Techno-economic review of Rooftop Photovoltaic Systems: Case Studies of Industrial, Residential and Off-grid Rooftops in Bangalore, Karnataka.

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Abstract

The objective of this study is to assess the financial feasibility of setting up Rooftop Photovoltaic (RTPV) systems in Bengaluru which is in the state of Karnataka, India. The Renewable Energy Policy of the state mandates the installation of 250 MW of RTPV systems by 2014, while research shows that the domestic RTPV potential in Bengaluru alone is around 560 MW. To achieve this potential, the Karnataka Renewable Energy Development Limited (KREDL) and the Karnataka Electricity Regulatory Commission (KERC) formulated policy incentives in the form of net metering at rates of Rs. 9.56/kWh (without the Ministry of New and Renewable Energy (MNRE) capital subsidy) and Rs. 7.2/kWh (with MNRE capital subsidy). Techno-economic assessment of RTPV systems show that these rates lead to viable business cases for the consumers. However, due to Bangalore Electricity Supply Company's (BESCOM) poor finances, a cap of 75% on the capacity of any installed RTPV system based on rated load has been set for all interested parties. Unless this cap is removed, the net metering scheme can never gain momentum in Karnataka because the power generated from the RTPV system will not exceed the monthly consumption. An additional amount of Rs. 81.6 crores per annum is required to reach the 250 MW target. BESCOM can tap the proposed State Clean Energy Fund (SCEF) to pay RTPV project developers. Other revenue models such as feed in tariffs (FiT) and the Renewable Energy Certificates (REC) schemes have been considered for analysis of larger RTPV systems on industrial and commercial rooftops.

Keywords: RTPV, net metering, REC, FiT, techno-economics, SCEF

Nomenclature

$	US Dollar	MNRE	Ministry of New and Renewable Energy
£	Pound Sterling	MoEA	Ministry of Economic Affairs
¥	Japanese Yen	MOHURD	Ministry of Housing and Urban-Rural Development of China
€	Euro	MOST	Ministry of Science and Technology
Ah	ampere hour	MW	Megawatt
BESCOM	Bangalore Electricity Supply Company	MYR	Malaysian Ringgit
BIPV	Building Integrated PV	NDRC	National Development and Reform Commission
BOS	Balance of System	NEA	National Energy Administration
CERC	Central Electricity Regulatory Commission	NPV	Net Present Value
CNY	Chinese Yuan Renminbi	PG&E	Pacific Gas and Electric Company
CPV	Concentrating PV	PLF	Plant Load Factor
Cr.	crores (10^7)	PV	Photovoltaics
DPV	Distributed PV	REC	Renewable Energy Certificate
FiT	Feed in Tariff	ROI	Return on Investment
GBI	Generation Based Incentive	RPO	Renewable Purchase Obligation
GW	Gigawatt	RPS	Renewable Portfolio Standard
IPP	Independent Power Producer	Rs.	Rupees
IRR	Internal Rate of Return	RTPV	Rooftop Photovoltaic
KERC	Karnataka Electricity Regulatory Commission	SCE	Southern California Edison
$kgCO_2$	kilograms of carbon dioxide	SCEF	State Clean Energy Fund
KREDL	Karnataka Renewable Energy Development Limited	SEDA	Sustainable Energy Development Authority
kW	kilowatt	SERC	State Electricity Regulatory Commission
kWh	kilowatt hour	SERIIUS	Solar Energy Research Institute for India and the United States
kWp	kilowatt peak	SME	Small and Medium Scale Enterprises
LCOE	Levelized Cost of Electricity	T&D	Transmission and Distribution
LSPV	Large Scale PV	WACC	Weighted Average Cost of Capital

1. Introduction

Although India has witnessed most of its growth in solar power in the utility scale power plant sector [1], most states are now focusing on policies which promote Rooftop Photovoltaic (RTPV) systems. RTPV systems have the following advantages in terms of distributed and decentralized electricity generation and consumption:

- No ground level land required
- Reduced gestation period
- Reduced transmission and distribution (T&D) losses because of the decentralized nature of power generation and usage
- Environmental benefits from displacing small-scale diesel generator (DG) sets
- Reduction in system congestion due to higher self-consumption
- Capacity building of local electricians

This article reviews the techno-economics involved in setting up a RTPV system in Bengaluru, Karnataka, taking the existing policy framework into account. Households, industries and commercial establishments with roofs made of concrete, machine made tiles, and corrugated galvanized iron/metal/asbestos sheets have been taken into consideration for this study. According to the recent census data [2], the total number of such households in urban Bengaluru is 1,999,994. Taking a conservative approach, it is assumed that an average urban household in Bengaluru (with a demand of 2.4 kW in 2012-13) has a demand for 3.5 kW in 2021-22 which rises to 4 kW in 2031-32 (this assumption is based on the historical trends of per capita consumption statistics provided by BESCOM and it also takes into account the inclusion of domestic air-conditioning loads in households with a rated load of more than 2.5 kW today [3] [4]. If 5% of such households set up RTPV systems with the designated rated load by 2021-22, the total installed capacity would be around 350 MW and if 8% set up RTPV systems by 2031-32, the total installed capacity would increase to 560 MW. Today, BESCOM reports a shortage of around 200 MW in the city with respect to the peak demand. The projected installed RTPV capacity in 2021-22 and 2031-32 will effectively contribute in reducing this shortage (which is likely to increase) by a great extent. Owing to lack of data regarding industrial and commercial rooftops in Bengaluru, projections of capacity of RTPV have not been made.

The Karnataka Renewable Energy Development Limited (KREDL) and the Karnataka Electricity Regulatory Commission (KERC) are aware of this tremendous potential and have recently come up with draft policy measures to encourage consumers to adopt RTPV systems. At a central level, the Ministry of New and Renewable Energy (MNRE) offers a capital subsidy of 30% on the initial investment required to set up a RTPV system. However, there are barriers in receiving this subsidy and recent reports suggest that it will be a while before capital subsidies for RTPV systems are disbursed through reliable channels in the country [5]. The next section of this article presents an overview of policies pertinent to RTPV systems in Karnataka.

2. RTPV policy regime in Karnataka

According to the Renewable Energy Policy of Karnataka [6], 250 MW of RTPV systems have been targeted to be set up by 2014. The recently released draft solar policy [7] targets a total of 2000 MW of solar PV installations (including RTPV and off-grid systems) by 2020. To reach these targets KREDL and KERC formulated certain policy incentives for prospective proponents of RTPV systems. These are described briefly in the following sub-sections.

2.1. Net Metering Scheme

The net metering scheme usually applies to domestic consumers with installed capacities of under 10 kW. In this scheme there are two meters installed for the RTPV system. One meter measures the monthly consumption of the consumer while the other measures the total monthly generation from the RTPV system. The difference between the two is considered for monetary compensation. If the consumption is more than the monthly generation, then the consumer pays the difference to the utility and vice-versa (Figure 1). Net-metering has been used successfully in countries like US and Thailand [8] [9]. There is a lobby which pushes for preferential rates for the PV generation to yield a higher return for the consumer since there are significant initial investment costs. KERC recently issued a tariff order fixing the net metering rate for RTPV systems at Rs 9.56/kWh (systems without 30% MNRE subsidy) and Rs. 7.20/kWh (systems with 30% MNRE subsidy) [10]. However, owing to the poor financial health of Bangalore Electricity Supply Company (BESCOM), the installed capacity of the RTPV system cannot exceed 75% of the consumer's connected load, i.e. if the rated load of a consumer is 4 kW, the capacity of a RTPV system will be restricted to 3 kW and anything more will not be considered for the net metering mechanism.

2.2. Renewable Energy Certificate (REC) Scheme

According to the Electricity Act, 2003, the National Electricity Policy, 2005, and the Tariff Policy, 2006, State Electricity Regulatory Commissions (SERCs) are mandated to purchase a certain amount of power from renewable energy sources [11] [12] [13]. These are known as the Renewable Purchase Obligations (RPOs). Amongst these RPOs there are solar RPOs for each state. The solar RPO target for the country is 3% (annual escalation as determined by respective SERCs) by 2021-22 [14]. These targets are imposed on state distribution utilities, captive power producers and open access consumers. If these obligated entities exceed their targets then for every excess 1 MWh they are entitled to one REC. The accrued RECs can be traded in the open market where they are bought by obligated entities who have not achieved their targets. In Karnataka, consumers who use the electricity generated from RTPV systems for captive purposes are eligible for accreditation under the REC mechanism. Hence industrial units with large rooftop areas can install RTPV systems, use all the electricity generated and gain RECs which can later be traded in the REC market. This scheme is usually beneficial for large industries or a cluster of Small and Medium-scale Enterprises (SMEs) - the latter being aggregated by the respective association, i.e. if there are a number of SMEs in a cluster and they all set up RTPV systems on their rooftops, the industry association will serve as an aggregator and represent all the RTPV systems as one entity. The entity will trade the generated RECs in the REC exchange/market and then distribute the revenues amongst the participants proportionately.

2.3. Feed in Tariffs (FiT)

Although there is no official policy for feed in tariffs in Karnataka as yet, there are ongoing discussions regarding this. FiT has been implemented with varying degrees of success in countries like Germany, Japan, Italy, Taiwan, UK, China and Malaysia. In the feed in tariff mechanism, the entire generation from an RTPV system is fed directly to the grid at regulated rates as per the norms set by the Central Electricity Regulatory Commission (CERC) or by the respective State Electricity Regulatory Commission (SERC). Independent Power Producers (IPPs) who cannot avail the REC mechanism can opt for feed in tariffs. Large rooftops of metro stations, railways stations, bus depots and junctions, warehouses, etc. can be leased out to these IPPs who can install RTPV systems and export the entire electricity directly to the grid.

2.4. Capital subsidy for off-grid RTPV systems

Apart from the 30% capital subsidy offered by MNRE for off-grid solar PV systems, there are state level policy measures being discussed within Karnataka which can provide more financial assistance to developers or households who are interested in installing RTPV systems with battery backup to meet the electricity demand.

2.5. Comparison of policy levers for RTPV in other countries

Researchers have compared the above policy levers used in other countries and this article sums up the performance of Net Metering, FiTs and other mechanisms in various countries based on literature review of scholarly articles. This summary is presented in Table 1.

Country	Policy lever for RTPV	Salient Features
USA [8] [15] (California)	Net Metering	• 2 distribution utilities participate in this scheme, viz. Pacific Gas and Electric Company (PG&E) and Southern California Edison (SCE) with non-time-differentiated inclining block retail rate with five usage tiers ($0.12/kWh in Tier 1 to $0.50/kWh in Tier 5 for PG&E and $0.13/kWh to $0.31/kWh for SCE) and time-of-use (TOU) rates • Net Metering allows customers to offset volumetric charges within each billing period and for TOU consumers calculations are performed within each TOU period, so that PV generation is credited based on the TOU period in which it occurs. Any excess bill credit at the end of a billing period is taken forward to the next billing period; however, at the end of the year, any excess bill credits are forfeited • Capacity limit is set at 5 MW for systems under the control of local government or universities and 1 MW for other systems • Total of 721 MW of rooftop PV has been installed under this scheme till date (457.3 MW with PG&E and 263.7 MW with SCE); the total amount of incentives provided are of the tune of $887 million ($540 million from PG&E and $347 million from SCE) [16] • Economic performance of RTPV system depends of the PV-load ratio, retail rate of these two utilities and the tracking systems or accuracy of installation involved with the system. A higher PV-load ratio with higher retail rates and better tracking system gives better economic performance in terms of bill savings. Since generation does not exceed consumption there are no revenues and the profitability of the systems arise from accrued savings. Payback period of systems are in the range of 8-11 years
Thailand [9] [17] [18]	Net Metering (2002-07)	• Solar plants (including RTPV) with capacity limit of 1 MW directly connected to the grid; for capacities greater than1 MW, net metering allowed only if sufficient electricity generated is consumed for captive purposes • If generation was lesser than consumption, then consumer had to pay the retail electricity rate for the difference to the distribution utility; if generation was more than consumption then the received revenue would be at the average pool purchase cost of electricity for the utility (~80% of the retail rate)
	FiT (2007-present)	• Transition from net metering to FiT occurred in 2007 when new renewable energy policies were introduced by the Department of Alternative Energy Development and Efficiency under the Ministry of Energy; program known as the “Adder” scheme • Small Power Producers (10 MW-90 MW) sell electricity directly to the Electricity Generating Authority of Thailand; Very Small Power Producers (<10 MW) sell electricity to the Metropolitan Electricity Authority and the Provincial Electricity Authority; the rate is fixed for 10 years for solar projects • Adder rates for solar projects are: Retail price +Adder rate; Adder rate was $0.267/kWh in 2007 which dropped to $0.217/kWh (an additional special rate of $0.05/kWh was assigned to projects which led to diesel abatement; for the three southernmost provinces another $0.05/kWh was added) • Applications for solar adder programs were stopped after 2010; the total installed capacity as of Dec 2011 was around 111 MW

Germany [19] [20]	FiT (2000-present)	• In 2000, Renewable Energy Sources Act provided remuneration of €0.51/kWh over 20 years for solar PV with an annual reduction of 5%; Maximum size of 5 MW for building integrated plants, 100 kW for others; Ceiling for cumulative installed capacity at 350 MW; cumulative capacity of 186 MW installed in 2001 • In 2002, the ceiling for cumulative installed capacity was raised to 1000 MW and in 2003 the ceiling was removed and there was no restriction imposed on the size of any PV plant; FiT was increased to €0.547/kWh for 20 years with an annual reduction of 5%; cumulative capacity rose to 4.17 GW in 2007 • In 2009, there was a dynamic annual reduction in FiT introduced depending on deployment (basic reduction of 8–10% for 2010 ± 1% if annual installed capacity < 1000 MW or >1500 MW); Options of self-consumption (€0.2501/kWh) or direct marketing to third parties was provided to reduce outflow of government funds • In 2010 and 2011 the annual reduction changed to 9% ± 4% depending on deployment in these years; reduction in FiT by 10% in July, 2010 and further by 3% in October, 2010; In 2012, remuneration for self-consumption was reduced depending on system size (max. €0.1236/kWh); cumulative capacity was 24.678 GW in 2011 • Today the total cumulative capacity of solar PV in Germany is more than 34 GW with over 65% on rooftops using the FiT scheme; although there are troubling times now because of the massive disbursal of FiTs each year, it clearly is one of the success stories of decentralized solar PV installations in a country
Japan [21]	Net Metering, Capital Subsidy, Renewable Portfolio Standard (RPS) and FiT; (1992-present)	• Voluntary net metering programme started by 10 utility companies in 1992 to purchase surplus electricity generated from PV installations at the retail rate (¥23/kWh) • In 1994, a national capital subsidy programme was announced for installations in the range of 1-5 kW_p; 50% of the installation cost with a cap of ¥900,000/kW_p was allowed; this was changed regularly and stopped in 2005 when the value was ¥20,000/kW_p; around 930 MW was installed in this period • Similar to India's RPO mechanism, the RPS policy was initiated in 2003 which obliged utilities to procure 1.35% of their electricity from renewable sources by 2010; this led to a decline in the annual installation rate since the utilities did not adopt an aggressive stance towards promoting solar power and in January, 2009 the capital subsidy programme was restarted with ¥70,000/ kW_p • In November 2009, FiT was introduced at ¥48/kWh with a cap of 10 kW payable for ten years without annual reductions; scheme obligated utilities to purchase only the surplus electricity generated making this a variant of the net metering mechanism; capital subsidy was also provided which dropped from ¥70,000/kW_p to ¥30,000-35,000/kW_p in 2012; cumulative capacity of 4.9 GW was installed till 2011 with 90% installations on residential buildings and rooftops; scheme ended on 30th June, 2012 • New FiT scheme introduced in July, 2012 with a target of 28 GW by 2020 and 50 GW by 2030; financed by consumers themselves, electricity bills will rise by around ¥100 per month; for residential installations the FiT is ¥42/kWh payable for 10 years without annual reductions along with a capital subsidy of ¥30,000-35,000/kW_p; cumulatively residential and rooftop PV installations have crossed 5.6 GW as of date

Italy [22] [20]	FiT coupled with Net Metering (2008-present)	• In the period of 2008-10, the FiT scheme favoured systems below 20 kW_p; the rate varied from €0.365-0.49/kWh for systems below 20 kW_p and for systems above 20 kW_p the rate varied from €0.346-0.422/kWh; no caps were put on overall amount of installations or power output • In 2011, the FiT scheme became more complex and there were three rates based on the months when the installations were completed; for systems ranging from 1-200 kW_p, if they were installed before April 30, the rate was €0.321-0.402/kWh; between May 1 and August 31, the rate was €0.309-0.391/kWh; between September 1 and December 31, the rate was €0.285-0.38/kWh; there was a monthly reduction in the FiT rate along with a cap of 23,000 MW • From 2012, the FiT scheme divided the incentives for building integrated PV (BIPV) systems and other installations with a major reduction of tariffs; plants in the range of 1-200 kW_p avail rates of €0.206-0.274/kWh with the same cap; the total installed capacity of solar PV in Italy was 16.202 GW in 2012 with more than 60% of installations being in the range of 1-200 kW_p
Taiwan [23]	FiT coupled with capital subsidy (2004-present)	• Between 2004-08, the Ministry of Economic Affairs (MOEA) implemented the Photovoltaic Generation Demonstration System Installation Subsidy Guidelines where a capital subsidy of $3,667 per kW_p was provided for grid-connected PV systems and $5,000 per kW_p for stand-alone PV systems with a maximum subsidy of 50% of installation costs • In 2006, the Photovoltaic Standard System Installation Subsidy Guideline Principles were introduced; subsidies offered for PV systems above 1 kW_p of $5,000 per kW_p with a maximum amount of 50% of installation costs; for national institutions, schools, and hospitals located in remote areas and on off-shore islands, the maximum subsidy per kW_p for the installation of emergency-use, stand-alone solar PV systems was $11,667; maximum subsidy for emergency disaster prevention systems (so-called mix-type systems) was $13,333 • In 2009, the Renewable Energy Development Act was passed which allowed a capital subsidy of $1,667 per kW_p for systems in the range of 1-10 kW_p with a FiT of $0.271/kWh; for systems above 10 kW_p, no subsidy would be provided and only a FiT of $0.3-0.311/kWh was applicable • Since January, 2011, capital subsidies of $1,667 per kW_p were provided for systems in the range of 1-10 kW_p with a FiT of $0.373/kWh; for systems without capital subsidy, the FiT was $0.487/kWh; for systems above 10 kW_p there was no capital subsidy and the FiT was $0.432/kWh • Today along with the capital subsidy, the FiT rates are $0.21-0.28/kWh for rooftop installations, and $0.20/kWh for ground-mounted installations; a total of 222 MW of solar PV has been installed [24] with over 60% coming from systems in the range of 1-10 kW_p

UK [25]	FiT (2010-present)	• In April, 2010, a FiT scheme was introduced in the UK to support PV installations; the rate was different for various sizes of installations; RTPV systems ≤ 4 kW_p received £0.361/kWh (new build) or £0.413/kWh (retrofit); systems between 4-10 kW_p received £0.361/kWh, 10-50 kW_p and 50-100 kW_p systems got £0.314/kWh; 100-150 kW_p and 150-250 kW_p systems availed £0.293/kWh; stand-alone systems got £0.293/kWh; cumulative installations on March 30, 2011, stood at 77.7 MW • After the first review in 2011, a new FiT scheme was introduced for the period of April 1, 2011-March 30, 2012; RTPV systems ≤ 4 kW_p received £0.378/kWh (new build) or £0.433/kWh (retrofit); systems between 4-10 kW_p received £0.378/kWh, 10-50 kW_p received £0.329/kWh; 50-100 kW_p and 100-150 kW_p systems got £0.19/kWh; 150-250 kW_p systems availed £0.15/kWh; stand-alone systems got £0.085/kWh; total installed reached 366 MW in November, 2011; 290.6 MW came from the domestic sector alone • Owing to the unexpected success of the scheme (137 MW was the 2nd year target which was surpassed in July, 2011), the government reviewed the FiT rate and reduced it for systems being installed after April 1, 2012; RTPV systems ≤ 4 kW_p receive £0.21/kWh (new build and retrofit); systems between 4-10 kW_p receive £0.168/kWh, 10-50 kW_p received £0.152/kWh; 50-100 kW_p, 100-150 kW_p and 150-250 kW_p systems get £0.129/kWh; stand-alone systems got £0.085/kWh; for each of these schemes an additional incentive was provided if any electricity generated was exported to the grid (rate increased from £0.03/kWh in the first year to £0.031/kWh today for all size ranges
China [26] [27]	Capital Subsidy (2009-11) and FiT (2011-present)	• In March, 2009, the Ministry of Finance and the Ministry of Housing and Urban-Rural Development of China (MOHURD) announced the "Rooftop Subsidy Program" which provided an upfront subsidy of CNY 15/W_p for rooftop systems and CNY 20/W_p for building-integrated PV (BIPV) systems, and a subsidy of 50% of the bid price for the supply of critical components; size of eligible systems ≥ 50 kW_p • In July, 2009, a second program known as the Golden Sun Demonstration Program was jointly introduced by the Ministry of Finance, the Ministry of Science and Technology (MOST) and the National Energy Administration (NEA) of the National Development and Reform Commission (NDRC); 50% upfront subsidy on the investment cost for grid- connected systems and a 70% upfront subsidy for off-grid PV systems over the period of 2009–11; cap of 20 MW for each province; in 2012, 3044.06 MW had been installed under this program • In July, 2011, NDRC announced a FiT scheme for solar PV; rate of CNY 1-1.15/kWh; did not take into account the variability of solar resources (some provinces with rich radiation benefited more compared to others) • Since the PV manufacturing industry of China suffered reduction in revenues (due to the global glut and trade disputes with USA and Europe), the government tried to incentivize a market for domestic utilization of PV products; Distributed PV (DPV) generation was encouraged along with large scale PV (LSPV) projects; DPV projects could connect to the grid and required no lengthy approval processes; a generation based incentive (GBI) of CNY 0.42/kWh (taxes included) was provided for all DPV plants; a resource based FiT was also introduced for ground-mounted DPV systems with a rate of CNY 0.9/kWh, 0.95/kWh, or 1/kWh dependent on the local resource availability; today China has more than 1.5 GW of DPV and RTPV installed

Malaysia [28]	FiT (2011-present)	• In December, 2011, a FiT scheme was introduced for various renewable energy sources in Malaysia and the scheme was to be is administered and implemented by a new entity called the Sustainable Energy Development Authority (SEDA); a fund was created by increasing the electricity bills of consumers (≥300 kWh/month) by 1% to support the FiT; • A quota on solar PV systems below 1 MW_p was imposed; 2011/12 – 10 MW, 2013 – 10 MW, 2014 – 5 MW; the FiT provided for solar PV was in the range of MYR 0.85–1.78/kWh; As of today, total installed PV capacity stands at 169 MW out of which 100 MW or more have come from DPV systems; • Since solar PV is using bulk of the allocated FiT in Malaysia and costs of solar PV is coming down globally, SEDA proposes to reduce the FiT over the next few years
India (Karnataka)	Capital Subsidy (2010-present) and Net Metering (2013-present)	• Since the inception of JNNSM, MNRE provides a 30% capital subsidy on any RTPV system • In 2013, KERC announced the Net Metering scheme for Karnataka in collaboration with KREDL and BESCOM; the rates are Rs. 9.56/kWh (without MNRE subsidy) and Rs. 7.2/kWh (with MNRE subsidy); BESCOM has a cap on size of the system (75% of rated load of consumer) • FiT is being discussed as a policy instrument for industrial and commercial consumers along with RTPV systems on bus stops or other unused rooftops • REC mechanism is present for systems above 100 kW_p; for captive consumers and OACs

Discussions

From the literature review of policy incentives for RTPV systems, it can be seen that FiTs - along with capital subsidies and other incentives such as simple authorization procedures and net metering schemes – form a robust policy framework which enables the penetration of RTPV systems in any society. Other research articles also provide the same conclusion based on studies in respective countries [29] [30] [31]. Yamamoto compared the effectiveness of FiTs with net metering, and net purchase and sale mechanisms in 2012 taking into account impact on social welfare and retail electricity rates [32]. He observed that even with the drawbacks of FiT, it still performed far better than the other two in isolation when it came to promoting RTPV installations. Other articles showed that FiT is more stable and provides long-term assurances for project developers in spite of having annual reduction rates and they also perform better than market mechanisms such as the RPS and RECs owing to the complexity of the latter [33]. FiTs need to be designed according to the solar resource availability in locations so that places with higher radiation profiles do not avail a chunk of the funds. Moreover, as most of the previous studies show, FiTs are invariably revised over time as the solar costs go down. Hence, projections need to be made considering the evolution of solar PV for FiT rates.

BESCOM in Bengaluru has been suffering losses for decades now and they are not in a position to provide FiTs for RTPV as of now. Hence, a net metering scheme was announced which announced local generation and consumption and savings in electricity bills. There was also a 75% cap on capacity with respect to the rated load of the consumer. Essentially, this is a model very similar to that of the California model where revenues were negligible and profitability of RTPV systems was measured in terms of savings in monthly bills and diesel abatement costs.

Table 1: Salient features of RTPV policy levers in other countries

The following sections of this article consider specific case studies which fall under the scope of each of the policies mentioned above and analyse the economic viability of RTPV systems in Bengaluru. Gaps in policies have been identified and suitable policy recommendations have been made.

3. Methodology

The objective of this research is to assess the techno-economic feasibility of installing RTPV systems in an urban context taking Bangalore to be a case study. Since RTPV is a decentralized distributed power generation system, specific case studies have been undertaken in the industrial, commercial and residential spaces to represent the entirety of the city. For the sake of confidentiality the names of the sites are not revealed. Five units have been identified for analysis in the Peenya industrial sector area, which is a hub for SMEs In the residential context, an urban house in central Bengaluru and an independent sub-urban villa in a gated community have been taken for analysis in this study. In the off-grid space a small household disconnected from the BESCOM supply has been considered.

To be able to accurately project techno-economics of any energy system, obtaining primary data is essential. For this study, field visits were made to the aforementioned locations. Monthly and annual electricity bills paid to the utility, i.e. BESCOM, were procured to determine the demand of electrical energy. The daily load profiles were analysed to figure out the periods of peak demand. Details of backup generators running on diesel were obtained in the form of monthly diesel consumption and capacity of generators.

It has been observed that in the industrial cluster, power outages exist for about an hour daily. However, the quality of power supply is unreliable and hence the units operate their diesel generators for about 2 hours a day. The rate at which industrial units purchase electricity from BESCOM is in the range of Rs. 4.5-5.5/kWh. The residential units in this study are found to operate the diesel generators for around one hour a day. The price paid by residential consumers to BESCOM ranges between Rs. 2.2-5.5/kWh [34]. The capacity and type of RTPV systems to be installed on each rooftop has been calculated taking the following factors into account:

- Available rooftop area for solar PV installations (m^2).
- % of demand to be displaced from grid and diesel abatement (kWh), dependent on the financial strength of the rooftop owner and the willingness to invest
- Total area of rooftop required to meet this demand using solar PV: efficiency of multi-crystalline PV modules has been taken to be 13.4% [35; 36], capacity factor has been assumed to be 19% and the average annual global horizontal irradiance (GHI) of 5.25 kWh/m^2/day [37], calculations show that 1 kWp of solar PV requires around 10 m^2 of rooftop area taking Balance of System (BoS) into account
- Requirement of battery systems for storage of electricity to supply at night is based on the number of ampere hours (Ah) reserve capacity requirement of each system. This is directly proportional to the power outages and demand of each of the consumers after sunset

Once the system capacity has been determined along with battery storage requirements, the analysis focuses on the economics of each RTPV system. The cost of each component, i.e. solar panels (string of modules), inverter, mounting structures, evacuation costs (cabling), battery, energy meters and preliminary and pre-operative expenses are determined. The total costs of these components amount to the total initial investment required for each system. This data has been obtained from system integrators and module manufacturers and is considered to be confidential. Hence the names of the companies are withheld and only the numbers are provided for the reader to understand the economics of each system.

The Levelized Cost of Electricity (LCOE) is calculated by determining the total amount of electricity generated by the RTPV system over its lifetime (taking degradation into account) i.e. 25 years and all numbers discounted to Net Present Value (NPV) and dividing the total cost of the RTPV system over its lifetime by the total amount of electricity generated.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{(I_t + M_t + F_t)}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \; [38]$$

Where,

I_t = Investment expenditures in the year t
M_t = Operations and maintenance (O&M) expenditures in the year t
F_t = Fuel expenditures in the year t (considered to be 0 in case of solar PV)
E_t = Electricity generated in the year t
r = Discount rate
n = Lifetime of the system (25 years in case of solar PV)

The revenue model is then calculated by taking into account the savings of the consumer due to displacement of grid-based electricity, diesel or kerosene and revenue from electricity sales through net metering scheme to the utility and REC sales in the market. The revenues are discounted over the lifetime and NPV, internal rate of return (IRR) and payback period for each system are calculated. The next section of this article shows how sample calculations are made using this methodology for specific case studies of RTPV systems in Bengaluru.

4. Calculations

This section will enable the reader to grasp the results of the research which are presented in the next section. The approach taken to arrive at the calculated techno-economics using the methodology mentioned above is described here. The specific case studies that have been considered for this analysis are:

1. An urban villa with a rated load of 7 kW and a RTPV system of 5 kWp capacity with and without storage; revenue model of net metering
2. A sub-urban villa (weekend or holiday home) with a rated load of 7 kW and a RTPV system of 5 kWp capacity without storage; revenue model of net metering
3. A cluster of five industrial units with RTPV systems of 50 kWp capacity each amounting to 250 kWp without storage; revenue model of REC mechanism
4. A warehouse rooftop with a RTPV system of 30 kWp capacity without storage; revenue model of FiT for the IPP
5. An off-grid hut with a RTPV system of 350 Wp with storage

The techno-economics of each of these case studies have been calculated with and without the subsidy, except for the five 50 kWp industrial RTPV systems, since the REC mechanism is invoked in this case and is hence ineligible for capital subsidy. The urban villa and the cluster of SMEs have been chosen to demonstrate how techno-economics have been calculated since the other systems are variations of these two. All the systems are financed by equity except for the SMEs. In case of the SMEs there is a debt-equity ratio of 75:25 with an interest rate of 13% and loan tenure of 10 years.

The other common assumptions and factors taken into consideration for the calculations are listed below:

- *Cost of modules*: Rs 43-47/Wp (Since available rooftop area is a constraint in RTPV systems, only high efficiency crystalline silicon cells have been considered and hence the market prices are comparatively higher)
- *Discount rate* – weighted average cost of capital (WACC) for debt financed cases and 10% for other cases
- *Lifetime of systems* – 25 years
- *Plant Load Factor (PLF)* – 19%
- *Inflation rate of components* – 5% per annum
- *O&M costs for RTPV systems* – 0.5% of initial investment
- *tax rate* – 33%
- *Emission factors* – diesel (0.7 $kgCO_2$/kWh), grid (0.8 $kgCO_2$/kWh), kerosene (2.53 $kgCO_2$/litre), PV (0.03 $kgCO_2$/kWh) [39] [40]
- *Battery reserve time* – 4 hours with 70% depth of discharge
- *Degradation factor* of cells: 0.5% per annum [41] [42]

The cost calculations for the two systems are shown in Table 2.

Description of parameters	**Values**	
Capacity of RTPV system	**5 kWp (Villa)**	**250 kWp (SME)**
Total cost of modules	Rs. 2,75,000	Rs. 1,35,00,000
Cost of land	0	0
Cost of battery	Rs. 85,000	0
Mounting structures and meters	Rs. 60,000	Rs. 26,25,000
Cost of inverter	Rs. 56,500	Rs. 20,00,000
Evacuation cost (cables and transformers)	Rs. 50,000	Rs. 26,25,000
Preliminary and pre-operative expenses	0	Rs. 20,00,000
Total cost of system (without MNRE subsidy)	**Rs. 5,26,500**	**Rs. 2,27,50,000**
Debt-Equity ratio	0:100	75:25
Loan tenure	-	10 years
Loan interest rate	-	13%
LCOE without MNRE subsidy	**Rs. 8.24/kWh**	**Rs. 9.30/kWh**
MNRE subsidy	Rs. 1,57,950	-
Total initial investment (after MNRE subsidy)	**Rs. 3,68,550**	**-**
LCOE with MNRE subsidy	**Rs. 6.15/kWh**	**-**

Table 2: Cost calculations for RTPV systems

Returns on investment for the 5 kWp system arise purely out of saving of grid or diesel based electricity costs. The 75% cap on the rated load as maximum RTPV capacity eligible for net-metering means that the electricity generated by the RTPV system will never exceed the consumption of the household and therefore no electricity will be exported to the utility. Hence the net metering scheme to actually generate revenue for the consumer will not be invoked. Only savings from diesel abatement (using the battery bank to replace the diesel generator) and displacement of grid-based electricity can be obtained. The financial implications of this are summarized in Table 3.

Description of parameters	Values
Total demand of electricity of consumer	31,886 kWh/year
Total diesel based electricity	1,594 kWh/year
Total diesel requirement	455.52 litres/year
Current price of diesel	Rs. 58.04/litre
NPV of total savings due to diesel abatement	Rs. 3,81,678
Weighted average price of electricity paid by consumer to utility	Rs. 4.48/kWh
NPV of total savings due to displacement of grid-based electricity	Rs. 4,37,060
NPV of total savings	**Rs. 8,18,738**
IRR	**10%**
Payback period	**8 years**

Table 3: Revenue model for 5 kWp RTPV system in urban villa

The revenue model of the 250 kWp system on industrial rooftops is very different compared to net metering. This is because the electricity generated from the RTPV system is for captive use and is not sold to the utility. Instead RECs are gained and traded in the exchange. The savings arise due to displacement of grid-based electricity and diesel abatement and tax benefits from depreciation. The calculations are summarized in Table 4 below.

Description of parameters	Values
Total demand of electricity of consumers	7,20,000 kWh/year
Total diesel based electricity	68,880 kWh/year
Total diesel requirement	19,680 litres/year
Total amount of diesel to be replaced by solar (60%)	11,808 litres/year
Current price of diesel	Rs. 58.04/litre
NPV of total savings due to diesel abatement	Rs. 98,93,866
Weighted average price of electricity paid by consumers to utility	Rs. 5.36/kWh
NPV of total savings due to displacement of grid-based electricity	Rs. 2,25,19,862
REC rate (10% annual decline after 2016-17)	Rs. 9,300/MWh
Total revenue gained from REC sales	Rs. 2,05,42,649
Total debt repayment amount	Rs. 3,14,44,405
Total tax benefits due to depreciation	Rs. 56,91,866
NPV of total savings	**Rs. 1,99,03,838**
IRR	**29%**
Payback period	**3 years**

Table 4: Revenue model for 250 kWp RTPV system on industrial rooftops

Similar calculations have been performed for all the other case studies and the results have been shown in the following section of this article.

5. Results and Discussion

Each of the case studies have been analysed in terms of financial feasibility for the consumer as well as the financial implications for the utility or the state/central government institution which enables the consumer to invest in RTPV systems. The significant results pertinent to each case study are highlighted in Table 6. The Net Cumulative Cash Flow of each system throughout its lifetime is shown in Figure 2, Figure 3, and Figure 4.

Some important inferences can be made from the findings in Table 6:

- A captive RTPV system feeding power to a private industrial unit is the most profitable of all business cases in this analysis. Since the consumer can avail the REC mechanism, there is added incentive for captive power consumption. Similarly commercial establishments in the city which are heavily dependent on diesel generators to meet their electricity needs can benefit to a great extent using RTPV systems for captive use. However, due to lack of data, this analysis has not included quantitative economics for this sector.

- In the case of an off-grid RTPV system with battery storage, the economics in terms of IRR and payback period are not viable for the customer because there is no revenue generated from the generation or consumption of electricity. Social engineering aspects such as growth of GDP due to energy access for the consumer need to be linked with this business case to understand the social costs and benefits.

- If net metering scheme is to be used for RTPV systems, then the concept of a cap of 75% of rated load does not make the business case viable. This is because the net metering rate of Rs. 7.2-9.56/kWh for solar power will never come into being since the electricity generated from the RTPV system will never exceed the consumption of a residential consumer within city limits and the only monetary savings arise from net electricity bill reduction and diesel savings. However, if this RTPV system is installed in the country/semi-urban residential villas and is used only during weekends and holidays, a feasible business case can be constructed.

- If the cap is to be removed in context to net metering, then the total corpus required to reach 250 MW in 2014 (taking 40% excess generation from RTPV systems) would be around Rs. 139.8 crores. Beyond the average pooled price of electricity of Rs. 3.5/kWh, BESCOM would require an additional amount of around Rs. 81.6 crores to support this scheme. The State Clean Energy Fund (SCEF) which is in its incipient stages can be tapped to avail this amount.

- The FiT scheme allows a customer to develop a feasible business case. However, BESCOM's poor finances will not allow them to actually pay the consumers a rate of Rs. 9.56/kWh. To reach the figure of 250 MW in 2014 using FiT, the total corpus required to support this scheme would be Rs. 397.8 crores. Taking the average pooled price of electricity for BESCOM into account, an additional amount of Rs. 252.16 crores is required which can be taken from the SCEF.

- A comparison of the economic performance of RTPV systems in Bengaluru is made with those in Japan, Germany, Italy and UK [21] in terms of Return on Investment (ROI). The spreadsheet tool used for calculating the IRR and Payback Periods of RTPV systems in Bengaluru is modified to calculate the ROIs for systems under the proposed FiT and announced Net Metering mechanism. The purpose of this is to determine the efficacy of either policy instrument in comparison with other countries. A similar comparison is made with RTPV systems in Cyprus, where the author calculates the IRR of RTPV systems under various scenarios [43]. In this case, the IRRs obtained for a similar capacity (5 kW_p) in Bengaluru (urban and semi-urban without MNRE subsidy) have been taken into consideration. The results of this comparison are presented in Table 6.These results show that both the FiT scheme and the net metering scheme in Bengaluru have encouraging results in case of lesser consumption (semi-urban) being considered.

- If the cap of 75% is not removed, the only way to have better economic performance of RTPV systems in urban Bengaluru is to increase the generation from installations. This can be achieved using tracking systems or by using concentrating PV (CPV) technology as explained by Gomez-Gil et al. in their article [44]. Although the capital costs for such systems are higher than the cases considered in this analysis, the returns are also proportionately higher since the capacity factor or efficiency of conversion of the former systems rise significantly. Calculations for systems using single and dual axis tracking systems are shown in Table 6. Systems using CPV are not analysed since there is no data available regarding commercialized developers or manufacturers in the Indian RTPV context as of now.

Size of RTPV system = 4kW_p (for FiT comparison) and 5 kW_p (for Net Metering comparison)

	Japan	**Germany**	**Italy**	**UK**	**Cyprus**	**Bengaluru (urban)**	**Bengaluru (semi-urban)**
FiT Rate (€/kWh)	0.30	0.14	0.17	0.21	0.28	0.12	0.12
Net Metering Rate (€/kWh)					0.20	0.12	0.12
ROI	3.04%	3.12%	2.19%	7.78%	-	2.3%	4.2%
IRR	-	-	-	-	4.1%	5%	10%

Table 5: Comparison of economic performance of RTPV systems in various countries

Type of Tracking System	*Description of RTPV system*	**250 kW captive system for SME sector**	**350 W off-grid with battery storage with capital subsidy**	**5 kW grid-connected without MNRE subsidy for semi-urban residential villa**	**5 kW grid-connected with MNRE subsidy for semi-urban residential villa**	**5 kW grid-connected without MNRE subsidy for urban residential villa**	**5 kW grid-connected with MNRE subsidy for urban residential villa**	**30 kW grid-connected (415 V or 220 V) without MNRE subsidy**
	Revenue model	REC mechanism (Rs. 9300/MWh and 10% annual decrease after 2016-17)	-	Net metering (Rs 9.56/kWh)	Net metering (Rs 7.2/kWh)	Net metering (Rs 9.56/kWh)	Net metering (Rs 7.2/kWh)	FiT/GBI (Rs. 9.56/kWh)
Fixed	***Initial investment (Rs. lakhs)***	227.5	0.305	5.26	3.69	4.82	3.37	27.65
	Payback period (years)	3	-	8	8	13	8	7
	IRR	29%	-7%	9%	10%	5%	10%	13%
Single Axis[1]	***Initial investment (Rs. lakhs)***	242.5	0.341	5.56	3.99	5.12	3.67	27.95
	Payback period (years)	3	-	7	7	11	7	7
	IRR	32%	-6%	10%	10%	7%	12%	14%
Dual Axis[2]	***Initial investment (Rs. lakhs)***	287.5	0.395	6.46	4.89	6.02	4.57	28.85
	Payback period (years)	2	-	7	7	11	7	7
	IRR	36%	-5%	12%	13%	8%	13%	16%

Table 6: Techno-economics of various RTPV systems in Bengaluru

[1] Cost per watt peak of single axis tracking systems is assumed to be Rs. 6/W_p (for systems above 1 kW_p) and Rs 7 (for systems below 1 kW_p) and O&M costs rise by 10%

[2] Cost per watt peak of dual axis tracking systems is assumed to be Rs. 24/W_p and O&M costs rise by 15%. Market data has been obtained from Renen Power Technologies Pvt. Ltd., Bangalore

6. Conclusions

This paper explores the profitability of various kinds of RTPV systems in Bangalore taking the different policy incentives existing today into account. Compared to other countries both the net metering and FiT schemes fare well in terms of financial performance in semi-urban spaces in the city. The reason why semi-urban domestic households have better financial performance with RTPV systems when compared to urban households is because the consumption from the grid is lesser along with higher diesel based electricity consumption. This is because the grid supply is unreliable in these areas and occupancy is limited throughout the week.

According to the KERC tariff order for net metering - Rs. 9.56/kWh without capital subsidy and Rs. 7.2/kWh with capital subsidy – domestic consumers can set up RTPV systems and get paid by BESCOM. The rates are sufficient to make a viable business case with an IRR of 14% and payback period of 6 years if the 75% cap is removed. However, today the cap is a stumbling block. BESCOM is not in a position to pay and the net metering clause is not invoked. Instead of a cap, consumers should be given the freedom to install any capacity of RTPV systems. Annual targets need to be set in terms of total RTPV capacity in the city and not on the number of consumers. BESCOM can tap the SCEF through KREDL and pay the consumers who have excess generation. The amount required to reach the target of 250 MW is Rs. 81.6 crores per annum.

If the cap of 75% is not removed, tracking systems or CPV technology can be used to increase the generation from the RTPV systems by increasing the capacity factor or efficiency of conversion respectively. Although the capital costs of RTPV systems increase with the use of single or dual axis tracking systems, the PLF increases from 19% to 23% and 26.5% respectively. This leads to an increase in RR of 2% and 4% respectively. Although the resultant IRRs are still not enough in urban contexts, RTPV systems with tracking mechanisms are lucrative options for semi-urban villas. Since research shows that CPV is less attractive than tracking systems [44] and there was no market data available, this article does not consider CPV based RTPV systems in the analysis.

FiT and REC mechanisms prove to be more lucrative than net metering for larger RTPV systems. A proper rooftop lease model needs to be developed for FiT along with a policy which allows BESCOM to use the SCEF to pay the IPP. In the REC mechanism, the industry association for a particular industrial cluster or a private institution needs to take up the role of aggregating all the RECs generated from distributed RTPV systems. This reduces the hassle of individual industrial units. Monitoring and verification activities can also be carried out by the aggregator.

Off-grid RTPV systems are still expensive and proper micro-financing models need to be developed for the urban and semi-urban context. Also, social engineering studies need to be carried out to calculate the opportunity costs and linkages to growth in productivity of the household which will install the RTPV system.

Further research has been planned in order to understand which PV technology is the most optimal choice for RTPV systems in Bengaluru. To this extent, installation of a test bed in Bengaluru is being planned within the SERIIUS consortium. Performance data from various modules in the test bed will be used for analysis. GIS assessment will be used to accurately calculate the potential of RTPV systems on various kinds of rooftops in the city. An agent based model will be developed to incorporate social interactions and dynamic policy measures and thereby depict the spread and penetration of RTPV systems in Bangalore over time. Similar studies will be conducted for other states with differing climatic conditions and varying RTPV policies. Also, commercial establishments and large apartment complexes will be considered in the next stages of this research.

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Figures

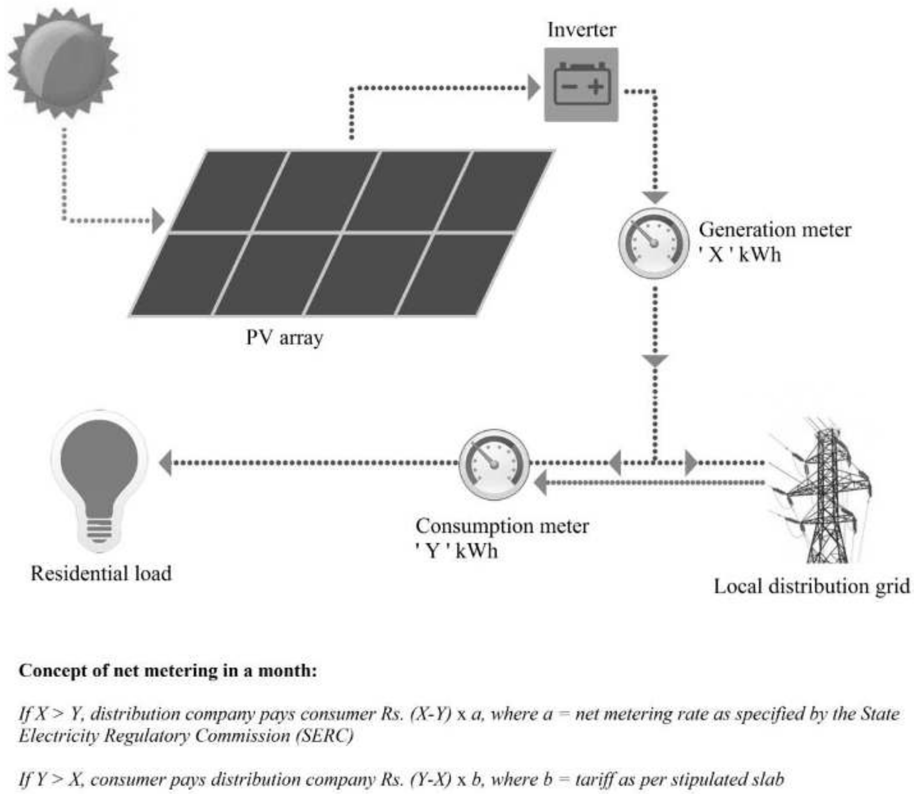

Figure 1 - Net metering concept for rooftop solar PV systems

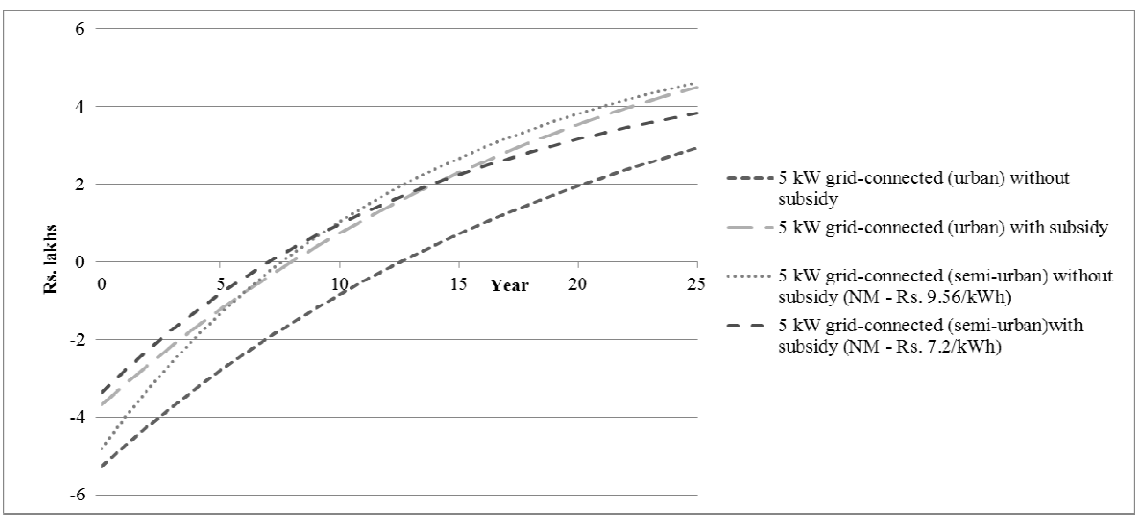

Figure 2 – Net Cumulative Cash Flow of residential villa RTPV systems in Bengaluru

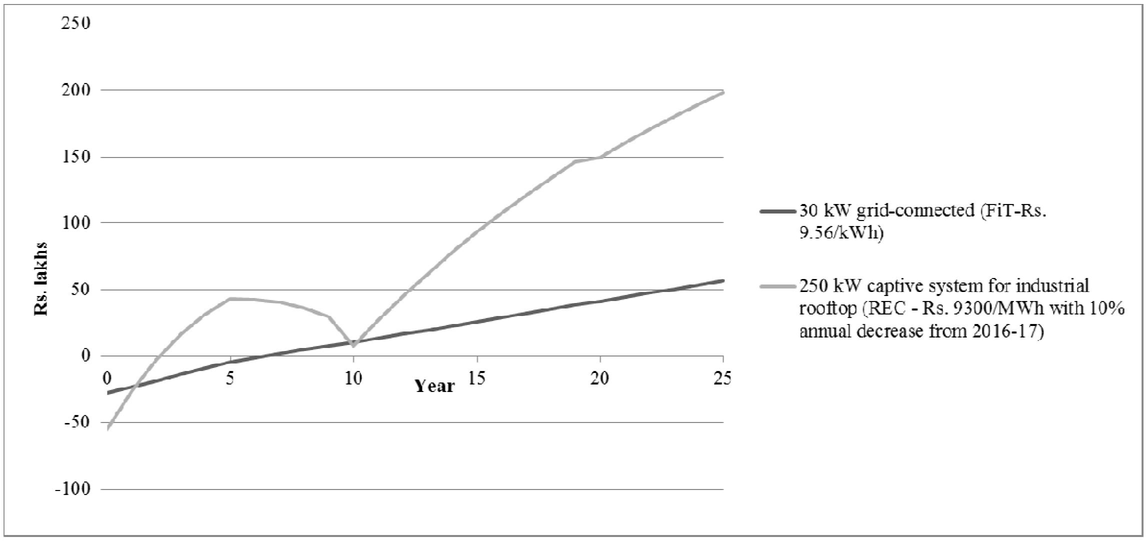

Figure 3 - Net Cumulative Cash Flow of RTPV systems using REC and FiT mechanisms in Bengaluru

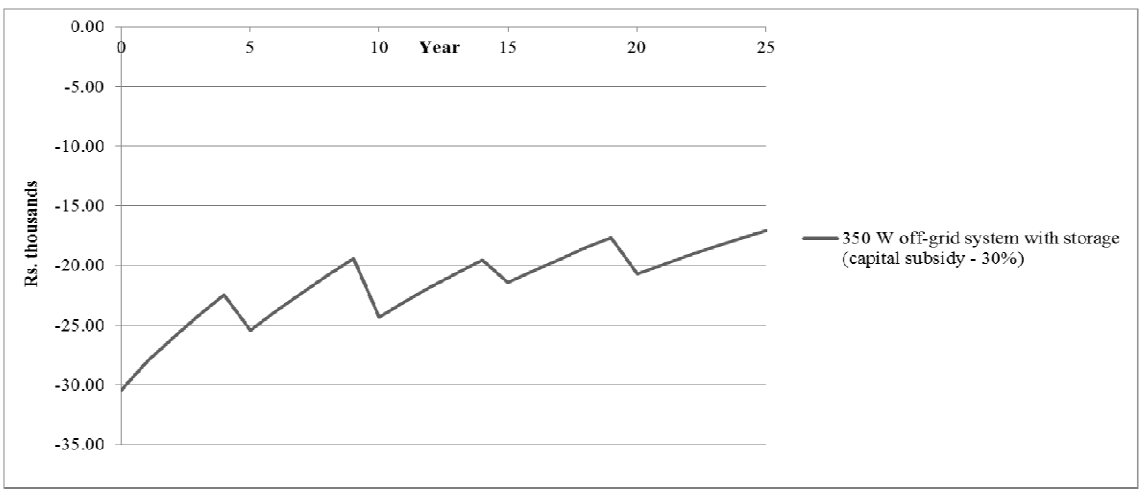

Figure 4 - Net Cumulative Cash Flow of off-grid RTPV system in Bengaluru

Net metering schematic

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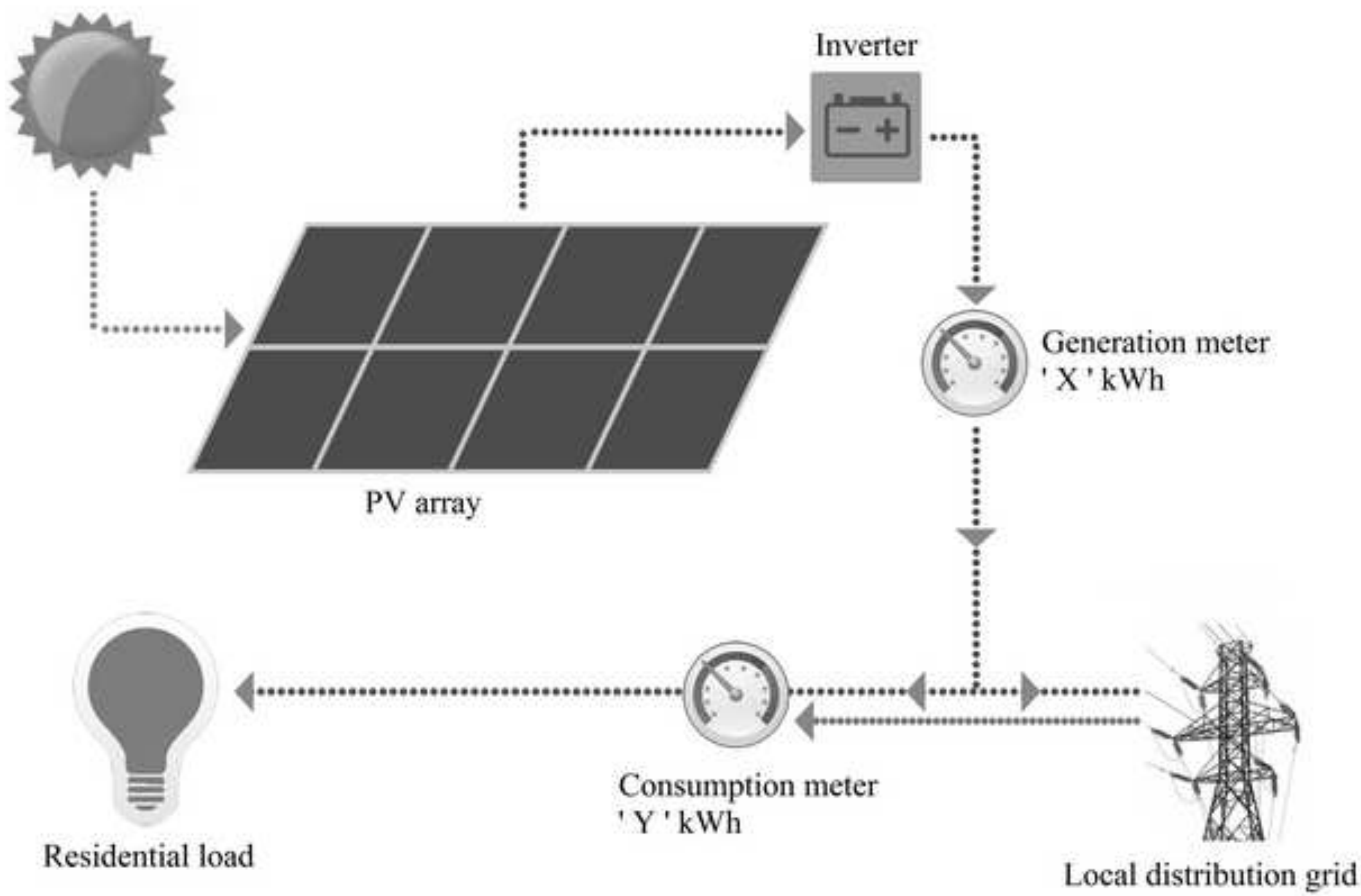

Concept of net metering in a month:

If X > Y, distribution company pays consumer Rs. (X-Y) x a, where a = net metering rate as specified by the State Electricity Regulatory Commission (SERC)

If Y > X, consumer pays distribution company Rs. (Y-X) x b, where b = tariff as per stipulated slab

residential RTPV net cumulative cash flow

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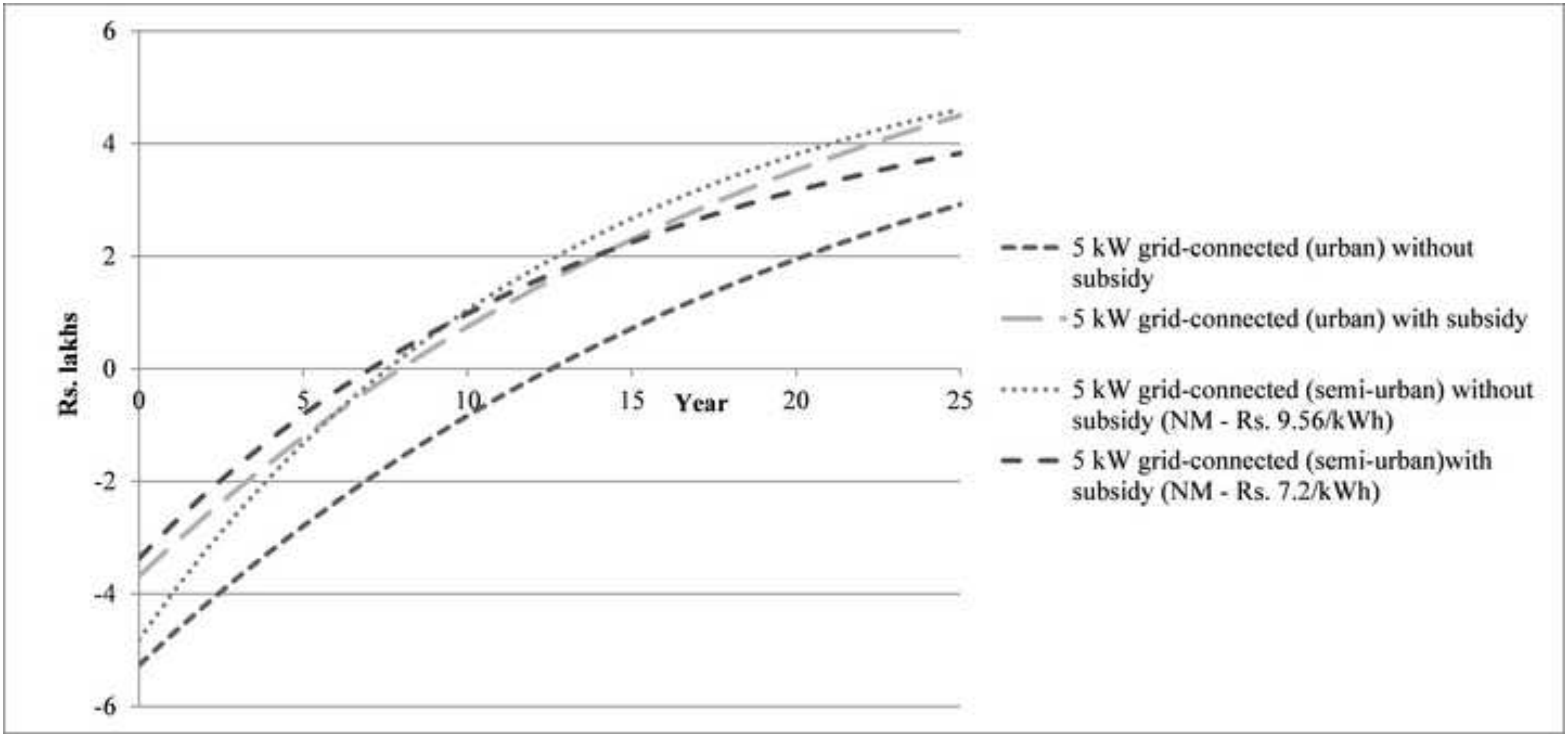

off-grid RTPV net cumulative cash flow
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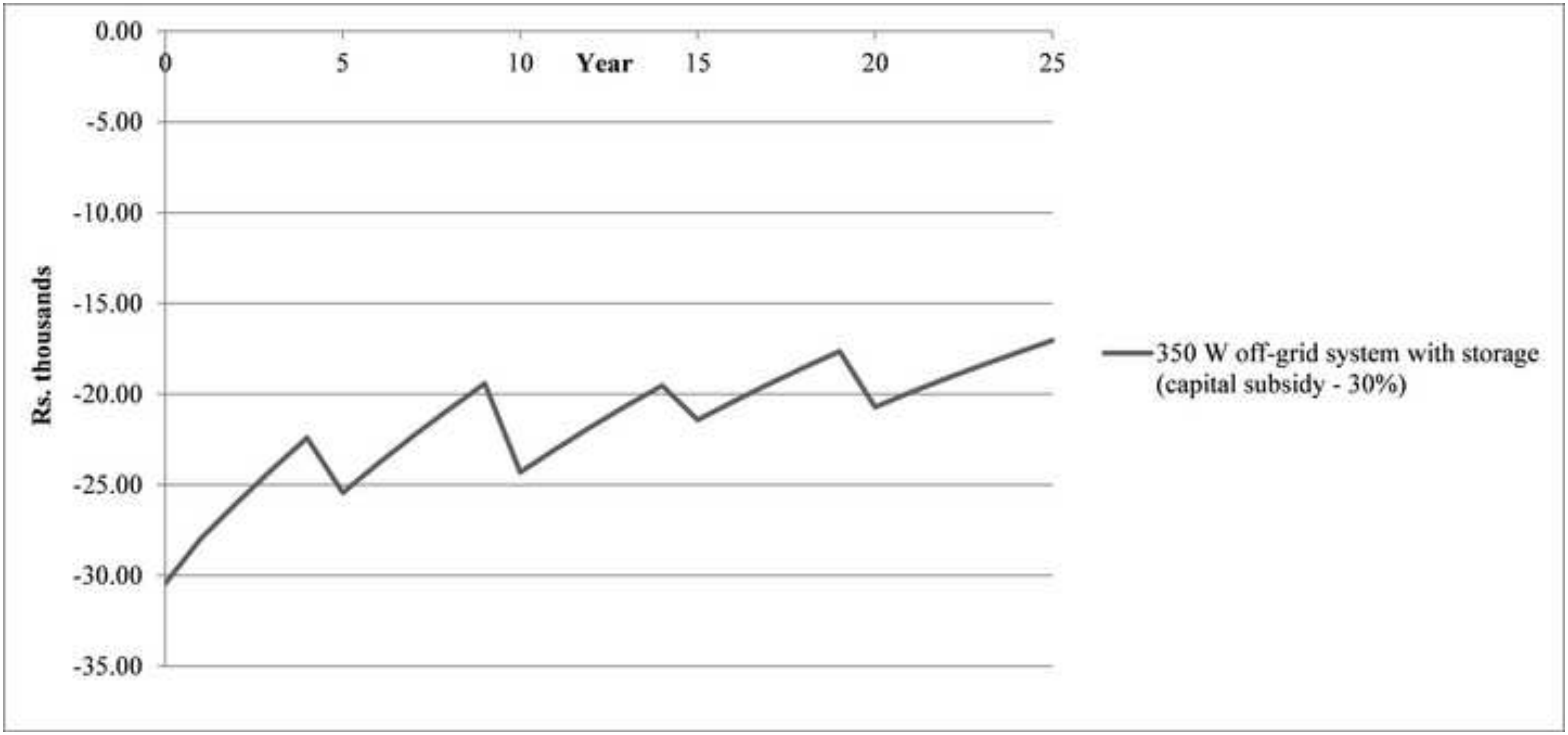

FiT and REC scheme net cumulative cash flow

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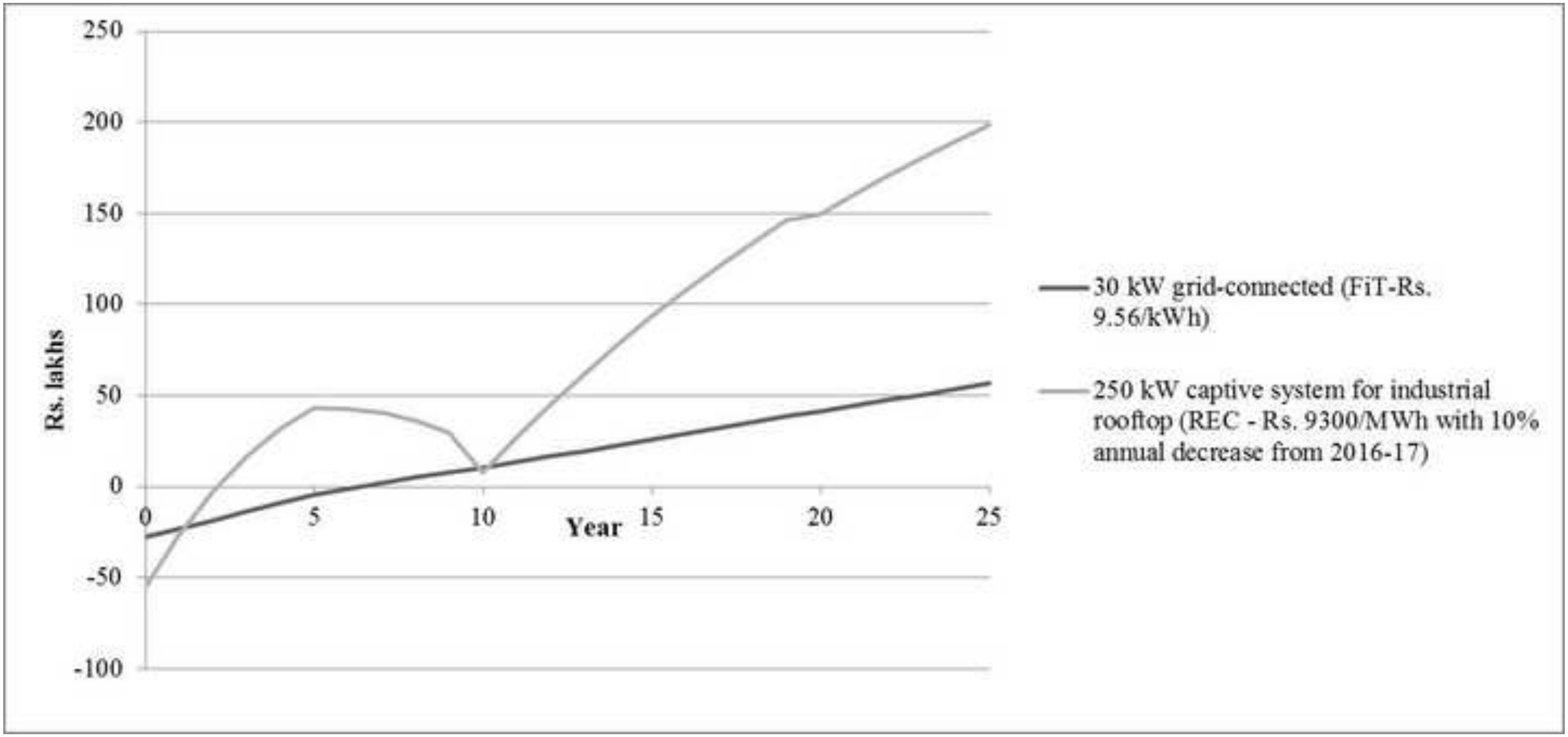

Tables

Country	Policy lever for RTPV	Salient Features
USA [1] [2] (California)	Net Metering	• 2 distribution utilities participate in this scheme, viz. Pacific Gas and Electric Company (PG&E) and Southern California Edison (SCE) with non-time-differentiated inclining block retail rate with five usage tiers ($0.12/kWh in Tier 1 to $0.50/kWh in Tier 5 for PG&E and $0.13/kWh to $0.31/kWh for SCE) and time-of-use (TOU) rates • Net Metering allows customers to offset volumetric charges within each billing period and for TOU consumers calculations are performed within each TOU period, so that PV generation is credited based on the TOU period in which it occurs. Any excess bill credit at the end of a billing period is taken forward to the next billing period; however, at the end of the year, any excess bill credits are forfeited • Capacity limit is set at 5 MW for systems under the control of local government or universities and 1 MW for other systems • Total of 721 MW of rooftop PV has been installed under this scheme till date (457.3 MW with PG&E and 263.7 MW with SCE); the total amount of incentives provided are of the tune of $887 million ($540 million from PG&E and $347 million from SCE) [3] • Economic performance of RTPV system depends of the PV-load ratio, retail rate of these two utilities and the tracking systems or accuracy of installation involved with the system. A higher PV-load ratio with higher retail rates and better tracking system gives better economic performance in terms of bill savings. Since generation does not exceed consumption there are no revenues and the profitability of the systems arise from accrued savings. Payback period of systems are in the range of 8-11 years
Thailand [4] [5] [6]	Net Metering (2002-07)	• Solar plants (including RTPV) with capacity limit of 1 MW directly connected to the grid; for capacities greater than1 MW, net metering allowed only if sufficient electricity generated is consumed for captive purposes • If generation was lesser than consumption, then consumer had to pay the retail electricity rate for the difference to the distribution utility; if generation was more than consumption then the received revenue would be at the average pool purchase cost of electricity for the utility (~80% of the retail rate)
	FiT (2007-present)	• Transition from net metering to FiT occurred in 2007 when new renewable energy policies were introduced by the Department of Alternative Energy Development and Efficiency under the Ministry of Energy; program known as the “Adder” scheme • Small Power Producers (10 MW-90 MW) sell electricity directly to the Electricity Generating Authority of Thailand; Very Small Power Producers (<10 MW) sell electricity to the Metropolitan Electricity Authority and the Provincial Electricity Authority; the rate is fixed for 10 years for solar projects • Adder rates for solar projects are: Retail price +Adder rate; Adder rate was $0.267/kWh in 2007 which dropped to $0.217/kWh (an additional special rate of $0.05/kWh was assigned to projects which led to diesel abatement; for the three southernmost provinces another $0.05/kWh was added) • Applications for solar adder programs were stopped after 2010; the total installed capacity as of Dec 2011 was around 111 MW

Germany [7]	FiT (2000-present)	• In 2000, Renewable Energy Sources Act provided remuneration of €0.51/kWh over 20 years for solar PV with an annual reduction of 5%; Maximum size of 5 MW for building integrated plants, 100 kW for others; Ceiling for cumulative installed capacity at 350 MW; cumulative capacity of 186 MW installed in 2001 • In 2002, the ceiling for cumulative installed capacity was raised to 1000 MW and in 2003 the ceiling was removed and there was no restriction imposed on the size of any PV plant; FiT was increased to €0.547/kWh for 20 years with an annual reduction of 5%; cumulative capacity rose to 4.17 GW in 2007 • In 2009, there was a dynamic annual reduction in FiT introduced depending on deployment (basic reduction of 8–10% for 2010 ± 1% if annual installed capacity < 1000 MW or >1500 MW); Options of self-consumption (€0.2501/kWh) or direct marketing to third parties was provided to reduce outflow of government funds • In 2010 and 2011 the annual reduction changed to 9% ± 4% depending on deployment in these years; reduction in FiT by 10% in July, 2010 and further by 3% in October, 2010; In 2012, remuneration for self-consumption was reduced depending on system size (max. €0.1236/kWh); cumulative capacity was 24.678 GW in 2011 • Today the total cumulative capacity of solar PV in Germany is more than 34 GW with over 65% on rooftops using the FiT scheme; although there are troubling times now because of the massive disbursal of FiTs each year, it clearly is one of the success stories of decentralized solar PV installations in a country
Japan [8]	Net Metering, Capital Subsidy, Renewable Portfolio Standard (RPS) and FiT; (1992-present)	• Voluntary net metering programme started by 10 utility companies in 1992 to purchase surplus electricity generated from PV installations at the retail rate (¥23/kWh) • In 1994, a national capital subsidy programme was announced for installations in the range of 1-5 kW_p; 50% of the installation cost with a cap of ¥900,000/kW_p was allowed; this was changed regularly and stopped in 2005 when the value was ¥20,000/kW_p; around 930 MW was installed in this period • Similar to India's RPO mechanism, the RPS policy was initiated in 2003 which obliged utilities to procure 1.35% of their electricity from renewable sources by 2010; this led to a decline in the annual installation rate and in January, 2009 the capital subsidy programme was restarted with ¥70,000/ kW_p • In November 2009, FiT was introduced at ¥48/kWh with a cap of 10 kW payable for ten years without annual reductions; scheme obligated utilities to purchase only the surplus electricity generated making this a variant of the net metering mechanism; capital subsidy was also provided which dropped from ¥70,000/kW_p to ¥30,000-35,000/kW_p in 2012; cumulative capacity of 4.9 GW was installed till 2011 with 90% installations on residential buildings and rooftops; scheme ended on 30th June, 2012 • New FiT scheme introduced in July, 2012 with a target of 28 GW by 2020 and 50 GW by 2030; financed by consumers themselves, electricity bills will rise by around ¥100 per month; for residential installations the FiT is ¥42/kWh payable for 10 years without annual reductions along with a capital subsidy of ¥30,000-35,000/kW_p; cumulatively residential and rooftop PV installations have crossed 5.6 GW as of date

Italy [9]	FiT coupled with Net Metering (2008-present)	• In the period of 2008-10, the FiT scheme favoured systems below 20 kW_p; the rate varied from €0.365-0.49/kWh for systems below 20 kW_p and for systems above 20 kW_p the rate varied from €0.346-0.422/kWh; no caps were put on overall amount of installations or power output • In 2011, the FiT scheme became more complex and there were three rates based on the months when the installations were completed; for systems ranging from 1-200 kW_p, if they were installed before April 30, the rate was €0.321-0.402/kWh; between May 1 and August 31, the rate was €0.309-0.391/kWh; between September 1 and December 31, the rate was €0.285-0.38/kWh; there was a monthly reduction in the FiT rate along with a cap of 23,000 MW • From 2012, the FiT scheme divided the incentives for building integrated PV (BIPV) systems and other installations with a major reduction of tariffs; plants in the range of 1-200 kW_p avail rates of €0.206-0.274/kWh with the same cap; the total installed capacity of solar PV in Italy was 16.202 GW in 2012 with more than 60% of installations being in the range of 1-200 kW_p
Taiwan [10]	FiT coupled with capital subsidy (2004-present)	• Between 2004-08, the Ministry of Economic Affairs (MOEA) implemented the Photovoltaic Generation Demonstration System Installation Subsidy Guidelines where a capital subsidy of $3,667 per kW_p was provided for grid-connected PV systems and $5,000 per kW_p for stand-alone PV systems with a maximum subsidy of 50% of installation costs • In 2006, the Photovoltaic Standard System Installation Subsidy Guideline Principles were introduced; subsidies offered for PV systems above 1 kW_p of $5,000 per kW_p with a maximum amount of 50% of installation costs; for national institutions, schools, and hospitals located in remote areas and on off-shore islands, the maximum subsidy per kW_p for the installation of emergency-use, stand-alone solar PV systems was $11,667; maximum subsidy for emergency disaster prevention systems (so-called mix-type systems) was $13,333 • In 2009, the Renewable Energy Development Act was passed which allowed a capital subsidy of $1,667 per kW_p for systems in the range of 1-10 kW_p with a FiT of $0.271/kWh; for systems above 10 kW_p, no subsidy would be provided and only a FiT of $0.3-0.311/kWh was applicable • Since January, 2011, capital subsidies of $1,667 per kW_p were provided for systems in the range of 1-10 kW_p with a FiT of $0.373/kWh; for systems without capital subsidy, the FiT was $0.487/kWh; for systems above 10 kW_p there was no capital subsidy and the FiT was $0.432/kWh • Today along with the capital subsidy, the FiT rates are $0.21-0.28/kWh for rooftop installations, and $0.20/kWh for ground-mounted installations; a total of 222 MW of solar PV has been installed [11] with over 60% coming from systems in the range of 1-10 kW_p

UK [12]	FiT (2010-present)	• In April, 2010, a FiT scheme was introduced in the UK to support PV installations; the rate was different for various sizes of installations; RTPV systems ≤ 4 kW_p received £0.361/kWh (new build) or £0.413/kWh (retrofit); systems between 4-10 kW_p received £0.361/kWh, 10-50 kW_p and 50-100 kW_p systems got £0.314/kWh; 100-150 kW_p and 150-250 kW_p systems availed £0.293/kWh; stand-alone systems got £0.293/kWh; cumulative installations on March 30, 2011, stood at 77.7 MW • After the first review in 2011, a new FiT scheme was introduced for the period of April 1, 2011-March 30, 2012; RTPV systems ≤ 4 kW_p received £0.378/kWh (new build) or £0.433/kWh (retrofit); systems between 4-10 kW_p received £0.378/kWh, 10-50 kW_p received £0.329/kWh; 50-100 kW_p and 100-150 kW_p systems got £0.19/kWh; 150-250 kW_p systems availed £0.15/kWh; stand-alone systems got £0.085/kWh; total installed reached 366 MW in November, 2011; 290.6 MW came from the domestic sector alone • Owing to the unexpected success of the scheme (137 MW was the 2nd year target which was surpassed in July, 2011), the government reviewed the FiT rate and reduced it for systems being installed after April 1, 2012; RTPV systems ≤ 4 kW_p receive £0.21/kWh (new build and retrofit); systems between 4-10 kW_p receive £0.168/kWh, 10-50 kW_p received £0.152/kWh; 50-100 kW_p, 100-150 kW_p and 150-250 kW_p systems get £0.129/kWh; stand-alone systems got £0.085/kWh; for each of these schemes an additional incentive was provided if any electricity generated was exported to the grid (rate increased from £0.03/kWh in the first year to £0.031/kWh today for all size ranges
China [13] [14]	Capital Subsidy (2009-11) and FiT (2011-present)	• In March, 2009, the Ministry of Finance and the Ministry of Housing and Urban-Rural Development of China (MOHURD) announced the "Rooftop Subsidy Program" which provided an upfront subsidy of CNY 15/W_p for rooftop systems and CNY 20/W_p for building-integrated PV (BIPV) systems, and a subsidy of 50% of the bid price for the supply of critical components; size of eligible systems ≥ 50 kW_p • In July, 2009, a second program known as the Golden Sun Demonstration Program was jointly introduced by the Ministry of Finance, the Ministry of Science and Technology (MOST) and the National Energy Administration (NEA) of the National Development and Reform Commission (NDRC); 50% upfront subsidy on the investment cost for grid- connected systems and a 70% upfront subsidy for off-grid PV systems over the period of 2009–11; cap of 20 MW for each province; in 2012, 3044.06 MW had been installed under this program • In July, 2011, NDRC announced a FiT scheme for solar PV; rate of CNY 1-1.15/kWh; did not take into account the variability of solar resources (some provinces with rich radiation benefited more compared to others) • Since the PV manufacturing industry of China suffered reduction in revenues (due to the global glut and trade disputes with USA and Europe), the government tried to incentivize a market for domestic utilization of PV products; Distributed PV (DPV) generation was encouraged along with large scale PV (LSPV) projects; DPV projects could connect to the grid and required no lengthy approval processes; a generation based incentive (GBI) of CNY 0.42/kWh (taxes included) was provided for all DPV plants; a resource based FiT was also introduced for ground-mounted DPV systems with a rate of CNY 0.9/kWh, 0.95/kWh, or 1/kWh dependent on the local resource availability; today China has more than 1.5 GW of DPV and RTPV installed

Malaysia [15]	FiT (2011-present)	• In December, 2011, a FiT scheme was introduced for various renewable energy sources in Malaysia and the scheme was to be is administered and implemented by a new entity called the Sustainable Energy Development Authority (SEDA); a fund was created by increasing the electricity bills of consumers (≥300 kWh/month) by 1% to support the FiT; • A quota on solar PV systems below 1 MW_p was imposed; 2011/12 – 10 MW, 2013 – 10 MW, 2014 – 5 MW; the FiT provided for solar PV was in the range of MYR 0.85–1.78/kWh; As of today, total installed PV capacity stands at 169 MW out of which 100 MW or more have come from DPV systems; • Since solar PV is using bulk of the allocated FiT in Malaysia and costs of solar PV is coming down globally, SEDA proposes to reduce the FiT over the next few years
India (Karnataka)	Capital Subsidy (2010-present) and Net Metering (2013-present)	• Since the inception of JNNSM, MNRE provides a 30% capital subsidy on any RTPV system • In 2013, KERC announced the Net Metering scheme for Karnataka in collaboration with KREDL and BESCOM; the rates are Rs. 9.56/kWh (without MNRE subsidy) and Rs. 7.2/kWh (with MNRE subsidy); BESCOM has a cap on size of the system (75% of rated load of consumer) • FiT is being discussed as a policy instrument for industrial and commercial consumers along with RTPV systems on bus stops or other unused rooftops • REC mechanism is present for systems above 100 kW_p; for captive consumers and OACs

Discussions

From the literature review of policy incentives for RTPV systems, it can be seen that FiTs - along with capital subsidies and other incentives such as simple authorization procedures and net metering schemes – form a robust policy framework which enables the penetration of RTPV systems in any society. Other research articles also provide the same conclusion based on studies in respective countries [16] [17] [18]. Yamamoto compared the effectiveness of FiTs with net metering, and net purchase and sale mechanisms in 2012 taking into account impact on social welfare and retail electricity rates [19]. He observed that even with the drawbacks of FiT, it still performed far better than the other two in isolation when it came to promoting RTPV installations. Other articles showed that FiT is more stable and provides long-term assurances for project developers in spite of having annual reduction rates and they also perform better than market mechanisms such as the RPS and RECs owing to the complexity of the latter [20]. FiTs need to be designed according to the solar resource availability in locations so that places with higher radiation profiles do not avail a chunk of the funds.

BESCOM in Bengaluru has been suffering losses for decades now and they are not in a position to provide FiTs for RTPV as of now. Hence, a net metering scheme was announced which announced local generation and consumption and savings in electricity bills. There was also a 75% cap on capacity with respect to the rated load of the consumer. Essentially, this is a model very similar to that of the California model where revenues were negligible and profitability of RTPV systems was measured in terms of savings in monthly bills and diesel abatement costs.

Type of Tracking System	*Description of RTPV system*	**250 kW captive system for SME sector**	**350 W off-grid with battery storage with capital subsidy**	**5 kW grid-connected without MNRE subsidy for semi-urban residential villa**	**5 kW grid-connected with MNRE subsidy for semi-urban residential villa**	**5 kW grid-connected without MNRE subsidy for urban residential villa**	**5 kW grid-connected with MNRE subsidy for urban residential villa**	**30 kW grid-connected (415 V or 220 V) without MNRE subsidy**
	Revenue model	REC mechanism (Rs. 9300/MWh and 10% annual decrease after 2016-17)	-	Net metering (Rs 9.56/kWh)	Net metering (Rs 7.2/kWh)	Net metering (Rs 9.56/kWh)	Net metering (Rs 7.2/kWh)	FiT/GBI (Rs. 9.56/kWh)
Fixed	***Initial investment (Rs. lakhs)***	227.5	0.305	5.26	3.69	4.82	3.37	27.65
	Payback period (years)	3	-	8	8	13	8	7
	IRR	29%	-7%	9%	10%	5%	10%	13%
Single Axis[1]	***Initial investment (Rs. lakhs)***	242.5	0.341	5.56	3.99	5.12	3.67	27.95
	Payback period (years)	3	-	7	7	11	7	7
	IRR	32%	-6%	10%	10%	7%	12%	14%
Dual Axis[2]	***Initial investment (Rs. lakhs)***	287.5	0.395	6.46	4.89	6.02	4.57	28.85
	Payback period (years)	2	-	7	7	11	7	7
	IRR	36%	-5%	12%	13%	8%	13%	16%

[1] Cost per watt peak of single axis tracking systems is assumed to be Rs. 6/W_p (for systems above 1 kW_p) and Rs 7 (for systems below 1 kW_p) and O&M costs rise by 10%
[2] Cost per watt peak of dual axis tracking systems is assumed to be Rs. 24/W_p and O&M costs rise by 15%. Market data has been obtained from Renen Power Technologies Pvt. Ltd., Bangalore

Description of parameters	Values	
Capacity of RTPV system	**5 kWp (Villa)**	**250 kWp (SME)**
Total cost of modules	Rs. 2,75,000	Rs. 1,35,00,000
Cost of land	0	0
Cost of battery	Rs. 85,000	0
Mounting structures and meters	Rs. 60,000	Rs. 26,25,000
Cost of inverter	Rs. 56,500	Rs. 20,00,000
Evacuation cost (cables and transformers)	Rs. 50,000	Rs. 26,25,000
Preliminary and pre-operative expenses	0	Rs. 20,00,000
Total cost of system (without MNRE subsidy)	**Rs. 5,26,500**	**Rs. 2,27,50,000**
Debt-Equity ratio	0:100	75:25
Loan tenure	-	10 years
Loan interest rate	-	13%
LCOE without MNRE subsidy	**Rs. 8.24/kWh**	**Rs. 9.30/kWh**
MNRE subsidy	Rs. 1,57,950	-
Total initial investment (after MNRE subsidy)	**Rs. 3,68,550**	**-**
LCOE with MNRE subsidy	**Rs. 6.15/kWh**	**-**

Description of parameters	Values
Total demand of electricity of consumer	31,886 kWh/year
Total diesel based electricity	1,594 kWh/year
Total diesel requirement	455.52 litres/year
Current price of diesel	Rs. 58.04/litre
NPV of total savings due to diesel abatement	Rs. 3,81,678
Weighted average price of electricity paid by consumer to utility	Rs. 4.48/kWh
NPV of total savings due to displacement of grid-based electricity	Rs. 4,37,060
NPV of total savings	**Rs. 8,18,738**
IRR	**10%**
Payback period	**8 years**

Description of parameters	Values
Total demand of electricity of consumers	7,20,000 kWh/year
Total diesel based electricity	68,880 kWh/year
Total diesel requirement	19,680 litres/year
Total amount of diesel to be replaced by solar (60%)	11,808 litres/year
Current price of diesel	Rs. 58.04/litre
NPV of total savings due to diesel abatement	Rs. 98,93,866
Weighted average price of electricity paid by consumers to utility	Rs. 5.36/kWh
NPV of total savings due to displacement of grid-based electricity	Rs. 2,25,19,862
REC rate (10% annual decline after 2016-17)	Rs. 9,300/MWh
Total revenue gained from REC sales	Rs. 2,05,42,649
Total debt repayment amount	Rs. 3,14,44,405
Total tax benefits due to depreciation	Rs. 56,91,866
NPV of total savings	**Rs. 1,99,03,838**
IRR	**29%**
Payback period	**3 years**

Size of RTPV system = 4kW$_p$ (for FiT comparison) and 5 kW$_p$ (for Net Metering comparison)							
	Japan	**Germany**	**Italy**	**UK**	**Cyprus**	**Bengaluru (urban)**	**Bengaluru (semi-urban)**
FiT Rate (€/kWh)	0.30	0.14	0.17	0.21	0.28	0.12	0.12
Net Metering Rate (€/kWh)					0.20	0.12	0.12
ROI	3.04%	3.12%	2.19%	7.78%	-	2.3%	4.2%
IRR	-	-	-	-	4.1%	5%	10%