Chapter 5

TECHNICAL ANALYSIS OF DSM OPTIONS

This chapter provides a technical analysis overview on Demand Side Management Options, such as Photovoltaic Solar and Energy Efficient Technologies.

5.1 DSM Efficient Air Conditioners

The residential sector is likely to be the driver of air-conditioning growth in India in the next two decades due to low existing penetration of air conditioners, increasing purchasing power, urbanization trends, etc. Room air conditioners constitute the dominant share of the sector's cooling energy consumption – at around 40% in 2017-18 and growing to about 50% in 2037-38 (Ozone Cell, Ministry of Environment, Forest & Climate Change, 2019). According to the report, room air conditioners show the highest growth at around 11 times of the current baseline (in terms of installed TR) and significant potential for optimization and energy savings. Since split-type air conditioners have the largest share in the household market, the analysis has been performed only for split-type ACs. For the sake of representative calculations and easier comparisons, all air conditioners are supposed to be of the same nominal cooling capacity, i.e., 1.5 Tonnes of Refrigeration (TR) capacity.

Inverter type air conditioners are fast picking up the market share close to 50% of all ACs in the market in 2020 expected to be inverter type. In technical terms, the only major difference between an inverter and a non-inverter air conditioner is that the inverter AC has a variable speed compressor, while the non-inverter AC has a fixed speed compressor. Inverter air conditioners can have the variable cooling capacity and hence variable power consumption, depending on requirements. Hence, they can adjust to seasonal variations and deliver the same utility at much less amount of electricity. Non-inverter (fixed speed) air conditioners have fixed cooling capacity and run-on full load for the complete duration, except when in standby mode (approximately 30% of total duration), where it consumes negligible energy. With BEE revising the efficiency standard guidelines for ACs every two years, non-inverter ACs are expected to become obsolete, and the split AC market is expected to transition to inverter technology over the next few years. Since almost all the 4-5 star rated ACs, and most of 3-star ACs in the market, are already of the inverter type. This illustrates the success of Demand-Side Management through the standard and labeling in the Indian air conditioning market. To keep up with the revised standards, the manufacturers also have the challenge of increasing air conditioning efficiency through other means. Thus, new innovative technologies are urgently needed in this field. The Space Cooling sector presents unique opportunities for optimizing cooling demand, including through energy efficiency, since a large portion of the cooling demand is yet to come.

Table 5.1 BEE star rating standards for split type room air conditioners

(From 1st January 2018 to 31st December 2020) Source: (BEE, 2020)

India seasonal Energy Efficiency Ratio (kWh/kWh)		
Star Level	Minimum	Maximum
Star 1	3.1	3.39
Star 2	3.3	3.49
Star 3	3.5	3.99
Star 4	4.0	4.49
Star 5	4.5	

Table 5.2 BEE star rating standards for split type room air conditioners

(From 1st January 2021 to 31st December 2023) Source: (BEE, 2020)

Indian Seasonal Energy Efficiency Ratio (kWh/kWh)		
Star Level	Minimum	Maximum
Star 1	3.3	3.49
Star 2	3.5	3.79
Star 3	3.8	4.39
Star 4	4.4	4.99
Star 5	5.0	

5.1.1 *Baseline Scenario*

A market research report (Motilal Oswal, 2018) from the year 2018 gives the latest share of different star rated residential split air conditioners in India.

Table 5.3 Market share of different star rated ACs (Source: Motilal Oswal,2018)

Star Rating	**Market Share in Percentage**
5-4 star	35
3 star	60
1-2 star	5

An exciting thing about the AC market is that the prices of ACs have almost no correlation with the machine's efficiency. The latest retail prices of split type ACs are presented in the graph below.

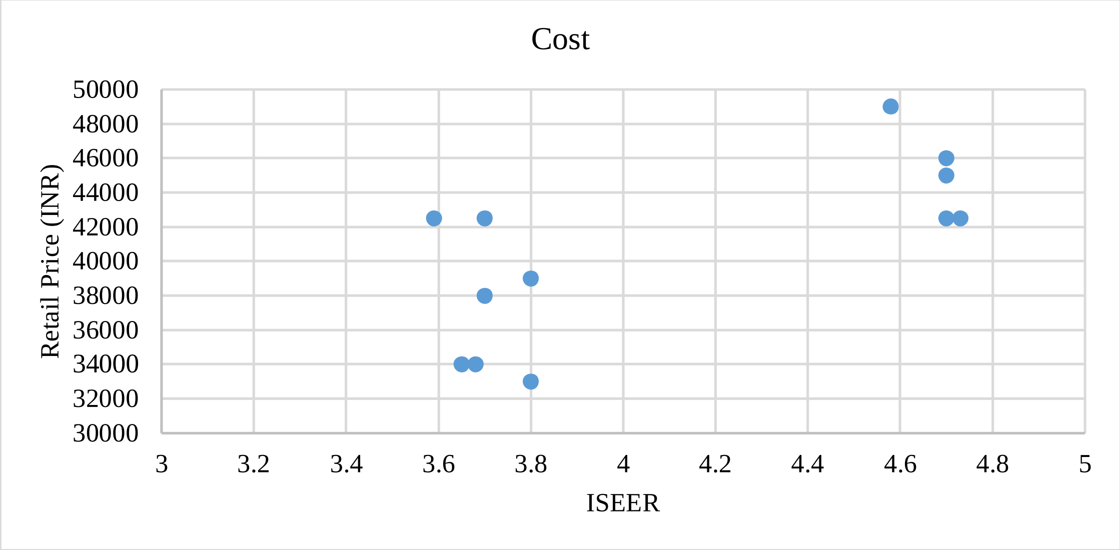

Figure 5.1 Latest retail prices of split type Air conditioners

Air Conditioning is a high trust value industry. Brand value and customer perception is the major driver of prices. Customers are ready to pay higher prices for a good quality machine with a friendly maintenance service. However, a higher ISEER does not directly imply higher monetary savings. Savings are calculated based on the total annual consumption of the air conditioner when operated for 1600 hours in a year, which is the average no of hours ACs are used in India. The annual temperature profile of India is based on the weather profile of 54 cities in India.

Average annual power consumption was calculated by extracting data from the BEE portal. For each of the categories in the table below, ISEER and thus individual values varied across the range of values as per Figure 5.1. Power consumption of more than 500 individual machines was used to calculate the average values. The deviation of annual consumption from the average value was +/- 50 (kWh). 5-star rated ACs are mostly available in the inverter type only. For non-inverter type machines, 30% standby time has been assumed (Jose, 2011).

Table 5.4 Average annual consumption of different star rated ACs.

Star Rating	Cooling Capacity (TR)	Avg. Annual Power Consumption (kWh)
3 star (Inverter)	1.5 ton	1072
5 star (Inverter)	1.5 ton	861
3 star	1.5 ton	1529

Cost-Effectiveness

Prices of the same capacity and same efficiency machines vary a lot based on the manufacturer's brand. Hence, to calculate the cost-effectiveness of different efficiency machines, 3-star and 5-star rated ACs of the same brand were compared. Comparing the costs of 1.5TR split ACs for three different brands, it was found that the average difference in cost of 3-star inverter AC and 5-star Inverter AC is INR 5000. The difference in average annual electricity consumption of 3-star inverter AC and 5-star Inverter AC is 211 kWh from table 5.4. Using this data and assuming the average lifetime of a split AC to be 15 years, the Cost of Conserved Energy (CCE) of a 5-star vs. 3-star rated AC is calculated.

CCE = Annualized incremental cost of efficient AC (INR) /Annual electricity saved by efficient AC (kWh)

CCE (5-star Vs 3-star AC) = 1.58 INR/kWh

This value of CCE, can be readily compared against the consumer tariff, cost of generation and distribution, and environmental costs. Cost of supplying electricity. Since the CCE is lower than the consumer tariff, it will be cost-effective for consumers to invest in efficient AC. This CCE value is used in the next chapter to calculate the overall saving to society if more efficient ACs are promoted in the future (Chunekar et al., 2016).

Future Savings in Different Scenarios

The number of air conditioners currently installed and projections for the coming years is available from the India Cooling Action Plan (Ozone Cell, Ministry of Environment, Forest & Climate Change, 2019).

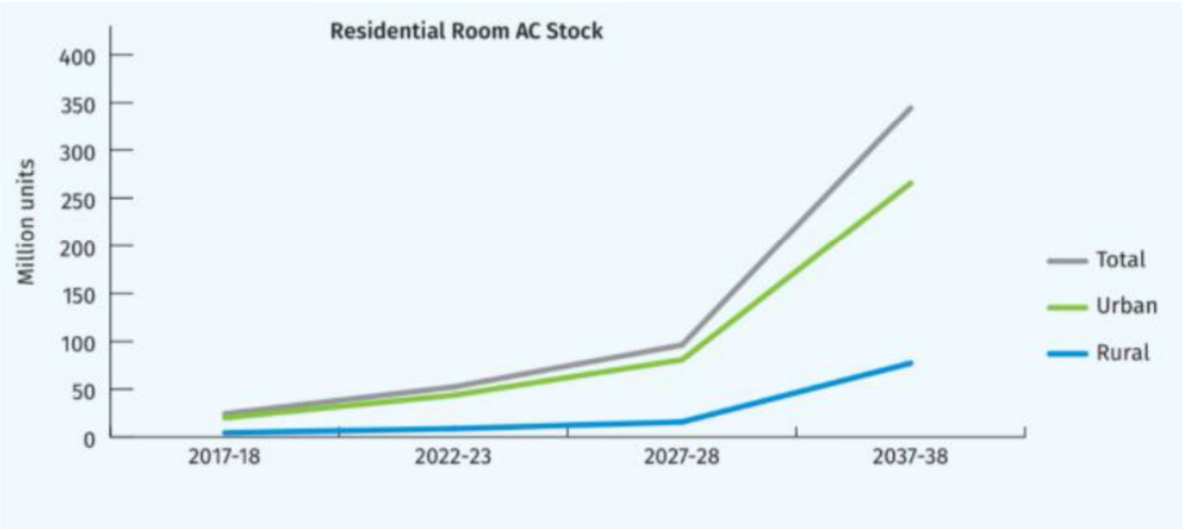

Figure 5.2 Room Air Conditioner Stock in Urban and Rural Households (Ozone Cell, Ministry of Environment, Forest & Climate Change, 2019).

According to the report's analysis, about 8% of the current households have room air conditioners. This is anticipated to rise to 21% and 40% in 2027-28 and 2037-38, respectively. As per NSSO 2011, there were approximately 1.2 room air conditioners per household in households with air-conditioners (Chunekar et al., 2011). The report also said that the numbers generated by the Working Groups are best estimates reached in the limited time available for setting out a plan of action. The report admitted the need for a comprehensive survey-based analysis for estimating the present and future stock of the key electrical appliances.

Table 5.5 Year wise Analysis of No. of ACs in million units in India. Source: (Chunekar et al., 2011).

YEAR	NUMBER (in million units)
2020	36.57
2025	57.06
2030	90.69
2035	202.21
2040	343.07

Some predictions regarding the future stock of room ACs in India are also available from (Phadke et al., 2014) table below, which also has remarkably close estimates for the year 2020. But their estimation for the year 2030 is above the estimate by ICAP. They estimate that about 30% of the urban households are likely to own a room air conditioner by 2020, and about 73% are likely to own a room air conditioner by 2030. Since it is an older report with highly hopeful numbers, future projections from ICAP 2019 are used for calculations.

Four different scenarios are assumed regarding the future share of different star rated air conditioners in India, as described in the table below. The baseline scenario is taken from table 5.7.

For each of these scenarios, total savings in the year 2030 and 2040 are calculated using the projections available from the ICAP report. Annual electricity savings of a 5-star AC over 3-star AC is taken to be 211 kWh from the previous section. We are aware that for split ACs of different cooling capacity, the annual savings will be liable on the capacity. 1.5 TR is assumed to be the average cooling capacity of all the split type ACs in the market because they are the major share of all ACs sold and mean of the other two highest sold ACs (1 TR and 2 TR).

Table 5.6 Estimation of future stock of ACs in India. Source: Phadke et al., 2014.

	2010	**2020**	**2030**
Total Electricity Consumption by room air conditioners (TWh/year)	8	77	239
Total stock of room air conditioners (millions)	4	37	116
Total number of urban households (millions)	99	127	159
Room AC penetration in urban areas assuming all room ACs arc installed in urban households (total stock as % of urban households)	4%	30%	73%

Table 5.7. Scenarios considered for calculating total savings.

Star Rating	**Market Share in Percentage**			
	Baseline Scenario	50% 5-star	75% 5-star	100% 5-star
5-4 star	35	50	75	100
3 star	60	50	25	Nil
1-2 star	5	Negligible	Negligible	Nil

Table 5.8 Future Savings if more efficient ACs are promoted in different scenarios.

Scenario	**Electricity Saved Over Baseline Scenario (GWh)**	
	2030	**2040**
50% 5-star	1913.77	7242.58
75% 5-star	6697.14	25336.88
100% 5-star	11480.51	43432.24

These values for future savings are used in chapter 6 to calculate the overall impact of replacing 3-star ACs with 5 star ACs. (Jose, 2011)

5.2 DSM Rooftop Solar Photo-Voltaic (PV) systems

Rooftop solar photovoltaic (PV) system is one of the most effective clean technological options for Demand Side Management. Distributed generation close to the point of consumption saves huge transmission losses. As per the recent estimates of MNRE (Ministry of Renewable Energy, Govt. of India), the total market potential for rooftop PV in India's urban settlements is found to be around 124 GW. (Byrne et al., 2019) The payback period for small scale PV systems for domestic and commercial purposes ranges from 6 - 10 years. Any grant/subsidy sponsored by central / state policies will help reduce this payback period. (The World Bank, n.d.). Rooftops of houses/buildings are increasingly being used worldwide to install solar panels for generating electricity. Sufficient transmission planning in India needs to be carried out to ensure network adequacy for the new ambitious renewable target of 450 GW. (CEA, 2020)

5.2.1. *System Description*

The rooftop solar PV system can be installed on rooftops of households to generate electricity that can be used by households, energy can be stored in batteries to be used in non-sunshine hours. The incoming solar radiations fall on the solar (PV) panels. The PV panels convert the incoming solar radiation into DC current due to electrons movement and holes inside the panels caused by the collision between a photon and an electron. The produced electrical energy which is in the form of DC current is sent to the inverter via DC cables. The inverter converts the DC current so produced into AC current. The AC current produced is sent to the electricity grid via AC cables, which can be used for electricity consumption. The excess electrical energy produced by the solar panels goes into the battery in the form of DC current. The PV system consists of the following components:

- Panels
- Inverter
- Structure
- DC cables
- AC cables
- MC4 connector
- Battery backup

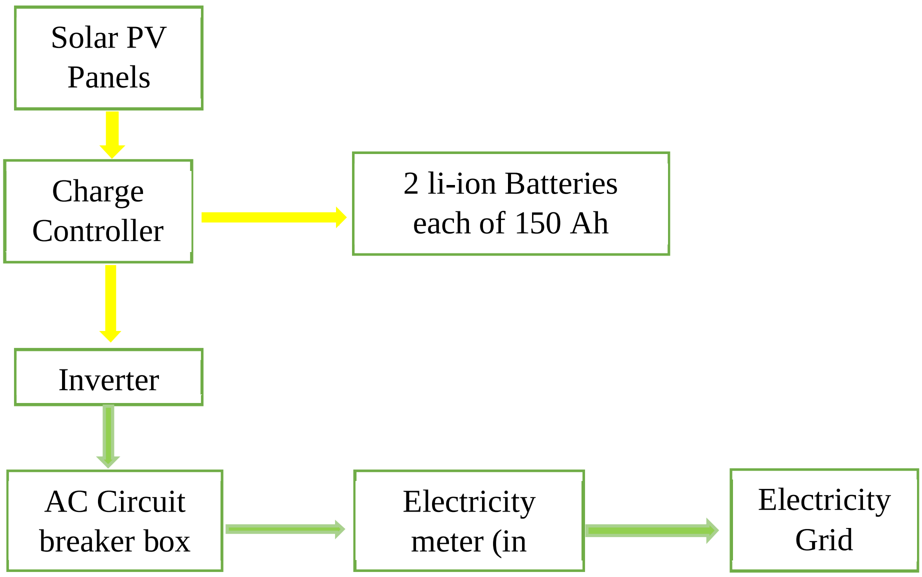

Figure 5.3 System Description of Rooftop Solar PV System with Battery

The yellow arrows depict the path of DC current, and the green arrows depict the path of AC current. Panels convert solar energy into electrical energy and produce Direct Current (DC). The inverter converts the incoming DC from the panels to AC, which can be directly used to run residential appliances. The structure holds the PV panel firmly in place and is usually made of Aluminum (S. Chopade et al., 2018).

PV panels and inverters are connected through DC cables, which carry the DC current produced by the panels to the inverter. The average length of the DC cable installed is 30 meters. But it usually depends on the amount of area present on the rooftop and the distance between the solar panels and the inverter in the system. The AC cables connect the inverter to the electricity grid. They carry the converted AC current from the inverter to the electricity grid. The average length of the AC cable is 20 meters, but it depends on the area available for setting up the system and the distance between the inverter and the electricity grid. The MC4 connectors hold the PV panels installed together. Without them, the panels will not be joined together and can result in damage to the panels. The battery is an important component of the PV system, especially in stand-alone systems wherein the system is not connected to the grid. The battery stores the extra DC current that comes from the PV panels, and that energy can be utilized later for electricity consumption in the nighttime when the sun is not up, and the PV panels cannot produce energy.

The module area required for 2k, 3k, 4k, and 5kW systems are as follows:

Table 5.9 System and Module requirement

SYSTEM	2 KW	3 KW	4 KW	5 KW
MODULE AREA (IN SQUARE METRES)	13	19.5	24.4	35.8

Cost of the proposed system

Ministry of New and Renewable Energy (MNRE) sets up benchmark costs for Grid-connected Rooftop Solar Photo-voltaic systems. For the financial year 2020-21 the benchmark cost shown below:

These benchmark costs are inclusive of total system cost including PV solar modules, inverters, the balance of systems including cables, Switches/Circuit Breakers/Connectors/

Junction Boxes, mounting structure, earthing, Lightning arrester, cost of meters, local connectivity cost, cost of civil works, foundations, installation, commissioning, transportation, insurance, the capital cost of online monitoring, comprehensive maintenance charges for five years, applicable fees and taxes, etc. The benchmark costs do not include net metering and battery back-up related costs.

A two kW PV system will cost INR 86,000 in general category states, excluding batteries. The battery being used has a capacity of 150 Ampere-hours (Ah), and for this system, two batteries are going to be installed (Byrne et al., 2017). The MRP (Maximum Retail Price) of each battery is 16000 INR. Since two batteries are installed, the cost amounts to 32000 INR. The total cost of the system comes out to be: 86000+32000= INR 1, 18,000.

Table 5.10 Benchmark Cost of rooftop Solar PV system. Source: MNRE

Capacity Range	**Benchmark Costs (INR per Watt)**	
	General Category States/UTs	**Special Category States***
1kW	47	52
>1 to 2kW	43	47
> 2 to 3kW	42	46
>3 to 10kW	41	45
>10 to 100kW	38	42
>100 to 500kW	36	40

* including North-Eastern States including Sikkim, Uttarakhand, Himachal Pradesh, Jammu & Kashmir, Ladakh, Andaman & Nicobar and Lakshadweep Islands.

Power Generation Capacity

Simulations were performed to gauge the power generation capacity using standard solar panels for 50 locations in India. Results were obtained for five cities, each in 10 major states.

Cities were chosen based on population and hence greater power consumption. Within each city, simulations were done for 10 locations. The locations selected were assumed to be independent houses with space to accommodate rooftop solar panels. The average of the 10 locations has been used to calculate generation capacity for each city. PVSyst software was used to perform the simulations.

The simulations of the rooftop solar PV systems were being performed on PVSyst. Once the latitude and longitude of the location are given, the software can provide data on the amount of solar radiation received at that specific location. The orientation of the panel was kept fixed at 30° with respect to the horizontal. The analysis was being done for 2 kW, 3 kW, 4 kW and 5 kW capacity systems. The brand of panels used was Vikram Solar, and the inverter used was Growatt New Energy. The panel model used for all the capacity systems was the Eldora VSP.60.260.05_U, which came out in 2017. Pictures below represent the software interface and values/ settings used for the simulations and simulated result files. Refer Figure 5.4 for the Software report. And Figure 5.5 for Software report – Graph.

Table 5.11 Inverter Model with Capacity

Capacity in kW	Inverter Model
2	Growatt 2000TL-US
3	Growatt 3000HF
4	Growatt 4000UE
5	Growatt 5000MTL

Once the simulations were done, the software can generate a report that gives us information about the monthly radiation data, the losses, the amount of irradiation, and the system's amount of energy.

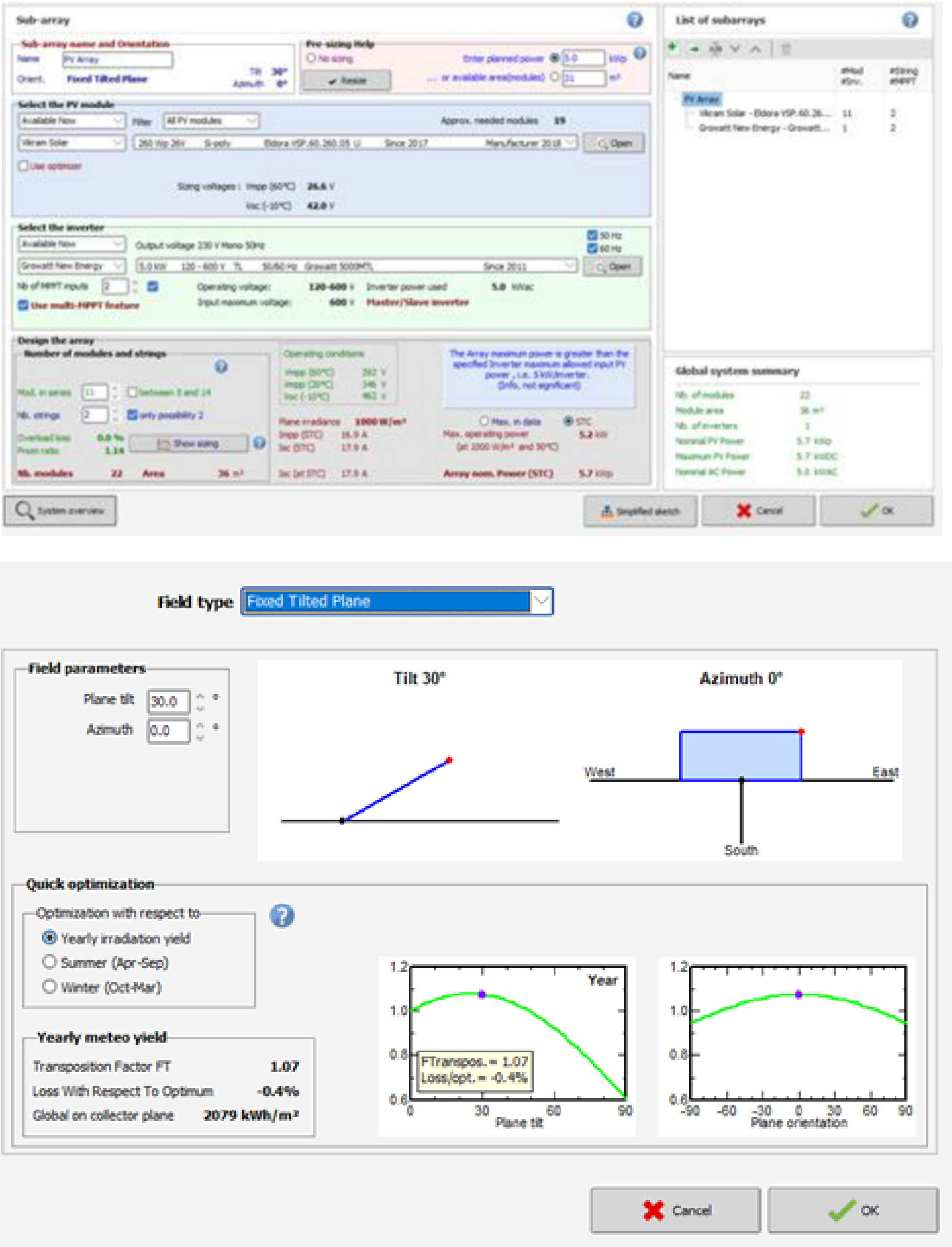

Figure 5.4 Software Report to gauge rooftop solar generation potential. Source: PVSyst Software

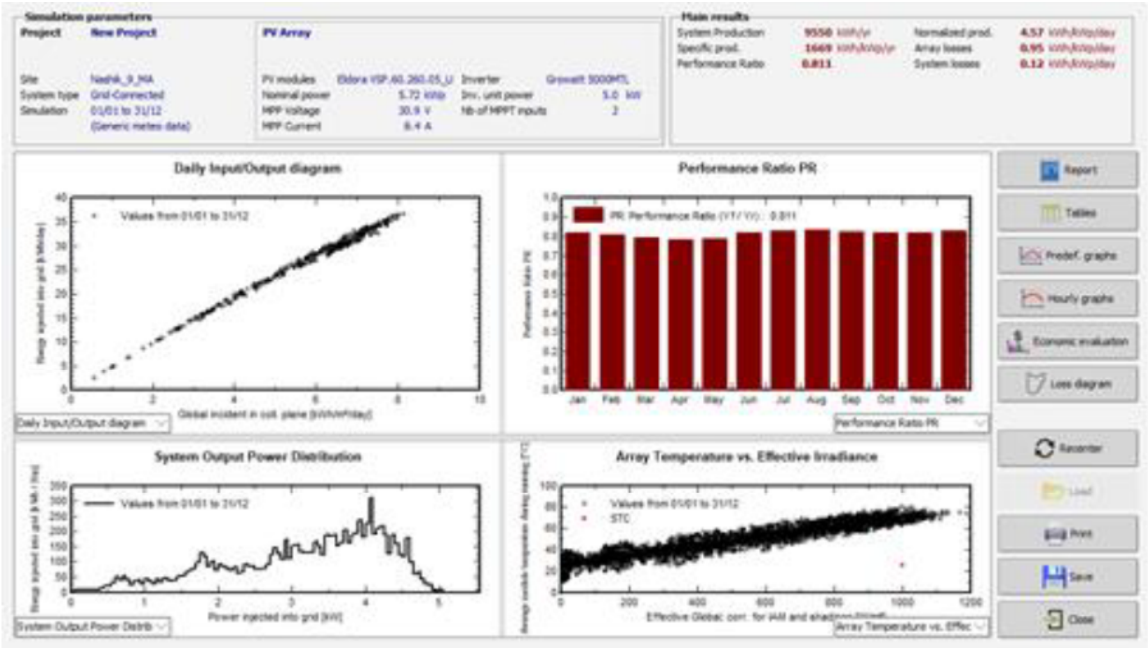

Figure 5.5 Software report: Graph to gauge rooftop solar generation potential. Source: PVsyst software

Average values for energy produced per month, and the energy produced per year by a 2kW rooftop PV panel in different states is shown in tables below.

1. **Bihar**

Table 5.12 Average Values for Bihar

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL (MWh)
BEGUSARAI	0.26	0.28	0.33	0.31	0.3	0.24	0.21	0.24	0.24	0.26	0.28	0.26	3.2
DARBHANGA	0.24	0.27	0.31	0.29	0.28	0.24	0.22	0.23	0.24	0.26	0.28	0.25	3.13
GAYA	0.29	0.3	0.33	0.31	0.3	0.25	0.22	0.23	0.25	0.27	0.3	0.31	3.36
MUZAFFARPUR	0.23	0.27	0.31	0.29	0.28	0.24	0.22	0.23	0.24	0.26	0.27	0.25	3.08
PATNA	0.24	0.27	0.31	0.29	0.29	0.24	0.22	0.23	0.23	0.26	0.26	0.25	3.1

2.Chhattisgarh

Table 5.13 Average Values for Chhattisgarh

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL (MWh)
BHILAI	0.31	0.31	0.33	0.3	0.29	0.22	0.19	0.19	0.24	0.29	0.3	0.31	3.28
BILASPUR	0.31	0.31	0.33	0.3	0.29	0.22	0.19	0.19	0.24	0.29	0.3	0.31	3.36
KORBA	0.33	0.32	0.34	0.31	0.3	0.23	0.2	0.2	0.24	0.3	0.31	0.33	3.42
RAIGARH	0.32	0.3	0.33	0.3	0.3	0.23	0.2	0.19	0.23	0.29	0.3	0.32	3.33
RAIPUR	0.31	0.31	0.33	0.31	0.29	0.23	0.2	0.19	0.23	0.29	0.3	0.31	3.29

3.Gujrat

Table 5.14 Average Values for Gujrat

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL (MWh)
AHMEDABAD	0.33	0.32	0.35	0.32	0.3	0.25	0.19	0.2	0.26	0.31	0.3	0.31	3.4
GANDHINAGAR	0.33	0.32	0.35	0.32	0.3	0.25	0.19	0.2	0.25	0.31	0.3	0.31	3.43
RAJKOT	0.39	0.35	0.37	0.34	0.32	0.26	0.21	0.21	0.29	0.36	0.34	0.36	3.78
SURAT	0.37	0.34	0.37	0.34	0.3	0.25	0.2	0.21	0.27	0.35	0.34	0.34	3.67
VADODARA	0.36	0.33	0.36	0.33	0.32	0.26	0.2	0.2	0.27	0.35	0.34	0.34	3.63

4.Jharkhand

Table 5.15 Average Values for Jharkhand

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL (MWh)
BOKARO STEEL CITY	0.31	0.3	0.33	0.3	0.3	0.24	0.21	0.22	0.22	0.28	0.29	0.31	3.32
DEOGHAR	0.32	0.3	0.33	0.31	0.29	0.24	0.21	0.23	0.24	0.27	0.3	0.31	3.35
DHANBAD	0.31	0.3	0.33	0.31	0.3	0.24	0.21	0.22	0.22	0.28	0.29	0.31	3.3
JAMSHEDPUR	0.3	0.29	0.33	0.3	0.29	0.23	0.21	0.21	0.23	0.27	0.28	0.3	3.22
RANCHI	0.33	0.32	0.34	0.31	0.31	0.24	0.21	0.21	0.23	0.28	0.3	0.34	3.43

5. Karnataka

Table 5.16 Average Values for Karnataka

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL (MWh)
BENGALURU	0.43	0.38	0.36	0.3	0.26	0.18	0.18	0.2	0.22	0.3	0.31	0.41	3.53
HUBLI	0.34	0.32	0.34	0.3	0.28	0.2	0.19	0.21	0.24	0.29	0.31	0.34	3.39
KALABURAGI	0.33	0.31	0.33	0.3	0.28	0.21	0.2	0.22	0.25	0.29	0.3	0.32	3.35
MANGALORE	0.36	0.32	0.33	0.29	0.25	0.16	0.17	0.2	0.24	0.28	0.3	0.35	3.27
MYSURU	0.42	0.37	0.36	0.3	0.25	0.18	0.19	0.21	0.23	0.31	0.31	0.41	3.55

6. Maharashtra

Table 5.17 Average Values for Maharashtra

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL (MWh)
MUMBAI	0.31	0.3	0.34	0.31	0.29	0.21	0.17	0.19	0.24	0.29	0.29	0.29	3.24
NAGPUR	0.32	0.3	0.34	0.31	0.29	0.22	0.18	0.19	0.24	0.3	0.3	0.31	3.3
PUNE	0.35	0.33	0.36	0.33	0.31	0.24	0.21	0.21	0.27	0.33	0.33	0.34	3.58
THANE	0.31	0.3	0.34	0.31	0.29	0.21	0.17	0.19	0.24	0.29	0.29	0.29	3.24
NASHIK	0.33	0.31	0.35	0.32	0.31	0.22	0.17	0.19	0.24	0.31	0.31	0.31	3.42

7. Orissa

Table 5.18 Average Values for Orissa

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL (MWh)
BRAHMAPUR	0.3	0.28	0.29	0.28	0.25	0.2	0.19	0.22	0.23	0.26	0.27	0.3	3.08
BHUBANESHWAR	0.3	0.28	0.31	0.28	0.27	0.21	0.19	0.2	0.22	0.26	0.28	0.29	3.09
CUTTACK	0.3	0.28	0.31	0.29	0.28	0.21	0.19	0.2	0.22	0.26	0.28	0.29	3.11
ROURKELA	0.33	0.3	0.33	0.31	0.31	0.23	0.2	0.21	0.22	0.29	0.3	0.33	3.37
SAMBALPUR	0.32	0.3	0.32	0.3	0.29	0.23	0.2	0.2	0.23	0.29	0.3	0.31	3.28

8. Rajasthan

Table 5.19 Average Values for Rajasthan

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL (MWh)
BIKANER	0.29	0.3	0.32	0.33	0.31	0.28	0.26	0.27	0.3	0.3	0.3	0.27	3.53
JAIPUR	0.31	0.33	0.36	0.33	0.32	0.27	0.24	0.25	0.3	0.32	0.29	0.3	3.63
JAISALMER	0.33	0.32	0.35	0.33	0.32	0.28	0.28	0.27	0.31	0.29	0.31	0.3	3.69
JODHPUR	0.32	0.31	0.35	0.33	0.32	0.27	0.25	0.25	0.3	0.33	0.3	0.32	3.66
UDAIPUR	0.34	0.35	0.37	0.34	0.33	0.27	0.23	0.23	0.29	0.35	0.32	0.34	3.76

9. Tamil Nadu

Table 5.20 Average Values for Tamil Nadu

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL (MWh)
CHENNAI	0.31	0.31	0.33	0.29	0.26	0.22	0.22	0.24	0.26	0.24	0.22	0.25	3.15
COIMBATORE	0.38	0.34	0.33	0.28	0.25	0.16	0.17	0.22	0.25	0.29	0.28	0.37	3.34
MADURAI	0.32	0.3	0.32	0.27	0.24	0.2	0.21	0.25	0.28	0.29	0.26	0.3	3.26
TRICHY	0.36	0.32	0.32	0.28	0.23	0.18	0.2	0.24	0.24	0.28	0.27	0.34	3.24
VELLORE	0.35	0.33	0.34	0.29	0.25	0.2	0.2	0.23	0.24	0.27	0.26	0.31	3.24

10. Uttar Pradesh

Table 5.21 Average Values for Uttar Pradesh

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL (MWh)
AGRA	0.26	0.3	0.34	0.33	0.31	0.26	0.23	0.25	0.27	0.29	0.27	0.27	3.38
KANPUR	0.25	0.28	0.34	0.32	0.31	0.26	0.23	0.25	0.26	0.28	0.28	0.27	3.31
LUCKNOW	0.24	0.28	0.33	0.31	0.31	0.26	0.23	0.25	0.25	0.29	0.28	0.27	3.31
NOIDA	0.27	0.29	0.34	0.33	0.31	0.27	0.23	0.25	0.26	0.3	0.26	0.26	3.59
VARANASI	0.25	0.28	0.31	0.29	0.3	0.26	0.23	0.23	0.25	0.28	0.28	0.28	3.23

Cost-Effectiveness

The system's cost-effectiveness and the corresponding savings potential are assessed by comparing the Cost of Electricity (COE) generated by the system to other electricity generation and distribution options.(Behi et al., 2020a)

The Cost of Electricity (COE) generation is calculated as the ratio of the net present value of total capital and operating costs of a particular system to the net electricity generated by that system over its operating life.(Behi et al., 2020b) The COE represents a conservative value for electricity generated by the rooftop PV system expressed in INR /kWh based on assumptions and the chosen discount rates (weighted average cost of capital).

Total capital cost of the system from the earlier section was found to be INR 1,18,000, the operation, and maintenance (O&M) cost of the PV panel system is assumed to be negligible, with only routine cleaning and maintenance required. The batteries have an expected life of 15-20 years; therefore, we have assumed that the batteries will need to be replaced in the 15th year. The total operational life of the system is taken to be 25 years, which has been used in multiple studies (Mahapatra et al., 2012) (Reddy, 2018).

Data from simulations have been used. The panel's efficiency usually becomes around 90% of the initial value in the 25th year (Mahapatra et al., 2012.) The Discount rate for the system's total cost is taken to be 7%, and no discounting has been done for energy generated. The Cost of Electricity for the 50 selected locations is shown in the table below. Interesting to note that no additional transmission infrastructure will be required if the system is designed properly according to consumption. The cost of electricity generation is significantly lower than other power sources.

Table 5.22 Cost of the Electricity generated

CITY	COST OF ELECTRICITY GENERATED INR/kWh	TOTAL AMOUNT OF ELECTRICITY PRODUCED IN 25 YEARS (kWh)
BEGUSARAI	1.62	80000
DARBHANGA	1.66	78250
GAYA	1.54	84000
MUZAFFARPUR	1.68	77000
PATNA	1.67	77500
BHILAI	1.58	82000
BILASPUR	1.54	84000
KORBA	1.52	85500
RAIGARH	1.56	83250
RAIPUR	1.58	82250
AHMEDABAD	1.52	85000
GANDHINAGAR	1.51	85750
RAJKOT	1.37	94500
SURAT	1.41	91750
VADODARA	1.43	90750
BOKARO STEEL CITY	1.56	83000
DEOGHAR	1.55	83750
DHANBAD	1.57	82500
JAMSHEDPUR	1.61	80500
RANCHI	1.51	85750
BENGALURU	1.47	88250
HUBLI	1.53	84750

CITY	COST OF ELECTRICITY GENERATED INR/kWh	TOTAL AMOUNT OF ELECTRICITY PRODUCED IN 25 YEARS (kWh)
KALABURAGI	1.55	83750
MANGALORE	1.59	81750
MYSURU	1.46	88750
MUMBAI	1.6	81000
NAGPUR	1.57	82500
PUNE	1.45	89500
THANE	1.6	81000
NASHIK	1.52	85500
BRAHMAPUR	1.68	77000
BHUBANESHWAR	1.68	77250
CUTTACK	1.67	77750
ROURKELA	1.54	84250
SAMBALPUR	1.58	82000
BIKANER	1.47	88250
JAIPUR	1.43	90750
JAISALMER	1.4	92250
JODHPUR	1.42	91500
UDAIPUR	1.38	94000
CHENNAI	1.65	78750
COIMBATORE	1.55	83500
MADURAI	1.59	81500
TRICHY	1.6	81000
VELLORE	1.6	81000

CITY	COST OF ELECTRICITY GENERATED INR/kWh	TOTAL AMOUNT OF ELECTRICITY PRODUCED IN 25 YEARS (kWh)
AGRA	1.53	84500
KANPUR	1.57	82750
LUCKNOW	1.57	82750
NOIDA	1.44	89750
VARANASI	1.6	80750

5.3 PM KUSUM Scheme

The first step to analyze any data is to collect the data. In the case of this study, the first data related to PM KUSUM component C was to be extracted. We found the data on the official MNRE (Ministry of new and renewable energy) website (MNRE, 2020).

On the official government portal, data is given on how many numbers of solar pumps are allotted to each state under PM KUSUM Scheme component C (Byrne et al., 2019). Table 3 illustrates that data. The number of pumps to be distributed are mentioned, but the types of pumps are not mentioned in the available data. This is because the government has only allotted the numbers in totality, and farmers can purchase the type of solar pump which suits their needs. Three options are available as far as the choice of solar pump goes, namely 3HP, 5HP and 7.5HP pumps. But since different power consumption induces different types of CO_2 emissions in the long run, it is advisable to get the pumps' exact category-wise distribution. Since this is the first year in which PM KUSUM Scheme will be implemented, there is no previous data of installation to estimate the category-wise distribution of these solar pumps. However, in Rajasthan, the state government previously had a scheme of distributing solar pumps to farmers at a subsidized rate. The implementation data of that scheme is readily available with the Department of Horticulture, Rajasthan (MNRE, 2018). Since the data set of that scheme implementation is huge, therefore it is only cited and not tabulated in this report.

Using the data of the previous distribution of pumps of various categories in Rajasthan, an estimation of farmers need was done on the distribution of allotted solar pumps in various states. The following table highlights that distribution. 3HP, 5HP and 7.5 HP pumps were distributed in approximately 21%, 78% and 1% ratio, respectively. The greatest integer function was applied everywhere to get a numerical value for the number of pumps.

It is clear from the projected pump distribution that 7.5HP pumps would constitute a minority of pumps while 3HP and 5HP pumps would be in high demand. And it also makes sense because most farmers in India do not have large agricultural lands. Next, it is important to note how much it will cost both the government and the farmer. For that, it is important to note the cost of individual pumps. The data for the cost of pumps was extracted from the Department of Horticulture's tender details, Rajasthan (MNRE, 2018). Table 5.25 illustrates the cost of solar pump installation.

Since the pumps available in each category are of two types, AC and DC, with a small difference in their price, the average price of those two is taken for each category for the calculations, for the implementation data in each subcategory is yet to be announced at the time of writing this analysis report.

Table 5.23 The table highlights the capacity/numbers to be installed as a part of 3 components of PM KUSUM Scheme, across various states (MNRE, 2020)

S.No	**State**	**Component A Sanctioned Capacity (MW)**	**Component B Sanctioned Capacity (Nos)**	**Component C Sanctioned Capacity (Nos)**
1	Maharashtra	300	30,000	9,000
2	Karnataka	50	6,000	-
3	Tamil Nadu	-	17,500	20,000
4	Andhra Pradesh	-	-	-
5	Uttar Pradesh	75	8,000	1,000
6	Jharkhand	10	10,000	500
7	Chhattisgarh	-	20,000	-
8	Odisha	-	2,500	-
9	Bihar	-	-	-
10	Gujarat	40	4,000	
11	Rajasthan	325	25,000	12,500
12	Delhi	10	-	-
13	Haryana	25	15,000	468
14	Himachal Pradesh	10	550	-
15	Kerala	10	-	5,200
16	Madhya Pradesh	100	25,000	15,000
17	Meghalaya	10	1,700	60
18	Punjab	30	4,500	3,900
19	Tripura	5	1,300	1,300
TOTAL		**1000**	**171050**	**68928**

Table 5.24 Predicted distribution of pump 3HP, 5HP and 7.5HP pumps as a part of PM KUSUM Scheme component C across various states, based on the past implementation data of a state specific solar pump scheme by Department of Horticulture, Rajasthan

(MNRE, 2018)

State	3HP	5HP	7.5HP
Maharashtra	1955	7041	4
Tamil Nadu	4345	15647	8
Uttar Pradesh	217	782	1
Jharkhand	109	391	0
Rajasthan	2715	9780	5
Haryana	101	366	1
Kerala	1130	4068	2
Madhya Pradesh	3259	11736	5
Meghalaya	13	47	0
Punjab	847	3051	2
Tripura	282	1017	1

As expected, it follows that 7.5HP pumps are the costliest, followed by 5HP and 3HP pumps. Costs from Table 5.25 were considered, and then the cost incurred by each government and the farmers (collectively) living in that state was calculated, illustrated in Table 5.26. The distribution among State government, Central government, and Famers (collectively) is done in the ratio 3:3:4 (Except Himachal Pradesh), since as per the PM KUSUM Scheme, 30% cost will be subsidized by central government, 30% cost will be subsidized by state government and the rest will be borne by the farmers.

Table 5.25 Selling prices being charger by the seller for the solar pumps (various categories) (MNRE, 2018)

S.No.	Details	DC/AC &Mounting Structure	3HP (INR)	5HP (INR)	7.5HP (INR)	Pump wise Average (5% GST Inclusive) (INR)
1	SPV Surface Pump	DC Manual	1,49,785.00	2,08,549.00	3,10,873.00	2,34,222.45
2		AC Manual	1,45,814.00	2,06,412.00	3,00,542.00	2,28,468.80
3	SPV Submersible Pump (Water filled motor)	DC Manual	1,55,950.00	2,18,513.00	3,23,422.00	2,44,259.75
4		AC Manual	1,52,500.00	2,12,402.00	3,08,027.00	2,35,525.15
5	SPV Submersible Pump (Oil filled motor)	DC Manual	1,63,917.00	2,33,990.00	3,63,990.00	2,66,663.95
6		AC Manual	1,62,590.00	2,33,590.00	3,46,690.00	2,60,004.50
Power wise Average (GST inclusive)			**1,62,847.30**	**2,29,854.80**	**3,41,870.20**	

Base Rate, Cost of Solar Pump along with controller (GST Exclusive)

The calculations established that the central government would be spending about INR445.3 Crore, and a similar amount would be spent by all the state governments combined. This highlights the importance given by the government to uplift the farmers out of economic plights (by providing them an additional source of income- the energy generated by solar pumps can be transferred to the grid when not in use) and promoting renewable energy in the country.

Table 5.26: Calculated expenditure of governments and famers (combined) in various states about PM KUSUM Scheme C component C.

State	3HP	5HP	7.5HP	Central Government (INR)	State Government (INR)	Farmer (INR)
Maharashtra	1955	7041	4	58,14,42,479.73	58,14,42,479.73	77,52,56,639.64
Tamil Nadu	4345	15647	8	1,29,20,53,360.71	1,29,20,53,360.71	1,72,27,37,814.28
Uttar Pradesh	217	782	1	6,46,27,856.37	6,46,27,856.37	8,61,70,475.16
Jharkhand	109	391	0	3,22,87,074.75	3,22,87,074.75	4,30,49,433.00
Rajasthan	2715	9780	5	80,75,45,914.35	80,75,45,914.35	1,07,67,27,885.80
Haryana	101	366	1	3,02,74,891.29	3,02,74,891.29	4,03,66,521.72
Kerala	1130	4068	2	33,59,25,154.74	33,59,25,154.74	44,79,00,206.32
Madhya Pradesh	3259	11736	5	96,90,01,390.35	96,90,01,390.35	1,29,20,01,853.80
Meghalaya	13	47	0	38,76,057.15	38,76,057.15	51,68,076.20
Punjab	847	3051	2	25,19,70,719.49	25,19,70,719.49	33,59,60,959.32
Tripura	282	1017	1	8,40,08,142.12	8,40,08,142.12	11,20,10,856.16
TOTAL COST				**4,45,30,13,041.05**	**4,45,30,13,041.05**	**5,93,73,50,721.40**

For calculating the carbon emissions saved, it is essential to first calculate the total energy saved. This is calculated by the given formula:

Grid energy saved=Power rating of solar pumps × Average Time usage

Average annual time usage of pumps was taken to be 0.5 hours per day for the study, based on the availability of agricultural power in various states and the size of land a farmer possesses on average (Kishore et al., 2019) (Mallapur, 2018). For agricultural purposes, a farmer on average uses the pump for 3 hours, sometimes on alternate days depending on the crop. But the irrigation season only represents about 13^{th} of the year; that is why 0.5 hours per day per year was chosen for calculations.

The calculations clearly show that states like Tamil Nadu, Rajasthan, and Madhya Pradesh have the maximum savings among the states listed for PM KUSUM Scheme component C.

Table 5.27 State-wise contribution of energy saved (x10 Giga Joules)

State	Daily	Monthly	Yearly
Maharashtra	5.52	165.57	2014.40
Tamil Nadu	12.26	367.91	4476.28
Uttar Pradesh	0.61	18.40	223.91
Jharkhand	0.31	9.19	111.85
Rajasthan	7.67	229.95	2797.74
Haryana	0.29	8.62	104.91
Kerala	3.19	95.65	1163.79
Madhya Pradesh	9.20	275.92	3357.07
Meghalaya	0.04	1.10	13.43
Punjab	2.39	71.75	872.96
Tripura	0.80	23.92	291.06
Total	**42.27**	**1268.01**	**15427.40**

Table 5.28 shows energy saved in MWh of various states by the implementation of PM KUSUM Scheme Component C:

Table 5.28 State-wise contribution in energy saved (in MWh) due to implementation of PM KUSUM Scheme component C

State	Daily	Monthly	Yearly
Maharashtra	15.33	459.91	5595.56
Tamil Nadu	34.07	1021.98	12434.12
Uttar Pradesh	1.70	51.12	621.98
Jharkhand	0.85	25.54	310.68
Rajasthan	21.29	638.75	7771.50
Haryana	0.80	23.95	291.42
Kerala	8.86	265.71	3232.76
Madhya Pradesh	25.55	766.45	9325.18
Meghalaya	0.10	3.07	37.30
Punjab	6.64	199.31	2424.88
Tripura	2.22	66.45	808.50
Total	**117.41**	**3522.24**	**42853.89**

The calculations show total annual energy savings of about 42.85 GW just by the successful implementation of PM KUSUM Scheme Component C.

5.4 Energy Efficient Appliances and ToU Jalgaon Household Appliances, A Case Study

A study is conducted for sample of 16000 residential premises of Jalgaon city of Maharashtra and studied their load profiles appliances-wise and calculated average hours used of these appliances for winter and summer seasons considering heating and cooling load in view of ToU and ToD tariff. Refer Table 5.29.

Table 5.29 The average usage in hours per day of widely used residential appliances.

APPLIANCE	AVERAGE HOURS USED
Television	4 hours/day
Washing Machine	7 loads/week
Air Conditioner	1440 hours/year
Air cooler	1440 hours/year
Fan	2520 hours/year
Refrigerator	24 hours/day
Electric Water Heater	140 days/year
Electric Oven	15 minutes/day
Electric Toaster	15 minutes/day
Microwave	6 minutes/day
Computer	2.2 hours/day
DVD	156 hours/year
Radio	2190 hours/year
CD player	1460 hours/year

Table 5.29 below gives the average usage in hours per day of widely used residential appliances. These average usages have been used to calculate the total consumption over the year.

The appliances television, washing machine, air conditioner, air cooler, fan, refrigerator, electric water heater (geyser), electric oven, electric toaster, microwave, computer, DVD player, Radio, CD /DVD player have been considered, and their consumption calculated with respect to their ratings and conclusion are drawn.

Table 5.30 Appliance wise average consumption per month Actual and after energy conservation. Energy saved per month in MJ.

House	Average consumption per month (MJ)	Average consumption per month with conservation (MJ)	Amount of Energy Saved per month (MJ)
House 1	3427.945	2546.305	881.6401
House 2	1949.677	1612.314	337.3631
House 3	3746.963	3012.203	734.7602
House 4	3015.81	2571.21	444.6
House 5	5027.562	4273.362	754.1998
House 6	1434.924	1266.084	168.8402
House 7	2827.576	2301.736	525.8401
House 8	1903.5	1589.94	313.56
House 9	5342.882	4777.323	565.5598
House 10	5783.378	5025.219	758.1598

Table 5.31 Appliance wise average consumption per month in Summer and Winter season in MJ

House	Energy in summer (MJ)	Energy in winter (MJ)	Average consumption per month (MJ)
House 1	28846.28	12289.06	3427.945
House 2	16550.7	6845.429	1949.677
House 3	30528.66	14434.89	3746.963
House 4	26505.36	9684.36	3015.81
House 5	44467.49	15863.26	5027.562
House 6	12349.15	4869.936	1434.924
House 7	24450.56	9480.352	2827.576
House 8	16169.76	6672.24	1903.5
House 9	45454.87	18659.72	5342.882
House 10	49187.35	20213.19	5783.378

Results are encouraging and found 15 to 20% savings in electricity bills with energy conservation. It is concluded that if all appliances and lighting load is replaced with energy-efficient lighting system having LEDs and other all appliances replaced with energy-efficient appliances, the energy savings go up to 62% with the execution of all DSM options together. It results in an effective reduction of consumer's energy bills. The details are given in Appendix C.