Rice is grown on 30 lakh hectares in Punjab state, with an annual production of 225 lakh tonnes of rice straw. This massive amount of rice straw must be swept up in around 15–20 days to grow the next batch consisting wheat crop. As a result, the majority of farmers burn rice leftover after combining rice harvesting. Aside from human/animal health and environmental hazards, burning crop leftovers results in a significant loss of plant nutrients (particularly nitrogen and sulphur) and organic carbon, which has serious implications for soil health. Given the National Green Tribunal's decision to prohibit the burning of rice leftovers, it's high time to abandon burning in favor of the numerous technologies and procedures established by scientists at the Punjab Agricultural University, Ludhiana to handle crop residues effectively and efficiently. Most recent strategies for utilizing the hidden nutrients in rice straw to contribute to soil health and the environment (in turn serving humanity) are presented here.

Punjab Agricultural University has recommended another technology that turns rice straw into *parali* char, which is then used in crop cultivation and results in increased productivity from the first year. The technique for preparing parali char, as well as the outcomes of its application in the rice-wheat system discussed below.

Procedure of Preparing Parali Char

Parali char/biochar is a carbon-rich porous substance produced by thermo-chemically converting rice straw at low temperatures with little or no oxygen. It is created using the heap method. A heap or pyramid-like structure (brick kiln) is raised to a height of 14 feet and a diameter of 10 feet. It is then filled with rice straw. To begin the combustion, rice straw is ignited from the dome's top, then covered with an iron lid and instantly sealed with mud (Figure 1). Vents are kept open to allow combustion products to escape. The paddy straw is partially burned until the fire is clean and a thin blue smoke begins to emerge from the vents positioned in the dome's upper half. It denotes the formation of biochar in this zone.

Clay is used to close the vents in the dome's upper part. Smoke begins to emerge from the vents when the combustion progresses to the center of the dome. As soon as extremely thin blue smoke begins to emerge, immediately plug the vents in the

(A) Kiln for preparing parali char (B) Parali char

Figure 1: Indigenous technique of preparing parali char

dome's center with clay. It demonstrates that biochar is also ready in this area. Finally, combustion reaches the lower portion of the dome, and the vents in the lower portion of the dome are sealed with clay once the thin blue smoke begins to emerge from these openings. Biochar is now being generated in this area as well. This entire procedure usually takes 10 to 12 hours. Following that, the cooling process is initiated by putting diluted clay into water. The biochar is removed after two days. It can also be removed the same day if it is cooled with water. Using this method, 12 quintals of rice straw can be transformed into 6.5–7.0 quintals of parali char.

Change in different nutrients

To understand the advantages of this technology, let us know explore what happens to nutrients when rice straw collected from one acre is subjected to burning in the open fields.

Paddy agriculture in North-western India yields 23 million tonnes of rice straw. The burning of this massive volume of rice straw will result in a loss of 2.67 lakh tonnes of nutrients (N, P, K, and S) worth INR 743 crore. Carbon loss during rice straw burning has not been accounted for thus far, which is critical for microbial activities in the soil—to make nutrients available to crop plants as well as improve soil health. Besides this monetary loss, approximately 46 million tonnes of CO_2 (carbon dioxide) will be released into the atmosphere, in addition to CH_4 (methane), N_2O (nitrous oxide), and other air pollutants. Approximately 75% of greenhouse gas (GHG) emissions from agro-residues burning are CH_4, with the remaining one-fourth being N_2O. Because of the negative consequences it has on the environment and soil production, burning should be prevented. On the other hand, parali char made from rice straw includes 30–36% carbon, 0.5–0.6% nitrogen, 0.16–0.22% phosphate, and 2.0–2.5% potassium on an average.

According to the data in Table 2, using 2 t/acre parali char coupled with 75 kg urea and 25 kg DAP resulted in a

Table 1: Nutrients lost from the crop fields due to paddy straw burning

S. No.	Nutrient	Nutrient (kg) per ton of rice straw	Nutrient lost (kg) during burning of one ton of rice straw	Nutrient lost (kg)/acre	Equivalent to fertilizer (kg/acre)	Equivalent cost of fertilizers/acre (INR)
1	Nitrogen	5.5	4.95	11.9	25.8 (Urea)	146.7
2	Phosphorus (P_2O_5)	2.3	0.575	1.4	8.6 (SSP)	77.6
3	Potash (K_2O)	25.0	5.0	12.0	20 (MOP)	240.0
4	Sulphur	1.2	1.08	2.6	2.9 (Bentonite sulphur)	311.0
5	Carbon	400	400	960		
Total						775.3

Table 2: Effect of parali char on the grain yield (q/acre) of rice during 2016 at USF, Ladhowal

Use of parali char	Grain yield of rice	% increase in rice yield
110 kg urea + 25 kg DAP	22.0	-
parali char–2t + 75 kg urea + 25 kg DAP	24.3	10.4

Table 3: Effects of parali char on the grain yield (q/acre) of wheat at different KVKs during 2017–18

Use of parali char	Wheat Grain yield				
	Pathankot	Amritsar	Gurdaspur	Ferozepur	Mean
(90 kg urea + 55 kg DAP)	19.1	20.4	15.9	21.5	19.24
(55 kg urea + 55 kg DAP) + parali char–2 t	22.2	23.2	17.5	22.5	21.47
(90 kg urea + 55 kg DAP) + parali char–2 t	19.2	21.4	16.8	21.7	19.78

10.4% increase in grain output over the recommended fertilizers. It also helped save 35 kg of urea. Table 3 shows the outcomes of demonstrations held at various Krishi Vigyan Kendras (KVKs).

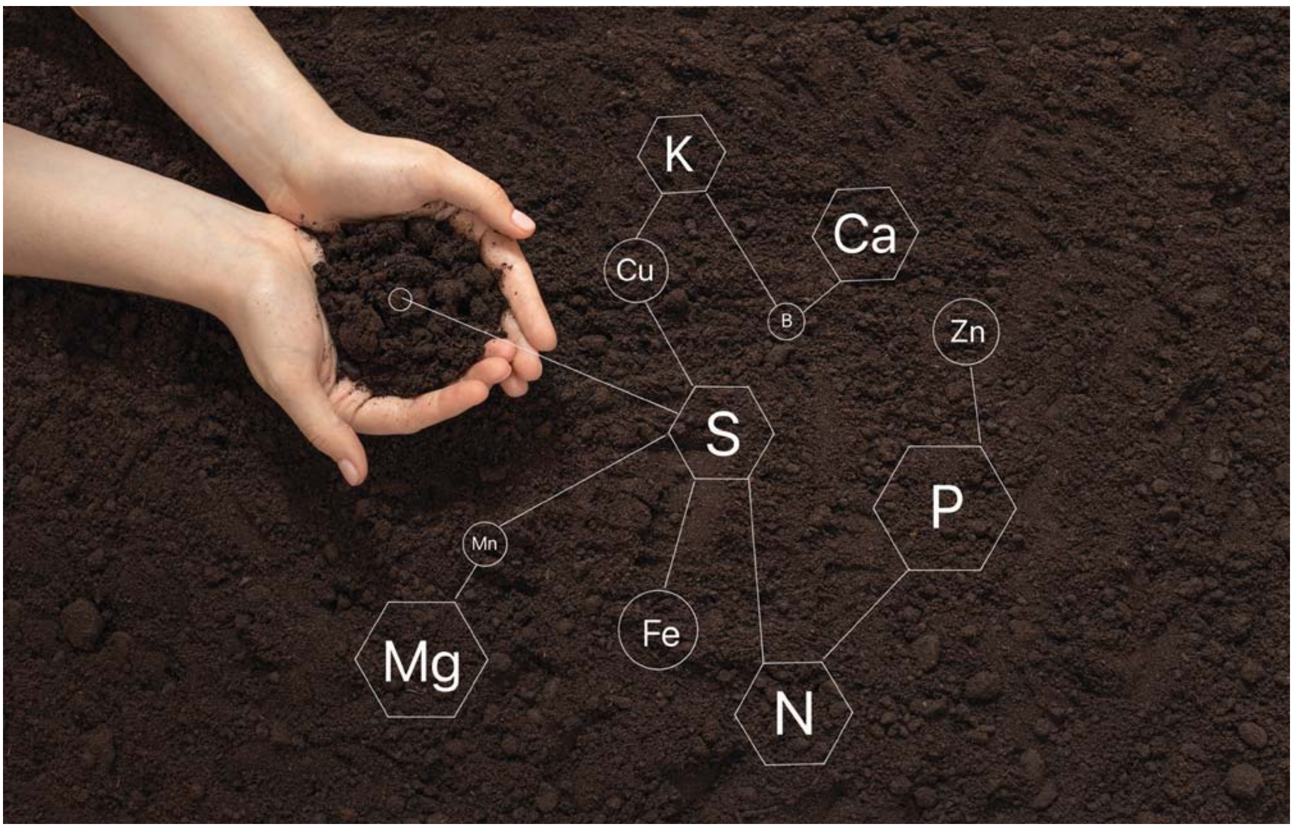
According to the results in Table 3, applying 2 tonnes of parali char combined with recommended fertilizers resulted in an 8.8%, 10.1%, 13.7%, and 16.2% increase in wheat grain production over recommended fertilizers at KVK Ferozepur, KVK Gurdaspur, KVK Amritsar, and Pathankot, arespectively. The application of parali char over recommended fertilizers resulted in an average 11.5% increase in wheat grain production at the four sites. The increase in wheat grain yield with the application of 75% of the prescribed fertilizers coupled with 2 tonnes of parali char over the recommended fertilizers ranged from 0.5 to 5.6%, with an overall increase of 2.8%. The data suggests that by applying parali char over prescribed fertilizer doses from the first year can either save 25% of the nitrogen with minimal gain in yield, or obtain 11.6% better yields.

Effects of parali char on soil health

After two years, the addition of parali char increased 26.8% organic carbon, 57% phosphorus, and 200% potassium (Table 4). Aside from these features, the soil's physical properties have improved dramatically.

Table 4: Effects of parali char on different soil properties

Treatments	pH	EC(dsm^{-1})	O.C (%)	P (kg/ha)	K (kg/ha)
Amendments					
No amendment	6.70	0.17	0.41	14.60	99.6
RSB -5 t/ha	6.70	0.22	0.52	22.93	299.7
CD(0.05)	NS	0.051	0.064	1.86	21.7
Initial values	6.73	0.10	0.41	13.2	138.0



B:C ratio of the technology
Cost of preparation of biochar
Collection of rice straw from one-hectare area: INR 3750 (INR 0.60/kg of rice straw by baling)
Labor required to convert rice straw of one hectare into RSB: INR 3750 (five cycles)
Total cost: INR 7500
Biochar Yield: 6500 q of rice straw × 0.65 conversion factor, or efficiency of biochar making kiln = 4225 kg
Price of 20 q (Dose for one acre) biochar: INR 3550
Yield benefit: 2.5 quintals of wheat grain/acre
Price of extra produce: INR 2.5 × 2000 = INR 5000
Net income: INR 5000 – 3350 = INR 1650

Hence, a net income or benefit of INR1650 was observed with significant improvements in soil health.

Conclusion

Hence, the final recommendation made via this paper is to avoid burning rice straw in the open and instead use straw management methods by preparing parali char as described above. It will aid in increasing crop yields, improving soil and human health, reducing chemical fertilizer and energy footprints, and keeping the environment clean. EF

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TECHNO-COMMERCIAL ANALYSIS OF SOLAR PHOTOVOLTAIC WATER PUMPING SYSTEMS FOR AGRICULTURAL PRACTICES

A case study

This article by **Anup P Kamath** and **Dr Jyotirmay Banerjee** presents a structured approach, through a case study, on the viability of solar PV systems for water pumping. Such studies can be easily extended for similar projects, and ultimately help in successfully incorporating renewables at the grassroots level.

Introduction

The increasing cost of electricity, attributed to depleting fossils, and the uneven distribution of electricity remain serious causes of concern for most of the developing nations.[1] Witnessing a decline in the installed capacity of fossils, the Indian power sector is at the cusp of a transformation using solar power (refer Figure 1).[2] The energy demand for agriculture in India is surging to meet the annual crop yield targets and to suffice the needs of the growing population. The electricity consumption for agriculture in India over the decade, as reported by the Ministry of Statistics and Program Implementation, Government of India (GoI) is depicted in Figure 2. Of the total electricity consumption in 2019–20, the Indian agricultural sector accounted for 17.67% of the share.[3]

The ground water pumps for irrigation in India are majorly operated by electricity and diesel in agricultural farms. In remote locations—far from electricity grids—diesel water pumping systems are more prominent. Foreseeing the decline in fossil reserves, the long term adoption of diesel operated water pumping systems appears unreliable. Hence, solar photovoltaic water pumping systems (SPVWPS) are prospective alternatives to tap water for irrigation and village water supply. Solar water pumping systems operate using motors that primarily convert electrical energy harnessed by the photovoltaic (PV) panels from the sun, into mechanical energy. This is ultimately converted to hydraulic energy by the pump. They are capable of lifting water beyond 200 m with outputs of around 250 m^3 per day. Solar irradiance and PV array sizing are prime governing factors for the flow rate of water pumped by such a system.

In recent years, researchers have contributed significantly towards tapping the potential of solar energy in pumping water to irrigate agricultural farmlands, intending to make such practices economically viable in the long run. Schematic of a direct coupled solar powered water pumping system controlled by a maximum power point tracker (MPPT) system is depicted in Figure 3.

1 Kumar SS, Bibin C, Akash K, Aravindan K, Kishore M, Magesh G. Solar powered water pumping systems for irrigation: a comprehensive review on developments and prospects towards a green energy approach. Materials Today: Proceedings. 2020 Jan 1; 33:303-7.

2 World Energy Outlook Special Report. India Energy Outlook 2021. International Energy Agency.

3 National Statistics Office. Energy Statistics 2021. Ministry of Statistics and Program Implementation. Government of India. 2021.

System Design

The theoretical design sequence of a SPVWPS involves hydraulic power computation, the photovoltaic array, and motor sizing along with determining the system efficiency. A flowchart indicating an overview of the bottom-up approach towards sizing the SPVWPS is shown in Figure 4.

Based on the system sizing flowchart, the horizontal global and effective irradiation data is first gathered for the specified site of deployment. The historical time series of irradiation is gathered from Meteonorm or through the National Solar Radiation Database

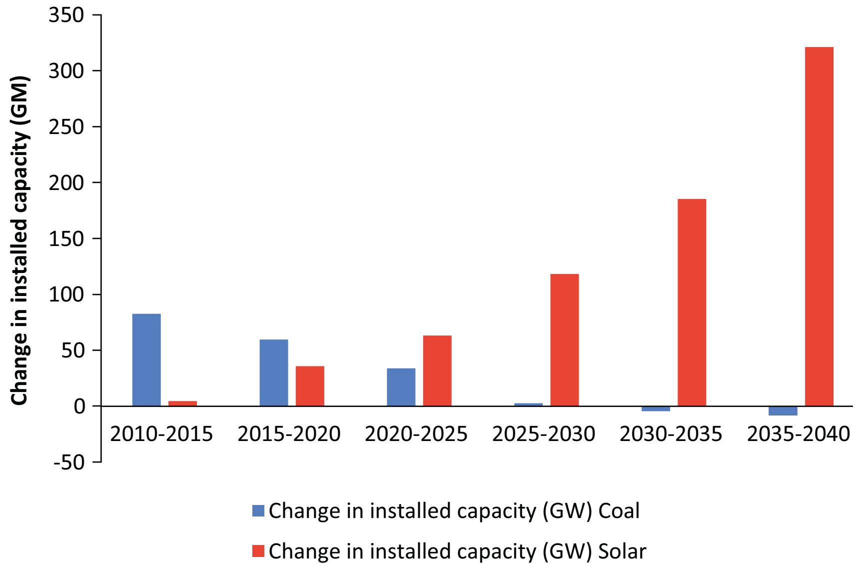

Figure 1: Projection of changes in coal and solar capacities in India from 2010–2040

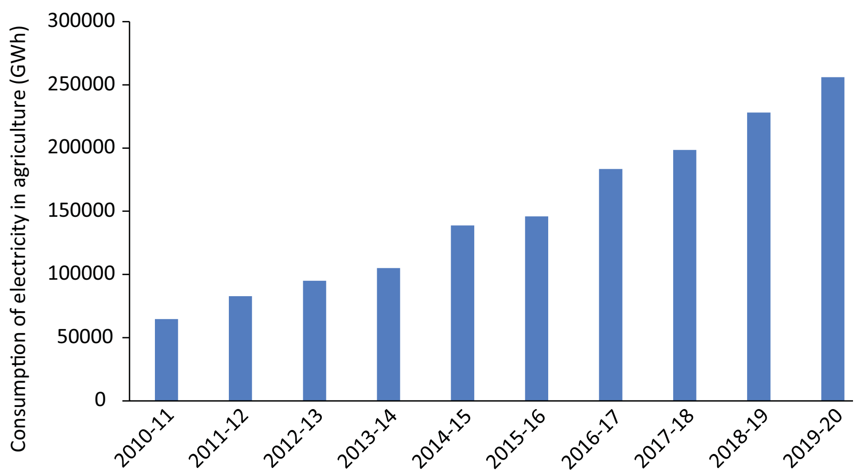

Figure 2: Year-wise consumption of electricity for agriculture in India

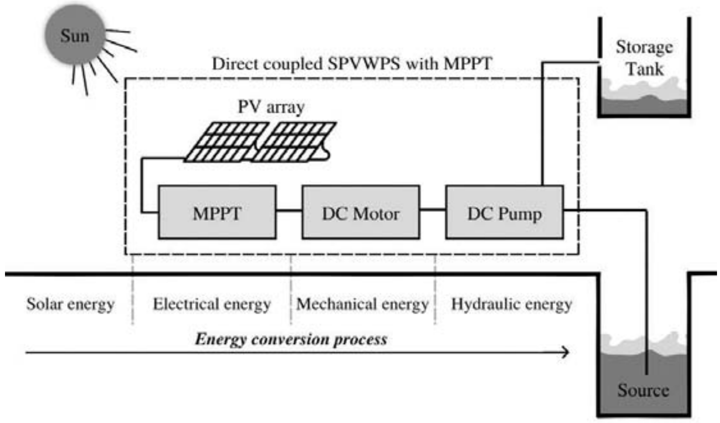

Figure 3: Schematic of a direct coupled SPVWPS with MPPT system

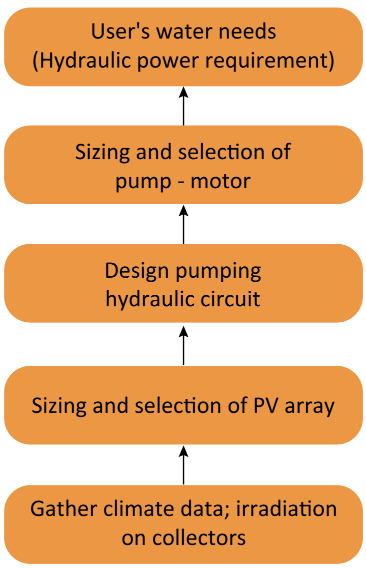

Figure 4: SPVWPS sizing flowchart

(NSRDB). The hydraulic pumping circuit is developed on the basis of estimation of the local water requirements through households and industrial surveys. The static pumping depth, storage tank capacity, and piping set-up are some crucial components to be examined while laying out the hydraulic circuit. The selection of motor and pump is made accordingly to meet these design requirements. The total power, number of modules, power from each module, as well as make and type of PV array are then estimated.

For the present case study, SPVWPS has been designed and analyzed for deployment in Rampur (22.7148 °N, 72.4761 °E, 23 m. ASL), a village in the Dholka tehsil of Ahmedabad district, Gujarat. As a large portion of the population in this area is active in agriculture, the prime motive lies in encouraging solar powered irrigation practices in place of diesel pumping systems. The operation of solar powered devices depends on changes in meteorological conditions. Thus, the selection of site and surveying of climate data pertaining to it is carefully done. The local climate information such as horizontal global radiation, diffused and beam radiation, and the ambient temperature is collected from Meteonorm 7.2 using the Meteo database of PVsyst V6.81.

PV panel orientation

The orientation of PV panels is an important parameter to ensure that maximum global radiation falls on the effective area of the solar array. The System simulation tool (PVsyst) helps in deciding the optimal orientation of the PV array through understanding the variation of transposition factor with plane tilt. A fixed configuration of the PV panels is preferred over multi-axis tracking to avoid costs associated with it. The effect of PV array tilt and azimuth on transposition factor generated through PVsyst is shown in Figure 5. For enabling the maximum irradiation on the PV array, an optimum fixed tilt of 25.5° to the panels was found to mitigate the transposition losses. An optimum transposition factor of 1.1 is attained at this orientation of the PV array.

Pumping hydraulic circuit

The water is pumped from a deep well and is to be stored in an overhead storage tank with a diameter to height ratio of nearly unity and a 40 m^3 capacity. The static head is 50 m, with a maximum pumping depth of 52 m. The submersible pump is at a depth of 55 m in the deep well, having a bore of 12 cm. For the piping circuit, DN50 is chosen with a total piping length of 70 m and only a single elbow to minimize piping friction losses. The water requirement for irrigation is 40 m^3 per day for a year. Table 1 enlists the characteristics of the pumping hydraulic circuit.

Table 1: Pumping hydraulic circuit characteristics

Well	
Water resource system	Deep well to storage
Static depth	50 m
Maximum pumping depth	52 m
Pump depth	55 m
Borehole diameter	12 cm
Storage tank	
Volume	40 m^3
Diameter	3.70 m
Water full level height	3.73 m
Hydraulic circuit	
Pipe choice	DN50 (2")
Piping length	70 m

Pump and PV array configurations

The pump is selected as per the hydraulic power requirement of the system. Based on the suggested pump power of 3.3 kW, Lorentz PS4000 C-SJ8-15 centrifugal multistage with DC motor and maximal power of 3.4 kW, 240V,

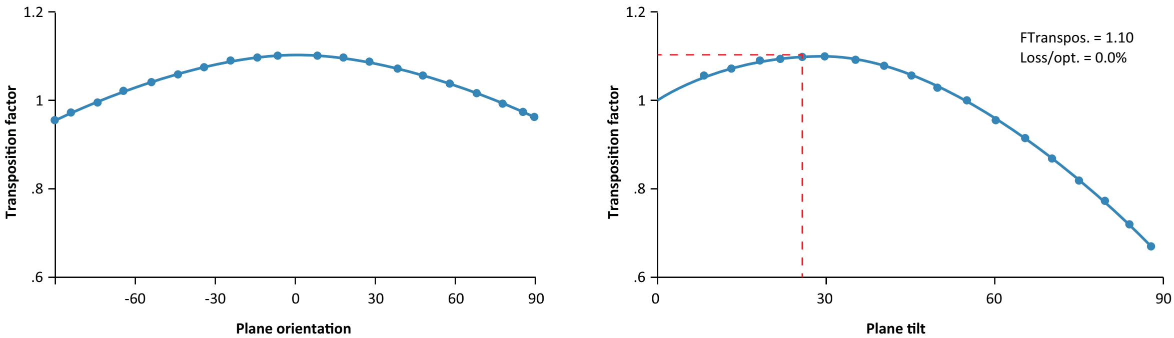

Figure 5: Effects of PV array tilt and azimuth on transposition factor

and 13.8A maximal current is found to be most suitable. The selected pump can deliver the required flow rate at the site, with an effective energy of 46.1%, given the operating conditions. This can be better understood through the flow rate–power characteristics of the selected Lorentz pump shown in Figure 6. As the electrical power supplied by the PV array to the pump increases, the flow rate also increases. For different head levels, the efficiency of the pump increases and saturates at a specific point.

The power requirement of the PV array depends on the system efficacy. For the suggested PV power of 4.1 kW, 195 Wp 32 V Mono-Si of Alex Solar (ALM-195D-24) is selected as the PV

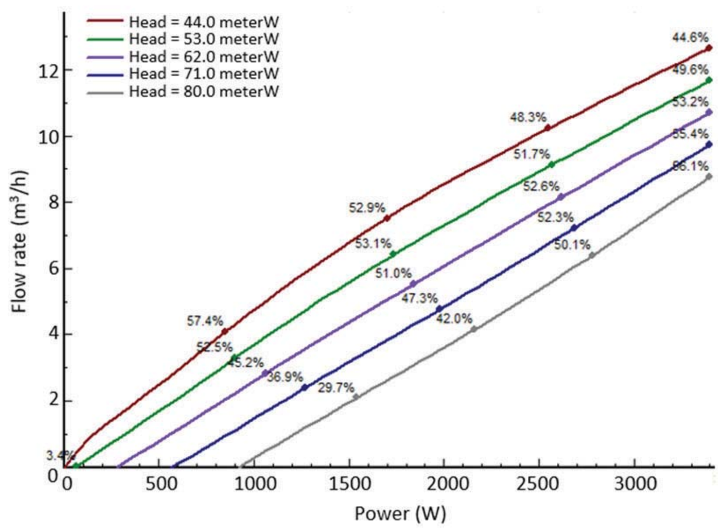

Figure 6: Flow rate–power curve of pump Lorentz PS4000 C-SJ8-15

panel. The selected PV panel has a low power tolerance band of nearly 3% which gives more certainty to the power produced. Another essential selection criterion is the temperature co-efficient of the array. With a very low co-efficient of –0.43 %/°C, the power capacity would be consistent even at elevated operating temperatures. Moreover, the chosen PV array has a fill factor of 0.746 (>0.7 suggested), which justifies the power harnessing capability to be more optimal. Based on the characteristic curves, the chosen PV array has its maximum power at the operating voltage of 32 V for different incident irradiation. Three strings each containing 7 solar cells are chosen to give the required PV power. The total area of the PV array, comprising 21 modules, is 27 m^2. From Figure 7 and Figure 8, it can be noted from the power characteristics that an output power of 178 W is attained under STC of 1000 W/m^2 incident radiation. To harness the maximum solar irradiation, a universal MPPT-DC controller is incorporated in the system for continuous tracking. This enhances the system performance. The details related to pump selection and the design of solar PV array are summarized in Table 2.

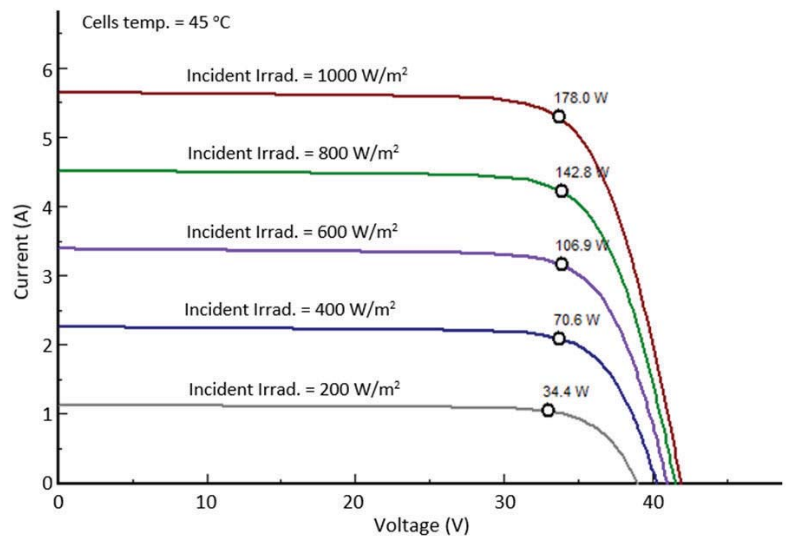

Figure 7: Current – voltage characteristics of Alex Solar ALM-195D-24

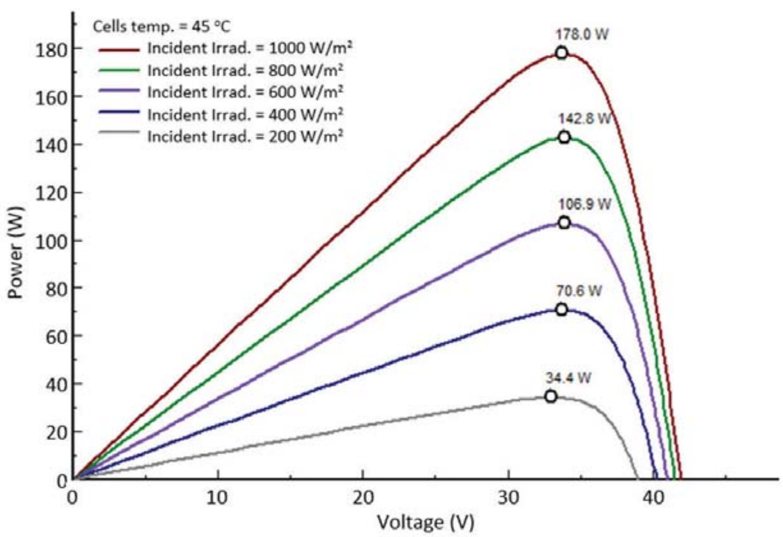

Figure 8: Power – voltage characteristics of Alex Solar ALM-195D-24

Table 2: Pump definition and PV array design

Pump	
Make	Lorentz PS4000 C-SJ8-15
Type	Centrifugal multistage
Motor	DC brushless
Maximal power	3.4 kW
PV array	
Make	Alex Solar ALM-195D-24
Type	Si-mono
Number of modules	7S 3P
Total array area	27 m^2
Power rating of module	195 Wp
MPP voltage	31.1 V
MPP current	6.3 A
Total power capacity of array	4.1 kW

Besides the design aspects discussed above, it is vital to model various system losses like field thermal losses, ohmic losses, module quality losses, light induced degradation losses, and mismatch losses. These system loss components are essential to be analyzed for optimization of the system.

System Simulation and Analysis

Having decided the location for SPVWPS installation, the selection and specification of system components like pump/motor, PV array, and storage tank must be completely defined. The climatic data pertaining to the selected geographic location such as temperature, beam, and horizontal radiation are gathered. The system designed is simulated using PVsyst to determine the overall efficiency and

understand the performance by varying key parameters.

A key system performance assessment factor is the performance ratio (PR), which is the ratio of the actual yield (Ya) to the reference yield (Yr). The performance ratio considers:

a. optical losses due to shading, soiling, and the array losses which are due to module quality, ageing, wiring; and
b. system losses as a result of inverter efficacy, storage, and battery losses.

For the present case study, the direct driven SPVWPS designed to meet the water demand of 40 m^3/day has been assessed using PVsyst V6.81 and the influence of various parameters is analyzed in detail. The normalized production—considering nominal power of 4095 Wp and the loss factors—is depicted in Figure 9. As can be seen, the unused energy (when the tank is full) accounts to 39.2%, the PV array collection losses are 11.6%, and the effective energy at pump is 46.1%.

The performance ratio, i.e., the ratio of the effective energy (actual yield) to the irradiance (reference yield) for all the months is shown in Figure 10. The performance ratio includes array losses, optical losses as well as system losses.

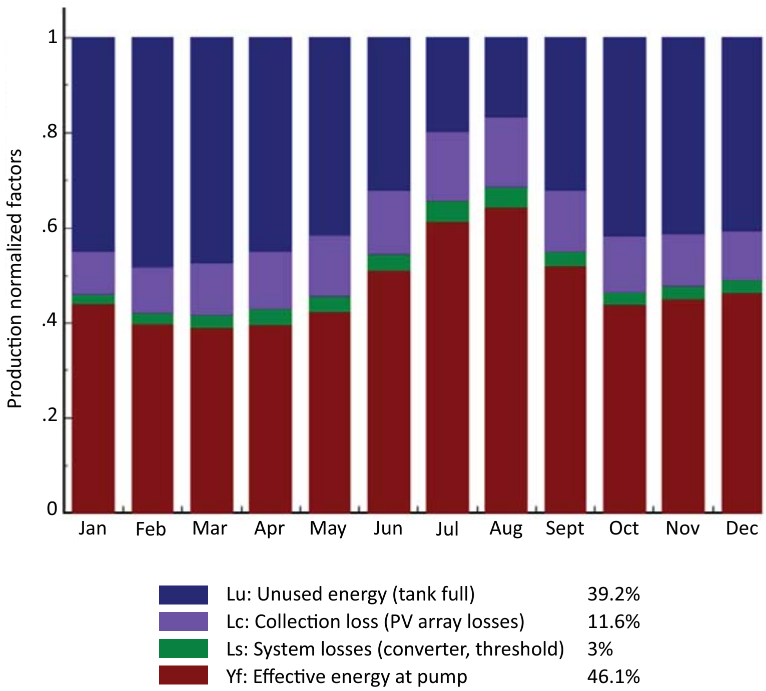

Figure 9: Normalized production and loss factors: Nominal power of 4095 W

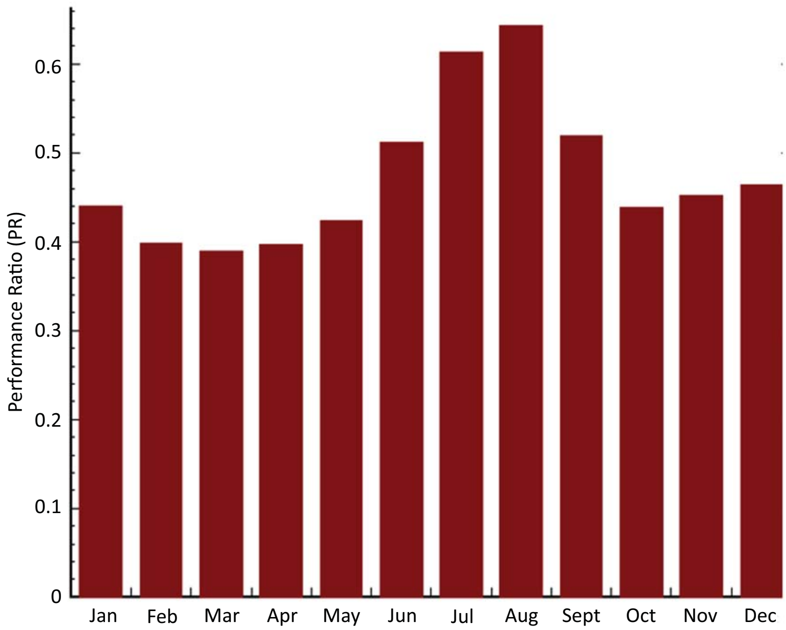

Figure 10: Performance ratio of the system

The overall performance ratio is 0.461. The surplus energy (when the tank is full) can be used to operate other units in pumping water between reservoirs. A detailed loss diagram is shown in Figure 11, providing an overall insight on the design quality of the SPVWPS. Based on the loss analysis, further improvements can be made to the system.

Out of an annual water requirement of 14600 m^3, the solar operated system is capable of pumping 14389 m^3, resulting in 1.4% missing water. The system is found to have an efficiency of 57.8%. Hence, by making use of 21 PV modules—each rated at 195 Wp with 3 strings of 7 modules in series—the daily water demand of 40 m^3/day can be met through this bottom-up design approach. To improve system reliability, the direct driven system can be transformed to a battery coupled SPVWPS to store the solar energy harnessed while the pump is not in operation.

System Optimization

For the optimal operation of solar driven pumping system, the ability to continuously track the solar radiation to harness the maximum possible power is essential. The SPVWPS is sized optimally through power point tracking and assessing the load demand variations to make it capable of meeting the power requirements with the least amount of average daily solar insolation on the PV array during winter months.

The optimal operation of a SPVWPS is achieved by integrating a control system, capable of maintaining the SPVWPS at its maximum power point. Besides enhancing system accuracy and efficacy, MPP trackers smooth starting of the motor-pump drive. There are several MPPT techniques that are developed, of which, the Perturb and Observe (P&O) method is known to extract the maximum energy from the solar operated system as it offers high yield under varying atmospheric conditions. This is mainly attributed to its ease of

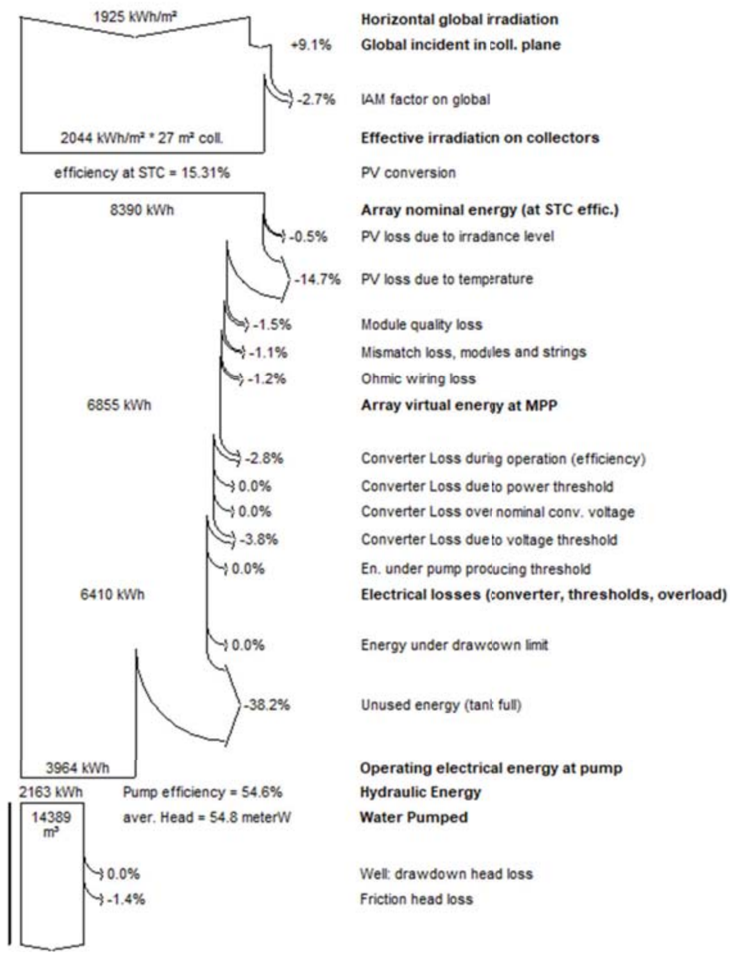

Figure 11: Sankey diagram indicating loss distribution

operation in its simplest form. Figure 12 specifies an overview of the various types of MPPT.

The power characteristics of a PV module are depicted in Figure 13. The P&O algorithm operates based on the direction of $\left(\frac{dP}{dV}\right)$. If $\left(\frac{dP}{dV}\right)>0$, the operating voltage of the solar array is found to move towards the MPP. The algorithm continues to perturb the voltage in the direction towards MPP. On the other hand, if $\left(\frac{dP}{dV}\right)<0$, the PV array is observed to be moved away from MPP and the algorithm reverses the direction of perturbation. Despite its advantages, P&O algorithm is known to be associated with oscillations around MPP whilst steady state operation, slow response, and deviated tracking under vibrant conditions [25].

The incremental conductance (IC) algorithm, another hill climbing MPPT technique, uses the incremental conductance, $\left(\frac{dI}{dV}\right)$to measure $\left(\frac{dP}{dV}\right)$. The expression derived at MPP from $\left(\frac{dP}{dV}\right)=0$ yields $\left(\frac{dI}{dV}\right)=\left(\frac{-I}{V}\right)$. Thus, the value of $\left(\frac{dI}{dV}\right)$ is used to perturb the operating point towards the direction of MPP. They are capable of tracking with higher accuracy

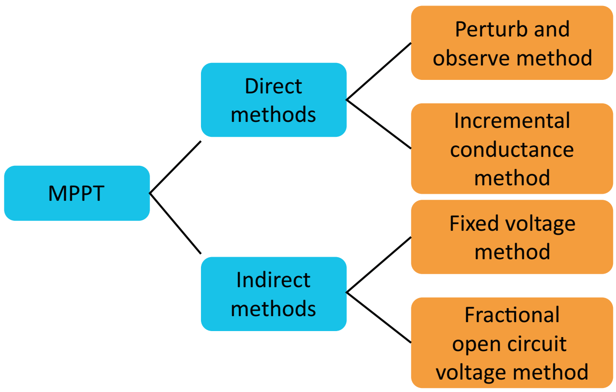

Figure 12: Classification of maximum power point trackers used in solar PV systems

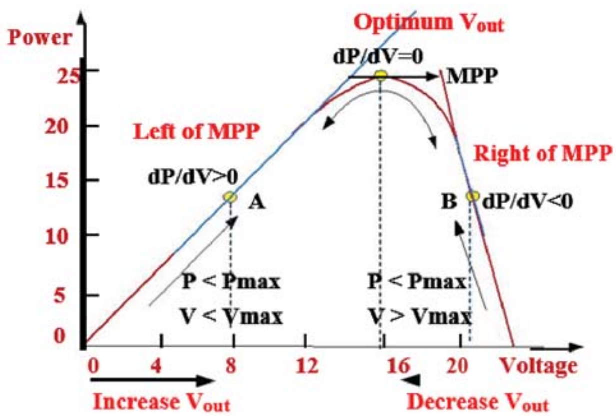

Figure 13: $\left(\frac{dP}{dV}\right)$at different instances on the PV module power characteristics curve

for increasing and decreasing solar irradiation.

The fixed voltage method is based on the fact that the MPP voltage is roughly 76% of the open circuit voltage ($V_{MPP}=0.76V_{OC}$). The algorithm initially sets the current passing to a null value, in order to measure the open circuit voltage. It then matches the operating voltage to 76% of the value to coincide with the MPP voltage. The cycle repeats over fixed time intervals. A key drawback of this MPPT algorithm is the estimation of MPP which is 76% of the PV array's open circuit voltage, which may not always hold true.

The fractional open circuit voltage method is an indirect MPPT technique, which operates based on the fact that the PV array voltage corresponding to MPP depends linearly on the array open circuit voltage for varying levels of temperature and irradiation. Despite being the simplest of all MPPT methods, this approach is of low practicality on account of intermittent disconnection from the load for sampling of array voltage, which results in power losses.

Technical Feasibility

The technical viability of a solar powered water pumping system is majorly governed by the availability of land to set up the PV array. The land area corresponds to the solar panel area and is given by,

$$A_s = \frac{P_m}{G_i \eta_{PV}} \quad (1)$$

where, P_m is the power needed to pump the water, G_i is the radiation incident on the panels during peak sunshine hours, and ηPV is the PV array efficiency. The power required to pump the water is evaluated using Equation 1.

The maximum flow rate of water needed is given by,

$$Q = \frac{ET \times A_f}{3600 \times t} \quad (2)$$

where, ET corresponds to the evapotranspiration rate for the crop in m/day, A_f is the field area in m^2 and t is the pumping hours per day, i.e., the peak sunshine hours per day.

The average monthly solar insolation for a specific location is calculated as,

$$G_{avg} = H_p \times G_i \quad (3)$$

where, H_p is the peak sunshine hours per day in the month which demands the largest quantity of water for irrigation.

Thus,

$$A_s = \frac{\rho g H \times ET \times A_f \times H_p}{3600 \times \eta_{PV} \times \eta_P \times G_{avg}} \quad (4)$$

The fraction of the PV array area occupying the field area is then computed,

$$\frac{A_s}{A_f} = \frac{\rho g H \times ET \times H_p}{3600 \times \eta_{PV} \times \eta_P \times G_{avg}} \quad (5)$$

The above ratio is the key factor influencing the technical viability of the SPVWPS for irrigating a particular crop at the specific geographical region. So, in regions in need of irrigation with an average solar insolation of 4–5 kWh/ m^2/day, SPVWPS would occupy an extremely small portion of the field area and is technically feasible. In the absence of excess land for the solar array installation, the field area would be reduced by less than 1.5%.

Economic Feasibility

SPVWPS is considered to be economically viable if its lifetime cost is lower when compared with its alternatives like diesel and grid-based electrical pumping systems. The lifetime cost components mainly include the capital expenditure, operation and maintenance costs, fuel expenses, carbon taxes and government subsidies, along with the equipment salvage value. A discounted cash flow (DCF) approach is used to convert future cost projection to its current value as per the following relation:

$$[PV] = \frac{[FV]}{1\ (1+i)^x} \qquad (6)$$

where, and are the present and future values respectively, *i* indicates the discount rate, and *x* the number of future years.

Capital expenses

For the solar PV system, capital costs, inclusive of arrays, inverters, control units, support structures, are given by the product of PV array power rating and unit cost per Watt. In case of diesel powered pumps, the power for the diesel generator to operate the pump/motor is given by the ratio of power required by pump to the load factor. Lastly, the capital cost for a grid based electrical system is the sum total of transformer retail price and the installation expenses.

Operation and maintenance costs

The costs pertaining to operation of SPVWPS comprise of the costs for cleaning and replacing the inverters. For the diesel system, the maintenance cost consists of the cost for maintaining air and oil separator filters, lubricant oil, and engine coolant changes. The cost for operating and maintaining the grid-based electrical system is assumed to be negligible.

Fuel costs

The fuel costs associated with SPVWPS are null, while they dominate the lifetime costs in case of diesel and grid-based systems. The fuel cost for diesel-based pumping system is a product of the current value of diesel fuel per litre, the fuel quantity consumed by the engine per hour, and the hours of operation for the year. Likewise, the fuel cost for the grid electricity powered system would be a product of current unit cost of electricity and the operating hours of the electrical system for the year.

Carbon taxes and government subsidies

With efforts to minimize greenhouse gas emissions, countries impose taxes on carbon emissions. This leads to an increased cost of operation for the diesel powered water pumping systems. The associated annual cost is the product of mass of CO_2 emitted annually and the carbon tax rate. In support of growth in renewable energy, subsidies and incentives like tax rebates, net metering, etc., are being offered which will help partially compensate for the large capital costs of the renewable energy systems.

The feasibility assessment will aid industrialists in estimating the investments needed and in planning out the funds required for the SPVWPS to be commercially yielding. By estimating gross investments and system financing, the pay-back period can be determined. A pay-back period nearly equivalent to half the lifetime of a project could be considered ideally feasible.

Conclusions

The present work systematically describes the design framework for SPVWPS through a practical case study. Various aspects of system sizing, analysis, and optimization of SPVWPS are reported. The design framework for SPVWPS and its optimization is established using a system simulation tool. Technical and economic feasibility of SPVWPS for a specific site is analyzed and the contributors to system losses are demonstrated using the Sankey diagram. The major conclusions from the present study are:

- The system designed using PVsyst is found to meet 14389 m^3 out of 14600 m^3 of water needs, with an overall system efficiency of 57.8%.
- For enabling the maximum irradiation to fall on the PV array, panels with a tilt of 25.5° were found to be optimum for mitigating the transposition losses. A centrifugal multistage pump with a 3.4 kW maximum power rating was chosen to operate, using a brushless DC motor in order to meet the peak load requirements. With the PV array spanning over 27 m^2 and composed of 3 strings with 7 cells each, a total array power capacity of 4.1 kW is attained.
- The unused energy (when the tank is full) accounts to 39.2%, the PV array collection losses are 11.6%, and the effective energy at pump is 46.1%. The overall performance ratio is found to be 0.461, with a system efficiency of 57.8%. From the Sankey diagram, PV losses due to temperature account for 14.7%. Incorporating air or water coolants aids to minimize such losses.
- Hybrid MPPT techniques are efficient in terms of tracking solar irradiation throughout the day. A hybrid of incremental conductance and fixed voltage method is effective; wherein IC method is active above 30% normalized irradiation intensity, while fixed voltage is used for lower figures. However, for deployment sites with minor fluctuations in daily solar irradiation during peak load demands, a fixed tilt PV array (as used in the present case study) can be considered to minimize the capital and maintenance expenses.
- As for economic feasibility, considering various operation and maintenance cost components, the system would indeed payback more optimally. Methods to lower the operating costs, such as appropriate surface coating and regular inspection of PV panels, must be adopted to make the system more economically viable.
- The structured approach followed in this article through the case study can be easily extended for similar projects requiring design, sizing, and estimation of the viability of solar PV systems for water pumping. EF

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IOT-BASED SOLAR POWER MONITORING SYSTEM

Based on Dual Axis with Wiping Mechanism

The growing demand for renewable energy sources, coupled with advancements in technology, has led to an increasing adoption of solar power systems. However, monitoring and managing solar power installations efficiently remains a challenge. In this article, **Animesh More**, **Ankit Wankhede**, **Raj Nikam**, **Akarsh Poddar**, and **Prof. Swati Gawhale** propose an IOT-based solar power monitoring system that addresses this challenge. It does so by leveraging the power of interconnected devices and data analytic. The proposed system employs a network of IOT devices to collect real-time data from solar panels, inverters, and other components of a solar power installation.

A solar power monitoring system is a specialized system designed to monitor and optimize the performance of a solar power installation. It provides real-time data and insights about the solar panels, inverters, and overall energy production of a solar power system. The system typically consists of hardware devices, such as sensors and meters, along with software applications for data analysis and visualization. This project deals with a gear-based solar panel tracking system.

The development of solar power tracking systems has been ongoing for many years now. As the sun moves across the sky during the day, it is good to have the solar panels track the location of the sun, such that the panels are always perpendicular to the energy that is radiated by the sun. This will help to maximize the amount of power absorbed by solar systems. It has been estimated that the use of a tracking system, over a fixed system, can increase the power output by 30–60%. The increase is evident enough to make tracking a viable preposition despite the enhancement in system cost. It is possible to match the tracking panel normally to the sun using electronic control by a micro-controller.

The design requirements are as follows:

1. When the sun is up, the system follows the sun's position in the sky.
2. This must be done with active control; timed movements are useful. It should be automatic and simple to operate.
3. The operator act should be minimal and restricted to only when it is required.

They help increase the time-period for which the panels directly face the sun and allow them to produce their peak power. Unfortunately, such systems can be/are usually expensive to buy. The authors of this article attempted to make their own solar tracker, to see if they produce the same at a decreased cost.

Through the integration of IOT sensors and actuators, the developed monitoring system enables comprehensive monitoring and control functionalities. It provides real-time visibility into solar power generation, allowing users to track energy production, identify performance issues, and optimize system efficiency. The system also facilitates remote monitoring, enabling proactive maintenance and reducing downtime.

Hardware Requirements

1. *Arduino Uno:* The Uno is based on the ATmega328P micro-controller running at 16 MHz's. It has 32KB of flash memory for storing your program, 2KB of SRAM for variables, and 1KB of EEPROM for data storage. Digital and Analog I/O has 14 digital input/output pins, among which 6 can be used as PWM (Pulse Width Modulation) outputs and the remaining 6 as analog input pins.
2. *Light-dependent resistors*: A light-dependent resistor (LDR), also known as a photo-resistor, is a passive electronic component that changes its resistance based on the intensity of light falling on its surface. It belongs to the class of light sensors and is commonly used in various applications to detect and measure light levels.
3. *Lead-acid battery*: Lead-acid battery is a type of rechargeable battery that has been widely used for various applications over the years. Lead-acid batteries consist of a plastic container filled with a mixture of sulphuric acid and water, known as electrolytes. Inside the battery, there are lead plates submerged in the electrolyte.
4. *Solar panel*: Solar panels, also known as photovoltaic (PV) panels, are devices that convert sunlight into electricity. A photovoltaic (PV) module is a packaged, connected assembly of typically 5x10 photovoltaic solar cells. They are an increasingly popular renewable energy technology due to their ability to generate clean and sustainable power.
5. *Motor driver***:** A system with a motor within is referred to as a motor drive. A system with a motor that can operate at different speeds is referred to as an adjustable-speed motor drive. A system with a motor and constantly variable speed is known as a variable-speed motor drive. Although this may technically be referred to as a generator drive—if the motor is producing electricity rather than utilizing it, the term 'motor drive' is nonetheless frequently used.
6. *Temperature sensor***:** Temperature sensors measure the temperature of their environment and convert the input data into electronic data, for monitoring or signaling changes in temperature. Temperature sensors come in many standards.

Software Requirements

1. *Arduino Ide***:** The C programming language is used to create the cross-platform Arduino integrated development environment (IDE), which runs on Microsoft Windows, Mac OS, and Linux. It is a ready-made software that is used to upload code to the board and program to the circuit board. Arduino provides a standard form factor for breaking the functions of the micro-controller into an easier-to-use package. Analog or digital input signals can be read by Arduino boards and turned into outputs that can either be connected to the cloud or be used in many other ways.
2. *ThinkSpeak*: ThinkSpeak is an IOT platform service that allows you to visualize and analyze live data. Once data is sent to ThinkSpeak from your devices you can create a visualization of live data.
3. *ThinkSpeak server***:** ThinkSpeak server and cloud are used for communicating between hardware and smartphone.
4. *ThinkSpeak Libraries*: Communication with the server allows for the execution of inbound and outbound commands from your ThinkSpeak hardware and app.

Results and Discussion

The solar panel, which is mounted to a structure in the dual axis solar tracking system, rotates in response to the sun's location as detected by the sensor. The four analogue pins of the Arduino—A1, A2, A3, and A4—are linked to four resistors and four LDR, respectively, that are internally connected in a voltage divider pattern, the two servo motors receive PWM inputs from the Arduino's digital pins 9 and 10. The primary light sensors are LDR. Two solar panels that are mounted to the building support the servo motor. The microcontroller receives an upload of an Arduino programmer.

The model's performance is as follows: each LDR detects light in the top, bottom, left, and right directions, depending on how much sunshine is falling on it. The analogue values from two top LDR and two bottom LDR are compared for north-south tracking, and the vertical servo will move in the direction where the bottom set of LDR receives more light. The servo motor travels in that direction if the upper LDR detect more light there. For angular deflection, the analogue values from two left LDR and two right LDR are

contrasted. The horizontal servo will move in that direction if the right set of LDR detects more light than the right set.

Conclusions

In this, the sun tracking system was implemented which is based on a microcontroller. After examining the information obtained in the data analysis section, it can be said that the proposed sun-tracking solar array system is a viable method of increasing the energy received from solar radiation. The controller circuit used to implement this system has been designed with a marginal number of components and has been integrated into a single PCB for simple assembly. The use of stepper motors enables accurate tracking of the sun, while keeping track of the solar panel's current position about its initial position.

The automatic solar tracker is an efficient system for solar energy collection. It has been shown that sun tracking systems can collect about 8% more energy than a fixed panel system collects and thus, high efficiency is achieved through this tracker. An 8% increase in efficiency is not the most significant figure; it can be more prominent in concentrating type reflectors. EF

Figure 1: Output of solar panel

References

1. Murizah Kassim, Fadila Lazim, 'Adaptive photovoltaic solar module based on internet of things and web-based monitoring system', *Journal of International Journal of Electrical and Computer Engineering*, *SN Appl. Sci.*, vol. 12, pp. 924-925, 2022.
2. Z B Abilovani, W Yahya and F A Bakhtiar, 'IoT Monitoring System Based on MQTT Publisher/Subscriber Protocol', *Iraqi Journal of Computers Communication Control & Systems Engineering*, vol. 20, pp. 3, 2020.
3. P Sivagami and NM Jothiswaroopan, 'IoT based statistical performance improvement technique on the power output of photovoltaic system', *Journal of Ambient Intelligence and Humanized Computing*, 2020.
4. Cemil Sungur 'Multi-axes sun-tracking system with PLC control for photovoltaic panels', *Journal of SN Appl. Sci.*, vol. 34, pp. 1125, 2009. IEEE.
5. Y Cheddadi, H. Cheddadi, F. Cheddadi, *et al.*, 'Design and implementation of an intelligent low-cost IoT solution for energy monitoring of photovoltaic stations', *SN Appl. Sci.*, vol. 2, pp. 1165, 2020.

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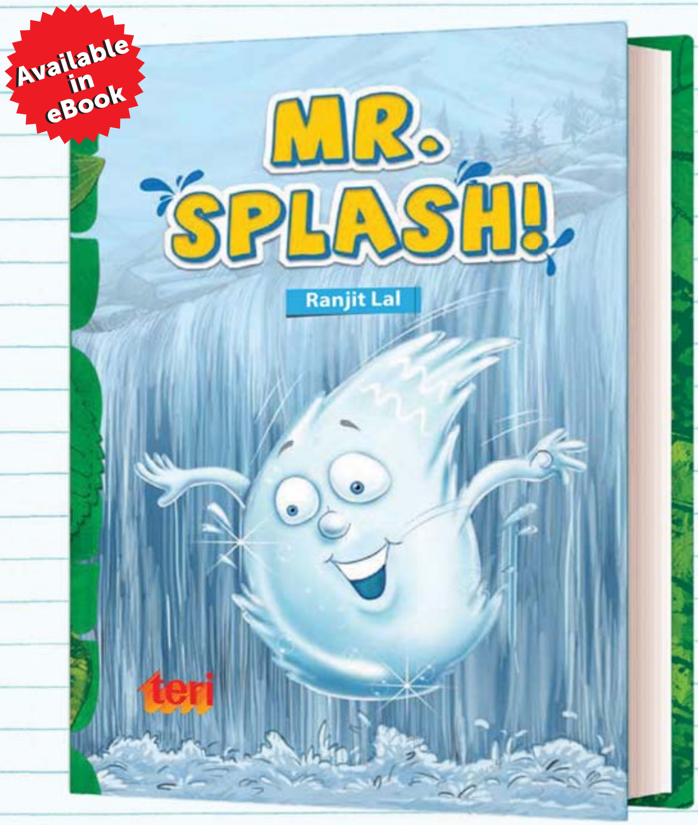

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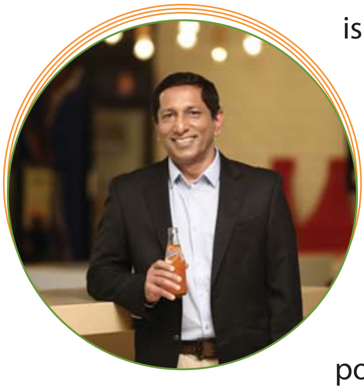
HCCB'S JOURNEY TOWARDS SUSTAINABILITY

Energy-efficient Manufacturing and Shift towards RE



As a leading beverage manufacturer, Hindustan Coca-Cola Beverages (HCCB) is committed to taking sustainable action throughout their value chain and beyond. Here, we are in an email conversation with **Alok Sharma**, Executive Director of Supply Chain, Hindustan Coca-Cola Beverages. He says central to their sustainability strategy is the shift towards renewable energy, aligned with India's focus on expanding solar and wind energy. They successfully achieved 'zero emission growth' in 2023 with a 19% increase in business volume, while maintaining greenhouse gas (GHG) emissions at the same level as in 2022. This accomplishment was made possible through a combination of renewable energy procurement, energy efficiency innovations, and behavioural changes, demonstrating their ability to decouple business growth from environmental impact.

What are the key innovations adopted by Hindustan Coca-Cola Beverages (HCCB) to reduce carbon emissions across its supply chain?
Central to our sustainability strategy is the shift towards renewable energy, aligned with India's focus on expanding solar and wind energy. We successfully achieved 'zero emission growth' in 2023 with a 19% growth in business volume—maintaining greenhouse gas (GHG) emissions at the same level as in 2022. This accomplishment was possible through a blend of renewable energy procurement, energy efficiency innovations, and behavioural changes, demonstrating our ability to decouple business growth from environmental impact.

In addition to harnessing solar and wind energy, key technologies' implementation, such as HHO (Oxy-hydrogen gas) and Subcarb, across our operational unit have been integral drivers in curbing energy consumption. This has resulted in a notable 3.4% decline in energy intensity compared to 2023. Further, we are also exploring group captive renewable energy projects across our major factory sites such as Maharashtra, Odisha, Telangana, and Andhra Pradesh. These capabilities effectively enable our 'Net-Zero' vision.

What are the unique initiatives undertaken by HCCB to transition to renewable energy?
Our journey towards sustainability goes beyond a response to climate change and is a consistent pursuit of environmental stewardship. We have set ambitious goals to reduce absolute GHG emissions by 25% across the value chain by 2030, compared to a 2015 baseline, with a long-term vision of achieving net-zero carbon emissions by 2050.
To this front, we have implemented diverse measures including the introduction of biomass boilers which contributes to 56% of our total renewable energy consumption. We have also installed solar rooftops in 7 factory locations across India, with plans to further expand these facilities.

Expanding our renewables portfolio, we are also actively engaging in Power Purchase Agreements (PPAs) with independent power producers across India to procure solar and wind energy. The collaboration has been instrumental in our green energy journey, as independent power producers help us source about 33% of our electricity needs from renewable sources, minimizing our dependency on non-renewable energy sources.

How did HCCB achieve carbon neutrality in its factory in Aranya, Karnataka?
Our Aranya factory in the Bidadi industrial area near Bengaluru, is the first bottling plant of Coca-Cola in India and Southwest Asia region to achieve the milestone of being certified 'Commitment to Carbon Neutrality' from DNV, according to the international standard PAS 2060. This certification

highlights the facility's implementation of advanced sustainable technologies and practices, serving as an example of how modern factories can significantly reduce their carbon footprints.

The factory obtains more than 90% of its electricity from renewable sources—solar and wind. The carbon management strategy involves using renewable power, eco-friendly fuels, and electric transportation. Further, addressing residual emissions at the facility, we plan to invest in the Gold Standard certified carbon credits project, further reinforcing our commitment to minimize carbon emissions. This is just the beginning, and we are setting the stage for a greener tomorrow across our supply chain, through focused actions leading to impactful environmental progress.

How does HCCB plan to reduce absolute emissions by 25% across its value chain by 2030?

Our goal to reduce absolute GHG emissions by 25% by 2030, and long-term vision of achieving net-zero carbon emissions by 2050 aligns with India's own transformative growth in renewable energy capacity, which saw a staggering 250% increase between 2014 and 2021. In order to curb carbon emissions by 25% across our value chain, we will continue to invest in energy-efficient infrastructure such as biomass boilers and solar rooftops, as well as explore Power Purchase Agreements (PPAs) across our manufacturing units. Our multi-faceted approach to sustainability is aimed not just to meet but to surpass new global standards. Further, building group captive renewable energy projects across plant sites for harnessing solar and wind energy will bolster the process.

From a logistics lens, a key aspect of green transition is the increasing use of electric vehicles (EVs). Reducing carbon footprints and supporting national goals for sustainable transportation, we have deployed over 300 electric vehicles across our distribution networks underscoring our commitment to leading by example in the adoption of green technologies.

How can manufacturing, especially bottling companies, across the country adopt green practices?

While the shift towards energy-efficient manufacturing comes with challenges such as substantial initial investments and the need for technological adaptation, this is also an opportunity to expand our innovation and commitment. The adoption of energy-efficient machinery minimizes waste and reduces energy consumption. Streamlining manufacturing processes with lean production techniques reducing waste, shifting to renewable energy sources, employing energy-efficient equipment, establishing energy management systems and optimizing resource efficiencies are key. Further, fleet electrification in logistics and exploring the benefits of returnable glass bottles (RGB) in packaging contribute to establishing circularity. EF

CURRENT R&D RENEWABLE

Effect of nano-metal doped calcium peroxide on biomass pretreatment and green hydrogen production from rice straw

Bioresource Technology **386***: 129489*

Periyasamy Sivagurunathan, Prakash C Sahoo, Manoj Kumar, Ravi Prakash Gupta, Debasis Bhattacharyya, SSV Ramakumar

In this study, calcium peroxide was modified and doped with metal-based nanoparticles (NP) to enhance the efficiency of pretreatment and biohydrogen generation from rice straw (RS). The findings revealed that the addition of MnO_2-CaO_2 NPs (at a dosage of 0.02 g/g TS of RS) had a synergistic effect on the breakdown of biomass and the production of biohydrogen. This enhancement resulted in a maximum hydrogen yield (HY) of 58 mL/g TS, accompanied by increased concentrations of acetic acid (2117 mg/L) and butyric acid (1325 mg/L). In contrast, RS that underwent pretreatment without the use of chemicals or NP exhibited a lower HY of 28 mL/g TS, along with the lowest concentrations of acetic acid (1062 mg/L) and butyric acid (697 mg/L). The outcome showed that supplementation of NP stimulated the pretreatment of RS and improved the formation of acetic and butyric acid through the regulation of metabolic pathways during acidogenic fermentation. EF

Keywords: Renewable energy, biohydrogen, rice straw

Exergy analysis of reversible SOFC coupled with organic Rankine cycle and hydrogen storage for renewable energy storage

International Journal of Hydrogen Energy **48**(99): 39169–39181

Uday Raj Singh, Satyasekhar Bhogilla

Due to the ever-rising demand for energy and the need to address the critical issue of global warming, efficient energy systems driven by renewable energy have gained a lot of attention. Integrating fuel cells with renewable energy is a very attractive and promising solution to achieve this aim. In this study, a novel tri-generation system is presented and analysed for its exergetic performance. A metal hydride hydrogen storage (MHHS) system is used in the study to supply hydrogen to the solid oxide fuel cell (SOFC). In the ORC cycle, n-octane is selected as the working fluid due to its high critical temperature. Exergy analysis of the overall system helps in finding out the system components where the most energy is getting degraded. For the analysis, the exergy efficiency pertaining to net electrical power output, heating and cooling performance and tri-generation is considered as the basis of exergy assessment. As per the outcome of the present study, the maximum exergy efficiency was reported to be 46.5% at specific operating conditions. The ORC evaporator, heating application and fuel heat exchanger were the major sites for the exergy destruction, with values of 258 kW, 175 kW, and 91 kW respectively. Also, a maximum gain in exergy efficiency of around 17.4% was reported after incorporating a tri-generation system instead of power cycle alone. EF

Keywords: Renewable energy, fuel cells, exergy efficiency

A zero discharge, carbon-neutral bi-fuel production process for algal biodiesel and renewable hydrogen

Journal of Cleaner Production **425**: 138865
Biswarup Mondal, Prasil Kapadiya, Amiya K Jana

This work proposes a novel, zero discharge, carbon-neutral bioprocess for the simultaneous production of algal biodiesel and renewable hydrogen. This innovative bi-fuel production process (BiFPP) consists of five units connected in a series for biodiesel production, biodiesel purification, glycerol separation, glycerol steam reforming, and hydrogen purification. To assess the techno-economic feasibility, a genetic algorithm based multi-objective optimization strategy is developed to minimize the total annual cost and CO_2 emission level, as well as to maximize fuel purity. The optimal BiFPP scheme yields 97.3 mol % biodiesel and 98.8 mol % hydrogen—thereby meeting the standard specifications, namely ASTM D6751 and EN 14214. A heat exchanger network is designed with thermal coupling to secure the energy savings of 79.5% (heating load) and 50% (cooling load), leading to 93% reduction in utility cost. To achieve carbon neutrality, a CO2 sink for algae cultivation is finally proposed to integrate with this industrial-scale BiFPP process that overall yields a novel zero discharge bi-fuel production technology. EF
Keywords: Renewable energy, BiFPP, algal biodiesel, renewable hydrogen

Do green energy markets catch cold when conventional energy markets sneeze?

The Electricity Journal **127 (part A):** 107035
Amar Rao, Brian Lucey, Satish Kumar, Weng Marc Lim

This study analyses the interconnectedness between conventional and green energy markets, in terms of daily returns and volatility through a time and frequency connectedness perspective. Comparing conventional energy indicators—like the S&P 500 Energy (ENERGY), S&P Global Oil Index (GOI), and Dow Jones Conventional Electricity Index (CEI)—to green energy benchmarks—such as the S&P Global Clean Energy Index (GCEI) and the S&P/TSX Renewable Energy and Clean Technology Index (RECTI)—the findings highlight the heightened sensitivity of daily returns and volatility to shocks, especially at extreme quantiles, in the time domain. On the frequency spectrum, the connectedness patterns of conventional and green energy indices' daily returns and volatility to shocks vary, exhibiting fluctuating roles between transmission and reception. The dynamic connectedness highlights the interconnectedness between conventional and green energy markets. These findings underscore the need for risk management strategies and resilient investment approaches in energy markets. EF
Keywords: Energy market, green energy, daily return, volatility

A comprehensive review on solar to thermal energy conversion and storage using phase change materials

Journal of Energy Storage **72 (part A)**: 108280
Bhartendu Mani Tripathi, Shailendra Kumar Shukla, Pushpendra Kumar Singh Rathore

Renewable energy plays a pivotal role for mankind in times of adverse climate change and global warming. However, renewable energy such as solar energy comes with inherent drawbacks of limited or varying availability. Consequently, it leads to poor performance of numerous solar thermal technologies. To overcome these constraints of solar energy, thermal energy storage (TES) can play a pivotal role in improving performance and feasibility of solar thermal technologies. TES using phase change material (PCM) is one of the effective techniques of charging, storing, and discharging thermal energy as and when required. PCM stores thermal energy in the form of latent heat by undergoing phase change at constant temperature. However, PCM suffers with drawbacks of low thermal conductivity, poor solar to thermal conversion efficiency, and risk of leakage during phase transition. These thermo-physical properties limit the applicability of PCM as a potential TES material. In view of the above facts and findings, this study comprehensively analyses the above mentioned thermo-physical bottlenecks of PCMs. It briefly discusses TES, various materials for TES, PCM, and properties of PCM. In detail, it presents various methods and mechanisms of improving solar to thermal performance and thermal conductivity of the PCM. Additionally, this study presents a robust discussion on techniques of minimizing the leakage of the PCM during phase transformation. EF
Keywords: Renewable energy, thermal energy storage, thermal conductivity, phase change material

A review of solar, electric, and hybrid cookstoves

Renewable and Sustainable Energy Reviews **188**: 113787
Journal of Cleaner Production **405**: 136942
S Rahul Kashyap, Santanu Pramanik, RV Ravikrishna

The research on clean and energy-efficient cooking technologies has focused on solar and electric cookstoves. Recent studies have proposed solar-biomass and solar-electric hybrid cookstoves towards developing renewable and sustainable cooking technologies. However, only solar cookstoves have been reviewed extensively, owing to the vast literature. This article reviews electric and solar-hybrid cookstoves for the first time and summarizes the recent developments in solar cookstoves. Though solar cookstoves offer clean and cost-free operation, they depend on sunlight availability and usually have longer cooking durations due to low operating power. Direct solar cookstoves require cooking outdoors, whereas indirect cookstoves enable indoor cooking using a heat transfer fluid. Thermal energy storage also facilitates night cooking. Electric cookstoves function based on induction, resistance or radiative heating principles. However, off-grid and rural areas lack a continuous supply of electricity. Hybrid cookstoves combine solar energy with fuels and electricity to achieve renewability. Total system efficiency—which includes the efficiencies of energy production, transportation, and end-use—is a better indicator of the cooking life cycle. Electric cooking depicts low total system efficiency despite having the highest end-use efficiency (about 80%) due to low efficiency of electricity production and transportation. In contrast, the total system efficiency of solar cooking equals its end-use efficiency. Recent advancements in solar cookstoves have shown efficiencies up to 35–40% with direct and 63–69% with indirect solar cookstoves. The present review also identifies directions for future research. Specifically, the gaps in hybrid cookstove literature call for future research to develop sustainable cooking technologies. EF

Keywords: Solar energy, solar cookstoves, hybrid cookstoves

Modelling an off-grid hybrid renewable energy system to deliver electricity to a remote Indian island

Energy Conversion and Management **281**: 116839
Dibyendu Roy

The study examines numerous off-grid hybrid renewable energy system (HRES) combinations to deliver electricity to a remote island settlement. Six different configurations were subjected to technical, economic, environmental, and social analyses in order to establish the best optimal design. The best-optimized system's sensitivity analysis was carried out. Furthermore, different machine learning models have been applied to predict the performance of the system. In terms of economic assessments, the lowest levelized unit cost of electricity (LCOE) (USD 0.31/kWh) and highest return on investment (ROI) (26.4 %) make System 6 much more competitive. Despite the fact that System 6 is partially powered by a diesel generator, the life cycle CO_2 emissions (LCE) of System 6 and System 3 are at similar levels—49517.68 kg/year and 46744.45 kg/year, respectively. For system 6, it was observed that a 30 % rise in diesel fuel prices increased the net present cost (NPC) and LCOE by 4.9 % and 4.8 %, respectively. Matern 5/2 GPR model is found to be the best option among all the studied machine learning models for predicting renewable fraction and levelized unit cost of electricity. EF

Keywords: HRES, LCOE, power generation, economic analysis, solar energy, machine learning

Renewable energy use and export performance of manufacturing firms: Panel evidence from six industries in India

Energy Economics **125**: 106894
Khanindra Ch Das, Mantu Kumar Mahalik

The authors measure renewable energy intensity and examine its impact on export performance of Indian manufacturing firms from six industries, over the panel period 2011–2021. Contrary to the negative impact of renewable energy use on export performance in macroeconomic studies, the firm-level panel analysis suggests that the impact of renewable energy usage on export intensity could differ from industry to industry. The authors use both system dynamic panel estimation and fixed effects with Driscoll and Kraay standard errors to correct for cross-sectional dependence. Under both methods, the results suggest a positive impact of renewable energy usage on export intensity in most of the industries analysed. However, the magnitude of effect differs from industry to industry. This has heterogeneous implication for energy policy for different industries. Use of renewable energy, especially in hard-to-abate sectors, will need special attention by the governments and policymakers in India. EF

Keywords: Export performance, Indian manufacturing, Energy policy, Driscoll and Kraay standard errors

Green financing of renewable energy generation: Capturing the role of exogenous moderation for ensuring sustainable development

Energy Economics **126**: *107021*
Avik Sinha, Vinit Ghosh, Nazim Hussain, Duc Khuong Nguyen, Narasingha Das

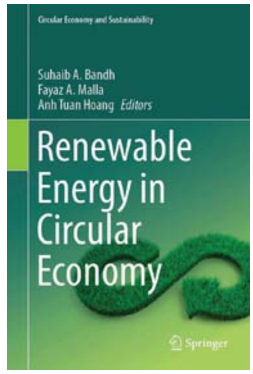
USA has been facing difficulties in attaining the objectives of Sustainable Development Goal (SDG) 7: Affordable and Clean Energy. One of the major reasons behind this is the policy lacuna prevailing in terms of financializing the renewable energy generation projects. While the policy documents are suggesting solutions to address this issue, the hidden moderations arising out of the socio-economic and political settings are largely ignored. Moreover, the dependence structure of green finance and renewable energy generation might follow a tail dependence, because of the extreme market conditions. The need for a policy reorientation involving these two factors has motivated the study. In this study, the inter-quantile association between green finance and renewable energy generation are analysed over January 1985 to December 2020. This study has also introduced a new method, 'Multivariate Quantile-on-Quantile Regression' (m-QQR). The outcomes reveal that the impact of green finance on renewable energy generation is susceptible to exogenous moderation, while demonstrating inter-quantile dependence. The policy framework recommended in the study is aimed at helping the USA in attaining the objectives of SDG 7. EF

Keywords: Renewable energy generation, green finance, USA, quantile SDG

Renewable Energy in Circular Economy

The book provides a comprehensive overview of the technologies and processes involved in renewable energy generation, with a specific focus on their role in improving the circular economy. It offers all the necessary information and tools to help readers select the most sustainable renewable energy solution for different conditions.

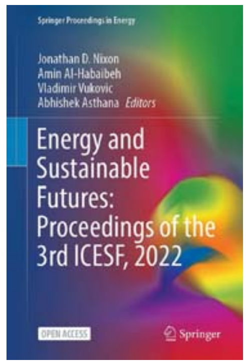
Exploring real-life examples, the book delves into the practical applications of the circular economy in the renewable energy sector. It takes a multi-faceted approach, examining the circular economy from various perspectives and incorporating methods such as lifecycle assessment, sustainability assessment, multi-criteria decision-making, and multi-objective optimization modes. Furthermore, the book explores the concept of blockchain, hybrid renewable energy models, technologies, and implementation. It also investigates the critical factors and key enablers that influence sustainable development in this field. By doing so, it not only facilitates the transition to a circular economy but also highlights the shift in recent research, trends, and attitudes towards a more scientifically grounded approach. EF



Authors: Suhaib A Bandh, Fayaz A Malla, and Anh Tuan Hoang
Publisher: Springer; 295p
Year: 2023

Energy and Sustainable Futures: Proceedings of the 3rd ICESF

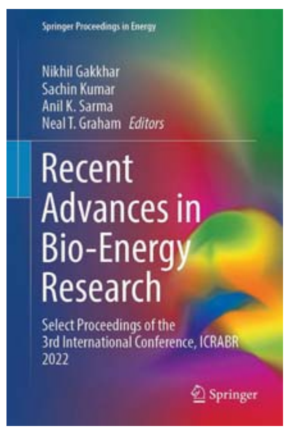
This is an open access book. This book contains research papers presented at the 3rd International Conference on Energy and Sustainable Futures (ICESF), which took place at Coventry University, UK, in 2022. The ICESF is an annual conference organized by the UK-based Doctorial Training Alliance (DTA) programme. It is a multidisciplinary conference focused on addressing the future challenges and opportunities for meeting global energy targets and sustainable development goals. The conference brought together academic researchers, industry experts and research students to showcase the latest innovations and research on a wide range of topics in the areas of energy and sustainability. EF



Authors: Jonathan D Nixon, Amin Al-Habaibeh, Vladimir Vukovic, and Abhishek Asthana
Publisher: Springer; 360p
Year: 2023

Recent Advances in Bio-Energy Research

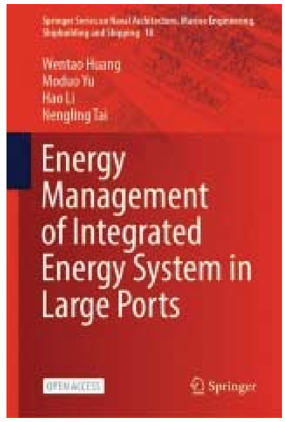
This book comprises select proceedings of the 3rd International Conference on Recent Advances in Bio-energy Research (ICRABR 2022), providing comprehensive coverage on bio-energy-related fields and prospects of bio-energy in terms of waste management for energy generation, storage, and application. The content includes themes such as optimization of energy systems, recent advances in biofuels and bioenergy, biomass hybrid systems, energy efficiency, electrochemical conversion of biofuels to renewable energy, energy management and policy, and the inter-linkages between energy and sustainable development. This book is of use to academics, researchers, consultants, and policymakers alike. EF



Author: Nikhil Gakkhar, Sachin Kumar, Anil K Sarma, and Neal T Graham
Publisher: Springer; 292p
Year: 2023

Energy Management of Integrated Energy System in Large Ports

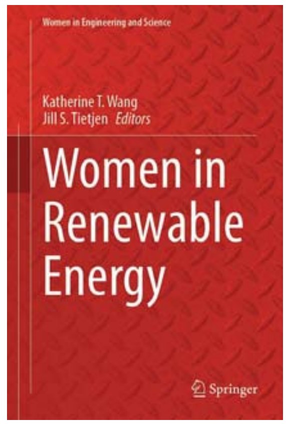
This open access book provides a detailed exploration of energy management in seaport integrated energy systems, highlighting their potential to replace conventional fuel-based energy usage and promote sustainable development of large ports. In order to achieve carbon neutrality, energy management technologies are crucial for the sustainable development of port systems that couple energies, logistics, and maritime transportation. Research on seaport integrated energy systems has attracted scholars and scientists from various disciplines, such as port electrification, logistics, microgrids, renewable energies, energy storages, and port automation. Taking a holistic approach, this book establishes a fundamental framework for the topic and discusses the electrification process, coupling mechanisms and modelling, optimal planning, low-carbon and economic operation, as well as applications of integrated energy systems in seaports. This book is intended for researchers, graduate students, and other readers interested in green seaport energy management and low-carbon operation technologies under the coupling between logistics and multi-energy systems. EF



Wentao Huang, Moduo Yu, Hao Li, and Nengling Tai
Author: Springer; 291p
Year: 2023

Women in Renewable Energy

This book provides a breadth and depth of innovative and impactful research led by women investigators in the field of renewable energy. This book showcases the diversity of renewable energy solutions being deployed commercially in the United States and internationally, including new research underway. The chapters collectively cover the entire spectrum of large, utility scale to small, distributed-scale renewable energy technologies, as well as new operating practices in buildings necessary to fully capture the value of renewable energy. The chapters also discuss technical and market considerations of renewable energy resources, plus customer attitudes and acceptance. These topics touch on many of the challenges facing the world today and these solutions by women researchers are valuable for their technical excellence and their non-traditional perspective. EF

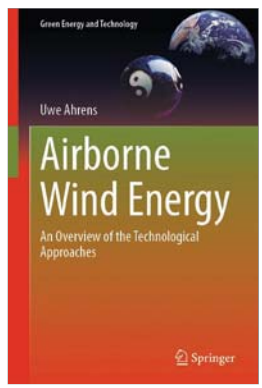


Authors: Katherine T Wang and Jill S Tietjen
Publisher: Springer; 244p
Year: 2023

Airborne Wind Energy

This book shows possible solutions to how a profitable energy supply can be implemented with almost no population resistance. Worldwide, more than 80% of our energy needs are still covered by fossil fuels. Under these circumstances, can climate change still be stopped?

Essential technologies for usage of wind energy with an emphasis on high-altitude wind utilization are presented. Airborne wind energy is one of the most promising technologies to enable a renewable energy turnaround in an economical way. The main problem of conventional renewable energy is the insufficient availability. To ensure a 10% supply of renewable energy, enormous and very expensive storage capacities would have to be built up. How we can cover our entire energy needs (electricity, mobility and heat) in the future without fossil fuels, without risking the competitiveness of our economy, is shown in this book. EF



Author: Uwe Ahrens
Publisher: Springer; 294p
Year: 2023

RENEWABLE ENERGY TECHNOLOGY DEVELOPMENT

A Solar Cell You Can Bend and Soak in Water

Researchers have developed an organic photovoltaic film that is both waterproof and flexible, allowing a solar cell to be put onto clothes and still function correctly after being rained on or even washed.

One of the potential uses of organic photovoltaics is to create wearable electronics— devices that can be attached to clothing that can monitor medical devices, for example, without requiring battery changes. However, researchers have found it challenging to achieve waterproofing without the use of extra layers that end up decreasing the flexibility of the film.

A group of scientists have been able to do precisely that. Photovoltaic films are typically made of several layers.

» There is an active layer, which captures energy of a certain wavelength from sunlight, and uses this energy to separate electrons and "electron holes" into a cathode and anode.
» The electrons and holes can then reconnect through a circuit, generating electricity.

For the current work, however, the researchers deposited the anode layer, in this case, a silver electrode, directly onto the active layers, creating better adhesion between the layers. They used a thermal annealing process, exposing the film to air at 85 degrees Celsius for 24 hours.

A group of researchers immersed the film completely in water for 4 hours and found that it still had 89% of its initial performance. They then subjected a film to stretching by 30% 300 times underwater, and found that even with that punishment, it retained 96% of its performance. As a final test, they ran it through a washing machine cycle, and it survived the ordeal, something that has never been achieved before.

Source: https://www.sciencedaily.com/releases/2024/03/240327124746.htm

New Study Unveils Scalable and Efficient Photoelectrode Modules for Green Hydrogen Production

In a groundbreaking development towards practical photoelectrochemical water splitting, a research team has achieved a remarkable technological breakthrough in the production of green hydrogen. Through their innovative approach, the team has overcome the challenges of efficiency, stability, and scalability in photoelectrodes, paving the way for practical implementation.

One of the key aspects of this breakthrough lies in the team's ability to address the limitations of perovskite solar cells (PSCs) and significantly increase the size of photoelectrodes by a staggering 10,000 times. By doing so, they have achieved unprecedented efficiency, durability, and scalability in the production of green hydrogen using solar energy.

» Solar hydrogen technology, which harnesses the abundant renewable energy of the sun to decompose water and obtain hydrogen, is an ideal approach for green hydrogen production.

The research team utilized perovskite as the photoelectrode material due to its efficiency and relative affordability. However, PSCs have been known for their vulnerability to ultraviolet rays and moisture, which posed significant challenges. To overcome these limitations, the team introduced formamide, rather than methylammonium, as a cation of perovskite. This modification greatly enhanced the stability of the photoelectrodes against ultraviolet rays. Additionally, the team sealed the contact surface with water using a nickel foil, ensuring stability even in water.

The research team's module-based design approach, connecting small photoelectrodes and arranging them in specific sizes, has paved the way for large-scale practical applications. With a solar hydrogen conversion efficiency exceeding 10% in this module-based design, the team has met the minimum condition for commercialization, achieving the world's highest efficiency in large-area photoelectrodes.

Source: https://www.sciencedaily.com/releases/2024/02/240228115301.htm

Artificial 'Power Plants' Harness Energy from Wind and Rain

Researchers developed literal "power plants"—tiny, leaf-shaped generators that create electricity from a blowing breeze or falling raindrops—and described them in *ACS Sustainable Chemistry & Engineering*. The team tested the energy harvesters by incorporating them into artificial plants.

Electrical energy can be produced by nature in several ways. For example, solar panels convert light energy from the sun, and wind turbines transform the kinetic energy of moving air. But these methods typically rely on a single source and therefore are only effective when that source is available. Solar panels don't work after sunset, for example, and a calm day won't generate much wind power. More recently, multi-source energy harvesters have emerged as a method to capture energy from different renewable sources in one device, maximizing potential output.

The team built two different types of energy collectors:

» A triboelectric nanogenerator (TENG) to capture kinetic energy from the wind.

» A droplet-based energy generator (DEG) to collect energy from falling raindrops.

The TENG consisted of a layer of nylon nanofibres sandwiched between layers of polytetrafluoroethylene, more commonly known as Teflon™, and copper electrodes. When the layers pressed into each other, static charges were generated and converted into electricity. Teflon was also used to make the DEG, which was waterproofed and covered with a conductive fabric to act as the electrodes. As raindrops hit one of the electrodes, it caused an imbalance in charges, generating a small current and high voltage. Under optimal conditions, the TENG produced 252 volts of power and the DEG 113 volts, but only for short periods.

The team mounted the DEG atop the TENG and incorporated leaf-shaped versions into an artificial plant. When the leaf-shaped generators were exposed to conditions mimicking natural wind and rain, it powered 10 LED lights in short flickers. This proof-of-concept "power plant" device could be further developed into larger systems or networks of power plants to produce clean energy from natural sources.

Source: https://www.sciencedaily.com/releases/2024/01/240117143636.htm

Harvesting More Solar Energy with Super Crystals

Hydrogen is a building block for the energy transition. To obtain it with the help of solar energy, LMU researchers have developed new high-performance nanostructures. The material holds a world record for green hydrogen production with sunlight. When Emiliano Cortés goes hunting for sunlight, he doesn't use gigantic mirrors or solar farms. Quite the contrary, the professor of experimental physics and energy conversion at LMU dives into the nanocosmos. "Where the high-energy particles of sunlight meet atomic structures is where our research begins," Cortés says. "We are working on material solutions to use solar energy more efficiently." His findings have great potential as they enable novel solar cells and photocatalysts. But there is one major challenge, Cortés knows: "Sunlight arrives on Earth 'diluted,' so the energy per area is comparatively low."

Solar panels compensate for this by covering large areas. Cortés, however, is approaching the problem from the other direction, so to speak: With his team at LMU's Nano-Institute, which is funded by the e-conversion cluster of excellence, Solar Technologies go Hybrid (an initiative of the Bayerisches Staatsministerium für Wissenschaft und Kunst) and the European Research Council, he is developing plasmonic nanostructures that can be used to concentrate solar energy. In a publication in the journal *Nature Catalysis*, Cortés, together with Dr Matías Herran and cooperation partners from the Free University of Berlin and the University of Hamburg, present a two-dimensional supercrystal that generates hydrogen from formic acid with the help of sunlight.

Source: https://www.sciencedaily.com/releases/2023/12/231201123649.htm

Indoor Solar to Power the Internet of Things

From Wi-Fi-connected home security systems to smart toilets, the so-called Internet of Things brings personalization and convenience to devices that help run homes. But with that come tangled electrical cords or batteries that need to be replaced. Now, researchers reporting in *ACS Applied Energy Materials* have brought solar panel technology indoors to power smart devices. They show which photovoltaic (PV) systems work best under cool white LEDs, a common type of indoor lighting.

Scientists have found ways to harness power from sunlight, using PV solar panels, but those panels are not optimized for converting indoor light into electrical energy. Some next-generation PV materials, including perovskite minerals and organic films, have been tested with indoor light, but it's not clear which is the most efficient at converting non-natural light into electricity.

The researchers obtained eight types of PV devices, ranging from traditional amorphous silicon to thin-film technologies such as dye-sensitized solar cells. They measured each material's ability to convert light into electricity, first under simulated sunlight and then under a cool white LED light.

- » Gallium indium phosphide PV cells showed the greatest efficiency under indoor light, converting nearly 40% of the light energy into electricity.
- » As the researchers had expected, the gallium-containing material's performance under sunlight was modest relative to the other materials tested due to its large band gap.
- » A material called crystalline silicon demonstrated the best efficiency under sunlight but was average under indoor light.

Gallium indium phosphide has not been used in commercially available PV cells yet, but this study points to its potential beyond solar power, the researchers say. They add that gallium-containing materials are expensive and may not serve as a viable mass product to power smart home systems. In contrast, perovskite mineral and organic film PV cells are less expensive and do not have stability issues under indoor lighting conditions. Additionally, in the study, the researchers identified that part of the indoor light energy produced heat instead of electricity—information that will help optimize future PVs to power indoor devices.

Source: https://www.sciencedaily.com/releases/2023/11/231109141449.htm

Solar-Powered Device Produces Clean Water and Clean Fuel at the Same Time

A floating, solar-powered device that can turn contaminated water or seawater into clean hydrogen fuel and purified water, anywhere in the world, has been developed by researchers.

- » The device could be useful in resource-limited or off-grid environments since it works with any open water source and does not require any outside power.

It takes its inspiration from photosynthesis, the process by which plants convert sunlight into food. However, unlike earlier versions of the 'artificial leaf', which could produce green hydrogen fuel from clean water sources, this new device operates from polluted or seawater sources and can produce clean drinking water at the same time.

- » A device that could work using contaminated water could solve two problems at once: it could split water to make clean fuel, and it could make clean drinking water.

Photocatalyst has been deposited on a nanostructured carbon mesh that is a good absorber of both light and heat, generating the water vapour used by the photocatalyst to create hydrogen. The porous carbon mesh, treated to repel water, served both to help the photocatalyst float and to keep it away from the water below so that contaminants do not interfere with its functionality.

The team used a white, UV-absorbing layer on top of the floating device for hydrogen production via water splitting. The rest of the light in the solar spectrum is transmitted to the bottom of the device, which vapourizes the water.

Source: https://www.sciencedaily.com/releases/2023/11/231113111636.htm

Physicists Develop More Efficient Solar Cell

Physicists have used complex computer simulations to develop a new design for significantly more efficient solar cells than previously available. A thin layer of organic material, known as tetracene, is responsible for the increase in efficiency.

The annual energy of solar radiation on Earth amounts to over one trillion

kilowatt-hours and thus exceeds the global energy demand by more than 5000 times. Photovoltaics, i.e., the generation of electricity from sunlight, therefore offers a large and still largely untapped potential for the supply of clean and renewable energy. Silicon solar cells used for this purpose currently dominate the market, but have efficiency limits. One reason for this is that some of the energy from short-wave radiation is not converted into electricity, but into unwanted heat.

According to scientists to increase efficiency, the silicon solar cell can be provided with an organic layer. Short-wave light is absorbed in this layer and converted into high-energy electronic excitations, so-called excitons. These excitons decay in the tetracene into two low-energy excitations. If these excitations can be successfully transferred to the silicon solar cell, they can be efficiently converted into electricity and increase the overall yield of usable energy.

Scientists have shown that special defects in the form of unsaturated chemical bonds at the interface between the tetracene film and the solar cell dramatically accelerate the exciton transfer. Such defects occur during the desorption of hydrogen and cause electronic interface states with fluctuating energy. These fluctuations transport the electronic excitations from the tetracene into the silicon like a lift.

Source: https://www.sciencedaily.com/releases/2024/02/240220144528.htm

Solar Design Would Harness 40% of the Sun's Heat to Produce Clean Hydrogen Fuel

Engineers have proposed groundbreaking technology for the efficient production of "solar thermochemical hydrogen" in a study published in *Solar Energy Journal*. This innovative system leverages the sun's heat to directly split water and produce hydrogen, a clean fuel ideal for powering long-distance vehicles while emitting zero greenhouse gas emissions. Unlike conventional hydrogen production methods that rely on fossil fuels, solar thermochemical hydrogen (STCH) is entirely emissions-free, driven by renewable solar energy. The MIT team's design aims to dramatically improve efficiency, potentially utilizing up to 40% of the sun's heat, which could significantly reduce the overall cost of the system. By enhancing the economic viability of STCH, this technology offers a promising path towards decarbonizing the transportation industry and achieving the Department of Energy's goal of producing green hydrogen at $1 per kilogram by 2030. EF

Source: https://www.sciencedaily.com/releases/2023/10/231016163109.htm

6 GW RENEWABLE ENERGY STORAGE TO BE ADDED BY FISCAL 2028

Healthy Pipeline and Government Push Towards Renewables Boost Adoption

India's renewable energy (RE) storage capacity is expected to surge 6 GW[1] by fiscal 2028 from less than 1 GW operational as of March 2024, driven by a robust pipeline of projects under implementation and expected healthy pace of auctions. Such an increase is crucial to sustainably absorb the rising share of renewable energy (RE) in the country's overall power generation mix.

Despite slow progress on project implementation, the government's push to develop RE power and tariffs for round-the-clock renewable energy, discovered in last two fiscals, being comparable with other sources of round-the-clock power—improves confidence around adoption. Storage is becoming crucial with the rising share of RE —both solar and wind—in the overall power generation mix.[2] This is because RE generation by nature is concentrated, happening at specific times in a day. For instance, solar generation happens largely during daytime. Such a generation profile does not match with demand that typically peaks in the morning and evening.

Hence, to manage absorption of such a profile of generation, surplus generation must be stored and discharged at the time of requirement to keep the grid balanced.

To address this issue, the government is working on developing the infrastructure needed through standalone storage systems (such as pumped hydro or battery storage systems) and storage-linked projects that combine RE generation with storage. The auctions of such projects have been ramped up. About 3 GW of standalone storage and ~10 GW of storage-linked projects with ~2 GW of storage were auctioned in the past two fiscals (vs less than 1 GW previously), resulting in a healthy pipeline of ~6 GW of storage as of May 2024.

1 Translating to 18–24 GWh of storage capacity depending on usage and configuration of storage systems.

2 The share of renewable generation is expected to expand to ~23% by fiscal 2028 from ~12% at present.

Development of at least this much storage capacity would be required to sustainably increase the proportion of RE power to 20–22%[3] in the overall power generation, as per government estimates.

Manish Gupta, Senior Director, CRISIL Ratings, says "However, progress on implementation has been tardy. Slow adoption by state distribution companies (discoms) has been a key deterrent to implementation—60–65% of such projects had not got their power purchase agreements (PPAs) executed until May 2024."

A major reason for the low traction is higher tariff (INR 4.3–5.5 per unit) on these projects compared with other RE bids (INR 2.6–3.2 per unit) because of additional cost of storage.

Going forward, it is expected that the government push to promote RE power and comparable tariffs of storage projects with other sources of round-the-clock power will provide a fillip to adoption. The government aims to increase RE capacity to 450 GW by 2030 from 130 GW as of March 2024. To promote this, Renewable Purchase Obligations (RPOs)[4] have been stipulated for discoms. They must increase the share of RE power from ~25% at present to 39% by fiscal 2028. This means discoms will need to buy more RE power and as its penetration increases, focus will sharpen on storage essential for grid balancing.

Says Ankit Hakhu, Director, CRISIL Ratings, "Though tariffs of projects with storage (INR 4.3–5.5 per unit) are above the typical renewable bids (INR 2.6–3.2 per unit), they are comparable with that of other round-the-clock sources, including tariffs discovered through medium-term power purchase agreements of coal thermal plants (~INR 5 per unit in fiscal 2024). This further provides confidence on increase in traction of signing of PPAs."

That said, 6 GW projection remains sensitive to project cost estimates and timely implementation. More than anticipated rise in cost or unavailability of key raw materials (such as solar modules and batteries) can impact viability since tariffs are fixed and do not provide a pass-through. Additionally, technological risk (such as estimates of water evaporation rate for pumped hydro projects and degradation and discharge rate for batteries) can also impact implementation and operations of these projects. This is because there is limited track record of large-scale development of such projects in India.

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For more information, visit www.crisil.com

3 As per Central Energy Authority and Ministry of Power estimates, over 6.5 GW of storage would be needed for absorption of ~20% of energy from renewable sources.

4 RPOs are a minimum percentage of overall power procurement by a discom through renewable sources.

NAVIGATING THE PROMISES AND PITFALLS OF 'LOW-CARBON' HYDROGEN IN EUROPE

'Low-carbon' hydrogen made with fossil gas must have strong safeguards if it is to make a positive contribution to Europe's transition to climate neutrality. A new analysis by Agora Energiewende and Agora Industry, building on modelling by Deloitte, highlights the risks in draft EU rules and shows why grid-based renewable and 'low-carbon' hydrogen are the better fit for Europe's climate protection and energy security interests.

Europe will need considerable amounts of hydrogen to decarbonize sectors where direct electrification is not an option, such as certain industrial processes, long-haul aviation and shipping. However, the scale-up of renewable hydrogen that does not add to climate pollution is slower and costlier than previously thought. To meet demand, the European Union will therefore also need to tap into other sources of hydrogen, such as that made from fossil gas using carbon capture and storage (CCS) or with power from the grid.

The European Commission is currently developing detailed requirements for what qualifies as 'low-carbon' fuels— including hydrogen—in Europe. This methodology will be central to the integrity of European climate laws and determine the future cost-competitiveness of renewable hydrogen.

Based on market modelling by consultancy Deloitte and cost and emissions data provided by consultancy Carbon Limits, a new Agora report recommends several safeguards through which the EU can maintain security of supply while ensuring that low-carbon hydrogen contributes to the 27-nation bloc's climate goals.

"Renewable and low-carbon hydrogen will make an important contribution to Europe's industrial decarbonization. But how the EU defines low-carbon hydrogen will decide whether investments in this field align with Europe's pathway to climate neutrality or create new fossil fuel import dependencies," said Matthias Buck, Europe director at Agora Energiewende. "The definition of 'low-carbon' hydrogen should reflect implications for Europe's energy security and the resilience of its transition to climate neutrality."

Reducing the Maximum-Emissions Threshold for Low-Carbon Hydrogen over Time

The Commission's delegated authority requires that the production of low-carbon hydrogen results in "at least" 70% less greenhouse gas than the liquid fossil fuel benchmark, which means a maximum of 3.38 kg CO_2-eq. per kg of hydrogen. For fossil gas-

based hydrogen, the 70% threshold can be met by combining measures to cut upstream emissions of methane and CO_2 with existing carbon capture technologies when producing the hydrogen. Currently, only fossil gas from Norway would be suitable to this end, while upstream emissions of fossil gas imported from countries such as Algeria and the United States would be too high. To be consistent with the EU's binding target to achieve climate neutrality by 2050 at the latest, the modelling underpinning the analysis suggests that the maximum-emissions threshold for 'low-carbon' hydrogen should be progressively lowered over time from 3 kg by 2030, to 2 kg by 2040 and 1 kg by 2050.

"Progressively lowering the maximum-emissions threshold for low-carbon hydrogen is an important signal for investors and operators to invest from the start in the best available technologies for reducing upstream emissions and technologies for capturing carbon at a rate of at least 90%," said Matthias Buck. "Europe will need growing volumes of renewable and low-carbon hydrogen going forward. To be consistent with the EU's climate neutrality objective, remaining greenhouse gas emissions from hydrogen production must be kept as low as technically possible."

Default Values for Upstream Methane Emissions Should be Complemented by Real-World Data

Current EU rules foresee applying a default value of 9.7 gCO_2 eq. per MJ for upstream greenhouse gas emissions if no specific emissions intensity value has been reported. The calculations underpinning this analysis show that this approach would significantly underestimate real-world emissions from fossil-based hydrogen by a factor of 2.5 for Europe by 2040. A recently leaked draft of the low-carbon fuels Delegated Act foresees a 40% increase on the methane intensity default value if no specific emission data has been reported.

"Applying only a 40% increase on the methane intensity default value, as seems to be the intention according to the recently leaked draft of the Delegated Act, would clearly not be enough," commented Matthias Buck. Agora therefore recommends complementing the default value with available country-specific, preferably basin-specific, emissions factors until site-specific rules under the EU Methane Regulation come into effect.

Grid-Based Low-Carbon Hydrogen Production Should be as Clean as Possible Soon

Running an electrolyser 24/7 to produce hydrogen with electricity drawn from the grid can today result in more emissions than producing conventional fossil hydrogen. In 2023, this would have been the case in 15 countries in the EU. By the mid-2030s, however, grid-based hydrogen will either be renewable or low-carbon in most parts of Europe as the emissions intensity of the electricity mix is increasingly lowered. The modelling also shows the benefits of hourly accounting of the emissions intensity of the electricity used for grid-based low-carbon hydrogen production. Compared to applying annual average values or default values, hourly accounting—which is already technically possible today—would save greenhouse gas emissions and incentivize investments into clean electricity.

Prioritizing Renewable Hydrogen and Grid-Based Low-Carbon Hydrogen Production

The analysis shows that the fossil gas-based low-carbon hydrogen route builds on several preconditions that are currently not met. While best available technologies and relevant behavioural measures exist to cut methane and CO_2 emissions along the fossil gas value chain, they are not yet widely used. Norway is the only major supplier of fossil gas to Europe currently capable of reducing upstream emissions of methane and CO_2 to levels that would allow for the production of 'low-carbon' hydrogen. Furthermore, highly efficient carbon capture technologies are not yet available at scale nor does Europe have the necessary infrastructure in place for transporting and permanently storing the captured carbon. This means Europe could become heavily reliant on a very limited number of suppliers of fossil gas for hydrogen production.

"The fossil gas-based low-carbon hydrogen route could create new fossil fuel import dependencies that put Europe's energy security at risk. Our analysis shows that there is no low-carbon hydrogen shortcut into a climate-neutral future. Rapidly scaling renewable electricity production in Europe should remain the absolute priority," Matthias Buck said.

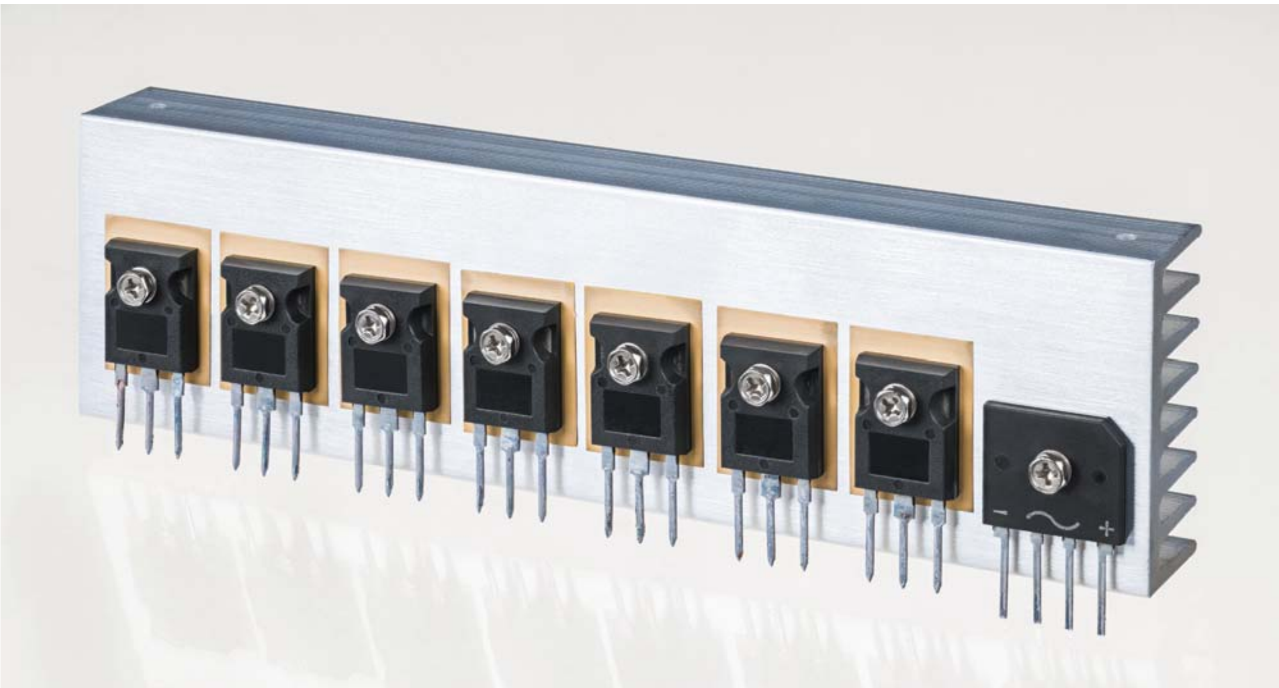
Considering the importance of international standards, Agora recommends that the EU engages in international partnerships, for example with the United States and the United Kingdom, to establish scientifically sound methodologies for low-carbon hydrogen and fuels, based on independently verified reporting of emissions.

Stakeholders will soon have the opportunity to engage with the European Commission's public consultation on the definition for low-carbon fuels. EF

The 47-page publication 'Low-carbon hydrogen in the EU – Towards a robust EU definition in view of costs, trade and climate protection' is available for free download at www.agora-energiewende.org

PERSON WITH THE WORLD'S LARGEST NEGATIVE CARBON FOOTPRINT

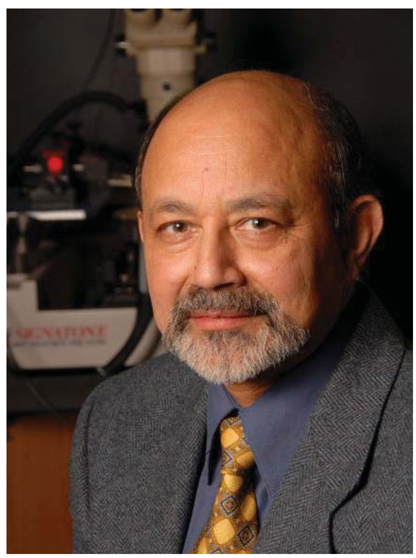
Wins the €1 Million Millennium Technology Prize



The 2024 Millennium Technology Prize has been awarded to Professor Bantval Jayant Baliga of North Carolina State University, United States, for his innovation that has enabled dramatic reduction in worldwide electrical energy and petrol consumption.

The €1 million global award for technology recognizes Baliga's leadership in the invention, development, and commercialization of the Insulated Gate Bipolar Transistor (IGBT). Since its development in the 1980s, the IGBT has been the most important semiconductor device for making electrical energy use and petrol consumption more efficient and less polluting during the last 40 years. The efficiency improvements and reductions of fossil fuels consumption and cost, achieved by the IGBT, revolutionized the power industry. The technology has reduced global carbon dioxide emissions by over 82 gigatonnes (180 trillion pounds) in the past 30 years. This is equivalent to setting off carbon dioxide emissions by all human activity for three years, based on the average of the past 30 years' time frame.

Prof. Baliga's innovation enables the worldwide green transition and mitigation of global warming by making electrification and the use of renewable energy efficient and profitable. All wind



and solar power installations utilize IGBT-based technology to convert the generated electricity into a form that is suitable for consumer and industrial applications. The IGBT is an essential technology in electric and hybrid-electric cars, as well as in most other electric motors in consumer and industrial use.

The IGBT technology is everywhere around us all over the world, reducing energy consumption and making electricity use reliable: in medical diagnostic machines like X-Ray machines, CAT scanners and MRI units at the hospital; in microwave ovens and induction stoves in our kitchens; in air-conditioning and refrigeration for homes and buildings; in portable defibrillators, which were made possible by the IGBTs and are now saving countless lives around the world every year. The performance capacities of modern IGBT have expanded to the point that today IGBT-based power converters and inverters dominate nearly every major application with a power rating between 1 kW and 10 MW.

Professor Bantval Jayant Baliga, who was granted the title of Progress Energy Distinguished University Emeritus Professor, said: "It is very exciting to have been selected for this great honour. I am particularly happy that the Millennium Technology Prize will bring attention to my innovation, as the IGBT is an embedded technology that is hidden from the eyes of society. It has enabled a vast array of products that have improved the comfort, convenience, and health of billions of people around the world while reducing carbon dioxide emissions to mitigate global warming. Informing the public of this impactful innovation will illustrate the betterment of humanity by modern technology."

Forbes Magazine named Professor Baliga the man with the world's largest negative carbon footprint when he was inducted into the Inventors Hall of Fame in 2016.

Baliga and his team are currently working on two new inventions for further improvement of the efficiencies in the fields of solar power generation, electric vehicles, and power delivery for AI servers.

Baliga said: "My first recent invention, the Baliga Short-circuit Improvement Concept (BaSIC), is designed to eliminate the roadblock of poor short-circuit withstand time for Silicon Carbide power MOSFETs used in motor drives for industrial and electric vehicle applications. My second new invention, a Bi-Directional Field-Effect Transistor (BiDFET), enables the matrix converter for power electronic applications. Matrix converters offer unprecedented improvements in size, efficiency, and reliability when compared with existing voltage source inverters. This will have a revolutionary impact on power delivery and management according to power electronics experts."

Professor Minna Palmroth, Chair of the Board of Technology Academy Finland, the foundation awarding the prize, said: "The IGBT has already had and continues to have a major impact on supporting sustainability with improved living standards worldwide, while mitigating environmental impact. The main solution to tackle global warming is electrification and moving to renewable energy. The IGBT is the key enabling technology in addressing these issues."

"I am particularly happy that the prize illuminates an innovation that is at the same time absolutely critical, has an enormous impact, but is not known to the vast majority of people. I think it is a great way to emphasize the power of science and innovation."

Professor Päivi Törmä, Chair of the International Selection Committee of the Millennium Technology Prize, said: "Two-thirds of the electricity in the world is used to run motors in consumer and industrial applications. Professor Baliga's innovation has allowed us to develop societies with electricity efficiently, while dramatically reducing energy consumption."

"Power electronics is a key enabling technology of any modern society in which automation of processes and energy systems plays an ever-increasing role. For the last 40 years, and still today, the IGBT is the most important power semiconductor device."

The Millennium Technology Prize will be presented to Professor Bantval Jayant Baliga in Finland on October 30, 2024 in an Award Ceremony that also celebrates the 20th anniversary of the Prize. The Millennium Technology Prize will be presented by its patron, the President of Finland.

The €1 million Millennium Technology Prize is the preeminent award focused on technological innovations for a better life. This includes work that improves human well-being, biodiversity, and wider sustainability. Overseen by the Technology Academy Finland, it was first awarded in 2004, and its patron is the President of Finland. Winners are selected by a distinguished international panel of experts from academia and industry. Innovations must be backed up by rigorous academic and scientific research and fulfill several criteria, including promoting sustainable development and biodiversity, having generated applications with commercial viability, and creating accessible socio-economic value.

Past winning innovations range from DNA sequencing that helped to develop COVID-19 vaccines, to ethical stem-cell research and versatile, affordable smart technology. EF

For further information, visit https://millenniumprize.org/

RENEWABLE ENERGY AT A GLANCE

Ministry of New & Renewable Energy		
Programme/Scheme wise Cumulative Physical Progress as on March, 2024		
Sector	**FY 2023-24**	
	Achievements (1st April 2023–31st March 2024)	**Cumulative Achievements (as on 31.03.2024)**
I. INSTALLED RE CAPACITY (MW)		
Wind Power	3253.39	45,886.51
Solar Power*	15,033.26	81,813.60
Small Hydro Power	58.95	5003.25
Biomass (Bagasse) Cogeneration	0.00	9433.56
Biomass (non- bagasse) Cogeneration	107.34	921.79
Waste to Power	1.60	249.74
Waste to Energy (off-grid)	30.16	336.06
Total	**18,484.70**	**1,436,44.51**

Source: https://mnre.gov.in/the-ministry/physical-progress

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