Research Paper

A policy framework for integration of renewable energy sources in the Pradhan Mantri Awas Yojna Program: a flagship program for Affordable Housing

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1. Introduction and Background

The world is urbanising fast and this is expected to pace up further leading to around 1.5 billion people residing in urban areas by 2050 (Sharif & Kazim, 2025). This is also backed by growing environmental concerns and adoption of sustainable practices in each of the sectors of economy. This applies to the housing sector as well where sustainability in the affordable housing sector also assumes a critical role. India's trend of urbanisation is also speeding up with increasing population growth evidenced in urban areas which leads to an increased demand for affordable housing. The housing affordability issue is not only affecting people in India but also globally where people at large don't have decent living spaces which affect their overall socio-economic wellbeing, stability and inclusivity of communities at large.

With the growing concerns of mitigating climate change and the attainment of Net Zero Target globally spelt out in in many international agreements, India is also not left behind in this mission. In the global agreements, India has also promised to cut down its carbon (C) emissions and to transition completely to renewable energy resources for meeting its energy requirements by 2030. This will in turn lead the country to achieve its Net Zero Target by 2070. The significant adaptations of RE made at COP 26 can be determined by diving deep into the happenings after the COP 21 (Sharif & Kazim, 2025). With the thrust being laid down by the nation towards reducing its carbon footprint, phasing out the use of coal completely will become absolutely necessary for electricity production by 2040 and reduce overall consumption by 99% by 2060 to attain net-zero carbon emissions by 2070 (Sharif & Kazim, 2025).

With the global shift towards the attainment of Net Zero Target by 2050 globally and 2070 in the Indian context the emphasis of reducing the carbon emmisions produced by the housing sector is limited. The building sector in India accounts for over 37% of the carbon emissions and 24% of GHG emissions in 2021 significantly impacting climate change (UNEP Global Status Report for Buildings and Construction, 2022). The SDG Goal 11 has spelt out that all the member nations should ensure provision of affordable housing with basic services and upgradation of slums by 2030 creating safe, inclusive and sustainable cities. This shows that on a global forum the integration of sustainability in the housing sector is considered, however it is in a very nacent stage in India where integration of sustainable practices in affordable housing sector are less observed demanding further exploration.

In India supply of affordable housing started with the implementation of the first ever National Housing Policy in the year 1988. Deepak Parikh Committee provided the first official definition which has evolved over time till date under the Pradhan Mantri Awas Yojna Urban (hence PMAY U), the most recent flagship program emphasizing on the provision of "Housing for All" by the year 2022. The program aims to bridge the affordable housing gap in the country. To continue with this novel attempt, a 2.0 version of the same program has already been launched with the same intention for another 5 years' period starting from 2024 to 2029. India's flagship PMAY-U has advanced ***"Housing for All"*** through four verticals as directly adopted from the reports published on PMAY including - **"*Slum rehabilitation*" of Slum Dwellers with incentivisation of private parties through provision of land, -*"Promotion of Affordable Housing through Credit Linked Subsidy", - "Affordable Housing in Partnership with Public & Private sectors", -"Subsidy for Beneficiary-Led individual house construction /enhancement"*** (Press Information Bureau, GOI, 2024). PMAY U being the most recent program for catering to the affordable housing need in the country in the era of sustainable development and climate change does not directly integrate the sustainability component like provision of RE in any form at the unit level (CSE, 2020).

The role of integrating RE in the housing sector is being increasingly felt. According to the Report by Godrej Properties Limited (2014) on RE Integration in Buildings: Solar, Wind, and Beyond, RE refers to the energy coming from inexhaustible sources including solar, wind, hydro, tidal, geothermal, and hydrogen. Amongst these solar, wind, geothermal, and hydrogen are the most potent sources for meeting energy demands of buildings (Gabbar and Ramadan, 2025). Unlike finite and harmful fossil fuels, these resources are sustainable and environmentally friendly. With the increasing thrust being laid upon the reduction of carbon footprints, combating climate change and to achieve sustainable development, the integration of RE in various sectors, including building and housing sectors, has become a critical component. The integration of RE in the buildings and housing sector offers both financial and environmental benefits. The RE integrated systems reduce overall carbon footprint and the materials with which these devices are made though have initial costs yet a long durability saving money over the life of the system. Besides RE systems integrated in the buildings enhances its overall value and attractiveness. It also facilitates attainments of valuable Green Building Certification enhancing economic advantages and overall appeal of real estate.

Amongst all the RE sources the sun and wind come for free. Leading to zero fuel costs for producing electricity solar and wind energy sources are already being used in some of the developed as well as rising nations including USA, Europe and China respectively for not only for buildings but also for industry and transport (Climate Action Network Europe, 2021). According to Amplus Solar Report on Hybrid Wind and Solar System – Everything You Need to Know (2024), a hybrid combination of solar and wind energy is emerging as a robust and reliable reserve of energy supply as compared to the traditional power generation solutions. Putting both the sources of energy together leads to power generation throughout the year as wind patterns and solar availability often display an inverse relationship in the Indian context. During the periods of low sunlight such as cloudy days, nights, or early mornings wind speeds tend to be higher. In contrast the on sunny days the wind speed might be lower. This natural inverse relationship ensures more consistent power generation when combined together.

Following a detailed yet concise literature review presented, the research gap was identified that the integration of RE in the affordable housing sector has not been till now adopted at the unit level in PMAY (U) at the unit level. The verticals of ISSR and AHP under the PMAY (U) have the component of integrating solar energy at the common level facilities, however nothing has been mentioned for the unit level integration. Furthermore, the adoption of wind energy which is another free solution to cater to the energy requirements has not been spelt out in the Affordable Housing sector at all, though a central level policy

on Wind-Solar Hybrid Policy was launched in May 2018. With this background of no measures being adopted to integrate solar and wind energy in the affordable housing market and the building sector contributing significantly to a significantly high proportion of carbon emissions and aligning with the country's target to achieve Net Zero emissions by 2070, the implementation of RE sources in the housing sector becomes very critical. Despite the relevance of RE sources being integrated into affordable housing sector, there is no framework that exists in the country for integrating both solar and wind, the most abundantly available RE sources is not yet adopted, and a lacuna exists in the sector. Hence the present study aimed at proposing a hybrid framework integrating solar and wind energy resources at the unit level in the affordable housing sector.

Following the above introduction and background study including a concise overview of relevant literature, the following section discusses the methodology followed by detailed discussion section on the hybrid framework proposed. The last section concludes the research highlighting the challenges and scope of future research.

2. Methodology

The research framework that has been adapted to develop a proposed hybrid framework for the study is entirely based on secondary research. It compromises of a detailed literature study related to background study of PMAY (U) and its overarching presence in the affordable housing sector of India. Further for a clearer and detailed understanding of what is RE and its different sources and how can this be integrated within the housing sector has been understood by conducting a comprehensive literature review. After understanding the different types of RE resources available, it was found that both solar and wind can be integrated together to propose a hybrid framework for integration at the unit level. Further, a detailed assessment of what are the site, location factors, system and equipment factors and financial and practical considerations that are essential for the installation of the hybrid model was assessed.

The following Figure 1 highlights the systematic flow of how the research gap was identified. Further, Figure 2 details out the methodological framework that has been adopted for the present study. In the present context, the study has dealt with in detail only till the identification of the annual savings that the residents are expected to have once the framework is implemented. The cost of installing the hybrid framework at the unit level with all the different components has also been calculated. As a part of the further work, the testing of the ground reality with real time data is needed. This will lead to highlighting any required modifications in the model with implications for the policy integration.

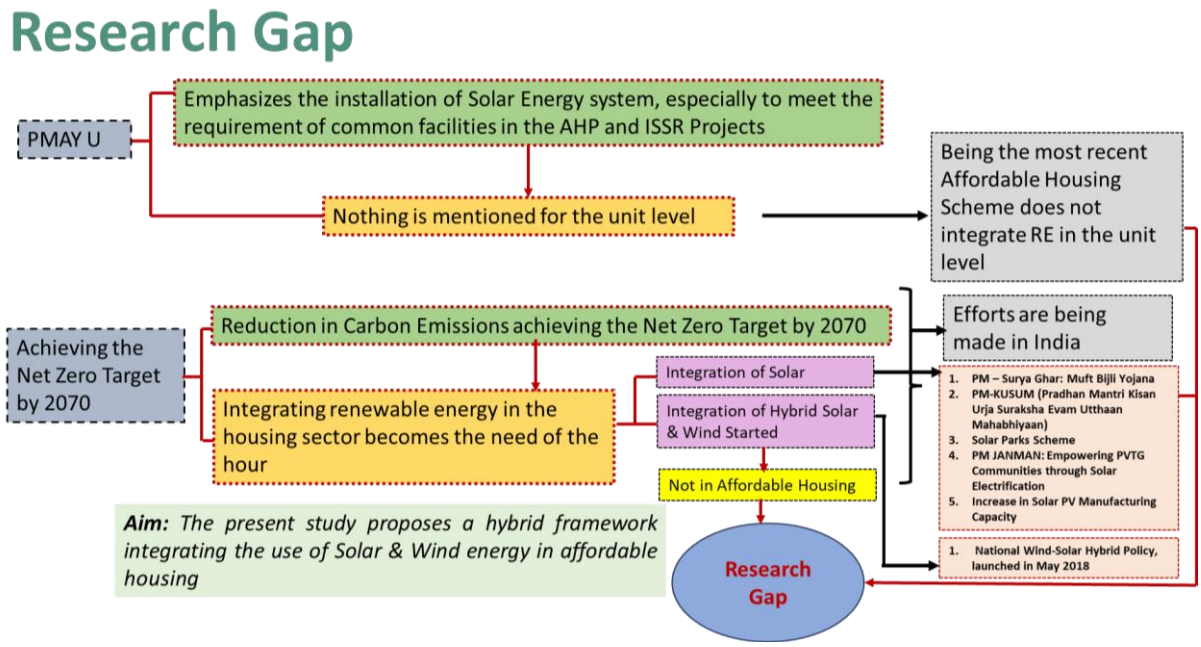


Figure 1. Identification of the Research Gap and need of the present study. Source: Author

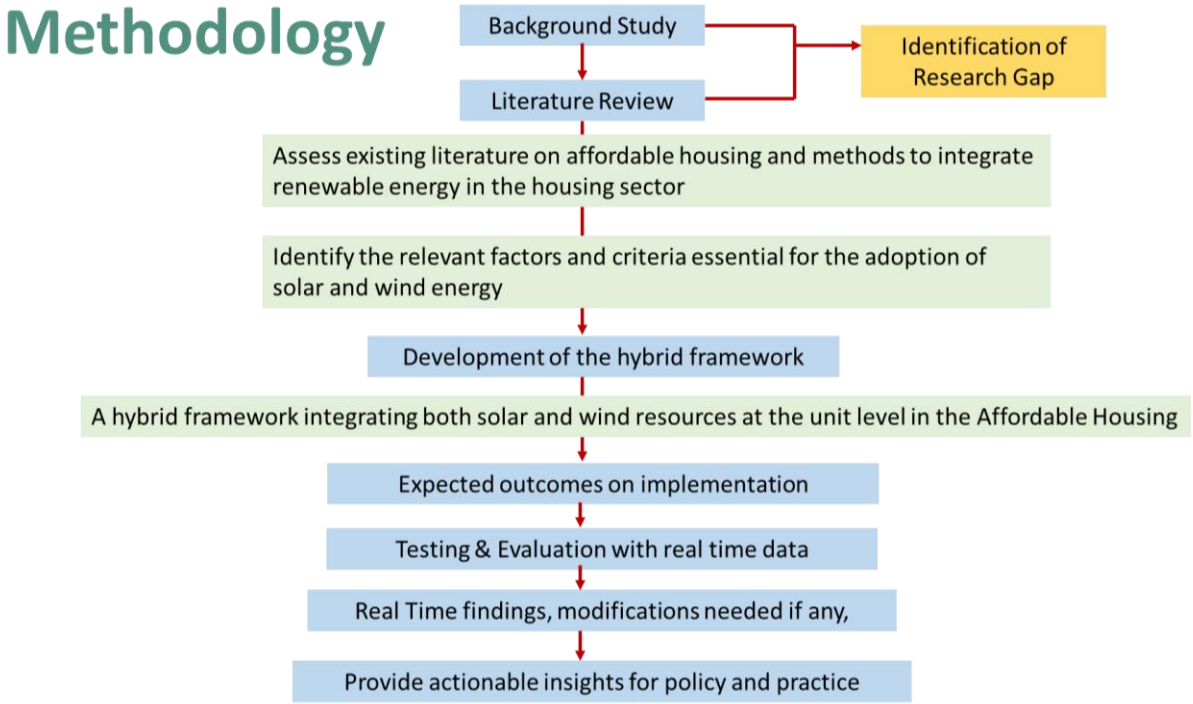


Figure 2. Methodological Framework adopted for the present study. Source: Author

3. Discussion

As the present study proposes a hybrid framework integrating solar and wind energy sources for the installation at unit level in the affordable housing programs, it was important to understand the considerations that are vital for the implementation of both the RE sources. It was equally critical to also identify the components of each of the systems. Hence the initial discussion focuses on the above two aspects. Further delving deeper into the detailed framework that has been developed integrating all the different components and the role of each one of them has also been dealt with and diagrammatically represented. The further subsections also highlight the cost of installation and the annual saving calculations that the residents are expected to gain by installation of the hybrid framework.

3.1. Considerations for the installation of Solar and Wind energy frameworks

Solar energy, being the most abundant and reliable RE resource, if tapped potentially well can cater to the unit's energy requirements to a greater extent. However, before a solar panel is installed there are few considerations that need to be accounted for. These are related to local weather conditions, site and location factors including the duration of sunlight available, type of shading, roof conditions including orientation and size, local regulations and incentives. Other than these, system and equipment factors including the panel efficiency and type, the inverters type, grid connections, warranty and maintenance of these are also equally important. Besides these, the financial considerations including cost of installation, cost and quality of different components, scale of the system are also vital considerations.

The installation of a wind energy system also has a set of considerations that must be kept in mind before installation. These are related to the local weather conditions like solar energy. Amongst the site and location factors the importance of wind speed, direction and consistency plays the most critical role. In the case of wind energy, the turbine settings are however the most important. Turbine conditions include sitting and mounting, tower height and location, obstacle avoidance, mounting type Standalone (pole-mounted) Building-mounted (rooftop), wire run distance are most critical. System and financial viability including the maintenance and safety aspects comprising of energy needs, grid connections, costs and incentives, professional installations are all equally important. However, in this case the neighborhood conditions, relations with neighbors and planning regulations also need to be considered critically before installing a micro wind turbine in a particular location.

Hence after detailing the factors that need to be investigated for the installation of both solar and wind energy systems, it is also necessary to understand the components of each of these systems. Hence the next section highlights the same.

3.2. Components of Solar and Wind Energy Frameworks

The following Figure 3 presents the different components needed to install solar and wind hybrid systems.

For Solar energy the entire system requires a solar panel, inverter, lithium-ion batteries for storage of direct energy, installation kit, cables and fitting wires, fuse, lighting protection box and installation switches.

For the micro wind turbines, the system requires a wind turbine with strong rotor and blades, low speed shat and gearbox, a generator, a nacelle which is a a streamlined enclosure that houses the core machinery of a wind turbine. A rigid control and safety system mechanism along with electronics and monitoring units.

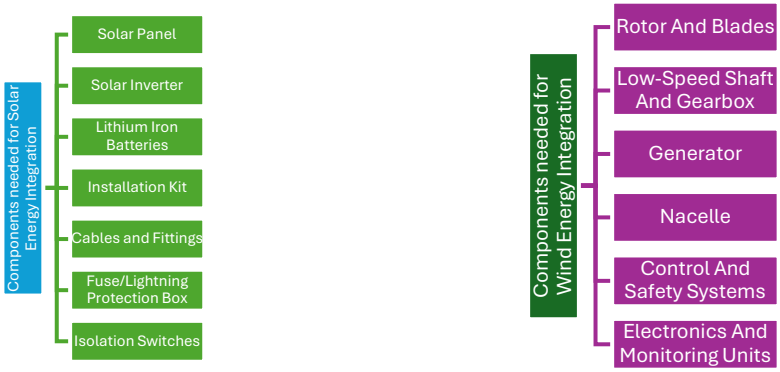


Figure 3. Components of Solar and Wind Energy Frameworks. Source: Author

3.3. The Proposed Hybrid Framework

The following Figure 4 shows the detailed hybrid framework that has been developed encompassing both solar and wind energy resources. It comprises of the following components.

Solar Photovoltaic systems where the primary driver is the sun comprise of a systems of cells made of semiconductors that absorb the sun's light converting it into electricity and transmit energy. Once the panel is exposed to the sun, the semiconductor gets heated leading to the movement of electrons. The panels produce electricity due to the imbalance created by different parts of the panels getting heated up.

Micro-wind turbines are energy producing systems that are driven movement of wind which causes the turbine to rotate leading to the generation of direct current which is then converted to alternating current with the help of an inverter. The micro wind turbines are usually small scale fit for residential use as compared to the conventional ones not suitable for residential energy production.

MPPT Solar Wind Hybrid Controller is a device that optimizes the energy output from both solar panels and wind turbines, using Maximum Power Point Tracking (MPPT) technology to ensure a more efficient and stable power supply to a battery system. This controller manages the charging process from both sources, maximizing power harvest and protecting the batteries from overcharging. It is a key component in off-grid systems for applications like street lighting, monitoring systems, and small power generation.

Battery Storage or battery energy storage systems (BESS), are devices that allow the RE to be saved and then released when the power is needed most. Large scale storage of the RE is facilitated by the Lithium-ion batteries. The electricity genrated from RE can also be used for charging the battery storage system itself. The modern intelligent battery software systems are trained with algorithms to coordinate energy production and have computerised control systems monitoring the storage and of energy to the grid. The supply of energy from the battery storage system peaks during demand periods, keeping costs down and electricity flowing.

The Direct Current(DC) generated from the RE sources needs to to be converted into Alternating Current (AC) for which **an inverter** plays a significant role. This is crucial for using DC power from sources like solar panels or batteries to run AC appliances in homes, or for other applications like in vehicles and solar power systems. Inverters work by using electronic circuits to rapidly switch the direction of the DC current to mimic AC power, allowing devices that need AC power to function when only DC is available. The energy generated is converted to AC current and supplied to the unit for daily use.

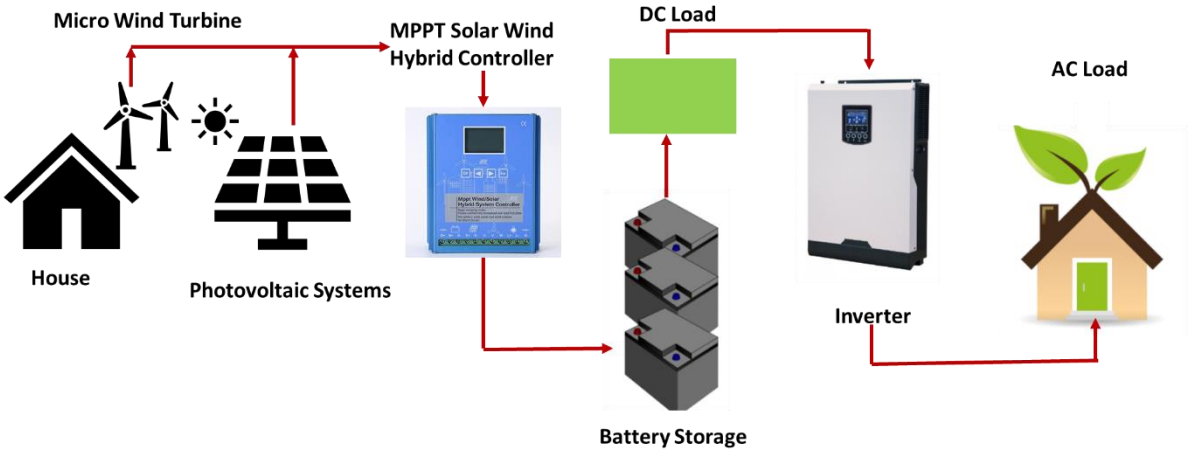


Figure 4. Proposed Hybrid Framework. Source: Author

3.4. The cost of installation required for the Proposed Hybrid Framework

After understanding the individual functions of the different components, it is also important to understand the cost that an individual household will bear for installing this model. In the Indian context the most adapted solar panel for residential use is of 5kW. However, as this framework specifically focuses on affordable housing units, hence it is assumed that 3kW is ideal for such households. Based on the energy requirements at least 10 such panels would be needed per unit cost being Rs 20,000/-, hence a total cost of Rs 2,00,000/- (approx.). A micro wind turbine of 1kW one-unit costs Rs 50,000/-. The cost of MPPT Solar and Wind Hybrid Controller is Rs 40,000/-. The cost of 48V 200Ah lithium batteries for the hybrid systems and the hybrid inverter are approximately Rs 1,15,000 and Rs 45,000 respectively. Summing up all the costs together, it accounts Rs 4,50,000 that an individual household will have to bear installation of this hybrid framework. However, under the Pradhan Mantri Surya Ghar: Muft Bijli Yojana, a household if installs a solar panel varying between 2 to 3 kW they are eligible for a subsidy for Rs 60,000/- to Rs 78,000/-. So assuming the subsidy amount received to be on the lower side and considering that the household is eligible for a subsidy of Rs 60,000, the total cost for installation is approximately Rs 3,90,000/-. The detailed calculations are listed below in Table 1.

Table 1 Total Cost to be incurred for the installation of the proposed framework

Cost Components	Per unit Cost	Cost as per prevailing market rates (₹)
Cost of Solar Panel of 3kW* (needed 10 in nos)	20,000	2,00,000
Cost of micro turbine 1kW needed 1 in no		50,000
MPPT Solar & Wind Hybrid Controller		40,000
A 48V 200Ah lithium battery for solar & wind power systems		1,15,000
Hybrid Inverter		45,000
Sum of all the component costs		4,50,000
Govt Subsidy (2-3kW) Subsidy = Rs 60000/- to 78000/-**		60,000
Total Cost of Installation		₹ 3,90,000.00

Source: Author *Most adopted for residential use in India

**Govt Subsidy under PM – Surya Ghar: Muft Bijli Yojana

3.4. Annual Savings Expected after the integration of the Proposed Hybrid Framework

The total expected annual savings that the household can incur is approximately around Rs 30,000 assuming a per unit retail energy charge from DISCOM (varies from state to state) of Rs 6.5 kWh/unit and the total hybrid energy that can be generated by the household is approximately around 5600 kWh/yr. This total energy produced considers total energy produced by Solar PV of 4700 kW after accounting for the Capacity Utilization Factor (CUF) of 18% which refers to how efficiently the installed capacity of the panel is being used over time. Similarly, the total energy produced by micro wind turbines is 876 kW after accounting for the CUF of 10%. The annual O & M maintenance is Rs 1200/-. Assuming that out of this total energy generated, 80% of the power generated is for self-consumption, the total available energy for use is 4500 kWh/yr.

Table 2 Total Annual Savings Expected after the integration of the Proposed Hybrid Framework

Energy Assumptions & Annual Savings Calculations	Calculations
Total energy produced by the Solar PV	26280 kW
Solar Panel CUF (Capacity Utilization Factor (sometimes called Capacity Factor: how efficiently the installed capacity is being used over time) (18%)	4730.4 kW
Total energy produced by Micro Wind Turbine	8760 kW
Micro Wind Turbine CUF (10%)	876 kW
Total Hybrid Energy Generation	5606.4 kWh/yr

Fixed Charge (Installation + minimum fixed connection charge) @ ₹100 / month	₹ 1200
O & M cost (As 2 % of total capital cost of installation)	₹ 7,800.00
Self-Consumption of the energy generated (Assuming 80% of power generated)	4485.12 kWh/yr
Annual Savings Calculated	
Retail Energy Charge from DISCOM (varies from state to state)	₹ 6.5 kWh/unit
Total Savings from Retail Energy (Annually)	**₹ 29153.28**

Source: Author

4. Conclusion

With the successful integration of the proposed hybrid framework at the unit level, a household is expected to incur the annual savings that have been calculated (Table 2). Besides, this the framework is expected to provide access to stable, affordable, and clean electricity along with the provision of ensured energy security during the power outages, climate-induced disruptions by reducing the dependency on central grids. It is also expected to reduce the overall carbon emissions of a household by 1–1.5 tons per year contributing to the country's Net Zero Target by 2070 and overall contribution to Sustainable Development Goals (SDG 7, SDG 11, SDG 13). Further it is also anticipated to facilitate the development of local green jobs in installation, maintenance, and system monitoring. This framework can also be replicated across affordable housing schemes including the PMAY (U) 2.0 mission. The integration can be easily customized across different geographic and climatic conditions as it is a proposed viable model for decentralized energy generation in low-income communities. From a broader perspective, if the framework is successfully implemented, it will significantly contribute to the broader policy framework for the creation of smart city with improved energy security and resilient housing encouraging public–private–community partnerships in clean energy access. It will also provide data and implementation framework for municipal replication and national policy adoption. However, implementation might face certain challenges like financial constraints, collaborative issues amongst all the stakeholders and different sectors thereby impacting the successful implementation of the model. Therefore, to overcome these challenges provision of financial assistance at all levels, simplified permission process and private sector participation might produce successful results. As a scope of future research, the framework needs to be implemented in units under PMAY (U) on ground and a monitoring of the detailed installation costs and annual savings made needs to be tracked. Further based on ground reality, if any modifications are required in the proposed framework can be integrated with better outcomes.

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