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Economic analysis of a business model of basin-type building material-based solar thermal desalination device

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ABSTRACT

The development of solar desalination technology industry can play an important role in the economic development of the country. In addition to reducing carbon emissions, these technologies can create more jobs in rural and urban areas and strengthen traditional energy systems. To start a new business, the profitability of the business should be evaluated separately based on economic analysis. Banks provide loans according to the economic attributes of the project. Therefore, an economic evaluation of basin-type building material-based solar thermal desalination device was carried out to evaluate the feasibility of solar technology investment in order to guide new entrepreneurs. For determining the economic viability of constructing solar desalination unit, many economic criteria such as break-even point, net present value (NPV), payback period (PBP), benefit-cost ratio (BCR), annuity (A), internal rate of return were determined. The entire annual operating cost of the business was calculated by adding fixed and variable charges. The business of solar thermal desalination unit has a huge potential because of the high BCR (1.15), NPV (INR 4,916,083) (59,040.68 USD), A (INR 721,151) (8,660.81 USD), and short PBP (1 month) values when producing 365 units/y. In addition, according to the break-even analysis, the manufacturing and sale of only 52 units are sufficient to achieve a condition of no profit and no loss. This firm generates a net average yearly benefit (A) of INR 721,151 (8,660.81 USD). Furthermore, this firm has the potential to not only generate cash but also provide work for four people. It also has a great potential for lowering CO_2 emissions.

Keywords: Techno-economic evaluation; Business model; Solar thermal desalination device; CO_2 emission

1. Introduction

Key resources required for the growth of human civilization are water and energy, and their demand has been increasing steadily. However, many regions of the world are facing drinking water scarcity, because they have insufficient freshwater resources to meet their human and environmental demands [1]. Water scarcity can be caused by natural factors such as, climate change, drought, and floods, or human factors such as population growth, urban development, pollution, and over-development [2]. Recent reports clearly show that groundwater table and precipitation are declining and people still rely on rivers, lakes, and groundwater for domestic needs, agricultural activities, and the fresh water industry [3]. However, the use of water from these sources is not always possible or desirable due to high salt content and harmful bacteria. The worst scenario occurs when there is lack of resources and local people have to use hyper-saline groundwater containing nitrates and fluorides or pathogenic microorganisms in lake water [4,5]. India has the second largest share in Renewable Energy Production after China. India's renewable energy

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(10.3 billion kWh) accounts for 9.11% (113.11%) of total electricity production. Solar energy alone has a share of 36.3% among renewable energy sources. Also, the Government of India has set ambitious targets to have 175 GW of solar photovoltaic (PV) capacity in the country by 2022, which is revised to reach 450 GW by 2030. According to these targets, approximately 40% and 60% of India's total electricity generation by 2022 and 2030, respectively, should be met by renewable energy. Also, as announced at the COP 26 climate conference in Glasgow in November 2021, the Indian government is committed to achieving 100% renewable energy use by 2050 and net zero carbon emissions by 2070 [6]. Solar power availability in India varies from 3–6 kWh/m^2·d, making solar thermal technology a potential contributor to renewable energy generation in the country. The hot arid region of India is rich in solar radiation, receiving more than 300 d of sunshine a year in Jodhpur, (India) has an average solar radiation of 6.0 kWh/m^2·d and 8.9 h/d of sunshine [7].

One way to meet the global demand for fresh water is to use solar thermal desalination [1]. Desalination is the process that evaporates water from saline water resources and condense it to get distilled water in the hot arid zone of India [3,5,8]. Therefore, low-cost solar thermal desalination technology is needed to improve the living conditions of people around the world. Scientists in many different parts of the world develop new ideas and conduct research work on desalination technology. Unfortunately, after the development of so many solar thermal and PV-based desalination devices, the final device/product does not enter the commercial market for many reasons, such as lack of business or business knowledge, and little or no cooperation with the business. Research is carried out without knowing what the market wants. For these reasons, many products are discarded after a lot of money has been invested in their development. Therefore, successful promotion, marketing, and commercialization of products require the efforts of researchers. Kalair et al. [9] report the process of technological transfer, from acquiring intellectual property (patents and copyrights) to licensing start-ups or directly to market, trade, and commerce. This work helps researchers working on new projects understand the rules and regulations that govern the work of research projects.

Many researchers around the world have proposed different types of technology to create business models for solar thermal and photovoltaic technologies. Kalair et al. [9], analyzing and interviewing companies and consumers in a cool place, developed a business model for solar heating and cooling for homes, refrigerators, and data centers around the world. Bocken et al. [10] propose different strategies for building business models, such as the impact of business models on business ecology. Risk analysis of the energy sector's sustainable business model and the business model difficulties faced by a German Solar Company [11–13]. Many research workers have also proposed very innovative business model such as the business model for distributed photovoltaic (PV) energy in China and a PV water pumping system in China [14,15]. In order to target the Indian market, Singh et al. [16] developed a business model for solar Thermal devices. They found that the model was based on a number of industries, an economic analysis of 300 units of production annually, good potential for solar thermal technology, and an average profit of INR 189,800 (2,279.44 USD). Li et al. [17] proposed a business model for solar water heat pump as an integrated energy system for the Chinese market. The business models of these kettles are rarely competitive, as there is no third-party model. The government provides appropriate subsidies to attract buyers, which will help reduce future electricity demand and energy costs. Singh et al. [18] also developed a business model for a solar dryer, showing that the company will generate an average annual profit of INR 2,17,672 (2,614.18 USD) per year for 300 d of solar dryer production. The results of other economic factors such as payback period (PBP), internal rate of return (IRR), net present value (NPV), and benefit-cost ratio (BCR) are 0.47 y, 225%, INR 1,334,026 (16,021.25 USD) and 13.8, respectively. Poonia et al. [6] developed a business model for an animal feed solar cooker for milch animals in India's Thar desert and the break-even point was 172 units. This firm generated a net yearly benefit of INR 682,220 (8,193.26 USD). The PBP, IRR, NPV, and benefit-cost ratio (BCR) were calculated to be 0.16 y, 670%, INR 4,650,690 (55,853.39 INR), and 1.26, respectively. Furthermore, this firm earns a large profit and employs four people.

To start a new business, a profitable business should be evaluated separately based on business analysis. Banks give loans according to the economic attributes of the project. Therefore, the cost and economic values of the brick cement-based solar thermal desalination device developed by CAZRI was tried to determine its investment and production feasibility and evaluated to bring in new businessmen. Most of these commercial models are solar photovoltaic water pumping systems or solar heat pumps. Therefore, this article develops and proposes a business model for a CAZRI-developed basin-type solar-thermal desalination device made of building materials. This analysis can help to develop a proper design for the researchers in developing a business model for the start-up and commercialization of the desalination project. The business model for solar thermal-based desalination devices in India in general and western Rajasthan, in particular, has a tremendous scope because 75% of water in arid western Rajasthan is saline.

2. Methodology

2.1. Design of solar desalination device

A double sloped basin type solar thermal desalination device was designed and developed at ICAR-CAZRI, Jodhpur, India (Fig. 1). The desalination device comprises brick, sand, cement, and plane glass of 3.5 mm thickness placed over the solar still. The inclination of condensing cover for solar still is 20° from the horizontal. The absorber area of the device is 4.2 m^2. The bottom of the still is coated with epoxy black enamel, which has a high solar radiation absorption along with salt and heat resistance. The longer dimension of the device is in the east-west direction so as to collect more solar radiation. The output from the solar desalination unit is collected into two distillate channels provided at the back side through a pipe into a cylinder (Fig. 2).

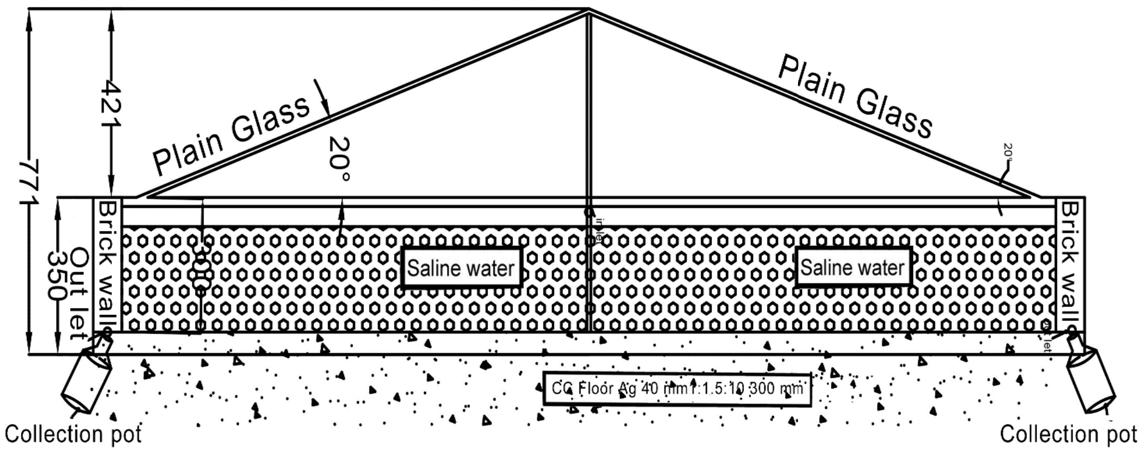

Fig. 1. Schematic diagram of basin type solar desalination device.

Fig. 2. Solar desalination devices made of brick-cement plastered material.

2.2. *Efficiency of solar desalination device (η)*

The performance evaluation of the basin-type brick-cement-based desalination device was carried out by measuring distilled water obtained per day in a measuring jar. Distillation efficiency and system efficiency were calculated using the Eqs. (1) and (2) [3,5].

$$\eta_{\text{distillation}}(\%) = \frac{m_e \times L \times 100}{I_{\text{bav.}} \times A_p \times \text{hr} \times 3600} \tag{1}$$

$$\eta_{\text{system}}(\%) = \frac{\left[m_{\text{water}} \times C_{\text{pw}}\left(T_f - T_i\right) + m_e \times L\right] \times 100}{I_{\text{bav.}} \times A_p \times \text{hr} \times 3600} \tag{2}$$

where A_p = aperature area (m^2); C_{pw} = specific heat (J/kg·°C); I_b = beam radiation (W/m^2); L = latent heat of distiller water (J/kg); m_e = mass of distilled water obtained (L); m_{water} = mass of water remaining in evaporative vessel (L); T_i = initial temperature of evaporative vessel (°C); T_f = final temperature of evaporative vessel (°C); $\eta_{\text{distillation}}$ = distillation efficiency (%); η_{system} = system efficiency (%).

2.3. *Economic analysis of solar desalination device*

Different economic parameters of manufacturing solar desalination device such as break-even point, NPV, PBP, BCR, annuity (A), and IRR were determined for judging the economic viability of the solar desalination device [3,5,19,20]. There are two types of costs associated with building solar devices: fixed or ownership costs and variable or operating costs. The main components of fixed costs are depreciation, interest, taxes, insurance, and mortgage/lease costs. Variable costs, or operating costs, are expenses incurred on electricity, materials, repair and maintenance, labor, and manufacturing-related fees [16]. The total annual operating cost of the device is obtained by adding up the fixed and variable costs. Fixed and variable or operating costs are calculated using the formula given in Table 1.

Table 1
Formulae and prevailing rate used to calculate fixed and variable cost

Type of cost	Component of cost	Formula	Remarks
Fixed cost	Depreciation/y	$D = \frac{C - S}{L}$	C = Initial cost = INR 54,000 (648.52 USD)
	Interest on average Investment/y	$I = \left(\frac{C + S}{2}\right) \times \frac{i}{100}$	i = 12% per annum (interest)
	Insurance and taxes	$I_n = \left(\frac{C \times \text{in}}{100}\right)$	in = 2% per annum
	Housing/rent	Rent/y	12 ′ 8,000 = INR 96,000 (1,152.93 USD)
	Fixed cost (FC) = D + I + In + Rent		
Variable cost	Electricity	5 kWh/unit = 5 ′ 8 = INR 40 (0.48 USD)	Unit (x) is defined as a basin type of brick-cement solar thermal desalination device
	Repair and maintenance (R&M)	(R and M) = INR 60 (0.72 USD)/unit	
	Materials	INR 11,200 (134.51 USD)	
	Operational and labour charges	INR 1,775 (21.32 USD)/unit	
	Variable cost (VC) = Electricity + R&M + Materials + Operational and labour charges		

- Fixed cost per year = Depreciation + Interest + Insurance & taxes + Housing/rent = 3,240 + 3,564 + 1,080 + 96,000 = INR 1,03,884 (1,247.62 USD)
- Variable cost = Electricity cost + Repair and maintenance + Materials + Operational and labour charges = 40 + 60 + 11,200 + 1,775 = INR 13,075 (157.03 USD)

where D = depreciation, I = interest on average investment, I_n = insurance & taxes, RM = repair and maintenance, P = purchase price, and S = salvage value.

2.3.1. Break-even point

The analysis of break-even point (BEP) was carried out to determine the minimum number of units that will allow the investor to receive the minimum amount to meet the total expenses. BEP was determined as the level of activity at which total revenue per unit of sales equals all expenses (fixed and variable). It was calculated based on fixed costs, variable costs, and sales revenue using the Eq. (3):

Fixed cost/y = x (Income/unit – Variable cost/unit)

$$\text{BEP}(x) = \frac{\text{Fixed cost}(\text{Rs./yr})}{(\text{Income from sale/unit} - \text{Variable cost/unit})} \quad (3)$$

2.3.2. Net present value

NPV was calculated at an interest rate of 12% (based on the State Bank of India's agriculture loans) and is considered the cost of capital for the business. This is the present value of the expected return that the investor will receive over the life of the project [7,17]. All cash outflows and cash inflows are discounted at the above discount rate to understand the present value of future cash flows. The net present value of solar devices was worked out using Eq. (4):

$$\text{NPV} = \frac{(E - M)}{a}\left[1 - \left(\frac{1}{1 + a}\right)^n\right] - C \quad (4)$$

where C = initial cost (INR 54,000) (648.52 USD), a = discount rate (12%) and n = life (15 y), E = gross annual benefit (INR), M = total annual cost (INR) = (variable cost + annual rent) ′ 365 and E = (total annual cost + profit margin of INR 2,000 (24.02 USD)/unit) ′ 365.

2.3.3. Benefit-cost ratio

The benefit-cost ratio was expressed as the ratio of gross benefits to total cost:

$$\text{BCR} = \frac{E\sum_{t=1\text{ ton}}\left(\frac{1}{1 + a}\right)^t}{C + M\sum_{t=1\text{ ton}}\left(\frac{1}{1 + a}\right)^t} \quad (5)$$

2.3.4. Annuity

The annuity (A) of the project indicates the average net annual returns. This term can be given as:

$$A(\text{Annuity}) = \frac{\text{NPV}}{\sum_{t=1\text{ ton}}\left(\frac{1}{1 + a}\right)^t} \quad (6)$$

2.3.5. Payback period

The payback period is calculated as the time required to return the initial investment from the average annual income from the investment. The payback period is used to determine the length of time required to pay back the initial capital of the project or investment [7,17,21]. The formula for calculating PBP:

$$\text{PBP} = \frac{\log\frac{(E-M)}{a} - \left(\log\frac{(E-M)}{a} - C\right)}{\log(1+a)} \tag{7}$$

2.3.6. Internal rate of return

IRR can be determined using the following relationship by equating NPV to zero:

Solving Eq. (4) for a, which is the IRR:

$$\text{NPV} = \frac{(E-M)}{a}\left[1-\left(\frac{1}{1+a}\right)^n\right] - C = 0$$

$$\text{or } \frac{(E-M)}{a}\left[1-\left(\frac{1}{1+a}\right)^n\right] = C$$

$$\text{or } a - \frac{(E-M)}{a}\left[1-\left(\frac{1}{1+a}\right)^n\right]$$

as we increase value of a,

$\left(\frac{1}{1+a}\right)^{15}$ tends to zero

$$\text{and } a = \frac{(E-M)}{a} = \text{IRR} \tag{8}$$

2.4. Energy saving

The annual energy savings using Solar Thermal Desalination Device for Jodhpur (India) conditions was calculated [16,22]. In addition, CO_2 mitigation for this much energy gain is also computed according to Rajput and Singh [23], if electricity is generated from coal-based plants, an average CO_2 equivalent is 0.98 kg of CO_2/kWh (approximately).

$$\text{Usefull energy gained} = \frac{A \times \text{efficiency} \times \text{average daily insolation} \times 3600 \times \text{days of use}}{1000} \tag{9}$$

$$\text{Carbon credit (kg)} = 0.98 \times \text{Energy gain} \tag{10}$$

where A = area of device (4.2 m^2), average daily insolation = 6 kWh/d, days of use = 365 d, efficiency = 25%.

3. Results and discussion

In this business, all land used for business, whether in the form of land or real estate, the property of others that have been leased out is considered. Machinery and tools included in the price of protection are all machinery and tools, whether purchased by businessmen or self-made, they are equivalent to a certain currency. The solar plant covers an area of 441 m^2 and a construction area of 81 m^2. The annual working day is 300 d and the production capacity is 365 units/y. The investment cost for this joint venture business is allocated to the start-up, including land, rent, machinery, and equipment. Table 2 lists the module market capitalization for solar products with the manufacturer.

Table 2
Details of investment costs

S. No.	Machines/tools	Quantity	Total cost (INR)
1.	Sheet-bending machine	01 no.	20,000.00 (240.19 USD)
2	Hand drill with stand	01 no.	5,000.00 (60.05 USD)
3	Cut off machine for angle-cutting	01 no.	7,000.00 (84.07 USD)
4	Hand cut-off machine	01 no.	2,000.00 (24.02 USD)
5	Scissor	02 nos.	20,000.00 (240.19 USD)
6.	Small size hammer	02 nos.	
7	Medium size hammer	02 nos.	
8	Screwdriver	01 set	
9	Centre punch	01 no.	
10	wooden chisel	01 no.	
11	Tri-square	02 nos.	
12	L-square	02 nos.	
13	Wooden hammer	02 nos.	
14	Measuring tape	02 nos.	
15	Silicon machine	01 no.	
16	Spanner set	01 no.	
17	Drill bit set	01 no.	
18	Manual wooden planer	01 no.	
19	Glass cutter	01 no.	
Total			INR 54,000 (648.52 USD)

Operating costs or variable costs always depend on the scale of production for each period. These operating costs include electricity, repair and maintenance costs for purchasing raw materials, operating equipment, machine maintenance, and labor costs. The most significant operational costs and expenses are the purchase of raw materials and skilled/unskilled labor for the construction of solar thermal desalination units, as shown in Table 3. The most significant of the operational costs expenditure was the purchasing of raw materials for the construction of a solar thermal desalination device as presented in Table 4. In this analysis, all fixed costs and variable costs are calculated. The purchase price of machinery and equipment for the construction of the solar desalination plant is INR 54,000 (648.52 USD) and an appropriate discount rate of 12% (based on the SBI, India 2020 loan rate) has been chosen to determine the time value of money. The discount rate indicates the minimum amount of return on investment. Use Eq. (3) to determine the breakeven point as the minimum level of production where total revenue from stock equals total debt (stock and variable costs). The minimum number of units must be 52 to cover the full cost.

The performance evaluation of the devices made of different construction materials of cement concrete hollow block, stone masonry, cement-concrete, brick masonry, and vermiculite-cement during winter and summer months by measuring the distilled water obtained per day. Brick cement-based desalination unit has better results due to better insulation and reduced heat loss. In the summer of May 2021, the daily production of brick cement blocks was 8,540 mL/d, which is 475 mL/d more than normal cement concrete hollow blocks. Similarly, the daily production of brick cement blocks in the winter of December 2021 is 7,595 mL/d, which is 566 mL/d more than cement stone hollow blocks. Using Eqs. (1) and (2) the distillate yield efficiency is 25% and the system efficiency is 30% for distillate and hot water taken together, respectively.

The net present value of total cash inflow and outflow for the fabrication of solar thermal desalination unit was calculated by the sum of all discounted net benefits (E-M) throughout the project. The initial cost of machinery and equipment for a solar desalination plant is INR 54,000 (648.52 USD), a = 12% and the equipment has a life span of 15 y. The gross benefit of selling of 365 units is INR 5,502,375 (66,081.87 USD) and the fabrication cost of 365 units is INR 4,772,375 (57,314.79 USD). Eq. (4) has been used to determine the NPV of the solar desalination device and it reveals that the NPV of investment made on the solar device is INR 4,916,083 (59,040.68 USD). The NPV of INR 2,359,764.44 (2,487,293.97 USD), with a discount rate of 0.05 (the discount rate is the return an investment with similar risk can earn), means the investment is profitable (NPV > 0) with written conditions and assumptions [24].

The benefit-cost ratio is calculated by dividing the present value of the benefit by the present value of the cost stream using Eq. (5) and it comes out as 1.15. Using Eq. (6) the annuity (average annual return of the plant) is determined as INR 721,151 (8,660.81 USD). The payback period is one month, which is far less than the expected life of the unit (15 y). Since investments with longer payback periods are considered risky and unreliable, investors may prefer systems with shorter payback periods [6,16,25]. Poonia et al. [6] estimated the business and economic model of animal feed solar cooker and the economic attributes, such as PBP, IRR, NPV, and cost-benefit ratio was 0.16 y, 670%, INR 4,650,690 (55,853.39 USD) and 1.26, respectively. Ghafoor et al. [26] studied the techno-economic feasibility of solar-based desalination with reverse osmosis in Pakistan and found that the

Table 3
Details of operational cost

S. No.	Cost	(Volume/month)	Total cost (INR)
1	Rent of land and building/month	One	8,000 (7.79 USD)
2	Carpenter/month	One	21,000 (252.20 USD)
3	Mason	One	21,000 (252.20 USD)
4	Helper	One	12,000 (144.12 USD)
Total INR 62,000 (744.60 USD)			

Table 4
Raw material for solar desalination unit

S. No.	Material	Quantity	Approx. price (INR)
1	Aluminium *T* angle (1 inch × 1 inch × 12 ft)	03 nos.	2,800.00 (33.63 USD)
2	Aluminium channel (3 inch × 12 ft)	02 nos.	1,600.00 (19.22 USD)
3	Plain glass (1.21 m × 0.914 m)	04 nos.	2,640.00 (31.71 USD)
4	Sand	–	600.00 (7.21 USD)
5	Cement (50 kg)	03 bag	1,100.00 (13.21 USD)
6	Brick (9.0 inch × 4.5 inch × 2.5 inch)	300 nos.	2,100.00 (25.22 USD)
7	Epoxy black paint	1.0 L	360.00 (4.32 USD)
Total			INR 11,200 (134.51 USD)

Table. 5
Economic attributes of solar thermal desalination unit

Attributes economics	Values
BCR	1.15
NPV	INR 4,916,083 (59,040.68 USD)
A	INR 721,151 (8,660.81 USD)
IRR (%)	1,350
PBP (y)	1 month

payback period for a solar desalination reverse osmosis system was 1.83 y. Izquierdo and Blanchard [24] developed a solar desalination system for irrigation/potable water and electricity generation in desert or arid regions. The study shows that the simple payback period (SPB) is 11.8 y without inflation. The payback period is 10.1 y after accounting for inflation and taking into account total annual income.

The IRR is 0.1041 (10.41%), which means that the project is still profitable with a discount rate of up to 10% [24]. Sherrick et al. [27] showed that the most commonly used financial method for decision-making by large companies is IRR (88% of companies) and NPV method (63% of companies). Therefore, the decision tool used here is the true IRR, which is found to be the highest (1350%). The IRR is much higher than the cost of capital (12%). All else being equal, with IRR as the deciding factor, the one with the highest IRR will be considered the better option. One reason for this decision is that higher IRR indicates lower risk [25]. Table 5 lists the results of five economic attributes, BCR, NPV, annual income (A), IRR, and PBP. Investors can use investment criteria based on NPV, IRR, PBP, and BCR to make investment decisions [28].

The solar desalination unit provides approximately 2,300 kWh of useful energy per year and reduces CO_2 emissions by approximately 2,254 kg/y. Considering the annual capacity of the plant, it will result in approximately 839,500 kWh of energy per year and a savings of approximately 822,710 kg of CO_2 emissions. Therefore, commercializing this technology will guarantee green energy use while reducing the use of conventional electricity. Based on the above points, legislators and the Indian government should support this by providing small subsidies that will have a major impact on social, economic, and environmental concerns.

4. Conclusion

On the basis of high values of BCR, NPV, annuity, and low value of PBP while constructing 365 units annually, the business of basin-type solar thermal desalination technology has great potential. Also, on the basis of break-even analysis only fabrication and sale of 52 units is sufficient to reach a state of no profit and no loss. The net average benefit accrued from this business is very high. This unit (365 desalination units/y) is in a position to save 839,500 kWh of energy per year and save about 822,710 kg of CO_2 on an annual basis if it replaces electricity. Thus, the business of construction of solar thermal desalination technology will not only supplement conventional sources of energy but also reduce CO_2 emissions considerably besides being a highly profitable business. Therefore, an energy policy for the transition from conventional energy sources to renewable energy sources (solar thermal) is urgently needed and it will lead to mitigating climate change.

Symbols

A_p — Aperature area, m^2
C_{pw} — Specific heat, J/kg·°C
I_b — Beam radiation, W/m^2
L — Latent heat of distiller water, J/kg
m_e — Mass of distilled water obtained, L
m_{water} — Mass of water remaining in evaporative vessel, L
T_i — Initial temperature of evaporative vessel, °C
T_f — Final temperature of evaporative vessel, °C
$\eta_{distillation}$ — Distillation efficiency, %
η_{system} — System efficiency, %.
C — Initial cost of unit, INR
D — Depreciation, INR
I — Interest on average investment, INR
I_n — Insurance & taxes, INR
RM — Repair and maintenance, INR
P — Purchase price, INR
S — Salvage value, INR
a — Discount rate, %
n — Life, y
E — Gross annual benefit, INR
M — Total annual cost, INR
BEP — Break-even point
NPV — Net present value of Unit, INR
BCR — Benefit-cost ratio
A — Annuity, INR
PBP — Payback period, y
IRR — Internal rate of return, %
A — Area of device, m^2

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