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Adaptive Decentralised Payback Normalisation for Socio-Economic Rebalancing of RE subsidies - A Case Study

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ABSTRACT

Clean energy subsidies are designed to stimulate consumer participation and deliver greater benefits to society. India has a fixed centralised federal subsidy model for residential rooftop solar (RTS). Different states have different tariff schemes for electricity consumption and RTS feed-in. Thus, grid parity, payback period (PBP), and willingness to pay (WTP) differ for consumers of different states and income classes, resulting in social and geographical disparity in RTS implementation. A Socio-Economic Rebalancing of RE subsidies thus becomes necessary. This paper proposes a novel adaptive decentralised heterogeneous PBP equalisation-based subsidy policy to enhance the WTP for all prosumers and ensure uniformity of RTS implementation. A two-stage subsidy optimisation is conducted using a case study in diverse states to achieve Grid Parity initially and subsequently desired PBP for all states and income classes. The proposed subsidy ensures grid parity for all, sufficient to transit all the prosumers to 100% net electricity from RTS. The subsidy is further normalised by equalising the PBP to a target PBP thereby ensuring uniformity of RTS implementation in the country bridging the rural-urban WTP disparity, leading to a better social scenario. The strategy is adaptive to the future, as the subsidy can be revised with changes in techno-economic parameters.

Keywords

Grid Parity;
Subsidy;
Rooftop solar;
Levelised Cost;
Willingness to pay

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Abbreviations

CAPEX	Capital Expenditure
CEA	Central Electricity Authority
CFA	Central Financial Assistance
DISCOM	Distribution Company
FIT	Feed In Tariff
ESR	Effective Subsidy Rate
GST	Goods and Service Tax
LCOE	Levelised Cost of Electricity
MEB	Monthly Electricity Bill
MNRE	Ministry of New and Renewable Energy
NDC	Nationally Determined Contributions
OCC	Overall Capital Cost
PBP	Payback Period
RTS	Rooftop Solar
SDG	Sustainable Development Goal
VNM	Virtual Net Metering
WTP	Willingness to pay

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1. Introduction

In order to meet the Paris climate agreement objectives and to keep global warming well below 2°C above pre-industrial level requires a complete transformation in the energy sector during the coming decades. A drastic decarbonisation of energy systems at an unprecedented scale and pace is required to address global warming [1].

The power industry is thus all set for the renewable energy revolution. India has a long term goal of achieving net zero emissions by 2070 [2]. As per updated Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCC), India commits to achieve 50% cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030 [3].

Solar is a segment that will contribute significantly to these national target. Deployment of RTS is an important component of India's solar target. As per the first NDC, India's target was to generate 100GW solar power by 2022 consisting of 60GW utility-scale and 40GW rooftop solar. National RTS installation is presently 4.6GW, far behind the target of 40GW by 2022. The 40GW target consists of 4 GW residential rooftop solar, of which 2.01 GW installed capacity is achieved by FY 2022. This low adoption of residential RTS is primarily attributed to the complicated subsidy scheme, with delayed subsidy disbursal [4]. A simplified new Direct Benefit Transfer (DBT) mechanism through a National Digital Portal is introduced in July 2022 to ensure that consumers receive the subsidies more easily and faster. The RTS WTP faces financial, political, regulatory, social, and psychological barriers. Barriers to PV installation are surveyed, and their relative significance among consumers is evaluated. Barriers include low Feed In Tariff (FIT), peer effect, and high upfront cost [5]. High capital cost is cited as the primary factor in many countries [6] including India, and subsidies as a solution to overcome the same.

Diverse RTS promotion policy measures such as capital cost subsidy [7], premium FIT [8], carbon credits, low interest loans, and incentives mechanisms [5] are implemented in different countries. A synergetic simultaneous implementation of multiple measures is also done. Capital Cost Subsidies are found to significantly induce RTS adoption in Japan [7]. PV systems without subsidies are not feasible in many countries, such as Argentina, in the residential sector; the net billing and FIT structure are identified as barriers [5]. In UAE also, the unsubsidised RTS is not economical because of the high initial RTS cost, low electricity tariff, and thus low price expectation of RTS-generated electricity [9]. Indonesia requires a decade to meet RTS grid parity [10]. Government-supported low-interest loans [5] and community partnerships [11] are suggested as a measure to overcome barriers such as high initial investment costs. The FIT in Thailand is insufficient to promote residential RTS [8] . A low-interest loan rate loan is suggested as a supportive measure. However in South Korea, PV systems without subsidy, are economically feasible for co-housing, such as apartments [12].

The Indian government has chosen subsidy as a policy measure to promote residential RTS. World Bank recently approved US$165 million credit line to directly finance 450MW for the Indian residential rooftop solar segment [13]. Subsidies will promote manufacturing in India. After Covid-19, the RTS market requires support to stimulate economic recovery. Subsidies play a significant role in encouraging renewables by controlling the energy market, resulting in economic development and energy security. However, the world's total direct energy sector subsidies include fossil fuels, nuclear, and renewables, of which fossil fuels account for a staggering 70% [14]. Fossil fuel subsidies encourage wasteful consumption and create market distortion. UN Sustainable Development Goal (SDG) 12.C focuses on rationalising and eventually phasing out fossil fuel subsidies.

India is yet to harness the immense residential RTS potential and meet the UNFCC RE targets of residential RTS. Despite the high federal subsidies, the country's uptake of residential RTS is low. The present centralised residential RTS subsidy model is uniform. Although the centralised subsidy is uniform across states and income classes, the household response to subsidies in India is quite diverse. The household's WTP significantly varies based on many factors such as the residential building type [15], the income class of the prosumer [16], the electricity tariff in that state, the upfront cost and the payback period. The electricity tariff in certain states is higher than in others. Thus, grid parity will be achieved, and RTS PBP will be lower for such states. However, in states with high tariff subsidies, the tariffs will be lower. Thus, achieving RTS grid parity will take longer, and RTS PBP will be higher for such states. Higher-income class prosumers with higher electricity demand pay higher electricity bills due to high tariffs. With higher initial investment potential, a low PBP and thus a high WTP, they are expected to invest in RTS [7]. In contrast, low-income classes are not expected to invest in RTS despite the subsidy due to low initial investment potential, longer PBP and thus, low WTP. RTS deployment will be concentrated in states with high electricity tariffs and consumers with high consumption and income levels. This PBP and WTP imbalance needs to be addressed, as it would result in a slow, geographically skewed and socially unbalanced deployment of RTS. Thus, subsidy strategy must consider regional social and economic diversities. As the power sector is diversifying from a centralised model to a more distributed one, it becomes necessary to include a heterogeneous decentralised subsidy policy to accommodate the diversity of consumers. Thus, RTS subsidy policies should be shifted from the presently followed centralised homogenous subsidy design and customised to suit all states and enable all sectors to participate and benefit. There arises the need for novel policy level strategies to solve these interrelated multidimensional problems and improve the existing subsidy regime to a targeted subsidy regime customised to meet the desired PBP and WTP expectations of each consumer and thus improve the residential RTS uptake in the country.

This paper proposes a novel strategy for the Socio-Economic Rebalancing of RE subsidies using the Adaptive Decentralised Payback Normalisation Strategy. Thus, the *main objective* of this paper is to formulate a decentralised heterogeneous subsidy policy design that enhances the RTS-WTP for all prosumers and ensures *uniformity* of RTS implementation among diverse regions and consumer types. This is done by adjusting the subsidy percentage to equalise the PBP, thereby ensuring *grid parity*. To this end, the *major contributions* of this paper include subsidy decentralisation, PBP equalisation, improved social scenario, adaptiveness and replication potential validation:

1. Formulation of a subsidy policy design that customised subsidy re-allocation strategy among states and income classes to enhance RTS penetration, thus enhancing the willingness to pay for all RTS prosumers.
2. Equalise the PBP across all states and all income classes.
3. This strategy bridges the Rural-Urban willingness to pay and ensures uniform implementation across regions, leading to a better social scenario.
4. Also, this strategy is *adaptive*. Subsidy changes with changes in techno-economic input parameters.
5. Replication possibility in all states and other nations is studied and validated.

The rest of this paper is organised as follows. Section 2 introduces the system architecture and business model of RTS. Section 3 discusses the problem formulation of an adaptive decentralised subsidy rebalancing strategy based on Indian residential case study. Section 4 discusses the results and discussion. Section 5 concludes the paper.

2. Case Study

This case study considers the techno-economics of the proposed decentralised heterogeneous targeted subsidy for prosumers in residential apartment buildings.

2.1 System Architecture of Residential RTS

We consider a prosumer having a Low Tension (LT) 3phase supply system. An 11kV/415V, 250 kVA distribution transformer connects the residential system to the utility grid. RTS (Figure 1).

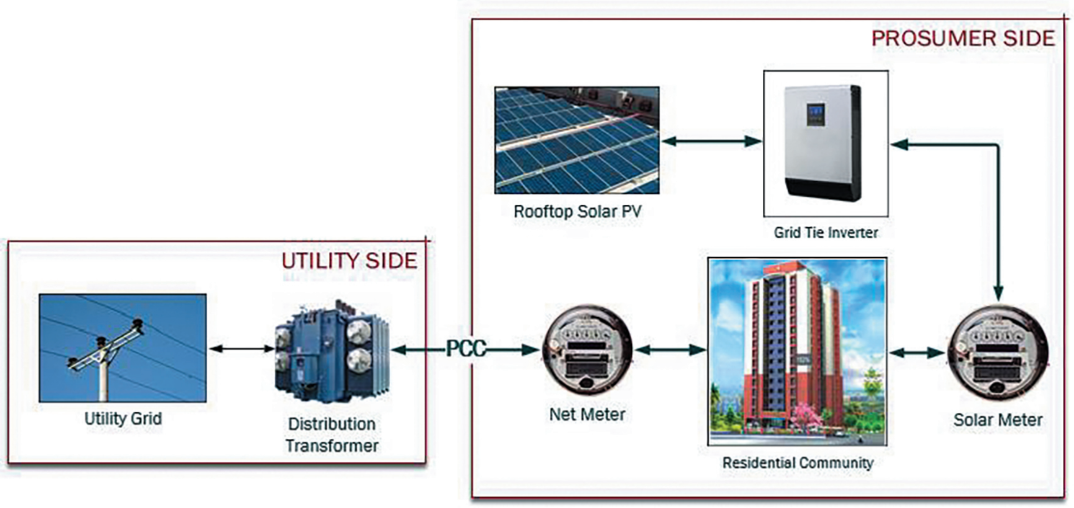


Figure 1: Block Diagram of Grid Connected Residential Electrical Distribution System with RTS

The residential apartment is connected to a rooftop solar PV system [17]. An average solar irradiation of 1266.52 W/m^2 is with 5.5 hours of sunshine is considered [18]. A 1kWp panel can generate 5kWh/day of electricity [19]. For solar integration, a net metering scheme is considered, as the provision for net metering is available for all residential prosumers in India. The respective state electricity regulatory commissions (SERCs) determine the compensation for the excess power. Above 100% export of electricity is allowed when compared to consumption. The study is conducted in the context of 3 Indian states under diverse scenarios.

2.2. Business Model

A Capital Expenditure (CAPEX) based financial model is considered for RTS implementation (Figure 2).

The CAPEX model is the most commonly used model in India for RTS deployment [20]. Consumers apply for capital Subsidy provided by the Ministry of New and Renewable Energy (MNRE) through Central Financial Assistance (CFA) and additional subsidies by certain state governments. The RTS capital cost is based on the benchmark cost inclusive of taxes proposed by MNRE. Recent MNRE benchmark cost was proposed for FY 2021-22 [21]. Subsequently, the Goods and Service Tax (GST) is revised by GST council to include the renewables energy equipment. Thus the benchmark cost is amended and is proposed excluding the GST [22]. Thus, the GST must be added to the proposed MNRE price for calculating CFA. However, MNRE's price is indicative. The state DISCOMs has to discover the lowest bid (L1 bid) through a transparent bidding process. All empanelled bidders should provide services to consumers at L1 rates. From the DISCOM perspective, RTS installations reduce capital cost associated with network expansions. This reduces the Average Cost of Supply (ACS) and thus the Average Billing Rate (ABR) to the customer.

2.3. Policy Simulations

Considering the spatial and policy heterogeneity of the problem [23], diverse policy simulation of the CAPEX model under diverse policy scenarios becomes necessary in the Indian context [24]. Two objective functions are optimised to desired values for 3 states, with prosumers of 3 income classes, under 3 subsidy scenarios. Thus a total of 54 policy scenarios are simulated, and their optimal objective functions are estimated in this study (Table 1).

Table 1: Policy scenarios considered for simulation

Scenarios	No's	Categories
Policy Objective Level: Objective Function	2	Grid Parity, PBP
National Level: Subsidy Scenarios RTS Benchmark Price	3	Centralised, Decentralised (Proposed), No subsidy
State Level: Electricity Tariff Schemes, Feed-In- Tariffs	3	Kerala, Maharashtra (Mumbai-Tata), Rajasthan
Prosumer Level: Electricity Demand/ Income classes	3	Type 1(Low), Type 2 (Medium), Type 3(High)
Total	54	

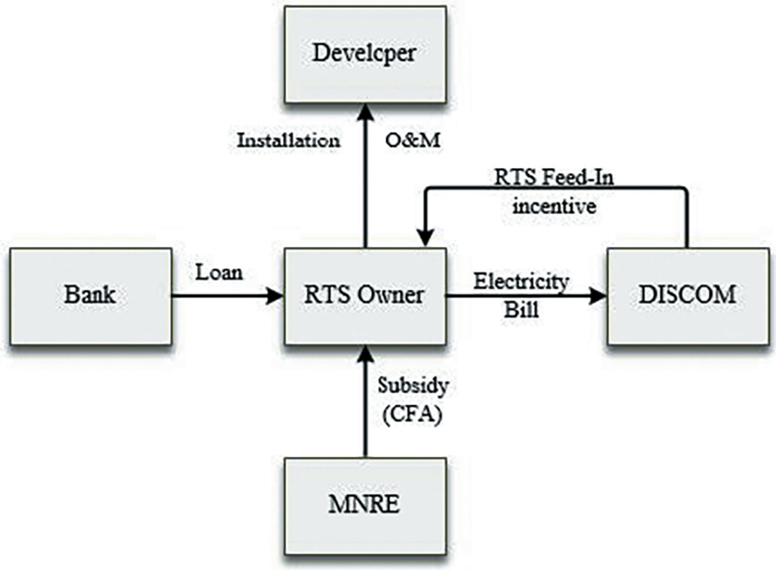


Figure 2: CAPEX Model: Stakeholder wise cash flow for residential RTS

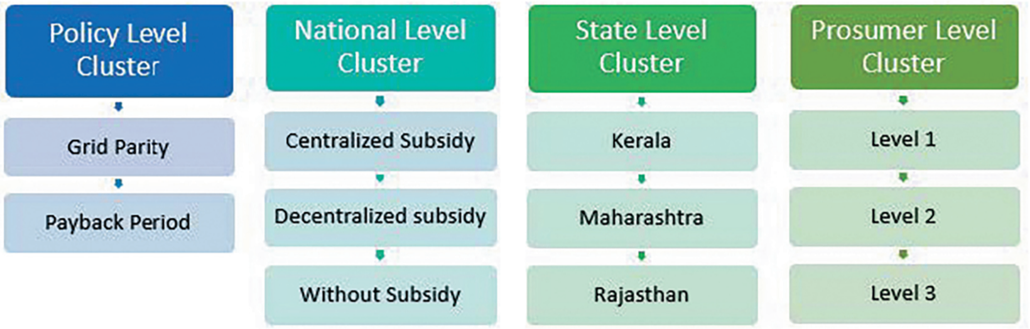


Figure 3: Clustering Strategy-Policy Objective, National, State and Prosumer Levels

Table 2: State Level Clustering

State	**Maximum RTS Capacity (% of Sanctioned Load) [25]**	**Feed in Tariff (INR/kWh)**
Kerala	100%	3.22 [26]
Rajasthan	80%	3.14 [27]
Maharashtra (Mumbai-Tata)	100%	3.05 [28]

Table 3: Prosumer Clustering- based on Electricity Demand/Income Level [29]

Prosumer Type	**Sanctioned Load**	**MEC**	**Income Level**
	kW	kWh/month	
1	2	200	Type 1
2	4	400	Type 2
3	5	500	Type 3

2.4. Clustering Strategy

A heterogeneous study is converted to a homogenous study by clustering strategy for independent analysis and comparative study. Policy Simulations are conducted for each cluster, and results are analysed and compared with other clusters (Figure 3).

Policy level clustering is based on the policy objective. Achieving grid parity for all states and prosumer income classes is considered as the primary objective. Upon achieving grid parity, achieving the desired PBP for all states and prosumer income classes is considered as the secondary objective. National-level clustering is based on the type of subsidy model- centralised (present), decentralised (proposed) and without subsidy (long term). State-level clustering is based on various state-level parameters influencing the RTS PBP. This includes the FIT, Electricity Tariff, Effective Electricity Rate (EER), maximum RTS capacity as a percentage of sanctioned load, and maximum RTS capacity as a percentage of distribution transformer capacity. 3 Indian States-Kerala, Maharashtra (Mumbai-Tata), and Rajasthan are selected for analysis (Table 2).

In India, State DISCOMs have a slab-based electricity tariff rate for residential consumers. The tariff increases with increase in electricity consumption. Some states follow a telescopic tariff throughout. However, some states follow a non-telescopic tariff after a specific monthly electricity demand. The electricity bill depends on the slab rate for the corresponding electricity demand. Thus, the relation between bill amount and unit consumption is not linear; EER is defined for comparing the cost analysis between states and income levels, typically nonlinearly increasing with an increase in energy demand. The Monthly Electricity Bill (MEB) and EER of Kerala, Mumbai, and Rajasthan will differ. A higher central subsidy is provided to promote RTS in few states with low solar irradiance. In few states, an additional state level subsidy is provided for RTS. However, the states selected for study have the general subsidy norms [21]. The monthly average residential electricity demand (kWh/month) is assumed to be the same for a given prosumer type, irrespective of the state. Considering the heterogeneous energy consumption behaviour, based on the Monthly Electricity Consumption (MEC) and the rooftop solar capacity, the prosumers can be clustered as Type-1, Type-2, or Type-3 (Table 3) [29].

This clustering is based on the consumer categorisation done by CEA based on sanctioned loads (kW) and consumption levels (kWh/Month), prosumers are clustered based on the sanctioned load and monthly consumption level such as 1kW/100kWh, 2kW/200kWh [29]. Type 1 prosumer has a sanctioned load of 2kW with low

MEC (200kWh/month). Type 2 prosumer has a sanctioned load of 4kW with moderate monthly average electricity consumption (400kWh/month). Type 3 prosumer has a sanctioned load of 5kW and a high MEC (500kWh/month). As Prosumer Type increases, the sanctioned load and the MEC increase. Thus Prosumer Type is assumed to be a direct indicator of income level. As the prosumer type changes from Type 1 to Type 3, the income level increases from Level 1 to Level 3. For example, Type-3 Consumer is typically an urban consumer with good income, and a Type-1 consumer is a rural consumer with moderate income or a moderate-income urban consumer.

With the tired tariff, as the electricity tariff for each tier changes with respect to the tier, the effective electricity rate is computed for each cluster. The effective electricity rate includes the energy rate, fixed charges, and tax per kWh.

3. Problem Formulation of Adaptive Decentralised Subsidy Rebalancing

3.1 Objective Functions

The problem is formulated as a two stage optimisation. In the primary stage, the objective is to achieve grid parity for all states and income classes. After achieving grid parity, in the secondary stage, the next objective is to achieve the global optima, i.e., desired PBP for all states and income classes. Thus, objective functions selected are achieving Grid Parity and then the desired PBP.

3.1.1. Objective 1: Achieving Grid Parity

Grid parity is the breakeven point where the Levelised Cost of Electricity (LCOE) of the RTS becomes less than or equal to the EER. The RTS can generate electricity at a cost less than the grid price. With Grid parity, the energy source is considered to be ready for widespread adoption. In many nations, consumers are yet to achieve RTS grid parity; however, with subsidy, they can achieve grid parity [9]. In nations where low FIT is the barrier for RTS adoption [8], if grid parity is achieved, solar PV can become feasible for self-consumption. To check for grid parity, LCOE and EER are to be computed. The condition for 100% grid parity for a prosumer is given by Eq. (1):

$$\mathrm{LCOE} = \mathrm{EER} \tag{1}$$

When 100% grid parity is not achieved, a performance index called the Grid Parity Index (GPI) is proposed as an indicator of RE penetration [30]. It is defined as the proportion of RE in annual electricity demand (Eq. (2)):

$$GPI = \frac{\mathrm{E}_{solar}}{\mathrm{E}_{demand}} \tag{2}$$

where $\mathrm{E}_{\mathrm{solar}}$ is the annual electricity generation from RTS (kWh/Year), and $\mathrm{E}_{\mathrm{demand}}$ is the annual Electricity demand of the residential apartment (kWh/Year).

LCOE in Eq. (1) is defined as Eq. (3):

$$LCOE = \frac{Cost_{LT}}{E_{gen\_LT}} \tag{3}$$

where $\mathrm{Cost}_{\mathrm{LT}}$ is the lifetime cost (INR); and is the lifetime electricity generation from RTS (MWh). The lifetime cost is computed using a discounted cash flow (DCF) study (Section 4).

The Lifetime cost of RTS is computed by Eq.(4):

$$\mathrm{Cos\,t}_{LT} = \sum\nolimits_{t=0}^{T} \mathrm{O\,\&\,M}(t) + \mathrm{D}(t) + \mathrm{I}(t) + \mathrm{R}(t) \tag{4}$$

where D (t) is the Depreciation Cost; I (t) is the Interest on the Term Loan; and R (t) is the Return on Equity. Lifetime electricity production is computed from the net annual electricity generation using Eq.(5).

$$E_{gen\_LT} = \sum_{n=1}^{LT} E_{gen\_annual}(\mathrm{n}) \tag{5}$$

The net annual electricity generation (MWh/annum) is estimated in Eq.(6):

$$E_{gen\_annual} = \frac{\mathrm{P}_{\mathrm{solar,ghs}}\ \mathrm{N}_{\mathrm{h}}\ \mathrm{CUF}\left(1-\mathrm{P}_{\mathrm{aux}}\right)\times \mathrm{T}}{100} \tag{6}$$

where $\mathrm{P}_{\mathrm{solar,ghs}}$ is the RTS capacity of the prosumer; Capacity Utilisation Factor (CUF) is specified as 21% [19]; is the auxiliary consumption. For solar PV projects, is selected as 0.75% [20]; T is the annual hours, specified as 8766 Hours. Power generation input parameters and the financial assumptions are provided in [38].

LCOE depends on subsidy %. As the subsidy % increases, the LCOE decreases, thus a higher chance of grid parity. Although centralised subsidy is uniform for every state, however in scenarios with additional state subsidies, *the LCOE may become different for different states*.

Electricity Tariff is decided by the respective SERCs depending upon the respective state electricity supply cost, which in turn depends on the energy supply mix of the state and the import [31]. Even within the same state, *EER will differ* for different income classes based on the consumption slab/tier. Thus, EER will be different for different states and income classes.

As electricity demand increases, EER increases, and the chance of grid parity increases. A high-energy prosumer is expected to achieve relative grid parity earlier than a low-energy prosumer; this has social implications. A wealthy household will break even faster compared to a poor household because of the inherent structure of the tiered electricity tariff mechanism.

3.1.2. Objective 2: Achieve Desired Payback Period

After achieving grid parity, the optimisation problem is defined with an objective is to equalise the PBP for all the states normalising the subsidy (Eq.(7)):

$$\mathrm{PBP}_{\mathrm{actual}} - \mathrm{PBP}_{\mathrm{target}} = 0 \tag{7}$$

The decision variable is the subsidy % (S). The Subsidy % is controlled to equalise the PBP. When Subsidy % changes, Overall Capital Cost (OCC) changes. When the overall capital cost changes, the LCOE changes.

3.2 Constraints

The optimisation problem is subject to various constraints. (Eq.(8)-(14)).

3.2.1. Energy Balance Constraint

The residential microgrid needs to meet the Power and Energy Balance Constraints [32] (Eq.(8)):

$$\sum_{t=1}^{T}\Big(\mathrm{P}_{\mathrm{dem}}(\mathrm{t}) - \big(\mathrm{P}_{\mathrm{grid}}(\mathrm{t}) + \mathrm{P}_{\mathrm{solar}}(\mathrm{t})\big)\Big) = 0 \tag{8}$$

The total energy supplied from solar (Esolar) is given to home (S2H Mode)and then to the grid (S2G Mode) [33] Eq.(9):

$$E_{Solar} = E_{S2H} + E_{S2G} \tag{9}$$

3.2.2.Grid Supply Limits

There are limits to transferring power from and to the grid based on the respective state regulatory limits (Table 1) and the power line's thermal limit. The state regulatory limits are expressed as a maximum RTS system capacity as a percentage of the sanctioned load, an artificial limit restricting the maximum allowable grid supply. In most states, this limit is specified as 'up to 100% of the sanctioned load. The Grid Power limit is given by Eq.(10)

$$\mathrm{P}_{\mathrm{Grid(min)}} \le \mathrm{P}_{\mathrm{Grid}} \le \mathrm{P}_{\mathrm{Grid(max)}} \tag{10}$$

where $\mathrm{P}_{\mathrm{Grid(min)}}$ and $\mathrm{P}_{\mathrm{Grid(max)}}$ are the upper and lower limits of the grid power (kW). $\mathrm{P}_{\mathrm{Grid(t)}}$ is the instantaneous power drawn from the grid (kW).

3.2.3. Subsidy Limit

The decision variable Subsidy % is given by Eq.(11):

$$0\% \le \mathrm{Subsidy}\ \% \le 70\% \tag{11}$$

For residential RTS of up to 3kW capacity, the MNRE gives a subsidy of up to 40% of benchmark cost for general states and around 70% for special states with low solar irradiaince.

3.2.4. Roof Area Limit

The RTS system must be able to meet the roof area limits of the residential consumer (Eq.(12)):

$$\mathrm{A}_{\mathrm{rooftop}} \ge \mathrm{A}_{\mathrm{RTS}} \tag{12}$$

where $\mathrm{A}_{\mathrm{rooftop}}$ is the roof area required by RTS; is the available roof area.

3.2.5. Sanctioned Load

As per the Electricity (Right of Customers) Rules, 2020, net metering is permitted for loads up to 500kW or sanctioned load, whichever is lower and gross metering is permitted for loads above 500kW [34]. Most states limit the RTS capacity equivalent to the contract demand [35].

3.2.6. Distribution Transformer (DT) Capacity Constraints

DT Capacity limits the RTS capacity. Many DISCOMs allow connecting RTS to 75-80% of the DT capacity. The cumulative power rating of homes shall not be a specified percentage of the rated capacity of the distribution transformer (Eq.(13)):

$$\sum_{n=1}^{N_H} P_{rated}(n) \le 0.75 \times S_{rated} \tag{13}$$

3.2.7. Voltage Limits

For single-phase prosumers, most states allow an RTS capacity of up to 5kW. For 3 phase, most states allow up to 100 kW or contract demand, whichever is lower. Based on the capacity of the RTS, state regulations prescribe the injection voltage level [35]

3.2.8. Average Monthly Electricity Demand

The monthly average residential electricity demand is considered to be the same for a given prosumer type, irrespective of the state (Eq.(14)):

$$E_{demand} = C \tag{14}$$

where C is a constant for a prosumer type in kWh/month. For Type-1 prosumers, monthly average residential electricity demand is 200 kWh/month, and for Type-2 prosumers it is 400kWh/month.

3.2.9. Energy Export Limit

Many states, including those under study (Kerala, Maharshtra, and Rajasthan), allow an energy export above 100% of the energy consumed. In 11 other states, exports should not exceed the energy consumed. In Chattisgarh, prosumers can export only 49% of the RTS electricity generation. The problem is thus formulated as summarised in Figure 4.

3.3. Cash Flow Study

The overall upfront capital cost payment excluding interest is given by Eq. (15):

$$OCC = \mathrm{C}(1-\mathrm{S})\mathrm{P} \tag{15}$$

where OCC is the overall upfront payment excluding interest (INR); C is the RTS MNRE Benchmark cost (INR/kW); P is the RTS power rating (kW); D is the MNRE RTS Phase II subsidy (%).

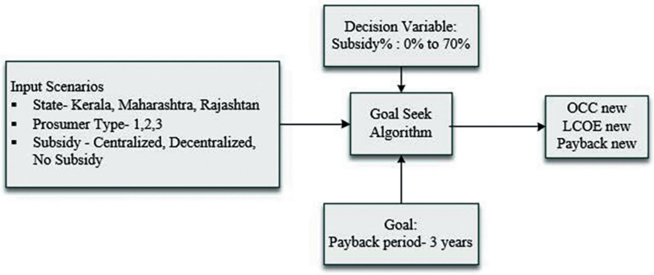


Figure 4: Problem Formulation

The total annual cash inflow, C_{Total} (INR/Year) is given by Eq.(16):

$$C_{Total} = C_{S2H} + C_{S2G} \tag{16}$$

The cash savings due to avoided electricity demand by consuming electricity from solar to home, C_{S2H} (INR/Year) is given by Eq.(17):

$$C_{S2H} = E_{S2H} \times EER \tag{17}$$

where E_{S2H} is the Energy from Solar to Home (kWh/year);

Electricity rates influence the grid parity and PBP and thus the RTS-WTP. An Effective Electricity Rate needs to be computed for a given electricity consumption for a prosumer type and then compared with LCOE to check for grid parity. The EER for a given month is calculated using Eq.(18):

$$EER = \frac{\sum_{n=1}^{E_{demand}} \mathrm{n} \times \mathrm{E}_{\mathrm{tariff}}(\mathrm{n})}{\mathrm{E}_{demand}} \tag{18}$$

where n is the n^{th} unit, E_{demand} is the monthly electricity demand in kWh/month; E_{demand}(n) is the tired electricity tariff for the n^{th} unit of electricity in INR/kWh.

The consumers are clustered based on the sanctioned load and monthly consumption levels, such as 1kW/100 kWh, 2kW/200kWh. With the tired tariff, as the electricity tariff for each tier changes with respect to the tier, the effective electricity rate is computed for each cluster. The effective electricity rate includes energy rate, fixed charges, and duty/tax per kWh.

The cash inflow due to electricity from solar to grid [36], C_{S2G} (INR/Year) is given by Eq.(19):

$$C_{S2G} = E_{S2G} \times FIT \tag{19}$$

where E_{S2G} is the Excess Energy from Solar to Grid in kWh/month ; FIT is the Feed-In-Tariff in INR/kWh.

The monetary value of exported energy in a state is based on the FIT. The SERC determines FIT for a state based on the state's Average Power Purchase Cost (APPC). APCC is the weighted average price at which the DISCOM purchases electricity. The FIT for the states under study is shown in Table 2.It doesnot consider the LCOE of the RTS prosumer.

From Eq.(15), Eq.(17) and Eq.(19), the mathematical relation between PBP and EER is modelled in Eq.(20):

$$PBP = \frac{C*(1-D)*P}{EER*E_{annual} + FIT*E_{S2G}} \tag{20}$$

This relationship can be used to compute the prosumerwise and statewise subsidy allocation for PBP equalisation.

3.4 Discounted Cash Flow (DCF)

The DCF Method calculates the present value of RTS investment by considering anticipated future cash flows and discount factors. These cash flows consist of income generated from RTS electricity generation. Cash outflows include fixed costs like operation and maintenance expenses, depreciation, loan interests, working capital, and return on equity. By discounting the cash inflows and outflows, we determine the DCF. The technical and economic parameter inputs for the DCF analysis is provided in [38]. Project-specific LCOE is determined for Solar PV projects. The capital costs are determined using MNRE (Ministry of New and Renewable Energy) benchmark prices and discount rates. Using DCF results, the Net Present Value (NPV), PBP, and LCOE over a 25-year project lifetime is computed. The performance indicators, along with a centralised standard subsidy, are compared against a decentralised and customised subsidy approach based on PBP normalisation.

3.5 Goal Seek Algorithm

With the goal seek algorithm, the PBP is equalised for all the states and all income classes. The Subsidy (%) is customised, with respect to the electricity tariff of the state, to equalise the PBP. RTS subsidy would become MNRE subsidy and the additional subsidy adjustment (Eq.(21)).

$$CS_n(s,i) = S_{MNRE} \pm S_{Adj}(s,i) \tag{21}$$

where is the normalised RTS subsidy in INR; S_{MNRE} is the MNRE subsidy; is the subsidy adjustment; s is the state; i is the income level/prosumer type.

For a centralised subsidy scheme, the objective function PBP is varied. The decision variable subsidy% is varied from 100% to 0%. The PBP for the corresponding value of subsidy% is then calculated using goal seek algorithm. The flow chart of the proposed goal seek algorithm for achieving grid parity and desired PBP are shown in Figure 5 and Figure 6, respectively.

3.6 Decentralised Heterogeneous Subsidy Policy Design: Proposed Algorithm

The algorithm for the proposed goal seek algorithm is given as:

Step1. Input

- State Type, Prosumer Type
- Electricity Tariff
- Monthly Electricity consumption
- Desired PBP

Step2. Size RTS Capacity

- For Grid Parity: Size RTS Capacity for self consumption subject to constraints (Eq.(8)-(14))
- For Desired PBP: Optimise RTS capacity subject to constraints (Eq.(8)-(14))

Step3. Goal Seek Algorithm

- Find the subsidy %, for grid parity
- Find the subsidy % for the desired PBP

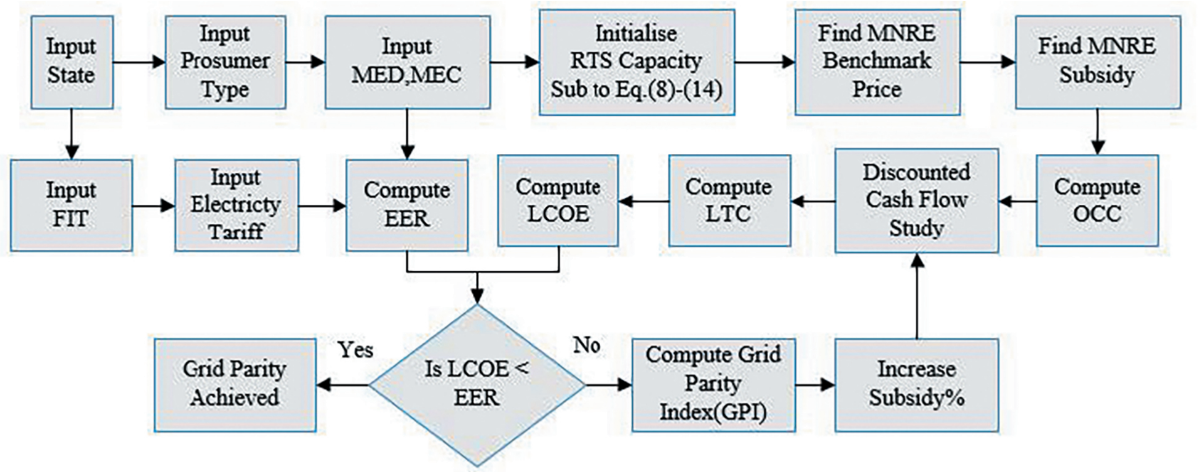


Figure 5: Flow chart of proposed subsidy rebalancing strategy- for achieving Grid parity

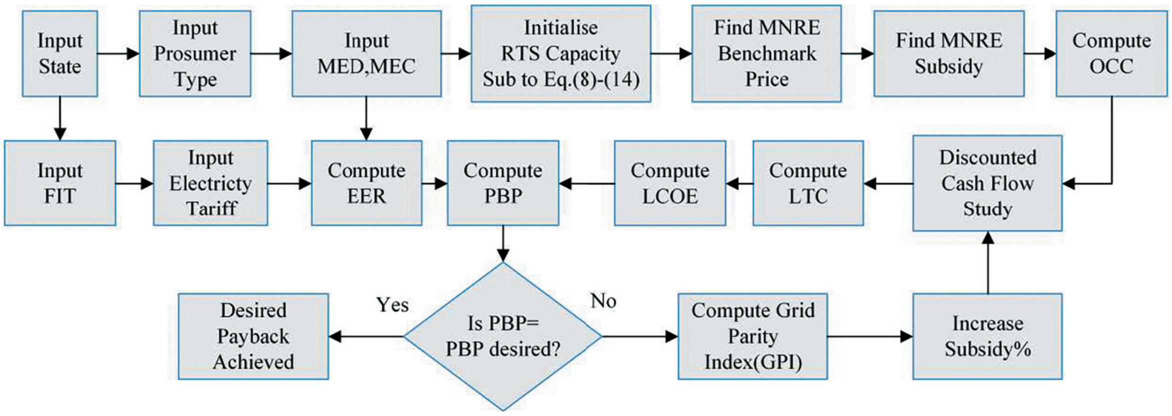


Figure 6: Flow chart of proposed subsidy rebalancing strategy- for achieving desired PBP

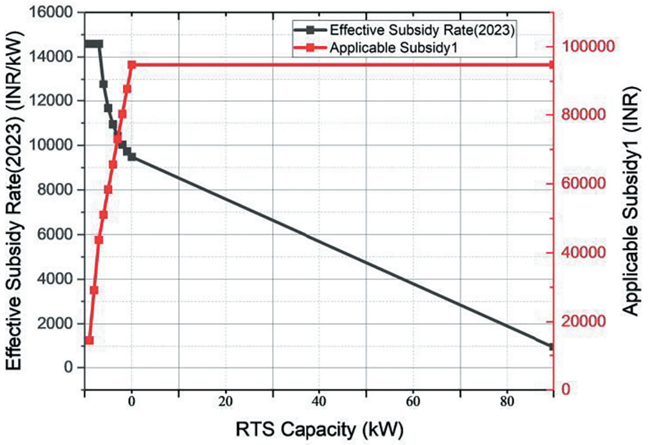


Figure 7: Effective Subsidy Rate and Applicable Subsidy

Step4. Conduct Discounted Cash Flow (DCF) Method, Compute

- LCOE, PBP, Grid Parity Index, OCC – before and after subsidy

Step5. Prosumer Types

- Repeat steps 1-4 for all prosumer types (Type-1, Type-2, Type-3)

Step6. States

- Repeat steps 1-5 for all States (Kerala, Maharashtra (Mumbai-Tata), Rajasthan)

4. Results & Discussion

A case study based validation of the proposed methodology is conducted considering 27 sample scenarios, which consist of 3 States, 3 Subsidy scenarios – (1) Without subsidy, (2) Centralised subsidy, (3) Decentralised PBP normalised subsidy, 3 Income/consumption levels, and 3 RTS capacity levels.

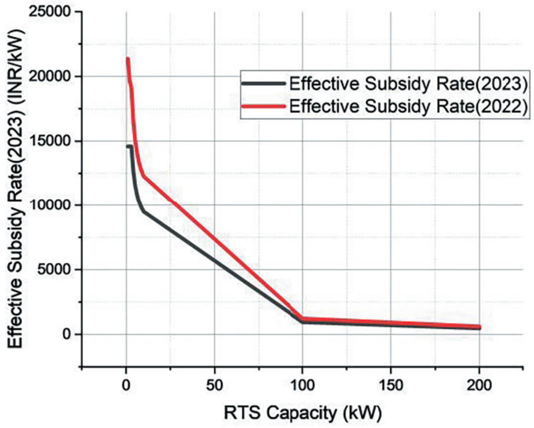


Figure 8: Effective Subsidy Rate – Comparison

4.1 Supply Side RTS Policy Analysis - Effective Subsidy Rate (ESR)

The MNRE subsidy scheme is recently amended in 2023[22]. The Subsidy was previously a percentage of the RTS capital cost. The Subsidy is now amended to a fixed amount for a given RTS capacity. A comparative analysis from a prosumer perspective is conducted for the effect of change in subsidy with the recent amendment in the MNRE subsidy scheme. A performance indicator Effective Subsidy Rate (ESR) is proposed as an indicator for comparison. ESR is the effective cost (INR/kW) the prosumer pays for RTS. ESR is compared for diverse RTS capacities and diverse subsidy policies. The study results suggest that the ESR is lower in the 1-100kW range, resulting in a 22-35% reduction in prosumer subsidies (Figure 7).

As the applicable subsidy amount becomes static after 10kW, the ESR (INR/kW) reduces significantly after 10kW. The ESR is lower in the 1-100kW range, resulting an in 22-35% reduction in prosumer subsidies (Figure 8).

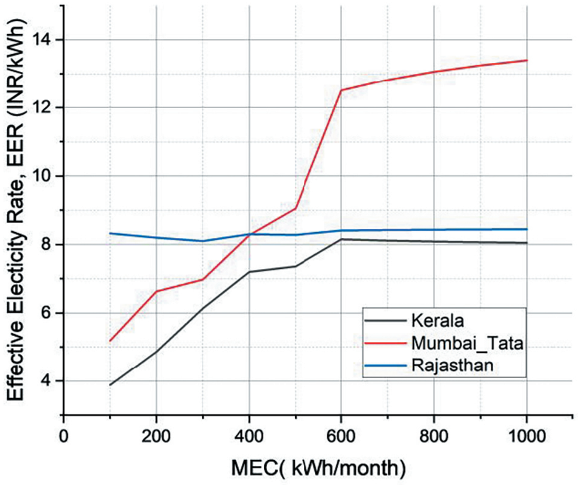


Figure 9: EER- State wise comparison

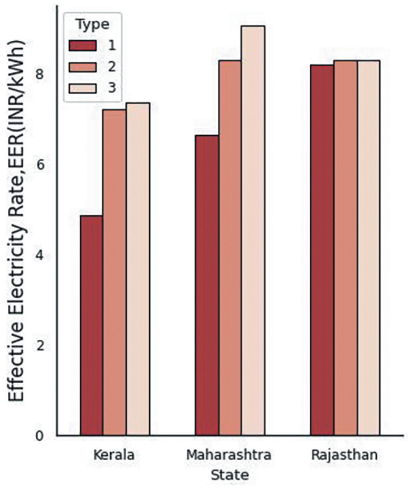


Figure 10: State wise Effective Electricity Rate for different prosumer types

4.2. Demand Side Energy Analysis- Effective Electricity Rate (EER)

The EER shows diverse trends for different states. The Mumbai tariff (Tata) significantly increases with increased monthly consumption. The EER is higher in Maharashtra (Mumbai-Tata) than in Kerala for all slabs. Kerala tariff is gradually increases with monthly consumption and then becomes a constant. Rajasthan maintains a consistently high electricity tariff at just above 8 INR/kWh, regardless of monthly consumption. Although Rajasthan follows a Tiered Tariff, the EER has a high mean but low Standard deviation.

EER vs. Prosumer Type shows that as the prosumer income level increases, the EER increases (Figure 10). EER is higher for prosumers with higher electricity bills as the tariff increases at higher slabs.

Each state has different levels of EER, with diverse Standard Deviations. Thus, the EER of a state significantly affects the RTS PBP and WTP. States with higher EER (E.g. Maharashtra (Mumbai-Tata)) will achieve grid parity faster with a lower PBP when compared to states with lower EER (E.g. Kerala). This is analysed in detail in Section 4.5.

4.3 Monthly Electricity Consumption (MEC)

The monthly electricity demand or consumption (MEC) for different prosumer types is shown in Figure 11. The MEC for a prosumer type is considered to fixed, irrespective of the state.

4.4 Monthly Electricity Bill (MEB)

For a given prosumer class, although MEC is considered fixed, however MEB will be different as EERs are different for different states (Figure 12).

As EER & MEC increases, MEB increases. MEB increases with an increase in Consumption level and state EER. Different states have billing frequencies of monthly or bi-monthly. All EB calculations in this study are normalised on a monthly basis. With net metering, the solar-to-grid injection will compensate for the entire MEC and MEB [37].

The MEB is higher for prosumers with higher MEC. With lower EER, the MEB is lower for Kerala. With an increase in consumption class (MEC), MEB increases. For the same MEC, the MEB is higher for states with higher tariffs. The highest MEB is observed for the case with the highest MEC and EER; this happens to be the Type3 prosumer in Mumbai. Prosumers need not pay this MEB; they must compensate for this MEC with an equivalent RTS feed-in. With lower EER, MEB for Kerala is lowest for all income classes. Although EB is affordable, there is a challenge as well.

Low EER increases the PBP of renewables. Germany achieved grid parity for Solar PV; a significant factor was the high electricity tariff in the country. The EER in Kerala is low due to the subsidised electricity tariff. As electricty predominantly comes from fossil fuels this societal subsidy translates into a fossil fuel subsidy. To make matters worse, this increases the PBP of RTS.

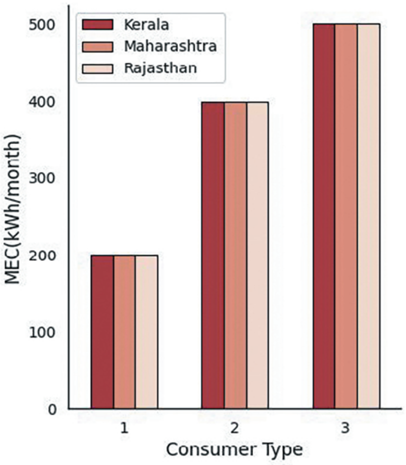


Figure 11: State wise Monthly Electricity Consumption- for different prosumer types

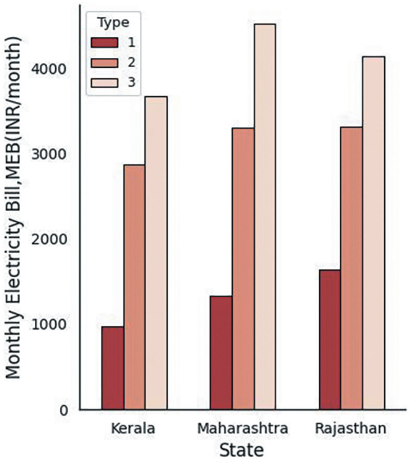


Figure 12: State wise Monthly Electricity Bill (MEB) - for different prosumer types

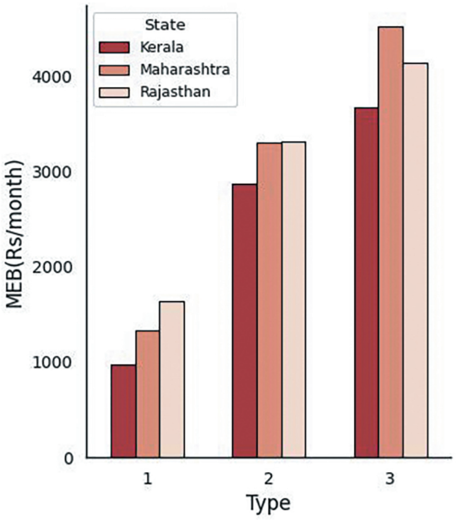


Figure 13: MEB for different states and prosumer types

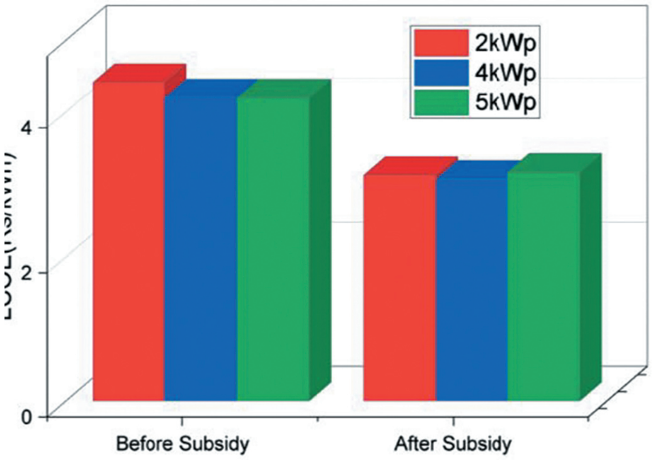


Figure 14: LCOE with and without subsidy

4.5 Grid Parity Objective

4.5.1 RTS LCOE- With and Without Subsidy

LCOE of RTS with and without subsidy is computed using discounted cash flow study. With subsidy, the capital cost reduces and thus levelised cost reduces (Eqn1) (Figure 14).

4.5.2 RTS Grid Parity Check - With and without subsidy

A prosumer of a state achieves complete grid parity when the RTS LCOE is <= EER of the state. With the recent grid price increase in most states, RTS with a subsidy can achieve grid parity in most states. Type 3 prosumers in Maharashtra and Rajasthan EER is always greater than LCOE. Thus, for Grid parity, the subsidy is not required. However, in Kerala, complete grid parity is achieved only with subsidy support (Figure 15).

4.5.3 RTS Sizing - For Self Consumption

With the subsidy, the states have achieved grid parity for all tiers of energy consumption (Figure 15). The subsidy must be increased if grid parity is not achieved for any state's income class. Thus, RTS is sized such that electricity generation from RTS (E_{RTS}) meets the entire annual electricity consumption (AEC) of the prosumer (Table 4). The rooftop area is also calculated. A 1kW rooftop requires 10 m^2 of shadow-free roof area. This can be considered the lowest RTS capacity model, with net zero grid feed-in (S2H).

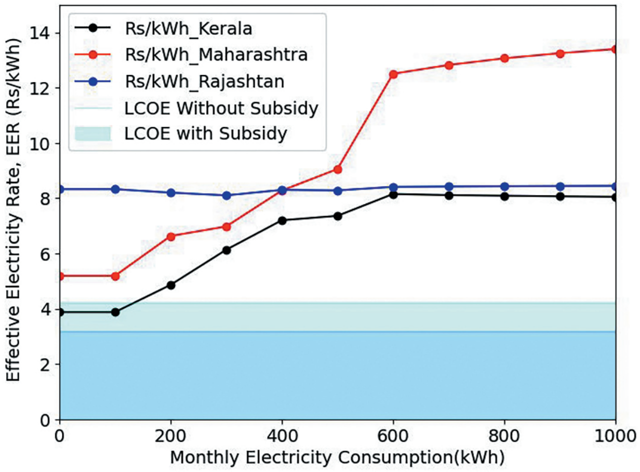


Figure 15: Grid Parity Check using EER and LCOE comparison with and without subsidy for different states for prosumer Type3

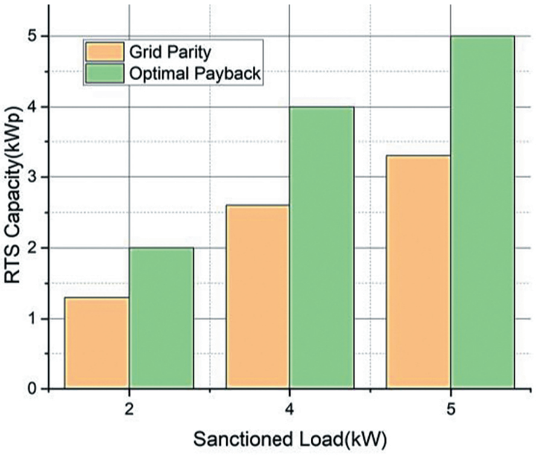


Figure 16: RTS Capacity- for grid parity, optimal payback

Table 4: RTS Capacity Sizing for achieving grid parity

Prosumer Type	**E_{demand}**	**E_{demand}**	**RTS Capacity1**	**Roof Area**	**ERTS / ES2H**	**ES2G**
	kWh/month	**kWh/year**	**kWp**	**m^2**	**kWh/year**	**kWh/year**
Type 3	500	6000	3.284	32.84	6000	0
Type 2	400	4800	2.627	26.27	4800	0
Type 1	200	2400	1.314	13.14	2400	0

Table 5: RTS Capacity Sizing for PBP Optimisation

Prosumer Type	**E_{demand}**	**E_{demand}**	**RTS Capacity2**	**Roof Area**	**ERTS**	**ES2H**	**ES2G**
	kWh/month	**kWh/year**	**kWp**	**m^2**	**kWh/year**	**kWh/year**	**kWh/year**
Type 3	500	6000	5	50	9136	6000	3135
Type 2	400	4800	4	40	7308	4800	2508
Type 1	200	2400	2	20	3654	2400	1254

The RTS capacity is sized to match the AEC (Figure 16). RTS capacity increases with an increase in MEC. Net Feed in to the grid (S2G) will be zero.

4.5.4 Policy Recommendation - Subsidy Rebalancing

Subsidy rebalancing is optional as all states have achieved grid parity with the subsidy support. A subsidy rebalancing study may become necessary if the subsidy is reduced further and the state shifts out of grid parity. However, subsidy rebalancing can be done to equalise the PBP across states and income levels.

4.6 Optimal Payback Objective

4.6.1 RTS Sizing for Optimal Payback

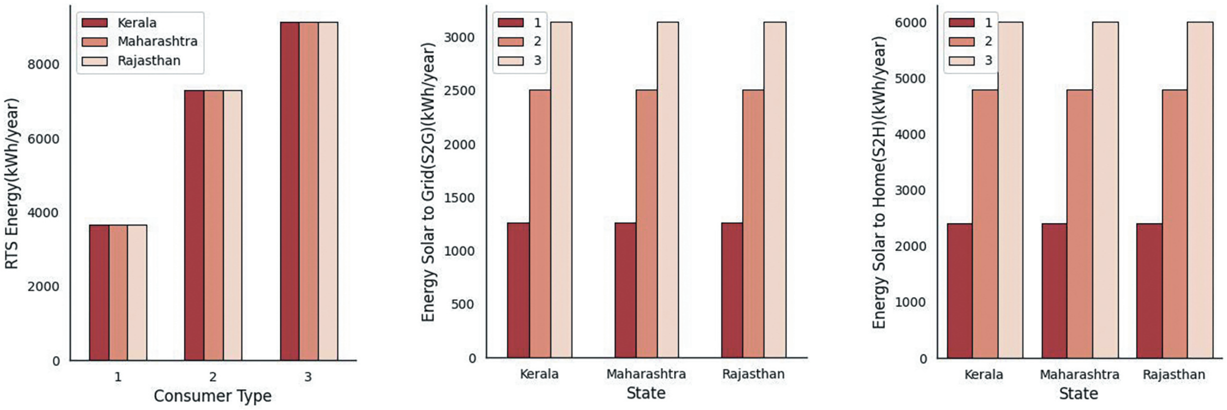
The states have achieved grid parity for all tiers of energy consumption. Maximum RTS is sized to get maximum revenues and high PBP (Table 5). This is the maximum RTC capacity model with maximum grid feed-in. The regulatory guidelines in India limit the RTS capacity to typically 100% of the contract demand [2].

4.6.2 Energy Balance

The RTS capacity is sized to increase with increase in electricity demand. As RTS capacity increases, the RTS generation also increases. The total energy supplied from solar (E_{solar}) is given to the home (S2H Mode) and the surplus to the grid (S2G Mode). Since E_{demand}, E_{RTS}, and E_{solar} are the same for a consumption class, The E_{S2H} and E_{S2G} will be identical. (Figure 17)

4.6.3 Cash Flow Study

Although E_{S2H} is the same, C_{S2H} (Figure 18) will be different for different states. It will be higher for Rajasthan (Type-1, 2) and Mumbai (Type 3), states with higher EER (Figure 18). Although E_{S2G} is the same, C_{S2G} (Figure 19) will differ for different states. It will be higher for Kerala, a state with higher FIT.



(a) E_{RTS} (b) E_{S2G} (c) E_{S2H}

Figure 17: Energy Analysis Supply Side for different states and Prosumer types.

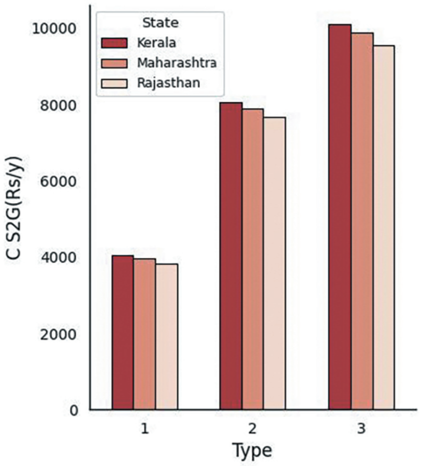


Figure 18: C_{S2H} for different States and Prosumer types

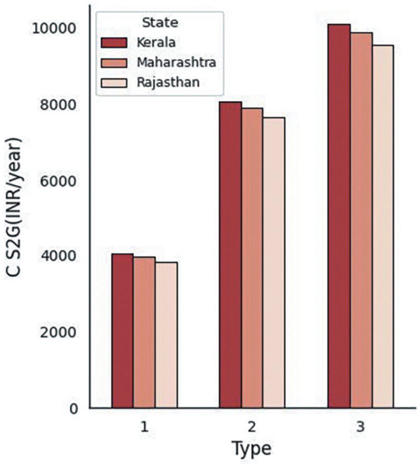


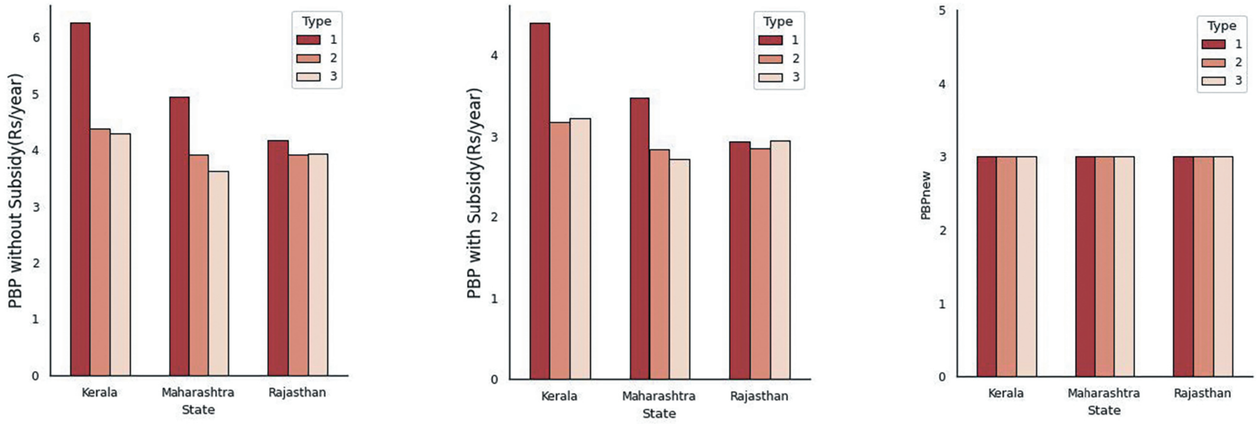
Figure 19: C_{S2G} for different States and Prosumer types

4.6.4 Payback Period - Before and After Equalisation

There is a difference in PBP across states and prosumer types. Type-2 prosumers have better (lower) PBP compared to Type-1 prosumers. Prosumers in states with higher electricity tariffs have better (lower) PBPs than prosumers with lower electricity tariffs. The PBP is low for states with higher tariffs for Type-2 prosumers, and with central subsidies, it further becomes very low. However, the PBP is high for states with low electricity tariffs for Type-1 prosumers, even with subsidies. Thus with a centralised approach, RTS is well suited only for prosumers with high electricity tariffs and high electricity consumption (Figure 20).

When considering different income levels within a state, there are significant differences in the residential RTS PBP for different consumption or income levels. For example, in Kerala, Type 1 and Type 3 prosumers have payback periods of 6.25 years and 4.29 years, respectively. With the centralised subsidy, the PBPs reduced to 4.39 years and 3.22 years, respectively. With centralised subsidy, a high energy-consuming family with a high-income level has a higher effective electricity rate (EER) and thus gets faster payback when compared to a low energy-consuming family with a low-income level having a lower Effective Electricity Rate (EER). Also, as the rural residential energy consumption is significantly lower than the urban consumption in India, residential RTS will be concentrated more in urban households. Subsidy rebalancing equalises both the PBPs to 3 years. Subsidy rebalancing thus rebalances all these social disparities and overcomes the biases of rural-urban and income-level social disparities.

When considering different states, with different Effective Electricity Rates (EERs), for Type1 prosumer,



(a) Before PBP equalisation - without subsidy (b) Before PBP equalisation - with subsidy (c) After PBP equalisation- with subsidy

Figure 20: PBP across states and income classes – before and after payback equalisation

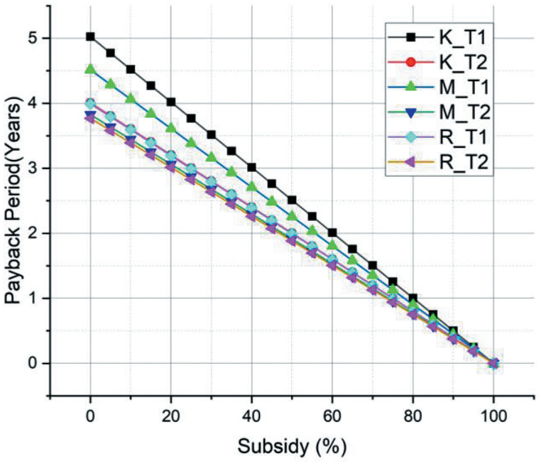


Figure 21: Payback Period for different Subsidy Level -State wise Analysis

the PBP for Kerala and Rajasthan are 6.25 and 4.17 years respectively. With centralised subsidy this reduces to 4.39 and 2.93 respectively. With Subsidy rebalancing this disparity is equalised to the desired value of 3 years. The centralised subsidy results in an unbalanced payback and thus WTP. Subsidy rebalancing equalises both the PBPs to desired level of 3 years, for prosumers of all income classes, thereby significantly improving their WTP. Thus subsidy rebalancing is able to overcome the biases in EER and PBP due to fossil fuel subsidies and residential electricity subsidies in electricity tariff.

4.6.5. Payback Period - Goal Seek Method

For a centralised subsidy scheme, the objective function PBP is varied from 0 to 6 years in steps of 1 year. The decision variable, subsidy % required for each PBP, is calculated using the goal-seek algorithm by varying the desired PBP. The decision variable subsidy% varies from 100% to 0%. PBP vs. Subsidy% plot follows an inverse relationship. As the subsidy increases, the PBP decreases. As the subsidy is centralised, PBP vs. Subsidy% will be the same for all the states and income classes. The present PBP is 3.65 years with a central subsidy. As centralised subsidy increases, PBP decreases. With the centralised subsidy, as EER increases, the PBP decreases. The subsidy is adjusted such that the PBP is equalised. PBP decreases with an increase in subsidy. It can be seen that PBP and EER have an inverse relationship (Figure 21).

With the decentralised subsidy, all prosumers, irrespective of their state, electricity tariff, or electricity consumption, will have the same PBP. Thus, RTS is well suited for all prosumers. This is demonstrated in Figure 23, where a desired PBP of 3 years is considered. Subsidy rebalancing based on the goal-seeking

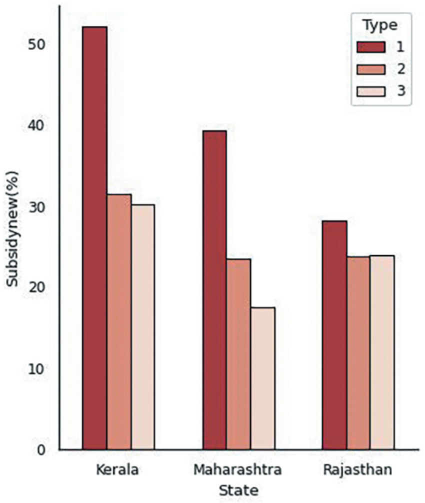


Figure 22: State-wise Rebalanced Subsidy -after payback equalisation

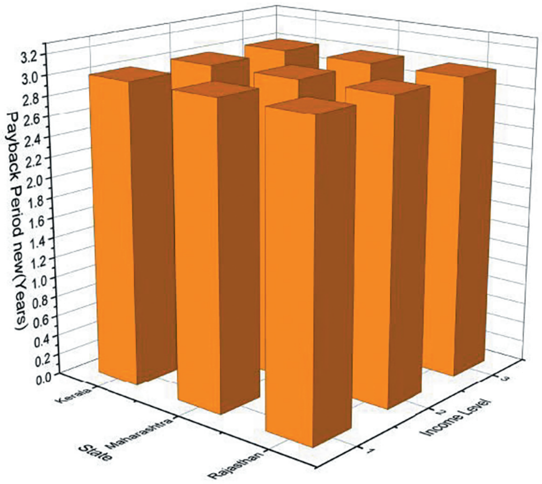


Figure 23: Payback Period across states and income classes with subsidy-after payback equalisation

algorithm is conducted to obtain the desired PBP equalisation. The CFA in the form of subsidy is being disbursed as 40% of capital cost for all states and prosumer types. With recent amendments, this will still remain a fixed amount for a given RTS capacity, irrespective of the state or prosumer type. However, with subsidy rebalancing approach, a higher subsidy is allocated for states with low EER (E.g. Kerala). Also, a higher subsidy is allocated for low-income prosumers (Type1) (Figure 22). This helps in minimising the social disparity. The payback is equalised to 3 years (Figure 23).

4.7 Policy Recommendations

- **Payback Equalisation.** We recommend implementing a PBP Normalised subsidy model instead of a generic one, as it is validated to be better than a standard subsidy irrespective of customer type and local tariff rates.
- **Subsidy Decentralisation.** Provision for normalised subsidy can be given as a generic guideline at the central level, and the specific subsidy can be decided at the individual state level. SERCs can be authorised to update the normalised subsidy while revising the respective state electricity tariff, as the tariff revision is done at the state level.
- **Subsidy Rebalancing.** This subsidy is not suggested for high-income high energy slab consumers, as their financial capability is high. Subsidies in RTS and electricity tariffs can be reduced for higher slab consumers with high-income levels. This Subsidy benefit can instead be allocated to the third-party developer (onsite/off-site), who will supply clean energy to residential consumers.
- **Extension to Time of Day (TOD) Tariff.** The future scope includes an extension of the PBP Normalised subsidy applied to the present slab-based Tired Tariff consumers, which can be extended to TOD consumers. Based on the recent amendments in the Electricity (Rights of Consumers) Rules, 2020, India has introduced the ToD tariff to integrate Solar PV, with a low tariff during solar hours and a high price during non-solar hours to be applicable from 2025.
- **Decentralised FIT.** The FIT is presently calculated based on APPC and varies every year. However, the LCOE of the participating RTS should also be considered. A decentralised FIT-based PPA can be implemented for each solar project.
- **Peer to Peer (PTP).** P2P trading models allow online trading of RTS electricity between supplier and consumer, thus reducing distribution side congestion.

It is essential to mention that the government subsidy scheme design and mechanism should account for multiple socio-political factors, including but not limited to what we have investigated in this paper. Future research is needed to operationalise the proposed models. The present study generates the state-level and prosumer consumption (income) level clustering accuracy of subsidy selection. For the study to have the best or individual prosumer level accuracy, a survey needs to be conducted, including available shadow-free roof areas, willingness to invest in RTS, etc. The WTP estimation for different subsidy levels can be conducted further to implement a WTP based subsidy rebalancing. The nation is moving towards tariff rationalisation and uniform electricity pricing in the future. Thus the subsidy percentage can then be directly mapped to the common national tariff slab.

5. Conclusion

As the power sector is diversifying from a centralised model to a more distributed one, it becomes necessary to include a heterogeneous decentralised subsidy policy to accommodate the diversity of consumers. A real-life case study of the proposed decentralised adaptive PBP Normalised subsidy strategy is conducted for 3 Indian states, and the benefits are validated. PBP equalised subsidy is validated to be better than a subsidy common to all, irrespective of customer type and regional tariff rates. Grid parity is achieved with subsidy for all prosumers of all consumption slabs, irrespective of the state. The PBP is normalised for states. OCC becomes customized within acceptable WTP. The PBP is normalised for urban and rural prosumers. LCOE becomes customised within the grid parity limits of the prosumer. The net LCOE is customised by adapting the subsidies to the respective state electricity tariffs and household income class/electricity demand. This strategy is also adaptive; subsidy changes with changes in input parameters. The proposed RTS targeted subsidy policy design is validated to be customised to suit all states in India and enable prosumers of all income levels to participate and benefit. This would help policymakers to improve the WTP for all prosumer types across all states and achieve the RTS targets in India. Thus, we recommend implementing a PBP Normalised subsidy policy instead of a generic centralised subsidy policy design.

The PBP Normalised subsidy model is validated to be better than the present centralised subsidy, irrespective of customer type and local tariff rates. The proposed model normalises the subsidy design by equalising the PBP between states and economic classes. Prosumer Grid parity is achieved for all states and income classes, ensuring uniformity of RTS implementation. All prosumers, irrespective of their state, electricity tariff, or electricity consumption, will have the same PBP. With targeted subsidies for poverty alleviation, this strategy bridges the disparity in Rural-Urban WTP, leading to a better social scenario. Net benefits are enhanced by allowing subsidy schedules to vary across states and prosumer types.

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