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WORKING PAPER

Assessing technologies for expanding renewable energy in Kerala

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HIGHLIGHTS

- Kerala aims to completely transition to renewable energy (RE) by 2040 for its electricity requirements, but currently depends heavily on electricity imports, most of which are fossil fuel based.
- This working paper uses a technology assessment framework to explore RE options and supporting technologies for expanding the state's RE capacity.
- Kerala's topography, along with the high cost and scarcity of land, makes installation of large-scale, land-based solar power plants difficult. Rooftop solar systems, other forms of distributed RE, and floating solar installations are alternatives.
- The limited availability of high-wind-potential sites and the complex terrain restrict the size of wind projects, reducing investor interest. Small wind turbines can be explored as an alternative.
- Small hydro power could be expanded in the state. Newer technologies such as hydrokinetic turbines could prove helpful. Land acquisition and obtaining clearances from the forest department due to environmental considerations are some of the major implementation challenges.
- Large biogas uptake is possible with improvements in plant maintenance, slurry removal, and disposal practices.
- Wave energy is another viable option. However, investments, technology optimization, and large-scale pilots are essential for its uptake.
- With a more diverse set of RE technologies, Kerala could transition to a clean energy future.

EXECUTIVE SUMMARY

Context

To reach India's declared goal of net zero emissions by 2070 and a cumulative RE capacity of 500 GW by 2030, the states will need to actively participate in the effort. It is essential to evaluate the current technological landscape in each state and explore RE options and supporting technologies that the states can adopt to accelerate clean energy production. This working paper focuses on Kerala, which has set more ambitious targets of becoming a 100 percent RE-based state by 2040 and achieving carbon neutrality by 2050 (ANERT n.d.; CSTEP 2024).

Kerala imports approximately 70 percent of its electricity, mostly from fossil fuel sources. As part of its plan to transition to clean energy, the state is in the process of expanding its RE capacity. The state has also announced plans to set up "hydrogen valleys" in Kochi and Thiruvananthapuram, and establish itself as a hub for green hydrogen production and export (ANERT n.d.). Kerala has a complex terrain and geography, with eco-sensitive zones. Suitable wind-rich sites and land for large-scale solar projects are limited. In this context, it is important to explore a wider set of RE options and related technologies that could benefit the state.

About this working paper

This paper develops a technology assessment framework called TAF and utilizes it to understand various RE and supporting technologies in the context of Kerala. It prioritizes these technologies based on the state's RE potential and strategic needs. The prioritized technologies are then further assessed using multiple indicators. Barriers to technology adoption and information supplementing the assessed parameters are also recorded. The current landscape of various RE technologies in the state is described. The output from the assessment of various technologies is then used to derive insights and provide recommendations for Kerala.

Methodology

The TAF is based on a two-step methodology in which the available RE options and associated technologies are first prioritized based on resource potential and strategic needs. These prioritized technologies are then further investigated under the following indicators: technical parameters, economic factors, resource availability, policy and regulatory framework, and environmental and social impact. The TAF is based on the technology assessment tools developed by the International Energy Agency (IEA) and the Center for Study of Science, Technology and Policy (CSTEP). The individual frameworks were simplified and modified to include additional parameters relevant to Kerala. The data used to determine the parameter values were collected through stakeholder consultations and a literature review. A detailed explanation of the methodology is provided in the section titled "Methodology." The TAF developed for this study is described in Appendix A.

Key Findings

Wind energy is a mature technology, and the development of large-scale wind energy projects is well understood. The wind sector in India is highly indigenized, with domestic supply chains and manufacturing facilities. The wind potential in Kerala is estimated at 2,621 megawatts (MW), and the installed capacity is only 70.27 MW. Large-scale wind farms are limited to certain pockets in Kerala because of the wind conditions in the state. Most of the existing wind energy projects are small to medium scale (about 15 MW or lower). Developing more medium-sized projects will require taking extensive on-site wind measurements and addressing issues related to land acquisition. The logistics of transporting wind turbine components is a challenge in the state, and extensive road surveys are required to address this issue. Land availability and acquisition are also major barriers.

Crystalline solar photovoltaic (PV) technologies (monocrystalline and multi-crystalline) are mature and highly popular. Bifacial modules are also being widely adopted owing to their higher efficiencies. The process of deploying and installing the technology is well understood, and domestic supply chains and manufacturing facilities are largely available. There is widespread awareness regarding this technology, and the associated risks and environmental impacts are estimated to be low. The potential for utility-scale solar PV projects in Kerala is estimated at 6,110 MW, and the installed capacity is about 322 MW (ground-mounted solar as of July 2024). Land availability and cost, land acquisition, and the limitations of the transmission and distribution system are challenges. Although Kerala released a solar policy in 2013, its provisions were not in line with the state's subsequent energy priorities.

Considering the challenges associated with large utility-scale projects and multiple other factors, rooftop solar (RTS) PV is a suitable option for the state. The installed capacity of RTS in the state was 817 MW as of July 2024. There is high awareness, and barriers to entry are low. Central schemes such as PM Surya Ghar also promote its uptake. However, after-sales service, quality control, limited availability of a skilled workforce, nonavailability of strong rooftops, and shared rooftops are issues. Changes in the existing favorable guidelines and regulations and reduction of power-banking time frames can reduce its adoption.

Kerala also has the potential to generate between 3 and 8 GW of floating solar power. However, there are only a few such projects in the state. PV panels can be floated on water bodies such as reservoirs owned by the state government. This would minimize land acquisition costs because the reservoirs are allocated under a lease model. However, appropriate site selection is key, considering factors such as elephant crossings and other wildlife issues, aquatic life, the water flow rate, susceptibility to flooding, as well as local fisheries and other livelihood activities. Kerala is reportedly in the process of developing a policy for supporting floating solar.

Small hydro power (SHP) projects in the state mostly generate power from run-of-the-river technology. These are mature technologies offering high efficiency rates. The technical aspects of setting up SHP projects are also well understood. Canal- and dam-toe-type SHPs (which are restricted to government utilities) also exhibit high capacity utilization factors (CUFs). However, SHPs have higher up-front capital expenditure and operations and maintenance (O&M) costs than other established RE technologies (solar PV, for instance). At present, about 276 MW of the state's identified SHP potential—647 MW—has been tapped in the state. The use of newer technologies such as hydrokinetic systems can help maximize deployment. However, multiple challenges lead to delays in project development, causing cost overruns. Considering this, the state government developed the Draft Small Hydro Power Policy of 2022, which aims to address many of these concerns (see Appendix B, Table B-5 for further details).

Biogas plants have been in use in Kerala for over 20 years. The technology is mature, well understood, and supported by domestic supply chains. It is estimated that a small biogas plant (0.75–1 cubic meters) can partly meet a household's cooking fuel requirements. The by-product slurry is also a good manure. Kerala is rich in biomatter and seasonal fruits, which can be used as input (feed material) for biogas plants. All this makes biogas a suitable technology choice for the state. Initially, smaller-capacity plants were developed and used. Improvements were made to the plants to address the concerns of odor leakage, mosquito growth, gas pressure, and flame intensity. At present, floating-drum-type plants are being used with certain modifications and are referred to as Hi-Tech plants. However, although these plants have been used for a long time, their adoption remains limited. Many of the larger plants are not functioning due to a lack of maintenance and issues with slurry disposal. Maintaining predictable supplies of quality feed material is also a challenge. The uptake of biogas plants is largely driven by subsidies. All this has reduced the demand for biogas plants and led to a decline in the number of manufacturers and suppliers of biogas units in the state, despite the technology's significant potential.

Kerala also possesses potential for harnessing wave energy. Consistent waves near Vizhinjam in Trivandrum make it a potential site. The technological and financial risks associated with wave energy technology are high, and the designs have also not reached commercial maturity. Supply chains and manufacturing facilities are yet to be developed. The success of wave energy technology depends on multiple parameters such as water depth, distance from the coast, and sea conditions. The project costs (approximately INR 20–30 crores/ MW) are estimated to be higher than for other RE options such as onshore wind, solar, and SHP (INR 6–10 crores/ MW). Due to its low technology maturity and the high variability between different sites, the development of wave energy would require technological collaborations between the various stakeholders. Other ocean technologies such as tidal, ocean current, and ocean thermal energy conversion (OTEC) have limited potential in Kerala. Considering the availability of backwaters and rivers joining the sea, the state can explore salinity gradient technologies. However, these technologies are still under development, and more studies are required to ascertain suitable locations and assess their potential.

Battery energy storage systems (BESS) and pumped storage hydroelectricity (PSH) are important to Kerala for time shifting, load supplementation, and mitigation of peak time charges, and for decentralized applications. In the case of BESS, lithium ferro phosphate (LFP) and lithium-nickel-manganese-cobalt (NMC) are the two battery chemistries that are commercially available in the market. Although these battery technologies are mature, other technologies and ancillary systems such as cooling, grid integration, and emergency management are in the nascent stage, and present challenges for BESS systems. Supply chains and manufacturing facilities are still being developed for the commercial BESS chemistries.

PSH is a fully mature technology with high efficiency. The establishment of PSH facilities is well understood, and the associated costs are comparable to those of large hydro projects. Except for certain types of installations, the components are available indigenously and supported by established supply chains and manufacturers. Kerala has a PSH potential of about 4,400 MW; however, there are currently no PSH facilities in the state. The timelines for project commissioning are long, comparable to those of large hydro projects.

Kerala has already announced plans of setting up green hydrogen valleys and is looking to become an export hub for green hydrogen in the country. Globally, fuel cell technologies for green hydrogen manufacturing are in the demonstration or early adoption stage. Electrolysis technologies such as alkaline fuel cells, polymer electrolyte membrane cells, and solid oxide fuel cells are at relatively higher levels of technological maturity. Currently, two types of electrolyzer systems are commercially used for green hydrogen technologies: alkaline and polymer electrolyte membrane. A draft Green Hydrogen Policy has been developed by the state government.

Note: The numbering system followed in this working paper is the Indian numbering system. Typical values used are lakhs (1 lakh = 100,000) and crores (1 crore = 10 million).

Recommendations

- Considering the potential and current installed capacities, large-scale solar and wind projects have significant growth potential. Government land, including land available with government companies, can be used. Expanding the transmission infrastructure to locations identified for wind projects and streamlining approval mechanisms can accelerate project implementation and create developer interest.
- Considering the challenges of developing large-scale RE projects, decentralized RE technologies such as RTS, which can ensure clean energy access and reliable power, become an attractive option. The effective deployment of these technologies requires continued policy and regulatory support.
- Technologies such as SHP and PSH offer considerable potential, but streamlined approvals and a mechanism for minimizing their environmental and social impacts are necessary for successful implementation.
- The lack of on-site resource measurements and quantifiable data is a common challenge for multiple technologies, including wind, wave, floating solar PV, and PSH. More studies can assess their potential and identify suitable locations, and the data could be made available publicly.
- Some of the state's RE policies, which are outdated, can be updated to align with its ambitions. Simultaneously, draft policies on, for example, floating solar and green hydrogen, could be finalized and notified, based on public comments.
- Adequate budgetary allocations for research and development in new technologies and pilot projects are required. End-of-life decommissioning and recycling of RE installations need consideration.
- Wind and solar projects face a shortage of skilled workers; therefore, the state should plan to train and upskill its workforce.

INTRODUCTION

India has set an ambitious target of net zero carbon emissions by 2070. By 2030, it aims to reach a cumulative non-fossil-based installed capacity of 500 GW and reduce the carbon intensity of the economy by 45 percent (PIB 2022). Given India's federal structure, it is the states that will implement clean energy policies and measures, making their efforts crucial to achieving the national targets. Therefore, it is important to examine the state-level technological landscape and unpack the emerging and alternative technologies that states can explore to ramp up their clean energy production. This research paper focuses on the state of Kerala, in southwest India.

The government of Kerala has announced its plans to become a 100 percent renewable energy (RE)-based state by 2040 and reach net zero by 2050. The state currently imports nearly 70 percent of its electricity, mostly from thermal power plants. Studies estimate that about 13.25 GW of additional RE capacity would likely be required by 2040 to meet electricity demands while conforming to state targets (CSTEP 2024). However, as of July 2024, the cumulative installed RE capacity was estimated at 1,507.49 MW (including small hydro power [SHP], wind, solar, and bioenergy) (CEA 2024a). Kerala's complex terrain, eco-sensitive zones, high population density, high land costs with a limited number of wind-rich sites, and limited large tracts of land for large-scale RE projects make it challenging to achieve its clean energy targets.

Kerala's power demand exceeds its supply. Despite the steady growth of RE, rapid adoption of clean energy technologies is crucial to meet the growing demand.

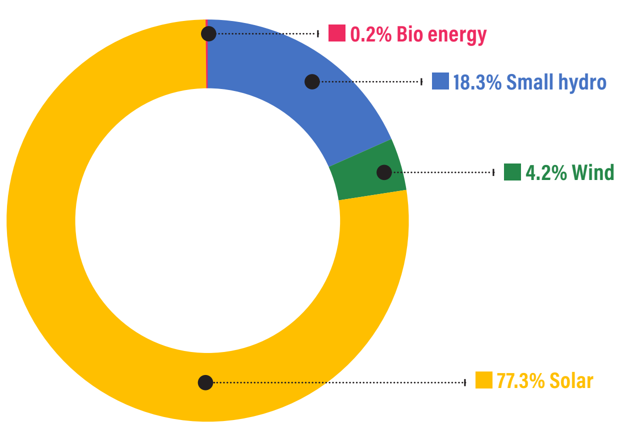
Between 2010 and 2021, the state's installed electricity generation capacity grew by 10 percent, from 2,752.96 MW in 2010 to 3,029.61 MW in 2021. Simultaneously, the annual power demand grew from 17,350 MU in 2010 to 25,144.99 MU in 2021 (a nearly 45 percent increase). Of the 25,144 MU consumed in 2021, 7,057 MU was met by the state's own generation capacity, and the remaining 18,912 MU was imported (KSEBL 2023). Figure 1 presents a snapshot of Kerala's power system characteristics over the years. Appendix C provides further information on Kerala's power-generating capacity and maximum demand over the years.

As of July 2024, Kerala had 1,507.49 MW of installed RE capacity, of which 276.52 MW was SHP; 63.50 MW, wind power (data by Kerala State Electricity Board Limited [KSEBL] indicate the wind capacity as 70.27 MW); 1,164.97 MW, solar power; and the remaining 2.5 MW, biopower (see Figure 2) (MNRE 2024). Of the total solar power, 322.79 MW was from ground-mounted solar; 817.25 MW from rooftop solar (RTS); and the remaining 24.93 MW from off-grid solar and Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (KUSUM) components. In financial year (FY) 2023–24, 7,359.96 MU of RE was generated in the state from the various sources (CEA 2024b). Appendix C summarizes Kerala's installed RE capacity and potential.

Figure 1 | **Year-wise installed capacity versus maximum demand in Kerala (Source (KSEB 2023))**

Source: KSEBL 2023.

Figure 2 | **Share of the various renewable energy generation sources in Kerala as of July 2024**



Source: Authors' analysis.

Given Kerala's current power scenario and its commitment to achieving 100 percent RE by 2040, the state should explore and prioritize various RE options and the associated technologies. Toward this end, this paper develops a technology assessment framework called TAF to understand various RE and supporting technologies in the context of Kerala. This methodology can also be applied to RE technology ecosystems in other states.

METHODOLOGY

This working paper relies extensively on the reports published by the State Government of Kerala, Agency for New and Renewable Energy Research and Technology (ANERT), Energy Management Centre (EMC), and KSEBL to identify the energy mix and capacity addition plans of the state. This paper also includes information collected through stakeholder consultations with scientists from central government institutions, officials from state government nodal agencies, experts with experience in RE projects, industry representatives, manufacturers, and developers, all of which have been helpful in assessing the technologies with the TAF. This paper also uses other research publications to assess the technologies against the TAF's parameters.

To examine general trends in emerging technologies and markets, we also conducted a secondary literature review of papers on various RE technologies, covering aspects such as Technology Readiness Levels (TRLs), future disruptions, and stakeholder interest. The review also included publications from Breakthrough Energy and International Renewable Energy Agency (IRENA) (Breakthrough Energy 2019; IRENA 2019).

Breakthrough Energy's report examines various RE technologies and the associated TRLs (Breakthrough Energy 2019). It also outlines opportunities for leveraging rapidly evolving technologies to advance the RE sector. Additionally, the publication analyzes new technologies and innovations; possible breakthroughs and disruptions; projections for the future; and levels of stakeholder interest in some of the new technologies. This report is useful for understanding the available RE technologies and their maturity levels. The report, however, focuses on the US ecosystem and cannot be directly applied to other regions.

To understand how different RE technologies and interventions have been used by different countries and regions, and gain insights into the ongoing innovations in the power sector, the authors referred to a report by IRENA (IRENA 2019). This report highlights the broad range of innovations available to accelerate RE deployment and integrate higher shares of variable renewable energy (VRE) across the world. It includes case studies on clean energy interventions and innovations from regions such as Denmark, Ireland, Texas, California, Southern Australia, Uruguay, Germany, and Tasmania.

However, although globally all these technologies are at various stages of commercial development and application, their suitability may differ across countries and subnational regions. This variation makes it important to assess the usefulness of a particular technology for a given country or state using factors such as its resource dynamics, demand-side considerations, geography, topography, and supply chains. This can be done using a technology assessment framework. We have considered frameworks developed by the International Energy Agency (IEA) (IEA 2016) and the Center for Study of Science, Technology and Policy (CSTEP) (CSTEP 2021).

The IEA's Clean Energy Technology Assessment Methodology (CETAM) measures and monitors clean energy technologies in accordance with the local context and policy objectives. CETAM uses three main steps: prioritization, metric formulation, and monitoring. High-priority technologies are identified based on factors such as resource availability, cost, strategic needs, technology ambition, and market opportunities. CSTEP's TAF uses six performance indicators—technical impact, economic impact, resource availability, policy and regulatory framework, environmental impact, and social impact—to evaluate technologies.

For this paper, the authors modified the above frameworks to create a Kerala-specific framework called TAF that captures key local parameters. We also considered expert opinion and feedback from stakeholder consultations, as stated above. Each parameter is assigned suitable metrics and measurable units to facilitate performance assessment. The final TAF used for this study is based on a two-step method: first, the available RE and clean technologies are "prioritized" based on resource potential and strategic needs, and second, these prioritized technologies are further investigated under five indicators: technical parameters, economic factors, resource availability, policy and regulatory framework, and environmental and social impact. Technology adoption barriers and additional information on the assessed parameters are also recorded. Appendix A presents the final framework used in this study.

THE TAF: FINDINGS FOR KERALA

This section summarizes the key observations on Kerala's prioritized RE technologies obtained from the TAF, based on the abovementioned performance indicators (see Appendix B for the detailed assessment). The prioritized technologies are onshore wind, land-based solar PV, rooftop solar PV, floating solar PV, SHP (run-of-the river, dam toe, and hydrokinetic systems), biogas, wave energy, green hydrogen, battery energy storage systems (BESS), and pumped storage hydropower (PSH). This section briefly describes these technologies and their development in Kerala.

Wind: Onshore

Kerala has been harnessing wind energy since the 1990s, and the first project, with 225 kW turbines and a capacity of 2.025 MW, was commissioned in 1995 (KSEBL 2023). The current installed wind capacity is 70.27 MW. Studies estimate the wind potential in Kerala as 2,311 MW and 2,621 MW at hub heights of 120 m and 150 m, respectively (NIWE 2023). Other studies have identified the site at Ramakkalmedu, Idukki, as a high wind resource site, with an estimated potential of 80 MW (GoK 2004). The state government specified policy guidelines for wind power development projects through private developers in 2004, with amendments in 2007 and 2008 (GoK 2004, 2008). The document also lists potential sites for developing wind energy projects. Currently, other than the initial installation by KSEBL, Kerala's wind power generation comes from captive power producers (CPPs) and independent power producers (IPPs), primarily in Idukki and Palakkad districts (KSEBL 2023). These installations utilize large wind turbines with capacities of 225 kW to 2 MW. Appendix C lists Kerala's wind power plants.

- **Technical parameters:** Wind energy technology is at a relatively mature stage (TRL 10) and is well understood. Setting up large wind projects in Kerala faces logistical difficulties, due to the challenge of transporting large components. A skilled workforce is required during the installation and operation of the project, which necessitates enhanced capacity-building and training. About 15–25 lakh units per megawatt are generated annually from Kerala's wind projects, with capacity utilization factors

(CUFs) of about 20–30 percent. The auxiliary consumption is less than 1 percent of the total generation. The associated technological risks are low, and the recycling processes are still being developed. Most of the projects were commissioned between 2008 and 2019, and repowering and associated recycling of blades is not an immediate concern. The technology risk is low.

- **Economic factors:** The capital expenditure for wind projects is INR 6–8.5 crores per megawatt. Transportation of wind components and the need for heavy lifting equipment for installation are major cost components. Wind projects typically require about 2.5 acres per megawatt. Kerala's land cost is high. Stakeholder discussions revealed that the land price for RE projects in Kerala is often about 10 times the national average, making land acquisition a significant challenge. Operations and maintenance (O&M) costs are 1.5 percent of the capital expenditure. The financial risks of setting up wind projects in Kerala depend on the power procurer, and the limited size (capacity) of these projects is an additional obstacle to sourcing external investment for projects.
- **Resource availability:** Kerala has a low-to-medium level of wind resources, concentrated in certain pockets. A large part of Kerala's wind potential is concentrated in remotely located, difficult terrain (SPB 2017). More on-site measurements of wind-related parameters are needed. The domestic share in components used for setting up projects is high, about 80 percent, which minimizes the impact of global supply chain disruptions.
- **Policy and regulatory framework:** Kerala's wind energy promotion policies are outdated and lack budgetary allocations. Due to low project capacities, developing interstate transmission projects may not be a viable option, except for certain locations near the Kerala–Tamil Nadu border. Support from the state government for research and development (R&D) activities is limited, hindering the exploration of new wind technologies such as small wind turbines (SWTs) and mechanisms for transporting large wind turbine blades to remote locations.
- **Environmental and social impact:** Wind energy technologies are widely known and generally accepted. Project implementation requires about 10 workers per turbine, while for operation, the workforce requirement reduces to about 1 worker for every 2–3 turbines. This is primarily due to the automated operations and advanced remote monitoring systems used in modern wind turbines. Wind turbine blades are of made of glass-fiber-reinforced plastic (GFRP), and recycling technologies for GFRP are being developed. Guidelines for end-of-life recycling and disposal of wind turbine blades are also needed. Although stakeholders estimate the environmental impacts of wind energy projects to be low, project-specific studies are required to determine impacts and understand mitigation measures.

Overall, the challenges to expanding Kerala's large-scale wind projects are mainly due to land acquisition and logistics, not technology. Solutions include using land available with government entities, conducting road surveys to understand and mitigate logistics-related issues, and using smaller-capacity turbines. Mechanisms to enhance developer interest and reduce timelines, such as single-window clearance systems, and planning for higher-capacity projects in the range of 50 MW can also help. Further, in line with stakeholder suggestions and a report by the State Planning Board (SPB 2017), Kerala can explore SWTs.

Solar: Land based, RTS, floating photovoltaics (FPV)

In 2013, the state government announced the Kerala Solar Energy Policy, with the vision of mainstreaming solar energy in Kerala's energy mix. The policy also targeted 2,500 MW of solar installations by 2030 (GoK 2013). The potential for utility-scale solar PV in Kerala is estimated to be about 6.1 GW (DoECC 2022). The floating solar potential in Kerala is expected to be approximately 3–8 GW (Samuel and Prasad 2018; Fernandes and Sharma 2023). Other studies estimate the overall solar potential in Kerala to be 10.9 GW (CSTEP 2024). The first large-scale project, with a capacity of 1 MW, was commissioned by KSEBL in 2015. The deployment of solar PV technology in Kerala has accelerated since 2018, when the state set a target of 1,870 MW of installed solar capacity by 2022. In 2021, Kerala launched Part 1 of the Soura Thejas initiative, wherein the state government aimed to install 25 MW of 2–10 kW rooftop domestic grid-connected solar power plants for domestic consumers and 500 kW plants for housing societies. To this end, the state government provides a 20–40 percent subsidy to residential sector consumers, group housing societies, and resident welfare associations (ANERT 2021).

Solar PV is currently being installed across the state in the form of ground-mounted solar power plants, RTS, and grid-connected floating solar. Large solar projects in the state include the operational 50 MW solar power plant in Ambalathara, Kasaragod, and the 40 MW solar installation at the Cochin International Airport. The total installed capacity of solar power in Kerala stands at 1,165 MW. Appendix C gives details of Kerala's solar PV installations.

- **Technical parameters:** Solar modules in use have efficiencies of about 19–24 percent under standard test conditions (STC) and are a relatively mature technology (TRL 9–10). The CUF of solar PV plants in Kerala is approximately 11–21 percent. The installation and setup of solar power systems is relatively easy, except for FPV. Recycling technologies are yet to be fully developed. The auxiliary consumption for the technology, about 0.25 percent, is lower than that for wind. Overall, the technological risks are low. However, in the case of FPV projects, the technical complexities of setting up projects can vary depending on site-specific characteristics such as wind and water currents, necessitating specific design of anchoring and mooring systems. Issues affecting FPV include rusting of metal connections and parts, safety hazards due to electrical connections being exposed to water, salt deposition, and the need for regular cleaning of panels due to bird fouling. For RTS, in certain cases the modules provided by some suppliers do not generate the expected energy yield, due to issues with module quality. Discontinuation of modules by manufacturers has also affected after-sales service.

- **Economic factors:** The capital expenditure (CAPEX) for solar projects is INR 4.5–5 crores per megawatt. O&M costs for large-scale solar projects are about INR 3–6 lakhs per megawatt. The financial risks depend on the power offtake arrangements, but difficulties in doing business and the slow pace of project development are major barriers to attracting investment in large-scale solar projects. These projects in Kerala also suffer from a lack of payment security mechanisms under the signed power purchase agreement (PPAs), thus increasing the risk. The cost of RTS in Kerala is higher than in other states (INR 60,000–65,000 per kilowatt in Kerala compared to INR 40,000 per kilowatt in other states), primarily due to the lower number of RTS suppliers operating in Kerala. Although the recently launched PM Surya Ghar scheme is expected to improve the uptake, the lack of post-installation maintenance of RTS systems is a persistent issue.
- **Resource availability:** The solar resource potential in Kerala is medium, and is further limited due to frequent cloudy conditions. Kerala's direct normal irradiance (DNI) is 3.71–5.55 kWh/m^2, which is low. Although solar photovoltaic (SPV) cells are largely imported, solar modules are manufactured domestically, with well-established supply chains. Studies have identified a floating solar potential between 3.8 and 8.6 GW, considering 10–20 percent utilization of the state's water bodies (Fernandes and Sharma 2023). However, detailed feasibility studies, which also consider aspects such as the periodicity of water availability in rivers, water currents, water flow rates, and wildlife crossing, are required to identify potential sites. Site selection is key for the successful deployment of FPV in Kerala.
- **Policy and regulatory framework:** Kerala developed a Solar Energy Policy in 2013, which needs to be updated in line with its RE ambitions. State government support for R&D in this domain is limited. The policy risk is estimated to be high because changes in policies and regulations for solar installations can affect the pace of installation. For example, changes in the metering arrangements from the currently available net metering mechanism to mechanisms such as gross metering or net billing can adversely affect the adoption of RTS.
- **Environmental and social impact:** In Kerala, awareness and acceptance of solar projects is high. Due to advances in remote monitoring systems and automated operations, the workforce requirement during operation is low (about 2 workers per 5 MW). It is likely that large projects in Kerala will be planned on government-owned uninhabited lands, thus minimizing adverse social impacts. Project-specific studies can help. The environmental impacts of FPV projects require more studies, and the impacts of RTS installations are estimated to be low. Technologies for end-of-life recycling are still being developed. In the case of FPV, the floats are made of plastics, and recycling could be a challenge.

Except for FPV, the development of solar projects is well understood, and many of the required policies and regulations are in place. Limited availability of land, difficulties in setting up businesses, delays in project development, limited information on potential FPV sites, low demand for RE power from state businesses and industries, and space constraints in the case of RTS are some major issues in Kerala. Leasing land available with government companies to developers can facilitate large-scale solar projects. Notifying virtual net metering guidelines can increase the uptake of RTS.

SHP

Kerala has an SHP potential of 647.15 MW (MNRE 2023). The state has been developing SHP since the early 1990s. The first project, with a capacity of 15 MW, was commissioned in 1994. As of December 31, 2011, 19 SHP projects with an installed capacity of 145.65 MW had been commissioned in Kerala. In 2012, Kerala notified the Kerala Small Hydro Power Policy to increase the installed SHP capacity to 295 MW by 2017. As of March 2022, the installed capacity was only 260 MW, primarily from projects implemented by the state utility, KSEBL. Sanctioned projects faced significant delays due to difficulties in obtaining government clearances, procedural difficulties in obtaining land, geographical challenges, and challenges with the tariff and project ownership timelines.

To address many of these challenges and further promote the uptake of SHP in Kerala, the draft Kerala Small Hydro Power Policy 2022 was developed. The policy aims to increase SHP capacity to 500 MW in eight years and encourage the participation of local self-governments, IPPs and CPPs, and cooperative bodies in the development of SHP projects in the state (EMC 2023). The policy also seeks to simplify the procedures for obtaining land and environmental clearances by setting up a single-window clearance system under the SHP cell. The installed SHP capacity in Kerala as of July 2024 was 276.52 MW. Appendix B describes the challenges to the uptake of SHP in Kerala, and Appendix C provides details of SHP installations in the state.

- **Technical parameters:** Most of the SHP projects in Kerala are run-of-the-river systems, achieving efficiencies of 80 percent. State-utility-owned SHPs are mostly canal drop and dam toe systems. A few screw-type projects are also being planned. Run-of-the-river, canal, and dam toe systems are mature technologies (TRL 11) and are relatively easy to set up. However, higher-capacity SHP projects require bigger machines, increasing the complexities. Overall, the CUFs of SHP are approximately 30 percent in Kerala. Dam toe projects have higher CUFs (30–35 percent) due to the availability of controlled water discharge. Irrigation-based canal projects have a slightly lower CUF due to the periodic unavailability of water. The auxiliary consumption is approximately 1 percent, similar to wind and solar. Hydrokinetic turbines are in the early stages of technology maturity, with efficiencies in the range of 40 percent. Hydrokinetic systems are easier to install due to their technology and design. More data are required to estimate the CUFs of this technology. Other than for hydrokinetic systems, the technological risks are low.
- **Economic factors:** The CAPEX for conventional SHP projects is in the range of INR 8–9 crores per megawatt. However, many recent projects in Kerala have witnessed higher costs in the range of INR 13–15 crores per megawatt, which are higher than those of wind and solar installations. High land prices and cost overruns due to delays in commissioning projects are contributing factors. The O&M costs are in the range of INR 26–36 lakhs per megawatt (i.e., about 2–3 percent of the CAPEX costs), which are higher than those for wind and solar projects. About 15 percent of the yearly O&M costs are spent on spares and consumables, and the rest on insurance, the workforce, and so on. More studies and data from actual projects are required to determine the costs of developing hydrokinetic projects. However, preliminary studies estimate that the CAPEX for these types of projects can vary widely, in the range of INR 15–46 crores per megawatt, and will likely require subsidies or support in the form of viability gap funding (VGF) to initiate and sustain projects. Depending on the technology used and the offtake arrangements, the financial risk can vary.
- **Resource availability:** Kerala has abundant RE resources for SHP development. Considering the identified potential of 647 MW and the status of the current installations, there is scope for expanding SHP in Kerala. Using hydrokinetic systems can further increase the installation base. Kerala has domestic manufacturing capacity for SHP systems and components, with well-established supply chains. The domestic share in components used for setting up conventional SHP projects is high, and global supply chain disruptions are not expected to impact project development.
- **Policy and regulatory framework:** Because the Small Hydro Policy, 2022, is still a draft, the primary policy today is the Small Hydro Policy of 2012. Budgetary allocations have been made for pilots and R&D for new SHP technologies. Except for projects that use new SHP technologies, the policy risks are not very high. However, policy and regulatory support to streamline approvals and fast-track approval processes—without compromising environmental and social safeguards—is essential.
- **Environmental and social impact:** In Kerala, awareness of SHP as an RE option is not very high. The draft Small Hydro Policy, 2022, encourages the participation of local self-government (LSG) institutions, PSUs, and cooperative bodies in SHP development. In line with this, awareness campaigns and workshops can be conducted to sensitize the potential stakeholders. In general, the impact on land and ecosystems is low when considering smaller SHP projects and newer technologies such as hydrokinetic turbines. For higher-capacity SHPs, these impacts will be in line with those of large hydro projects. However, the precise environmental and social impacts depend on the size and the location of the project and need to be determined on a case-to-case basis. The workforce requirement during the operational phase also depends on the size of the project. On average, about three workers are required to maintain a project. Available technologies can reduce the operational workforce requirements; however, the systems used in existing projects require some manual intervention.

Overall, conventional SHP projects use established technologies, and their development processes are well understood. Their CUFs are higher than those of solar energy, and supportive policies are in place. Instituting mechanisms to expedite clearances without compromising environmental and social norms, lease government-owned land to developers, and raise awareness among LSG institutions, cooperatives, and PSUs about the benefits and potential of SHP development can further accelerate growth in this sector.

Bioenergy: Biogas

- The bioenergy potential for Kerala is estimated at 778.41 MW (ASCI 2021). Although potential exists, bioenergy for electricity generation is not widely tapped in Kerala. The existing biomass cogeneration (non-bagasse) and waste-to-energy (off-grid) plants total only 2.5 MW. Most of the bioenergy is harnessed through smaller biogas plants, primarily as a substitute for cooking fuel. These plants are used in industrial establishments, communities, and by individual users. Although biogas plants have been in use in Kerala for the last 30 years, they have not witnessed large-scale uptake. Various schemes have been implemented by ANERT in Kerala, such as the Biogas State scheme and the Biogas MNRE Scheme (KSPB 2021). The Biogas State Scheme included portable and fixed 0.75–1 cubic meter biogas plants that utilized between 4 to 6 kg of biowaste. A subsidy of INR 8,000 was granted per house or institution (only one plant was allowed per house or institution). The Biogas MNRE Scheme included fixed 2–6 cubic meter biogas plants with subsidies ranging between INR 8,000 and 9,000 (KSPB 2021). The total number of biogas plants in Kerala is estimated at 1.54 lakhs (as of March 2023) (Statista 2024), with only 4,208 plants being installed over the last five years (2018–22) (PIB 2023).
- **Technical parameters:** These are relatively mature technologies (TRL 10). Project setup is simple and well understood. Conventional floating drum (FD) systems suffered from low gas pressure, leading to low-intensity flames. Hi-Tech FD systems were developed to tackle this issue. As of now, Hi-Tech FD biogas plants are widely used in Kerala. Their technology risk is estimated to be low.
- **Economic factors:** The O&M of biogas plants suffers from lack of proper maintenance and systems to dispose of the generated slurry. Slurry disposal locations are limited, and the price of slurry disposal systems is not considered in the design of the system. This has led to the closure of several biogas plants in Kerala. There are very few O&M service providers in Kerala, and availability of skilled labor is also an issue. The plants also suffer from the rising cost of raw materials, which has increased significantly over the last few years. This has led to the cost of biogas systems increasing from INR 12,000 to the present price of INR 24,000 for a 1 cubic meter plant with an input of about 1–2 kg. The uptake of biogas plants is subsidy driven, and the financial risk is low.
- **Resource availability:** Kerala's abundant biomatter ensures resource availability. Feed material is widely available from seasonal fruits and harvests. However, the quality and consistent supply of feed material is a challenge. Local manufacturing exists, with well-established supply chains and a high domestic share in components. The associated risks are low.
- **Policy and regulatory framework:** Only limited policies and schemes are available in Kerala. Subsidies were initially provided for biogas plants, which resulted in many new installations. ANERT provided subsidies for large-scale plants to be installed in panchayats (LSG bodies). Biogas plants, obtained from empaneled suppliers, were also distributed to panchayats through the Suchitwa mission. Even for larger plants, initial development occurs through government support, and once subsidies are received, the interest gradually diminishes, with maintenance being neglected, leading to the loss of the plant. Hence, the policy risks are on the high side.
- **Environmental and social impact:** There is general awareness about the technology. Also, as has been observed over the years, there is minimal likelihood of physical displacements or adverse impacts to local habitats when setting up biogas plants. Impacts on the ecosystem and land are low if slurry is safely disposed of (slurry can be converted to chemical-free fertilizers). Biogas plants generally contain GFRP components and concrete for the supporting structures, posing recycling challenges.

Overall, biogas plants can be deployed far more widely in Kerala. The issues related to maintenance and slurry disposal need to be addressed. The state can also consider refurbishing the existing plants.

Ocean: Wave energy

Ocean energy is derived from the ocean's movements or its physical and chemical state: waves, tides, currents, ocean temperature differences, and salinity gradients. The potential for ocean energy in India is large, with a 2014 study estimating the tidal power potential at 12,455 MW from parts of Gujarat, Tamil Nadu, and West Bengal (MNRE n.d.-a). Similarly, the wave energy potential along Indian coasts is estimated to be approximately 41,300 MW (MNRE n.d.-a), mainly from the western coast, including the Kerala coastline. Kerala's wave energy potential alone was identified to be approximately 4,900 MW (IREDA 2014). Currently, wave energy is not harnessed in Kerala, although the first and only pilot wave energy project in India (150 kW) was set up at Vizhinjam in Thiruvananthapuram district of Kerala in the 1990s. The project was later decommissioned in 2011.

- **Technical parameters:** Wave energy technology is in its large prototype and demonstration stage, with TRLs of 6–7. The technology is less mature than other RE technologies such as wind, solar, and SHP. Efficiencies can vary widely depending on the technology used. It is estimated that CUFs of about 15–30 percent are possible using this technology. The ease of setup varies depending on the technology used. Floating systems are easier to set up than fixed-shore systems. Wave energy systems need design optimization for local wave conditions. Also, off-the-shelf components cannot be used directly for developing new wave energy devices. Each design requires the manufacturer to invest in R&D, which increases costs and development timelines.

- **Economic factors:** Currently, project costs are estimated to be in the range of INR 20–30 crores per megawatt, which are higher than those of other onshore RE technologies such as wind, solar, and SHP, which are about INR 5–10 crores per megawatt. For cost reduction, projects can be planned with multiple systems sharing a common mooring infrastructure. Overall, scale-up is required for the technology to become cheaper. The O&M costs are also estimated to be high (INR 20–30 lakhs per megawatt). However, data from more projects are required to accurately estimate the overall costs. The financial risks are estimated to be high.
- **Resource availability:** The potential for harnessing wave energy in Kerala is large, mainly due to the consistency and power of the waves. Sites near Vizhinjam, in Trivandrum district, have locations with a high wave power of 25.08 kW/m (IREDA 2014). The potential for harnessing wave energy in Kerala is estimated as 4,900 MW. Domestic manufacturing facilities and supply chains need to be developed. The associated technological risks are medium.
- **Policies and regulatory framework:** A policy and regulatory ecosystem needs to be developed around wave energy in Kerala. Budgetary allocations are needed for resource assessment, data acquisition for baseline designs, and development of pilot projects.
- **Environmental and social impact:** Awareness is lacking and needs to be improved. More studies are required to understand the environmental and social impacts of the technology.

Overall, the technology has low TRLs with high capital costs. No policies are in place for the promotion of the technology, and interest from private players and the government is low. A working group could be formed to accelerate its development. Higher-capacity pilot projects could be developed to sensitize the government to the viability of the technology, leveraging the technical expertise of organizations such as the National Institute of Ocean Technology (NIOT). Budgetary allocations are also required.

Energy storage: BESS and PSH

Energy storage is crucial to expand RE and mitigate some of the associated challenges. Implementing energy storage systems is seen as a solution for grids with a high share of VRE to balance the grid and maintain stability. The technology can also help mitigate peak time shortages and meet the variations in electricity generation from RE due to daily weather changes. Studies estimate the energy storage requirement for Kerala to be 509 MWh and 953 MWh by 2027 and 2032, respectively (ISGF 2019).

The state government has acknowledged the importance of BESS in long-range resource planning under high VRE scenarios. A pilot 10 MW (20 MWh) BESS project in Kerala is under development (KSEBL n.d.-a). In September 2024, KSEBL also developed a proposal for setting up BESS projects at eight locations across Kerala with a combined capacity of 205 MW (*The Hindu* 2024b). KSEBL has also noted that BESS will be required in the public transport sector to manage uninterrupted overnight charging of e-buses and opportunity charging in transport depots (KSEBL n.d.-a).

PSH is another option for energy storage in Kerala, with an estimated potential of 4.4 GW (Amalnath 2017). Kerala currently has no active PSH projects. Nine potential sites, including those in Idukki (700 MW) and Pallivasal (600 MW) were identified by Tehri Hydro Development Corporation India Limited (THDCIL) and KSEBL. On the basis of certain criteria, KSEBL further shortlisted Manjappara (30 MW) on the Karappuzha reservoir in Wayanad district and Mudirapuzha (100 MW) on the Ponmudi reservoir in Idukki district for pilot PSH projects with an approximate cost of INR 180 crores and 573 crores, respectively (KSEBL 2024a).

- **Technical parameters:** Commercial BESS solutions generally utilize lithium ferro phosphate (LFP) or nickel-manganese-cobalt (NMC) chemistries. The efficiency of the available systems is 80–90 percent. The technologies are relatively mature (TRL 9) and easy to set up. Although battery technologies are mature, ancillary systems such as cooling and emergency management are a challenge for BESS. The auxiliary consumption is relatively higher than that for wind and solar, mainly due to the cooling requirements. Technologies for recycling BESS are under development. Containerized BESS systems are popular and are being actively deployed. These are modular and pre-packed containers that store and manage energy. The technology risks are medium. PSH is a mature technology (TRL 11) with high efficiencies of 70–80 percent. PSH projects are difficult to set up, due to the need for extensive tunneling and construction. The normal operating head is in the range of 90–630 m. The technology risks are low.

- **Economic factors:** The cost of industrial-scale BESS containerized solutions is estimated at US $350 per kilowatt-hour (INR 2.9 crores per megawatt-hour). The costs of BESS technologies have declined and are expected to decrease further. The O&M costs are dependent on the battery chemistry, energy discharge, and type of housing, but are estimated to be approximately 1 percent of the CAPEX. The financial risk for the technology is expected to be in the medium-to-high range.

The costs associated with PSH projects are similar to those for hydro power. Based on the construction cost of hydro projects in Kerala and other sources, the costs for PSH are expected to be in the range of INR 7–15 crores per megawatt. Low-head projects require large conduits and are less cost-effective than high-head projects (heads greater than 750 m). The O&M costs are estimated to be high, about 3–5 percent of the CAPEX. These costs are higher than those for wind and solar projects, but are comparable with those of hydro projects. The financial risk is medium.

- **Resource availability:** Kerala will need 953 MWh of energy storage systems by 2032. In the case of containerized systems, the domestic availability is limited because many of the systems currently in use are imported in knockdown condition and assembled from kits. Domestic manufacturing facilities and supply chains are being developed. Hence, the risk due to global supply chain disruptions is medium–high. The PSH potential is estimated at 4,400 MW, and nine sites have been identified. Indigenous technologies and suppliers are available. Projects with lower capacities can be developed indigenously, whereas in the case of large-capacity/high-head projects, components have to be imported. Overall, the risk due to global supply chain disruptions is low–medium.
- **Policy and regulatory framework:** Policies still need to be formulated for the integration of BESS into the state's energy mix. Certain storage purchase obligations are in force at the state level. Similar to the other technologies, there are no technology-specific grants or budgetary allocations for innovation and R&D in this area; however, KSEBL is planning to set up a pilot project. It is important for Kerala to develop regulations and guidelines on battery recycling and safe disposal. PSH-specific policies are not available at the state level. The state government has provided in-principle approval for the implementation of two PSH projects with a total capacity of 130 MW at an approximate cost of INR 753 crores (GoK 2024). Budgetary allocations are not available for R&D on the technology.
- **Environmental and social impact:** For BESS, there is limited awareness regarding the technology and its use. Although the threat of local habitat displacement is low, more studies are required to estimate the environmental impacts. Recycling and safe disposal are important aspects that need to be considered in order to prevent negative environmental impacts. The impacts on the land due to the mining of elements critical for BESS systems also need to be studied. There is awareness on PSH as an energy storage option. Setting up of PSH projects is labor intensive; however, for operations, the workforce requirements reduce to three workers per shift working three shifts a day. The impacts on land are high and depend on the storage capacity of the project. Initial PSH projects are being planned in government-owned land, using existing reservoirs to minimize social impacts, costs, and project timelines.

Kerala is in the process of expanding its energy storage capacity utilizing both BESS and PSH. Pilot projects are being developed. The use of decentralized BESS can be explored to manage peak demand and reduce the peak time charges borne by industries. For PSH, more studies are required to identify suitable sites and map the technology's potential.

Green hydrogen

Hydrogen, being an energy vector, is seen as an alternative that can be used for the storage and transport of energy. The hydrogen generated from RE sources is termed green hydrogen. The primary method of production utilizes biogas, a gaseous form of methane obtained from biomass; the secondary method uses electrolysis powered by energy generated from RE sources. This hydrogen can then be directly used as a fuel for transportation or for other industries that require hydrogen as an input material. It can also be used in a fuel cell to generate electricity.

Kerala has industries that currently use hydrogen for various processes and can therefore be substituted with green hydrogen. For example, Fertilizers and Chemicals Travancore (FACT) produces hydrogen-based fertilizers with a demand of 175 tonnes per day (TPD) of hydrogen, which is currently being met through steam reforming of methane (Umagine 2024a). Recent studies point to the projected demand for green hydrogen from Thiruvananthapuram district alone to be around 1,800 tonnes per year (Umagine 2024b). Kerala also plans to set up domestic manufacturing and export green hydrogen to international markets. It is planning to add more RE into the energy mix, necessitating energy storage options.

Kerala is in the process of developing its green hydrogen policy along with green hydrogen certification guidelines and standards. In February 2023, Kerala announced a grant of INR 200 crores for setting up green hydrogen hubs in Kochi and Thiruvananthapuram (GoK 2023a). In November 2023, Kerala approved a proposal by ANERT for setting up a center of excellence in green hydrogen and for developing green hydrogen pilot projects (GoK 2023b).

- **Technical parameters:** Currently, two types of electrolyzer technologies are commercially deployed for green hydrogen projects: alkaline fuel cell (AFC) and polymer electrolyte membrane (PEM). These are relatively mature technologies with efficiencies of 60–70 percent. PEM and AFC electrolyzers require about 50–55 kWh to produce 1 kg of hydrogen and use about 9 liters of freshwater. Water is also required for process cooling; hence, the cumulative water requirements could be higher. Studies are investigating the use of treated gray water and desalinated sea water to reduce the freshwater requirement. The uptime of electrolyzers depends on the type of RE resource that it is coupled to. Consequently, electrolyzers powered from the grid can have high uptime. Setting up such plants requires a skilled workforce, and the ease of setup is medium. Recycling technologies are still being developed, and the technology risk is medium.
- **Economic factors:** Although more data from actual projects are required, the CAPEX is expected to be in the range of $1,000–2,000 per kilowatt (INR 8.4–16.8 crores per megawatt). Studies estimated a cost of INR 6.2–11.6 crores per megawatt for the electrolyzer stack, with additional expenses for developing storage facilities to the tune of INR 65,000 per kg (Umagine 2024a). The O&M costs are 3–5 percent of the CAPEX. The financial risk is expected to be medium.
- **Resource availability:** Kerala can tap into its available RE potential to power green hydrogen projects. Electrolyzer manufacturing facilities and supply chains are being developed and need to be further strengthened. The resource risk is medium.
- **Policy and regulatory framework:** Kerala's Green Hydrogen policy is still in the draft stages. Budgetary allocations are available for promoting green hydrogen projects through technology development, studies, and demonstration projects. The policy risk is high.
- **Environmental and social impact:** Awareness of green hydrogen technologies needs to be improved. Although the impact on biodiversity and land is low, the impact on water resources needs to be further studied. Green hydrogen projects are expected to be sited near RE installations, which may lead to varying levels of water stress depending on the availability of freshwater in the area (Mongabay 2023). Other studies suggest that the water requirements for green hydrogen production can be effectively managed through efficient project siting and planning (Ramirez et al. 2023).

Kerala is promoting the development of green hydrogen. There are budgetary allocations for R&D, capacity-building, and pilots. Policies, standards, and guidelines are also being developed.

CONCLUSION

This working paper develops and deploys a TAF to explore various RE and supporting technologies for Kerala. Overall, onshore wind, RTS, land-based solar, floating solar, SHP, wave energy, biogas, BESS, PSH, and green hydrogen are some of the technologies that Kerala can focus on.

Land-based solar requires access to suitable land, especially in government-owned land and land held by government companies. Our TAF finds that floating solar projects are a suitable solar PV technology for the state, with a potential of at least 3 GW. Kerala could examine existing water bodies (reservoirs, lakes, ponds) for this purpose and consider leasing government-owned water bodies to minimize costs. However, more studies are needed to identify suitable locations, such as inland water bodies, freshwater reservoirs, and backwaters, and to accurately estimate the environmental and social impacts.

Considering the difficulties in procuring and accessing large tracts of land for setting up large-scale land-based solar projects, our TAF finds decentralized deployment of solar technology, such as RTS, to be a suitable technology for the state. Penetration of RTS in urban areas is restricted due to space constraints, the shadows of nearby buildings, and people staying in high-rise buildings and villa-type dwellings where the roof or common areas are not owned by a single party. Encouraging government buildings to adopt RTS could be an option.

Kerala has limited wind-rich sites. The existing wind projects in Kerala are land based, with small to medium capacities. This limitation, in addition to the prevailing business environment in Kerala, reduces developer interest in setting up new wind projects. Moreover, the logistics of transporting wind turbine components are a challenge due to the difficult topography and concentration of windy locations in select pockets of the state. Planning higher-capacity projects could improve developer interest in the projects and facilitate wind capacity additions in the state. To further improve the wind capacity, the state government might need to facilitate on-site wind measurements at more locations and make the data publicly available. Such data could help developers with site identification and project planning, which could improve their participation. Considering the difficulties in setting up large wind turbines, small wind energy can be explored as a possible option for Kerala.

Regarding SHP projects, about 276 MW of the identified 650 MW potential has been tapped. The new Small Hydro Policy, 2022, can help facilitate greater uptake by addressing many of the associated challenges. Newer technologies such as hydrokinetic systems can help further expand the SHP capacity in Kerala beyond the previously identified potential.

Kerala's bioenergy potential is estimated at 778.41 megawatts electric (MWe), but its actual utilization for electricity generation is minimal, small-scale biogas plants being the primary cooking fuel. Despite the mature technology of biogas systems and their low risks, challenges such as inadequate maintenance, limited slurry disposal options, and rising raw material costs hinder widespread adoption.

Green hydrogen is a current policy focus area for Kerala, which plans to set up green hydrogen valleys. It also plans to set up domestic manufacturing of green hydrogen and export it to other states and countries. Initially, the state could supply green hydrogen to domestic industries to replace gray hydrogen, which is currently used. PSH is a mature technology in Kerala. It has low risks and can support the use of RE. BESS can help the state reduce peak time charges. Innovative financial incentives and business models could help industries integrate BESS.

Sites near Vizhinjam in Trivandrum district are a hotspot for wave energy, with great potential due to the consistency and power of the waves. This potential, however, has not been widely recognized and utilized. Pilot projects to harness the available wave potential and the subsequent setting up of large-scale installations could help sensitize the government to the viability of the technology and pave the way for the requisite policies and ecosystem. The state government could consider collaborations between companies, state government bodies, and research institutes along with budgetary allocations for resource assessment, studies, and pilot projects.

Overall, this working paper has identified several technologies that have significant potential to help Kerala meet its RE goals and significantly accelerate its clean energy transition.

APPENDIX A: THE TECHNOLOGY ASSESSMENT FRAMEWORK (TAF) AND PRIORITIZATION OF TECHNOLOGIES

Table A1 | **The Technology Assessment Framework (TAF)**

				SCORING	TECHNOLOGY	COMMENTS
STEP 1	Prioritization	Resource potential	Is resource potential available in the state for deploying a particular renewable energy (RE) generation system?	Yes/no		
		Strategic needs	Are the RE source, RE generation system, and supporting technologies being prioritized or supported in the state for achieving any goals/targets?	Yes/no		
Considered for assessment under Step 2 if any two parameters are scored Yes						
	INDICATOR	**PARAMETER**	**METRIC**	**UNIT**		
STEP 2: ASSESSMENT	1. Technical parameters	Technical efficiency	Ratio of output to total input	%		
		Technological maturity	Technology Readiness Level[a]	TRL 1–11		
		Installation	Ease of setup[b]	Easy/medium/difficult		
		Operation				
			Workforce resource requirement	Skilled/semiskilled/unskilled		
			Electricity generation	Total units produced per megawatt (MW) per year		
			Capacity utilization factor (CUF)/plant load factor (PLF)	%		
			Auxiliary consumption	%		
		Recycling potential[c]	Recycling technology availability	Yes/no/limited		
		Technology risk	Due to a change in technology, upgrade, or obsolescence affecting the implementation, profitability, or viability of a project	High/medium/low		

INDICATOR	PARAMETER	METRIC	UNIT		
2. Economic factors	Cost				
		Capital expenditure (CAPEX)	INR/MW		
		Operations and management (O&M)[d]	INR/MW		
	Return on investment	Return on equity (ROE), internal rate of return (IRR)	%		
	Financial risk	Due to uncertainties related to project cost, revenue, market conditions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low		
3. Resource availability	RE resource	Availability of this particular RE resource in the state	High/medium/low		
	Domestic availability of equipment				
		Availability	Available/not available		
		Domestic share	% addition in the total value chain		
		Resource risk	Due to global supply chain disruption, internal trade restrictions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	
4. Policy and regulatory framework	Policies, laws, and regulations	Availability of policy and regulations (state specific)	Exists (yes/no)		
		Installation/capacity targets (state level)	Exists (yes/no)		
		Government budget allocation (state level)	Exists (yes/no)		
	Policy instruments				
		Price instruments	Generic tariff INR/unit		
		Renewable Purchase Obligation (RPO)	% of total consumption		

INDICATOR	PARAMETER	METRIC	UNIT		
	Innovation governance				
		Budget allocation for technology innovation or R&D (state specific)	Exists (yes/no)		
		Budget allocation for technology upgrade or refurbishment	Exists (yes/no)		
	Policy risk	Due to uncertainties or changes in policy, laws, or regulations affecting the implementation, profitability, or viability of a project	High/medium/low		
5. Environmental and social impact	Social acceptance	Awareness	Exists (yes/no)		
	Land acquisition	Physical displacement of local community or groups	Yes/no/partial		
	Number of potential beneficiaries	Direct and indirect beneficiaries	Number of persons		
	Job creation potential	Direct, indirect, full, part, induced jobs	Number of jobs		
	Impact on the ecosystem				
		Impact on biodiversity and marine ecosystem	High/medium/low		
		Impact on land	High/medium/low		
	Life cycle environmental impact	Greenhouse gas (GHG) emissions over the whole lifecycle; avoided emissions	g CO_2 equivalent per unit		
	Noise pollution	Sound levels	High/medium/low		
Other comments on the application of the technology for Kerala					

Notes:

a. TRLs are defined by the IEA on a scale of 1 to 11 (IEA 2020) (see Table A-3).

b. The ease of installation is quantified by comparison with the installation of well-understood and well-established RE installations such as wind and solar.

c. Resource potential is the availability of that particular RE resource in the state for supporting installations.

d. O&M costs are the expenses incurred while running a facility, such as a power plant, and include labor and materials costs.

Decommissioning a technology, recycling and its associated environmental impacts, aspects of circularity, and the disaster resilience of a technology have not been assessed in this study. The social costs and impacts of livelihood have also not been assessed in this study.

Qualitative parameters are recorded largely based on stakeholder feedback on the technology. Quantitative parameters are recorded based on stakeholder inputs and compared with available data from the literature. Where there are differences between the numbers, data from the literature are used and stakeholder inputs summarized in the comments. The authors have also used the comments column to provide clarifications and additional information.

Source: Literature review, stakeholder consultations, IEA 2016, and CSTEP 2021.

The renewable energy technologies assessed by this study include the following:

Energy technologies

- Wind energy technologies: Onshore, offshore, small wind
- Solar energy technologies: Land-based utility-scale photovoltaic (PV), rooftop solar, floating solar, concentrated solar power, solar heating and cooling
- Small hydro power (SHP): Run-of-the-river, canal/dam toe, hydrokinetic systems
- Bioenergy: Bagasse-based cogeneration, non-bagasse-based cogeneration, biomass, briquette pellet manufacturing, biogas
- Ocean: Wave, tidal, current, ocean thermal energy conversion (OTEC), salinity gradient
- Geothermal energy technologies

Supporting technologies and emerging industries

- Energy storage: Pumped storage hydropower (PSH) and battery energy storage systems (BESS)
- Green hydrogen

The technologies mentioned above are individually assessed through the framework. The detailed Step 2 assessment of a technology proceeds only after it clears Step 1, as shown in Table A-2. The technologies shortlisted for detailed analysis are wind: onshore wind; solar: land based, rooftop solar (RTS), floating photovoltaics (FPV); SHP: run-of-the-river, dam toe, hydrokinetic; bioenergy: biogas; ocean: wave energy; energy storage: BESS, PSH; and green hydrogen. Data from the detailed assessment of the prioritized technologies are provided in Appendix B.

Table A2 | **Prioritizing the technologies for further assessment (Step 1)**

	STEP 1: PRIORITIZATION			
WIND	**Renewable energy (RE) technology** RE technology and methods of harnessing RE technology	**Resource potential** Is resource potential available in the state for developing a particular RE generation option?	**Strategic needs** Are the RE source, RE generation system, or supporting technologies being prioritized or supported in the state for achieving any goals/ targets?	**Further assessment** Considered for assessment under Step 2 if any two parameters are scored Yes
	Onshore wind	Yes	Yes	Yes
	Offshore wind	Further studies required	Limited	No[a]
	Small wind	Further studies required	Limited	No[a]
SOLAR	Land-based photovoltaic (PV)	Yes	Yes	Yes
	Rooftop solar	Yes	Yes	Yes
	Floating solar	Yes	Yes	Yes
	Concentrated solar power (CSP)	Yes	No	No[b]
	Solar heating and cooling (SHC)	Yes	No	No[b]
SMALL HYDRO POWER (SHP)	Run-of-the-river	Yes	Yes	Yes
	Canal/dam toe	Yes	Yes	Yes
	Hydrokinetic	Yes	Yes	Yes
BIOENERGY	Bagasse cogeneration	No	No	No
	Biomass (non- bagasse cogeneration)	Yes	No	No[c]
	Briquette pellet manufacturing	No	No	No
	Biogas	Yes	Yes	Yes

	STEP 1: PRIORITIZATION			
OCEAN	Wave	Yes	No	Yes[d]
	Tidal	No	No	No[d]
	Current	No	No	No
	Ocean thermal energy conversion (OTEC)			
	Salinity gradient	No	No	No[e]
GEOTHERMAL		No	No	No
ENERGY STORAGE	BESS	Yes	Yes	Yes
	PSH	Yes	Yes	Yes
GREEN HYDROGEN		Yes	Yes	Yes

Note:

a. Assessment of offshore wind and small wind potential requires further studies; these technologies were not considered for the detailed assessment.

b. Although some studies report that CSP and SHC potential exists in the state, these two technologies are not considered for further analysis considering the limited success of previous installations and stakeholder inputs.

c. Although potential exists, the use of non-bagasse cogeneration is not prioritized, considering stakeholder inputs, the available potential, and other factors.

d. Some studies point to the potential of wave and tidal technologies; however, stakeholder consultations suggested that potential exists only for wave energy in Kerala. Hence, these technologies were not considered for further assessment.

e. Estimating the potential for salinity gradient technology requires further studies. Also, this technology is in the very early stages of development. Hence, it was not considered for the detailed analysis.

Source: Literature review and stakeholder consultations.

Table A3 | Technology Readiness Levels

CONCEPT	1	Initial idea	Basic principles have been defined.
	2	Application formulated	Concept and application of solution have been formulated.
	3	Concept needs validation	Solution needs to be prototyped and applied.
SMALL PROTOTYPE	4	Early prototype	Prototype has been proved in test conditions.
LARGE PROTOTYPE	5	Large prototype	Components have been proved in conditions to be deployed.
	6	Full prototype at scale	Prototype has been proved at scale in conditions to be deployed.
DEMONSTRATION	7	Pre-commercial demonstration	Solution is working under the expected conditions.
EARLY ADOPTION	8	First-of-a-kind commercial	Commercial demonstration, full-scale deployment in final form.
	9	Commercial operation in relevant environment	Solution is commercially available but needs evolutionary improvement to stay competitive.
	10	Integration needed at scale	Solution is commercial and competitive but needs further integration efforts.
MATURE	11	Proof of stability reached	Predictable growth.

Source: IEA 2020.

APPENDIX B: DETAILED ASSESSMENT OF THE PRIORITIZED RENEWABLE ENERGY TECHNOLOGIES FOR KERALA

Table B1 | **Wind: Land based (utility scale)**

				SCORING	TECHNOLOGY	COMMENTS
STEP 1	Prioritization	Resource potential	Is resource potential available in the state for deploying this particular renewable energy (RE) generation system?	Yes/no	Yes	
		Strategic needs	Are the RE source, RE generation system, or supporting technologies being prioritized or supported in the state for achieving any goals/targets?	Yes/no	Yes	
Considered for assessment under Step 2 if any two parameters are scored Yes.						
	INDICATOR	**PARAMETER**	**METRIC**	**UNIT**		
STEP 2: ASSESSMENT	1. Technical parameters	Technical efficiency	Ratio of output to total input	%	30–45	
		Technological maturity	Technology Readiness Level	TRL 1–11	9–10 Market uptake	
		Installation	Ease of setup	Easy/medium/difficult	Medium	For medium-to-higher-capacity turbines, transportation of parts to the potential locations will be an issue. Detailed road surveys will need to be conducted to estimate the maximum size of the turbine parts that can be transported.
		Operation				
			Workforce resource requirement	Skilled/semiskilled/unskilled	Skilled	Training on wind energy installations and the associated operations and maintenance (O&M) is lacking in Kerala. It is important to have a trained pool of operators for the successful installation and operation of wind power plants.
			Electricity generation	Total units produced per megawatt (MW) per year	15–25 lakh units per megawatt per year	The overall average annual generation for wind power plants in Kerala is about 19 lakh units per megawatt per year.
			Capacity utilization factor (CUF)/plant load factor (PLF)	%	20–30%	The overall average CUF for wind installations in Kerala is about 21%. More recent wind installations have CUFs of about 30%.

INDICATOR	PARAMETER	METRIC	UNIT		
		Auxiliary consumption	%	<1%	Compared to solar photovoltaics (PV), the auxiliary consumption is high. Also, higher-voltage transmission lines are required for wind power projects.
	Recycling potential	Recycling technology availability	Yes/no/limited	Limited	Limited recycling technology is available, but it is costly. However, turbines have a long life. Recycling the blade is a challenge; the feasibility of using the blade materials for tarring roads—and other similar use cases—needs to be explored.
	Technology risk	Due to a change in technology, upgrade, or obsolescence affecting the implementation, profitability, or viability of a project	High/medium/low	Low	Technological improvements will not create any risk, but disruptive technologies may introduce risks.

INDICATOR	PARAMETER	METRIC	UNIT		
2. Economic factors	Cost				
		Capital expenditure (CAPEX)	INR/MW	6–8.5 crores/MW	A major cost component involved in installation is transportation of wind components and operation charges of cranes used for installation. Viability requires five or more turbines to be installed in an identified area. According to stakeholder inputs, the contribution of land acquisition costs to project costs is higher in Kerala than in other states. Land acquisition requires about 40–50 lakhs/acre in Kerala, which is about 10 times higher when compared to other states. However, the land requirement for wind energy plants is slightly lower because only the plant's footprint needs to be acquired. The area for erecting one turbine is approximately 1–1.5 acre per turbine. On average, about 3.5 acres per megawatt is required for wind power plants.
		Operations and maintenance (O&M)	INR/MW	7.5–8.94 lakhs/MW	The cost escalation is about 5.72–7.5% per year.
	Return on investment	Return on equity (ROE), internal rate of return (IRR)	%	14% (ROE)	Usually, the debt-to-equity ratio is 70:30 with an interest rate of 8.65–9%.
	Financial risk	Due to uncertainties related to project cost, revenue, market conditions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	Low–high	The financial risks depend on the seller and the offtake arrangement.

INDICATOR	PARAMETER	METRIC	UNIT		
3. Resource availability	RE resource	Availability of this particular RE resource in the state	High/medium/low	Low–medium	In Kerala, wind resources are available in some pockets only. Turbines with a hub height of 120 m are used in Kerala. Installations with higher hub heights can be challenging due to various factors, such as logistics and land availability. Hence, project size is the major issue in Kerala. To attract external investors for wind power projects, higher capacities (50 to 100 MW) are required, but lower-capacity projects are being tendered in Kerala.
	Domestic availability of equipment				
		Availability	Available/not available	Available	Currently, cranes available in Kerala are suitable only for turbines with a hub height of 120 m.
		Domestic share	% addition in the total value chain	70–80%	Most of the components are available locally, including cables, electrical components, steel, etc. Local manufacturers are able to produce even new components within a few years.
		Resource risk	Due to global supply chain disruption, internal trade restrictions, etc., affecting the implementation, profitability, or viability of a project	Low	Excess capacity is available, but the pace of supply of turbines by original equipment manufacturers (OEMs) is slow (about 6–12 turbines/month). The waiting periods after placing an order is about 9 months, unlike solar, where modules are delivered within 30 days.
4. Policy and regulatory framework	Policies, laws, and regulations	Availability of policy and regulations (state specific)	Exists (yes/no)	Yes	Due to the lower capacity, viability gap funding (VGF) and the Inter State Transmission System (ISTS) are not possible.
		Installation/capacity targets (state level	Exists (yes/no)	No	Wind-specific targets have not been officially notified.
		Budget allocation (state level)	Exists (yes/no)	No	Most states do not have budgets for RE projects. Private investors are implementing wind energy projects. Because wind and solar technologies are stable, there is no subsidy support.
	Policy instruments				
		Price instruments	Generic tariff INR/unit	3.94 (generic tariff)	The generic tariff is INR 3.94/unit for wind projects of capacities less than 5 MW. The project-specific tariff is determined by the Inter State Transmission System (KSERC) for higher capacities.
		Renewable Purchase Obligation (RPO)	% of total consumption	0.67 (FY2025) 3.48 (FY2030)	The state specifies a non-solar RPO of 10.68% for FY2024.

INDICATOR	PARAMETER	METRIC	UNIT		
	Innovation governance				
		Budget allocation for technology innovation or R&D (state specific)	Exists (Yes/ no)	No	
		Budget allocation for technology upgrade or refurbishment	Exists (yes/ no)	No	
	Policy risk	Due to uncertainties or changes in policy, laws, or regulations affecting the implementation, profitability, or viability of a project	High/medium/ low	Medium–high	
5. Environmental and social impact	Social acceptance	Awareness	Exists (yes/ no)	Yes	Social acceptance is there in the state.
	Land acquisition	Physical displacement of local community or groups	Yes/no/partial	Partial	Projects and location specific.
	Number of potential beneficiaries	Direct and indirect beneficiaries	Number of persons	X	Difficult to assess due to the type of projects being developed in Kerala: grid-connected captive power producers (CPPs) and independent power producers (IPPs).
	Job creation potential	Direct, indirect, full, part, induced jobs	Number of jobs	X	More workers are required during implementation. Local employment benefits are about 10 workers per turbine during implementation and 1 worker per 2–3 turbines during operation.
	Impact on the ecosystem				
		Impact on biodiversity and marine ecosystem	High/medium/ low	Low	Studies are required on a project-specific basis to determine the impact precisely.
		Impact on land	High/medium/ low	Low	The foundation area is occupied; removing the foundation after its service life is difficult; technologies for recycling blades need to be developed. Overall, project-specific studies are required to determine the environmental and social impacts and understand mitigation measures.
	Life cycle environmental impact	Greenhouse gas (GHG) emissions over the whole lifecycle; avoided emissions	g CO_2 equivalent per unit	34.1 g CO_2/kWh (whole lifecycle)	0.823 tonnes of carbon dioxide per megawatt-hour (t CO_2/MWh) (avoided emissions) is generally reported when using RE sources.
	Noise pollution	Sound levels	High/medium/ low	Low	Not very high (within the pollution control board's standards). These levels are usually specified in the wind turbine data sheet.

Any other comments on the application of the technology for Kerala

To further expand wind energy in Kerala, there is a need to improve the transmission infrastructure, which can promote more interstate power exchanges. The logistics of transporting wind turbine blades to remote locations is also a challenge. The state can be proactive in supporting the adoption of new technologies. Small wind turbines and hybrid systems can be explored for Kerala, considering the challenges with large wind.

Note: X = data not available or collected.

Sources: Literature review and stakeholder consultations; CEA 2023; EPA 2013; IEA 2024; Bennun et al. 2021; KSEBL 2023; KSERC 2018, 2020, 2022; MNRE n.d.-b; *The Hindu* 2024c; WINDExchange n.d.; Xie et al. 2020.

Table B2 | **Solar: Land based (utility scale)**

				SCORING	TECHNOLOGY	COMMENTS
STEP 1	Prioritization	Resource potential	Is resource potential available in the state for deploying this particular renewable energy (RE) generation system?	Yes/no	Yes 41.8 gigawatts (GW)	
		Strategic needs	Are the RE source, RE generation system, or supporting technologies being prioritized or supported in the state for achieving any goals/targets?	Yes/no	Yes	
Considered for assessment under Step 2 if any two parameters are scored Yes.						
	INDICATOR	**PARAMETER**	**METRIC**	**UNIT**		
STEP 2: ASSESSMENT	1. Technical parameters	Technical efficiency	Ratio of output to total input	%	19–24%	Bifacial solar photovoltaic (PV) modules available in the market usually have higher efficiencies, which can be further improved if reflected light is available and by using trackers. The quality of certain modules available in the market is a concern due to efficiency drops.
		Technological maturity	Technology Readiness Level	TRL 1–11	9–10 Market uptake	
		Installation	Ease of setup	Easy/ medium/ difficult	Easy–medium	Land is difficult to procure due to limited availability and high cost. The distribution system in Kerala is not strong enough to absorb electricity from large solar power plants. The state is more suited to distributed RE (DRE) solar systems, where land from the owners can be leased out, minimizing the need for displacement of people or change in land ownership.
		Operation				
			Workforce resource requirement	Skilled/ semiskilled/ unskilled	Skilled	The initial installation is a labor-intensive process. However, now, due to the availability of remote monitoring systems (RMSs), the plant's operational requirements have reduced from the initial 2 workers/megawatt (MW) to about 2 workers/5 MW. Automated operation is usually possible for solar power plants. A skilled workforce with specialized training is needed. The Industrial Training Institutes (ITIs) can train and create a workforce for solar plants.
			Electricity generation	Total units produced per megawatt (MW) per year	12–18 lakh units per megawatt per year	The use of trackers increases generation by 7–8% but also raises costs. However, 60–70% of the solar project cost is from modules, and in many cases, it is viable to install trackers.

INDICATOR	PARAMETER	METRIC	UNIT		
		Capacity utilization factor (CUF)/plant load factor (PLF)	%	13–21	The overall average CUF for wind installations in Kerala is about 21%. More recent wind installations have CUFs of about 30%.
		Auxiliary consumption	%	0.25	Compared to solar photovoltaics (PV), the auxiliary consumption is high. Also, higher-voltage transmission lines are required for wind power projects.
	Recycling potential[c]	Recycling technology availability	Yes/no/limited	Limited	Recycling technologies are still being developed.
	Technology risk	Due to a change in technology, upgrade, or obsolescence affecting the implementation, profitability, or viability of a project	High/medium/low	Low	Panel costs are decreasing with time.

INDICATOR	PARAMETER	METRIC	UNIT		
2. Economic factors	Cost				
		Capital expenditure (CAPEX)	INR/MW	4.5–5	For projects of capacities 5–10 MW, the CAPEX is about 4.5–5 crores/MW. For larger installations, the cost will decrease. Module cost is high in Kerala because low volumes or capacities are purchased.
		Operations and maintenance (O&M)	INR/MW	3–6 lakhs/MW	For projects outside Kerala, the O&M cost is about INR 2 lakhs/MW for large installations. However, in Kerala, the cost is higher at INR 3 lakhs/MW for larger projects and INR 4.5 lakhs/MW for lower-capacity projects. The cost escalation is estimated at about 5% per year.
	Return on investment	Return on equity (ROE), internal rate of return (IRR)	%	14% (ROE)	Usually, the debt-to-equity ratio is 70:30 with an interest rate of 8.65–9%.
	Financial risk	Due to uncertainties related to project cost, revenue, market conditions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	Low–high	The financial risks to developers and lenders depend largely on the power offtake arrangement and the financial condition of the procuring party.

INDICATOR	PARAMETER	METRIC	UNIT		
3. Resource availability	RE resource	Availability of this particular RE resource in the state	High/medium/low	Low–medium	Kerala's cloudy weather sometimes limits the available irradiation.
	Domestic availability of equipment				
		Availability	Available/not available	Available	
		Domestic share	% addition in the total value chain	X	Solar modules are manufactured domestically. Cell-manufacturing facilities are being developed in India. Most of the cells are currently being imported.
	Resource risk	Due to global supply chain disruption, internal trade restrictions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	Low	Manufacturing is expanding to countries other than China. India is also increasing its module-manufacturing capacity. Hence, availability of modules is not an issue and may not be a concern going forward. However, the major issue would be the module cost of Indian-made modules, which is higher than that of imported modules.
4. Policy and regulatory framework	Policies, laws, and regulations	Availability of policy and regulations (state specific)	Exists (yes/no)	Yes	
		Installation/capacity targets (state level	Exists (yes/no)	No	
		Budget allocation (state level)	Exists (yes/no)	No	
		Price instruments	Generic tariff INR/unit	INR 3.23–3.91/unit (generic tariff)	The generic tariff is available for smaller-capacity plants. Project-specific tariffs are determined by the Kerala State Electricity Regulatory Commission (KSERC) for capacities higher than 0.5 MW.
		Renewable Purchase Obligation (RPO)	% of total consumption	10.5%	The state specifies a non-solar RPO of 10.68% for FY2024.
	Innovation governance				
		Budget allocation for technology innovation or R&D (state specific)	Exists (Yes/no)	No	
		Budget allocation for technology upgrade or refurbishment	Exists (yes/no)	X	
	Policy risk	Due to uncertainties or changes in policy, laws, or regulations affecting the implementation, profitability, or viability of a project	High/medium/low	Medium–high	In Kerala, the power purchase agreement (PPA) is signed after the KSERC notifies the tariff, which increases the project risks. Workable payment security mechanisms are also required.

INDICATOR	PARAMETER	METRIC	UNIT		
5. Environmental and social impact	Social acceptance	Awareness	Yes/no/partial	Yes	There is social awareness and acceptance, but financial constraints hinder project implementation.
	Land acquisition	Physical displacement of the local habitat	Yes/no/partial	Partially	Projects and location specific.
	Number of potential beneficiaries	Direct and indirect beneficiaries	Number of persons	X	
	Job creation potential	Direct, indirect, full, part, induced jobs	Number of jobs	X	Around 1–2 workers are required for project capacities in the range of 1–5 MW.
	Impact on the ecosystem				
		Impact on biodiversity and marine ecosystem	High/medium/low	Low	Humans are not affected, but the natural habitat of the area could sometimes be affected. For example, animals living in burrows are affected due to land heating. Water is needed to clean the panels, which can be an issue in areas with low water availability.
		Impact on land	High/medium/low	Low	The solar panel can be easily removed after the project is completed. The environmental impact will stem from the need for module recycling.
	Life cycle environmental impact	Greenhouse gas (GHG) emissions over the whole lifecycle; avoided emissions	Grams of carbon dioxide (g CO_2) equivalent per unit	49.9 grams per kilowatt-hour (g/kWh) (whole lifecycle)	0.823 tonnes of carbon dioxide per megawatt-hour (t CO_2 per MWh) (avoided emissions) is generally reported when using RE sources.
	Noise pollution	Sound levels	Low/medium/high	Low	Not very high (within the pollution control board's standards). These levels are usually specified in the wind turbine data sheet.

Any other comments on the application of the technology for Kerala

Currently, the process of setting up a project starts with the developer applying to the Agency for New and Renewable Energy Research and Technology (ANERT) or state nodal agency for the subsidy. The subsidies are provided to the supplier. It would be better if benefits are provided directly to the beneficiary. Also, there is a need to relook at the actual cost estimates provided by the nodal agencies because the costs tend to be higher due to the time required for subsidies to reach the installer. To attract investment for setting up projects in Kerala, the project sizes should be in the range of 100–200 MW. However, the project sizes coming up in the state are lower. Even for rooftop solar (RTS) projects, larger-capacity projects are coming up in other states, with capacities of 200–300 MW. Ease of doing business and speed of project implementation are issues in Kerala. Unused government land can be used for SPV projects.

Notes: SPV = solar photovoltaic. X = data not available or collected.

Source: Literature review and stakeholder consultations; GoK 2013; IEA 2024; KSEBL 2023; *The Hindu* 2024a.

Table B3 | **Solar: Rooftop solar**

				SCORING	TECHNOLOGY	COMMENTS
STEP 1	Prioritization	Resource potential	Is resource potential available in the state for deploying this particular renewable energy (RE) generation system?	Yes/no	Yes	
		Strategic needs	Are the RE source, RE generation system, or supporting technologies being prioritized or supported in state for achieving any goals/ targets?	Yes/no	Yes	
Considered for assessment under Step 2 if any two parameters are scored Yes.						
	INDICATOR	**PARAMETER**	**METRIC**	**UNIT**		
STEP 2: ASSESSMENT	1. Technical parameters	Technical efficiency	Ratio of output to total input	%	19–24%	The Ministry of New and Renewable Energy (MNRE) guidelines specified a minimum efficiency requirement of 20% for RTS and 21% for ground-mounted solar. This is a top-down approach, and these efficiency numbers are yet to be seen in the field.
		Technological maturity	Technology Readiness Level[a]	TRL 1–11	9–10 Market uptake	After-sales service is an issue in Kerala. Supplied modules sometimes do not deliver the expected output. Also, if the manufacturer discontinues certain module types, module replacement will be affected. Inverter suppliers have a limited service network. Also, inverters need to be sent to China for repairs. Post-sales barriers in Kerala are a significant obstacle.
		Installation	Ease of setup	Easy/ medium/ difficult	Easy	Entry barriers to the solar business are low. However, mechanisms for quality check and control can be further strengthened. Programs need to be promoted for QC training and vendor rating.
		Operation				
			Workforce resource requirement	Skilled/ semiskilled/ unskilled	Skilled	There is low availability of skilled workers in Kerala, and the available workers have limited knowledge of various aspects of solar installation and maintenance. Initial efforts under the Suryamitra skill development program resulted in a pool of skilled workers. However, the state has not been able to retain or increase this pool of trained workers, mainly because the Suryamitra program is not recognized by the state when considering job applicants, reducing the interest of potential candidates.

INDICATOR	PARAMETER	METRIC	UNIT		
		Electricity generation	Total units produced per megawatt (MW) per year	9–15 lakh units per megawatt per year	The electricity generated depends on the locations and type of installation. Currently, one-year banking is available, but this facility is being slowly reduced and withdrawn in other states and may be withdrawn in Kerala too in the near future. On average, approximately 2.3 units per kilowatt per day of generation is calculated for all the RTS plants in Kerala, from stakeholder inputs.
		Capacity utilization factor (CUF)/plant load factor (PLF)	%	11–18%	For all practical purposes, the CUF of well-maintained RTS plants with crystalline technology in Kerala is about 16–17%. Higher CUFs are possible with the newer modules incorporating newer technologies. Also, a high grid uptime of 97% is observed in Kerala.
		Auxiliary consumption	%	<0.25%	Negligible.
	Recycling potential	Recycling technology availability	Yes/no/limited	Limited	
	Technology risk	Due to a change in technology, upgrade, or obsolescence affecting the implementation, profitability, or viability of a project	High/medium/low	Low	
2. Economic factors	Cost				
		Capital expenditure (CAPEX)	INR/megawatt (MW)	55,000–60,000/kW	The price per kilowatt is at affordable levels in Kerala. It has come down to 1/10th of the initial levels due to the presence of more players and manufacturers. Also, more features and add-on benefits are provided by manufacturers, such as plant monitoring. About 400 agencies are active in Kerala. The cost per kilowatt in Kerala, about INR 60,000/kW, is higher than that of other states. The benchmark costs of grid-connected RTS power plants, as notified by the MNRE, are in the range of 45,000–54,000/kW (FY2020), 36,000–54,000 (FY2021), and 40,838–53,398/kW (FY2023).
		Operations and maintenance (O&M)	INR/MW	X	No maintenance is carried out on RTS plants after their installation. The scope of O&M work is often unclear in many RTS use cases.
	Return on investment	Return on equity (ROE), internal rate of return (IRR)	%	X	
	Financial risk	Due to uncertainties related to project cost, revenue, market conditions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	Low	The technology is mature, and the policy is well written. Further improvements are anticipated.

INDICATOR	PARAMETER	METRIC	UNIT		
3. Resource availability	RE resource	Availability of this particular RE resource in the state	High/medium/low	Medium–high	Upskilling of technicians is required.
	Domestic availability of equipment				
		Availability	Available/not available	Available	No scarcity of material and equipment
		Domestic share	% addition in the total value chain	X	
	Resource risk	Due to global supply chain disruption, internal trade restrictions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	Low	
4. Policy and regulatory framework	Policies, laws, and regulations	Availability of policy and regulations (state specific)	Exists (yes/no)	Yes	Policies and regulations are in place but need to be improved. Regulations must keep pace with the rapid advances in technology.
		Installation/capacity targets (state level)	Exists (yes/no)	No	The Renewable Purchase Obligation (RPO) trajectory is in place. However, the state's solar policy is 10 years old and needs to be updated.
		Budget allocation (state level)	Exists (yes/no)	No	
		Price instruments	Generic tariff INR/unit	INR 3.1/unit	A feed-in tariff (FiT) of about INR 3.1/unit is applicable under net metering arrangements as determined by the Kerala State Electricity Regulatory Commission (KSERC).
		Renewable Purchase Obligation (RPO)	% of total consumption	10.5%	The Ministry of Power (MoP) has specified an RPO to be met from a distributed renewable energy (DRE) source to the tune of 1.5% for FY2025, increasing to 4.5% by FY2030.
	Innovation governance				
		Budget allocation for technology innovation or R&D (state specific)	Exists (Yes/no)	No	In general, limited grants are provided for clean energy initiatives by different government organizations. Technology-specific grants are not available.
		Budget allocation for technology upgrade or refurbishment	Exists (yes/no)	X	
	Policy risk	Due to uncertainties or changes in policy, laws, or regulations affecting the implementation, profitability, or viability of a project	High/medium/low	Medium–high	

INDICATOR	PARAMETER	METRIC	UNIT		
5. Environmental and social impact	Social acceptance	Awareness	Yes/no/partial	Yes	In general, overall awareness of solar technology is good in Kerala.
	Land acquisition	Physical displacement of the local habitat	Yes/no/partial	No	
	Number of potential beneficiaries	Direct and indirect beneficiaries	Number of persons	X	
	Job creation potential	Direct, indirect, full, part, induced jobs	Number of jobs	X	Around 1–2 workers are required for project capacities in the range of 1–5 MW.
	Impact on the ecosystem				
		Impact on biodiversity and marine ecosystem	High/medium/low	Low	
		Impact on land	High/medium/low	Low	
	Life cycle environmental impact	Greenhouse gas (GHG) emissions over the whole lifecycle; avoided emissions	Grams of carbon dioxide (g CO_2) equivalent per unit	49.9 grams per kilowatt-hour (g/kWh) (whole lifecycle)	0.823 tonnes of carbon dioxide per megawatt-hour (t CO_2 per MWh) (avoided emissions) is generally reported when using RE sources.
	Noise pollution	Sound levels	Low/medium/high	Low	

The penetration of RTS in urban areas faces challenges because people stay in high-rise buildings and villa-type dwellings, where the roof or common areas are not owned by a single party. According to previous norms, the effective transformer capacity available for connections was limited to 67% of the actual capacity, which has now been enhanced to 90% of the transformer capacity. There are also policy barriers, and implementation of smart metering is not being actively promoted. Additionally, petitions have been filed to change the existing guidelines, and if they are adopted, the uptake of RTS in the state would be further decreased. Some of these changes include partially shifting infrastructure upgrade responsibilities to the consumer and implementing stricter guidelines for testing.

Kerala is one of the leading states for RTS adoption in the country. The PM Surya Ghar Yojana is expected to further accelerate this adoption. Kerala ranks third in installation of RTS projects under PM Surya Ghar, with 5,270 installations as of May 2024. However, the challenge in this sector includes capping of feasibility on reaching out to the low-consuming category of the society, nonavailability of strong rooftops to install solar panels, etc. In collaboration with local self-governments bodies, this can be achieved by installing solar panels in a common place. However, the regulator needs to issue a notification regarding virtual net metering in the state.

Note: X = data not available or collected.

Sources: Literature review and stakeholder consultations; IEA 2024; KSEBL 2023, 2024b; Ranjan 2021; Nugent and Sovacool 2014; TANGEDCO n.d.

Table B4 | **Solar: Floating photovoltaics**

				SCORING	TECHNOLOGY	COMMENTS
STEP 1	Prioritization	Resource potential	Is resource potential available in the state for deploying this particular renewable energy (RE) generation system?	Yes/no	Yes	
		Strategic needs	Are the RE source, RE generation system, or supporting technologies being prioritized or supported in state for achieving any goals/ targets?	Yes/no	Yes	The Kerala government has constituted a high-level committee for setting up floating solar in the state.
Considered for assessment under Step 2 if any two parameters are scored Yes.						
	INDICATOR	PARAMETER	METRIC	UNIT		
STEP 2: ASSESSMENT	1. Technical parameters	Technical efficiency	Ratio of output to total input	%	19–24%	Bifacial-type solar panels are recommended for FPV, mainly due to their performance and warranty aspects. FPV plants are more efficient than ground-mounted projects.
		Technological maturity	Technology Readiness Level	TRL 1–11	8 Demon-stration	The technology is not yet fully mature. The cost of newer technological systems may be high. The appropriate technology is needed for large-scale plants. To adopt a suitable technology, more parameters need to be considered, such as site-specific wind, wave, and currents.
		Installation	Ease of setup	Easy/ medium/ difficult	Easy	Apart from issues with the anchoring and mooring systems, installation is not that difficult.
		Operation				
			Workforce resource requirement	Skilled/ semiskilled/ unskilled	X	In most cases, FPVs are situated in non-dusty environments, but bird droppings are an issue. Therefore, one cleaning cycle/ month is required. Automated sprinkler systems and robotic systems are available for this. For cleaning and maintenance, workers who can operate in water bodies are required. Strict adherence to safety precautions is required. Precautions need to be observed regarding the exposure of electrical connections to water, rusting of metal parts, and salt deposition.
			Electricity generation	Total units produced per megawatt (MW) per year	12–18 lakh units per year per megawatt	

INDICATOR	PARAMETER	METRIC	UNIT		
		Capacity utilization factor (CUF)/plant load factor (PLF)	%	14–25.11	Higher CUFs are estimated for the recently commissioned NTPC Kayamkulam FPV.
		Auxiliary consumption	%	<0.25%	Negligible.
	Recycling potential	Availability of recycling technology	Yes/no/ limited	Limited	Floats are recyclable, and recycling technologies for other components are being developed.
	Technology risk	Due to a change in technology, upgrade, or obsolescence affecting the implementation, profitability, or viability of a project	High/ medium/ low	Low	
2. Economic factors	Cost				
		Capital expenditure (CAPEX)	INR/ megawatt (MW)	X	The cost is site specific, depending on the location, water depth, etc. It can vary significantly and is usually estimated at between 4.8 crores per megawatt peak (MWp) to 8 crores per MWp. Water bodies can be used at low cost. The lease model is usually adopted for FPVs.
		Operations and maintenance (O&M)	INR/MW	X	1.5 lakhs to 3 lakhs per megawatt
	Return on investment	Return on equity (ROE), internal rate of return (IRR)	%	14% (ROE)	For all practical purposes, the ROE will be lower. However, a clearer picture will emerge after commercial operation of a number of plants for a few years.
	Financial risk	Due to uncertainties related to project cost, revenue, market conditions, etc., affecting the implementation, profitability, or viability of a project	High/ medium/low	High	The technology is mature, and the policy is well written. Further improvements are anticipated.
3. Resource availability	RE resource	Availability of this particular RE resource in the state	High/ medium/low	High–medium	
	Resource utilization	Energy input/auxiliary consumption	Watt-hours per day (Wh/day); kilowatt-hours per month (kWh/ month); joules		

INDICATOR	PARAMETER	METRIC	UNIT		
Domestic availability of equipment					
	Availability	Available/not available	Available		
	Domestic share	% addition in the total value chain	X		
Resource risk	Due to global supply chain disruption, internal trade restrictions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	Low		
4. Policy and regulatory framework	Policies, laws, and regulations	Availability of policy and regulations (state specific)	Exists (yes/no)	No	The state is in the process of finalizing its power policy, which contains provisions for promoting floating solar.
		Installation/capacity targets (state level	Exists (yes/no)	No	The state has set overall RE targets; however, the contribution from FPV is unclear.
		Budget allocation (state level)	Exists (yes/no)	No	
	Policy instruments				
		Price instruments	Generic tariff INR/unit	X	Project-specific tariffs determined by the Kerala State Electricity Regulatory Commission (KSERC) are generally applied. For a recently commissioned FPV project by NTPC at Kayamkulam, the tariff was INR 2.94/unit.
		Renewable Purchase Obligation (RPO)	% of total consumption	10.5%	The state has specified a solar RPO of 10.5% for FY2024.
	Innovation governance				
		Budget allocation for technology innovation/R&D (state specific)	(Yes/no)	No	In general, limited grants are provided for clean energy initiatives by different government organizations. Technology-specific grants are not available.
		Budget allocation for technology upgrade or refurbishment	(Yes/no)	X	
	Policy risk	Due to uncertainties or changes in policy, laws, or regulations affecting the implementation, profitability, or viability of a project	High/medium/low	Medium	

INDICATOR	PARAMETER	METRIC	UNIT		
5. Environmental and social impact	Social acceptance	Awareness	Yes/no/partial	Partial	
	Land acquisition	Physical displacement of the local habitat	Yes/no/partial	No	
	Number of potential beneficiaries	Direct and indirect beneficiaries	Number of persons	X	
	Job creation potential	Direct, indirect, full, part, induced jobs	Number of jobs	X	Around 1–2 workers are required for project capacities in the range of 1–5 MW.
	Impact on the ecosystem				
		Impact on biodiversity and marine ecosystem	High/medium/low	Low	
		Impact on land	High/medium/low	Low	
	Life cycle environmental impact	Greenhouse gas (GHG) emissions over the whole lifecycle; avoided emissions	Grams of carbon dioxide (g CO_2) equivalent per unit	49.9 grams per kilowatt-hour (g/kWh) (whole lifecycle)	0.823 tonnes of carbon dioxide per megawatt-hour (t CO_2 per MWh) (avoided emissions) is generally reported when using RE sources.
	Noise pollution	Sound levels	Low/medium/high	Low	
Limitations regarding the availability of land can be overcome with FPV. Two projects are underway in Kerala, but the progress is very slow. The Cochin International Airport (CIAL) has identified 15 water bodies. A conservative estimate suggests a potential of 3 GW for FPV in the inland water bodies of Kerala, such as freshwater reservoirs, backwaters, and paddy fields. Offshore FSPV presents difficult challenges. The required modular structures and rigid structures increase the overall CAPEX. Further, the cost of the evacuation infrastructure increases the project costs. Much potential is available in Kerala, but detailed feasibility studies are required. The locations selected for the Kerala State Electricity Board Limited's (KSEBL's) tender were not so suitable for FPV. Some of the identified sites present challenges such as wildlife issues, especially elephant crossings; high water flow; and changes in water level. Hence, site selection is key for successful FPV in Kerala. Stakeholders are of the opinion that the draft floating solar policy of the state, which is under development, focuses on artificial water resources and government-owned water bodies (dams, etc.).					

Note: X = data not available or collected.

Sources: Literature review and stakeholder consultations; Fernandes and Sharma 2023; IEA 2024; Koundal 2022; KSEBL 2023; PIB 2024b.

Table B5 | **Small hydro power**

				SCORING	RUN-OF-THE-RIVER (ROR) (ON-GRID/ DISTRIBUTED RENEWAL ENERGY [DRE])	CANAL/ DAM TOE (ON-GRID/ DRE)	HYDROKINETIC SYSTEMS (ON-GRID/DRE)	
STEP 1	Prioritization	Resource potential	Is resource potential available in the state for deploying this particular renewable energy (RE) generation system?	Yes/no	Yes 0.7 gigawatts (GW)	Yes	Yes	
		Strategic needs	Are the RE source, RE generation system, or supporting technologies being prioritized or supported in state for achieving any goals/targets?	Yes/no	Yes	Yes	Yes 3 megawatt (MW) target	
Considered for assessment under Step 2 if any two parameters are scored Yes.								
	INDICATOR	PARAMETER	METRIC	UNIT				
STEP 2: ASSESS-MENT	1. Technical parameters	Technical efficiency	Ratio of output to total input	%	73–88%	73–88%	40–48%	Most SHP projects in Kerala are ROR type with maximum efficiencies in the range of 70–80%. Canal and dam toe systems are restricted to government utilities. A few screw-type projects are also being developed, and there is potential for screw-type projects in both ROR and canal drop applications.
		Technological maturity	Technology Readiness Level	TRL 1–11	11 Mature	11 Mature	6–8 Full prototype to commercial operation	ROR systems are a proven technology, and manufacturers are present in India. Hydrokinetic systems are in the early stages of maturity with higher costs.

INDICATOR	PARAMETER	METRIC	UNIT				
	Installation	Ease of setup	1-Easy, 2-medium 3-difficult	Easy–medium	Easy–medium	Easy	This depends on the size of the project. For larger-capacity projects, bigger machines are required, increasing the complexity and cost. More than the technical difficulty of setting up the projects, a major barrier and cause of delays is the difficulty in obtaining the required approvals from the various departments for setting up the projects. Once these are obtained, installation is not a challenge. Hydrokinetic systems are easier to install than other technologies due to their smaller capacities and technical and operational parameters.
	Operation						
		Workforce resource requirement	Skilled, semiskilled, unskilled	Skilled, semiskilled	Skilled, semi skilled	Skilled, semiskilled	The workforce must include workers with the required technical skills as well as semiskilled personnel.
		Electricity generation	Total units produced per megawatt per year	30 lakh units per megawatt per year	30 lakh units per megawatt per year	X	This depends on water availability. Projects in northern India will have higher values than those in Kerala due to continuous water availability. In Kerala, water availability is more seasonal.
		Capacity utilization factor (CUF)/ plant load factor (PLF)	%	33%	33%	X	Overall, CUFs of about 30% are observed. ROR projects and dam toe projects have CUFs of 30–35%. Irrigation-based canal projects have slightly lower CUFs (31%) due to periodic availability of water. Due to the new technology and early stages of maturity, the efficiencies of hydrokinetic systems are lower (30%).
		Auxiliary consumption	%	1%	1%	X	For hydrokinetic systems, more data are required to accurately estimate this aspect, but it is estimated to be similar to that of other SHP technologies. .
	Recycling potential	Recycling technology availability	Yes/no/limited	Yes	Yes	Yes	Other than the civil works carried out, recycling is possible for projects. For hydrokinetic systems, reuse/ recycling feasibility depends on the material of the blade used.

INDICATOR	PARAMETER	METRIC	UNIT				
	Technology risk	Due to a change in technology, upgrade, or obsolescence affecting the implementation, profitability, or viability of a project	High/medium/low	Low	Low	Medium	
2. Economic factors	Cost						
		Capital expenditure (CAPEX)	INR/MW	7.8–9 crores/MW	7.8–9 crores/MW	15–46 crores/MW	In general, the project cost ranges from 7.8 to 9 crores/MW. The state has also seen higher project costs of 15 crores/MW for projects developed by the state utility. An SHP project set up by the Cochin International Airport (CIAL) cost 13 crores/MW. Overall, the average prices are about 10 crores/MW. In the case of hydrokinetic turbines, the costs can vary significantly, depending on the technologies chosen and percentage of indigenization of components. Land prices are generally high in Kerala, with prices of INR 40 lakhs/acre. However, prices are highly site-specific and vary significantly. The problem is that even in remote locations, the land price is hiked by sellers after they learn that the land is needed to set up SHP projects. Leasing land from the forest department offers developers a low-cost alternative to land acquisition. However, in this case, there is the added risk associated with getting clearances, which takes 7–10 years, which increases the project costs. In case of hydrokinetic turbines, the land requirement is minimal for control rooms, etc.
		Operations and maintenance (O&M)	INR/MW	26–36 lakhs/MW	26–36 lakhs/MW	X	First-year O&M costs are about 25 lakhs/MW and increase by about 5–6%. About 15% of this is spent on spares and consumables and the rest on insurance, the workforce, etc. Hydrokinetic systems have higher O&M costs due to their lower capacities; however, more studies and data from actual projects are required before a firm conclusion can be drawn.

INDICATOR	PARAMETER	METRIC	UNIT				
	Return on investment	Return on equity (ROE), internal rate of return (IRR)	%	14% (ROE)	14% (ROE)	X	Aggregation of loans, loan availability with more flexible terms, and the possibility of external funds with better terms can make projects profitable. Viability gap funding (VGF) or governmental assistance can help. Hydrokinetic systems have good potential, but their CUF is low.
	Financial risk	Due to uncertainties related to project cost, revenue, market conditions, etc., affecting the implementation, profitability, or viability of a project	High/medium/ low	Medium	Low	Medi um–high	For ROR, the risk is higher due to delays in getting clearances and the expenses incurred during this waiting period for maintaining a basic staff, etc. For dam toe projects, the risk is low because the land and the dam are already available. Also, controlled discharge is available for dam toe projects; hence, the PLF is high. Risks are higher for hydrokinetic systems, because it is a newer technology, and data are limited.
3. Resource availability	RE resource	Availability of this particular RE resource in the state	High/medium/ low	High	High	X	More studies are required to assess the potential of hydrokinetic turbines.
	Domestic availability of equipment						
		Availability	Available/not available	Available	Available	Limited	
		Domestic share	% addition in the total value chain	>90%	>90%	50–90%	
4. Policy and regulatory framework	Policies, laws, and regulations	Policy/ regulations availability (state specific)	Exists (yes/no)	Yes	Yes	Yes	Hydrokinetic systems are included in the revised SHP policy draft.
		Installation/ capacity targets (state level)	Exists (yes/no)	Yes	Yes	Yes	Hydrokinetic systems: 3 MW (determined by assessing the feasibility of the pilot projects being implemented).
		Budget allocation (state level)	Exists (yes/no)	No	No	Yes	Budget allocation has been made for developing pilot projects involving hydrokinetic turbines.
		Price instruments	Generic tariff INR/unit	INR 5.39–5.72 (generic tariff)	INR 5.39–5.72 (generic tariff)	INR 5.39–5.72 (generic tariff)	A project-specific tariff is determined by the Kerala State Electricity Regulatory Commission (KSERC) for capacities higher than 2 MW.
		Renewable Purchase Obligation (RPO)	% of total consumption	X	X	X	State-specific hydro purchase obligation of 0.66% for FY2024. The Ministry of Power (MoP) specified a hydro RPO of 0.38% by FY2025, increasing it to 1.33% by FY2030.

INDICATOR	PARAMETER	METRIC	UNIT				
	Innovation governance						
		Budget allocation for technology innovation/R&D (state specific)	(Yes/no)	No	No	Yes	Budgetary allocation is available to support hydrokinetic technology. Limited grants are provided for clean energy initiatives, generally by various government organizations.
		Budget allocation for technology upgrade or refurbishment	(Yes/no)	X	X	X	
	Policy risk	Due to uncertainties or changes in policy, laws, or regulations affecting the implementation, profitability, or viability of a project	High/medium/low	Low	Low	Low–medium	
5. Environmental and social impact	Social acceptance	Awareness	Yes/no/partial	Partial	Partial	Partial	
	Land acquisition	Physical displacement of the local habitat	Yes/no/partial	Partial	No	No	
	Number of potential beneficiaries	Direct and indirect beneficiaries	Number of persons	X	X	X	
	Job creation potential	Direct, indirect, full, part, induced jobs	Number of jobs	X	X	X	Fully automatic systems are also available worldwide. However, most of the systems used in existing projects require some degree of manual intervention, unless higher-cost automatic systems are used. The operation typically uses a shift-based workforce, with three shifts and three workers required on average per shift. Very large capacities may necessitate more workers. Low-capacity projects in the kilowatt range can be automated to minimize operation costs and improve project viability.
	Impact on the ecosystem						
		Impact on biodiversity and marine ecosystem	High/medium/low	Low	Low	Low	
		Impact on land	High/medium/low	Low	Low	Low	

		Life cycle environ-mental impact	Greenhouse gas (GHG) emissions over the whole lifecycle/ avoided emissions	Grams of carbon dioxide (g CO_2) equivalent per unit	23–24 grams of carbon dioxide per kilowatt-hour (g CO_2/kWh) (complete lifecycle)	23–24 g CO_2/kWh (complete lifecycle)	23–24 g CO_2/kWh (complete lifecycle)	
		Noise pollution	Sound levels	Low/medium/ high	Low	Low	Low	Studies measure noise in the range of 80.4–109.6 dB at a distance of 1 m from the operating turbo generator.

Any other comments on the application of the technology for Kerala

In Kerala, 200 MW of SHP potential has been tapped. Technically, an additional 500 MW of capacity is potentially available. The main issues pertain to land acquisition and use, the additional sanctions required, and clearances from the forest department. A mechanism for streamlining this procedure is needed. Environmental Impact Assessment (EIA) is not required for SHP. Pico turbine generators can also be considered for the state.

The capacity targets of Kerala Small Hydro Policy 2012 were not achieved, mainly because the policy did not adequately address the varied use cases and finer aspects of SHP development, leading to bottlenecks such as the need to obtain clearances from the forest department and the government for using river and adjacent embankments, and land use constraints in the title deed. The previous policy lacked clarity regarding developers' use of their own land for SHP development and the tendering guidelines for projects abandoned by previous developers. There is also a need to scale the compliance burden to the size of the project. Greater clarity is also required regarding the formation of partnerships for collaborative SHP development. Greater cooperation between different government bodies is needed to ease the project development process. Clear inspection timelines must be established to ensure the integrity of the project. Data sharing and new technologies must be promoted, and project timelines should be extended if the project specifics require it.

Note: X = data not available.

Sources: Literature review and stakeholder consultations; CEA 2021; CTCN n.d;IEA 2024; IHA n.d; IITR 2012; KSEBL 2023; A. Kumar et al. n.d.

Table B6 | **Biogas**

				SCORING	RUN-OF-THE-RIVER (ROR) (ON-GRID/ DISTRIBUTED RENEWAL ENERGY [DRE])	CANAL/ DAM TOE (ON-GRID/ DRE)	HYDROKINETIC SYSTEMS (ON-GRID/DRE)	
STEP 1	Prioritization	Resource potential	Is resource potential available in the state for deploying this particular renewable energy (RE) generation system?	Yes/no	Yes			
		Strategic needs	Are the RE source, RE generation system, or supporting technologies being prioritized or supported in state for achieving any goals/targets?	Yes/no	Yes			
Considered for assessment under Step 2 if any two parameters are scored Yes.								

	INDICATOR	PARAMETER	METRIC	UNIT		
STEP 2: ASSESSMENT	1. Technical parameters	Technical efficiency	Ratio of output to total input	%	X	
		Technological maturity	Technology Readiness Level	TRL 1–11	10 Market uptake	Biogas plants have been used in Kerala for 20 years. Initially, the plants, which were of two types, had capacities of 0.5 to 1 cubic meter. Ring-type plants were developed for higher capacities of 10 cubic meters. These were gobar gas plants, which used cow dung as input. Later, due to difficulties in obtaining input material and managing slurry, these were converted to biogas plants that used food waste. Later, large-scale plants were developed and installed in panchayats. Ordinary biogas plants are susceptible to mosquito breeding and odor leakage. To mitigate these problems, floating drum (FD) plants were developed, and about 1,000 such plants are operational in the state. FD plants have the disadvantage that because the gas pressure is low, a low-intensity flame is produced. Another technology, known as the Hi-Tech plant, was developed to mitigate this problem and is also widely used.
		Installation	Ease of setup	Easy/ medium/ difficult	Easy	
		Operation				
			Workforce resource requirement	Skilled/ semiskilled/ unskilled	Semiskilled, skilled	
			Electricity generation	Total units produced per megawatt (MW) per year	X	
			Capacity utilization factor (CUF)/plant load factor (PLF)	%	NA	
			Auxiliary consumption	%	X	For hydrokinetic systems, more data are required to accurately estimate this aspect, but it is estimated to be similar to that of other SHP technologies.
		Recycling potential	Recycling technology availability	Yes/no/ limited	X	Parts contain glass fiber reinforced plastic (GFRP) components and concrete for supporting structures.
		Technology risk	Due to a change in technology, upgrade, or obsolescence affecting the implementation, profitability, or viability of a project	High/ medium/ low	Low	

INDICATOR	PARAMETER	METRIC	UNIT		
2. Economic factors	Cost				
		Capital expenditure (CAPEX)	INR/ megawatt (MW)	X	INR 24,000 for a 1–2 kg input, 1 cubic meter plant. Biogas plants of 0.8 cubic meter capacity that were initially sold for INR 12,000 are now priced at INR 24,000. Raw material costs have contributed to this price increase.
		Operations and maintenance (O&M)	INR/MW	X	Plant closures are primarily due to inadequate maintenance and the lack of effective slurry disposal systems. Skilled labor and slurry disposal locations are not available, and efforts to remedy the situation have been ineffective. Trained workers are in short supply.
	Return on investment	Return on equity (ROE), internal rate of return (IRR)	%	X	
	Financial risk	Due to uncertainties related to project cost, revenue, market conditions, etc., affecting the implementation, profitability, or viability of a project	High/ medium/low	Low	
3. Resource availability	RE resource	Availability of this particular RE resource in the state	High/ medium/low	Medium–high	Feed material is widely available in Kerala. The state is rich in biomatter—seasonal fruits and crops—that can be a source of very good feed material. Seasonal fruits such as jackfruit, and nutmeg husk could be used.
	Domestic availability of equipment				
		Availability	Available/not available	Available	
		Domestic share	% addition in the total value chain	90–100%	
	Resource risk	Due to global supply chain disruption, internal trade restrictions, etc., affecting the implementation, profitability, or viability of a project	High/ medium/ low		

INDICATOR	PARAMETER	METRIC	UNIT		
4. Policy and regulatory framework	Policies, laws, and regulations	Availability of policy and regulations (state specific)	Exists (yes/no)	No	Central government support is available through the National Bioenergy program. The Agency for New and Renewable Energy Research and Technology (ANERT) was giving subsidies to large-scale plants, which were being promoted and installed in panchayats. Some of the plants are in operation, but most are inactive. Even in those that continue to be operated, the generated gas is wasted by burning. Improper maintenance is the major issue, not the technology. Biogas plants were also obtained from empaneled suppliers and distributed to panchayats through the Suchitwa mission.
		Installation/capacity targets (state level)	Exists (yes/no)	No	Central government support is available through the National Bioenergy program.
		Budget allocation (state level)	Exists (yes/no)	No	Central government support is available through the National Bioenergy program.
	Policy instruments				
		Price instruments	Generic tariff INR/unit	NA	
		Renewable Purchase Obligation (RPO)	% of total consumption	NA	
	Innovation governance				
		Budget allocation for technology innovation/R&D (state specific)	(Yes/no)	No	In general, limited grants are provided for clean energy initiatives by different government organizations. Technology-specific grants are not available.
		Budget allocation for technology upgrade or refurbishment	(Yes/no)	X	
	Policy risk	Due to uncertainties or changes in policy, laws, or regulations affecting the implementation, profitability, or viability of a project	High/ medium/ low	Medium –high	Biogas plants in Kerala witnessed higher uptakes when state government schemes supported its uptake, which decreased considerably after the supporting schemes were discontinued.

INDICATOR	PARAMETER	METRIC	UNIT		
5. Environmental and social impact	Social acceptance	Awareness	Yes/no/partial	Yes	There is awareness regarding biogas plants. However, the issue is that once the government subsidy is stopped, interest in setting up plants decreases. Consequently, demand for biogas plants has been weak, leading to the closure of many manufacturing facilities.
	Land acquisition	Physical displacement of the local habitat	Yes/no/partial	No	
	Number of potential beneficiaries	Direct and indirect beneficiaries	Number of persons	X	
	Job creation potential	Direct, indirect, full, part, induced jobs	Number of jobs	X	
	Impact on the ecosystem				
		Impact on biodiversity and marine ecosystem	High/medium/low	Low	
		Impact on land	High/medium/low	Low	
	Life cycle environmental impact	Greenhouse gas (GHG) emissions over the whole lifecycle; avoided emissions	Grams of carbon dioxide (g CO_2) equivalent per unit	NA	
	Noise pollution	Sound levels	Low/medium/high	Low	

Any other comments on the application of the technology for Kerala

The use of gas directly in stoves for cooking and other applications is the best and most successful use case that has been seen thus far in the context of Kerala. As a thumb rule, about 30% of household requirements for cooking fuel can be met by a home biogas plant. Biogas plants offer diverse use cases in Kerala, such as in industries, factories, and hospitals, mainly for supplementing the cooking fuels used in canteens and for heating applications. The use of fish waste as input materials is another example.

One of the major issues is that the slurry needs to be properly disposed of; otherwise, the plant could eventually fail. The slurry needs to be removed in accordance with the schedule stipulated by the manufacturer. Funds for slurry disposal are not considered in the design. The lack of disposal sites for slurry is also an issue. Slurry is a good fertilizer, and various applications for its effective disposal should be explored. Plant maintenance is another major issue. The uptake of biogas plants is subsidy driven. Even large plants require government support for the initial launch. However, once the subsidy is received, interest gradually diminishes. Maintenance is not carried out, leading to the eventual loss of the plant.

Note: NA = data not applicable. X = Data not available.

Source: Literature review and stakeholder consultations.

Table B7 | **Ocean: Wave energy**

				SCORING	RUN-OF-THE-RIVER (ROR) (ON-GRID/ DISTRIBUTED RENEWAL ENERGY [DRE])	
STEP 1	Prioritization	Resource potential	Is resource potential available in the state for deploying this particular renewable energy (RE) generation system?	Yes/no	Yes	
		Strategic needs	Are the RE source, RE generation system, or supporting technologies being prioritized or supported in state for achieving any goals/ targets?	Yes/no	No	
Considered for assessment under Step 2 if any two parameters are scored Yes.						
	INDICATOR	PARAMETER	METRIC	UNIT		COMMENTS
STEP 2: ASSESS-MENT	1. Technical parameters	Technical efficiency	Ratio of output to total input	%	50–90%	The efficiency of a wave energy system varies widely based on the technology used.
		Technolog ical maturity	Technology Readiness Level	TRL 1–11	6–7 Large prototype to demonstration stage	The success of wave energy devices depends on multiple parameters such as water depth, distance from the coast, and sea conditions. The technology is relatively mature, but has not yet reached commercialization. There are also multiple designs available. The issue is that off-the-shelf components cannot be directly used.
		Installation	Ease of setup	Easy/medium/ difficult	Easy–medium	Floating systems are rated medium–easy in installation difficulty. This is because once all the components have been assembled, they can be towed over water to the desired location of operation. Fixed-shore systems on the seashore are medium in difficulty. Such structures may not be commercially feasible due to the specific characteristics of the waves found in India.
		Operation				
			Workforce resource requirement	Skilled/ semiskilled/ unskilled	Skilled	Autonomous operation of systems. Highly skilled maintenance workers are required.
			Throughput rate	Total units produced per kilowatt per day	X	
			Capacity utilization factor (CUF)/plant load factor (PLF)	%	X	Lower than for other RE technologies due to the early stages of technology maturity. Typical CUFs of installations worldwide are in the range of about 15%.

INDICATOR	PARAMETER	METRIC	UNIT		
		Auxiliary consumption	%	X	More data required
	Recycling potential	Recycling technology availability	Yes/no/limited	Yes	Metal components are usually used. Composites may not be a cost-effective option in India.
	Technology risk	Due to a change in technology, upgrade, or obsolescence affecting the implementation, profitability, or viability of a project	High/medium/low	X	
2. Economic factors	Cost				
		Capital expenditure (CAPEX)	INR/megawatt (MW)	20–30 crores/MW	Can become cheaper when it is scaled up. Multiple systems sharing the same mooring infrastructure, etc., could become feasible in the future, which would help reduce the cost.
		Operations and maintenance (O&M)	INR/MW	X	Studies estimate costs to be in the range of 20–30 lakhs/MW
	Return on investment	Return on equity (ROE), internal rate of return (IRR)	%	X	
	Financial risk	Due to uncertainties related to project cost, revenue, market conditions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	High	
3. Resource availability	RE resource	Availability of this particular RE resource in the state	High/medium/low	Medium–high	In India, the west coast has more wave energy potential that the east coast. Kerala possesses abundant resources compared to other Indian states. Studies estimate the annual average wave energy potential at sites near Vizhinjam to be between 5 and 8 kilowatts per meter (kW/m).
	Domestic availability of equipment				
		Availability	Available/not available	Partial	Some Indian players can deliver some of the required components. In general, procurement of these components from Indian manufacturers requires large order quantities. This would not be a problem after the ecosystem matures. Also, collaboration between foreign and Indian companies might be required.
		Domestic share	% addition in the total value chain	X	Depends on the technology. Some of the technology might have been imported. Manufacturing and scaling can be done in India.
	Resource risk	Due to global supply chain disruption, internal trade restrictions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low		The supply chain has not been fully established yet. Initiatives are underway to manufacture components in India.

INDICATOR	PARAMETER	METRIC	UNIT		
4. Policy and regulatory framework	Policies, laws, and regulations	Availability of policies and regulations (state specific)	Exists (yes/no)	No	
		Installation/ capacity targets (state level)	Exists (yes/no)	No	
		Budget allocation (state level)	Exists (yes/no)	No	
		Price instruments	Generic tariff INR/unit	X	
		Renewable Purchase Obligation (RPO)	% of total consumption	X	
	Innovation governance				
		Budget allocation for technology innovation/R&D (state specific)	(Yes/no)	No	
		Budget allocation for technology upgrade or refurbishment	(Yes/no)	X	
	Policy risk	Due to uncertainties or changes in policy, laws, or regulations affecting the implementation, profitability, or viability of a project	High/medium/ low	X	

INDICATOR	PARAMETER	METRIC	UNIT		
5. Environmental and social impact	Social acceptance	Awareness	Yes/no/partial	No	
	Land acquisition	Physical displacement of the local habitat	Yes/no/partial	X	More studies are required.
	Number of potential beneficiaries	Direct and indirect beneficiaries	Number of persons	X	
	Job creation potential	Direct, indirect, full, part, induced jobs	Number of jobs	X	
	Impact on the ecosystem				
		Impact on biodiversity and marine ecosystem	High/medium/low	X	
		Impact on land	High/medium/low	X	
	Life cycle environmental impact	Greenhouse gas (GHG) emissions over the whole lifecycle; avoided emissions	Grams of carbon dioxide (g CO_2) equivalent per unit	X	
	Noise pollution	Sound levels	Low/medium/high	Low	This is estimated to be low.

Any other comments on the application of the technology for Kerala

The potential for harnessing wave energy in Kerala is large. Sites near Vizhinjam, in Trivandrum district, are a hotspot with high potential due to the consistency of the waves. The peak values may be lower, but they are consistent. Also, the presence of the Vizhinjam seaport can provide logistical support for setting up the projects. Industries need to come together. Small-scale testing and pilot projects can be promoted and technologies showcased. Optimal designs need to be developed. More field data and studies are required. Funding is a major challenge and needs to be addressed. A large-capacity project need to be developed, which can then sensitize the government to the viability of the technology and pave the way for the policies and the ecosystem. Awareness is lacking and needs to be improved. The existing technical expertise of organizations such as the National Institute of Ocean Technology (NIOT) can be leveraged while setting up projects. It is suggested that a small working group or think tank with relevant state government stakeholders can be formed to accelerate the development of the technology. Baseline design development requires budget allocation for resource assessment and data acquisition. This can then facilitate prototype creation, secure funding, and inform policies.

The potential for other ocean technologies, such as tidal and current, is limited in Kerala, hampered by a lack of initiative from the government and the private sector, as well as limited R&D. Both marine currents and tidal streams are weak along the state's coast. The waters off the coast of Kerala are not deep enough for ocean thermal energy conversion (OTEC) technologies, which are difficult to set up on land. However, due to the availability of backwaters and rivers joining the sea, salinity gradient technologies could be an option for the state. However, more studies are required to assess the potential and develop the required technologies, which are in the very early stages. Currently, the NIOT is working on one of the coastal inlets in Kerala and conducting studies on salinity gradient technologies.

For wave energy systems, there is a need to optimize designs considering the specific wave conditions present in India. This is because wave energy technologies are different from other RE technologies, in that the large spatial and temporal variabilities between locations require the available designs to be adapted for Indian wave conditions. The state's marine infrastructure is also a consideration when considering technologies; currently, it may not be able to handle the transport and installation of heavy and large wave energy generators.

Note: NA = data not applicable. X = data not available.

Source: Literature review and stakeholder consultations; Foteinis 2022; IRENA 2014; MEDA n.d.

Table B8 | **Energy storage: Battery energy storge system**

				SCORING	RUN-OF-THE-RIVER (ROR) (ON-GRID/ DISTRIBUTED RENEWAL ENERGY [DRE])	
STEP 1	Prioritization	Resource potential	Is resource potential available in the state for deploying this particular renewable energy (RE) generation system?	Yes/no	NA	
		Strategic needs	Are the RE source, RE generation system, or supporting technologies being prioritized or supported in state for achieving any goals/ targets?	Yes/no	Yes	
Considered for assessment under Step 2 if any two parameters are scored Yes.						
	INDICATOR	PARAMETER	METRIC	UNIT		COMMENTS
STEP 2: ASSESS-MENT	1. Technical parameters	Technical efficiency	Ratio of output to total input	%	>80%	A battery energy storge system (BESS) generally has high round trip efficiencies of about 90%. However, high auxiliary consumption and battery degradation reduce the storage capacity.
		Technolog-ical maturity	Technology Readiness Level[a]	TRL 1–11	9 Commercial operation	The technology is mature. However, other ancillary systems, such as cooling, grid integration, and energy management, are the challenge. Container solutions require high cooling energy; therefore, the auxiliary consumption is high. Grid-scale BESS utilizes lithium ferro phosphate (LFP) and lithium-nickel-manganese-cobalt (NMC) ion battery chemistries.
		Installation	Ease of setup	Easy/medium/ difficult	Easy	
		Operation				
			Workforce resource requirement	Skilled/ semiskilled/ unskilled	Skilled	Skilling is required for design, engineering, and integration.
			Electricity generation	Total units produced per kilowatt per day	NA	
			Capacity utilization factor (CUF)/plant load factor (PLF)	%	NA	
			Auxiliary consumption	%	X	In the case of containerized BESS of commercial chemistries, the auxiliary consumption is higher than that of RE technologies such as wind and solar because the system must be cooled and the optimum operating temperature must be maintained.

	Recycling potential	Recycling technology availability	Yes/no/limited	Limited	Recycling technologies are being developed. Regulations and guidelines are required.
	Technology risk	Due to a change in technology, upgrade, or obsolescence affecting the implementation, profitability, or viability of a project	High/medium/low	High	
INDICATOR	**PARAMETER**	**METRIC**	**UNIT**		
2. Economic factors	Cost				
		Capital expenditure (CAPEX)	INR/megawatt (MW)	X	The cost of industrial-scale BESS containerized solutions is estimated to be in the range of 2.5–3 crores/MW. It is expected to decrease.
		Operations and maintenance (O&M)	INR/MW	X	The cost of O&M depends on the energy discharge, battery chemistry, housing, etc. It is estimated to be approximately 1% of the CAPEX.
	Return on investment	Return on equity (ROE), internal rate of return (IRR)	%	X	Scope for improvement.
	Financial risk	Due to uncertainties related to project cost, revenue, market conditions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	Medium–high	
3. Resource availability	RE resource	Availability of this particular RE resource in the state	High/medium/low	NA	
	Domestic availability of equipment				
		Availability	Available/not available	Limited	There is a high dependence on imports. Facilities are being set up in India, which can increase the domestic share.
		Domestic share	% addition in the total value chain	X	There is a high dependence on imports. Facilities are being set up in India, which can increase the domestic share.
	Resource risk	Due to global supply chain disruption, internal trade restrictions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low		The supply chain has not been fully established yet. Initiatives are underway to manufacture components in India.

INDICATOR	PARAMETER	METRIC	UNIT		
4. Policy and regulatory framework	Policies, laws, and regulations	Availability of policies and regulations (state specific)	Exists (yes/no)	No	
		Installation/ capacity targets (state level)	Exists (yes/no)	No	Kerala State Electricity Board Limited (KSEBL) is planning to set up BESS projects at eight locations in the state. These projects have a combined capacity of 205 MW.
		Budget allocation (state level)	Exists (yes/no)	No	
	Policy instruments				
		Price instruments	Generic tariff INR/unit	X	
		Renewable Purchase Obligation (RPO)	% of total consumption	X	The draft Kerala State Electricity Regulatory Commission (KSERC) Renewable Energy and Net Metering (Second Amendment) Regulations 2024 specifies energy storage obligations (ESO) of 0.25% in FY2026, increasing to 2% in FY2030.
	Innovation governance				
		Budget allocation for technology innovation/R&D (state specific)	(Yes/no)	No	In general, limited grants are provided for clean energy initiatives by different government organizations. Technology-specific grants not provided.
		Budget allocation for technology upgrade or refurbishment	(Yes/no)	X	
	Policy risk	Due to uncertainties or changes in policy, laws, or regulations affecting the implementation, profitability, or viability of a project	High/medium/ low	Medium–high	

INDICATOR	PARAMETER	METRIC	UNIT		
5. Environmental and social impact	Social acceptance	Awareness	Yes/no/partial	Partially	
	Land acquisition	Physical displacement of the local habitat	Yes/no/partial	No	
	Number of potential beneficiaries	Direct and indirect beneficiaries	Number of persons	X	
	Job creation potential	Direct, indirect, full, part, induced jobs	Number of jobs	X	
	Impact on the ecosystem				
		Impact on biodiversity and marine ecosystem	High/medium/low	Low–medium	Recycling and safe disposal are important aspects that need to be considered, which can otherwise have negative environmental impacts.
		Impact on land	High/medium/low	Low–medium	Recycling and safe disposal are important aspects that need to be considered, which can otherwise have negative environmental impacts.
	Life cycle environmental impact	Greenhouse gas (GHG) emissions over the whole lifecycle; avoided emissions	Grams of carbon dioxide (g CO_2) equivalent per unit	X	
	Noise pollution	Sound levels	Low/medium/high	Low	
Any other comments on the application of the technology for Kerala					
Batteries are used as a grid ancillary service now, but considering the transition, the focus should be capturing energy when it is available and using it later. This stored energy can be used to manage the peak load requirement. Many industries can use BESS to reduce peak time charges, and it can also be used to decarbonize micro, small, and medium enterprises (MSMEs). Loans and other business models need to be developed to help industries implement energy storage projects. Storage is a workable solution in Kerala due to peak time charges. Project storage capacity additions can be planned in stages depending on the requirement.					

Note: NA = data not applicable. X = data not available.

Source: Literature review and stakeholder consultations; Deorah et al. 2020; EIA 2021; EnerTech n.d; KSERC 2022; MoP 2022; Geethalakshmi et al. n.d., *The Hindu* 2024b.

Table B9 | **Green hydrogen (electrolyzer technologies)**

				SCORING	RUN-OF-THE-RIVER (ROR) (ON-GRID/ DISTRIBUTED RENEWAL ENERGY [DRE])	
STEP 1	Prioritization	Resource potential	Is resource potential available in the state for deploying this particular renewable energy (RE) generation system?	Yes/no	Yes	
		Strategic needs	Are the RE source, RE generation system, or supporting technologies being prioritized or supported in state for achieving any goals/ targets?	Yes/no	Yes	
Considered for assessment under Step 2 if any two parameters are scored Yes.						
	INDICATOR	PARAMETER	METRIC	UNIT		COMMENTS
STEP 2: ASSESS-MENT	1. Technical parameters	Technical efficiency	Ratio of output to total input	%	50–70%	The efficiency of hydrogen production depends on the technology utilized. The efficiencies for electrolysis technologies are as follows: alkaline fuel cell (AFC: 60–70%), polymer electrolyte membrane (PEM: 60%), solid oxide electrolyzer cell (SOFC: 60%), phosphoric acid fuel cell (PAFC: 40%), and molten carbonate fuel cell (MCFC: 50%).
		Technolog-ical maturity	Technology Readiness Level	TRL 1–11	7–10	AFC (9–10) and PEM (9–10) are more mature than MCFC (7–9) and SOFC (7–9).
		Installation	Ease of setup	Easy/medium/ difficult	Easy–medium	
		Operation				
			Workforce resource requirement	Skilled/ semiskilled/ unskilled	Skilled, semiskilled	A semiskilled workforce is required for operations, and a skilled workforce is required for maintenance.
			Electricity generation	Total units produced per kilowatt per day	X	PEM and alkaline electrolyzers require about 50–55 kilowatt-hours (kWh) to produce 1 kilogram (kg) of hydrogen and use about 9 liters of freshwater. Water is also required for process cooling, and the cumulative water requirements could be higher.
			Capacity utilization factor (CUF)/plant load factor (PLF)	%	NA	The electrolyzer operates as long as electricity is supplied to the system. This depends on the type of RE resource that the electrolyzer is coupled to. Hence, the overall CUFs will depend on the RE resource being utilized. Electrolyzers powered from the grid offer the potential for high uptime.
			Auxiliary consumption	%	X	

	Recycling potential	Recycling technology availability	Yes/no/limited	Partial	Recycling and end-of-life management of electrolyzer technologies is still being developed.
	Technology risk	Due to a change in technology, upgrade, or obsolescence affecting the implementation, profitability, or viability of a project	High/medium/low	Low	
INDICATOR	**PARAMETER**	**METRIC**	**UNIT**		
2. Economic factors	Cost				
		Capital expenditure (CAPEX)	INR/megawatt (MW)	INR 6.2–11.6 crores/MW (cost of the electrolyzer stack)	Additional costs could be incurred for developing storage facilities for hydrogen, and these are estimated at approximately INR 65,000/kg.
		Operations and maintenance (O&M)	INR/MW	INR 18 lakhs/MW	Estimated at 3–5% of CAPEX
	Return on investment	Return on equity (ROE), internal rate of return (IRR)	%	15% (IRR)	Scope for improvement.
	Financial risk	Due to uncertainties related to project cost, revenue, market conditions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	Medium–high	The financial risk will reduce as the technology develops further.
3. Resource availability	RE resource	Availability of this particular RE resource in the state	High/medium/low	Medium	
	Domestic availability of equipment				
		Availability	Available/not available	Limited	India needs to further develop indigenous technology and supply chains.
		Domestic share	% addition in the total value chain	X	Electrolyzer manufacturing facilities are being developed.
	Resource risk	Due to global supply chain disruption, internal trade restrictions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	Medium–high	The risk depends on the technology and is higher for SOFCs.
4. Policy and regulatory framework	Policies, laws, and regulations	Availability of policies and regulations (state specific)	Exists (yes/no)	No	A policy is in the draft stage in Kerala.
		Installation/capacity targets (state level)	Exists (yes/no)	Yes	Kerala is looking to set up green hydrogen hubs in Trivandrum and Kochi.
		Budget allocation (state level)	Exists (yes/no)	Yes	An INR 200 crore scheme has been announced for viability gap funding, grants, or equity support for setting up green hydrogen hubs in the state.

INDICATOR	PARAMETER	METRIC	UNIT		
	Policy instruments				
		Price instruments	Generic tariff INR/unit	X	
		Renewable Purchase Obligation (RPO)	% of total consumption	X	
	Innovation governance				
		Budget allocation for technology innovation/R&D (state specific)	(Yes/no)	Yes	The state supports pilot projects on green hydrogen, including new technology development, demonstrations, and studies with the Agency for New and Renewable Energy Research and Technology (ANERT) as the nodal agency. The state has approved an INR 92 lakh proposal by ANERT to support pilot projects on green hydrogen, set up a center of excellence in green hydrogen, and conducted publicity and outreach workshops, etc.
		Budget allocation for technology upgrade or refurbishment	(Yes/no)	X	
	Policy risk	Due to uncertainties or changes in policy, laws, or regulations affecting the implementation, profitability, or viability of a project	High/medium/low	High	
5. Environmental and social impact	Social acceptance	Awareness	Yes/no/partial	Partially	
	Land acquisition	Physical displacement of the local habitat	Yes/no/partial	No	Projects are planned to be implemented using empty land and land owned by government entities. Also, smaller decentralized facilities are being explored for Kerala.
	Number of potential beneficiaries	Direct and indirect beneficiaries	Number of persons	X	
	Job creation potential	Direct, indirect, full, part, induced jobs	Number of jobs	X	More data from actual projects are required.
	Impact on the ecosystem				
		Impact on biodiversity and marine ecosystem	High/medium/low	Low	More studies are required.
		Impact on land	High/medium/low	Low	Recycling and safe disposal are important aspects that need to be considered, which can otherwise have negative environmental impacts.
	Life cycle environ mental impact	Greenhouse gas (GHG) emissions over the whole lifecycle; avoided emissions	Grams of carbon dioxide (g CO_2) equivalent per unit	X	Producing hydrogen from unabated fossil fuels can result in emissions of 27 kg CO_2-eq/kg H_2. Hydrogen production using RE-powered electrolysis avoids emissions.

		Noise pollution	Sound levels	Low/medium/ high	Low	
Any other comments on the application of the technology for Kerala						
Given the availability of water, solar energy potential, and ports, the state has good export potential for green hydrogen.						

Note: NA = data not applicable. X = data not available.

Source: Literature review and stakeholder consultations; GoK 2023b; IEA 2023; KPMG 2022; V.S. Kumar et al. 2023; Miltrup 2024; Ramirez et al. 2023, *The Hindu* 2023, Uekert et al. 2024; Umagine 2024b.

Table B10 | Pumped storage hydropower

				SCORING	RUN-OF-THE-RIVER (ROR) (ON-GRID/ DISTRIBUTED RENEWAL ENERGY [DRE])	
STEP 1	Prioritization	Resource potential	Is resource potential available in the state for deploying this particular renewable energy (RE) generation system?	Yes/no	Yes	
		Strategic needs	Are the RE source, RE generation system, or supporting technologies being prioritized or supported in state for achieving any goals/ targets?	Yes/no	Yes	
Considered for assessment under Step 2 if any two parameters are scored Yes.						
	INDICATOR	**PARAMETER**	**METRIC**	**UNIT**		**COMMENTS**
STEP 2: ASSESS MENT	1. Technical parameters	Technical efficiency	Ratio of output to total input	%	70–80%	
		Technolog ical maturity	Technology Readiness Level	TRL 1–11	11 Mature	Mature technology. If upper and lower reservoirs are available, setting up pumped storage hydropower (PSH) is easy.
		Installation	Ease of setup	Easy/medium/ difficult	Difficult	The difficulty is due to the geological conditions and the associated complications; in some cases, tunneling will be required.
		Operation				
			Workforce resource requirement	Skilled/ semiskilled/ unskilled	Skilled	
			Electricity generation	Total units produced per kilowatt per day	NA	
			Capacity utilization factor (CUF)/plant load factor (PLF)	%	NA	
			Auxiliary consumption	%	1%	
		Recycling potential	Recycling technology availability	Yes/no/limited	Partial	Metal components can be recycled.

	Technology risk	Due to a change in technology, upgrade, or obsolescence affecting the implementation, profitability, or viability of a project	High/medium/low	Low	The technology is fully mature.
INDICATOR	**PARAMETER**	**METRIC**	**UNIT**		
2. Economic factors	Cost				
		Capital expenditure (CAPEX)	INR/megawatt (MW)	INR 7–15 crores/MW	The cost is similar to that of large hydro projects and larger-capacity small hydro power (SHP) projects. The Kerala State Electricity Board Limited (KSEBL) has acquired land at the rate of INR 57 lakhs/acre for a recent hydroelectric project at Mankulam, Kerala (40 MW, 600 crores).
		Operations and maintenance (O&M)	INR/MW	X	It is estimated to be about 5% of the CAPEX.
	Return on investment	Return on equity (ROE), internal rate of return (IRR)	%	X	
	Financial risk	Due to uncertainties related to project cost, revenue, market conditions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	Medium to low	
3. Resource availability	RE resource	Availability of this particular RE resource in the state	High/medium/low	Medium	Indigenous technology is available
	Domestic availability of equipment				
		Availability	Available/not available	Available	
		Domestic share	% addition in the total value chain	>90%	
	Resource risk	Due to global supply chain disruption, internal trade restrictions, etc., affecting the implementation, profitability, or viability of a project	High/medium/low	Medium–low	Similar to the case of hydroelectric projects, for PSH projects too, the components for high-head and high-capacity plants need to be imported from China. Hence, there is a chance of resource risk due to global supply chain disruptions. Lower-capacity projects can be fully procured and implemented domestically.
4. Policy and regulatory framework	Policies, laws, and regulations	Availability of policies and regulations (state specific)	Exists (yes/no)	X	
		Installation/capacity targets (state level)	Exists (yes/no)	Yes	Potential is available, and the government has sanctioned implementation of two projects of capacities 30 MW and 100 MW.
		Budget allocation (state level)	Exists (yes/no)	Yes	

INDICATOR	PARAMETER	METRIC	UNIT		
	Policy instruments				
		Price instruments	Generic tariff INR/unit	X	No subsidy
		Renewable Purchase Obligation (RPO)	% of total consumption	X	State-specific hydro purchase obligation of 0.66% for FY2024. The Ministry of Power (MoP) specified hydro RPO of 0.38% by FY2025, increasing to 1.33% by FY2030. The draft Kerala State Electricity Regulatory Commission (KSERC) Renewable Energy and Net Metering (Second Amendment) Regulations 2024 specifies energy storage obligations (ESO) of 0.25% in FY2026, increasing to 2% in FY2030.
	Innovation governance				
		Budget allocation for technology innovation/R&D (state specific)	(Yes/no)	No	
		Budget allocation for technology upgrade or refurbishment	(Yes/no)	X	
	Policy risk	Due to uncertainties or changes in policy, laws, or regulations affecting the implementation, profitability, or viability of a project	High/medium/low	Medium	
5. Environmental and social impact	Social acceptance	Awareness	Yes/no/partial	Yes	Awareness is high
	Land acquisition	Physical displacement of the local habitat	Yes/no/partial	Partial	The first-phase projects planned in Kerala will not cause habitat displacement because it will use revenue land and existing reservoirs.
	Number of potential beneficiaries	Direct and indirect beneficiaries	Number of persons	X	This is difficult to assess because it is directly connected to the central grid.
	Job creation potential	Direct, indirect, full, part, induced jobs	Number of jobs	X	The project implementation phase is labor intensive, requiring approximately 10,000 workers. For the operational phase, 3 workers per shift with 3 shifts per day are generally required.
	Impact on the ecosystem				
		Impact on biodiversity and marine ecosystem	High/medium/low	Low–medium	
		Impact on land	High/medium/low	High	The impacts on land will depend on the storage capacity: if the storage requirement is high, the impact on land will also be high.
	Life cycle environ-mental impact	Greenhouse gas (GHG) emissions over the whole lifecycle; avoided emissions	Grams of carbon dioxide (g CO_2) equivalent per unit		

	Life cycle environ-mental impact	Greenhouse gas (GHG) emissions over the whole lifecycle; avoided emissions	Grams of carbon dioxide (g CO_2) equivalent per unit		
	Noise pollution	Sound levels	Low/medium/high	Low	Very low or nil in the case of underground powerhouses.

Any other comments on the application of the technology for Kerala

The identified PSH potential in Kerala is estimated to be approximately 4,400 MW. More studies need to be conducted to assess the exact potential, and some studies on this are underway. At least three years are required for the implementation of PSH projects; however, small projects can be implemented in two years following approval. The delay from the project identification stage to the implementation stage is mainly due to the detailed survey and design process, and the time needed to obtain clearances and approvals. In general, this time frame applies to both PSH and conventional hydroelectric projects.

Note: NA = data not applicable. X = data not available.

Source: Literature review and stakeholder consultations; EMC 2018; Amalnath 2017; KSEBL n.d.-c, n.d.-d; Menéndez et al. 2020; PIB 2024a.

APPENDIX C: COMPLETED RENEWABLE ENERGY PROJECTS IN KERALA

Table C1 | **Available potential and installation of various renewable energy technologies in Kerala as of July 2024**

TECHNOLOGY	POTENTIAL (MW)	INSTALLATION (MW)
Wind: Onshore	2,621	70.27
Solar	10,953[a]	1,164.97
SHP	647[b]	276.52
Bioenergy	778.41	2.5[c]
Ocean: Wave energy	4,900	0

Note: GW = gigawatts. MW = megawatts. SHP = small hydro power. Indicative potential of various renewable energy technologies for Kerala that have been prioritized in this working paper.

a. The overall solar potential in Kerala is estimated to be 10.9 GW (CSTEP 2024). The potential for utility-scale solar PV in Kerala is estimated to be about 6.1 GW (DoECC 2022). The floating solar potential in Kerala is expected to be approximately 3–8 GW (Samuel and Prasad 2018; Fernandes and Sharma 2023). More studies are required to determine the rooftop solar (RTS) potential.

b. The estimated small hydro potential using conventional technologies such as run-of-the-river, canal, and dam toe.

c. The installed capacity from biomass cogeneration (non-bagasse) and waste-to-energy (off-grid) plants. The number of biogas plants in the state is estimated at 1.54 lakhs (as of March 2023).

Source: ASCI 2021, NIWE 2023.

Table C2 | **List of solar projects in Kerala (as of March 2023)**

STATION NAME	UNIT CAPACITY (MW)	DATE OF COMMISSIONING
KSEBL SOLAR		
Kanjikode Substation GM	1	August 20, 2015
Kollengode Substation GM	1	August 8, 2016
Edayar Substation premises GM	1.25	September 5, 2016
Barapole Canal bank	1	November 7, 2016

STATION NAME	UNIT CAPACITY (MW)	DATE OF COMMISSIONING
KSEBL SOLAR		
Barapole Canal top	3	November 17, 2016
Pezhakkappilly, Muvattupuzha GM	1.25	January 15, 2018
Pothencode Substation GM	2	February 2, 2018
Agali GM	1	January 22, 2022
Kanjikode GM	3	February 19, 2022
Brahmapuram	2.75	February 3, 2023
Other small solar installations	7	As on March 31, 2023
SOURA under KSEBL fund	23.29	As on March 31, 2023
PRIVATE SOLAR		
Cochin International Airport Ltd. (prosumer)	39.88	March 24, 2018
Solar Park, RPCKL Ambalathara (IPP)	50	2016, 2017
ANERT, Kuzhalmandam (IPP)	2	December 9, 2016
Hindalco (prosumer)	3	March 31, 2016
KMRL (prosumer)	10.6	July 21, 2019
THDCIL-Paivalike Solar Park (IPP)	50	December 31, 2020
Bharat Hospital (captive)	1.1	
Agali Goat Farm	0.5	
Kayamkulam Floating Solar (IPP)	92	
CIAL Ettukudukka	10	
LT solar prosumers	369.51	As on March 31, 2023
Other HT and EHT solar prosumers	58.29	As on March 31, 2023
TOTAL	**734.42**	

Note: ANERT = Agency for New and Renewable Energy Research and Technology. CIAL = Cochin International Airport Ltd. EHT = extra high tension. GM = ground-mounted. HT = high tension. IPP = independent power producer. KMRL = Kochi Metro Rail Limited. KSEBL = Kerala State Electricity Board Limited. LT = low tension. MW = megawatts. RPCKL = Renewable Power Corporation of Kerala Ltd. THDCIL = Tehri Hydro Development Corporation India Limited.

Source: KSEBL 2023.

Table C3 | **List of wind energy projects in Kerala (as of March 2023)**

NO.	STATION NAME	CAPACITY, UNIT WISE (MW)	DATE OF COMMISSIONING	INSTALLED CAPACITY (MW)
1	Kanjikode	9 × 0.225	1995	2.025
2	Ramakkalmedu (IPP)	19 × 0.75	2008, 2009, 2010	14.25
3	Agali (IPP)	23 × 0.6	2008, 2010	13.80
4	Kavundikkal (IPP)	8 × 0.6	2010	4.80
5	Ahalya (IPP)	4 ×2.1	2016	8.40
6	Inox (IPP)	8 × 2	X	16
7	Kosamattam (IPP)	4 × 0.25	X	1
8	Malayala Manorama (CPP)	5 × 2	2019	10
		TOTAL		**70.275**

Note: CPP = captive power producer. IPP = independent power producer. MW = megawatts. X = data not available.

Source: KSEBL 2023.

Table C4 | **List of small hydro power projects in Kerala (as of March 2023)**

NO.	STATION NAME	UNIT CAPACITY (MW)	YEAR OF COMMISSIONING
	KSEBL		
1	Kallada	15	1994
2	Peppara	3	1996
3	Malankara	10.5	2005
4	Madupetty	2	1998
5	Chembukadavu Stage I & II	6.45	2003
6	Urumi Stage I &II	6.15	2004
7	Malampuzha	2.5	2001
8	Lower Meenmutty	3.5	2006
9	Kuttiyadi Tailrace	3.75	2008, 2009
10	Poringalkuthu Left Bank Extension (LBE)	16	1999
11	Neriamangalam Extension	25	2008
12	Poozhithode	4.8	2011
13	Ranni-Perunad	4	2012
14	Peechi	1.25	2013
15	Vilangad	7.5	2014
16	Chimmony	2.5	2015
17	Adyanpara	3.5	2015
18	Barapole	15	2016

NO.	STATION NAME	UNIT CAPACITY (MW)	YEAR OF COMMISSIONING
	KSEBL		
19	Vellathooval	3.6	2016
20	Poringalkuthu Micro	0.011	2016
21	Perunthenaruvi	6	2017
22	Kakkayam	3	2018
23	Deviyar MHEP	0.05	2020–21
24	Chathankottunada Stage II	6	2021
25	Upper Kallar	2	2021
26	Poringalkuthu New	24	2022
	CPP		
1	Maniyar	12	1994
2	Kuthungal	21	2001
NO.	**STATION NAME**	**UNIT CAPACITY (MW)**	**YEAR OF COMMISSIONING**
	IPP		
1	Ullunkal	7	2008
2	Iruttukkanam	4.5	2010, 2012
3	Kaarikkayam	15	2013, 2017
4	Meenvallom	3	2014
5	Kallar	0.05	2015
6	Pampumkayam (Mankulam)	0.11	2012
7	Pathankayam	8	2017
8	Anakkampoil	8	X
9	Arippara	4.5	X
	TOTAL	**260.221**	

Note: CPP = captive power producer. IPP = independent power producer. KSEBL = Kerala State Electricity Board. MW = megawatts. X = data not available.

Source: KSEBL 2023.

Table C5 | **Generating capacity, maximum demand, and load factor in Kerala (2001-2023)**

YEAR.	INSTALLED CAPACITY (MW)	ENERGY INPUT TO THE SYSTEM (MU)	MAXIMUM DEMAND (MW)	LOAD FACTOR (%)
2000–01	2,422.61	12,464.00	2,316	61.43
2002–03	2,608.71	12,391.13	2,347	60.27
2004–05	2,623.86	12,504.84	2,420	58.99
2006–07	2,662.96	14,427.96	2,742	60.07
2008–09	2,744.76	15,293.41	2,765	63.14
2010–11	2,869.56	17,340.28	3,119	63.47
2012–13	2,881.22	19,877.21	3,268	69.43
2014–15	2,835.63	21,573.16	3,602	68.37
2016–17	2,915.80	23,763.57	4,004	67.75
2018–19	2,866.19	24,849.15	4,242	66.87
2020–21	3,029.61	25,132.93	4,284	66.97
2021–22	3,145.98	26,703.19	4,380	69.60
2022–23	3,514.81	27,977.17	4,517	68.26

Note: MU = million units. MW = megawatts.

Source: KSEBL n.d.-b, 2023.

ABBREVIATIONS

AFC	alkaline fuel cell
ANERT	Agency for New and Renewable Energy Technologies
BESS	battery energy storage system
CUF	capacity utilization factor
CETAM	Clean Energy Technology Assessment Methodology
CIAL	Cochin International Airport Limited
CPP	captive power producer
CSTEP	Center for Study of Science, Technology and Policy
CAPEX	capital expenditure
DRE	distributed renewable energy
DNI	direct normal irradiance
EMC	Energy Management Centre
FACT	Fertilizers and Chemicals Travancore
FD	floating drum
FPV	floating photovoltaic
GFRP	glass fiber reinforced plastic
IEEE	Institute of Electrical and Electronics Engineers
ISTS	Inter State Transmission System
IEA	International Energy Agency
IPP	independent power producer
KSEBL	Kerala State Electricity Board Limited
KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan
LFP	lithium ferro phosphate
MoP	Ministry of Power
NIOT	National Institute of Ocean Technology
NMC	Nickel-manganese-cobalt
O&M	operations and maintenance
OTEC	ocean thermal energy conversion
PLF	plant load factor
PEM	polymer electrolyte membrane
PPA	power purchase agreement
PSH	pumped storage hydropower
R&D	research and development
RE	renewable energy
RPO	Renewable Purchase Obligation
RTS	rooftop solar
ROR	run-of-the-river
SHP	small hydro power
SECI	Solar Energy Corporation of India
TAF	Technology Assessment Framework
THDCIL	Tehri Hydro Development Corporation India Limited
TPD	tonnes per day

ENDNOTES

1. We have considered frameworks developed by the IEA (IEA 2016) and another developed by CSTEP (CSTEP 2021) for the purpose of this study. The Energy Technology Assessment Methodology (CETAM) developed by the IEA looks at some of the clean energy technologies that can be measured and monitored in accordance with local circumstances and policy objectives.

2. CSTEP's Technology Assessment Framework (TAF) uses six performance indicators—technical, economic, resource, policy and regulatory, social, and environmental impact—to evaluate technologies.

3. A power plant's CUF is the ratio of its actual output over a year to its rated output in that same time frame.

4. This is the percentage of domestic content in the total value chain.

5. According to the report of the Comptroller and Auditor General of India on public sector undertakings (PSUs) in Kerala, there were 128 public sector undertakings as of March 31, 2016. Stakeholders are of the opinion that land available with many of these PSUs can be used for the development of solar projects. However, more studies are required to ascertain the exact potential.

6. Although higher-capacity projects are expected to improve developer interest, a previous KSEBL tender for 100 MW received less than 50 percent bidding, and none was executed. This was primarily because the unique challenges in Kerala, such as shortage of available land and the complex terrain, compelled KSEBL to make certain adaptations. One key change included reducing the minimum bid capacity to 5 MW. The minimum project size at a single site was adjusted to 2 MW. Further, a ceiling tariff of INR 4.10 per unit was stipulated in the bid documents.

7. The floating solar potential in Kerala is estimated as 3.6 GW by considering the total area of the water bodies in the state to be 769 km_2 and assuming that 10 percent of this area is being utilized for floating solar (Samuel and Prasad 2018). A recent report estimated the floating solar potential to be at least 8.6 GW, based on the assumption of 20 percent utilization of the water bodies in Kerala and considering reservoirs, private ponds, panchayat ponds, quarry ponds, village ponds, irrigation tanks, and public sector freshwater fish farms (Fernandes and Sharma 2023).

8. Solar modules comprise a collection of solar PV cells.

9. Although stakeholders are of the opinion that the environmental impacts of floating solar projects are generally low, studies would be required to determine project-specific environmental and social impacts that can affect the overall viability of a project. This can be captured with the help of an environmental impact assessment (EIA).

10. To manage this issue, several agencies are working to convert disposed slurry into chemical-free fertilizers. Similar interventions can also be considered.

11. The discovered tariff under BESS tenders more than halved from INR 10.84 lakhs ($12,987)/MW/month in the first Solar Energy Corporation of India (SECI) tender in August 2022 to INR 4.49 lakhs/MW/month in the latest tender by Gujarat in March 2024, reflecting the decline in battery prices.

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ABOUT WRI INDIA

WRI India, an independent charity legally registered as the India Resources Trust, provides objective information and practical proposals to foster environmentally sound and socially equitable development. Our work focuses on building sustainable and liveable cities and working towards a low carbon economy. Through research, analysis, and recommendations, WRI India puts ideas into action to build transformative solutions to protect the earth, promote livelihoods, and enhance human well-being. We are inspired by and associated with World Resources Institute (WRI), a global research organization. Know more: www.wri-india.org

Our challenge
Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our vision
We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our approach
COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to inform government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.