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ORIGINAL ARTICLE

Leveraging information technology for accelerating residential rooftop solar: A case study from Odisha, India

Ishan Purohit[1] · Ashish Kumar Sharma[1] · Pallav Purohit[2]

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Abstract
Rooftop solar (RTS) projects have the potential to contribute to climate change mitigation and sustainable development objectives. The Indian government has set an ambitious target of adding 100 GW of solar capacity by 2022, with 40 GW allocated for RTS segment. However, only 8.2 GW (< 25%) of this target has been achieved thus far. The low uptake of RTS is attributed to the complexity and inefficiency in the current implementation process, along with a lack of coordination among various implementing agencies. Leveraging information technology (IT) has emerged as a promising strategy to address these challenges and unleash the full potential of RTS systems. This approach seeks to consolidate key stakeholders onto a unified web platform, simplifying administrative tasks for agencies, reducing processing times, and fostering connections between consumers and legitimate vendors. By delineating roles and responsibilities within defined timeframes, the adoption of IT measures aims to support RTS implementation at both state and national levels. This study examines the potential of incorporating a web-based IT platform into the current RTS implementation process of the Odisha Renewable Energy Development Agency. A simplified approach was developed to expedite RTS projects in Odisha with reduced reliance on human intervention and resources. This methodology was effectively demonstrated with the State Nodal Agency (SNA), resulting in the execution of around 850 projects, totaling 33 MWp (with capacities ranging from 1–10 kW) of residential grid-connected RTS projects. As a result, other SNAs have embraced this model, fostering RTS advancement and consumer engagement through web-based IT platforms.

Keywords Information Technology · Rooftop Solar · Net-metering · State Nodal Agencies · DISCOMS

✉ Pallav Purohit
purohit@iiasa.ac.at

[1] International Finance Corporation (IFC), The World Bank Group, New Delhi 110037, India

[2] International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria

1 Introduction

For nearly three decades, intergovernmental negotiations have been in progress to tackle climate change, and India has actively participated in these discussions. India has demonstrated its commitment to addressing climate change by pledging to achieve net-zero emissions by 2070 (van Soest et al. 2021; ASPI 2022; Das et al. 2023) and aiming to fulfill 50% of its electricity needs from renewable energy (RE) sources by 2030 (IEA 2022; UNFCCC 2022). The country's first commitment to the Paris Agreement, known as a Nationally Determined Contribution (NDC), included a target of having 40% of installed electric power from non-fossil-based energy resources by 2030 (MNRE 2010; UNFCCC 2015). Now, India has set additional goals, including reducing the carbon intensity of its economy by at least 45% by 2030 compared to the 2005 level and meeting 50% of its energy demand from RE by 2030 (UNFCCC 2022; Chateau et al. 2023). In order to fulfill these obligations, the nation has set a goal to install a cumulative capacity of 500 GW for power generation based on RE sources (primarily solar and wind) by 2030 (GoI 2024). In pursuit of these objectives, the Indian Government launched the National Solar Mission (NSM) in 2010, initially targeting 20 GW of solar power capacity by the end of 2022 (MNRE 2010). This target was later revised and raised to 100 GW in 2015 (MNRE 2015a), with 60 GW aimed through ground-mounted utility-scale solar projects and 40 GW through rooftop solar (RTS) projects (Purohit and Purohit 2018).

To meet the set targets, the Indian Ministry of New and Renewable Energy (MNRE) has assigned specific capacity targets (refer to Table S1 in the supplementary information) to each state in India (MNRE 2022a). States have implemented policies and regulations to encourage the adoption of RTS among end users, aiming to achieve their respective targets (Chandel et al. 2022; Dutta & Das 2020; Jain et al. 2019; MNRE 2022b; Sarangi and Taghizadeh 2021). Besides the central government policies, almost every state, through their respective State Nodal Agencies (SNAs), has also introduced their own RTS policies and regulations (refer to Table S2). Additionally, the MNRE has established separate objectives to promote RTS adoption in the residential sector and launched the phase-II scheme for grid-connected RTS implementation in February 2019 (MNRE 2019). This scheme targets a cumulative 40 GW capacity of RTS installations by the end of 2022, with allocation to all states (as shown in Table S1). Figure 1 illustrates the yearly progress of RTS projects in India, presenting capacity and the comparison between targets and actual implementation (BTI 2024). Nevertheless, as of December 2023, the total installed capacity of RTS in India remained at around 14.5 GW (3.7 GW residential, 3.2 GW commercial and 7.6 GW industrial), which falls below the Indian Government's goal of 40 GW. Consequently, the deadline for reaching the 40 GW target has been extended to 2026 (Joshi 2022).

The Indian government has introduced a number of financial and regulatory measures to encourage the installation of RTS systems, such as capital subsidies for residential consumers and net metering regulations (Tarai & Kale 2018). Almost every state in the country has introduced dedicated solar power policies and net metering regulations for grid connected RTS installations across various consumer categories (i.e., commercial, industrial, residential etc.). However, several barriers hinder the growth and transition towards RTS, including high upfront costs, limited access to financing, complex administrative procedures, lack of standardized policies and regulations, limited awareness and information, technical and infrastructure challenges, perceptions of unreliable quality and service, and lack of transparency in policy implementation and coordination among stakeholders or implementing agencies (Dhingra et al. 2023; Goel 2016; Mahadevan et al. 2023; Purohit and Kandpal 2005).

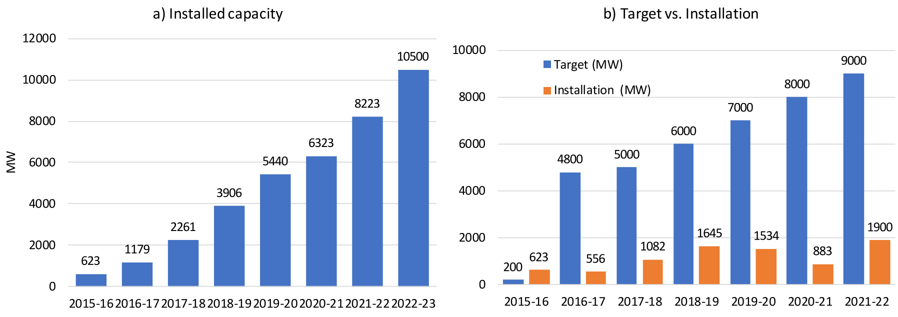

Fig. 1 Year-wise implementation of RTS projects in India **a**) capacity and **b**) targets vs. actual implementation

Information Technology (IT) solutions have proven transformative in the RE sector, enhancing operational efficiency, grid management, and consumer engagement. This study explores the potential of IT solutions for accelerating RTS adoption in Odisha, India. The manuscript is organized into several sections. Section 2 provides a concise literature review on the potential of RTS in India, while Section 3 delves into the scant research on IT solutions in RTS and identifies significant obstacles impeding implementation in the country. Section 4 introduces the critical stakeholders involved in RTS projects within the chosen state. Section 5 details the current process for implementing RTS projects in the state. Section 6 critically analyzes the limitations of the existing implementation approach. Section 7 proposes a novel approach leveraging a web-based IT platform to streamline RTS project implementation in Odisha. Section 8 provides an overview of existing national and state-level initiatives utilizing web-based solutions for RTS implementation. Finally, Section 9 concludes the study by summarizing the key findings and their implications for advancing RTS adoption.

2 Rooftop solar in India: Literature review

India's annual average Global Horizontal Insolation (GHI) spans from 3.2 kWh/m^2/day to 6.1 kWh/m^2 per day (MNRE 2016), and the National Institute of Solar Energy (NISE) estimates the country's total solar potential at 749 GWp (MNRE 2015b), if 3% of the wasteland area will be covered by Solar PV modules. A substantial potential for rooftop solar projects across India has been identified by several studies (Gulia et al. 2022; Singh 2020; IEA 2021; Sharma et al. 2017a; Sharma et al. 2012; Pandey et al. 2016; Sudhakar et al. 2014). The Energy and Resources Institute (TERI) conducted research estimating a technical potential of approximately 352 GW and an economic potential of nearly 210 GW for RTS in urban areas (Sudhakar et al. 2014). The realistic market potential for rooftop solar PV in urban settlements is estimated to be around 124 GW.

Another study by Joshi et al. (2021) assessed RTS potential of approximately 1815 TWh for India, utilizing high-resolution global spatiotemporal analysis. Furthermore, investigations have been undertaken to evaluate the potential of grid connected RTS systems in residential (Dondariya et al. 2018) and educational buildings (Mokhtara et al. 2021) in arid environments. Anwar and Deshmukh (2018) utilized an Artificial Neural Network (ANN) in conjunction with Geographic Information System (GIS) to assess and map the potential solar energy sources across 28 distinct locations in South India, leveraging data spanning approximately 22 years. Mishra et al. (2020) investigated the RTS potential in thirteen districts of Uttarakhand, India, employing remote sensing and GIS techniques, and utilized statistical clustering to assess the available rooftop areas. Their findings revealed that 58% of the rooftop areas receive over 4 kWh per m^2 of solar radiation annually, suggesting the potential to generate 57% of the electrical energy consumption in Uttarakhand.

Despite this significant potential, the progress of the RTS sector has been slow, lagging the expected targets (Fig. 1). Several studies analyzed the factors influencing the growth and development of both utility and RTS markets in India (Beck & Martinot 2004; Pandey and Sharma 2021; Rathore et al. 2018; Shukla et al. 2018; Singh and Banerjee 2015). These studies focus on analyzing RTS policies, regulations, and business models currently in practice to facilitate sectoral growth, while also highlighting key challenges faced by the RTS segment in India (Adithya 2016).

Information Technology (IT) solutions offer valuable tools, expertise, insight, and support (Omer 2008). They optimize resources and reduce paper usage, revolutionizing the landscape of energy services (Bañales 2020; IRENA 2019a, b; Luthra et al. 2011; Vallecha et al. 2021). By leveraging web-based IT solutions, implementing agencies, SNAs, and distribution utilities can work toward demand aggregation and streamline RTS deployment through a systematic, efficient, and less time-consuming approach. This study assesses the potential for deploying web-based IT platform in the existing RTS implementation process of the Odisha Renewable Energy Development Agency (OREDA) and proposes a simplified approach for executing RTS projects more efficiently, minimizing human involvement and resource usage.

3 Barriers to the RTS implementation in India

As previously mentioned, the RTS sector encounters various barriers, including rigid net-metering practices enforced by electricity distribution companies (DISCOM), issues related to bankability, limitations in scaling up smaller residential installations, limited network infrastructure for connecting multiple small RTS projects, shortage of skilled personnel within implementing agencies, and the prevailing conventional approach to project installation adopted by executive agencies (Dhankhar & Anwer 2019; Garg & Buckley 2019; Kappagantu et al. 2015; Thakur & Chakraborty 2019). The following sub-sections delve into these key barriers that have impeded the progress of RTS installations in India:

3.1 Lack of awareness

One of the primary barriers to the growth and development of RTS in India is the lack of awareness about RE, particularly solar power, among potential consumers in the residential sector (Dutt 2020). The high capital cost of RTS systems also poses a challenge, prompting the central and state governments to provide 30% capital subsidies for residential RTS installations (Garg & Buckley 2019). Nevertheless, the average cost of RTS installation in India has decreased significantly over the years, reaching INR 50,000 (US $658) per kilowatt (kW) in 2023 (Him Urja 2023), a 73% reduction compared to the 2013 level. Notably, RTS costs in India are substantially lower than in other leading countries like Japan, the United Kingdom, Switzerland, and the U.S., where they are 3.3 to 6.4 times higher than in India (Gulia et al. 2022).

The lack of awareness among potential consumers significantly impacts their decision-making ability, resulting in a failure to achieve the desired adoption of RTS systems, despite the availability of capital subsidies and other supportive measures (Sharma et al. 2012). A survey report quantified this issue, revealing that approximately 64% of the rural population and around 39.5% of the urban population lack knowledge about RE and its supporting measures (MERCOM 2014). Several studies have highlighted this concern emphasizing the need for robust mechanisms by government institutions to raise awareness about state support measures and the potential benefits of RTS technology (Painuly 2001; Rathore et al. 2018; Yaqoot et al. 2016).

3.2 Lack of clarity in rooftop solar policies

While each state in India has introduced dedicated solar policies, including those for the residential sector, there is a significant lack of clarity in these policies (Aggarwal et al. 2020; Chandel et al. 2022). For instance, in the residential sector, net metering policy allows RTS system owners to receive credit for the electricity they inject into the grid. However, despite this benefit, progress under net metering has been slow. The average time taken to deploy an RTS system in the residential sector in some states of India is as high as 120 to 150 days, primarily due to inadequate training and process protocols in implementing agencies (BTI 2016). The absence of clear guidelines for application approval, metering or energy sale agreements, and technical requirements further hampers the pace of RTS installations. International studies have shown that the effective implementation of net metering can potentially boost RTS adoption by up to 50% (Rathore et al. 2019). Hence, the sector urgently requires robust mechanisms and implementation plans to fully utilize the benefits of RTS policies and make them more user-friendly. This necessitates coordination among all implementing agencies, such as SNAs, SERCs, and the respective DISCOM.

Moreover, policy and regulatory uncertainties remain significant barriers to the rapid adoption of RTS systems (Kumar et al. 2023). For instance, the initial RTS sector growth was driven by capital subsidies, which later became sector-specific under the respective central/state governments. Several changes in the RTS segment, particularly for commercial and industrial (C&I) consumers (e.g., gross metering, net metering, FiT, open access, group captive, etc.), have led to communication gaps at the ground level (Das 2022; Deloitte 2019; E&Y, 2022; PwC 2018). SNAs often struggle to adapt their processes quickly in response to these abrupt changes.

3.3 Poor technical or commercial skills

According to a study conducted by the Council on Energy, Environment and Water (CEEW), achieving the target of 40 GW RTS deployment in India would require a workforce of 210,800 skilled plant design and site engineers, along with approximately 624,600 semi-skilled and low-skilled technicians for construction (CEEW 2016) The lack of sufficient institutional capacities for workforce training contributes to the limited access to education, training, and the availability of a skilled workforce for the development of RTS systems (Timilsina et al. 2012). Moreover, the necessary skills and manpower are predominantly concentrated in urban areas of the states, whereas SNAs implement projects across the entire state, including rural areas.

3.4 Challenges to the implementation agencies and other stakeholders

Figure 2 illustrates the various agencies and stakeholders involved in RTS implementation in India. The institutional mechanism in the country is effectively regulated and established, with each agency assigned specific roles and responsibilities (Fig. 2). The successful implementation of RTS projects necessitates effective coordination among regulatory commissions, DISCOMS (for metering and approvals), SNAs (for subsidy consideration and release, approval of channel partners, etc.), financial institutions (for loans), urban/municipal local bodies (for building byelaws), rooftop owners (for roof access), and SNA's endorsed channel partners (for project implementation and maintenance). However, this coordination often leads to delays in the overall process. DISCOMS/Utility companies also face challenges in terms of revenue loss, particularly from C&I sector customers whose electricity bills are reduced due to RTS implementation. SNAs and DISCOMS encounter difficulties in handling RTS projects of smaller and medium capacities (i.e., residential and institutional sectors) due to a lack of awareness, infrastructure constraints, reliance on manual and conventional approaches, limited technical manpower, and managing subsidy disbursement with minimal technical due diligence. Additionally, project developers find it challenging to aggregate demand, as identifying enthusiastic and financially capable customers can be arduous.

3.5 Location specific constraints

Apart from the reasons mentioned earlier, the adoption of RTS in India is also affected by location-specific miscellaneous constraints, both technical and non-technical. In densely populated cities with substantial electricity demand, many potential locations for RTS exist (MNRE 2011), but not every resident in multi-story buildings has rooftop access or usage rights. For example, in Nagpur, a city with ample solar insolation and around 532,000 properties with RTS potential, only 0.5% (approximately 2,500 residential and non-residential properties) have installed RTS systems, despite a 5% rebate on property

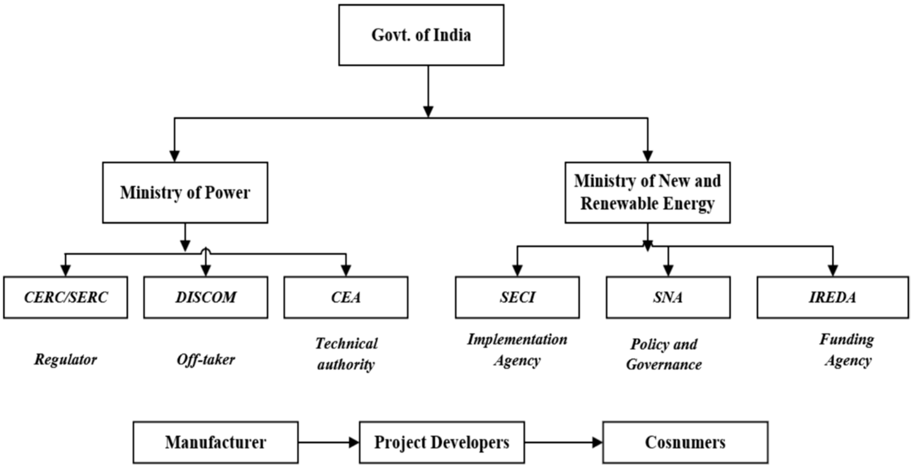

Fig. 2 Stakeholders and their role in RTS implementation in India

tax offered by the city administration for adopting RTS (Khandekar 2021). The connection and integration of residential RTS systems face challenges due to technical limitations of the distribution transformer, potentially operating at partial or full capacity, with reported barriers including high investment costs, complex installation processes, and delayed services. In urban areas, residents of multi-story buildings typically share a single electricity meter but lack access to rooftop space, presenting a significant constraint despite being non-technical in nature. As a result, potential consumers may refrain from adopting RTS systems due to non-technical reasons.

Despite the presence of comprehensive net and gross metering regulations in most Indian states (refer to Table S2), there is a significant delay in capacity expansion. This lag could be attributed to the variation in these regulations across states, where not only the maximum capacity of RTS systems is restricted (Sarangi and Taghizadeh 2021), but also there is a cap on the amount of power that can be fed back into the grid. Additionally, managing reactive power by the DISCOM affects the economics of RTS projects.

4 Key stakeholders in Odisha for rooftop solar implementation

As stated earlier, the implementation of RTS in India is carried out through multiple agencies in a collaborative manner, and this holds true for Odisha as well. The various agencies involved (as outlined in Table 1) and their respective roles in executing RTS projects in Odisha are elaborated in the following subsections.

4.1 The state nodal agency: Odisha Renewable Energy Development Agency (OREDA)

The State Nodal Agencies (SNAs), including OREDA for the state of Odisha, are state-owned bodies with the primary responsibility of implementing MNRE policies, achieving targets for the RE mix, and promoting overall RE projects. SNAs facilitate the implementation of RE projects within the states by providing a policy framework, offering support and incentives to individuals or groups for development, and working towards fulfilling the Renewable Purchase Obligation (RPO) targets set by the GoI (Gupta and Purohit 2013, Purohit and Purohit 2017; Sharma et al. 2017b) Consequently, SNAs play a central role in spearheading the RTS program in the states, in collaboration with other local agencies such as DISCOMS, SERC, etc.

4.2 Urban local bodies

Urban local bodies (ULBs) in India serve as government entities responsible for urban planning, formulating regulations for building construction, and ensuring various population-related services such as public health, sanitation, conservancy, and solid waste management. Municipalities and city corporations are active participants in RTS initiatives, aligning with the country's commitment to promoting RE and achieving targets set under the NSM. Their dedicated efforts contribute to the widespread adoption of RTS, leading to enhanced energy self-sufficiency, reduced greenhouse gas (GHG) emissions, and the overall development of sustainable urban areas. The Solar City program of GoI further encourages ULBs to create a roadmap for 'renewable energy cities' or 'solar cities' (Trivedi et al.

Table 1 Key stakeholder in Odisha for RTS implementation

Stakeholder	Role
Odisha Renewable Energy Development Agency (OREDA)	• Policy formulation • Target setting • Consumer awareness • Development assistance • Subsidy oversight and distribution • Monitoring and evaluation
Urban Local Bodies (ULBs)	• Structural planning • Regulations/by-laws • Setting timelines • Providing incentives • Consumers encouragement • Monitoring and enforcement
Odisha Electricity Regulatory Commission (OERC)	• Drafting rules and regulations • Formulating implementation guidelines • Deciding fees/charges • Ensuring timelines
Distribution Companies (DISCOM)	• Feasibility assessment • Ensuring connectivity • Metering and billing • Commercial settlement • Parodic inspection
Consumers	• Application filing • Selection of project • Project installation • Operation and maintenance • Funding arrangements

2018). However, in the context of RTS, ULBs face several challenges, including: a) lack of ULB-focused policies, programs, and targets for RTS implementation, b) limited consumer awareness about RTS benefits, c) insufficient amendment, adaption, and enforcement of existing building bylaws to support RTS installations, d) limited RTS installations at ULB establishments, e) coordination gaps among ULBs, SNAs, and smart cities in RTS initiatives, and f) lack of a suitable financing mechanism to support RTS projects.

4.3 Odisha Electricity Regulatory Commission (OERC)

OERC is the regulatory body responsible for overseeing the electricity sector in the state of Odisha, India. It was established under the provisions of the Electricity Regulatory Commissions Act of 1998 (The Electricity Act 2003). The primary objective of OERC is to regulate various aspects of electricity including generation, transmission, distribution, supply, and usage, while safeguarding the interests of both consumers and utilities. OERC plays a pivotal role in promoting RTS installations by enacting net metering regulations, determining suitable tariffs, setting RPOs, providing regulatory guidance, and addressing consumer grievances. Through these initiatives, OERC fosters a favorable environment for the growth of RTS, leading to increased adoption of RTS and promoting sustainable and clean energy generation in Odisha.

4.4 Distribution utility (DISCOM)

DISCOMs play a vital role in promoting and integrating RTS in India. Their contributions encompass connecting to the grid-network, facilitating net metering, ensuring grid compatibility, handling metering, energy banking and billing processes, as well as conducting capacity-building activities. These efforts significantly aid in the growth of RTS installations in India and promote sustainable and decentralized RE generation. As a result, the involvement of DISCOMs in RTS initiatives is crucial for the successful integration of distributed solar power into the electricity grid.

4.5 Consumer/applicant

Consumers or applicants are potential and enthusiastic individuals who are eager to adopt RTS systems. They start by applying for the project, going through regulations, following necessary steps and procedures, and ultimately choosing the RTS system. Hence, consumers need to be well-informed about the overall approach to RTS implementation, including the application process, required approvals, available supporting measures, identification of appropriate technology and project developers, etc. Additionally, they should have access to information about capital investment, annual energy generation, cost economics, etc., before proceeding with the RTS system installation. It is equally important for consumers to be acquainted with the operations and periodic maintenance requirements of the RTS system. The implementation of RTS requires coordination and approvals from the various agencies and stakeholders mentioned above. The following section offers a comprehensive overview of the standard process followed by OREDA for RTS implementation, outlining each step-in detail.

5 Current practices for RTS implementation in Odisha

Grid-connected RE projects in India generally follow a well-defined step-by-step approach, beginning from information collection to project installation and, if applicable, subsidy disbursement (MNRE 2017, 2018). It is important to note that subsidies are exclusively available for residential consumers of RTS in India. This approach is relatively consistent across all states in the country. In this section, we review the existing process in the state of Odisha, considering it as a representative case. Figure 3 illustrates the sequential steps involved in the implementation of RTS projects in Odisha.

5.1 Information access

The first step in the RTS installation process involves accessing information, wherein the consumer or applicant gathers essential details about RTS, native state policies, regulations, application procedures, available vendors/ channel partners, or installers in the market, estimated investment, subsidy provisions, annual energy yield, and financial benefits, among others. In most cases, this information is provided through the Customer Relationship Centre (CRC) established by the State Nodal Agency (SNA) of Odisha (i.e., OREDA), aimed at assisting potential applicants. The CRC delivers this information through OREDA's website or helpline numbers. Additionally, applicants may also receive

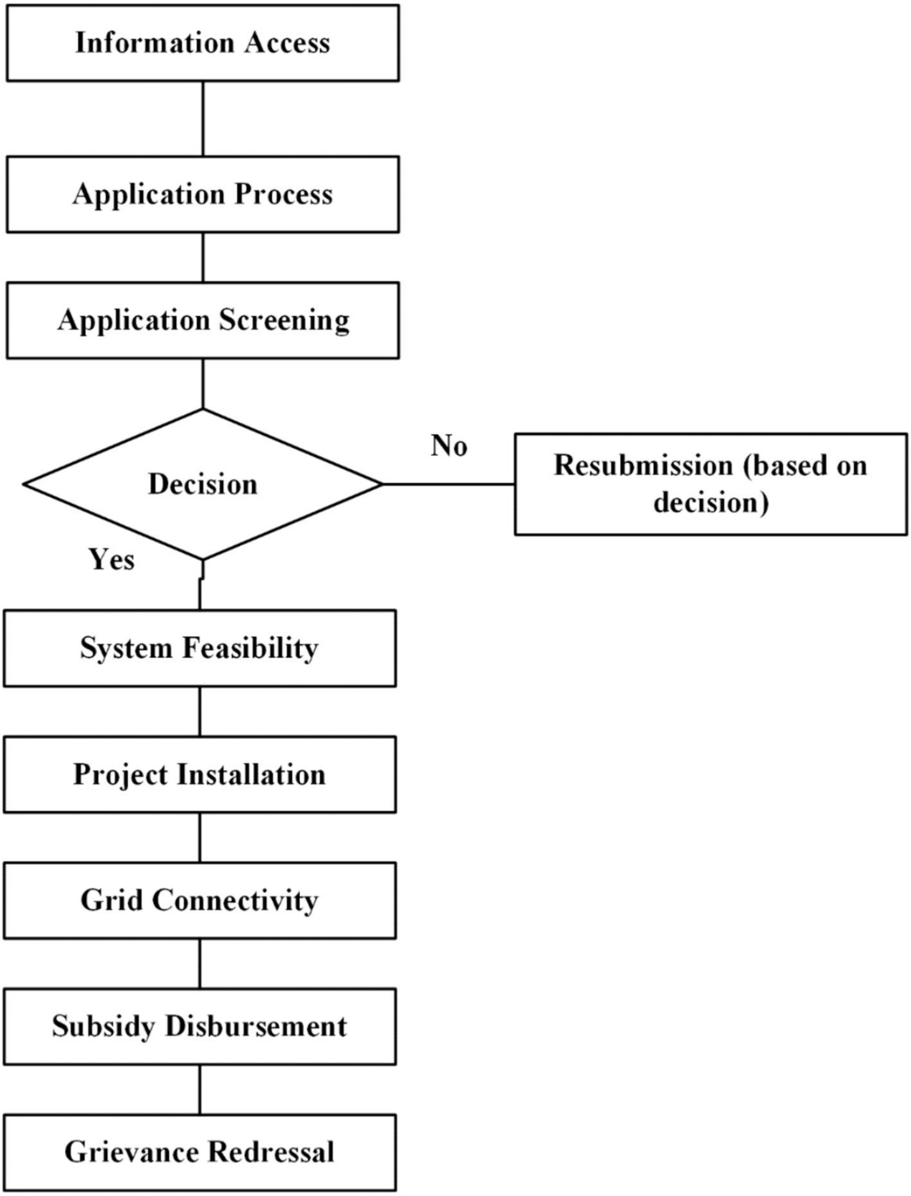

Fig. 3 Key steps of RTS implementation in Odisha

details about authorized vendors and channel partners for RTS installations, as empaneled by OREDA. However, in some instances, applicants still need to put in considerable effort to collect relevant information, forms, and formats required for RTS project installation from DISCOMS or OREDA offices.

5.2 Application process

Once the applicant has gathered all the necessary information as described in the first step, they proceed to apply for the RTS project and submit their application to the relevant implementing agencies. The application, along with other required documents, undergoes a screening process, typically conducted at the Division Office of the local utility and DISCOMS. If the RTS project falls under a subsidy scheme, the applicant must submit a separate form to avail the subsidy benefits to the SNA. In Odisha, the submission of both the forms for grid connectivity and subsidy was done offline.

5.3 Application screening and system feasibility

After the applicant submits the application, the third step involves a thorough review by the relevant authorities in accordance with the regulations governing the installation of RTS projects. This review includes examining details such as the applicant's name, project site or location, project capacity, sanctioned load, and eligibility for subsidy disbursement, etc. Once the initial screening of the application is completed, it undergoes technical scrutiny at the utility or DISCOMS offices. During technical screening, DISCOMS assess various parameters, including connected and contracted load, transformer interconnection, feeder capacity, metering details, etc., based on the specific regulations of the state where the RTS project is being applied for. In many states across India, both the SNA and DISCOMS participate in application screening. The SNA conducts general screening for subsidy disbursement, while the DISCOMS handles both general and technical screening. Under general screening, SNA officials inspect and verify the information provided by the applicant in the application form, such as roof area, project capacity, and the applicability of subsidies or other supportive measures.

On the other hand, DISCOMS conducts a generic screening to ensure the completeness and accuracy of the application, while technical screening involves an onsite feasibility assessment of the RTS project. This assessment verifies the technical parameters, such as the sanctioned load, transformer capacity, metering arrangement, and other relevant factors stated in the application. As per the regulations, DISCOMS officials must carry out the onsite feasibility assessment within seven days of receiving the application. Once the feasibility check is completed, a technical feasibility report is prepared. If the report confirms that the project meets the necessary criteria, the applicant receives a no objection certificate (NOC) to proceed with the installation of the RTS project. The entire screening process before the web-based IT solution is depicted in Fig. 4.

5.4 RTS project installation

Following the application screening and feasibility assessment, the subsequent phase involves the actual installation of the RTS project. In Odisha, regulators allocated a timeframe of 90–180 days for project installation. The applicant can either procure the necessary project equipment/material directly or engage empaneled vendors (channel partner) to handle the procurement and installation process. Upon completion of the project installation, a work completion certificate is issued by the respective empaneled vendor.

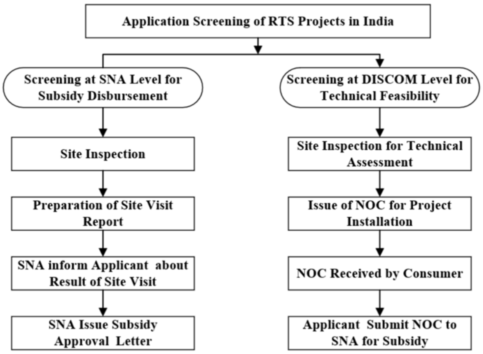

Fig. 4 Application screening process of the RTS project

5.5 Grid connectivity

The crucial step of "grid connectivity" commences after the project installation is finalized. Grid connection ensures the safety and quality of power supply. Upon receiving the work completion report from the applicant or project owner, a representative from DISCOM conducts a site visit. During this visit, testing, commissioning, and synchronization of the RTS project are ensured. Upon successful commissioning, a letter of synchronization is issued to the applicant by the DISCOM.

5.6 Subsidy disbursement

Subsidy disbursement requires prior approval from the relevant agencies responsible for project implementation, typically SNA and DISCOMS. In most cases, the MNRE allocates funds to SNAs, and subsequently, the SNAs disburse the subsidy to the end consumer. The disbursement process is also influenced by the policies of the respective state. Figure 5 illustrates the subsidy disbursement under various scenarios of project implementation, including consumers opting for RESCO or financing institutions.

Upon completing the installation and commissioning, eligible consumers apply for subsidy disbursement by submitting a copy of the project completion report to SNA.

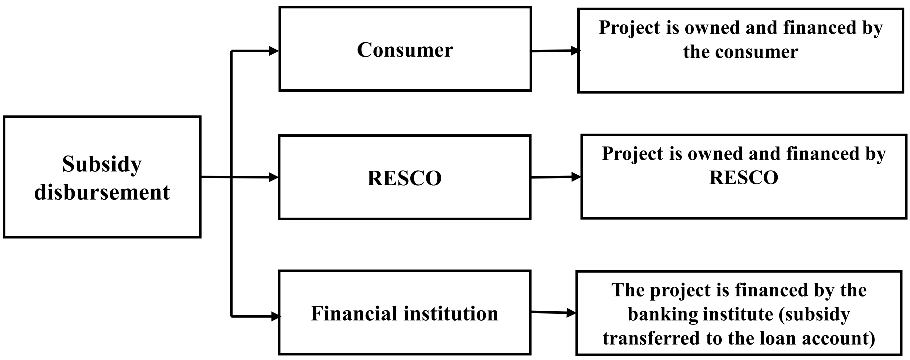

Fig. 5 Subsidy disbursement of RTS project under different scenarios

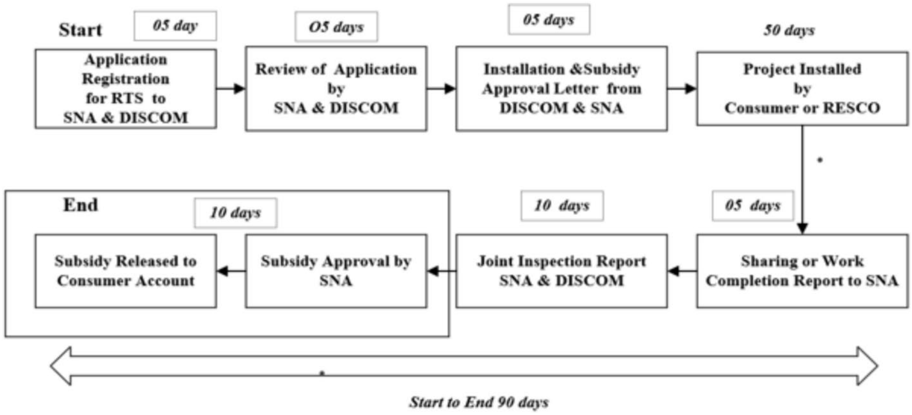

Fig. 6 Subsidy disbursal mechanism for RTS projects in SNA

Subsequently, SNA schedules a site visit and, upon satisfactory results of the inspection, releases the subsidy to the applicant's bank account given at the application stage. The detailed steps involved in the entire process, along with the corresponding time consumption, are depicted in Fig. 6.

5.7 Grievance redressal

The grievance redressal step is the final stage of RTS installation, encompassing all the preceding steps, and provides support to the applicant in case any grievances arise during the entire execution process. SNA has established customer relationship centers and helpline numbers to assist the applicant in resolving their concerns. In most states across India, consumer grievances are addressed through helpline numbers. However, if the consumer is not satisfied with the resolution, they have the option to approach the nodal person at local SNA offices for further assistance.

6 Limitations of the existing approach to RTS implementation in Odisha

The steps outlined in Section 5 may appear straightforward and well-organized, but in reality, they suffer from significant chaos and time-consuming processes. Each project installation requires the involvement of multiple agencies, which can be quite cumbersome. Additionally, while the subsidy scheme aims to alleviate the financial burden for potential RTS customers and make the projects financially appealing, availing the subsidy itself proves to be a tedious task. This is due to the involvement of various government agencies such as MNRE, SNA (OREDA), local DISCOM, etc. Consequently, the disbursement of subsidies into the applicant's account typically takes around six months to a year. The primary gaps in the existing process of RTS implementation in India, along with recommendations for improvement or replacement, are summarized in Table 2.

As observed in Table 2, the intricate and repetitive nature of the RTS implementation process leads to significant delays in responses from distribution utilities, SNAs, and other relevant agencies. This delay creates a substantial gap between the targeted and actual status of RTS project implementation by the state. To address these gaps, it becomes imperative to adopt an efficient framework, which can be achieved by thoroughly analyzing the overall RTS implementation process. The framework proposed in the following section aims to integrate all key stakeholders involved in RTS project implementation onto a unified web-based IT platform. However, implementing such an intervention requires first defining the roles and responsibilities of each agency involved in the RTS project implementation and subsequently standardizing the existing process. Adoption of IT solutions can play a crucial role in resolving the aforementioned challenges and pave the way for developing a novel RTS implementation framework in the states, which can potentially be replicated in other states across India.

7 IT-based RTS implementation approach

As discussed in earlier sections, accelerating RTS project implementation and meeting clean energy targets necessitate stakeholders to adopt efficient practices. Consumer awareness, technical knowledge, and cost–benefit assessments are crucial for seamless project implementation. Barriers faced in RTS implementation in India, particularly in Odisha, underscore the need for IT solutions. A web-based platform integrating all implementing agencies aims to streamline processes, reducing time and manual interventions. The web-based IT platform approach enhances efficiency and streamlines the roles of individual agencies in RTS implementation. It centralizes approvals and subsidies availing through a single window, enabling parallel processing of various tasks. This multi-faceted system grants stakeholders' access to project information through a unified master platform. The subsequent sub-sections detail the proposed IT-based approach to RTS implementation in Odisha.

7.1 Registration and application process, support on decision making

In the proposed approach, prospective customers are required to register under a specified category corresponding to their application. To facilitate initial techno-commercial due diligence, the web-based IT platform integrates a solar calculator that provides essential technical requirements such as annual solar irradiance, energy generation estimates, shadow analysis, sun-path analysis, technical details, GHG reductions, project cost estimates, and financial metrics (such as payback period, internal rate of return). Additionally, it suggests key products like solar PV modules, inverters, cables, etc. It also generates a high-level bill of quantity based on input parameters from the consumer, such as geographical location, roof area, orientation, tariff, and sectioned/connected load. Additionally, consumers can utilize a mobile application (Mobile App) to support their decision-making process. In addition, consumers unfamiliar with gadgets and digital technologies can receive registration assistance from Lok Mitra Kendras, which are established at the Panchayat[1] level. These centers play a vital role in aiding and educating citizens about government schemes, including those involving online components.

[1] "Panchayat" refers to a local self-government institution in rural areas of India, typically consisting of elected representatives who govern at the village or small-town level.

Table 2 Gaps and recommendations on existing consumer proliferation of RTS in India

Parameters	Limitations	Recommendation(s)
Information access	• Limited information regarding the implementation of RTS projects	• A comprehensive online platform should provide data on project strategy, resource evaluation, essential components, financial viability, funding options, and government-endorsed installers with pricing estimates to aid consumers in making informed choices
Application process	• Online application submissions are limited in Indian states. Currently, applicants must fill separate forms for SNA and DISCOM for subsidies and connectivity. Online fee submission is unavailable	• A unified web platform is needed for applicants to access and submit all required forms, including payments. SNAs and DISCOMs should have access to download and process applications electronically, promoting online fee submission
Application processing	• In the current practice, SNAs perform two site inspections before and after project installation, causing delays. The process lacks online approval inclusion	• DISCOMs issuing NOCs before SNA review could streamline evaluation and save time. Collaborative site inspections with both SNA and DISCOM during project connectivity could expedite subsidy disbursement, reducing processing time and administrative burden
Feasibility assessment	• At present, DISCOM officials conduct two feasibility assessments for grid connectivity and RTS project viability, both before and after project installation	• Feasibility assessments and interconnection verifications can follow RTS project installation, with site assessments afterward. DISCOMs may exempt consumers selecting approved vendors
Interconnection agreement	• In the current practice, applicants must sign an interconnection agreement with DISCOM before installing the project, constituting a separate process	• Integrating the agreement into the application form, particularly for small consumers, would simplify the process by eliminating the need for a separate agreement signing
Subsidy disbursement	• There is currently no mechanism for disbursing subsidies through online channels	• Subsidies ought to be directly transferred to the beneficiaries' accounts
Metering and billing	• At present, transparency is lacking in on-site metering and billing, especially regarding surplus power fed back to the grid, causing uncertainty and confusion among consumers about surplus energy resolution	• DISCOMs must furnish consumers with clear explanations, especially regarding net metering, and ensure their billing software aligns with the net metering framework for RTS projects
Vendor empanelment	• In the current practice, the Ministry determines benchmark costs for subsidy distribution without considering potential competition among vendors, thus potentially missing opportunities for cost reduction	• A more efficient strategy would be to solicit price quotes from certified vendors, organized by project capacity ranges and fundamental components, following MNRE guidelines, on a biannual basis.

Moreover, applicants will receive evaluations on pertinent information concerning the project site, technology, sanctioned load, key equipment, solar resources, cost economics, prevailing business models in the market, and SNA's empaneled channel partners. These vendors or channel partners have been empaneled following MNRE guidelines through a standardized process. Once applicants have reviewed this information, they can proceed to complete the application form. The required fee for SNAs can be conveniently deposited online, with an acknowledgment receipt available online upon payment. Subsequently, after uploading the payment receipt, applicants will receive an official work application form from DISCOMS through the web-based IT platform. Similarly, applicants will obtain a subsidy application form from the SNA through the same process.

7.2 Application screening and system feasibility assessment

Upon successful completion of the registration process, the application will be forwarded for technical screening. To keep the authorities informed, both an email and an SMS notification will be sent. During this screening phase, both DISCOMS and SNA will assess the feasibility of the RTS project, taking into account factors such as the applicant's credentials, location, project capacity, and other relevant details. The technical screening will focus on parameters like interconnection, rooftop area, tentative capacity, and expected energy generation etc. The purpose of the technical screening by DISCOMS is to ensure the feasibility of the RTS systems, their impact on the utility grid, adherence to sanctioned load limits, and eligibility for the subsidy based on the information provided in the application. It is important to note that the screening processes carried out by both DISCOMS and SNA will run concurrently.

Upon completion of the screening, the applicant will receive approval to sign an interconnection agreement with the local DISCOMS. Additionally, the authorities will prepare a feasibility report. Once the feasibility report is completed and submitted, an online NOC will be issued to the consumer to connect the project to the grid. The applicant will then submit this NOC to the SNA, and SNA will subsequently approve the subsidy and issue the sanction letter. The sanction letter for the subsidy will also be sent through similar means to the NOC.

7.3 Installation of the project

Once grid connectivity and subsidy approval are obtained, the next crucial step is the installation of the RTS project. However, at this stage, the applicant may have limited knowledge about the channel partners approved by the SNA. To address this, the web-based IT platform will provide comprehensive information about the authorized channel partners/vendors, along with the standards and regulations applicable to the RTS system's equipment. The platform will also be accessible to vendors, allowing them to submit installation price quotes, fostering healthy competition in the market.

With the availability of detailed vendor information, the applicant can make an informed choice and select the most suitable vendor to commence the project installation. Once the installation is completed, a work completion report must be uploaded on the web platform. By leveraging the web-based IT platform, the entire process of project installation is expected to take 45 days, compared to 55 days in the absence of such a system. This reduction in time is attributed to the streamlined processes facilitated by the web platform, enhancing efficiency and expediting project implementation.

7.4 Site inspection and commissioning of the project

As mentioned in the preceding section, the applicant will submit the work completion report and request DISCOM officers to conduct a site inspection for the project's commissioning. During this site inspection, DISCOM authorities will thoroughly assess the project in accordance with their regulations and requirements. Following a satisfactory inspection, the DISCOM officials will prepare a site inspection report, which will be uploaded on the web platform. Based on this report, higher authorities will issue a project commissioning certificate, which will then be forwarded to the applicant's registered email address and the SNA for reference. Upon receiving this information about the project's commissioning, an SNA officer will schedule a site visit to ensure compliance with the standards set by MNRE for subsidy disbursement. Upon finding the project compliant, the SNA will issue certificates to both the applicant and the system installer.

7.5 Subsidy disbursement

The inspection report from SNA and the certificates issued to both the installer and the applicant will be submitted to higher authorities for their final approval. Subsequently, the accounts department will be notified to release the subsidy once the report's outcomes are deemed satisfactory. Finally, the accounts department of SNA will disburse the subsidy to either the applicant or the project installer, following the regulations of the state. To expedite these administrative approvals, the targeted time for completion will be just 15 days. The entire proposed process is depicted in Fig. 7 for clarity.

7.6 Impact on RTS implementation

The proposed web-based IT platform and mobile app have been finalized after integrating all the suggestions from OREDA, and the final version has been launched on the website. The finalized web platform includes the capability to register all types of consumers, including residential, commercial, institutional, and industrial. However, particular

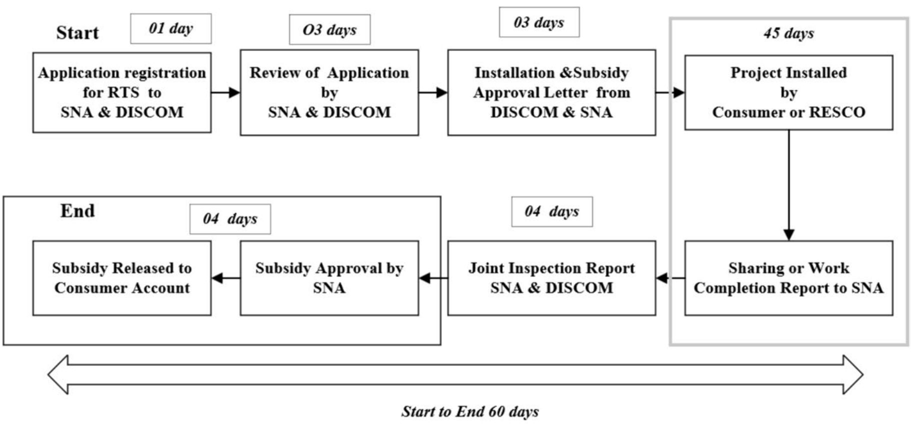

Fig. 7 Proposed IT-based consumer proliferation and RTS implementation process

emphasis was placed on registering residential consumers eligible for subsidies. The platform commenced operations in the financial year 2019–20, and to date, 850 projects totaling 33 MWp (with capacities ranging from 1–10 kW) of residential grid-connected RTS projects have been installed. As illustrated in Fig. 8, the installed capacity of RTS in the residential sector of Odisha exhibited a significant increase after (light blue bars) the implementation of the web-based IT platform compared to before (dark blue bars). Consumer service feedback has been gathered, and the entire duration of project execution from application to subsidy disbursement has been monitored. For example, three representative RTS systems with capacities of 5 kW, 2.5 kW, and 5 kW were implemented at the premises of three consumers in 47, 58, and 55 days, respectively. Overall, the process was completed in fewer than 50 days on average.

8 Consumer proliferation

Traditionally, most Indian states have relied on conventional approaches to encourage RTS adoption. Nevertheless, notable web-based platforms have been introduced at the central level by the MNRE. One such initiative is the online platform called Solar Photovoltaic Installation (SPIN) introduced by the MNRE. SPIN enables monitoring of the RTS sector's progress in India and offers features to ensure transparency in RTS implementation. These features include empanelment of RTS stakeholders, time-bound achievement of RTS targets with involvement from empaneled agencies, monitoring of installed RTS projects, public awareness campaigns, and the creation of a Geo-referenced database of all RTS projects.

On January 22, 2024, the Indian government launched the Pradhan Mantri Suryghar Yojana (PMSY), with the goal of outfitting 10 million homes with rooftop solar panels, focusing primarily on low and middle-income residents. This initiative offers reliable electricity and income opportunities by selling surplus power. Additionally, the PM Surya Ghar: Muft Bijli Yojana (PM-SGMBY) was launched on February 13, 2024, aiming to provide 300 free units of electricity to another 10 million households nationwide. Online registration for both schemes has commenced via the national portal (PMSY at https://pmsuryodayyojanaonline.in and PM_SGMBY at https://pmsuryagharyojana.in/). However, it is

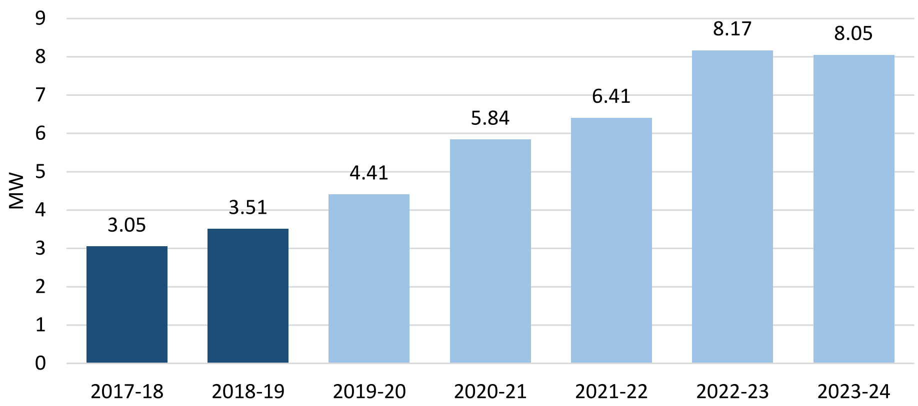

Fig. 8 Year-wise RTS installed capacity (in MW) before (dark blue bars) and after (light blue bars) in the residential sector in Odisha Source: MNRE (2024)

uncertain whether these schemes will supplant the existing RTS implementation mechanism or run alongside it. Both initiatives promote RTS, with PM-SGMBY catering to all residential consumers and PMSY focusing on low and middle-income households. PM-SGMBY provides central financial assistance of 60% for 2 kW systems and 40% for systems between 2 to 3 kW capacity (MNRE 2024), while PMSY offers a subsidy of up to 60%, increasing to 70% for consumers in hilly/northeastern states and union territories (Sharma 2024). Application procedure for PMSY scheme is also using IT solutions where a dedicated online portal is launched for registration process. However further guidelines for installation and subsidy disbursement are not clear yet.

Furthermore, the MNRE, along with the World Bank, Asian Development Bank (ADB), German Corporation for International Cooperation (GIZ), European Union (EU), and the United States Agency for International Development (USAID), has collaborated on a joint program to provide technical assistance and support for RTS implementation in India. As part of this program, a PV Rooftop Cell has been established at MNRE through technical cooperation with the EU. The PV Rooftop Cell aims to expedite RTS implementation and support stakeholders. It provides technical support to Discoms and SNAs to facilitate faster deployment of grid connected RTS projects in the country. The support covers various aspects of RTS projects, including gap assessment and action plans to boost installations, establishing a dedicated RTS program as a platform for technical experts, facilitating technology handholding, and providing training/capacity building. Additionally, dedicated web portals are being developed at the national and state levels to inform, assist, and support potential customers regarding RTS installations. A brief overview of the activities conducted by these organizations is presented in the following subsections.

8.1 IFC interventions on web-based consumer proliferation

The International Finance Corporation (IFC) has structured and provided support to the SNA of Odisha, in developing and launching an IT-based consumer proliferation platform to accelerate the adoption of RTS in the residential sector of the state, as part of the Eco-Cities initiative of the EU (Eco-Cities India Programme 2015). Following a thorough review of the existing RTS proliferation process in the state, an optimized approach was recommended, integrating IT into the entire RTS implementation process for both small-scale (residential sector) and large-scale capacities (commercial and industrial sectors). To facilitate this initiative, a web platform (http://rts.odisha.gov.in/) and a mobile application named "OREDA Solar" were created and made publicly available (OREDA 2019). As a result, the time taken for application processing and subsidy approval was reduced by approximately 60 days (based on the RTS model) compared to the previous process, which used to take minimum 90 days to complete both connectivity approvals from the DISCOM and subsidy approval from the SNA. After the introduction of this IT platform, approximately 5 MWp of RTS projects were executed in the state within a mere six-month period. Furthermore, the insights gained have been applied in collaboration with the State Nodal Agency (SNA) of Maharashtra, namely MEDA, as part of the Eco-Cities program.

8.2 IGEN- GIZ initiative

Since 2015, the Indo-German Energy Program (IGEN) has been actively supporting the growth of the RTS sector in India through skill transfer and capacity development (IGEP 2022). The program is dedicated to enhancing the capabilities of various stakeholders of

RTS sector, encompassing policy and regulations drafting, ground implementation, and accelerated diffusion of RTS projects. As part of achieving these objectives, web-based IT consumer proliferation platforms have been developed for selected SNAs in specific states and Union Territories (UTs) in India, namely Himachal Pradesh, Jharkhand, and Daman and Diu. For instance, a web-based IT platform enabling online application submission and subsidy disbursement has been created for the state of Jharkhand. This platform is hosted on the website of the respective SNA of Jharkhand, facilitating seamless interactions and streamlining the process for consumers.

8.3 EU- MNRE initiative

The EU-India Technical Cooperation Program has been operational since September 2014 (MNRE 2017), offering beneficiaries and participants opportunities to enhance their technical and institutional capacity. In alignment with its objectives, a project team is closely collaborating with the rooftop cell of the MNRE and assisting various SNAs in India to develop IT-based consumer proliferation approaches for RTS implementation. As part of this program, a web-based platform for consumer proliferation has been successfully developed for the SNAs of Uttar Pradesh, Punjab, and Delhi states in India. Additionally, mobile applications facilitating consumer proliferation and RTS installations have been developed for these states. Moreover, apart from the IFC's work in Maharashtra, the EU team has also supported the Maharashtra Energy Development Agency (MEDA) in developing a mobile application for RTS consumer proliferation. Through these efforts, the EU-MNRE initiative aims to streamline RTS implementation and promote widespread adoption of solar energy technologies across different states in India.

8.4 World bank initiative

The World Bank is actively supporting the MNRE in its mission to promote widespread grid connected RTS installations by providing a loan of US$ 625 million to the State Bank of India (SBI) (World Bank 2020). In partnership with the World Bank, MNRE has launched a collaborative program titled "Sustainable Partnership for Rooftop Solar Acceleration in Bharat" (SUPRABHA) to tackle barriers in the RTS sector (SUPRABHA 2022). This five-year solar technical assistance program focuses on various activities, including policy and regulations enhancement, capacity building, consumer awareness raising, process streamlining, and demand aggregation for RTS. One of the key aspects of the SUPRABHA program involves introducing IT solutions to SNAs for the development of digital web portals to standardize the RTS application process. Additionally, state governments are provided support and infrastructure to update policies/regulations, thereby facilitating the growth of RTS.

At present, more than 17 states in India have been identified to receive technical assistance under this program, aimed at expediting the adoption of grid-connected RTS. States like Meghalaya and Sikkim have already begun formulating their RTS policies. Furthermore, the program has been successful in generating demand aggregation support for bidding, with partner states such as Delhi, Madhya Pradesh, and Chhattisgarh collectively seeking over 120 MW of RTS installations (Shah 2018). The SUPRABHA scheme involves a diverse range of stakeholders, including consumers, regulators, distribution companies, financial institutions, and entrepreneurs. As part of the program, the SBI has recently conducted solar training for its employees to enhance their understanding of solar concepts and streamline the approval process for solar loans. So far, 150 SBI officers have undergone training as part of this initiative. Overall, the SUPRABHA program is making significant strides in promoting RTS and enhancing solar energy adoption in India.

9 Conclusions

Rooftop solar energy is a crucial element in promoting RE at the household level, contributing significantly to combating climate change and achieving Sustainable Development Goals. Despite its potential, India fell short of its 100 GW solar target by 2022, and RTS plays a significant role in this gap. Despite the availability of capital subsidies, the residential sector accounts for only 2.7 GW of the approximately 11 GW total installed capacity of RTS in the country by the end of 2023. This study analyzes the conventional approach to RTS project installation and reviews existing practices by executive agencies, seeking opportunities for improvement. Integrating IT in the RE sector can streamline the implementation process, and the case study in Odisha, India, highlights the benefits of IT solutions in reducing time and enhancing efficiency. For instance, 850 projects with capacities ranging from 1–10 kW (~33 MWp total) were completed through this initiative. Before the adoption of the web-based IT platform approach, the process of single installations and subsidy disbursement typically lasted 90–120 days. However, with the implementation of the web-based IT platform, this timeframe was reduced by 60 days, leading to increased efficiency. The conventional method of consumer outreach and RTS project execution in India is time-consuming and burdensome for consumers and implementing agencies. Involving multiple agencies results in redundant processes, wasting resources and hindering RTS installation targets. The Odisha case study illustrates that such web-based IT platforms can significantly reduce execution time and improve implementation processes overall.

One major challenge faced by potential consumers is the lack of access to a centralized platform providing information on the benefits of RTS systems through cost–benefit assessments. Integrating an IT platform for consumer outreach, including site-specific energy yield assessments and financial calculators, can bridge this information gap. Such a platform empowers consumers with essential information, helping them make informed decisions about RTS implementation. Moreover, it offers details on vendors and empaneled channel partners, simplifying the process of selecting suitable contractors for RTS projects. To further enhance the implementation process, the introduction of competitive bidding through the IT platform can be game-changing. Empaneled vendors submitting price quotes on a platform enable consumers to compare different options, fostering increased vendor competition and potentially reducing installation costs. This may ease the subsidy burden on the government and lower the overall cost of solar energy generation.

In Odisha, as the representative state, the use of web-based interventions via an IT platform led to the installation of approximately 33 MW of RTS projects in residential areas, highlighting the potential for IT-driven consumer outreach to accelerate renewable energy adoption nationwide. State specific policy and regulation may require customization of such platform however, this could be well drafted by an IT expert. To ensure data privacy and security, IT platforms undergo security audits by approved organizations and are hosted servers owned by the state governments. Such IT-based platforms are mandated by MNRE to facilitate the monitoring of national-level RTS projects. Moreover, the

COVID-19 pandemic has emphasized the need for secure and low-contact solutions. The IT-based approach integrated key stakeholders, facilitating the entire RTS implementation process with minimal physical interaction, reducing the administrative burden on implementing agencies and supporting the adoption of RTS projects across India.

In conclusion, the integration of IT interventions in the RE sector has proven to be a valuable solution for streamlining the implementation process and increasing transparency and efficiency. Despite challenges posed by diverse state-specific policies and regulations, IT solutions have demonstrated their ability to streamline processes, improve efficiency, and facilitate widespread RTS adoption. Moreover, the periodic publication of energy generation data from such projects by SNAs or other stakeholders on web-based IT platform could benefit not only the research community but also promote the broader adoption of clean energy options. The insights gained from this exercise could be effectively utilized in the execution of the 'PM Surya Ghar Muft Bijli Yojana,' which aims to provide 300 units of free electricity to 10 million residential consumers in India through RTS. The Odisha case study showcases the potential to replicate this approach nationwide and in other developing countries, expediting RTS adoption and enhancing RE implementation.

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Data availability Data supporting this study is included within the article and supporting materials.

Declarations

Conflict of interest The authors declare no competing interests.

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