from Tamil Nadu to Karnataka and Andhra Pradesh, which is likely to be commissioned in 2015.

RE projects like wind are generally at remote locations away from load centres, and long transmission lines may be required to connect the projects to major load centres. Local substation loads near the wind farm sites are also likely to be low during peak wind season. In such a scenario, the entire wind generation may have to be transported to the nearest major grid substation for further absorption in the grid and this ability of the network has to be checked in grid integration studies. Hence, transmission planning for RE generation projects has to be carried out on a case-to-case basis depending upon the topology of the local grid, spatial distribution of renewable sources, and the total quantum of power to be evacuated.

Any large RE grid integration study in India has to recognize that peak RE generation season (particularly of wind, which is in July/August in Tamil Nadu) does not coincide with the system peak demand months (February/March). SRLDC data indicates that during peak wind season (July/August), the peak system demand in Tamil Nadu is only around 80% of the annual system peak. Wind generation pattern over the day in peak wind season (in August) in Tamil Nadu indicates that it will occur during late afternoon (around 3.30 p.m. to 5 p.m.) on most days and the corresponding system demand will be 80% of the annual peak demand in this season. Wind integration studies in Tamil Nadu will therefore have to assume that system demand will be around 80% of the annual peak during peak wind power injection periods. Peak wind season in the southern region covering Karnataka, Andhra Pradesh (having substantial wind power potential), and Kerala is almost the same as that in Tamil Nadu, i.e. June to September, except in Tamil Nadu, the season extends up to November. Any wind integration study in the southern region has to recognize this aspect while modelling the network and preparing load-generation balance for such studies. Further analysis of hourly wind generation over a day indicates that in Karnataka and Andhra Pradesh, peak wind generation will be at night or late evening hours and this diversity in peak wind generation between states within a day is to be conveniently used to evacuate any excess wind power from Tamil Nadu to adjacent states (and vice-versa) and balance RE power to adjacent regions without exceeding the interconnecting tie line capacities and without backing down wind generation.

10.7 Operational Philosophy and Balancing Requirements with Large Scale Wind Integration

A major barrier to grid integration of large RE is its uncertainty (difference between forecast and actual generation) and variability (change of output over a fixed interval of time). Because of its dependence on the weather, the output cannot be guaranteed at any particular time. This makes planning for the overall balance of the grid difficult, and biases utilities against using RE. Accurate forecasting of power inputs from RE farms into the grid could improve the integration of RE by reducing network operation issues caused by fluctuating wind power.

The CERC, recognizing this variability and uncertainty of RE, amended the Indian Electricity Grid Code in April 2010 to allow flexibility to wind and solar plants in scheduling and dispatch of solar/wind power. The new grid code of CERC mandates that all new RE power sources of 10 MW and above and connected to the grid at 33 kV and above shall schedule power generation and provide a forecast to the system operator. The code provides that a +/- 30% variation between scheduled and actual RE power injections will not attract any penalties for the RE developer (with states taking all the UI liabilities through RRF). Any variation beyond +/- 30% will be to the account of the RE developers. Therefore, good short-term (day-ahead and 3-hour ahead) forecasting facilities of RE power, especially for wind power, using modern tools are necessary to reduce forecasting errors and reduce the impact of UI penalties. Grid operators will also need adequate tools to assimilate all the forecasting data received from all the wind power developers/operators (as detailed in the new grid code), and forecast possible wind generation from other existing wind farms (where forecasting facilities are not mandated and hence not available). This is necessary to optimize generation schedules from conventional power plants within the state or reschedule drawals from the central generation, based on latest wind power forecasts. This 3-hour ahead forecast will reduce errors in wind power forecasting and reduce the balancing requirement. Tamil Nadu, with its large RE penetration will have to establish this grid-level RE forecasting facility at the earliest for better operational flexibility, even with large RE penetration, and for reducing balancing requirements.

In order to schedule wind energy resources with acceptable accuracy based on an online monitoring system, a short-term prediction system (a few hours ahead), a day-ahead forecast, and a WEMS is recommended. The wind energy management system is a control system for wind farms in the entire control area with the aim to reduce fluctuations in the energy fed into the grid by wind farms.

10.7.1 Wind Energy Management System

The wind energy management system is a control system for overall management of wind farms in a state to manage intermittency and schedule power generation as done by the conventional sources. The main tasks of the WEMS are given below.

- Online monitoring of wind farms including data from wind turbines.
- Wind forecasting in the short-term (a few hours ahead) and also a day-ahead.
- Submitting a system-wide schedule to the SLDC.
- Effective management of the resource with effective control based on instructions from the SLDC.

Although online monitoring of wind farms that have been commissioned recently is possibly equipped with the SCADA facility, the older wind farms may not have the necessary facility and it would not be possible to obtain the necessary data from such farms. In this scenario, online monitoring requires an evaluation model to extrapolate the total power fed in by the wind turbines over a larger grid area or control area from the observed time series of power output of representative wind farms.

The block diagram of WEMS is shown in **Figure 10.2.**

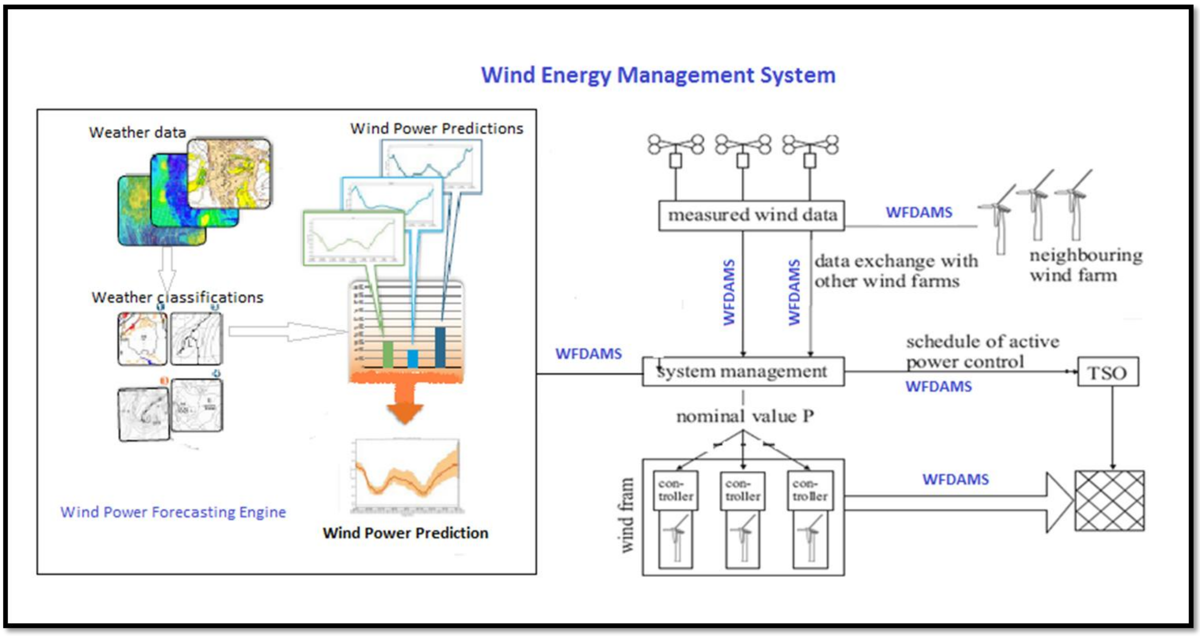

Figure 10.2 Typical WEMS for wind farms

The WEMS consists of two major functionalities.

- Wind farm data acquisition and management system (WFDAMS)
- Wind power forecasting

Further, the variability of RE generated can also affect the price that is paid for wind generated electricity. Under these regimes, producers may have to commit themselves to providing firm power and further being penalized if they overproduce or under produce. This reduces the value of the energy they sell, which, in turn, reduces the incentive to invest in RE. By aggregating the power output of RE farms and accurately predicting the power that will be fed into the grid, it may be possible to get a better price, and this would make RE a more favourable investment option. Higher prices would also mean that more sites will become feasible, as those with lower average wind speeds would also become economically justifiable. This would be possible with the proposed WEMS.

10.7.2 Operational philosophy for large-scale wind integration

It is well known that a perfect balance has to be always maintained in a power system between demand and generation so that the system frequency is within limits. The imbalance has to be set right first by fast-response primary controllers like gas-based generators or storage-based hydro and later on by secondary and tertiary controllers using hot/cold reserves in the system. The variable nature of RE generation together with variation in estimated demand brings up operational issues in meeting the balancing requirements and increases such requirements, particularly with large-scale penetration of variable generation in the grid. A well inter-connected regional grid and a national grid will reduce these additional balancing requirements. Penetration levels of RE (the ratio of wind power injected into the system demand at that time) in Tamil Nadu may be well over 50% in 2016–17 even in the business-as-usual scenario, as peak RE generation comes at times of low system demand periods; this figure will be even higher in 2021–22 and will cause serious problems in balancing, as other thermal or nuclear stations in the grid cannot be backed down below their technical limits. The diversity in peak wind generation hours in Tamil Nadu and adjacent states, and large storage-based hydro in Karnataka, Andhra Pradesh, and Kerala, can be advantageously used to meet the additional balancing requirements. The total storage based hydro and pumped storage schemes in Karnataka, Andhra Pradesh, and Kerala amount to 7,723 MW in addition to 1,375 MW in Tamil Nadu. This is about 70% of total RE power planned by 2016–17 in the business-as-usual scenario and is likely to help in meeting the balance requirement of the entire southern region if suitable regional operational plans are drawn up.

It is observed from the past data in the southern region that wind generation variation based on similar-day forecasts (the least preferred form of forecast with the highest error) varies from less than 10% during high wind to more than 50% during low wind. This translates to a variance (+ 2σ) of 700 MW during the high wind season with a probability of more than 95%, given the present conditions. Further, unlike conventional generation, the reduction in wind generation is slower; it takes a few minutes to reduce or increase 500 MW of wind generation, by which time the system operator can respond if sufficient spinning reserves are available.

Analysis of past data also showed that during high wind season, contribution from hydro projects varies from 3,000 MW to 6,500 MW. When wind power recorded its peak demand of 3,470 MW on 13 August 2011 for Tamil Nadu, hydro projects contributed around 5,500 MW in the southern region. By reducing it to the minimum (very few run-of-the-river hydro projects are present in the southern region and their contribution is not substantial), nearly 60%–70% of 5,500 MW can be regulated and stored.

In future, the variation in the business-as-usual scenario would be around 1,700 MW and 2,800 MW during 2016–17 and 2021–22 respectively. In the aggressive scenario, the corresponding figures are 2,800 MW and 5,200 MW with high probability. These variations can be better managed through hydro resources and gas generators, along with operating the conventional thermal power plants at their technical minimum. Further, there is a need to have a regional or national balancing mechanism along with a special dispensation mechanism to compensate for UI.

Although the chances of the variation being much higher are small, that possibility needs to be considered and dealt with through a special protection mechanism for inter-tripping of wind generation combined with loads.

Based on the actual available RE generation, it is clear that Tamil Nadu will have surplus generation in peak wind season and will have to export power to neighbouring states during 2016–17 in the BAU scenario. In this scenario, all hydel projects in Tamil Nadu may have to operate at their minimum or near zero-generation level (with all pumped storage schemes in pumping mode during low system demand period), so that the generation can be balanced with demand. Stored water in such hydro plants can be used during off-wind season. In addition, Tamil Nadu may have to enter into contracts with the neighbouring states for sharing the balancing resources in those states to fully absorb RE power.

In view of the large RE generation in Tamil Nadu in 2021–22, it is estimated that not only Tamil Nadu, but the entire southern region will have surplus generation in this season in both the scenarios. All hydel projects in the southern region will have to operate at their minimum or near-zero along with conventional thermal power plants at their technical minimum (and planning annual maintenance of their generating units in peak RE season). All the stored resources can be used for the southern region during off-wind season based on techno-commercial considerations. In such a scenario, the balancing cost of reduction in conventional power plants needs to be considered because it entails the loss of PLF of these units.

Although it will be possible to evacuate the entire RE generation during the selected times frames, in the aggressive scenario, it is to be noted that during high monsoon, when the reservoirs are full and surplus water is being released, wind generation may also have to be curtailed to manageable limits.

10.8 Smart Grid

10.8.1 Smart transmission grid - need for RE systems

The large renewable capacity with wind generation as its main component is intermittent and, when integrated into the grid, would make the monitoring and control of such large grid more complex. The widespread grid and increasing complexities of its operation and that of the electricity market require wide area monitoring, which may only be possible by the application of the emerging synchrophasor technology. WAMS (wide area measurement system) is the key to achieving the higher grid performance that is required in this changed scenario. WAMS requires installation of phasor measurement units (PMUs) at the substations and power plants. The existing SCADA/EMS-based grid operation can provide only a steady-state view of the power grid. PMU-based technology with synchrophasor measurements over wide-area facilitates dynamic real-time measurements and visualization of the power system, which are useful in monitoring safety and security of the grid as well as in taking control/corrective actions. Developments in WAMS and other technologies in the field of measurements, communication, control and automation, advanced meters, IT infrastructure, energy storage, etc., have prominent roles to play in successful development of the smart grid.

Full implementation of WAMS technology would require installation of PMUs in each region (about 1000–1500 PMUs initially in the 12th five-year plan in India) and a reliable communication network with very high bandwidth and least latency. Phasor data concentrators (about 30–60 initially in the 12th plan) are to be installed at various strategic grid locations and control centres. The state load dispatch centres may have master Phasor Data Concentrators (PDC), and national and regional load dispatch centres may have super PDCs working in hierarchy for real-time dynamic-state monitoring of the complete national grid in a unified manner (**Figure 10.3**).These can be started in RE-rich states like Tamil Nadu, Karnataka, Gujarat, Rajasthan, and Maharashtra, to help integrate renewable power reliably with the grid. Better system monitoring with WAMS may reduce the network reinforcements required for wind power, particularly because these power plants operate for only 4–6 months in a year when ambient temperatures are low and higher thermal/dynamic loadings are possible on associated networks.

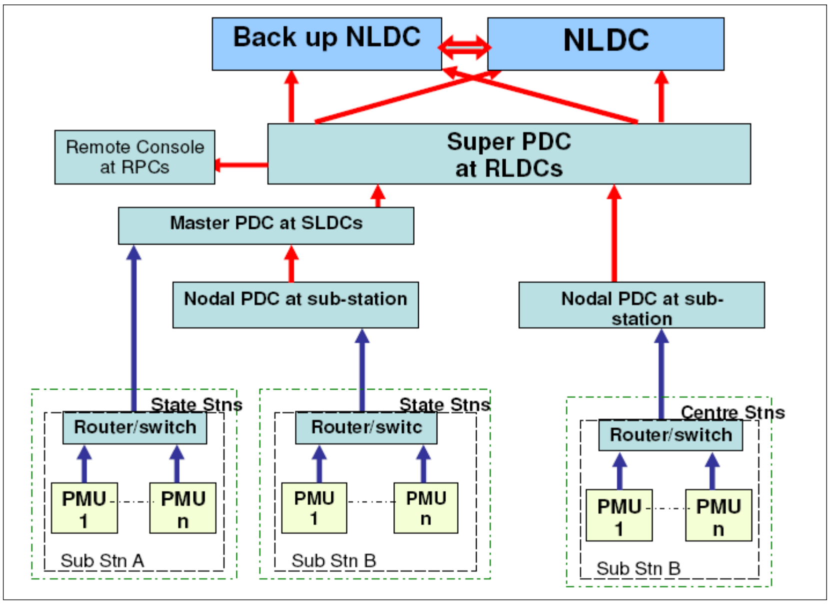

Figure 10.3 Schematic diagram of WAMS

Source: NEP (transmission)

10.8.2 Possible benefits of smart transmission grid

Availability of PMUs and PDCs at strategic locations in the grid, robust fibre optic communication network and implementation of enabling applications will facilitate the following:

- Situational awareness of grid events and dynamic state of the grid in terms of angular stability and voltage stability.
- Optimization towards transmission corridor capability.
- Control and regulation of power flow to maintain grid parameters.
- Load shedding and other load control techniques such as demand response mechanisms to manage a power system.
- Deployment of remedial action schemes (RAS) and system integrated protection schemes (SIPS).
- Identifying corrective actions to be taken in the event of severe contingency to prevent grid disturbances.
- Monitoring of Inter-area oscillations.
- Adaptive islanding.
- Network model validation.
- CT/CVT calibration, etc.

10.9 Storage Technologies

Renewable energy by its nature is variable and, as a result, differs from the majority of generation technologies supplying the electric grid. The seasonal and diurnal variation of RE generation vis-à-vis system demand needs storage devices either in the form of a large grid or other storage options. A number of energy storage methods can convert these sources into on-demand power plants, and a number of technologies can store the energy from large-scale intermittent power such as a wind farm or very large photovoltaic installations. Renewable energy can be stored in many ways, including batteries, flywheels, hydrogen, compressed air, super capacitors, and pumped hydropower. The advantages and disadvantages of different storage technologies are tabulated in **Table 10.21**.

Table 10.21 Advantages and disadvantages of different storage technologies for RE

Storage option	Advantages	Disadvantages	Applications	Efficiency (%)
Pumped storage	High power capacity, very high energy capacity, lower cost	Special site requirements, low efficiency	Spinning/standing reserve, arbitrage	70–85
Flow batteries	Medium power capacity, high energy capacity	Low power density	Variability reduction, spinning/standing reserve	75–85
Sodium sulphur (NaS) batteries	Medium power and energy capacity, high power density, high efficiency	Higher cost, production challenges	Variability reduction, uninterruptible power supply (UPS)	85–90
Lithium ion (Liion) batteries	Medium power and energy capacity, high power density, high efficiency	Higher cost, special circuitry	Variability reduction, uninterruptible power supply (UPS)	90–95
Compressed air	High power capacity, very high energy capacity, lower cost	Special site requirements, gas connection	Spinning/standing reserve. arbitrage	70–80
Flywheels	High power capacity	Low energy capacity, low power density	Power quality	90–95
Capacitors	Long cycle life, high efficiency	Low power density	Power quality	90–95
Hydrogen storage	High power and energy capacity	High cost, low efficiency	Variability reduction, spinning/standing reserve	Low
Plug-in hybrid	Widely distributed, low cost to power system	Difficult to manage	Variability reduction, spinning/standing reserve.	80–90

Currently, the simplest and most promising storage technology is pumped hydropower, or water pumping and storage. Using this technology, water is pumped uphill, stored in a reservoir, and used later to drive turbines when the power is needed. This process has 80% efficiency rate, which is higher than other storage techniques. The other positive quality of this storage technique is that unlike other conventional sources, which may have fuel loading or warm up times, hydroelectric power is available immediately on demand.

Most of the pumped water storage sites use power off the grid to operate the pumps during non-peak times or during higher generation times, to replenish the reservoir. Renewable energy can fit into this scheme by providing power to the grid during high-demand times to help with the peak load, and to supplement the energy for pumping uphill during non-peak times. By using the abundant power produced by RE sources during non-peak hours to power the pumps and replenish the upper reservoirs, valuable and lucrative energy can essentially be stored until the high-demand hours.

As the cost of conventional sources of electrical generation continues to rise, wind power will continue to experience growth. As the costs rise even more, water storage and other storage technologies will be utilized more and more. According to NREL, US, "They [DOE researchers] are also conducting research to develop low-power hydropower resources, optimize project operations, and combine hydropower with other renewable technologies such as wind power, to provide a stable supply of electricity to our nation's grid."

From the foregoing discussion, it is observed that as of now, there is no utility-scale storage option that can meet the requirements of large-scale RE generation except pumped storage plants and storage-based hydro resources. There was no pumped storage scheme or unit in operation in India until the Fifth five-year plan. It was only in the sixth plan, that pumped storage schemes came into operation. For the 12th plan, capacity addition of 1,500 MW is planned in the Kundah PSS (500 MW) and Tehri (1000 MW). Large storage-based hydro in the southern region (Sharavathi, Nagajahri, etc) can also help in accommodating large variations in RE generation until the associated reservoirs reach full levels and they become must-run hydros.

In addition to this, resources can also be saved by operating all hydro projects at their minimum. Based on the past data for the southern region, it is observed that the contribution from hydro projects in the region during peak wind season varies from 3,000 MW to 6,500 MW. When wind power recorded its peak demand of 3,470 MW on 13 August 2011 in Tamil Nadu, the contribution from hydro projects was around 5,500 MW in the southern region. By reducing it to the minimum (very few run-of-the-river hydro projects are present in the southern region and their contribution during this time is not substantial), nearly 60%–70% of 5,500 MW of power can be regulated and stored. In addition, by judicious planning of conventional power plants, the variation in RE generation can be balanced.

10.10 Conclusion and Recommendations

10.10.1 Business-as-usual scenario

- **2016–17 CONDITIONS**

Renewable power evacuation studies were carried out for 2016–17 network conditions with existing and proposed renewable generation, to determine the adequacy of the existing and proposed systems in order to evacuate 14,713 (MW) of renewable power, considering a capacity utilization factor of 60%. This includes 12,953 MW of wind energy, 1,500 MW of solar energy, 200 MW of biomass and 60 MW of other forms of RE. Based on the above, load flow studies were carried out, and it was concluded that a few 110 kV lines and one 230 kV line in the following areas need to be strengthened. The additional 400 kV substations considered for evacuation of renewable power are given in **Table 10.22**.

Table 10.22 Additional 400 kV sub-stations considered in the 2016–17 BAU scenario

No.	Area
1	Kayathar
2	Kannarpatti
3	Kazhugumalai
4	Anikadavu
5	Thapagundu

Further, additional 21 nos. of 230 kV substations and 47 nos. of 110 kV substations are required for the evacuation of renewable power in particular for connecting RE resources to the grid.

All 765 kV and 400 kV lines are loaded within their thermal limits. Export of power from Raichur (Southern Region) to Sholapur (Western Region) on the 765 kV line is 513 MW. In a few cases, 110 kV line loadings are above the limits, which can be resolved by changing the existing ACSR Panther conductor to an equivalent HTLS (high tension low sag) conductor. The loadings on 230 kV lines in a few cases are beyond their thermal limits, and can be resolved by adding more lines.

▶ **2021–22 CONDITIONS**

Renewable power evacuation studies were carried out for the 2021–22 network conditions with the existing and proposed renewable generation to determine the adequacy of the existing and proposed systems to evacuate 24,520 MW of renewable power, considering a capacity utilization factor of 60%. This includes 20,453 MW of wind energy, 3,500 MW of solar energy, 440 MW of biomass, and 130 MW of other forms of RE. Based on the above, load flow studies were carried out and it was concluded that a few 110 kV lines and 230 kV lines in these areas are being overloaded.

The additional 400 kV substations considered for the evacuation of renewable power are listed in **Table 10.23**.

Table 10.23 Additional 400 kV sub-stations considered in the 2021–22 BAU scenario

No.	Area
1	Kayathar
2	Kannarpatti
3	Kazhugumalai
4	Anikadavu
5	Thapagundu
6	Kadambur
7	Alangulam
8	Samugarengapuram
9	Ayyanarpuram
10	Kilankundal
11	Paruthiyur

Further, 49 nos. of 230 kV substations and 60 nos. of 110 kV substations are required for the evacuation of renewable power in particular, for connecting to wind, solar, and biomass power plants.

There are increased power flows in the Salem-Nagapattinam 765 kV line (from 631 MW to 2,142 MW) and also in the Raichur-Sholapur 765 kV line (from 513 MW to 1,345 MW) in the 2021–22 BAU scenario as compared to those in the 2016-17 scenarios, mainly because of additional RE considered in Salem and Tuticorin areas and corresponding re-adjustment of conventional generation in Karnataka and elsewhere.

The proposed 400 kV between Kannarpatti and Tirunelveli substation is loaded beyond its thermal limits and higher size conductor is recommended. All 765 kV lines are loaded within thermal limits.

10.10.2 Aggressive scenario

▶ **2016–17 CONDITIONS**

Renewable power evacuation studies were carried out for 2016–17 network conditions with existing and proposed renewable generation to determine the adequacy of the existing and proposed systems in order to evacuate 23,613 MW of renewable power, considering a capacity factor of 60%. This includes 20,353 MW of wind energy, 3,000 MW of solar energy, 200 MW of utilization biomass, and 60 MW of other forms of RE. Based on the above, load flow studies were carried out, which showed that a few 110 kV lines and some 230 kV lines in these areas are overloaded.

The additional 400 kV substations considered for the evacuation of renewable power are shown in **Table 10.24**.

Table 10.24 Additional 400 kV sub-stations considered in 2016-17 aggressive scenario

No.	Area
1	Kayathar
2	Kannarpatti
3	Kazhugumalai
4	Anikadavu
5	Thapagundu
6	Kadambur
7	Alangulam
8	Samugarengapuram
9	Ayyanarpuram
10	Kilankundal
11	Paruthiyur

Further, 49 nos. of 230 kV substations and 61 nos. of 110 kV substations are required for evacuation of renewable power in particular for connecting wind, solar, and biomass power plants.

All 765 kV and 400 kV lines are loaded within their thermal limits. It is seen that power flows increase in the Salem-Nagapattinam 765 kV line (from 631 MW to 2,130 MW) and in Raichur-Sholapur 765 kV line (from 513 MW to 1,345 MW) in the 2016–17 aggressive scenario, as compared to those in the 2016–17 BAU scenario, because of large solar power injection in Salem/Tuticorin, leading to backing down of hydel generation in Karnataka and elsewhere to accommodate the increased RE power. The western region has to accommodate the increased flow from southern region, an issue that needs to be examined. The overloading in some 110 kV and 230 kV lines could be resolved by augmenting with high temperature conductors and with additional lines.

▶ **2021–22 AGG CONDITIONS**

Renewable power evacuation studies were carried out for 2021–22 network conditions with existing and proposed renewable generation to determine adequacy of the existing and proposed systems in order to evacuate 43,423 MW of renewable power, considering a capacity factor of 60%. This includes 35,353 MW of wind energy, 7,500 MW of solar energy, 440 MW of biomass, and 130 MW of other forms of RE. Based on the above, load flow studies were carried out, which showed that a few 110 kV lines and 230 kV lines in these areas are overloaded. The additional 400 kV substations considered for the evacuation of renewable power are given in **Table 10.25**.

Table 10.25 Additional 400 kV sub-stations considered in the 2021–22 aggressive scenario

No.	Area
1	Kayathar
2	Kannarpatti
3	Kazhugumalai
4	Anikadavu
5	Thapagundu
6	Kadambur
7	Alangulam
8	Samugarengapuram
9	Ayyanarpuram
10	Kilankundal
11	Paruthiyur
12	Coimbatore
13	Dindigul
14	Krishnagiri
15	Nagapattinam
16	Ramanathapuram
17	Theni
18	Thoothukudi
19	Thiruvarur

Further, 74 nos. of 230 kV substations and 63 nos. of 110 kV substations are required for the evacuation of renewable power in particular, for connecting to generation outlets. A few 400 kV lines are overloaded beyond their thermal limits. All 765 kV lines are loaded within their thermal limits. However, large increases are expected in power flows in the Tuticorin-Salem 765 kV line (from 2,280 to 4,719 MW) and in the Raichur-Sholapur 765 kV line (from 1,345 to 2,864 MW) in the aggressive scenario, as compared to those in the BAU scenario of 2021–22, mainly because of large RE power coming into the grid (including solar power) in Salem and Tuticorin areas.

Due to the large-scale integration of RE into the grid under this scenario, SVCs are required in selected places of the southern grid to an extent of 3200 MVAr for better voltage management.

Development of RE power as per the aggressive scenario has to be carefully examined considering the feasibility of exporting large quantum of power to the western region as detailed above, the measures needed for voltage control, a suitable operating philosophy of the entire southern region in peak RE season (with backing down of generation in all storage-based hydro plants), and taking out thermal plants for annual maintenance in the entire region during the peak RE season.

It is noted that Tamil Nadu may have to export bulk of its power to the neighbouring states because of large RE injection into the grid, for which suitable contractual arrangements need to be put in place. Further, Tamil Nadu may exceed its RPO, and this additional RE may have to be sold to other utilities who have to meet their RPO through the mechanism of RECs.

A national perspective has to adopted in harnessing RE on a large scale in states like Tamil Nadu by allocating funds for developing RE-associated transmission infrastructure from sources like the NCEF and adopting regional/national power system operation concepts so as to fully absorb all available RE generation at the time and season in which it is available.

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PART – IV

RE ACTION PLAN & IMPLEMENTATION ROADMAP FOR TAMIL NADU

11. RE Action Plan for the State

11.1 Interventions in Governance and Resource Development

After confirming the resource availability, addressing the challenges, and suggesting solutions, the next step was identifying specific action points or interventions for implementing the action plan and developing a set of priorities and detailed activities through an implementation roadmap required to put the interventions into action.

A comprehensive action plan will have to factor in the complex interplay of actions, participants, stakeholders and decision makers before identifying specific action points that will make plan deployment possible. Based on our visualization, a schematic representation of such an interplay is shown in **Figure 11.1.**

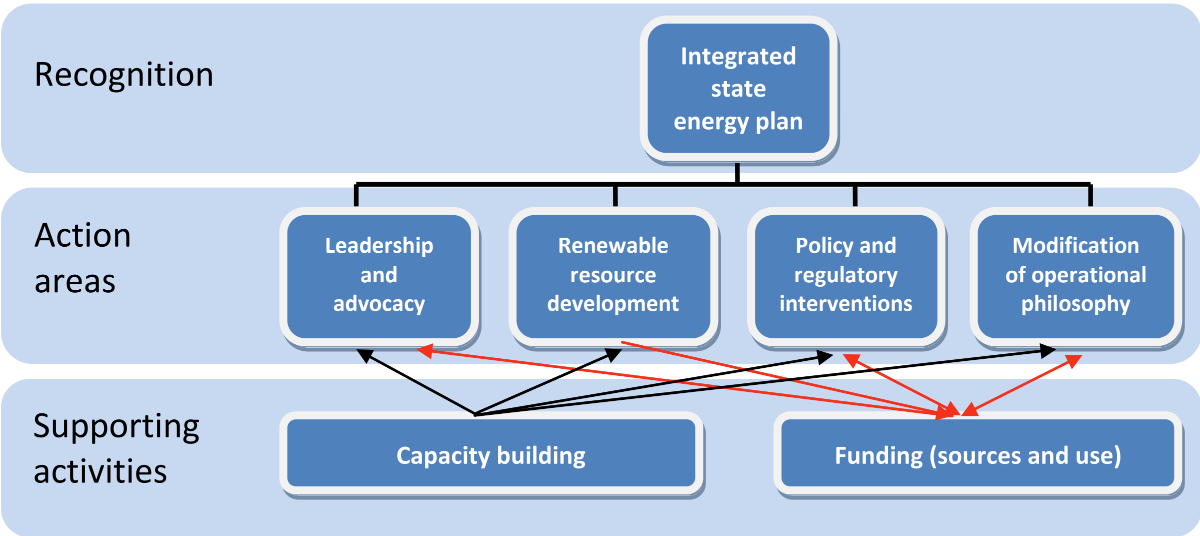

Figure 11.1 Interplay of various actors and objects for the action plan

The first and foremost requirement is obviously the recognition of the need for RE and an acceptance to accommodate RE. Once this is established, the most immediate action areas are all based on proactive government-driven action. The state is an interdependent entity and has to take a leadership role in many larger issues to secure the benefits of choosing a renewables-focused development path. At the state level, the state also has to look at specific actions that it can take within its own jurisdiction to provide support for renewables. For simplicity, these action areas are divided into four major focus points: leadership and advocacy by the state at the national level, renewable resource development, policy and regulatory interventions and grid augmentation, and changes in operational philosophy of grid management.

However, before working on the action areas, it is also necessary to assess practical impediments and deploy supporting activities that can strengthen the state's efforts. The subsequent sections focus on critical areas of development and try to identify specific interventions for making the action plan successful.

However, the first and foremost requirement before developing an action plan is acceptance of the need to integrate RE in the power system planning. In this context, the most immediate requirement for the state would be to prepare an integrated energy plan that not only captures the risks in existing sectoral planning but also acknowledges the acceptance of RE addition in the long-term and approves targets for RE capacity-addition for the 12th and 13th five-year plans. Once such a plan is in place, the next actions are all based on proactive government-driven steps in the identified areas of focus.

11.1.1 Leadership and advocacy by the state at the national level

Tamil Nadu has the distinction of being the leading state in RE development, especially wind. With present wind installations accounting for 40% of total nationwide installed capacity coupled with an ambitious solar policy, the state is all set to surpass its past record and take the lead over other states. However, where actual implementation of RE is concerned in the coming years, it cannot happen in isolation. Tamil Nadu will have to take a leadership role at the national level on issues that impact the power sector and its ability to integrate renewable energy generation capacity effectively into the grid. Some of the main issues in which the state will have to play a leadership role are:

Advocate changes in the power planning process at the national level
The need to integrate renewable energy capacity additions in the planning process has already been mooted in the MoP document. However, considering the present RE installations and expected new capacity additions, the state has to take a leading role in ensuring that the process is formalized and put into practice as soon as possible.

Conduct a detailed grid study to assess power system stability and load flow at inter-state and inter-regional levels
A detailed study is required to assess the actual effects of such high renewable penetration on power system safety and protection aspects, not only for the state, but also for the southern region, and finally for the national grid. The study can also assess the proposed plan from the perspective of inter-state and inter-regional corridor capacity to evacuate power and to flag requirements of new inter-regional or inter-state transmission lines. This study can only be done by involving expert system consultants and national-level agencies like CEA and RLDCs, who are involved in planning and operations.

Demand early commissioning of the inter-regional link to facilitate operationalization of the national grid
The proposed renewable energy plan will effectively mean that Tamil Nadu and even the southern region will become power surplus in 2021-22. In such a scenario, the availability of an inter-regional corridor to evacuate power to the western and northern regions will be necessary. The state will have to highlight the criticality of an inter-regional link and its timely completion at appropriate fora, including the plan panel and CEA, to ensure early commissioning of such corridors.

Advocate creation of an ancillary market to enable intra-day and spot trading of power
Formulation of enabling regulatory provisions to facilitate creation of short-term and spot power markets would provide maximum benefit to the state by allowing it to trade surplus power at higher costs and buy deficit power at lower costs. The state can take the lead in approaching the central regulator or MoP to enact enabling provisions for facilitating creation of such ancillary markets.

Streamlining approval processes for offshore wind
Preliminary GIS-based assessment indicates huge offshore potential in Tamil Nadu. Offshore represents a very good opportunity for the state, primarily because a large-capacity cluster would not affect land, would have more predictable generation and would not be as distributed as onshore wind, making it easier to manage issues of the transmission corridor. Considering the present status

of offshore development in India, the state has to take a proactive role by identifying and approving possible sites for offshore development. It is learnt that MNRE has already prepared a policy paper for off-shore, which is in the draft stage but may be released soon.

11.1.2 Capacity building plan for state government agencies

All state agencies directly or indirectly related to the power sector have to be strengthened both in terms of personnel strength and in terms of overall management (administrative, financial and technical). The five main state-based entities identified for capacity-building are the Department of Energy, TEDA, TNEB (including generation and transmission companies), TNERC, and the State Planning Commission.

The capacity building plan for these entities has to mainly focus on technical capacity building and sensitization to renewables. The Department of Energy, the State Planning Commission and TNERC have to be sensitized to the need and benefits of RE, whereas TEDA, TANTRANSCO, TANGEDCO and SLDC have to be strengthened mainly on the technology and grid management side.

In addition, the capacity-addition plan also has to include aspects related to organizational restructuring, planning/procedures/rules/laws, management information system, human resource development, financial management, financial autonomy, communication/outreach strategy and most importantly, training needs identification for RE-specific aspects related to policy, regulation, technology, grid impact, finance, etc.

The first requirement in this regard will be a report on training needs assessment in terms of specific RE-related focus areas and development of an agency-specific curriculum and training course for ensuring that each agency and its senior staff have a 360 degree perspective on RE.

11.1.3 Renewable Resource Development

The renewable resource re-assessment exercise indicates an RE potential significantly greater than the existing estimates. The GIS-based assessment for grid-tied wind and solar power has provided significant data in spatial terms and important takeaways for energy sector planning and policy design. The following action points summarize the required interventions in renewable resource development.

- The available modelled datasets (NASA, NREL, Meteonorm, SolarGIS, etc.) have substantial variations in the values of direct normal irradiance. At the ground level, a large deviation in DNI value can affect the economics of any CSP project substantially because solar irradiance requirements for CSP are more stringent than those of solar PV. In this context, it is important for the state to assess the solar resource potential areas and notify them so that investors are assured of a minimum availability of resource and carry out due diligence for installing CSP projects on the identified locations. This is important as CSP investors would be more interested in developing projects only at known locations in western India. According to our analysis based on NREL data, the best locations for installing solar DNI measuring instruments (pyrheliometers) would be in Thottukudi, Tirunelveli, Tirupur and Krishnagiri districts. Preliminary estimates indicate that installing about 20–30 such instruments spread across these locations would not cost more than Rs. 70 lakh.
- The second area that requires validation is the installation of offshore wind masts. In the present scenario, the policy vacuum in offshore wind is not attracting private development in offshore resource assessment. In this area also, state intervention and direct investments would give the

state an idea of the developable potential. The resource data collected for these offshore locations can then be shared with private developers on cost basis as and when required. CWET is in the process of installing a mast near Ramanathapuram [Ref 38]. Based on our resource assessment, installing additional masts off the coast at southern Thottukudi and Tirunelveli would be a substantial value addition. Initially, installation of 10 offshore wind masts across these locations would provide term data on offshore wind resource that would be readily available for quick deployment of turbines. Rough estimates indicate a total cost for these masts at Rs. 50 crore.

- The third area of resource validation would be assessment of biomass resource utilization at the taluka level. The results of this assessment can be used to prioritize highest-value residues based on their end-use importance and combustion potential. The state can then enact suitable regulations to control diversion/collection of such agro-residues.

11.1.4 Establishing pilot projects

Developing CSP pilots

CSP potential, although estimated at 78,505 MW using the NREL dataset, is not recommended for immediate private development. There are considerable differences in DNI data between various modelled datasets, with other (SolarGIS) datasets indicating no CSP potential in Tamil Nadu. As DNI is derived data, the assumptions that go between the measurements and the derived value impact the end results. In the absence of any validation of one dataset over another, any decision on CSP potential cannot be done unless validated by field experience. Considering this, it will be advisable for the government to install small pilot plants through its own funds and understand the resource and the generation profile before asking private investors to scale it up. A small-scale set of two 5 MW projects, one with storage and one without storage, can be planned in Thottukudi and Tirupur.

Pilot for energy plantation

While there is no dispute that energy plantations should only be promoted in designated non-farmland areas, the availability of water for such areas is a big question mark. Furthermore, the projected yield figure of 200 acres/MW for species like Beema bamboo and Napier bajra grass seem to be very high, considering traditional yields of other energy plantation species. Even if the yield is assumed to be sustainable, land utilization for energy plantation at 1.25 MW/sq. km is simply too low as compared to wind at 7 MW/sq. km and solar PV at 50 MW/sq. km. Furthermore, considering the unproven capability of these new energy plantation species, it would be advisable to establish a pilot project to validate the capability of this alternative before actually making a large-scale policy commitment.

11.2 Interventions in Policy and Regulatory Implementation

11.2.1 Policy Interventions

At present, Tamil Nadu has no notified RE policy, though TEDA, has prepared an RE policy draft, which is awaiting approval. In the absence of a notified policy draft, a state-specific policy-oriented exercise was undertaken to understand areas in which targeted policy interventions can make the maximum impact. Based on the analysis, the following interventions are suggested.

Creation of a state clean energy fund

The state can choose to levy green cess on electricity consumption by industrial and commercial consumers. It would be easier to amend existing legislation through an ordinance to impose this levy. While laying down the procedures for utilization of the green cess by creating a 'Clean Energy Fund', it would helpful to study the Maharashtra experience. Maharashtra was the first state to impose such a cess and its implementation experience would help in avoiding loopholes. It should be ensured that the cess is fully passed on to TEDA and proper norms are laid down to ensure its effective utilization solely for RE development**.**

Land policy for renewable projects

Land availability is a major constraint for deployment of large-scale, grid-tied renewables. Furthermore, different land acquisition models (lease, outright sale, etc.) and the procedure for acquiring land (even revenue land) is time consuming and costly. For wind power, there are right of way (ROW) issues that lead to thefts or hamper development during the installation and operation stages. For solar projects, acquisition of large tracts of contiguous land could also be a constraint considering the small land holdings and availability of large wasteland tracts. A comprehensive land policy that specifies revenue land allocation policy, mixed land use criteria in addition to clear recommendatory guidelines for private land acquisition, and provisions related to RoW will go a long way in addressing bottlenecks.

Approval of pending wind project applications

There are about 13,400 MW of project applications pending with TNEB. The main reason for delay in approvals seem to be the inadequacy of the existing infrastructure to evacuate the proposed power. Prolonged delay in project approvals is one of the biggest impediments to accelerated wind deployment. Urgent and effective actions are needed to grant express approvals to pending projects.

Policy on PPP partnerships for development of RE pilot projects

For solar power development, especially CSP, it is important to verify the availability of commercially feasible potential through small pilot studies. The state can opt for a specific pilot project development model through innovative mechanisms like PPP. Possible multilateral or bilateral funding can be secured for such an initiative. This model, once a part of RE policy, can be replicated for development of new and unexplored technologies including offshore wind, tidal and wave energy systems.

Strengthening of policy and approval process for biomass projects

The unexploited biomass potential in Tamil Nadu is only to the tune of about 440 MW. While the main advantage of biomass power generation is its firm nature, the actual possibilities of scale-up seem limited. Based on the report, the surplus biomass availability itself is very low, and is calculated after discounting all alternative uses of a particular biomass residue. Understandably, the surplus biomass availability varies with production, location, season and price. Furthermore, past experience indicates that biomass prices see substantial variation based on the claimant's ability to pay. Many organic products (cardboard, etc.) using such surplus biomass can pay a higher price than that paid by power producers, who have to bear significant overheads in addition to fuel costs. There have been instances of suppliers hiking biomass prices after the power plant comes into operation, resulting in significant losses for the investors. The price increases are also known to divert traditional fodder to the biomass plants, affecting marginalized communities who require cheap fodder for their cattle. Furthermore, the practice of using biomass plants as a backdoor for installing coal-based plants is also affecting the credibility of biomass resources. Considering the present market dynamics, even at project-level planning, substantial due diligence has to be shown by the investor and the approving authority. The immediate measure is strengthening of the policy and approval processes. Another way of partly mitigating adverse impacts is to promote small-scale plants, initially approving small plants in defined areas and encouraging them to expand after a certain period of stipulated technical and successful commercial operation.

Relaxation of micrositing criteria for wind

Another area of concern is TNEB's insistence of the 5D × 7D turbine spacing rule. Worldwide, micrositing criteria are decided by the developer based on the site topography, wind profile and other techno-economic parameters. Furthermore, as the main objective of micrositing is to optimize energy yield, which only concerns the investor and the supplier, there is no role of any third agency in dictating the micrositing parameter. Even in India, all the major wind power states (except Maharashtra) have no compulsory micrositing criteria. In this context, TNEB's insistence of 5D × 7D criteria is perplexing. As a way forward, TNEB has to relax this criterion and give liberty to the wind developers to freely site their turbines based on scientific optimization processes.

Clearances for repowering

As Tamil Nadu hosts some of the oldest turbines in India at the best wind resource sites, it has significant potential for repowering. However, TNEB's insistence on continuing with the old tariff and the existing name-plate capacity is literally precluding repowering possibility for all sites, including those that may have additional capacity in evacuation infrastructure. Repowering, if adopted, can be a win-win formula for all. While it will mean monetary benefits to the investors, it will also mean better land utilization and high-quality generation, as the new machines would have more grid-friendly features than the old machines. TNEB should initiate necessary measures for supporting repowering on a large scale.

Creation of a state RE law

Policies gather muscle if they are complemented by legislative measures. Since energy is a concurrent subject, Tamil Nadu could have a state RE Law suited to its local needs and circumstances without contradicting the national legislation. In the United States, many states have such provincial laws, besides federal laws. Such a law amended suitably to meet state-specific concerns can address issues like renewable purchase obligation (RPO) compliance, jurisdiction limit of utilities, infrastructure strengthening responsibility, payment schedule, must-run status, etc.

Creation of single window clearance mechanism for all RE

Developing an efficient administrative framework may be useful for promotion of grid-connected and off-grid RE power development in the state. This can include set-ups that ensure single window clearance, which can be co-ordinated by TEDA.

Specific interventions for supporting off-grids

The development of off-grid solar in Tamil Nadu requires three major interventions: enactment of state-based incentive or disincentive mechanisms, fast subsidy disbursal, and awareness generation. In the past, the state-initiated diktat on water harvesting worked really effectively. A similar strategy for commercially available and proven applications like solar water heating, LED lights, solar street lights, etc., can prove effective. For costlier technologies like rooftop solar PV and solar water pumping, a suitable incentive mechanism aimed at households, institutions and commercial establishments will help in accelerated deployment. It is leant that the slow pace of subsidy disbursal and discriminatory standards for subsidy eligibility are two main reasons for diversion of investments from off-grids. Awareness generation is another aspect that can substantially help in this regard. A majority of potential end users, especially in solar process heating, are not aware of the technologies, their advantages and subsidies.

Small hydro development to be kept under the jurisdiction of TEDA

The small hydro potential assessment exercise could only be done for limited locations due to unavailability of long-term data. However, considering the gap of about 554 MW between the SHP potential and the installed capacity, it seems that there is considerable scope for improvement. The present hydro development in Tamil Nadu is the responsibility of TNEB and there is no demarcation in jurisdiction of large and small hydro areas, with the result that small hydro development lags behind. Furthermore, private participation has been a major driver of SHP development in states like Karnataka and Himachal Pradesh. This has also not happened in Tamil Nadu, probably because of resistance to private development. It would be advisable for the state to hand over the jurisdiction of small hydro development to TEDA, in line with the standard practice in other states. Tendering for identified sites through TEDA would help in attracting experienced players in this space.

Preferential payment disbursement to RE generators

The delay in payment to wind energy generators in the state has severely hit new capacity additions in the state. While the new solar policy talks about payment guarantees to solar energy generators, no such mechanism is being considered for wind energy generators. The state has to ensure that the pending payment to WEGs is made at an early date and future payments are guaranteed.

11.2.2 Regulatory Interventions

An aggressive policy framework alone cannot guarantee a deployment-friendly climate. It has to be supported by a dynamic regulatory framework that is tuned to the prevalent economic situation and is sensitive to market signals. At the same time, regulation should not become an instrument to curtail or benefit a specific technology choice.

Regulation in Tamil Nadu has been largely influenced by the peculiar power situation in the state. In view of crippling power shortages, delays in new project implementation, and precarious financial position of the state utility, the Tamil Nadu Electricity Regulatory Commission (TNERC) has to enact appropriate regulatory interventions if renewables have to be promoted. Some of the proposed interventions are suggested below.

Revision of tariff determination methodology

At present, TNERC uses single part average tariff computation methodology for all RE (except solar) as against a more robust levellized-tariff computation methodology, which captures the time value of money and thus provides the investor a revenue stream, considering the future value of money based on a certain discount rate. Even in the recent tariff order on wind in 2012, TNERC has used single part average tariff stating the matter related to tariff determination methodology is sub judice.

Revision of methodology to determine APPC

The TNERC RPO Regulations, 2011, while defining the methodology for computation of APPC, exclude power purchased from power projects based on liquid/gas fuel and cost of the short-term power purchases. The incorrect estimation of APPC will not only affect investment in RE projects but also project an incomplete picture to power sector planners and financiers.

Tariff orders for large state-based off-grid solar

Considering the constrained power supply situation and extended load-shedding hours, off-grid and micro-grid applications can help consumers as well as the utilities. Micro-grids especially could have a good potential as many consumers would be willing to pay a higher price for electricity during load-shedding hours. However, large-scale development of such applications cannot be done without a strong off-grid regulation that specifies tariff, connectivity standards, connection points, grievance redressal mechanisms, etc. In this context, specific regulation on off-grid metering practices and tariffs would be beneficial. A recent study by ABPS Infrastructure Advisory has proposed a business model called *Off-grid Distributed Generation Based Distribution Franchisee*, which suggests a viable way to power community level off-grid applications [Ref 39]. The state may look at the proposed model and decide to support and implement a similar or customized business model that can run sustainably.

Revision of RPO targets and RPO compliance mechanism

Revision of RPO targets upwards, especially for solar power, is necessary because the present solar RPO level of 0.05% and a weak solar REC market will not be able to sustain accelerated solar power development in the state. The present level of solar RPOs in Tamil Nadu is 0.05%. To ensure scaling-up in solar capacities, revision of RPO to bring it in line with the national target set by the National Tariff Policy (as amended on 20 January 2011) at 0.25% with a yearly increment of 0.25% up to 2020 is required. Formulation of a strong RPO compliance mechanism that ensures appropriate penalties for non-compliance will be beneficial to the state.

Regulation on RE-dictated interstate power transfer

There is a need to develop an effective regulatory framework for a workable inter-state power transfer model for RE power exchanges, especially during peak RE season. This can be done with the help of the Forum of Regulators (FoR), CERC, and SERCs. The existing regulations related to inter-state power transfer and UIs attributable to RE generation variation/uncertainty are hindering Tamil Nadu to draw or export power from/to neighbouring states because of commercial implications. This is leading to backing down precious wind power during peak wind season when system frequencies are high.

11.3 Grid Planning and Operational Management Interventions

Based on the action points identified in the previous chapter, the implementation plan for RE has to essentially address a multitude of technical and non-technical issues. From the perspective of high RE integration under an AGG scenario, it is obvious that the integration can only happen at the regional and national level. In this context, integration of the southern grid with the NEW (North-East-West) grid and enactment of a commercial mechanism for inter-state export of power are two most important requirements for RE integration. The following specific action points highlight the requirement from the perspective of transmission planning and operational management practices.

Incorporating RE capacity-addition in long-term transmission planning

The existing evacuation bottlenecks in Tamil Nadu are a result of grid expansion planning that did not consider requirements of the rapidly building RE portfolio. Therefore, it is important for the state to create an apex transmission planning body comprising members from TNEB, wind developers, solar power developers, independent consultants, SLDC and CTU representatives to create long-term plans and decide on budgetary provisions for new intra-state and inter-state transmission capacity.

Short-term measures for strengthening evacuation infrastructure

The second major area of concern is the condition of evacuation infrastructure. Load flow studies of 2011-12 conditions indicate that a large number of 100 kV and 220 kV lines get loaded beyond their thermal limit during the high-wind season. While the long-term solution is to create new grid infrastructure and connect large wind capacities at 400 kV level, short-term measures like replacing standard conductors with HTLS conductors and changing single circuit lines to double circuit lines may help immensely. This modification can be done for the highly loaded lines and will require smaller investments than those for installation of new capacities.

Modify operational philosophy of grid management

The state has to overhaul the existing operational management practices to allow accommodation of high RE in the grid. The conventional operational philosophy cannot accommodate RE simply because it is modelled around the predictable system behaviour of conventional sources and the new philosophy has to essentially be centered on the need for accommodating renewables as and when they come. The state can avail services of reputable national/international consultants to look at this aspect. Detailed consultative exercises with operations experts in European utilities and grid planners can help in developing the guiding precepts for the new operational management philosophy.

11.4 Financial Interventions (sources and uses)

The most fundamental requirement for implementing the RE plan is the availability of funding. For RE development, the funding requirement will essentially be only for supporting infrastructure and pilots as the capital investments are expected to come predominantly from the private sector. However, the funding requirement for infrastructure as estimated for high RE integration (AGG scenario) is to the tune of Rs.11,000 crore, a substantial amount by any standards.

It seems that TNEB has also realized this and has asked for central assistance of Rs. 17,570 million from the National Clean Energy Fund to develop a transmission grid infrastructure to evacuate about 4,000 MW of renewable power. This expansion is aimed at evolving a power grid to facilitate free flow of power across regional boundaries by raising the transmission voltage from 230 kV to 400 kV and, if required, enhancing transmission capability to 765 kV level. (Source: MNRE, TNEB websites). It has also sought assistance from the Japanese Industrial Cooperative Agency (JICA) which will provide financial assistance in certain transmission schemes to be taken up during the next five years. The Official Development Assistance (ODA) loan by JICA will strengthen the transmission network at a cost of Rs. 3,572.93 crore by establishing five 400 kV sub-stations and fourteen 230 kV sub-stations with associated lines during the next five years. Further, to evacuate power from wind generators, a separate corridor with three new 400 kV sub-stations at Thappagundu, Anaikadavu, and Rasipalayam is to be built, along with the associated 400 kV lines of 336 circuit (ckt) km length. These sub-stations will be connected to the proposed 765 kV sub-stations being executed by Power Grid Corporation of India Ltd. at Salem. (Source: *Policy Note 2012-13*, Energy Department, Government of Tamil Nadu).

However, on the other side, there are many opportunities of sourcing funds in addition to other possible initiatives that can create new funding avenues. The subsequent sections try to analyze the funding requirements from the source and use perspective.

Sources of funds

The state has already applied for funds of about Rs. 1,756 crore from NCEF for grid augmentation. An additional Rs. 3,572 crore has been sourced from JICA for grid strengthening and new capacity-addition.

However, the state also has other avenues to raise funds. The 13th Finance Commission has earmarked a corpus of Rs. 5,000 crore for incentivizing RE development. The total corpus is expected to be distributed among the states based on their performance in developing RE. Considering the present status of renewables and projecting an RE development path as proposed in the AGG scenario, a preliminary analysis indicates that the state can expect to get a share of Rs. 1,200-1,400 crore from the CFA by the end of 2014.

Additionally, there are other initiatives that the state can take to divert existing funds or create new funding avenues. Based on preliminary calculations, AGG scenario of RE development will mean an investment of Rs. 22,6976 crore over the 12th and 13th five-year plans. Assuming 90% of investment as equipment cost and a state VAT of 4%, the VAT receipts would translate into a minimum revenue realization of approximately Rs. 8,171 crore over the 12th and 13th plans from the AGG scenario. The state, if it wants, can decide to channel all or some of these receipts into infrastructure development. Another way of diverting funds could be to make budgetary allocation in line with allocations made for coal-based projects. Assuming a capital cost of Rs. 5 crore/MW for new thermal plants, allocation of funds for 1,000 MW power plants would imply a capital cost of Rs. 5,000 crore. Even a partial diversion of this budgeted capital cost for grid augmentation will actually translate into a long-term benefit for the state.

Another very simple way to create a new funding avenue could be to create a state clean energy fund. The concept of charging an additional green cess on industrial and commercial customers has created a large corpus fund in Maharashtra. Based on the projected energy sales of commercial and industrial customers in FY 2012-13, a nominal green cess of 8 paisa/unit (at par with the existing green cess in Maharashtra) would translate into a fund of Rs. 227 crore for FY 2012-13. Assuming a moderate demand increase of 5% per annum for this category of customers, the total fund over the 12th and 13th plans could amount to Rs. 2,850 crore.

Uses of funds

The immediate requirement of funding could be payment of pending wind generation tariffs to wind turbine owners, majority of whom have not been paid for the last one year of generation. This non-payment is severely affecting the capabilities of IPP players, some of whom have no alternative sources of income to even meet their debt obligation. This has curtailed IPP investments in Tamil Nadu. To build investor confidence and push development, immediate measures are needed to pay the pending balance over a committed time limit. Considering the present financial position of TNEB, it can choose to make partial payments along with a commitment letter for full payment within a stipulated time. This will allow many IPPs to restructure their debts, saving them from considerable hardships. Assuming 4,000 MW of wind under sale to DISCOM mode, generation of 2 MU/MW and the present tariff of Rs. 3.39/kWh, a one-year payout figure would translate into approximately Rs. 2,700 crore.

The other more immediate requirement for fund deployment would be to modify or augment existing transmission lines and associated network. A load-flow study of present conditions indicates thermal overloading of some transmission lines in the high-wind season. Without any augmentation, these lines would not support even a business-as-usual growth. In this context, a short-term measure could be to change such transmission lines having ACSR conductor to HTLS conductor which can be used on existing towers or converting single circuit lines to double circuit lines after adding new bays. A rough estimate suggests that the maximum possible costs for such an upgradation will be about Rs. 2,000 crore.

The third immediate focus should be to initiate capacity building activity. This would involve comprehensive technical training coupled with exposure to best international practices in integrating RE. The capacity building can also include overseas experience sharing trips or exchange visits of system planning and operations experts from European countries like Denmark, Germany, Spain, and Ireland. The actual funding requirement for such an initiative will not be significant for the state but the value addition of such an exercise will be long term. A tentative outlay of Rs. 10–20 crore can effectively take care of all aspects of capacity building.

The fourth area of fund use should be providing equity for pilot projects. To promote hitherto unexplored technologies, the state can look at the possibility of commissioning a study involving resource assessment, DPR preparation, supply and execution of at least two CSP pilots, one energy plantation pilot, and one offshore pilot. Assuming 2 × 5 MW of CSP at Rs. 15 crore/MW, energy plantation of 2 MW × 1 at Rs. 6 crore/MW and a 10 MW offshore project with a capital cost of Rs. 12 crore/MW, the expected fund requirement for these pilots would be around Rs. 282 crore.

Another area for fund use would be investments for renewable resource validation. As mentioned earlier, state investment in resource validation will be beneficial in the area of CSP (DNI measurement), offshore wind (wind data) and biomass power (utilization ratio). Based on preliminary estimates, the costs for the proposed level of resource assessment equipment would be about Rs. 60 crore.

Wind energy management systems that can aggregate wind power forecasting with generation data at 110 kV level would be another major area of fund use. Based on the study, the funding requirement for state-wide adoption of WEMs would be about Rs. 120 crore.

The most critical area of fund use should however be installation of new transmission capacity and associated infrastructure. Integration of synchrophasor technology can also go a long way in adding value to the physical infrastructure by enhancing the dynamic response of the system operators. Detailed load-flow study for present and proposed scenarios indicates a funding requirement of about Rs. 11,025 crore over the 12th and 13th plans for AGG scenario, including Rs. 650 crore for SVCs for voltage control. As this funding is spread over 10 years, the actual implication would only be to the tune of Rs. 1000–1200 crore per year. **Table 11.1** summarizes the funding options in terms of sources and uses.

Table 11.1 Funding (sources and uses) for 12th and 13th five-year plans

Possible sources/avenues	Rs cr
CFA from 13th Finance Commission	1200
Diversion of VAT receipts from RE	8171
Allocation of funds in line with allocations made to imported coal-based projects	5000
Creation of state clean energy fund	2870
Total	**17241**

Proposed uses	Rs cr
Capacity-building for state agencies	20
Short-term augmentation of overloaded lines	2000
Clearance of 1 year payment for wind power	2700
Pilots (CSP, Energy plantations, Offshore)	300
Resource assessment for offshore, CSP and biomass	60
Integrating WEMs in the existing infrastructure	120
New grid infrastructure and SVCs	11025
Total	**16225**

As can be seen, even using conservative estimates, the proposed funding sources or options can effectively cover all the proposed expenses that will be required for long-term RE integration.

11.5 Other Suggestions

Creation of a trading company to manage all interstate power exchanges

Another option worth exploring would be the establishment of a PPP, a JV, or a financially independent state-owned entity in the form of a trading company (TRADECO), that can be made responsible for all electricity trading including long-term power from IPPs, day-ahead demands, and spot purchases. The TRADECO can then enter into a long-term contract with TANGEDCO to supply power at predefined rates. This will effectively insulate TNEB from financial risks and at the same time allow the financially independent TRADECO to raise funds for meeting periodic shortfalls. The arrangement would also allow more experienced TRADECO professionals to optimize trading practices.

Activating advanced wind energy management systems

WEMS can couple forecasting with monitoring and remote management capabilities through an enhanced communication backbone. It is expected that a fully developed WEMS will be able to monitor wind farms and integrate with a wind forecasting system to generate a system-wide schedule for the SLDC. It is learnt that the state is already contemplating installation of aggregator WEMS systems. A rough estimate of the cost for implementation of this system would be about Rs. 120 crore.

Adoption of new technologies

The technical integration aspect has to be looked at from the point of view of existing and new technological options for managing variability of RE generation. Currently, the simplest and most promising storage technology is pumped hydropower. By using the surplus RE to power the pumps and replenish the upper reservoirs during RE peak generation hours, valuable energy can be stored for use during high-demand hours. Unlike other conventional sources, which may have fuel loading or warm-up times, the pumped hydro storage is available immediately on demand. A new pumped storage scheme, the 500 MW Kundah PSS, can help in balancing power from renewables. Other large storage-based hydro schemes in the southern region like Sharavathi and Nagajahri can also contribute to accommodating RE generation variation. In addition to this, resources can also be saved by operating all hydro projects at their minimum capacity. Beside, a dynamic RE forecasting model coupled with smart grid applications like synchrophasor technologies can also help to manage variability by facilitating supply forecasts to grid operators.

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12. Implementation Roadmap, Benefits & Conclusion

12.1 Implementation Roadmap

An action plan has to move beyond paper and unfold in the real world. For this to happen, a practical implementation roadmap is essential. For an action plan on renewable energy, an implementation roadmap is even more essential because renewables are still on the growth curve and there is a great deal of scope for accelerated actions through a well thought-out and co-ordinated activity plan that can help the state to set short-term and long-term priorities. **Table 12.1** charts out the actual implementation roadmap based on the action points and interventions proposed in the previous section. The implementation roadmap orders the desired action points in terms of priorities, project expected outcomes from the action points, and develops an implementation roadmap in terms of sequential actions required for implementing the action points. It also tries to identify and assign the action points to the relevant government department or agency.

Table 12.1 Implementation roadmap for RE action plan for Tamil Nadu

Priority 1: Interventions (Immediate)

Priority	Action points	Expected outcomes	Implementation measures	Responsibility
Level 1 (Immediate)	Preparing an energy planning document for the state	Risk identification of existing sectoral planning and acknowledgement of the need for RE.	1. Preparation of the terms of reference of the study and timeline (3 months). 2. Inviting EOI for preparing the study. 3. Discussion on study report and formulation of an integrated energy plan. 4. Approval of RE capacity addition plan targets for 12th and 13th plans.	Energy Department
Priority 2 Interventions (To be initiated between 1-3 months)				
Level 2 (1–3 months)	Capacity-building of identified state agencies	Awareness-generation and enhanced ability of state government entities to support deployment	1. Appointing consultants for identifying training needs, assessment of identified state agencies and providing comprehensive capacity-building services 2. Provide fund disbursal for proposed workshops/technical training programs, exchange visits, overseas visits, etc.	Energy Department
Level 2 (1–3 months)	Incorporating RE capacity addition in long-term transmission planning	Higher transmission corridor availability for renewable.	1. Prepare ToR for an apex transmission planning committee 2. Creation of a state transmission planning committee comprising members from TANTRANSCO, wind developers, solar	TNEB/TNERC

Priority	Action points	Expected outcomes	Implementation measures	Responsibility
			developers, IPPs, SLDC officials, PGCIL 3. Finalize terms of service, responsibility areas and reporting procedures for committee members	
Level 2 (1–3 months)	Modification of operational philosophy	Enhanced ability of grid operators to mange RE and other conventional generation	1. Appointing reputable consultants for designing a detailed training program for SLDC and planning engineers on best practices for technical integration and trading intricacies. (Literature, training in exchanges, and exchange trip with European grid operators) 2. Disbursal of funds for training/visits 3. Adoption of new RE-friendly operational guidelines	TNEB
Level 2 (1–3 months)	Explore funding sources	Fund availability for pilots, grid infrastructure and other initiatives	1. Creation of a separate fund under a JV between TANTRANSCO and state finance department. 2. High-level deliberation on fund diversion from additional VAT receipts to RE development 3. High-level deliberation on allocation of fund in line with allocations made to coal-based power plants. 4. High-level deliberation on creation of a state clean energy fund 5. Approaching multilaterals (ADB, World Bank etc.) for infrastructure funding under their RE program	Chief Secretary/ Energy Department
Level 2 (1–3 months)	Planning funding outlay	Assurance of year-wise fund availability for long-term planning	1. Detailing year-wise fund availability 2. Prioritize use of funds on a yearly basis 2.1 Immediate allocation for capacity-building expenses (2–3 months) 2.2 Allocation of renewable resource validation (2–3 months) 2.3 Short-term augmentation of lines (6–12 months) 2.4 Fund allocation for pilots (1–2 years) 2.5 Clearance of wind generation payment (1–2 years)	Chief Secretary/ Energy Department

Priority	Action points	Expected outcomes	Implementation measures	Responsibility
			2.6 Infrastructure development based on preliminary development locations	
Level 2 (1–3 months)	Resource validation for CSP, offshore wind and biomass	Assurance of availability for integrating these technologies in long-term planning	1. Allocation of funds for resource assessment to TEDA 2. Inviting tenders for supply, installation, commission and operation of 30 pyrheliometers (solar DNI measuring instruments). 3. Inviting tenders for site survey, supply, installation and commissioning and operation of 10 offshore wind masts at 80 m 4. Inviting EOI for taluka-level biomass residue utilization study for the state.	TEDA
Priority 3 Interventions (To be initiated between 3-6 months)				
Level 3 (3–6 months)	Clearance of pending applications for wind projects and repowering applications	Accelerated deployment of wind	1. Call all developers with pending applications to assess readiness on project deployment under 10(1). 2. Approve pending applications based on readiness of developers.	TNEB
Level 3 (3–6 months)	Clearance of past payments of wind power projects	Increase in investor confidence, especially the growing IPP segment	1. Depending on fund availability, preparation of a plan for eventual payment of dues after ensuring payment prioritization to IPPs. 2. Providing letter of commitment for clearance by a stipulated time frame to IPPs. 3. Creation of a mandate to enable preferential payment seniority to wind energy generators.	Energy department/TNEB
Level 3 (3–6 months)	Declaration of solar tariff for state-based projects	Generation of investor interest in solar projects	1. State government to request TNERC to issue tariff order for state-based solar power projects. 2. Issuance of solar tariffs under state-based projects or extension of tariffs of NVVNL.	Energy Department/TNERC
Level 3 (3–6 months)	Solar RPO to be set at the NAPCC level	Demand assurance to investors	1. State government to request TNERC to issue a revised RPO order for solar. 2. Issuance of new solar RPO target	Energy Department/TNERC

Priority	Action points	Expected outcomes	Implementation measures	Responsibility
Level 3 (3–6 months)	Creation of a land policy for renewables	Investor is assured of land availability and timeliness of project	1. The state to prepare a policy for transfer of land to RE projects, mainly solar and wind. 1.1. The policy can identify all revenue wasteland on priority basis and agree to allocate it to RE based on a certain technology priority and capacity cap. 1.2. The policy should also describe the standard procedure for land acquisition of private land in addition to specifying the provisions for mixed land-use and demarcate jurisdiction related to RoW issues.	TEDA/Planning Department
Level 3 (3–6 months)	Creation of a single-window mechanism for RE project approvals	Fast paced deployment	1. TEDA can create a single approval interface by inducting special liaison officials to coordinate inter-departmental approvals (including those from TNEB).	TEDA
Level 3 (3–6 months)	Shifting the responsibility of SHP development to TEDA	This will enable private participation	1. The state government can issue an order to promote private developers to participate in SHP development and pass the jurisdiction of existing untapped hydro resources to TEDA and PWD.	Energy Department
Level 3 (3–6 months)	Preparing a detailed grid-planning document	Identification of exact infrastructure requirements based on pipeline and proposed projects	1. Consolidation of pipeline and planned project data. 2. Prepare ToR for grid study (some indicative terms could be identification of new infrastructure, new smart-grid monitoring technologies, operational philosophy, new commercial mechanisms, capacity of inter-state transfer, capacity of inter-regional transfer, recommendations for future expansion, etc.). 3. Appoint a consultant for detailed grid study. 4. Identify specific interventions and exact infrastructure requirements with locations for capacity addition.	Energy Department

Priority	Action points	Expected outcomes	Implementation measures	Responsibility
Level 3 (3–6 months)	Preparation of a separate off-grid regulation	Demand management through adoption of decentralized models	1. The state can request TNERC to develop a separate off-grid regulation that specifies tariff, connectivity standards, connection points, and includes two-way transfer mechanism like net metering. This can be along the lines of the ODGBDF model endorsed by FoR.	TNERC
Priority 4 Interventions (To be initiated between 6-12 months)				
Level 4 (6–12 months)	Demand creation of inter-state, inter-regional corridor capacity	Long-term ability of the state to transfer power flexible	1. Priority demand from Planning Commission, Finance Commission, CEA representative and MoP for creation of high-capacity inter-state and inter-regional corridor.	State Planning Commission
Level 4 (6–12 months)	Demand for inter-state regulation for RE or creation of a commercial mechanism for power transfer without borders	Mitigation of commercial risk to TNEB	1. Explore options for power transfer agreements with other states outside the existing commercial mechanism to accommodate excess RE as and when it comes. 2. Approach central regulator, MoP for allowing short- to medium-term bilateral power transfer agreements outside the existing commercial framework for state owned utilities.	TNEB
Level 4 (6–12 months)	Pilots for unexplored technologies (CSP, energy plantation, offshore wind)	Demonstration of technical feasibility for large-scale private participation	1. Outsourcing of resource assessment of DNI and WPD at selected locations in onshore and offshore respectively. 2. Finalization of locations for CSP/offshore. 3. Exploration of pilot project funding through PPP mode. 4. Inviting consultants for preparation of procurement ToR through tendering. 5. Inviting tenders for pilots. 6. Award of pilot and monitoring of work.	TEDA
Level 4 (6–12 months)	Establishing a TRADECO	Professionalization of trading operations and insulating TANGEDCO from market risks	1. Inter-government consultation of the desirability of TRADECO establishment with respect to promoting RE integration 2. Deciding on the financial and administrative structuring of the	Energy Department

Priority	Action points	Expected outcomes	Implementation measures	Responsibility
			TRADECO. 3. Prepare a detailed order covering jurisdiction, role and RE specific mandate for the new establishment. 4. Recruitment of highly experienced trading professionals. 5. Incorporation of TRADECO.	
Level 4 (6–12 months)	State's financial support for grid-tied technologies	Incentivize investments	1. Internal consultation on fund allocation for state financial support. 2. Based on emerging technology priorities, decide on incentive allocation for various technology choices, qualifying criteria, control period and disbursement schedule.	Energy Department
Level 4 (6–12 months)	Formulating RPO compliance mechanism	Specific focus on solar power development	1. The state government to request TNERC to develop a separate RPO compliance mechanism.	TNERC
Level 4 (6–12 months)	Revision in tariff determination methodology	Award of higher tariffs for RE	1. The state government to request TNERC to use standard levellized costs methodology.	TNERC
Level 4 (6–12 months)	Timely renewal of tariff orders after expiry of control period	Maintain investor interest in future prospects	1. The state government to request TNERC to renew tariff for RE after expiry of control period.	TNERC
Level 4 (6–12 months)	APPC determination	Increase in REC customers	1. The state government to request TNERC to revise APPC every year (as per CERC's stipulation) and include short-term purchases in evaluating APPC.	TNERC
Level 4 (6–12 months)	Enactment of state RE law/Policy	Investors are assured of long-term government support for RE	1. The state to adopt the national RE law (in case it is notified) and modify it based on the specific dynamics of resource availability and desirability of technologies.	TEDA
Level 4 (6–12 months)	Operationalizing wind energy management systems at 100 kV level across the state	Enhanced dynamic operation and readiness for integrating forecasts	1. Closed call for consultants for complete concept-to-commissioning support for operationalizing WEMs. 2. Appointing consultants for comprehensive project management from procurement through installation, commissioning, operations testing to operations	

Priority	Action points	Expected outcomes	Implementation measures	Responsibility
Level 4 (6–12 months)	Doing away with 5D × 7D criteria for wind	Greater land utilization and support for repowering	1. TNEB to issue notification stating relaxation of micrositing criteria for new wind installations and repowering projects.	TNEB
Level 4 (6–12 months)	Carry out a detailed biomass resource assessment field study	Clarity on biomass potential in Tamil Nadu	1. Prepare ToR for detailed biomass resource assessment on similar lines to the 2005 study by IISc. 1.1. The ToR should include mandate on identification of the most suitable residues for biomass generation (preferably gasification) based on availability and quality. 1.2. Decision on notifying use of all identified residue only for power generation.	TEDA

12.2 Benefits to the State

High renewable energy deployment translates into significant benefits for the host state in terms of direct benefits like increased investments, increased revenues, notional savings, employment generation, etc., in addition to many indirect benefits like enhanced energy security and a friendlier environmental footprint. The subsequent sections try to quantify these benefits and compare the value of benefits with regard to the two action plan scenarios: business-as-usual and aggressive.

12.2.1 Investment inflows

The bulk of investments in the renewable energy sector has come from private investments. High RE deployment will mean a very high level of private investment in the state. The subsequent sections try to estimate the quantum of investment inflow for the two action plan scenarios: BAU and AGG.

- The capital cost of all RE technologies is taken as per CERC document titled 'Terms and conditions for tariff determination from renewable energy sources', 2012 [Ref 40].
- In the absence of any specific reference data on annual capital cost escalation for FY 2012-13, costs for wind, biomass and other RE are assumed to continue till 2016-17, and a 10% escalation over 12th plan prices is considered thereafter for the 13th plan period.
- The capital cost for solar technologies is considered constant till 2016-17 and is subsequently lowered by 30% at the start of the 13th Plan, remaining constant thereafter. **Table 12.2** specifies the capital cost of various technologies based on CERC's 'Terms and conditions for tariff determination from RE sources', 2012.

Table 12.2 Capital cost based on CERC document

Technology	Capital cost 2012-13 to 2016-17 (Rs.Cr/MW)	Capital cost 2016-17 to 2021-22 (Rs.Cr/MW)	Remarks
Wind	5.75	6.32	
Solar PV	9.34	6.54	Module + Non-module
CSP	13	9.1	
SHP (>5MW)	5.5	6.05	SHP <5 MW is Rs 6 Cr/MW
Biomass	4.45	4.89	Combustion process

Based on the above assumptions, the investment inflow for the two scenarios viz BAU and AGG is shown in **Table 12.3.**

Table 12.3 Investment flow for BAU & AGG scenarios in Tamil Nadu

Investments for BAU Scenario (Rs.Cr)					
FY12-13	**13-14**	**14-15**	**15-16**	**16-17**	**12th Plan**
6418	8354	9974	11540	13653	**49939**
17-18	**18-19**	**19-20**	**20-21**	**21-22**	**13th Plan**
11452	11555	13114	13588	14063	**63772**
Total Investment for 12th and 13th Plan (Rs.Cr)					**113711**
Investments for AGG Scenario (Rs.Cr)					
FY12-13	**13-14**	**14-15**	**15-16**	**16-17**	**12th Plan**
14891	16907	19385	22292	25033	**98508**
17-18	**18-19**	**19-20**	**20-21**	**21-22**	**13th Plan**
22949	23809	25753	27150	28807	**128468**
Total Investment for 12th and 13th plan (Rs.Cr)					**226976**

The difference in investment inflow for the two plan periods is substantial, (Rs. 1.13 lakh crore in BAU as against Rs. 2.19 lakh crore in AGG).

12.2.2 Tax revenues

Tamil Nadu applies a value added tax (VAT) of 4% on equipment and supplies. Assuming that these contribute to 90% of the total investments, the VAT receipts for the state are estimated in **Table 12.4.**

Table 12.4 VAT revenue receipts for BAU and AGG scenarios

VAT revenues for BAU Scenario (Rs.Cr)					
FY12-13	**13-14**	**14-15**	**15-16**	**16-17**	**12th Plan**
231.05	300.74	359.06	415.44	491.51	**1797.80**
17-18	**18-19**	**19-20**	**20-21**	**21-22**	**13th Plan**
412.27	415.98	472.10	489.17	506.27	**2295.79**
Total tax revenues for 12th and 13th Plan (Rs.Cr)					**4093.60**

VAT Revenues for AGG Scenario (Rs.Cr)					
FY12-13	**13-14**	**14-15**	**15-16**	**16-17**	**12th Plan**
536.08	608.65	697.86	802.51	901.19	**3546.29**
17-18	**18-19**	**19-20**	**20-21**	**21-22**	**13th Plan**
826.16	857.12	927.11	977.40	1037.05	**4624.85**
Total tax revenues for 12th and 13th Plan (Rs.Cr)					**8171.14**

The difference in tax receipts from the two scenarios is about Rs. 4,078 crore.

12.2.3 Notional savings due to surplus REC generation

Tamil Nadu is presently buying renewable power at notified preferential tariffs. The Electricity Act (EA), 2003, specifies preferential treatment to RE by paying a higher SERC-specified tariff for renewable sources. However, new mechanisms like RECs can effectively mean some notional savings as the projects under the REC mode will be bought at APPC, which is usually less than the notified preferential tariff. The difference in the two payouts means a notional saving for the state utility.

Note: According to unconfirmed reports, many utilities are asking allowance to sell excess RECs directly in the REC trading market. Even tough the modalities of such a process are to be worked out, allowing such provision would in fact translate the notional benefits into real benefits.

The following sections try to estimate the impact of surplus RECs generated in Tamil Nadu under the two plan scenarios.

As per REC registry data, about 2,251.83 MW capacity is registered under RECs (as on 31.01.12), out of which Tamil Nadu accounts for 528.3 MW (409 MW of wind and 119 MW of biomass), amounting to around 23.46 %.

Data use and assumptions for calculation of surplus RECs in Tamil Nadu

The main assumptions of the REC calculations are summarized below.

- Demand projections for 12th and 13th plan are taken from 18th EPS draft.
- The values as provided by TEDA (website: *www.teda.in*) are taken as base installed capacity (as on 31 October 2011), where wind installed base as 6,548 MW, SHP installed base as 90.05 MW, biomass as 771.15 MW, and solar as 7 MW.
- Normative CuFs are assumed for RE technologies (wind 23%, SHP 38%, biomass 70%, and solar 21%).
- As per NAPCC requirements, the FY 2012-13 targets for non-solar and solar RPOs are 7% and 0.25 % respectively. NAPCC further envisages a yearly increment of 1% and 0.25% in non-solar and solar RPOs up to 2020. As the present project scenario is up to the end of the 13th plan, the yearly increment is assumed to continue up to the end of the 13th plan.
- For FY 2012-13, the non-solar RPO target (9%) of Tamil Nadu is 2% more than the recommended target (7%) specified in NAPCC. The estimation methodology assumes a consistent 2% increment over NAPCC values for all years.
- However, the notional savings can only be calculated on the basis of the difference between preferential tariff and APPC. Preferential tariffs for solar power projects (>2MW) has not been notified. In view of the above, notional savings from solar RPOs are not estimated.
- Furthermore, as the bulk of non-solar capacity is coming from wind power, wind power preferential tariff (presently at Rs. 3.39/Kwh) is assumed for calculating cost savings for non-solar RECs.

- APPC is assumed as Rs. 2.73/kWh (as notified by TNERC).
- It is assumed that all surplus generation after meeting the state RPO obligation is registered under RECs.

Estimation of surplus RECs in Tamil Nadu

Based on the above assumptions, **Table 12.5** shows the indicative methodology for benefit estimation and **Table 12.6** summarizes the cumulative savings achieved from all surplus RECs in the 12th and 13th plan periods.

Table 12.5 Indicative methodology for benefit estimation

Description	Unit	Equation
Total Energy Requirement	Billion Units (BU)	A
RPO%	%	B
Proposed generation	BU	C
Surplus power after RPO	BU	D=A*B-C
Preferential tariff (wind)	Rs/kWh	E
APPC (last notified)	Rs/kWh	F
Notional Saving	Rs 100 Cr	G=D*(E-F)
Potential of REC	Lakh	F=D/1000

Table 12.6 Cumulative savings from surplus RECs in Tamil Nadu in the 12th and 13th plan (BAU & AGG scenarios)

Estimated benefits	Unit	BAU		
		12th Plan	13th Plan	Total
Notional savings from REC (non-solar)	Rs Cr	2634	3403	6037
Estimated benefits	**Unit**	**AGG**		
		12th Plan	**13th Plan**	**Total**
Notional savings from REC (non-solar)	Rs Cr	4535	10303	14838

Based on the above calculations, it can be seen that savings achieved from the AGG scenario are twice as high as those achieved from the BAU scenario. The difference in savings accruing from the two plan scenarios (Rs. 8,801 crore) is high enough to warrant a serious look at the landed commercial implications of this aspect.

12.2.4 Central Financial Assistance of 13th Finance Commission

The 13th Finance Commission is a statutory body that sets the formulae governing fiscal transfers from the Government of India to state governments for a specified horizon. For the horizon period 2010-15, the Commission introduced a grant for grid-connected RE.

Background of CFA for grid-tied renewables

The total budgetary provision for this grant was set at Rs. 5,000 crore, payable in FY 2014-15. The grant was designed to be apportioned between state governments as a reward for states' relative achievement in renewable energy capacity-addition from 1 April 2010 to 31 March 2014. The allocation to a particular case was assessed on the basis of a two-part formula that allocated the following weightage to two main performance parameters:

- 75% for achievement in installed capacity addition (over 2010-14) relative to aggregate installed capacity addition across all states; and
- 25% for achievement in installed capacity addition (over 2010-14) relative to unachieved potential.

The formula for estimating the state's relative achievement was designed as shown.

For the ith state:

X_i = Installed capacity addition up to 2014

Value of the 1st component for the ith state = $X_i / \Sigma X_i$

The formula for the state's relative achievement vis-á-vis its potential is

For the ith state

If A_i = RE potential for the state

And Y_i= Achieved potential up to the end of FY 2008-09

And if $CA_i= X_i/ (A_i-Y_i)$

Then the coefficient for the 2nd component for the ith state will be $CA_i/\Sigma\ CA_i$

As Tamil Nadu may have a negative CA_i, the highest value of CF_i for any state can be used. The total value of the grant is capped at Rs.1.25 crore per MW of installed capacity (X_i) for general category states like Tamil Nadu. The actual grant disbursal is also subject to the following conditions:

- it will be based on data published by the Government of India on capacity-addition by states;
- the state should permit RE developers/projects access to competitive power markets, at charges not exceeding the levels specified by the CERC; and
- transmission charges and losses applicable for renewable energy targets are not to exceed a level of Rs. 0.25/kWh and 5% respectively, or, the state transmission utility should have implemented rational alternate transmission pricing frameworks (including point of connection tariffs) if so recommended by the CERC, within 12 months of such recommendations coming into force.

Data-use and assumptions for CFA calculation

- Calculation of value for the second component of the CFA is not possible as it would require a projected data for all states. Therefore, value of only the first component is estimated for both the scenarios.
- Existing installed values of RE were taken from MNRE and TEDA. **Table 12.7** shows the installed capacity figures

Table 12.7 Estimated installed capacity of RE in Tamil Nadu as on 31 March 2012

Technology	TN: installed 31.03.12) (MW)	India: installed 31.04.12 (MW)
Wind	6984	17389
Biomass /Bagasse	771	3158
Solar PV	7	979
Solar thermal	0	0
Small hydro	90.05	3401
Total	**8462.05**	**26919**

- Capacity-addition figures for Tamil Nadu for FY 2012-13 and FY 2013-14 were derived from the two scenarios. The estimate for the rest of India capacity-additions for FY 2012-13 and FY 2013-14 was done after assuming a 5% annual increase over the existing installed base.

Estimation of CFA for Tamil Nadu

Based on the above estimations, the required data for CFA estimation was compiled for both the scenarios. **(Table 12.8**)

Table 12.8 Base figures for CFA estimations for BAU and AGG scenarios

Base Figures for CFA Estimation- BAU		
Region	**Installed base on 31.03.2014 (MW)**	**Estimation of first component (Rs Cr)**
Tamil Nadu	10891	1222
India	33427	
Base Figures for CFA Estimation- AGG		
Region	**Installed base on 31.03.2014 (MW)**	**Estimation of first component (Rs Cr)**
Tamil Nadu	13793	1326
India	39020	

Assuming CFA continuation with the 14th Finance Commission, the additional CFA from the first component will be Rs. 1,138 crore and Rs. 1,865 crore for the BAU and AGG scenarios, respectively.

12.2.5 Employment generation

To estimate employment generation from the proposed action plan, the report from CII and MNRE in October 2010 was referred [Ref 41]. The report identifies employment potential of various technologies based on the employment figure statistics in FY 2009-10. **Table 12.9** summarizes the sectoral manpower requirement and estimates the technology-wise employment index (Employments/per MW of capacity)

Table 12.9 Average manpower requirement for various grid-tied technologies

Technology	Installed base in Oct 2009 (MW)	Direct employment (Nos)	Direct employment potential (Nos./MW)	Total indirect employment (Nos)	Indirect employment potential (Nos/MW)
Wind	10900	14000	1.28	28000	2.57
Solar PV	200	4000	20.00	0	0.00
CSP**	0	0	20.00	0	0.00
Biomass	820	12000	14.63	23000	28.05
Small hydro	2500	12500	5.00	0	0.00

** CSP employment potential assumed to be same as that of solar PV

Based on the per MW employment indexation, the employment generation potential of the two scenarios is shown in **Table 12.10.**

Table 12.10 Employment generation estimates for BAU and AGG scenarios

Employment generation BAU Scenario			
Type of Employment	**Total 12th Plan**	**Total 13th Plan**	
Total direct employment	40910	53461	
Total indirect employment	21038	26007	**Total**
Total employment	**61948**	**79468**	**141416**
Employment generation AGG Scenario			
Type of Employment	**Total 12th Plan**	**Total 13th Plan**	
Total direct employment	80378	113061	
Total indirect employment	40048	158343	**Total**
Total employment	**120426**	**271404**	**391830**

Based on the above, it can be seen that the employment generation potential for the two scenarios is markedly different, with the potential of AGG scenario being almost double that of the BAU scenario.

12.2.6 Carbon emissions savings

The most important and least understood benefit of renewables is their climate friendliness, their ability to save carbon (CO_2) emissions. A wind turbine typically takes three to six months to produce energy that goes into producing, operating and recycling the wind turbine after its 20-25 year lifetime. After that, wind generation produces no CO_2 emissions. All renewables have low or positive lifecycle emission footprints. On the other hand, a conventional power system generates significant emissions of CO_2 and its equivalent. According to CO_2 baseline data released by CEA, the average emission, measured in tonnes of CO_2/per MWh of energy for the southern grid is 0.81 [Ref 42].

Integration of renewables would mean displacement of an equivalent energy component from conventional generation implying an effective savings in CO_2 emissions. This is the basis for estimating CO_2 emissions for the two scenarios. To model the CO_2 emissions saving potential, the MW capacity of renewables has to be converted into equivalent generation. For this, the capacity utilization factors of various technologies are assumed as follows: 23% for wind power, 21% for solar power, 70% for biomass, and 38% for small hydro. Based on the assumptions, the net emissions savings due to new capacity-additions from the start of the 12th plan are shown in **Table 12.11.**

Table 12.11 Cumulative CO_2 savings due to new capacity-additions for BAU and AGG scenarios

Emission Savings (Tons of CO_2) BAU Scenario	
12th cumulative savings (thousand tons of CO_2)	228.4
13th cumulative savings(thousand tons of CO_2)	1271.8
Total savings (thousand tons of CO_2)	**1500.2**
Emission Savings (Tons of CO_2) AGG Scenario	
12th cumulative savings (thousand tons of CO_2)	472.2
13th cumulative savings(thousand tons of CO_2)	2515.2
Total savings (thousand tons of CO_2)	**2987.4**

The results indicate that the CO_2 savings in the 12th and 13th plans due to new capacity are to the tune of 2987.4 thousand tonnes of CO_2.

12.2.7 Summary of Benefits

The following **Table 12.12** tries to capture all the benefits together to assess their impact

Table 12.12 Summary of benefits for BAU and AGG scenarios

Estimated Benefits	**Unit**	**BAU**			**AGG**		
		12th Plan	**13th Plan**	**Total**	**12th Plan**	**13th Plan**	**Total**
Investment inflow	Rs. Cr	49939	63772	**113711**	101334	117765	**219099**
Tax revenues (TNVAT@4%)	Rs. Cr	1798	2296	**4094**	3546	4625	**8171**
Central financial assistance	Rs. Cr	1222	NA	**1222**	1326	NA	**1326**
Notional savings from REC	Rs. Cr	2634	3403	**6037**	4535	10303	**14838**
Employment generation	Nos.	61948	79468	**141416**	120426	271404	**391830**
Emissions savings	thousand tCO_2	228.4	1271.8	**1500.2**	472.2	2511.2	**2987.4**

The benefits as estimated above are not exhaustive. The state would actually get many more direct benefits from other taxes and registration, and stamp duty charges for land registration, agreements, etc., statutory /application fees. However, the most important benefit for the state would be a more environment friendly development, free from intensive water consumption and pollution.

12.3 Conclusion

The report is an attempt to dispel key misconceptions surrounding renewables and to start a fresh dialogue to challenge existing perceptions and to create solutions to promote a high level of renewable integration in the state. The report has tried to flag the risks of 'business-as-usual' approach in the state power planning by highlighting the risks associated with coal-dependent power planning. At the same time, the report has established that the renewable energy potential of the state is in multiples of the existing estimates and is not a constraint for the state.

The report has further found that even an aggressive RE integration (**an addition of 36,340 MW of new RE capacity over the 12th and 13th five-year plans**) is technically feasible and can be managed by appropriate infrastructure augmentation and operational modifications. Further, the study has also assessed the commercial impacts of the aggressive RE capacity addition plan and has tried to estimate the extent of burden (in monetary terms), in addition to estimating the direct and indirect benefits/losses to the state. Finally, the report also prioritizes the action points and interventions into an implementation roadmap by developing a procedure-focused format along with identification of key departments or agencies that will have the responsibility to implement the proposed actions.

The message from the project's findings is very clear: given the present situation and the emerging scenario in terms of resource ownership and our choice of the development path, renewables seem to be the most optimal option for the state from a long-term perspective.

In case the state decides to opt for renewables, it has to be open to bringing about swift and unconventional changes in the way we perceive the sources and uses of power.

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