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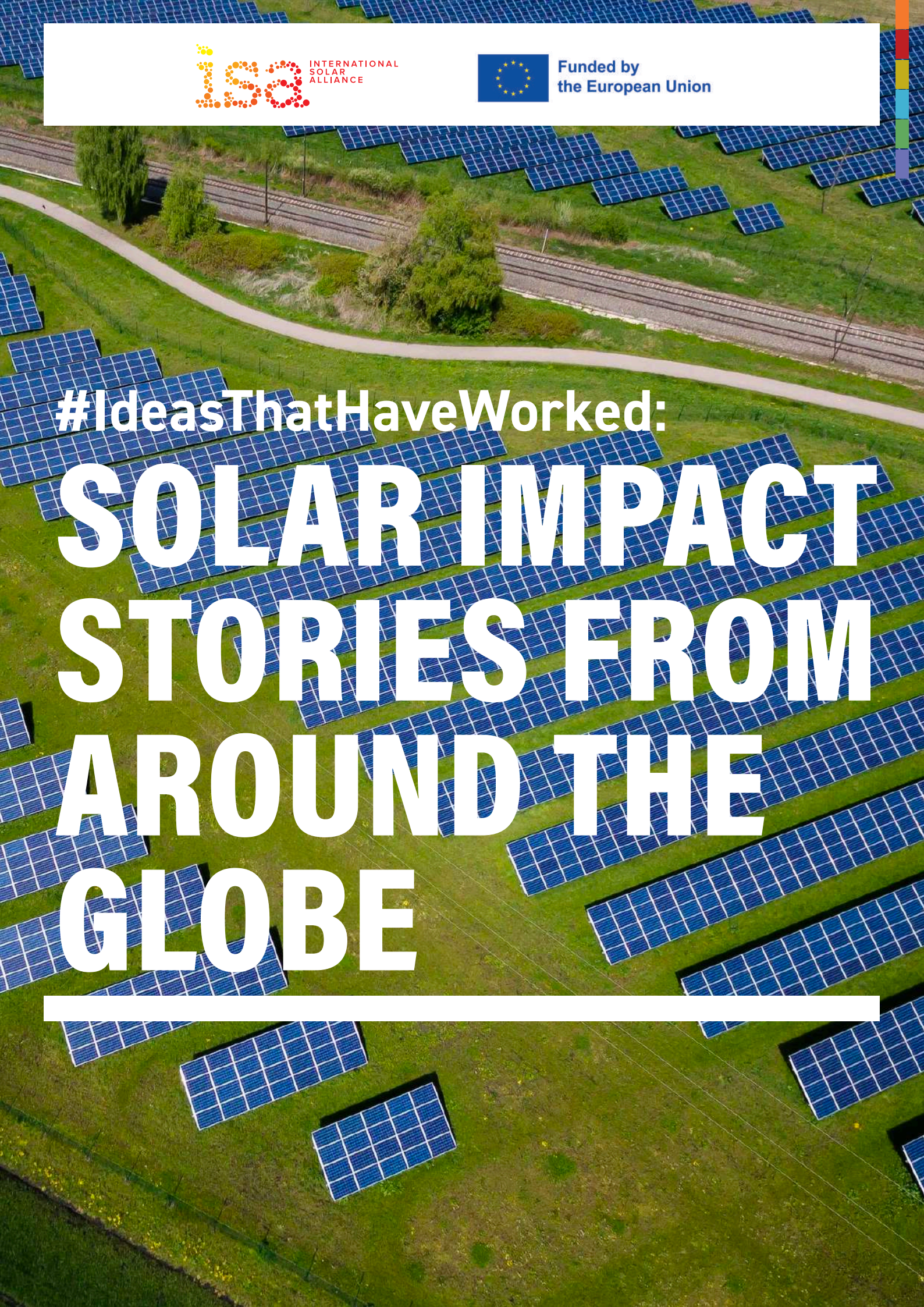

#IdeasThatHaveWorked:

SOLAR IMPACT STORIES FROM AROUND THE GLOBE

Preface

Solar PV technology has progressively been mainstreamed in recent decades and has been applied at various scales of operations. Over the years, Solar PV technology has been researched through case studies owing to the specifics of each deployment, the resource conditions and the geography, the policy environment, the risks involved, and above all, the limited availability of relevant information in the public domain. This situation mandates the study of cases that cover technologies, financial structures, market conditions, risk factors and sector-specific applications.

The present compilation of case studies from across countries and cultures involves contemporary PV and battery technology used for lighting and other end-use applications. The collection highlights the real-world situations facing individual projects and brings out the strengths and weaknesses of the underlying PV application. Many of the cases studied relate to first-of-their-kind initiatives, successful or otherwise, which deserve our appreciation for the effort invested in implementation and the prospect of creating new opportunities for the future.

- The compilation is a summary of real-life PV technology development and deployment experience with data sourced from publicly available sources believed to be reliable.
- The examples and case studies carry information covering financial and technical aspects and quantitative and qualitative analyses to help readers develop multiple perspectives relating to a given situation.
- The cases cover several countries, a range of policy environments, PV technology variants, and resource conditions to benefit policy makers, project analysts and potential investors.

For Solar PV technology and solutions to be scaled-up and replicated, capital from private as well as public sources would need to be deployed and optimized to suit the specific context. Such applications are to be supported by streamlined supply chains for equipment, spares and services, and backed by the institutional frameworks to manage the Operations and Maintenance (O&M) service delivery and to mitigate the potential risks from deficient O&M.

The case studies and examples suggest that supply as well as demand side management constitute equally important components of solar PV deployment, especially for standalone and small-scale systems and energy policy. The use of energy-efficient appliances and careful planning of their use during the day could help optimize sizing of the generation and storage capacities more effectively. Improved matching between generation and consumption could minimize the need for energy storage, reduce round-trip losses, and minimize maintenance requirements.

It flows from the case studies and implementation examples that electrification programs involving mini-grids or other PV system configuration to serve previously underserved clusters, both, the business case and the development argument need to be strong and compelling.

Disclaimer:

The case studies and example summaries are intended to help guide discussion on the underlying issues and are not meant to serve as an endorsement, or to judge regulatory prescriptions, management styles, decision-making or outcomes. The case summaries are designed to provide multiple perspectives on a given situation, to aid informed discourse, and to help evolve alternative recommendations subject to relevant assumptions.

This compilation of case studies and case examples was prepared with the financial assistance of the European Commission. The listing of case studies and case examples is the work of the consultants and is not the work of the European Commission.

This compilation is “work-in-progress” and is therefore not exhaustive and is verified as of 31 July 2023. To offer suggestions or to raise queries relating to the content or to add information relating to Solar PV related case studies and case examples, please write to info@isolaralliance.org.

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Mobile Agrivoltaic And Hydrogen Production System

The mobile agrivoltaic system "H2arvester" is expected to improve soil quality and biodiversity of agricultural fields. The first prototype of the mobile system had been deployed on sugar beet land in Oude-Tonge in South Holland and was inaugurated in April 2022. The system deployed in Oude-Tonge comprised four solar cars and 168 solar panels and an irrigation system costing the host-farmer Euro 166,000. A part of the project costs was borne by InnovationQuarter, the regional economic development agency for the Province of Zuid-Holland. The second prototype was being tested at Wageningen University, Lelystad. The 12.0m x 6.0m cars built on lightweight structures and supported on wheels, were designed to move at 10 meter per hour and could be moved out during harvesting. The pilot projects were designed to assess the effects on farm yields and on the land.

When not used for agriculture, the system could be combined with an electrolyzer to produce hydrogen, while the waste heat from the process could be recovered to dry crops (oats, for instance) and grass. In addition to enhancing the efficiency of asset use, such alternative end-use applications help balance production and use of energy independent of reinforcements to the electricity network.

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https://www.pv-magazine-india.com/2022/04/27/mobile-agrivoltaic-system-from-the-netherlands/

H2arvester
Source: PV Magazine

Solar Parks Database

The past decade witnessed a drastic decline in the cost of manufacturing solar modules, making solar PV energy among the cheapest and most affordable sources of electricity in most parts of the world. Consequently, governments world over and corporations alike have pursued the design implementation and operation of large "utility-scale" solar projects.

To put this in perspective, in year-2020, solar photovoltaic (PV) technology was the largest contributor to the total renewable energy (RE) capacity added around the world, with new capacity additions growing by about 22% year-on-year, reaching 127 GWp of new capacity commissioned.[1]

However, the development of RE projects, and more specifically solar PV projects, is often uncoordinated, potentially leading to the accumulation of too much capacity or the access to too little capacity in certain jurisdictions. This could lead to sub-optimal use of the project asset, especially in the absence of commensurate transmission infrastructure. The limited availability of robust geospatial information on the rapid expansion of RE capacity could be problematic for other reasons as well. For instance, the long-term impacts of large-scale solar PV installations on indigenous biodiversity have not been studied extensively. Some of the studies have indicated that large-scale plants could result in soil degradation and leave an adverse impact on water availability.[2]

Moreover, while choosing new plant locations, planners use solar irradiation maps or solar suitability maps superimposed with technical and socioeconomic constraints, as a proxy for actual location data. "Sufficient location data would allow researchers to interrogate the socioeconomic drivers of renewable energy infrastructure siting at a global scale to produce probability surfaces for energy development. "[3]

In recent times a few service providers and think tanks have created databases to address the need for aggregating and disseminating geospatial information on plant location. Wiki-Solar, (https://wiki-solar.org/) one of the solar databases, holds both geographical and technical information of utility-scale solar photovoltaic power plants in operation around the world; Wiki-Solar also carries information relating to several PV plants at various stages of development. The database contains information relating to over 12,000 projects including details of some 8,500 operational projects. The data provided on Wiki-Solar is believed to be comprehensive for projects of over 10MWp in capacity but might be considered incomplete for smaller projects.[4]

Another, more recent, database is the Global Solar Power Tracker (GSPT) by Global Energy Monitor (GEM): an online tool that maps solar power plants around the world with capacities exceeding 20MWp. Currently, the GSPT includes 5,190 operational solar projects across 148 countries and an additional 3,551 potential projects at various stages of development and implementation. Every solar project is linked to a wiki page on the GEM wiki platform.[5] Such geospatial information could be useful for concerned stakeholders, to plan the location of utility-scale solar PV plants and to meet projected demand, while also working on conserving existing biodiversity and natural resources at these sites.

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Solar PV Module For Pavement Application

Hungary's Platio Solar have developed a Solar PV module line featuring both monocrystalline and polycrystalline cells, covered with a 10 mm tempered clear or opal glass and a frame structure providing adequate protection for the glass surface. The frame was made entirely of recycled plastic. The 6.5kg, 359mm x 359mm x 41mm module could potentially be used for pavements, terraces, driveways, sidewalks, bicycle tracks and other low-traffic roads, in addition to being used for routine off-grid applications.

Individual modules are designed to bear a maximum superimposed load of 2 tons and are projected to offer useful lives comparable to mainstream crystalline solar PV modules, while the low voltage ensures the safety for passersby.

https://platiosolar.com/

Platio Solar 2
Source: Platio Solar

Fast-Deploying Solar/Hydrogen Nano-Grid Wheels Emergency Power Off-Grid

Solar for healthcare is a promising new pathway for solar pv applications. Michingan-based company, Sesame Solar leveraged on that front and have developed a solar module which can be moved to different locations and used to run medical equipment, operate water purifier systems and even charge communications equipment and e-bikes.

In June 2022, Sesame Solar from Michigan, USA, (https://www.sesame.solar/), announced the launch of the 100% renewable "mobile nano-grid." The physical size of the nano-grid varied between 10 and 40 feet (3.0m -12.0m) and was designed to take the shape of either a dual-axle trailer (length varied between 14 feet and 20 feet) or an ISO shipping container (length varied between 10 feet and 40 feet). This enabled the grid to be transported by ship, cargo plane, truck, helicopter, train – or be moved by crane or forklift – to any off-grid location including for applications in natural disaster relief, in medical response or in military operations. It was designed to run emergency medical equipment, to operate water purification systems, to run connectivity and communications equipment, or to charge electric bikes. Depending on the model, the Sesame Solar nano-grids could produce between 3 and 20 kW of solar power, with total battery storage of 15 - 150 kWh. [1]

The nano-grid also has a solar-powered electrolyzer which produces hydrogen to power a fuel cell that works in conjunction with the solar PV system. The green hydrogen gas is stored in solid state storage tanks at low pressure (less than 300 psi) on the outside of the nano-grid making it safe to transport. The oxygen gas from the electrolysis can be safely vented out. When the batteries discharge to 35%, the onboard Hydrogen Fuel cell starts charging the batteries using the stored, green hydrogen gas. When the batteries are recharged, the Hydrogen Fuel cell shuts down automatically. The electrolysis process continues to produce hydrogen gas until the storage tanks are full; the process then stops, and the batteries are charged using solar power. This system provides a clean energy loop, ensuring uninterrupted power supplies.

The nano-grids were reportedly robust enough to withstand hurricanes, heavy rains or other adverse climatic conditions, and could remain in operation for 20 years. The grid could operate in a range of ambient temperatures as well. The solar charging operated in temperatures between 32 and 120° F (0 to 49° C), while the batteries discharged in a range between -4 and 140° F (-20 to 60° C). Subject to size and configuration, the cost per unit of the nano-grid ranged between USD 100,000 (~€94, 000 Euro) to USD 300,000 (~€285,000)[2]. Estimated shipping time for the grid was 45 business days from the time the order was confirmed. It was pre-configured to be set-up by one person in less than 15 minutes. Sesame Solar already has acquired a range of clients including the US Air force, non-profit organizations and telecom companies to name a few.[3]

Telecom company, Comcast deployed Sesame Solar Mobile Nanogrid in Houma and La Plain, Louisiana following hurricane Ida to set up crisis response offices. In addition to the small retail outlets offering voice and data connectivity and emergency assistance, the nano-grid provided power supplies to trailers with toilets and shower facilities.

Medical charity, Direct Relief deployed the nano-grid to support a clinic in the remote community of Grand Fond following Hurricane Maria in Dominica. In addition to the routine features, the nano-grid was configured with a rain-water filtration system, equipped with space for patient triage and other medical and communication devices.

https://www.sesame.solar/ sales@sesame.solar

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Jiangxia Experimental Tidal Power Station - A Case of Complementary Green Harnessing

China's Jiangxia Tidal Power Station is the fourth largest in the world and uses a complementary green energy harnessing approach through tidal and solar sources.

The Jiangxia Experimental Tidal Power Station, located near the city of Wenling, Zhejiang Province, China, was commissioned in the year 1980. At the time, it was the fourth-largest system of its kind globally, with a capacity of 4.10 MW by way of its six dual-way tidal power generators. The facility was owned and operated by Longyuan Power, a partially owned subsidiary of state-owned China Energy Investment ("CHN Energy").

In June 2022, CHN Energy connected a 100 MWp floating solar plant to the grid in Zhejiang province linking it to the Jiangxia tidal power station thereby making the combined project China's first hybrid cleaner energy power station. The floating solar PV employed 185,000 bifacial solar modules and was built over 133 hectares for the project. The plant was also remotely monitored using Unmanned Aerial Vehicle (UAV) inspection technology and an artificial intelligence based (AI) diagnosis system. The maintenance system was designed to make use of an early warning model that enabled rapid and remote diagnosis of the condition of the equipment. The UAV enabled daily inspections, facilitated routine patrol and maintenance of the station without the use of requisite manpower and boats and other amenities required to access the floating solar power plant.

The solar plant was estimated to generate 100 million kWh of energy annually (approximated to meet the energy needs of 30,000 urban Chinese households). This project marked China's approach towards complementarily harnessing two green energy sources. Supply from the solar PV project was to be complemented by the generation from the tidal wave power project. The hybrid energy power station was projected to result in savings of about 28,716 tonnes of standard coal and hence, to reduce carbon dioxide emissions by 76,638 tonnes annually (in comparison to the baseload thermal power plants operating in the country).

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Using Solar to Combat Noise Pollution

Of the many applications of solar energy, solar noise barriers are little talked about. Photovoltic noise barriers, also known as PVNBs were introduced in Switzerland as early as 1989 and have since been scaled up for pilot projects in the EU.

The World Health Organization (WHO) has recognised traffic noise as an important contributor to noise pollution which causes discomfort and leaves a significant negative impact on the health of those living in the vicinity of noisy thoroughfares. Photovoltaic noise barriers (PVNBs) were often prescribed as a solution to this issue.

Such barriers involve the combination of noise minimization technology and clean energy generation. PVNBs, as an integrative concept, were introduced in Switzerland in 1989 and have since been successfully adopted by other countries. Such barriers are designed to stand upright, lower noise reaching surrounding areas and to shield immediate residents from noise pollution generated by road or rail traffic, while also producing energy from solar PV systems.

The structure consists of a noise barrier system combined with photovoltaic (PV) panels. The photovoltaic modules are integrated into the barriers as support elements within the soundproofing/sound-absorbing panels. The barriers are also equipped with acoustic dampers, thereby reducing noise from all directions. The photovoltaic cells use the acoustic foam as insulators, which allow for more efficient collection of solar energy. In order to guarantee optimal performance, the design of the photovoltaic noise barriers (PVNBs) was required to consider elements such as materials, location of the barriers, local climatic conditions, orientation, the amount of solar radiation, dimensions, and the azimuth of the barrier.

The performance of the photovoltaic panels within the noise barrier largely depended on factors such as orientation and tilt (inclination), the amount of dust accumulated and implementation of maintenance protocols, shading and climatic conditions. In recent times, the constraints on orientation had been overcome using bifacial PV technology which offered greater flexibility in deployment.

In addition, PVNBs also provided an easy option for installation without demanding additional land use in densely crowded areas, while enabling decentralised clean power generation, reduced costs of energy transmission and emission reduction of CO2 and other pollutants. Since, vehicular traffic was also likely to affect the natural views and the visual quality of an area, these environmental noise barriers offered solutions to such issues.

Source: unknown

Solar Highway

PVNBs have since then structurally evolved since solar cells were increasingly integrated within the noise barrier itself and had not been merely layered to them. On 8 April 2014, the European Commission granted a LIFE+ program grant to the Solar Highways pilot project which was then tendered in October 2017. TNO a Dutch independent contract research organization had brought out a pilot project on the A50, Uden, Netherlands–Solar Highways in which a 400-metre long and five-metre-high motorway noise barrier incorporated 1,600 square metres of solar cells that converted sunlight into electricity on both sides. TNO realised this innovation on behalf of, and in cooperation with, Rijkswaterstaat (Ministry for Infrastructure and Water). Heijmans Infra commenced construction in June 2018 and completed work by December the same year.

The vertical positioning facilitated noise blockage attenuation and helped capture light on both sides, thus generating power more efficiently. The energy generated was independent of the direction in which the motorway ran, and the cells optimised the use of all the available sunlight. The pilot installation which was large enough to generate energy to meet the power demands of about fifty local households. The PV array on the noise barrier was connected to the national grid and was monitored as a demonstration project until year 2020.

The Solar Highways project was considered an example of successful cooperation involving government, research, industrial and social agencies. The vertical placement of these integrated solar panels had opened up new possibilities of applications across sectors. TNO in collaboration with ProRail, had been testing barriers alongside railway tracks that had a potential for 500 to 700 kilometres of noise barriers while also providing the opportunity for the generation of clean energy.

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Aurora Solar Project - A Beacon for Environmentally Friendly Solar Set-Ups

The Aurora Solar project by Enel Green Power was approved in 2014 and was among the US state of Minnesota's first large-scale solar project development. The unique strength of this project is its use of environmentally friendly, multiple-land-use solutions that are now abundant with bees, sheep and flowering plants.

In 2015, the Minnesota Public Utilities Commission approved a permit for the Aurora project, but the Commission rejected three of the sites that were originally proposed (in Pipestone, Wyoming, and Zumbrota) because of local land-use objections. After listening to the farmers' environmental concerns, the company worked on objections to change in land use by working on solutions which helped them garner requisite local support[1].

As a result of these outreach efforts, the 100 MW project was built with 16 pollinator-friendly sites spread across central and southern Minnesota and was completed in 2017 with an investment of USD 290 million. Aurora had capacity to generate approximately 210 million kWh annually, which was estimated to meet the energy consumption needs of over 17,000 U.S. households[2].

The project included flowering ground cover for pollinators like bees and birds, low-growing grass meadows, sheep grazing, and adjacent honeybee hives and at the time was considered one of the best examples for multiple-land-use solar practices. The solar park had integrated many practices such as establishing large-scale habitats for pollinator insect species to boost crop yields and hosted sheep grazing to reduce maintenance costs and to increase solar competitiveness. The benefits of such measures could be enjoyed by both local ecosystems and the neighbouring farmers alike.

The 907-acre Aurora solar plant was divided into sections and each one was managed differently based on its own landscape conditions and ecological goals for regenerative land management. At the time of commissioning, Aurora Solar was the nation's first large-scale solar project designed and built to meet Minnesota's Habitat Friendly Solar Program (2016)[3]. Even though the upfront costs of planting turf grass and a native pollinator mix were similar - the turf grass fescue mix, and the native pollinator mix could each cost in the region of USD 500 per acre – the long-term management and maintenance expenses were higher for the turf grass.

After an initial pilot, the project used mob grazing with sheep to control vegetation on more than half of the Aurora project's land area, and this was managed by Minnesota Native Landscapes (MNL). The sheep also helped to enhance vegetative growth by allowing aeration of the soil and stomping seeds into the ground. Grazing was superior to the use of mechanical lawn mowers, which could also kick up rocks and damage the solar equipment. The pollinator-friendly ground cover required an annual mob graze over a two-week period or a single mowing each year. MNL was working with the National Renewable Energy Laboratory (NREL) on a cost comparison study of the use of grazing vs. mowing in solar farms.

The Aurora Solar Park had also partnered with local beekeeping initiatives, such as Bare Honey[4] in order to install beehives on the periphery of its solar farms. This further supported bee populations and could help promote crop productivity when bees pollinated plants on adjacent farms. Bare Honey was harvested and sold as solar-grown honey to fine dining restaurants, distilleries, and breweries. This created a symbiotic relationship between landowners, community members and solar operators with the added benefits to the environment and the local economy.

A survey and assessment of the Aurora Solar project undertaken in 2020 re-affirmed the state's recognition and certification of the Aurora Solar project for having provided beneficial habitat and meaningful ecosystem services[5,6].

Aurora Solar Project
Source: Enel Green Power

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Solar PV Water Heater From Sunerg Solar

In June 2022, Italian PV module manufacturer Sunerg Solar (https://www.sunergsolar.com/en/) launched a 1,500W water heater equipped with two resistances and powered both by solar energy and grid-supplied energy. The package consisted of a 400 Wp solar PV module, a boiler of 80 litre capacity and a Maximum Power Point Tracking (MPPT) charge controller for optimizing the DC current flow between the panel and the heater. The controller worked on a Perturb and Observe algorithm consisting of an artificial neural network to reduce the oscillations at the MPP, thereby maintaining the point of maximum energy transfer from the panel to the water heater and overcoming limitations imposed by uneven illumination of the PV module.

The module accompanying the heater could generate an estimated 2.800kWh of electricity each day and could raise the temperature of the stored water by 30 degree Celsius. The efficiency of the solar module ranged from 19.18% to 20.38%, while it was said to be tolerant to ambient operating temperatures between -40 o C and +85 o C. The water heater – PV module – power electronics package was to retail at €1,200 (~USD 1,290) excluding VAT and installation costs. Sunerg offered a 3-year warrant on the water heater, a 2-year warranty on the controller and a 25-year product warranty and a 30-year performance warranty on the solar PV module[1].

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Electrostatic Repulsion To Clean Solar Panels

According to an estimate by the United Nations International Children's Emergency Fund (UNICEF) in 2022, nearly four billion people in the world experienced severe water scarcity for at least once a month each year[1]. Water is becoming the most contested resource globally. In such a scenario, using water to clean solar arrays cannot be a sustainable option in several countries. Dust accumulation on solar arrays could reduce their energy output by as much as 30% per month. It was estimated that for a 150MW plant, even a 1% reduction in energy output could result in a reduction of USD 200,000 from annual revenue. With many countries looking at solar power installations to solve the energy crisis, alternative methods to clean the arrays had to be found.

A group of researchers from Massachusetts Institute of Technology (MIT), USA, developed a way to clean solar panels without water. The team's "contactless" method used electrostatic repulsion that caused dust particles to detach from the panel's surface. The system used a simple electrode placed just above the surface of the solar panel that imparted an electrical charge to the dust particles. These dust particles were then then repelled by a charge applied to the panel itself. The team suggested that the process could be automated by attaching railings on each side of the solar panel, with an electrode spanning across the panel. The researchers tested their method of cleaning in humidity ranging from 5% to 95% and observed that the system worked best when humidity was 30% or higher. The team claimed that the contactless method of cleaning could save enough water to serve the needs of an estimated two million people [2].

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Dusty solar panels in Gansu province
Source: Credit-Michael-Hall-Getty-Images

Solar Site Runoff Issue Leads to Jury Award for Damages

BayWar.e, (https://www.baywa-re.com/en/) a global renewable energy producer, service provider and distributer have developed a solar farm in 27 acres of land, adjacent to the properties of Honeybee Ranch[1]. The company had planned to clear the vegetation that was in the way of the construction of the solar farm and access roads. Some news reports also stated that the company had informed the San Diego County Planning Commission that the solar site runoff would not see an increase, and that the vegetation would be replanted after construction.

A lawsuit was filed against BayWar.e in 2017 by two landowners of the properties adjacent to the solar farm alleging negligence and trespass. The plaintiffs claimed that the vegetation clearance was not limited to the installation of solar plant and to building access roads; that instead the vegetation on the site had been cleared completely. Consequently, the runoff from the solar site had flown across a road and further down to the Honey Bee Ranch property when the area experienced heavy rainfall. The complaint alleged that such irreversible alterations to the upstream landscape caused damage to the plaintiff's properties.

The co-owners of the damaged properties, Honey Bee Ranch had succeeded in convincing the San Diego Superior Court of the cause, the damage and the loss, and were awarded USD 6.50 million in compensation. A news report claimed that while one portion of the compensation reflected the negligence of the solar farm developer and failure to install preventive measures to channelize the runoff, another portion – of about USD 4.0 million – represented the abnormal profits earned by commissioning the solar farm by a certain date.

BayWar.e claimed in court that the company had installed a soil stabilizer after clearing the property. However, the soil stabilizer did not prove effective enough during a rainstorm that led to runoff. The company also stated that BayWar.e had taken remedial measures soon after. Subsequently, the property was reseeded, and the vegetation revived, and no damages relating to floods were observed or reported subsequently.

Silicon Ranch Lumpkin Solar Farm
Source: renewableenergysource.com

Solar Powered Marine Plastic Collecting Robot

In 2022, the United Nations Environment Program estimated that more than 400 million tons of plastic waste was produced every year, and less than 10% of the plastic produced got recycled. The remaining ended up in landfills or got thrown away in water bodies like rivers and seas. As of 2022, somewhere between 75 and 199 million tonnes of plastic might have found itsway into the oceans[1]. Marine animals could ingest these plastic products and through the food chain such plastics could reach the human body, affecting the functioning of liver, spleen, kidneys and other organs.

Recyclamar Pampa, an environmental protection company in Argentina teamed up with engineers from the Electronics, Control, and Signal Processing Research Institute (LEICI) at the National University of La Plata (UNLP) in Argentina to tackle the problem of plastic pollution in water bodies. While Recyclamar Pampa provided expertise on water treatment processes, the team from LEICI built the model, and provided the algorithms for the sensors [2]. The deck of the robot resembled a small catamaran, and housed the solar panels that charged the batteries. The robot had the capacity to clean water bodies up to a depth of 40 cm. Macro-plastics such as water bottles and packaging containers were the main pollutants that the cleaning robot could collect[3]. Recyclamar Pampa aimed to commercialize the robot in Latin America and the Caribbean, though the company did not discuss the costs involved or the market price of the robot itself.

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Solar Robot
Source: inhabitat.com

Solar Skin – Camouflage Solar Panels

Aesthetics of solar panels were a significant barrier to rooftop solar adoption for residents of many communities in the USA. To tackle this issue, Sistine Solar (https://www.sistinesolar.com/), a US based start-up, designed a solar panel with a new, integrated component that allowed home-owners to customize the aesthetics of their solar panels, so that the modified solar panels blended with the rooftops. In 2015, the company received USD 1.0 million through Technology to Market: Incubator 10 run by the Office of Energy Efficiency and Renewable Energy, US Department of Energy, to "properly develop a fully tested, verified, and certified product that is ready for market deployment[1]. By 2017, the company had developed and completed tests on several installations and had received significant interest from the market.

Sistine Solar's design consisted of placing a thin, printable layer within the panel: this layer could be customized to customer's needs. The layer allowed light through to the photovoltaic cells while projecting the customized image. The solar panels utilized a racking system without rails that allowed the panels to "sit" lower on the roof to give a sleeker finish to the installation[2].

According to the company, the design increased the cost of installations by 10% over the traditional rooftop installations[3]. However, it still offered savings of many thousands of dollars over the life of the panels. The company was also contemplating using the solar skins on billboards for advertising. By 2022, solar skins were considered one of the technologies that would revolutionize energy production in the USA.

Figure 1: A comparison of a traditional solar panels vs the panels with "solar-skin"
Source: unknown

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Low Temperature Coefficient TOPCon Module from AE Solar

In October 2022, AE Solar of Germany (https://ae-solar.com/) announced the launch of three solar module designs based on n-type tunnel oxide passivated contact cell technology ("TOPCon" technology: https://ae-solar.com/topcon-technology/). The modules were designed with glass-glass sandwich and with polyolefin elastomer as encapsulation material. This made the module durable when deployed in extreme climates including in deserts. The glass-glass modules were also projected to be more durable when exposed to windy and snowy conditions[1].

AE Solar proposed to manufacture the modules in upgraded production lines at the company's factory in China. The largest module series included variants offering power output in the 555W – 575W range, with projected operating efficiencies of about 21.50% - 22.28%. The "mid-size" series announced by the company offered products in the 460W – 480W range, projected to operate at conversion efficiencies in the 21.26% - 22.18% range. The smallest modules were rated between 410 and 430W and were slated to operate within the 20.00% - 22.01% range.

Above all, the new series of AE Solar modules were designed to operate between (negative) 40 deg C and (positive) 85 deg C with a temperature coefficient of (negative) 0.35% per degree C rise in ambient temperature. AE Solar offered a 15-year product warranty on the new modules and a 30-year power output guarantee of 87.4% of the initial power yield. These guarantees were based on projections relating to lower degradation rates suffered by TOPCon technology modules in the early stages of deployment[2].

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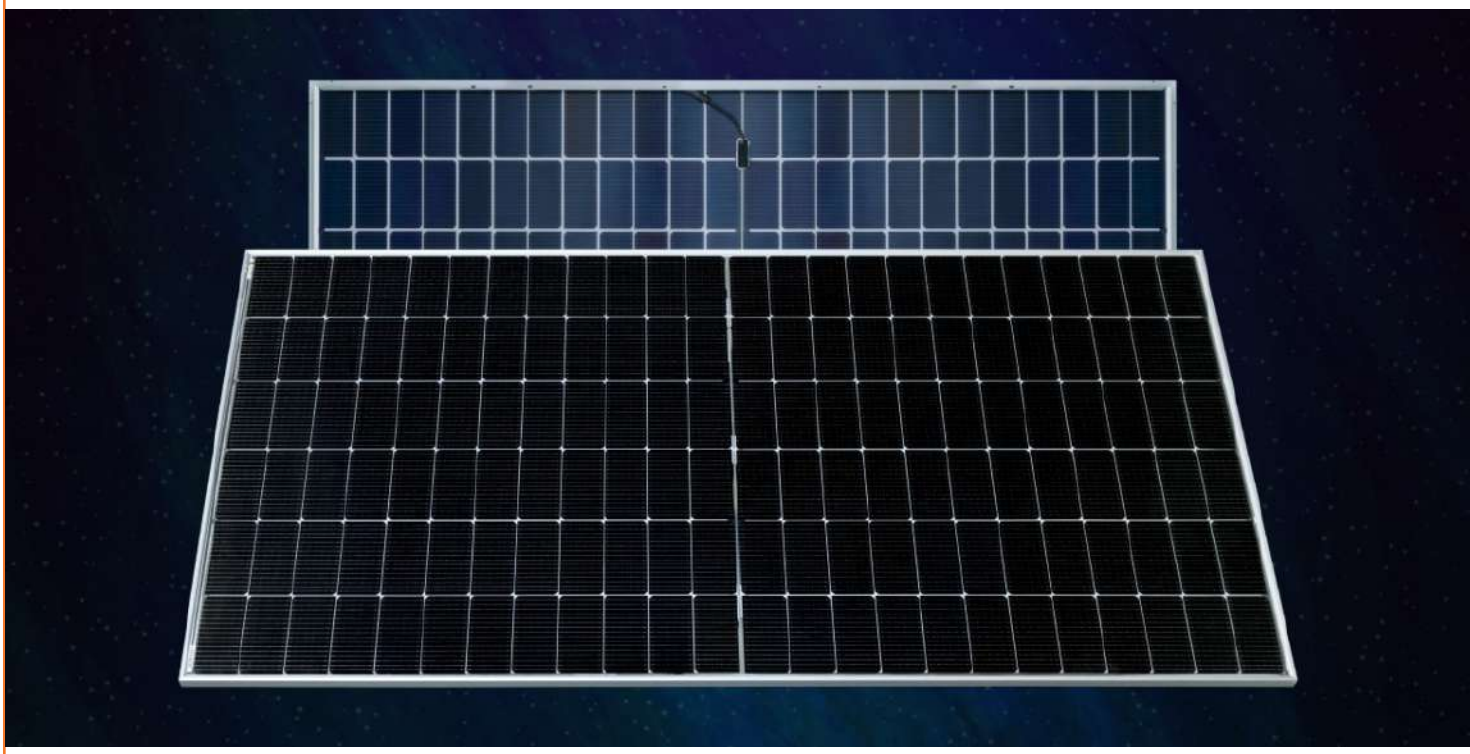

Solar topcon model
Source: AE Solar

Volt Light-Weight Solar Roof Tile

In October 2022, solar roof-tile manufacturer Volt, part of Australia's Leeson Group, (https://www.leesongroup.com.au/) launched the light-weight Clean Energy Council certified Volt tiles, a solar PV module that integrated seamlessly with the traditional roof profile. Volt launched the 115W "Planum" model rated at 18.8% solar-conversion efficiency and 105W "Lodge" variant rated at 19.4% conversion efficiency. The Planum and Lodge tiles had been under development for about 8 years and the launch symbolized readiness for global distribution and installation. The solar roof tile was 7 times as wide as the traditional terracotta roof tile and the solar section was designed to be framed by the terracotta roof tiles. The company offered a 15-year product warranty and a 30-year performance warranty on the Volt tiles on the strength of automatic production and stringent quality assurance processes[1].

Volt believed that integrating PV into the roof structure was a critical part of scaling-up PV deployments. The Volt offering was slated to give the company a selling proposition to access the newly built market and to install large volumes relatively quickly. At the time of the launch, a 5.0kW Volt system was projected to cost AUD 12,000 net of rebates available at the time.

Following demonstrations in Australia, the China-made product was scheduled for deployment in Spain[2]. The company also intended to set up a manufacturing unit in Australia to produce frame extrusions, and for cutting and assembly in Australia. These components represented 50% of the volume and cost of the product and represented a significant part of the intellectual property embedded within the product. The company then proposed to expand the line to manufacture the entire module in Australia[3] by year 2025.

Figure 2: Volt Solar Roof tile
Source: unknown

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Solar Powered Temperature Sensor for Compost Dumps

Australia's Rhino Instruments have developed an independent solar powered temperature monitoring device with its own modem for internet connectivity to help track temperatures of waste dumps and thereby reduce risk of fires.

Given the high temperatures from exothermic reactions, municipal solid waste containing combustible waste material is consistently faced with the risk of ignition. Once ignited, such fires usually sustain for several days and leave short and long-term health and environmental harm in their wake. Such waste dumps typically contain paper and cardboard, wood, plastic, rubber, textiles, electronic waste and surfaces with paints and other combustible material. Often dump sites ran on generators and the sites were left with no reliable power or internet communication outside of routine office hours. Consequently, poor temperature monitoring processes have been linked to waste dump fires and to delayed responses and extended response times.

Given these circumstances, Rhino Instruments of Australia (https://rmac.io/: subsidiary of Sequence Digital) commenced work on developing an independent solar powered temperature monitoring device with its own modem for internet connectivity. Product development was supported by the Victorian Government and by an AUD 26,000 grant from Cleantech Innovations Geelong, a collaboration between the City of Greater Geelong and the Geelong Manufacturing Council, Australia[1].

The weather–proof solar-powered temperature sensors ("RM1") developed by Rhino instruments were designed to track temperatures of waste dumps and thereby to reduce the risk of fires from compost piles. The hardware was designed to be rugged with a powder-coated metal enclosure and was "repairable" while offering "one button: press and walk away" operation. Each device was equipped with a 4G modem and SIM card to transmit the temperature data to monitoring centers.

The operator was required to insert the RM1 into a compost stockpile, to make sure that the panel faced the afternoon sun, to press the button and to carry on with routine work. In addition to monitoring temperatures of compost piles, the sensor could be used for other materials and higher temperatures as well[2].

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IEA-PVPS Guidelines for O&M of Utility Scale PV Plants

The International Energy Agency (IEA) paper of October 2022 presenting Guidelines for Operation and Maintenance of Photovoltaic Power Plants in Different Climates defined operation and maintenance (O&M) programs for four climate zones – moderate, hot and dry, hot and humid and deserts at high elevation areas. The paper also assessed plant performance and O&M protocols in the context of climate events like floods, cyclones and snow fall. The paper serves to create a clear O&M framework through defining performance indicators and standardized O&M procedures for third-party operator services.

Tied to systematic O&M is plant performance and evidently, forecasting plant performance routinely assumes the continuation of systematic O&M measures at the plant. The paper describes maintenance services and inspections, offering a series of recommendations for zone – specific protocols. While mentioning the activities that need to be included, the action plans also specify activities that could be excluded to optimize O&M effort and costs, given a plant's size and design. The Guideline report is intended to assist PV plant engineers and investors in defining operational risks and in designing O&M protocols customized to suit specific climatic zones and to facilitate investment decisions[1].

The Guideline recommends on-site evaluation of vegetation, wildlife and the presence of farm animals to assess the need for vegetation management, grazing of livestock, and other such measures to assess cleaning and maintenance actions required. Cleaning products are to be chosen to respond to specific climates and prevailing ambient conditions. In hot and dry climates, for instance, O&M protocols entail assessment of wildlife risks, planning for hydration, anti-venom, travel to and from plant sites and associated logistical risks and the like. Further, nesting insects and animals could cause arc flashes and short-circuits. Extreme temperatures and exposure to salt are known to accelerate the degradation of modules, frames, junction boxes and transmission cables.

In hot and humid conditions, the Guideline advises special attention to rodents, snakes and termites that could potentially cause failures in PV components and electrical systems. Dust accumulation in these zones could lower the power output from the plant while cleaning schemes could be designed to avoid production losses, especially during the dry months. Agricultural activities in the vicinity, and slash and burn in particular, could contribute to fire risks which would need to be managed appropriately. Adequate ventilation during the hot months is reportedly crucial for operating inverters [2].

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Case Development of India's First Solar Town

A short overview of India's ambitious and successful project to electrify an entire town with solar energy.

Modhera, a town in the Mehsana district of the western Indian state of Gujarat, is famous for an archeologically significant, protected Hindu temple dedicated to the Solar deity (Sun God) and not surprisingly also endowed with an abundance of sun throughout the year. In August 2021, the town became the first in India to be completely powered by solar energy.

The solar electrification project involved setting up a 6.0MW solar PV plant on a 12-hectare plot of land three kilometres away from the town. The plant was combined with a 15 MWh Battery Energy Storage System (BESS), 271 rooftop installations of 1.0kW capacity placed on residential buildings, 1,610 smart meters and an EV charging station. The Gujarat Power Corporation Limited, the electricity utility had appointed a private firm Mahindra Susten (https:/www.mahindrasusten.com/) as the Engineering, Procurement, and Construction (EPC) contractor; the company was also entrusted with the responsibility of maintaining the plant for a period of 10 years. The investment cost of INR 650 million (€ 7.9 million) was borne equally by the Central and the Gujarat state government[1, 2, 4, 5].

This project met the domestic and agricultural needs of approximately 1,400 homes, which aggregated to approximately 10,000 units a month. Further, it was found that the project generated fourteen times more energy than needed to meet such demand; such surplus power was to be exported through the utility grid network.

In addition to this, Green Power Monitor (GPM), a renewable energy digital services company, provided data driven digital solutions to the monitor and control the project components. GPM's power plant controller and energy management system enabled the batteries and other components to cater to black start, islanding, anti-islanding, energy shifting, state-of-charge management and balancing, frequency and voltage support. This was a unique hybrid solar project in the whole of India, both for having used renewable energy to electrify an entire village, and for providing uninterrupted power supply enabled by the battery storage system[1, 2, 3].

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Floating Solar PV at Kayamkulam to Replace Fossil Fuel Plant

India's first ever floating solar plant installed in Kerala's brackish backwaters is a great learning curve on utilising solar in unique topographical areas to maximise the use of land as well as water.

India's National Thermal Power Corporation (NTPC), state owned power generation utility and the country's largest integrated energy company owned and operated the Rajiv Gandhi Combined Cycle Power Plant (RJCCPP), located at Kayamkulam in the southern Indian state of Kerala. In 2017, when cost+ prices of electricity reached INR 15.0 per kWh (~€ 20 cent per kWh) the Kerala State Electricity Board (KSEB), the electricity utility serving the state of Kerala halted the purchase of power from the 359-MW naphtha-fuelled RGCCPP.

Ever since, the plant had been idle. The state government continued to pay INR 2.0 billion (~€24.0 million) each year to NTPC in accordance with the agreement between the state government and NTPC and as prescribed by the Central Electricity Regulatory Commission, to meet the fixed costs associated with the plant. This amount was revised to INR 1.0 billion (~€12.0 million) in 2020.

By 2017, NTPC had commissioned a pilot 100kWp floating solar PV plant in Kayamkulam, which at the time was India's largest floating PV power plant[1]. Following the successful commissioning of the pilot, NTPC redeployed personnel from the fossil fuel-based power plant and shifted focus to floating solar energy as the company was already in possession of approximately 1,000 acres of land area that included water bodies suitable for setting up floating solar projects. The Kayamkulam floating solar project was thus built over 350 acres upon a several reservoirs owned by NTPC. More importantly, the project was India's first floating solar plant installed in brackish back waters.

The 92.0 MW project was implemented at a cost of INR 4,650 million (~€55.0 million) deploying 216,000 solar panels mounted on floaters. The project implementation work was awarded to two companies – Tata Power Solar (70.0 MW contract awarded in Sep 2019) and state-owned Bharat Heavy Electricals Ltd (BHEL, 22.0 MW). After the award of contracts however, project implementation had to be rescheduled due to delays in import of solar cells from China[2].

The facility also provided for a platform for floating inverters of 5-Megawatt (MW) capacity each. This floating platform had been indigenously developed by NTPC Energy Technology Research Alliance, (NETRA) the R&D arm of NTPC Ltd, in collaboration with the Central Institute of Plastic Engineering & Technology (CIPET). Project engineering, supply, and installation of floats, anchoring and mooring was completed within 70 days by Ciel & Terre India, (the subsidiary of French floating solar pioneer Ciel & Terre International)[3]. The Central Monitoring and Control Stations (CMCS) and the 33/220 kV switchyard were anchored by 134 cast pile foundations, bored to a depth of 20 metres below reservoir bed. This was accomplished by dredging the underwater soil layers, where high groundwater levels posed severe challenges to the stability of the structure. The installation was completed within the stipulated time period, despite the project's having to accommodate fluctuating water depths, high sea tides, and severe water salinity concerns.

The 22.0 MWp phase was commissioned by BHEL in March 2022[4]. TATA Power Solar commissioned 35 MWp capacity in May 2022. When the second 35 MWp unit was commissioned by TATA Power and the plant started to feed electricity into the grid in June 2022, NTPC, declared the Kayamkulam floating solar project as having been fully commissioned[5, 6]. The project supplied the power generated to KSEB through the 220kV GIS substation at the NTPC Rajiv Gandhi Gas-based power plant; KSEB was contracted to purchase power from the floating solar station at INR 3.16 per kWh (~€ 4 cent per kWh).

Photo credit: TATA Power, https://www.power-technology.com/news/tata-power-floating-solar/, last accessed 29th June 2022.

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Solarstone Solar Tile

Estonia's Solarstone developed a dual-function solar tile that served the purposes of being a roof covering, and simultaneously, generated electricity from the embedded solar cells.

Two variants branded the "Solarstone 90" and "Solarstone 180" – which differed in their power output and in their physical sizes – were developed to cater to most sloping roof designs. The 90Wp "Solarstone 90" variant measuring more than 1.5 meters in length and weighing 7kg, consisted of mono-crystalline PV cells arranged in a rectangular fashion covered a prismatic glass, offering an efficiency of 19.5% [1]. The "Solarstone 108" variant demonstrated an efficiency of about 19% and was only slightly bigger in size. Both the tiles were made weather-resistant by integrating the solar cells with a patented aluminum based framing kit branded "Click-On"; both variants had an operating temperature coefficient of -0.41% per C and a maximum system voltage of 600V [2,3]. It was estimated that a 10.6 kWp solar roof of this kind would generate approximately 9,600 kWh per year, offsetting about 9,600 kg of CO_2 emissions every year in addition to reducing the electricity costs for the consumers [2].

These building integrated modules were projected to be ideally suited for new homes that would prefer to have a tiled roof, since the solar tiles had been designed to interlock with most clay and concrete tiles. The Solarstone tiles were slated to not compromise on building aesthetics as the product was also positioned as a viable option for carports, facades, canopies and other commercial/public buildings.

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Solarstone solar tile
Source: Solarstone

Using Solar For Safe Drinking Water In Tanzania

With limited access to clean drinking water in rural Tanzania, poor health conditions and use of polluting wood fuel were on the rise. The use of Solar wave water purifier made by the Swedish Company, Tricorona helped address this issue using solar technology.

SolarWave Water Purifier
Image credit: SolarWave Uganda

Ensuring sustained access to clean and safe drinking water to people in sub-Saharan Africa has always been a challenge. The problem is more acute in some countries than others where natural spring water is high in certain harmful salts or chemicals. UNICEF estimated that close to half the population in Tanzania had no access to clean drinking water, contributing to widespread and largely preventable deaths in the country.

People in rural areas of Tanzania use a 3-stone stove to boil water that is available for drinking to remove impurities and contaminants and make it safe to drink. However, this led to another issue in the country: deforestation. Due to a lack of access to cooking fuel, people were rampantly chopping wood from forested areas across the country to use as fuel to boil water.

The extraction of wood from natural forests and the use of such fuelwood interferes with the natural carbon capture [ecological services] offered by the trees and releases greenhouse gas emissions (particularly carbon-di-oxide) and particulate matter upon burning. This adds to air pollution and thereby worsens health conditions among people. Additionally, women and young girls ended up spending considerable time collecting wood and water supplies on foot from long distances.

"Solar wave" water purifier, funded by Swedish company Tricorona (https://tricorona.se/), was a water purification system powered by solar energy to fulfil the basic drinking water requirement of rural Tanzania more sustainably. The purification technologies complied with the relevant national drinking water standards (TZS 789 "Drinking (potable) water – Specification") and were installed in water kiosks, hospitals, schools and rural households and other locations across the country.

SolarWave water purifier demonstration
Image Courtersy: SolarWave AB, YouTube

The project was implemented by Carbon Asset Management Sweden AB while the coordinating/managing entity (CME) was SolarWave Tanzania Ltd. A local partner in Tanzania managed distribution and monitoring requirements.

A single water filter unit is capable of purifying 700 litres of water every hour for eight hours, catering to at least 280 persons' daily consumption. Ten units were installed as part of the pilot project. In terms of impact, the project estimated to have avoided the emissions of 5,184 metric tonnes CO2 equivalent per annum from displaced fire-wood consumption.

Additionality the CDM-registered project was established based on each CPA being a micro-scale project that would emit less than 20,000 tCO2 emissions annually, against a non-renewable emission intensive scenario, in a least developed country like Tanzania.

Sunnyside Landfill Solar Project

The City of Houston in Texas, USA chose to develop a solar PV project on an urban landfill site after winning the 'C40 Reinventing Cities Competition', where cities had come together to propose creative ways to redevelop underutilized sites in a sustainable manner

The City of Houston proposed to redevelop the 240-acre landfill site near the Sunnyside village to produce clean energy. This was achieved through efficient utilisation of an unused parcel of land in the city, while also attempting to meet the rising electricity demand through cleaner energy options; such deployment was a part of the city's Climate Action plan as well.

The chosen landfill was left unutilized since its closure and capping in the 1970s. An incinerator was then built in the vicinity to manage the growing waste in the region. The residents of Sunnyside, majorly members of historically disadvantaged communities who lived in the vicinity of the landfill faced multiple problems that included groundwater contamination, air pollution, and strong stench among others [1,2].

Wolfe Energy and BQ Energy were contracted to develop a 50 MWp ground-mounted solar capacity and a 50MW battery storage system, along with other community targeted initiatives. To additionally benefit the communities nearby, 2.0MW in capacity had been set aside for a community solar project. Members of the community were trained to operate and maintain the solar PV project. An agricultural hub had been dedicated to train the locals on growing food and increasing biodiversity in the region, so as to increase income levels while achieving food security. The city leased the land at 1$/year/acre to the company, while other investment costs were privately financed by the companies. The project [scheduled to be fully operational by year 2023] was estimated to supply power to approximately 10,000 households, thereby offsetting around 120 million pounds of CO2 per year, compared to the fossil fuel counter factual.

It was made mandatory for the companies to take measures to not disturb the landfill capping during installation, which would help keep toxic methane explosions at bay. This project had served as a good demonstration of having reutilized environmentally degraded land to generate renewable energy, and to meet growing energy demand in the region. Once commissioned, this project would be the biggest urban landfill solar project in the United States, bringing significant and positive economic and environmental outcomes [2,3].

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CDM-Registered Solar PV Project in Thailand

Over the decade spanning 2000-2010, the increase in electricity consumption helped lift large sections of the Thai population out of poverty. However, over 90% of the electricity consumed at the time was supplied by fossil fuel – coal and natural gas – fired power plants that contributed significantly to greenhouse gas emissions in the country: as a consequence, the greenhouse gas emissions grew by almost 70% over this period.

At the turn of the decade in 2010, the utility scale solar photovoltaic (PV) market in Thailand was virtually non-existent, with installed solar energy capacity accounting for fewer than 2.0 megawatts (MW). This weak performance was reported despite the incentives offered by the government and despite diminishing technology costs. Thailand was also the first among the Association of Southeast Asian Nations (ASEAN) member states to institute the equivalent of a feed-in tariff (FiT) for solar PV, among other RE options[1]. However, potential investors were relatively unfamiliar with solar PV technology and had found the incentives provided by the Thai government inadequate, or potentially unsustainable over the longer term. This perception therefore prevented long-term commercial capital from being applied to solar PV projects in the country[2].

Given the above circumstances, the International Finance Corporation (IFC), the private sector arm of the World Bank Group, initially provided an USD 8.0 million loan from its own funds, which was then "blended" with USD 4.0 million in concessional financing from the "Clean Technology Fund," a multi-donor fund within the Climate Investment Funds that provided middle-income countries with concessional resources for climate change mitigation projects with high impact potential[3]. This fund was meant to help leverage the government's efforts and to support Solar Power Company Group (SPCG), to develop a utility scale solar PV power plant in Thailand.

The funding was to be utilized to construct and commission a total of 36 solar photovoltaic plants adding up to an aggregate installed capacity of 260 MW by 2014[4]. Concessional donor participation, under these circumstances, helped with awareness creation among banks and helped provide comfort to local banks to engage in long-term financing of solar PV projects.

"The Solar Power Company 94 MW Solar PV Project" was a grid-connected project located in the provinces of Nakhon Ratchasima (Karat), Sakon Nakhon, Nakhon Phanom and KhonKaen, in northeastern Thailand. The project had installed 78.41 MW of inverter capacity and 81.53 MW of PV units at twelve sites across the four provinces. The project was projected to generate 109,213 MWh of electricity from 81.53 MWp DC of PV capacity at the twelve sites[5].

The commissioning of SPCG's solar plants demonstrated the power of early-stage strategic investments that could help unlock a "climate-smart" opportunity, which opportunity could then be financed by mainstream intermediaries on commercial terms, past the initial support period.

Kyocera Corporation, a Japanese based PV supplier, installed a total of 174,960 KD210GH-2PU poly-crystalline modules with a power rating of 210 Wp DC, 155,520 KD240GH-2PB poly-crystalline modules with a power rating of 240 Wp DC and 31,104 KD240GH-4PB poly-crystalline modules with a power rating of 240 Wp DC for the plant[6]. At the time, the solar modules had an estimated life of 25 years. The inverters connected to the grid were 5.94 MW in output capacity at six of the sites and 7.13 MW in output capacity at six of the remaining sites.

Each of the twelve plants was connected to the 22kV grid located adjacent to the project site and the first of the plants (KR1) began commercial operation in April 2010. As a part of the installation of the solar plants, SPCG undertook comprehensive environmental and social assessments, expanded public consultation efforts, and thereby garnered local support. The commissioning of Solar Power Company's 36 plants helped create more than 20,000 local jobs in construction and during operations[7].

The "Solar Power Company 94 MW Solar PV Project" was registered as a Clean Development Mechanism (CDM) project in December 2012 (Id:TH8625).(The difference in plant capacity relative to capacity mentioned in the CDM registered project title arose when four of the sixteen originally proposed sites failed to meet some of the qualifying criteria for CDM registration.) The energy yield estimate had forecast a total electricity capacity of 109,213 MWh in the first year for the newly installed solar plants and the estimated annual average GHG emission reductions stood at 56,063 tCO2e, relative to a fossil-fuel-heavy baseline.

During the first monitoring period (01/01/2013 to 31/05/2014) for the CDM-registered project, the net electricity exported to the grid by the Project Activity was 170,731 MWh and the total net emission reductions claimed in the monitoring report were 94,824 tCO2e[8]. Owing to the specific and pioneering nature of the project and to such performance, the project was accorded the "Gold Standard Project" status in 2017[9]. The power produced by the project activity helped mitigate the release of CO2 that might have otherwise emanated from the combustion of fossil fuels in the power plants connected to the Thailand national grid. The Solar PV project ensured that Thailand stayed on a low-carbon growth path and had, additionally, reduced the country's reliance on imported fuel for power, while driving economic growth in the country.

Given the performance of the project, the National Energy Policy Council, Thailand's highest energy policy-making agency, subsequently raised the country's Renewable Energy target to 30% of the total energy produced in year 2037, with solar PV capacity projected[10] to reach 15,574 MW.

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500MW Dau Tieng Solar Project in Vietnam

Vietnam's nascent solar market witnessed a sudden boom in solar installations in the year 2019, on the back of some very attractive feed-in-tariffs. The total installed capacity increasing from a little more than 100MW in 2018 to 5,700 MW by the end of December 2021. One of the major projects implemented during this period was the USD 392.5 million (~€ 344.22 million), 500 MW Dau Tieng solar array which was considered to be one of the largest installations in all Southeast Asia.

The three-stage solar PV plant with a 220kV substation and inverters was built by PowerChina Huadong – the EPC contractor – on behalf of Vietnamese project developer Xuan Cau and Thailand based B.Grimm Power. Jinko Solar of China supplied the 330 W multi-crystalline PV modules for the project.[1] The first two stages of the project with a cumulative capacity[2] of 350MW had been commissioned by June 2019, while the third stage with a capacity of 150MW was commissioned in September 2019.[3] The project sold power to the state-owned utility Electricity of Vietnam (EVN).

The solar array was built on the Dau Tieng Reservoir, where the water levels fluctuated wildly throughout the year: this made Dau Tieng one of the most challenging installations ever. Since floating solar structures could not work under such conditions, special concrete pillars with heights ranging from 2.5m to 8.0m were sourced from Arctech Solar. Using a special vessel, these pillars were planted on the bed of the lake. Special zinc brackets were mounted on top of the pillars upon which the panels were mounted. Notwithstanding the attention paid to the design, the project faced many challenges during the installation, including supply shortages and fluctuating water levels. However, the contractors succeeded in completing the project in time, as contracted.[4]

Apart from such big projects, massive scaling up of roof-top installations were seen in Vietnam. More than 9GW was installed in 2020, of which 6.1GW was done in December 2020 alone. This was because the government offered a feed-in-tariff (FIT) of 8.38 US cents/kWh, for a duration of 20 years, for projects commissioned by 31 December 2020. The installation companies had to comply with the EVN grid codes, and obtain required licenses prior to installations. The EVN was responsible for signing the Power Purchase Agreements (PPAs), supplying and installing 2-way meters, calculating the power production and making yearly payments. The optimal financing model for Vietnam was considered to be equity for the first 5-10MW, then once scalability and sufficient track record was proven, getting debtors involved.[5]

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Scaling Rooftop Solar in Vietnam

According to the 2018 Vietnam Electricity (EVN) Annual Report, energy demand was predicted to increase by 8% per annum between the years 2021 and 2030. To meet this demand, the country had to install 60,000MW of electricity generation capacity by 2020, 96,500MW by 2025, and 129,500MW by 2030[1] to meet such projected demand.

The Vietnamese Government decided to promote renewable energy installations in the country through attractive feed-in-tariffs, especially in the roof-top solar segment. Many investors also focused on the rooftop solar segment, since this segment offered flexible installation time frames and availability of investment capital options. Further, rooftop installations attracted the attention of industries due to self-consumption and trade alternatives, especially since the average power price in Vietnam rose by 8% in 2019, as compared to the previous year.[2] Rooftop solar PV was considered a viable investment option due to a confluence of factors working in its favor.

The government had offered a feed-in-tariff (FIT) of 8.38 US cents/kWh, for a tenure of 20 years, for projects commissioned by 31 December 2020. The installation companies had to comply with the EVN grid codes, and to obtain required licenses prior to installation. EVN was responsible for signing the Power Purchase Agreements (PPAs), supplying and installing 2-way meters, calculating the power production and export and making periodic payments.

The optimal financing model for Vietnam was considered to be equity for the first 5-10MW, and then getting lenders involved once scalability and track record of the project developer was proven,[3] Vietnam installed more than 9.0GW of rooftop solar in year 2020, of which 6.1GW was commissioned in December 2020 alone, shortly before the feed-in-tariff scheme was set to end. According to the state-owned Electricity of Vietnam (EVN), approximately cumulative 10GW of rooftop solar was installed by September 2021, accounting for 10% of the total renewable energy capacity installed in the country.

Following this accomplishment, the German Development Cooperation Agency (GIZ) and the Electricity and Renewable Energy Authority (EREA) of the Ministry of Industry and Trade (MoIT), Vietnam, partnered to implement the "Commercial and Industrial Rooftop Solar" (CIRTS): a rooftop solar project in Vietnam's commercial and industrial sectors, which was to be completed by year-2025. Through the CIRTS project, the partners aimed to conduct a gap analysis for technical rules and standards for the grid integration of rooftop solar, strengthen EVN's operational capacity for technical and administrative adaptation of power supply activities, and improve access to knowledge for stakeholders concerned.[4]

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Infrastructure Woes Limiting Solar Potential In Vietnam

Vietnam's policy support for rooftop solar is worthy of credit for its rapid expansion in capacity. This policy push and the resulting capacity addition is considered unique among the ASEAN Member States (AMS).

Vietnam witnessed a solar boom from 2018 to 2020 on the back of some very attractive Feed-in-Tariffs, with solar installations growing[1] from 105 MW in year 2018 to 16,500 MW in year 2020. Over this period, rooftop-solar was also deployed at a rapid pace, with cumulative installed rooftop-solar PV capacity reaching 9,000 MW, of which 6710 MW was commissioned in December 2020 alone.[2] Vietnam's policy support for rooftop solar was considered the primary reason for this rapid expansion in capacity. This policy push and the resulting capacity addition was considered unique among the ASEAN Member States (AMS).

Malaysia and Thailand were encouraging rooftop solar PV using a net-metering scheme aimed at self-consumption, while Indonesia mainly focused on residential usage. However, Vietnam's policy support for solar rooftop was the use of Feed in Tariff (FiT) to export the generated power to the utility grid network, similar to the country's policy for ground-mounted solar.[3] The tariff rate was set at 8.38 US cents/kWh for a period of 20 years, which was far higher compared to the FIT rates being offered by other countries in the region, attracting international investors to the solar segment.

While the government of Vietnam was focused on promoting solar installations, the agencies concerned might not have foreseen the infrastructure challenges due to such rapid installations. For instance, in Vietnam, it took an average of around three years to construct a transmission line, while a solar farm took around one year; a rooftop solar installation took much less time. Lines needed to be planned well in advance. However, when policies related to rooftop solar were introduced in 2018, and the policy makers and the utility had not anticipated such a sudden increase in installations.

By mid-2022, the rapid boom in rooftop solar installations meant that the existing transmission infrastructure could not handle the production spike during peak sunshine hours. Added to the problem, businesses were shut during the CoVid-19 pandemic, leading to reduced demand. To handle this situation, the state power company requested individual stakeholders, small scale producers, and industrial solar farms to limit their operations during peak sunshine hours ("curtailment"). As a result, individual rooftop systems were disconnected from the grid for around 12 days in a month, reducing their average output by about 40%. Larger solar farms were being forced to operate at 50% capacity, affecting their ability to service their project debts. Many stakeholders threatened the government with lawsuits, in an attempt to force an early solution out of these constraints.[4]

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Floating PV Learning from Aquaculture, Norway

Ocean Sun (https://oceansun.no/), a Norwegian company, developed an innovative floating solar solution that was based on the learning from aquaculture and maritime experience.

Norway's Ocean Sun created an innovative technology adaptation consisting of modified silicon solar PV modules that were attached to a thin, flexible floating membrane for near-shore ocean sites or reservoirs. The technology was developed based on Norway's NS 9415 marine fish farm standard, which provided stringent rules for aqua farming facilities, developed with a view to avoiding ecological disasters. The standard established requirements for "site survey, risk analysis, design and installation dimension as well as for the production, installation and operation of fish farms. " Ocean Sun adopted these standards to its floating solar plants, especially the standards relating to structural design and mooring systems.

Ocean Sun's patented design consisted of a floating buoyancy ring anchored to the seabed with four mooring points and twelve lines. Unlike a fish farm, however, the ring did not host fish cages underneath it, but supported the system weight of the surface where the modules were deployed. According to the company, rectangular structures and galvanized steel used in conventional floating solar designs were prone to corrosion and material fatigue at the interconnections. Instead, the circular design and the buoyant high-density polyethylene (HDPE) ring which Ocean Sun used in its design were more robust even in unfavorable conditions of high wind and repeated waves. The disk shape of the floating membrane worked similar to a wheel with spokes, with the centre enhancing the integrity of the entire system.

The 1mm thick membrane allowed the solar PV modules to be in direct contact with the water, which helped in heat dissipation (cooling of the panel), thereby increasing the energy yield of the panels as well. A single membrane could host 600 kW of PV module generation capacity. Glass-glass modules which are used in conventional PV panels were used for the floating unit. These modules were connected to special water-proof junction boxes. The modules were then "connected to the membrane through marine-grade aluminum profiles which engage in welded attachment features in the membrane"[1].

Ocean Sun set up a 223 kWp pilot project in 2019, on the Magat Dam in the Philippines, which was itself located in the middle of a typhoon belt[2]. The unit was built on a 50m diameter membrane, with onshore inverters[3]. It could withstand wind speeds of up to 275km/h and seasonal variations in reservoir levels going as wide as 30m. The project successfully weathered two years of typhoon speed winds in the area and provided valuable inputs to the company to improve upon its initial design. While the company did not disclose the exact cost of the project, Ocean Sun emphasized that the performance – cost ratio was the best available in the floating PV market.

With the success of the pilot project at Philippines, Ocean Sun entered into an agreement with Statkraft (www.statkraft.com/), Albania, to develop a 2.0MW floating plant. The plant was to be built over four PV floaters at the Banja Hydropower plant in Albania, each with 0.5MW in capacity. The estimated cost of the project was €2.3 million[4]. The first floater was commissioned in April 2022, and the remaining three were to be commissioned in the fourth quarter of 2022. Ocean Sun had reported having received supply and implementation contracts for several projects from China and Singapore.[5]

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Spain's Solar PV Bubble – The Solar Boom in 2007

The year 2007 saw major changes in the Solar PV panels sector in spain, that led to a boom in the industry. However, the law enforced by the Government has its pros and cons. This example is about the solar boom as well as the lessons learnt from it.

Decarbonization of the global economy has been elevated to the highest priority across countries, resulting in commitments made to reach "net-zero" greenhouse gas (GHG) emissions in the years and decades to come. Governments have aggressively promoted renewable energy (RE) deployment by implementing supportive policies and providing fiscal incentives. Spain has been an early mover in the area of solar PV deployment, largely owing to the abundant solar resources in the country. The experience with Solar PV policy implementation in Spain and the industry response to such measures offer important lessons for governments seeking to design and roll out RE policies. The present narrative is a summary of the case study developed by the Global Subsidies Initiative along with the International Institute for Sustainable Development [1], covering the 'solar boom' that occurred in Spain in 2008.

The Spanish government has been supporting RE deployment, particularly solar PV, in the country since the 1990s. Feed-in tariffs (FITs) are the main policy mechanism, as they are relatively easy to administer and perform better compared to alternative policies in some of the other European countries. The FIT provides a guaranteed premium price for the electricity generated by the RE installation but does not impose a cap on the volume of energy output that is eligible for such support. This enables interested investors to project future revenue streams with a degree of confidence. The FITs, however, were rigid and lacked built-in mechanisms for modification of payments in response to changing market conditions, for instance, in the event of the installed capacity being higher than anticipated. The Spanish government does not expect social or political opposition. Since RE penetration is low in the country, RE deployment is desirable, investors support FITs, and the cost of the policy to the exchequer is not expected to be high, at least in the short term.

The government introduced the Electricity Sector Law in 1997, under which a special scheme was implemented to provide for a preferential price for electricity fed into the grid by Renewable Energy Sources (RES-E). Subsequent policies provided differentiated tariffs based on system size. The Solar PV electricity generators were given a choice of a fixed FIT or a premium on top of the electricity market price, both of which were revised annually. However, RES-E generators were not happy with the scheme, as the annual revisions of support prices were not transparent and posed a high risk to investors. The deployment of solar PV remained stable but low. Consequently, in 2004, the target for solar PV capacity addition was set at 150 MW, and the support price was set as a percentage of the Average Electricity Tariff (AET) that was revised every four years in place of annual revisions as proposed previously. This arrangement of support price was discarded in 2006 since the AET rose by nearly 4.5% between 2005 and 2006, increasing the cost of the RES-E support system. From this point forward, solar PV installations had to accept a fixed FiT rate.

In 2007, Royal Decree 661/2007 was enforced, bringing about major changes to the solar PV sector. To encourage large installations, remuneration for solar PV installations in the range of 100 kW to 10 MW increased by 82% compared to installations in lower configurations. Under the provisions of the new decree, FiT revisions were to be made every four years, starting in 2010, or once the given target capacity of 371 MW had been reached. Additionally, after 85 percent of the target had been achieved, additional capacity for a period of 12 months thereafter was to be compensated at the wholesale electricity price. The time period of one year was provided to allow for the negotiation and enactment of a new FIT regime. Further, a 'cap-and-floor' price system was introduced, where the RES-E generators received the cap-level price if the market price plus the premium was above the cap and the floor price if the market price plus the premium was below the floor level. Soon after Royal Decree 661/2007 was implemented, Spain saw a boom in solar installations, growing from 103 MW in 2006 to 544 MW added in 2007 and 2708 MW added in 2008.

There were several reasons for this solar boom:

1. As indicated earlier, the solar PV installations between 100 kW and 10 MW had the highest FIT rates. Investors realised that rather than building one big plant, they could benefit more by aggregating power from smaller, closely located plants. By setting up such "solar orchards," investors could benefit from economies of scale while receiving tariffs meant for smaller, possibly costlier installations.

2. Communication between the Ministry of Industry and the solar PV investors and generators was ad hoc and not streamlined. There was no robust mechanism for information flow between the government and the groups of stakeholders. In many cases, the government relied on external consultants to contact the PV sector to obtain information; such consultants would then relay recommendations based on stakeholder feedback. Further, technology costs were not assessed by the government; instead, the cost estimates were communicated by the solar PV generators to the government. Due to such a lack of communication, the government failed to notice that while technological advancements had reduced the cost of PV installations, the FIT rates had remained unchanged for a long time. When the FIT rates were defined in 2007, the targeted rate of return for the projects was 5 to 9%, but actual internal rates of return for projects are estimated to have been between 10 and 15 percent without changes in underlying risks assumed by investors.

3. The Royal Decree 661/2007 allowed existing plants to replace their equipment as long as the plant was of the same nominal capacity. However, since the new modules were more efficient than the old modules, PV plants could generate nearly 33% more electricity for the same installed capacity upon such a replacement.

4. The Royal Decree 661/2007 stipulated that once 85% of the target 371MW was reached, new FIT rates would be determined within one year. Solar PV investors, anticipating lower FIT rates, rushed to submit proposals to qualify under the operating FIT scheme. The quota of 371 MW was reached in June 2007, grew to 544 MW by the end of 2007 while discussions were on to revise the FIT rates, and by the time the new FIT rates were defined in 2008, the installations had reached 3,116 MW (cumulative).

5. Several financial factors also encouraged the solar boom. Firstly, the real estate sector had begun to stagnate in 2007, making solar PV investments more appealing. Spain had joined the Euro currency zone, and the Spanish banks had received large deposits and loans from foreign banks. Given the liquidity available, the banks were ready to provide up to 100% financing at lower interest rates. Thirdly, the US dollar weakened against the Euro, making the import of USD-denominated solar modules cheaper.

6. There was no specific deadline for issuing permits for solar PV installations. Further, the communication between the regional and local governments and the central government was poor, with delays of several weeks being quite common. A general election in March 2008 further delayed communications with local governments and other stakeholders concerned. Up until April 2008, the government had no information relating to the total volume of installations in the country.

All these factors led to the total subsidies paid to the PV generators growing from €194 million in 2007 to €990 million in 2008 to €2.6 billion in 2009. Since 2008, the tariffs received by the solar PV sector have accounted for close to 50% of the tariffs provided to the RES-E sector, even though PV generated just about 10 percent of all renewable energy generated and 3 percent of overall electricity generated. In the subsequent years, Spain brought in several changes to the RES-E policy, such as defining annual capacity quotas, capping the running hours eligible for FIT payments, reducing FIT rates, setting a lifetime of FIT payments at 25 years, etc.

There are several policy lessons learnt from Spain's "solar boom":

- The policy should incorporate cost-containment mechanisms into subsidy schemes and define exposure limits to the exchequer, as opposed to making open-ended commitments.
- The policy should be updated to stay relevant to evolving market circumstances and should avoid excessively long transitions from one set of policy conditions to another.
- At the operational level, communication protocols among government agencies and stakeholders need to be more robust and the communication itself must be responsive to relevant quantitative data.
- Policy frameworks must provide incentives for long-term commitments and should create disincentives to prevent speculation and short-term arbitrage.

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World's First Offshore Solar Sea Farm: Netherlands

This is a study about the project by Oceans of Energy in the Netherlands. It combines solar and wind projects for the growth of renewable energy sources and has established the World's first offshore solar sea farm.

In 2019, Oceans of Energy, a Dutch company, implemented possibly the world's first offshore solar farm in the North Sea. The farm called the North Sea 1 (NS1), consists of a 50 kW near-shore unit installed at a distance of less than 1km from the Dutch coast and a second 50 kW offshore unit at a distance of 15km from the coast designed to withstand waves of up to 13m. In the first year of its installation, the pilot project withstood heavy storms "Ciara," "Dennis," and "Bella," which produced wave heights up to 10 metres, wind speeds up to 62 knots, and tidal currents up to 4 knots. The project provides valuable data on loads, movements, power output, and interactions with the hostile far-offshore environment.

Based on the experience, the company implemented its next project, NS2, which is a 1.0 MW offshore unit located on the test site provided by the North Sea Farmers, about 12km off the coast at Scheveningen. For this project, the company partnered with the Seaweed Company in the EU-funded UNITED project to produce seaweed and solar energy. This project is expected to produce 15,000 kg of seaweed and take up 1.8t of CO_2. The test site is split into six plots of 100 hectares each, of which one plot was used for growing seaweed. The NS2 is funded by the Demonstration Energy and Climate Innovation (DEI+) arrangement, provided by the Netherlands Enterprise Agency (RVO), and received the support of 20 other partners. The company received more than €15 million to scale up production and projects from various sources, including the European Union's Horizon 2020 programme. The United States-funded project is expected to end in June 2023.

According to the company Ocean of Energy,"The system is ready for the realisation of combined offshore solar and wind projects, creating 100 to 5000 MW of offshore solar energy per project. By using only 5% of the Dutch North Sea, half of the energy demand in the Netherlands can be met. This can be accomplished by using the space between wind turbines."

A Solar Balconies Initiative By The Government In Germany

The concept of solar balconies, or Solarbalkon, as it is referred to in Germany, was introduced in early 2011. A solar balkon consists of a solar PV array, or at times, a single solar panel, with an integrated inverter plugged into a wall socket to meet the in-house "baseload. " It is estimated that an average German family of four members need 3,800 kWh of electricity per year, which will cost the family an estimated €1,064 each year. GP Joule, a Solarbalkon manufacturer, sold a 165 Wp panel with a micro inverter for €450 and claimed, that the product will pay for itself in six years. While the product has already gained popularity in countries like the Netherlands, Czech Republic, and Switzerland, the German regulatory system is still uncertain about the product's safety, which is delaying the implementation of the concept [1].

Nearly a decade later, the German state is actively promoting the deployment of "balcony solar" installations through several subsidies. For instance, the government of Mecklenburg-Vorpommern allocated €10 million to support the deployment of balcony solar modules of up to 600 Wp. The government introduced a scheme for households to install a balcony solar module of up to 600 W without prior approval, and such households are eligible for a rebate of €500. The unit is to be registered with the energy supplier, and the energy needed to be entirely used by the household. According to 2022 estimates by the North Rhine-Westphalia consumer association (VZ NRW), a capital investment of €350 to €500 can provide electricity with a contemporary value of €54 per annum [2].

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SolarBalkon Germany
Source: Wo Do Solar

Solar Biopanels - A Sustainable Solution For Solar PV Modules

The disposal of large volumes of end-of-life solar PV modules is projected to be a major undertaking in the years and decades to come, largely due to the material used in mainstream solar panels. Researchers around the world have been working on cost-effective methods to recycle or otherwise dispose of end-of-life solar modules. Researchers are also engaged in finding a way to manufacture solar modules that will be easier to recycle at the end of their useful lives or will leave little in the form of residues or both. Greenfluidics, a Mexican company, has been working on "Solar Biopanels" since 2018 and has succeeded in developing a more sustainable solution. The company's patented "Intelligent Solar Biopanel" technology combines microalgae and nanotechnology to generate electricity, oxygen, and biofuel. The company received the "Innovator of the Year" award in 2019's Latin American Innovators under 35 LATAM for the design.

Each biopanel is triangular, measuring 1m on each side, and could be placed on roofs, windows, walls, or any surface that received sunlight.The panels are infused with water-containing strains of algae that absorb carbon dioxide and generate oxygen. For every kg of algae in the panel, up to 2kg of CO2 can be captured. Electricity is produced by heat transfer. As the panel is exposed to sunlight, it absorbs heat, which is then transferred by the water to a thermoelectric generator. According to the company, each biopanel can generate 328 kWh/m^2 per year. The water also has a cooling effect on buildings, saving up to 90 kWh per m^2 of energy annually, assuming that the building would otherwise have been air-conditioned. The biomass in the panels can be filtered periodically and used as biofuel or fertiliser. The company continues its work on the design and has been exploring the possibility of astronauts' using the biopanels on other planetary bodies.

Pre-Loved Solar Panels From Australia Get A Second Life In Africa

Australia witnessed a "home solar revolution" around the year 2010, when more than 198,000 home solar systems were installed. The number of systems installed in 2010 alone was more than the cumulative number of systems installed during the previous nine years. While the life of the solar panels in these home systems was estimated to be 20–25 years, many home owners began to replace the panels in just 10–12 years to try and "upgrade" their systems because the inverters died or because one or two solar panels in the array failed [1]. Such early replacements were leading to an accumulation of solar modules. It is projected that the cumulative volumes of decommissioned solar PV from the residential sector alone in Australia could reach 1.5 million tonnes by the year 2050. As of 2021, Australia had yet to reach any comprehensive nationwide scheme to deal with the issue of mid-life and end-of-life solar waste [2].

In 2021, Solahart Hervey Bay, a solar installation company in Queensland, Australia, decided to work on this solar waste issue. At the time of commissioning new installations, the company found that nearly 80% of the 'pre-loved' solar panels can be suitably redeployed and could continue to be used. The company decided to partner with the Alight Project, a non-profit organisation, to ship these solar panels to African communities. Another solar installation company, Venergy Australia, has also been shipping such mid-life modules to West Africa. According to World Bank reports, only 42% of the total population and 8% of the rural population in West Africa had access to electricity in 2022. Initiatives like the ones by Solahart and Venergy helped communities in Africa gain access to electricity [3]. According to Solahart, large volumes of second-hand panels are being sold in Africa to cover the shipping costs, and many units are donated to disadvantaged communities in Nigeria and other African nations. Arrangements for the recovery of the end-of-life solar PV modules and other system components are yet to be made to ensure safe disposal.

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Preloved solar panels
Source: completehome.com

A Bangladeshi Start-Up is Revolutionising Solar Peer-to-Peer Electricity Systems in the Country

The Bangladesh-based startup, SOLshare is revolutionising the solar peer-to-peer electricity trading system in the country through an ICT-enabled network. Their efforts have enabled over 25 million people across Bangladesh to avail electricity and lead better lives

In the early 2010s, a sizable proportion of Bangladesh's population had no access to the utility grid, and some of these communities had limited electricity supply from standalone home system installations or mini-grid networks. While many homes had individual solar house systems (SHS), they were of limited capacity and could not power large devices like televisions.

The deployment of mini grids was limited by the need for large upfront capital expenditures. In 2014, SOLshare, a Bangladesh-based start-up company entered a joint venture with German consulting company MicroEnergy International GmbH to address the issue. SOLshare introduced an Information and Communication Technology (ICT)-enabled peer-to-peer electricity trading network that connects houses with SHS to other houses in the vicinity that do not have electricity. The system spreads the costs of the SHS over larger use volumes, increases the capacity utilisation of SHSs by 30%, and reduces the annual energy access cost by at least 25% compared to a business-as-usual scenario while providing more people access to electricity [1].

SOLshare implemented a pilot project at Shariatpur village in Bangladesh, with the help of its implementation partner, the NGO UBOMUS, the financing partner IDCOL, and the research partner United International University-Centre for Energy Research. The company installed a bi-directional DC electricity meter called a "SOLbox" in every household in the village, which measures power inflows and outflows and enables peer-to-peer electricity trading with mobile money payments. The meters also help SOLshare with smart grid management, remote monitoring, and data analytics.

SOLbox has created a DC smart grid by connecting a solar home system or battery through the SOLbox with other SOLboxes in nearby homes or businesses. Users can even monitor their electricity trading portfolio through a mobile application called the SOLapp, enabling them to connect to hundreds of other households [2].

With the success of their pilot project, SOLshare implemented the system in other villages across Bangladesh. As of 2022, the system had been implemented to serve six million households and has impacted as many as 25 million people. SOLshare is expected to operate more than 20,000 nano grids by the end of the year 2030, supplying electricity to more than 1,000,000 customers in Bangladesh and interconnecting them with the national utility grid network through a single point of common coupling.

In recognition of such efforts, SOLshare won several awards, including 'World's Best Energy Startup' by the Free Electrons energy accelerator programme in 2018, the 2020 Global Final at innoEnergy's 'The Business Booster', and 'MIT Solver' under SOLVE's 2020 Global Challenges for Good Jobs and Inclusive Entrepreneurship+.

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Concrete Blocks For Pumped Storage Of Energy In China

This is a study about the storage facility created by Energy Vault to store energy generated through renewable sources. This initiative is a noteworthy step in the face of scarcity of resources.

The concept of pumped storage has been used for a long time, built and operated in conjunction with hydropower generation, where two water reservoirs at different elevations are used to generate electricity as well as store energy. In a pumped storage scheme, water is pumped from a lower reservoir to a higher reservoir during periods of surplus power, and the raised water is then released to turn turbines and generate electricity to meet demand.

A similar concept is used by Energy Vault, a Swiss company, to store energy generated by renewable sources. The company's EVx gravitational energy storage platform involves a six-arm crane tower designed to be charged by grid-scale renewable energy. The tower lifts 35 tonnes of composite bricks using electric motors during periods of surplus generation. When power needs to be exported to the grid to meet end-use demand, the bricks are lowered, harvesting the kinetic energy. The company believes that the storage capacity of the raised composite bricks has suffered no degradation over time.

These composite bricks are made from local soils and materials otherwise destined for landfills or incinerators, including recycled coal ash, waste tailings from mining operations, and wind turbine blades. The EVx tower is projected to have a useful life of 35 years, a round-trip efficiency of 80–85%, and the potential to scale up to multiple GWh in storage capacity. The gravity-driven storage is more crucial in a world facing scarcity in global lithium supply, with the EVx tower offering an alternate solution to store solar and wind energy [1].

This storage innovation, using the potential of raised bricks, received attention from various stakeholders around the world. In 2022, Energy Vault announced its intention to build five storage projects with a combined storage capacity of 2.0 GW in China. For this project, the company formed a consortium with US-based Atlas Renewable Energy, Chinese NGO EIPC, China-based telecommunications company China Tianying, and select provincial and local governments. The construction of the first phase of the project started in March 2022 for a 25 MW or 100 MWh system in the Pudong district, outside Shanghai. Energy Vault had also signed an agreement with Indian utility NTPC Ltd. to deploy gravity-based energy storage technology in India based on the outcome of a joint feasibility study. Korea Zinc invested USD 50 million in Energy Vault to use the EVx technology at the former's Australian refinery [2].

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Germany's Rooftop Solar Tiles With A Sunny Outlook For PV Innovation

The German company Creaton, in collaboration with building-integrated photovoltaic specialist Autarq, developed a new solar roof tile. Creaton is a leading European roofing company that produces clay roof tiles, concrete roof tiles, and system accessories, including a range of solar solutions. They distribute these products throughout Central and Eastern Europe. Creaton's roof-integrated and post-mounted photovoltaic arrays result in roof-mounted power plants that offer protection from rain and leaks. Creaton's strategic partner, the German company Autarq (funded by the European Union), is in the business of producing aesthetically appealing solar tiles [2].

The 'Creaton PV Autarq' product is based on the existing Domino black tile and consists of a smooth black brick that doubles as a carrier for small microcrystalline PV elements that Autarq created. These elements are protected by a 3.2-mm safety glass pane on the front side. The tiles are connected using plug-in connections, which remain under the bricks and are protected from weather-related damage. The modular nature of the tiles allows for easy installation in combination with the existing tiles while also allowing for flexibility in the size of the photovoltaic (PV) array. The module's overlay grid pattern is closely attuned to the tile model as well as its shade of colour. The product is made available in two colour variants: black or anthracite engobe. Upon installation, this tile is designed to provide a back-ventilated in-roof system that integrates seamlessly into the roof.

The solar tile is designed to operate in temperatures between -40 °C and +85 °C and to withstand mechanical stress levels of up to 5,400 Pascal. The product is also compatible with all common inverters. The Creaton PV Autarq tile is IEC 61215 compliant for durability and quality and IEC 61730 compliant in terms of safety. Consequently, the product is offered with a guarantee of up to 25 years for its components.

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Bio Battery Heat Pump For Storing Solar Energy

Phase change materials (PCM) have the ability to absorb or release large amounts of latent heat when they go through a change in physical state and have often been used by researchers for cooling PV modules or for storing heat. In 2021, a team of researchers from SINTEF, a Norway-based research organisation, developed a "bio battery," using PCM materials in combination with heat pumps[1]. SINTEF and the Norwegian University of Science and Technology (NTNU) jointly operated a Zero Emissions Building (ZEB) in Trondheim, Norway, where the bio-battery was built and tested. The energy from the building's 180 kWp solar installation is conducted via a heat pump into the bio-battery.

The battery consists of 3 tonnes of liquid biowax made from vegetable oil, enclosed in a silver-coloured container. The biowax remains in a crystalline form at temperatures below 37 °C and is melted at higher temperatures. When in the solid state, the molecules of the biowax cluster close together. At higher temperatures, when the wax changes from solid to liquid, the bonds holding the molecules loosen, increasing the kinetic energy of the molecules. When the temperatures drop, the wax changes from a liquid to a solid again, converting the kinetic energy into heat, which is dissipated. The heat generated during the phase change is captured by 24 "cushion plates" that are surrounded by water. The water serves as an energy carrier that removes heat from the storage system. The heated water is directed to the radiators and the ventilation system, which supplies heated air to the building. The researchers claim that the battery has a heat storage capacity of 200 kW, which is sufficient to heat the building for three to four days during the coldest part of the year. It has a life of 25 years and is believed to be virtually "maintenance-free."

Researchers charged the bio-battery prior to the coldest parts of the day and avoided the consumption of valuable grid electricity at times of peak demand in the city of Trondheim. The first year of operations provided the team with data that helped optimise the system. The researchers have proposed to install pilot bio-battery systems at various industrial equipment manufacturing companies by the end of 2023[2].

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Bio battery heat pump
Source: SINTEF

Source Hydro - A Solution For Clean Water For All

Constrained access to clean drinking water has been one of the major problems facing large parts of the developing world, prompting the United Nations to include "ensuring reliable access to safe drinking water for all" as one of its Sustainable Development Goals (Goal 6). Many researchers have been working on possible technical and market-based solutions to address the problem. In 2014, one such technical solution was developed by Cody Friesen, a professor at Arizona State University's Ira A. Fulton Schools of Engineering, USA[1]. Prof. Friesen then launched the company "Zero Mass Water," later renamed Source Global, to help commercialise the idea.

The "hydropanel" harnesses solar energy through solar PV cells present at the centre of the assembly. This energy is used to power a fan to draw in air and push the air through a hygroscopic [water-absorbing] material that traps water vapour from the air. The water vapour is then condensed into liquid water, which is collected in the panel's reservoir. Minerals like calcium and magnesium are added to the water to optimise the taste. Each panel measures 1.2 m x 2.4 m x 1.1 m, weighs 154 kg, can generate two to five litres of water each day on average, and have an estimated life span of 15 years. The annual maintenance of the panel includes the replacement of air and water filters, while the mineral cartridge has to be replaced once every five years[2]. Each panel costs USD 2,000 (€ 2000).

The company received funding from various organisations, including Breakthrough Energy Ventures, Black Rock, Duke Energy, Lightsmith Group, and the Bill Gates Foundation. By 2022, the company had installed hydro-panels in 52 countries in 450 separate projects[3].

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Source Global
Source: uplink.weforum.org

Surya Nutan - An Indoor Solar Cooking Solution In India

As of 2017, India was importing nearly 50% of the Liquefied Petroleum Gas (LPG) consumed in the country. To reduce the dependence on imported fuel, Indian Oil Corporation Limited took up an initiative to develop a viable solar solution to fuel Indian kitchens. IOCL worked with the Ministry of Petroleum and Natural Gas to develop a solar cooktop, 'Surya Nutan,' and launched the first working model in June 2022. The design has been patented by the R&D division of IOCL [1] (Indian patent number 391 905).

According to the company, Surya Nutan is a "stationary, rechargeable, and always kitchen-connected indoor solar cooking" solution. The stove includes a customised thermal battery with optimised insulation. The stove is a hybrid model that works on both solar energy and auxiliary energy sources, making it an ideal alternative cooking solution for all weather conditions. Surya Nutan's in-built insulation system reduces radiative and conductive heat losses.

The cooktop is available in three models, with prices ranging from INR 12,000 (€ 146) for the base model to INR 23,000 (€ 280) for the premium model. The premium model can cook three meals for a family of four on any given day, irrespective of solar resource availability. IOCL is looking at options to either independently manufacture the cooktop at large scale or resort to licensing the design for contract manufacturing [2].

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Mango Power – Home And Portable Battery Systems

Mango Power Union, a USA-based company, launched a portable battery solution for the home-energy segment. The battery has a capacity of 3.5 kWh, which is further extended to 14 kWh. The battery consists of lithium-iron-phosphate (LFP) battery cells from Contemporary Amperex Technology Co., Limited and is projected to offer a life span of 2000 cycles. The battery could be charged through AC wall outlets (up to 3,000 W), solar panels (up to 2,000 W, 60 V to 150 V), electric vehicle chargers (EV1772), or generators. The battery has a "quick-charge" mode that enables it to be charged up to 80% in one hour. The battery provides various output modes, including four 20 A (AC) output ports, six 27 W USB-A ports, two USB-C ports (65 W and 100 W), one car power output at 12 V/10 A, two DC 551 ports, and one AC RV port at 30 A. Different versions are available for EU and US markets to support either single- or triple-phase connections with 12 kW of output capability. The retail price of the battery varies from USD 19,499 for a 12 kW/15 kWh system to USD 22,999 for a 2 kW/20 kWh system [1].

The battery consists of two parts, a large, heavy-duty home base and a smaller, detachable unit designed for portability. The portable unit has a capacity of 2.4kWh. The battery comes with a mobile phone "app" that helps monitor the available power, charging rate, temperature, and charging mode. The app also provides data on the conversion of solar energy in KWh, carbon emissions expressed in tons, and "tree planting equivalents." The app also estimates the savings if solar power is utilized for charging, as against grid usage [2].

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Mango Power
Source: storagereview.com

'CIZO' - The Project To Light Up Rural Areas

Togo, in Western Africa, made significant progress in electrification between 2000 and 2016, advancing from 17% country-wide electrification in 2000 to 35% in 2016. However, there was a large disparity in access to electricity in the country and to reliable supply, with 87% of the urban areas being electrified as against the 7% electrification rate in rural areas [1]. To improve access to electricity in rural areas, the Togolese government launched an initiative called "CIZO. "

The CIZO project was launched in 2017. The word "cizo" means "to light up" in Mina, a Togolese language. The initiative sought to increase the rural electrification rate to 40% by the end of 2022. To begin with, a two-year pilot project was launched in 2017 to focus on building technical capability and an agent network, for which the Togolese government received a grant fund of USD 975,000 (€ 865,337) from the Sustainable Energy Fund for Africa (SEFA) managed by the African Development Bank. The Togolese Agency for Rural Electrification and Renewable Energy (AT2ER) was appointed as the project execution agency. The project set up a solar academy consisting of five training centres specialising in PV technology applications in the Savannah, Kara, Central, Plateaux, and Maritime regions of Togo. The academy has trained 50 trainers and more than 3,000 technicians in installing and maintaining PAYGO solar kits. The country's Post Office (PO) network is used to deploy an initial agent network. The PO's existing network platform is integrated with mobile money payment services. Kya Energy Group, a local company, helped with setting up the training centres, while Horus Telecom and Utilities, a French company, helped with establishing the agent network [2]. Following such coordinated efforts, AT2ER won the 2020 Ashden Award for "System Innovation for Energy Access" for the successful completion of this pilot project [3].

The next phase of the project aimed to deploy 300,000 pay-as-you-go ("PAYG") solar systems for households, electrify 1,000 health centres, and provide 1,000 solar-powered water pumps by 2022. The total project cost was estimated to be €61,840,000. The Togolese government received a grant of €9,990,000 from the European Union Africa Infrastructure Trust Fund (EU-AIF) for the "electrification of 314 health centres and equipping 122 health centres with solar water heaters; the equipping of 400 drinking water supply systems with solar powered water pumps; 600 small farms with solar powered pumps; the electrification of approximately 2000 households by 10 smart solar mini-grids or solar home systems (SHS); and the implementation of a PayGo management platform for the integration of payments and data collection" [4]. About 150 technicians, from among the 3000 who were trained during the pilot phase were recruited by companies like BBoxx Capital Togo, Solergie Sarlu, and Aress Togo, etc for implementing their solar projects in rural areas. Further implementation and recruitment were delayed due to the COVID-19 pandemic [5].

The Cizo Cheque Subsidy Program

The feasibility study undertaken by the CIZO project reveals that the affordability of the SHS might impede the implementation of the project. To overcome this problem, the government launched a "CIZO Check,," an end-user subsidy programme. The programme bridges the "affordability gap" for eligible households by partially covering their payments for off-grid companies 6. The companies, BBoxx and EDF Energy partnered with the government to conduct a market study to determine the subsidy amount. The study concluded that the BBoxx-EDF SHS, which was priced at USD 8 (€ 9) per month, was affordable for a mere 30% of the Togolese rural population. It was decided that the government will bear USD 3.30 (€ 3.40) of the cost, and the remaining USD 4.70 (€ 5.30) had to be borne by the end-users. To be eligible for the subsidy, the end-user had to be located in an off-grid rural area, have an active mobile phone connection, not have received any earlier subsidies and have made the first payment to the off-grid solar company. Off-grid solar companies that could provide an SHS system with a minimum 20 Wp capacity and could meet the minimum quality and service standards were awarded a 15-year licence to supply SHS under the CIZO Cheque Subsidy Programme. The Togolese Post Office and the mobile operators together maintain a database of interested and eligible end-users. The schematic representation of the CIZO Cheque programme is presented in Figure 1.

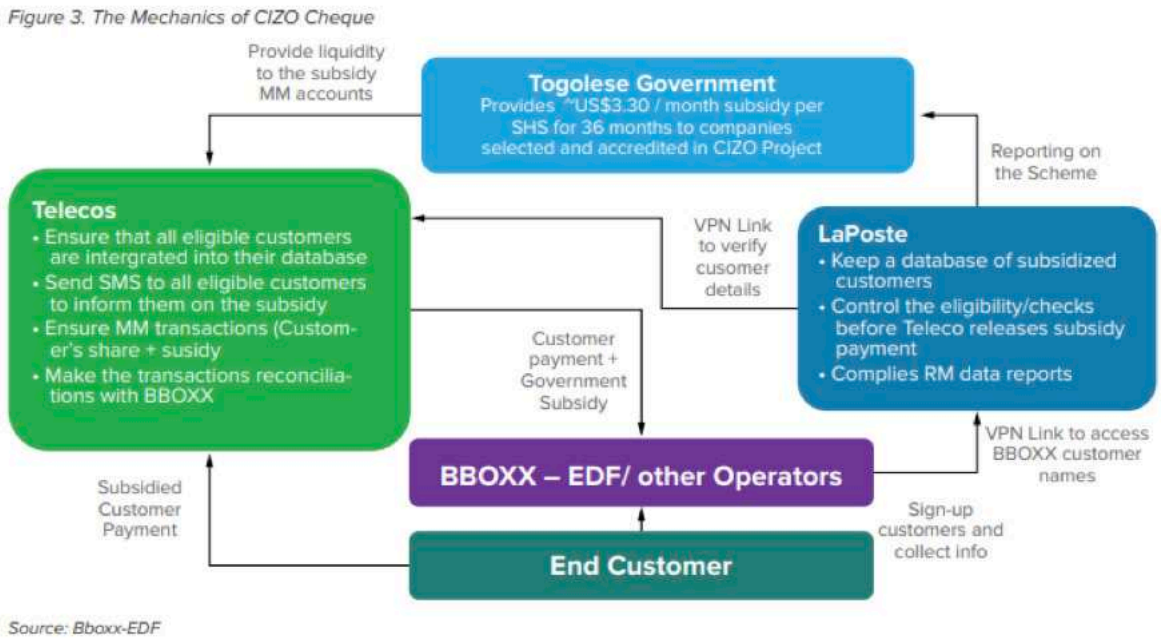

Figure 1: Schematic representation of the working of the CIZO Cheque Program
Source: End User Subsidies Lab (2020) "Togo CIZO Cheque Program," https://www.gogla.org/sites/default/files/resource_docs/case_study_-_togo_cizo_cheque_program.pdf, last accessed 25 October 2022.

Solar Powered Irrigation Systems For Togolese Farmers

The companies BBoxx, EDF Energy, and SunCulture, formed a consortium in 2019 with the Togolese government to expand access to solar-powered irrigation systems for farmers. SunCulture has extensive experience implementing irrigation projects in Africa; EDF has expertise in the installation of off-grid solutions; and Bboxx's comprehensive management platform used Internet of Things (IoT) technology that allowed remote management and monitoring. This irrigation system project was an extension of the "CIZO Cheque" subsidy programme launched by the government in 2019. As per the partnership agreement, the government covered 50% of the cost of irrigation systems for 5,000 farmers and also provided tax exemptions on import duties and VAT on the water pumps. The services were provided on the same pay-as-you-go (PAYG) model used for the Bboxx-EDF Solar Home Systems (SHSs), where the government paid USD 3.30 (€ 3.40) of the cost and the remaining USD 4.70 (€ 5.30) had to be borne by the end-users. The consortium claims that the project increased farmers' productivity by five times as compared to a "Business-as-usual" scenario where farmers had to travel long distances to bring back water to the farm. The irrigation systems also helped farmers irrigate their farms even during dry seasons and secure a harvest.

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Hydro Solar Water Pumps - An Initiative To Make Water Available For All

Côte d'Ivoire, or Ivory Coast, is a tropical country in South-Western Africa with a population of over 23 million people reported in 2015. However, an estimated 16 million people have access to clean drinking water in the country. With the signing of the Paris Agreement in 2015 and the adoption of the 2030 Agenda for Sustainable Development Goals in 2016, the government of Ivory Coast made "access to drinking water for all" one of its priorities and included it in the country's National Development Plan. Since then, the government has received funding and technical assistance from several international organisations like the World Bank, World Health Organisation, Habitat for Humanity, USAID, etc, to achieve such goals [1].

In 2019, the government launched the "Water for All" program to ensure continuous access to drinking water in both urban and peri-urban areas of the country [2]. One of the many projects implemented under the programme was the conversion of 1,000 human-powered pumps into solar pumps by the French company Vergnet Hydro in collaboration with the local partner Saher. The project cost €26.0 million and is implemented in four regions of Ivory Coast: Lôh Djiboua, Agneby Tiassa, La Mé, and Sud-Comoé.

Vergnet Hydro undertook the preliminary work which involves blowing out, cleaning, and checking each borehole. Each installation is equipped with a solar and a manual pump, a tank of 4 m3, taps, and related equipment, including pipes and cables. The project was started in March 2021 and was expected to be completed in two years. The project is designed to reduce the hardship of pumping water for women and children in the areas covered.

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Hydro Solar Water Pumps
Source: Vergnet Hydro

A Step To Become The First African Country Entirely Reliant On Green Energy

The East African country of Djibouti is located near some of the world's busiest shipping lanes between the Red Sea and the Indian Ocean, kept busy by large oil tankers carrying oil to various markets. However, the country has been dependent on neighbouring countries to fulfil its electricity needs. In 2011, a 283-km high-voltage line was built linking the Ethiopian town of Dire Dawa to the suburbs of Djibouti City; such electricity imports from Ethiopia met 60–65% of the country's electricity demand in 2011.

The electricity demand in Djibouti has been increasing at a rate of 10% each year since 2011, and the country's power ministry has estimated that the country's demand would reach 1,000 MW by the end of 2030. The government has committed to reaching the goal of 100% electrification in the country by 2030. In addition, at the 2012 World Energy Forum in Doha, the President of Djibouti announced the government's intention of becoming the first country in Africa to be entirely reliant on green energy by 2025. The government has established a roadmap to work achieving these goals. A 50MW solar power plant built at the Grand Bara desert was one of the first projects approved towards achieving the country's 100% RE objectives [1]. This project was slated to be built by Swiss company Green Enesys, and be a part of a bigger solar power complex of 300 MW whose cost was estimated at €360 million. However, no progress was made even three years after the initial foundation stone was laid in 2016.

The government then decided to collaborate with France's Engie to build a USD 40 million (€44.7 million) 30MW solar power plant. This project was to be expanded to 100 MW in the next phase once production estimates were confirmed. Djibouti's [sovereign] financial arm, the FondsSouverain de Djibouti (FSD) has a 20% stake in the project[2].

The government is also looking at other renewable energy options to help reach the goal of 100% green energy. A USD 160 million, 60 MW Goubet wind power plant was to be built by Spanish company Siemens-Gamesa and was expected to be completed by the end of 2022. A USD 150 million, 35MW–40MW biomass plant was being planned in collaboration with US investors CREC Energy. Djibouti also has an estimated potential of 500–1,000 MW of geothermal energy, which is being explored by Kenyan companies along with Djibouti's Red Sea Drilling Company. In 2019, it was also estimated that the country may have vast pockets of pure hydrogen in its subsoils, which could be exploited. France planned to invest USD 5 billion every year in Djibouti to develop this alternative fuel. A delegation from the University of Paris is already based in Djibouti to explore the possibility of harnessing this energy source [3].

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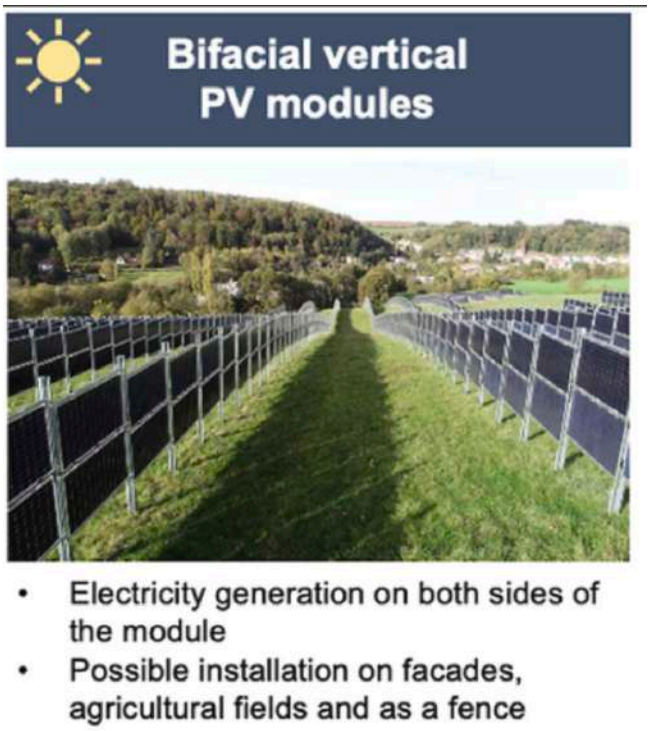
Vertical PV Installation For Airport In Frankfurt

In June 2022, a pilot project featuring 20 vertically installed bifacial solar PV modules aggregating 8.40kWp in capacity was commissioned at Frankfurt Airport in Germany. The pilot offered the operational experience and the data to help scale the project up to different parts of the airport, including having such installations parallel to runways and to other such zones where the installation could be re-imagined as a fencing system as well.

The airport operator, Fraport AG, who installed the panels cited high electricity yields along with biodiversity protection as the justification for the vertical arrangement. The vertical installation avoids glare experienced by pilots while also ensuring minimal solar curtailment by the utility.

It is believed that this arrangement could be beneficial in agricultural fields as well, due to lower space requirements and increased room for sunlight penetration to the crops being cultivated. This configuration is also viable in other congested land spaces for mitigating biodiversity impacts while producing electricity for local consumption.



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Underground Heat Exchanger To Cool Down Solar Panels

By being directly exposed to the sun, and especially in tropical and temperate locations, Solar PV panels often get heated under normal working conditions, which reduces their efficiency. Overheating of modules could also create additional problems related to thermal cycling and more rapid performance degradation. In 2021, a group of scientists from Spain developed an "underground heat exchanger" which could be coupled with solar panels to reduce their operating temperatures, and to improve performance efficiency [1].

The system was tested at an off-grid PV installation with a single-axis tracking system. The array consists of two PV modules, each rated at 270 Wp in capacity and with a temperature coefficient of -0.43% per degree Celsius, implying a corresponding reduction in efficiency with each degree rise in temperature. The heat exchanger of the solar panel consists of a set of six "plastically deformed, flattened U-shaped copper tubes," each measuring 15 mm in diameter, through which the coolant fluid flowed. The tubes are thermally isolated by polyethene foam and connected to common 18-mm-diameter inlet and outlet collectors. The heat exchanger is mounted on the back side of the solar panel with a constant coolant flow rate of 3 l/min, or 1.8 l/min per square metre of solar panel. The heat is transferred to another U-shaped underground heat exchanger that is installed in a borehole at a depth of 15m. The underground exchanger is filled with natural water from the underground aquifer. The cooling system needs extra energy to operate a pump that keeps the coolant in motion.

According to the researchers, the heat exchanger reduces panel temperatures by 17% and improves performance by 11% compared to a traditional PV panel. The system is also economically viable with investment amortization periods that range between five and ten years [2].

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Underground heat exchanger to cool down solar panels
Source: PV Magazine

A 25 MW Solar PV Solar Project In Gujarat, India

Visual Percept Solar Projects Private Limited (VPSPPL), later acquired by Torrent Power, has commissioned the 25.0 MW solar photovoltaic power project at Surel Village in the Surendranagar district of Gujarat. The project spreads over 200 acres and is commissioned with technical assistance from the UK-based Environment Agency. The project is implemented by Louroux Bio Energies Ltd. (later acquired by Samta Energy)[1]. VPSPPL had entered into a power purchase agreement (PPA) with the state electricity utility, Gujarat Urja Vikas Nigam Limited for the export of power from the plant for 25 years. The project was implemented under Phase II of the Gujarat State Solar Power Policy 2009 and was commissioned on January 28, 2012[1].

Multi-crystalline silicon technology, which has a highly established track record of performance in the field, was used for this project. It is also considered one of the most reliable technologies available. VPSPPL procured Solar Modules from China-based Hanwha Solar One and China Sun Energy, two of the world's leading Tier I Module Suppliers at the time; the project sourced inverters from Italy-based Power One, one of the world's leading Inverter manufacturers. VPSPPL contracted Sterling & Wilson Ltd. to provide engineering, procurement, and construction (EPC) services for the project.

The project's total cost is reported as INR 3.450 billion, of which INR 1.035 billion (30%) is contributed as equity investment, and the balance is procured through a term loan. The State Bank of India is the sole banker for VPSPPL for the project[2].

Local personnel are hired and trained to build and operate the solar plant. Louroux Bio Energies, the implementing agency, mentions that the state government's "single window clearance" and progressive policies helped complete this project in record time. Per the monitoring report for the reporting period of 1 December 2015 - 31 May 2019, the project avoids emissions of the order of 128,725 tCO2e relative to a projected business-as-usual scenario against the ex-ante estimate of 114,715 tCO2e[3].

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Rock-Based Industrial Scale Thermal Energy Storage (TES) Facility

Italian company Eneland Israel's Brenmiller Energy has been working for nearly 10 years to develop a resilient and scalable storage solution that could meet on-demand access to clean energy. In 2022, the companies succeeded in developing a rock-based industrial scale Thermal Energy Solution (TES) that could be integrated with renewable energy resources to store the energy generated. The Israeli Innovation Authority partly funded the project through a grant of €1 million. The new technology was tested and inaugurated at Enel's 390-MW Santa Barbara power plant near the Tuscan town of Arezzo, Italy [1].

The storage system can store 24MWh of thermal energy and can be fully charged and discharged in about five hours. The system has a Heat Recovery Steam Generator (HRSG) that uses high-pressure steam at a pressure of about 80 bar and feeds 9 tons of steam per hour at 550°C to charge the TES. During the discharge phase, liquid water at 150°C is fed into the TES at around 6 tons per hour. The TES uses rocks to store excess energy in the form of heat, and the rocks release the heat to generate steam for electricity production. The TES could also be used as 'power-to-heat' equipment for industrial purposes [2].

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Underground heat exchanger to cool down solar panels
Source: PV Magazine

Electricity Generating Solar Windows

Energy-generating windows made from transparent solar cells have been on the market for several decades. These cells are made from photo-sensitised dye applied to the surface of a semiconductor to convert visible light into energy. They are called Grätzel cells or dye-sensitised solar cells (DSCs) and rely on direct sunlight. However, DSC-based windows often have limited capacity to generate electricity compared to traditional solar cells.

After over 12 years of research, a group of scientists from the École Polytechnique Federale de Lausanne found a way to make transparent solar cells (DSCs) more efficient. The researchers developed special filters that could be applied to the glass panels, enabling them to reflect certain wavelengths of the visible spectrum while absorbing the rest to be converted into energy. The researchers can define the colour of their solar panels, such as brick red, royal blue, golden yellow, or sea green, by applying various oxides in nanometric layers varying from three to 13 layers to meet the solar power requirements. According to the scientists,"the panels thus become architectural features in their own right." However, the efficiency was still lower compared to a conventional solar panel.

EPFL formed a joint venture with Emirates Glass to mass produce tinted solar glass (DSC). The window pane is produced as one large piece of 3.0 x 6.0 metres, 4 mm thick, and then cut to the architects' specifications. In 2017, the Copenhagen International School inaugurated its new building, which has approximately 12,000 blue-hued but transparent solar panels that use the same DSC technology. It is claimed by the researchers that these DSCs generate around 300 megawatt hours (MWh) of electricity per year, and meet over half of the school's annual energy needs [1].

The team continued to research the DSC design, and in 2022, succeeded in a new "molecule design," that achieved a power conversion efficiency of "beyond 15 per cent in direct sunlight and up to 30 per cent in ambient light conditions." To put this in perspective, a conventional solar panel operates at about 20% efficiency. These new DSCs also demonstrate "long-term operational stability" of at least 500 hours [2].

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EPFL sets up first solar tinted glass window on its campus
Source: EPFL

Frameless Solar Panels For Reducing Maintenance Operations

Dust accumulation on solar panels could reduce the power output and might necessitate frequent cleaning in addition to routine maintenance operations. The Chinese company, DAH Solar has designed solar panels with frameless front sides to try and prevent the accumulation of dust. The new DHM-72X10/FS(BW) solar modules, as they are branded, come in four versions, with capacities ranging from 540Wp to 555Wp, with efficiency ratings from 20.89% to 21.48%. Each panel measures 2,279 mm x 1,134 mm x 32 mm and weighs 29 kg. The operational temperature of the frameless panels ranges from -40 C to 85 C. The solar panels are expected to be in service for over 25 years, with no less than 84.80% of the nominal output power generated at the end of this period [1].

The company claims that the PV module's drainage function allows rainwater to wash away any dust and prevented dust sedimentation on the panels. This reduces the frequency of cleaning and maintenance activities required. These frameless modules are perfectly suited for steel rooftop applications with small installation angles. The frameless modules feature a 3.2 mm "anti-reflective glass" and an IP68 enclosure - an international standard for electrical enclosures. The digits "6" and "8" mentioned within the international standard respectively indicate the maximum level of protection against "solid ingress" and "water ingress, up to and including complete submersion below one meter and for more than 30 minutes." [2]

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Frameless solar panels from DAH
Source: DAH Solar

Solar Turtle - Portable Solar Revolution That Helps Thwart Thieves

In 2013, a team of researchers from the Centre for Renewable and Sustainable Energy Studies (CRSES), a research division at Stellenbosch University, South Africa, decided to assess the needs of the rural community, and the viability of micro-grids. The team undertook a series of field visits around the town of Cofimvaba in the Eastern Cape, South Africa. The researchers found that none of the four previously installed microgrids were operational. Theft, vandalism, and lack of ownership among the locals were identified as the main causes of the failure of these micro-grids. The situation was so bad that the provincial government in Gauteng, one of the regions visited, had almost dismissed solar power as a possible electricity solution for schools and community centres [1].

James van der Walt, who has been part of this research team, came up with the idea of a Solar Turtle, which is 'an ultra-secure solar kiosk for community electrification with a special focus on schools.' He launched a company Ugesi Gold, to commercialize the idea, and received grant funding from several agencies including South Africa's Technology Innovation Agency (TIA), the Department of Science and Technology (DST) and others.

The company launched its first pilot project in 2015 at Pheasant Folly Primary School in Gauteng. The school had no grid connection and diesel-based generation was too expensive for the school to operate and maintain. The 'power turtle', as this version of the solar turtle is called, has a unique, container-based design with unparalleled security. Early morning sunshine triggers the solar panels to roll out of the 6.0m long container on a specially designed rail system. In the evenings, as the sun's rays fade, the panels roll back into the container for safekeeping. The power turtle has 16 numbers of 300Wp solar PV panels, lithium batteries and top-of-the-range 8.5kW Schneider solar inverters [2]. The container also has an emergency panic button, which enables the operating staff to quickly fold the panels and lock them in, when the assets are at risk. The container survived civil unrest in its first year of deployment, suffering just a few scratches [3]. With the pilot project's success, the company launched the Solar Turtle in other parts of South Africa, and in countries like Tanzania and Lesotho. The company has won several awards over the years, including Africa Prize for Engineering in 2017, and The Index Project Award in 2019, for the "affordable and clean" energy category [4].

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Solar Cow And Power Milk - Facilitating Sustainability And Empowering Communities

In many developing countries in Africa, millions of children drop out of school each year due to extreme poverty and such children are generally forced to work on farms, undertake household chores and the like. Poverty also forces families to spend on energy sources like kerosene, given that they can not invest in solar lanterns and other cleaner and more efficient options.

YOLK, a South Korean electronics company, believes that problems of child labour, education, and energy infrastructure, could be tackled simultaneously. In view of solving these problems in developing countries, a team of engineers from the company, built a 'solar cow', in 2018. With the help of NGOs like Energy-4-Impact, and Upya, the company set up solar cows at several schools in Kenya [1].

A solar cow consists of a solar charging station, with customized ports to charge over a hundred "Power Milk" batteries. Each 'Power Milk' battery provides 10W of power which can provide power for 6-8 hours. It can be used to charge any device rechargeable by USB cable via the USB port on the bottom of the battery: cell phones, radios, flashlights, etc. School children were given a Power Milk battery each, which could be charged at the solar cow installed at the school; such charging materialized when the children attended school. The children were allowed to take the batteries home at the end of the school day [2].

These batteries have custom charging sockets compatible only with solar cow charging systems [3]. This incentivised parents to send their children to school, as the power milk batteries helped save up to 15% of family income, which would have otherwise been used to pay for kerosene. The battery also reduced the kerosene dependence of the average family by up to 50%. The solar cow initiative helped increase school enrolments by 5%.

With the success of the solar cow initiative in Kenya, the company installed solar cows in schools in Tanzania, Congo, Zanzibar, and Cambodia. The company, Yolk, raised more than USD one million from the crowd-funding website Kickstarter. The initiative also won many awards like the IF Social Impact Prize, AidEx Innovation Challenge, Times Magazine Best Innovation award in 2019.

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Sun-Tracking Floating Solar Islands

Portuguese company Solaris Float contracted the Institute of Science and Innovation in Mechanical and Industrial Engineering, a Portuguese research institute, to develop a floating system of photovoltaic panels that could track the sun[1]. In 2020, the team developed a floating solar solution branded the "Protevs," and a pilot project was installed on Lake Oostvoornse Meer, near Maasvlakte, Netherlands. This installation includes 130 PV modules adding up to an installed capacity of 50.7 kWp on a single-axis tracker. The floating solar island rotates around a central point, tracking the sun, and is powered by electric engines that consume less than 0.5% of the opposite energy produced by the array. The system rotates in one direction during the day, tracking the sun, and then rotates in the direction during the night to return to its original position. Solaris Float claimed that the system produced up to 40% more electricity than comparable floating fixed-tilt systems [2].

In 2022, Solaris Float launched two versions of the system; "Protev +" and "Protev 360. " The Protev+ version features 180 numbers x 370W modules with dual axis tracking, amounting to an installed capacity of 73 kWp. The Protev 360 system is a single-axis system with 360 numbers x 410W PV modules amounting to an installed capacity of 147kW. The PV modules are mounted at a fixed slope of 10 degrees. Both versions were "modular, detachable and scalable." The floating systems are ideal for calm water bodies such as lakes and reservoirs. They are secured in place with an outer ring attached with cables and anchors that allow up and down movements of up to 30 meters. The systems can also tolerate waves up to one meter high. The supporting structure is made of 100% recycled materials which could be recycled [again] at the end of the project's lifetime.

According to the company, the floating islands can be merged to form a solar farm. A farm of 15 floating islands can have an installed capacity of 1.0 MW, occupying an area of 25,000 square meters and generating 2,500 MWh/year of power under normal conditions. The merged farm can satisfy the demand of 800 people per year [3]. Nuno Correia and Carla Gomes, two of the main researchers from INEGI who were involved in the development of the system were nominated for the "European Inventor Award 2022." [4]

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The First Floating Solar Auction With The Lowest Tariff In The World

Floating solar plants are being widely deployed across Europe as a result of the EU's decision to increase the share of renewables in the energy mix. Such deployment of RE accelerated after Russia invaded Ukraine. This is the case of the first floating solar auction.

Portugal's first commercial floating solar auction conducted in 2022 helped discover a negative price of Euro 4.13 per MWh ($4.50/MWh) – a negative price means that the bidder EDPR will supply energy and pay the Portuguese electricity system, representing a 110% discount on the reference tariff initially set for the auction. This price is the lowest tariff discovered anywhere in the world.

This winning bid by EDPR was for a 70 MW floating solar power plant at its giant hydroelectric dam over Alqueva (Western Europe's biggest artificial lake). The project consists of arrays of more than 12,000 panels and combined hydropower (from the powerhouse associated with the reservoir) with 14.0 MW of existing solar capacity and 70 MW of wind energy generation capacity. EDPR is a subsidiary of the EDP utility in Portugal that operates almost three-quarters of Portugal's hydroelectric capacity. EDP has access to readily available grid connections and as an early mover in floating solar, wants to leverage in-house expertise in the solar, wind and hydroelectric domains.

According to an EDPR spokesperson, the record-low price is attained through economies of scale and an optimal combination of technologies. The company benefited significantly from its technological experience including a pilot floating solar project at Alto Rabagao in 2017 and a 5.00 MW project at Alqueva in 2022. By mid-2022, 78 per cent of EDP's 25.6 GW of installed capacity comprised renewable energy.

The auction result signals positive prospects for similar hybrid projects across Europe. The Alqueva project, which is scheduled to go live in 2025, is projected to be Europe's largest floating solar plant. The company expects the market prices from its existing solar and wind components to compensate for the negative floating solar cost (internal cross-subsidy). The negative price contract is based on the "Compensation to the National Electric System" model. The project is expected to supply 1,500 families with power, comparable with approximately a third of the requirements of the nearby towns of Moura and Portel. The contracts allocated in the auction are applicable for 15 years of plant operations. Portugal also removed permitting hurdles by granting both water surface rights and grid connection rights for 30 years.

The energy produced by the other projects can be sold in the Portuguese MIBEL market at the daily market price. In 2021, the average day-ahead MIBEL price (the Iberian Electricity Market) stands at Euro 112 /MWh. This provides a sharp contrast to the negative price discovered by the auction.

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PV Array Convective Cooling Through Changing Array Spacing

In a bid to decarbonize the energy sector, governments all over the world have been looking at harnessing renewable energy technologies including solar PV and wind energy generators. Though solar energy is abundantly available, it is limited by the solar panels' conversion efficiency, which ranges between 15-20% for most of the first two decades of the present century. Researchers from several countries have been working on improving PV module efficiency. A team of researchers from the US Department of Energy's, National Renewable Energy Laboratory (NREL) believe that controlling photovoltaic (PV) module temperature is crucial to enhancing energy performance and improving economic evaluations of PV projects [1]. The team proposed the utilization of convective heat transfer for cooling solar modules in large-scale solar power plants to improve PV system efficiency and thereby lower the project's Levelized Cost of Energy (LCOE).

The team conducted a 'techno-economic' analysis on a 1.0MW south-facing PV system located in Phoenix, Arizona, with a fixed tilt angle of 30 degrees. The researchers varied the row spacing of the modules from 2.0m to 11.0m, corresponding to a range of ground coverage ratio (GCR) from 0.73 to 0.08. Based on these tests, the team concluded that the optimal levelized cost of energy (LCOE) point was $0.29/kWh, with row spacing varying between 4.83 and 7.34 meters [2].

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Increasing space between solar panels to demonstrate increased cooling of the panels
Source: NREL, PV Magazine

Vertical Agrivoltaics For High Snow Loads

Having exhausted almost all available 'wasteland' for solar PV installations, Japan has shifted its attention to agrivoltaic solutions. Japan's Institute for Sustainable Energy Policies and Japanese EPC contractor Ryoeng Co., Ltd., worked together to build Japan's first vertical agrivoltaic system at Nihonmatsu City, Fukushima Prefecture [1]. The solar modules for the project are procured from German manufacturer Luxor Solar, and the mounting systems are from another German company Next2Sun. The solar array is oriented south due to topographical restrictions, with 8-10m between panel rows. The land between the rows is to be used as pasture for grazing livestock [2].

The companies Luxor Solar and Next2Sun also work together to install vertical arrays of similar configurations at the parking lot of a rice processing factory owned by Eco Rice Niigata in Niigata prefecture, Japan. Niigata is known to receive heavy snowfall of up to three meters in winter. The 8.3kWp capacity array installed at the facility is mainly to test the durability of the system during periods of heavy snowfall and to quantify the unusual energy yield from the system contributed by reflection from the snow. The electricity from the system is to be ed to support the rice processing activities in the Eco Rice facility. The project received JPY 2.0 million (€13,803) from the city council of Nagaoka. With the success of this project, the team planned to build more vertical arrays in other cities which received heavy snowfall [3].

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Eco Rice Facility by Luxor Solar
Source: Luxor Solarr

A Submarine Solar Cable: Connecting Sustainably With The Antipodas Project

Globally, the process of transitioning to 100% renewable energy is facing challenges posed by the unpredictability of weather conditions, limited availability of daylight hours, and changing seasons, especially at higher latitudes. These challenges have been addressed to a certain extent by the use of 'smart' storage systems that store excess energy generated during 'ideal' conditions and are fed back to the grid to meet peak demand. However, storage systems still do not help balance the global supply and demand for several technical, commercial and legal reasons. In the year 2021, the governments of Chile and China thus have taken an entirely different approach to solving the problem. The countries decided to build a submarine cable system running along the bottom of the ocean to help export energy generated by PV plants in Chile to China.[1]

The Atacama Desert in Chile, which has among the world's highest solar radiation, is chosen for the project 'Antipodas' to harness the solar resource. The USD 2.0 billion (€ 1.95 billion) project will lay a cable covering a distance of approximately 15,000km between Chile and China. When completed, it is estimated that the cable line will help transmit 200GW to 600GW of electricity – when it is daytime in Chile (Western hemisphere) and night-time in China (Eastern hemisphere), or when it is summer in Chile (Southern hemisphere) and winter in China (Northern hemisphere).[2]

Smaller projects during the time include the North Sea Link between Norway and the UK (720km, 700MW) and the Australia-Asia Power Link between Australia and Singapore (4,200km) which are scheduled to be commissioned by 2027. As of 2022, the feasibility of such a submarine cable is still being evaluated since there has never been a precedence of a submarine cable project of this magnitude [3]. However, experts believe that the Antipodas project might take several years to be implemented and for the link to be commissioned.

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An Innovative Photovoltaic Signboards Solution By Dansk Solenergi

From solar balconies to solar trees, companies all over the world have developed innovative solutions to harness solar energy. In addition to the long list of innovations are the photovoltaic signboards developed by Danish company Dansk Solenergi, also called Danish Solar Energy Ltd, which is a 'building-integrated PV specialist.' The company has over 20 years of global experience in innovative solar PV solutions, ranging from stand-alone solar systems to solar parks [1].

The company has developed the PV signboard in collaboration with Danish artist Bo Karberg. The 95W PV signboard is circular, having an efficiency of 18.5%, and is hidden behind an image of the earth. The module contains 35 solar cells supplied by Singapore-based solar manufacturer Maxeon. The module is based on Dansk Solenergi's "Color, Form, Reflection (CRF)" technology, which hides the solar cells with a coloured compound that is stuck to the glass. The company claims that even with the solar cells covered, the module can produce enough energy to charge a battery during daylight hours on a normal day in south Denmark. The sign board also has a 760-lumen LED light powered by solar energy to illuminate the sign during darkness [2].

Source: unknown

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The PV Shade Screens For Greenhouses In Saudi Arabia

A Saudi Arabia-based solar solutions manufacturer, Mirai Solar works with King Abdullah University of Science and Technology to develop a foldable, flexible and modular solar panel for agrivoltaic applications. The "PV shade screen" is made of mono-crystalline silicon solar cells and is suited for greenhouses in locations with high solar radiation levels. The shade screens have a retraction mechanism which helps control the light availability for plants. The proprietary screen design has a standard building block that is replicated to cover either all or part of the greenhouse [1].

A module has a nominal power of more than 100 W per square meter. The glass-free design weighs 1.5 kg per m2, which allows its deployment inside the greenhouse using the same infrastructure as conventional shade screens. The installation of the shade screen does not require heavy steel structures. The company tests the shade screen on greenhouses in three different locations and finds that the greenhouse output is on par with conventional shade screens. The company intends to test the screen in several other locations, preferably where the levelized cost of electricity (LCoE) is in the range of $0.03/kWh to $0.05/kWh.

The company also claims that its proprietary module design can also be used for other applications such as car parks, mobile shipping containers, boats, and cars [2].

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Solar panels at King Abdulaziz City for Science and Technology
Source: Reuters File Photo, Arab News

Gravitricity Energy Storage System – Demonstration Projects In India

UK-based energy storage firm Gravitricity partnered with Panitek, energy storage specialists in India, for 12 months to identify and shortlist demonstration sites suitable for gravity energy storage technology. Gravitricity secured GBP 194,000 (€225,118) from the UK government's Ayrton Fund for project [1].

Gravitricity's energy storage system uses electricity from renewable energy to lift weights of up to 12,000 tons in deep shafts. The weights are released when renewable energy generation stops during a 24-hour daily cycle, and the potential energy is converted to electricity to meet demand. Such storage and re-conversion help solve the problem of "intermittent power generation" experienced by renewable energy plants, especially solar plants [2].

It is projected that the storage system can operate for up to 50 years at about half the cost of lithium-ion batteries. The company also claims that the storage system is an affordable solution for India, which aims to install 500GW of renewable energy by 2030.

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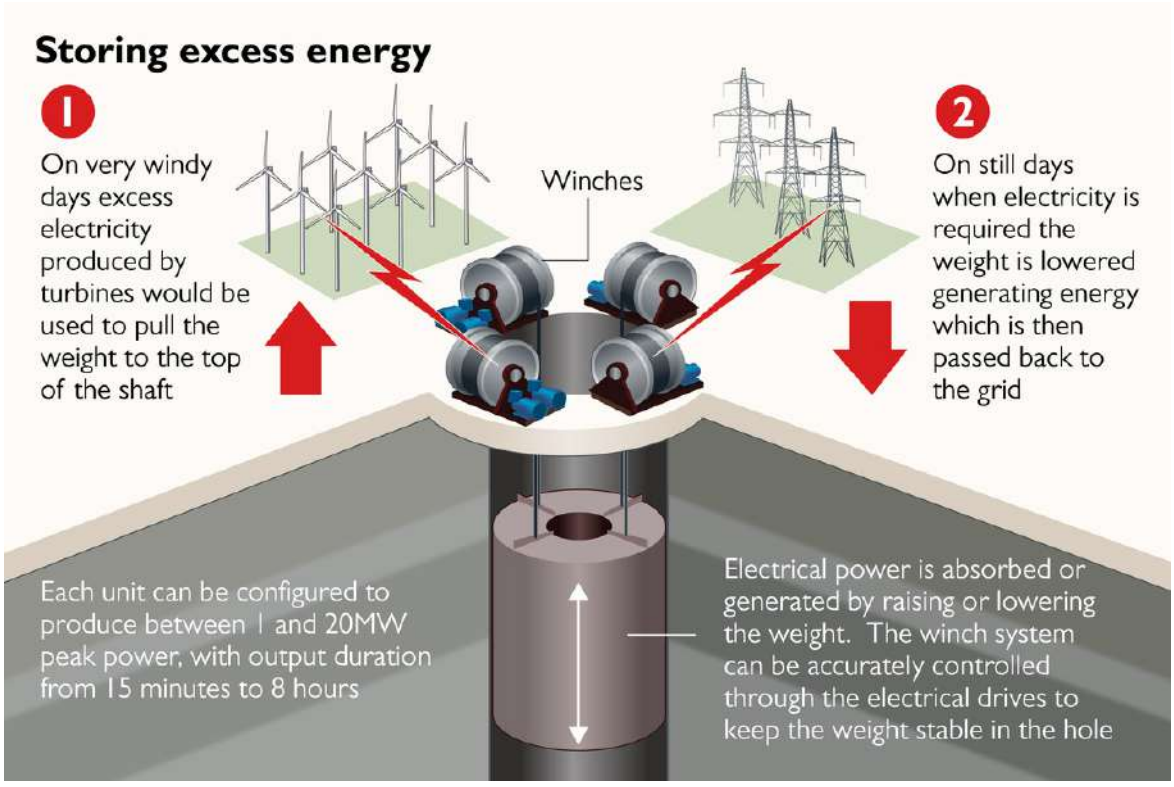

Gravity energy storage for grid balancing pilot
Source: Gravitricity

Solar Shingles – An Alternative To Traditional Rooftop Solar Panels

In 2011, the US-based Dow Chemicals introduced "Solar shingles" as an alternative to rooftop solar modules. These shingles are designed to resemble standard asphalt shingles used for rooftops and are made from thin layers of photovoltaic sheets over a glass base. The shingles can be integrated flat on the roof, as opposed to having to elevate them above the surface of the building, as was the case with traditional solar panels. This feature adds to the aesthetics of the building. The product can withstand rain, hail, and wind like regular rooftop tiles, with the added benefit of generating electricity. However, the shingles were less efficient compared to traditional solar panels, and the company had to close its "shingles" division in 2016 due to low market uptake [1].

In 2022, solar rooftop installations in the USA were gaining momentum due to the solar tax credit and other provisions being made by the government [2]. It was during this time that solar shingles made their appearance again in the US market, with several companies like Luma Solar, Tesla Solar Roof, Sun Tegra Shingles and Tiles, etc, offering solar shingle roofing options. Each shingle is 12 inches by 86 inches by 1 inch in size and weighs around 6 kg. They are made from copper indium gallium selenide (CIGS) cells and produce 13–70 W per shingle, with an efficiency range of 14%–18%. In comparison, the traditional monocrystalline solar panel produces up to 400 watts of power and operates at a conversion efficiency of 24%. In other words, 20–30 shingles are needed to match the power output of a single solar panel. An average roof will need around 350 solar shingles. Due to the number of shingles needed to meet the power requirements of the building, solar shingle installation was projected to cost USD 40,000 to USD 60,000, compared to the standard 5.0 kW solar panels, which cost about USD 15,500. Also, with proper upkeep, solar shingles could have an operational life of up to 20 years, which is comparable to the lifespans offered by traditional solar PV modules. Even though solar shingles are less efficient compared to traditional solar panels, homeowners who prefer a less conspicuous solar installation seek them [3].

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Solar Shingles
Source: This Old House

Best Practices To Avoid Fires In Rooftop PV Systems

As of 2022, the annual fire incident frequency for PV installations was 0.029 fires per MW on average, and with the surge in global demand for rooftop PV installations, the failure rate due to fire was expected to increase significantly in the subsequent years. A team of researchers from the University of Putra, Malaysia, compiled a series of fire safety practices that should be followed by installers the world over to try and avoid rooftop PV fires. According to the team, improper installation practices by inexperienced installers or simple and avoidable errors by experienced installers are the common causes of PV fire hazards. The team systematically studied the fire safety practices prescribed in 40 installation guidelines that were published by national agencies, regulatory bodies, and national associations mostly from the United States [1].

The team categorises the safety practises into 10 groups, which also act as a fire safety checklist that can be consulted before installing and commissioning the PV systems [1].

The 10 groups of safety practise in focus are:

- General practises to ensure the PV system is designed by qualified contractors only;
- Site surveys, like size, shade management, accessway, tilt, orientation, and location;
- Roof structure and material;
- Marking systems for all PV equipment, including PV input and output, conduit, cabling, inverter, enclosures, combiner, box, and isolator switches;
- Roof waterproofing and flashing;
- Electrical cabling and grounding system;
- Array mounting, ventilation, and PV panels;
- combination box and connectors;
- DC/AC inverter, and
- DC isolator and other protection devices.

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Foldable rooftop solar panels
Source: Electrek

Smartflex - A Revolutionary Foldable Rooftop PV System

Through most of 2022, several governments of EU member countries continued to urge people to install and operate rooftop solar systems to try and reduce such countries' dependence on oil or gas as primary sources of energy. In conjunction, companies like Kopp were working on new designs for rooftop solar systems, expecting to make it convenient for people to install solar PV arrays and eventually contribute to expediting the uptake of solar PV systems across these markets. In December 2022, Kopp unveiled "Smartflex," a foldable four-panel rooftop PV system that is easier to install compared to the more conventional rooftop solar PV mounting structures.

The Smartflex system uses n-type TOPCon solar modules with an output of 430 W and efficiency ratings of about 22%. Magnelis, a zinc-aluminium-magnesium alloy, is used for the mounting structure. The number of ballast stones used to anchor the installation depends on the wind speeds at the site and the prospects for extreme weather conditions in the region. The total size of the array is approximately 6.80 square meters when open, and the installation weighs between 150kg and 300kg subject to the number of ballast stones used for the installation [1]. A crane would have to lift the array onto the roof, where it could be installed by just two technicians [2]. The Smartflex system is easy to install and according to the company, proves to be "a revolutionary solution for the growing need for autonomous energy supply. "

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Solar Shingles
Source: This Old House

Hydrophobic Nano Coating On Solar Panels To Reduce Soiling

For solar plants to operate efficiently, solar panel surfaces must be cleaned regularly to remove dust and soil particles that might cover the surface and reduce power output. In most cases, the process of cleaning accounts for a significant part of the total operation and maintenance (O&M) costs of the solar plants. Subject to site conditions, inadequate cleaning could result in large losses, rising to one-quarter of the power output[1]. Moreover, across countries, the availability of water to clean solar panels is proving to be a challenge, especially in arid regions. While researchers from around the world are working on ways to reduce water usage, a team of researchers from Al Azhar University in Egypt worked on creating a self-cleaning, hydrophobic coating for solar panels.

The Egyptian scientists employed a coating solution based on polydimethylsiloxane (PDMS) and silicon dioxide (SiO2) nanocomposites mixed with ethanol and isopropanol. This mixture is produced using an ultrasonic washer and then spray-coated onto the solar panels. The spray coating helps increase the surface roughness of the solar panels increasing the panels' hydrophobicity[2]. The cost of the coating is not yet made public.

The researchers applied coating to a 100W panel and compared its performance with a non-coated 100W panel over 40 days in Cairo, Egypt. To assess the performance of the coated panel relative to the test module, the team measured various parameters such as solar radiation, the surface temperature of the panels, output from the PV panels (DC, DC voltage), and dust accumulation density (g/m2), among others. After 40 days of exposure to outdoor conditions, the team concluded that the accumulated dust density on the test PV panel - the panel coated with hydrophobic nanocoating - is lower by 57% compared to the uncoated reference panel. Moreover, 74% of the dust on the test panel could be removed by water droplets, due to the self-cleaning properties of the PDMS-SiO2 nano-coating, as compared to just 52% for the reference panel[3]. In addition, the efficiency of the nano-coated panel is 30.70% higher than the performance efficiency of the reference panel.

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Customizable Stickers To Convert Solar Panels Into Advertisement Billboards

Sunspeker, an Italian company, was started with the mission to fight climate change through an innovative Out Of Home (OOH) advertising solutions. The company was exploring the possibility of using solar panels as advertisement billboards, totems, and displays on buildings and other infrastructure[1]. In 2022, the company successfully developed a "customisable, fully recyclable sticker to wrap photovoltaic panels." High-definition images could be printed on the stickers, which remain permeable to light. The company claims that when these stickers are applied to the solar panels, the panels could retain between 80-90% of their efficiency. However, the loss in power yield could be compensated by the income from advertising. The company also explored the possibility of using stickers with a "tile" texture for rooftop solar systems. A pilot project was launched In the Veneto region in Italy in November 2022 in partnership with a local energy company to test these "tile" stickers[2].

The technology, however, is still a level six on the technology readiness level (TRL), with nine being the most mature technology which is ready for commercial application. The company received funding of €115,000 from the Italian state-run investment bank CassaDepositi e Prestiti (CDP) to further develop its technology. Sunspeker hopes to raise another €450,000 via new funding rounds.

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Solar stickers for outdoor panels
Source: Sunspeker

Floating PV For Water Pumping And Desalination At Irrigation Community

Comunidad de Regantes de Aguilas, an irrigation community in Murcia, in southern Spain, has built and commissioned a 786.0 kW floating solar array, which is designed to power the community alongside supplying energy to a solar water pumping system and a water desalination unit. A total of 1,728 solar PV modules of nominal power rating of 455 Wp each are deployed as a part of the system [1]. The PV installation is directly attached to the slopes of the pond on aluminium profile supports. In addition to the floating PV installation, modules are installed on the raw water storage bays, rack hall and the transformation centre increasing the total installed PV to 1,264.50kWp, generating an estimated 2,056 MWh annually. The power generated from floating Solar PV modules is to feed into two 600 hp lift pumps each and two 340 kW racks of reverse osmosis desalination plant [2].

The community's overall energy initiative, including solar installations, aims to reduce 1,440 tons of CO2 annually and is projected to yield estimated annual cost savings of Euro 193,000. The total investment of Euro 1,172,000, which includes the floating PV installation and supporting infrastructure, is co-financed by the European Agricultural Fund for Rural Development and the Ministry of Agriculture[3].

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Source: unknown

An Autonomous Solar Panel Cleaning Robot By Greenleap Robotics

Water is often scarce in arid and semi-arid regions that might be better suited for PV plant installation. Keeping solar arrays clean is of paramount importance to ensuring design performance by the plant. In cases of narrow margins, a relatively minor reduction in output may adversely affect project viability. The accumulation of dust most certainly causes such a reduction in energy output [1].

The Lotus A4000 robot and the P4000 robot are built to clean solar PV arrays operating in harsh conditions and arid regions. The robot is built with automotive-grade components and designed with ultra-soft microfiber cleaning fins that combine airflow and a controlled impact to "flick off" dust particles from the surface of the solar PV panels. The impact is slated to be soft enough to ensure that the robot does not damage the anti-reflective coatings on the modules themselves. In addition to removing dust, the robot is equipped to remove bird-dropping deposits throughout four cleaning cycles. Further, the drive system is designed with adequate orientation control to overcome panel-to-panel irregularities of up to 40 mm. The autonomous robot can be controlled through a web application and dock into a charging station after cleaning.

Greenleap Robotics, the company producing the robot, observes that waterless cleaning leads to an increase of 10% in generation relative to bi-weekly wet cleaning. The robot is run by a built-in lithium battery that can be charged in under two hours and provides sufficient power to clean a 1.0MWp solar PV power plant in 2.5 hours [2].

The LOTUS P4000 is also a waterless solar panel cleaning robot but is branded and sold as a "semi-autonomous" variant. While the A4000 is dedicated to a row of panels within the power plant, the P4000 is shared across multiple solar rows. The increased efficiency of use brought the estimated payback period for the P4000 to under 1 year. Assuming that the robot works for 6 hours each day, a single P4000 robot is reportedly capable of cleaning 25 MW of installed capacity each day.

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Lotus P4000 solar panel cleaning robot
Source: Greenleap Robotics

Using Selenium For Indoor Solar Photovoltaics

Charles Fritts from New York, USA, constructed the first solar array in 1884, consisting of metal plates with a thin layer of Selenium (Se) and a semi-transparent gold leaf film. It was reported that this solar array produced a continuous, constant current of considerable force when exposed to direct sunlight, diffused light, and even to lamplight.[1] However, these solar modules were considered commercially unviable since they produced just 5W per square meter and converted less than 0.5% of the incident sunlight into electricity; evidently, this quantum of power was not sufficient to power everyday appliances[2]. Scientists continued research on improving the efficiency of Se solar cells till the early 1950s, until the invention of silicon solar cells that are five times more efficient than Se solar cells. With the shift in focus towards silicon-based solar cells, extensive research on Se solar cells was abandoned.

In 2022, a group of researchers from China revisited the Se solar cells for use in indoor photovoltaics (IPV). The team found that the absorption spectrum of Se perfectly matches the emission spectra of commonly used indoor light sources in the 400–700 nm range. Further, the thin layers of Se used in the panels have minimal toxicity and could even be beneficial to the human immune system. This makes it an ideal material for IPVs since the regulation of materials used to manufacture IoT products is strictly governed by the restrictions on the use of certain hazardous substances in some countries.

A widely used superstrate configuration of glass with F-doped tin oxide (FTO)/TiO2 and Tellurium (Te) is used to fabricate Se thin-film solar cells. The Te layer serves as an adhesion layer between TiO2 and Se to improve the adhesion and uniformity of Se films. The Se cells developed by the team exhibit an efficiency of 15.1% under 1000 lux indoor illumination. The cells show no efficiency loss after 1000 hours of continuous indoor illumination without encapsulation. These cells outperform the amorphous silicon cells used in the IPV industry at the time in both efficiency and stability. The team also fabricated Se cells of size 6.75 cm^2, that produced 232.6 μW of output power under indoor illumination, powering a radio-frequency identification–based localization tag[3]. This study demonstrates the great potential of Se for IPVs.

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Indoor solar panels
Source: The Star, Getty Images

India's Solar Canals - A Smart Solution for Space Issues

A major blockade in large scale solar projects is the need for space to set up the panels. In India's Gujarat, a unique solution has been to cover its water canals with solar panels, helping save land, water and carbon emissions in one.

Gujarat's Canal-Top-Solar panels are suspended on a metal structure over the canal
Credit: Getty Images

One of the main challenges in building relatively large solar farms has been that of finding the right parcel of land at the right location, especially in densely populated countries and regions, and in situations where property ownership might be weakly defined. India faces this challenge and has committed to an aggressive target of commissioning 300,000 MWp of installed solar PV capacity by the year 2030.

Consequently, across various parts of the country, the solar energy industry has shifted focus to making the most efficient and innovative use of available land parcels and spaces. The western Indian state of Gujarat has found an innovative solution by installing solar arrays on canals carrying water for irrigation and for consumption.

This avoids land acquisition, lowers the rate of water evaporation and cools the panels above, thereby enhancing power output as well. In 2011, the provincial government of Gujarat proposed the idea of "canal-top solar" as the means to enhance energy generation without having to specifically allocate land for PV plant construction. By 2014, a pilot project involving a 750m (about 2460.63 ft) stretch leading off the Narmada River led to the first large-scale canal-top solar power plant in Vadodara district.

The pilot was soon followed by plans for large scale replication of "canal-top solar" installation along the lengths of the canals in the state. The long stretch of the canals was slated to permit the evacuation of electricity from multiple points.

The first large scale canal-top Solar Power Project (1.0 MW) was implemented on the Sanand Branch Canal of the Sardar Sarovar Project, at Chandrasan village near Mehsana, 45 kms from Ahmedabad, Gujarat. By being located right above the flowing water, the panels remained cooler resulting in lower temperatures and more efficient

production of energy compared to traditional ground mounted arrays. Additionally, the shade from the panels helped curtail the growth of pervasive algae in the canals that contribute to water toxicity and clog water pumps.

On the flip side, these canal-top solar plants were more expensive to construct compared to ground-mounted plants of similar capacities. They required custom designed and heavier galvanized support structures to minimize and delay corrosion. Additionally, the winding contours of the canals made it difficult for the arrays to be oriented for maximum power output. Further, limited physical access to individual panels means that cleaning or maintenance work of the panels could only be done by using ramps and mechanical sprayers. Being in outdoor and unrestricted public spaces also opened up the prospect of theft of the arrays, requiring additional investments into the deployment of cameras and security personnel to preserve and protect the power plant equipment.

The pilot for this project was completed in 2015 at a cost of USD 18.3 million and received the Prime Minister's Award for Best Project in Public Administration in India for the year 2015. The large-scale canal top solar power project on Sanand Branch Canal was projected to generate 1.6 million kWh of electricity per annum and helped prevent the evaporation of 9.0 million litres of water from the canal.

As the project was largely located in rural areas that do not have regular access to power, the energy generated from the canal-top-solar project could be transmitted to the local region directly, reducing power transmission losses. The energy was used to provide electricity for farmers during the energy-intensive irrigation season, and the surplus electricity during the off-seasons was fed to the state utility grid, used by the canal authority, or sold to distribution companies. These pilot initiatives were followed by the commissioning of 10MWp canal-top capacity in November 2014 and 25MWp of similar capacity in 2017.

Notwithstanding such risks and additional costs, in May 2022, Sardar Sarovar Narmada Nigam (SSNN), the Gujarat government-owned enterprise, proposed the installation of 100 MWp of solar PV capacity over the branch canals of the river Narmada.

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500MW Dau Tieng Solar Project in Vietnam

Vietnam witnessed a sudden boom in solar installations leading up to December 2021. One of the biggest projects implemented on the back of this was the 500MW Dau Tieng Solar Array – the largest in Southeast Asia.

Bird's eye view of the DauTieng Solar Reservoir in Vietnam.
Taken from Wikipedia creative commons https://commons.wikimedia.org/wiki/File:DAU_TIENG_PROJECT_BIRDSIGHT.jpg

Vietnam's nascent solar market witnessed a sudden boom in solar installations in the year 2019, on the back of some very attractive feed-in-tariffs. The total installed capacity increased from a little more than 100MW in 2018 to 5,700 MW by the end of December 2021. One of the major projects implemented during this period was the USD 392.5 million (~€ 344.22 million), 500 MW Dau Tieng solar array which was one of the largest installations in all Southeast Asia.

The three-stage solar PV plant with a 220kV substation and inverters was built by PowerChina Huadong – the EPC contractor – on behalf of Vietnamese project developer Xuan Cau and Thailand based B.Grimm Power. Jinko Solar of China supplied the 330 W multi-crystalline PV modules for the project[1].The first two stages of the project with a cumulative capacity[2] of 350MW had been commissioned by June 2019, while the third stage with a capacity of 150MW was commissioned in September 2019[3]. The project sold power to the state-owned utility Electricity of Vietnam (EVN).

Notwithstanding the attention paid to the design, the project faced many challenges during the installation, including supply shortages and fluctuating water levels. However, the contractors succeeded in completing the project on time, as contracted[4].

The solar array was built on the Dau Tieng Reservoir, where the water levels fluctuated wildly throughout the year: this made Dau Tieng one of the most challenging installations ever mounted.

Since floating solar structures could not work under such conditions, special concrete pillars with heights ranging from 2.5m to 8.0m were sourced from Arctech Solar. Using a special vessel, these pillars were planted on the bed of the lake. Special zinc brackets were mounted on top of the pillars upon which the panels were installed.

Apart from such big projects, massive scaling up of roof-top installations have been seen in Vietnam. More than 9GW was installed in 2020, of which 6.1GW was done in December 2020 alone. This was because the government offered a feed-in-tariff (FIT) of 8.38 US cents/kWh, for a duration of 20 years, for projects commissioned by 31 December 2020. The installation companies had to comply with the EVN grid codes and obtain required licenses prior to installation. The EVN was responsible for signing the Power Purchase Agreements (PPAs), supplying and installing 2-way meters, calculating the power production and making yearly payments. The optimal financing model for Vietnam was equity for the first 5-10MW, then once scalability and sufficient track record was proven, getting debtors involved [5].

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Djibouti Aims To Be The First African Country Entirely Reliant On Green Energy

With a significant potential in renewable energy such as solar, geothermal and wind, the Djibouti government is aiming for a 100% share of renewables in the country's energy mix in a bid to increase energy security and ultimately aid sustainable economic and social development.

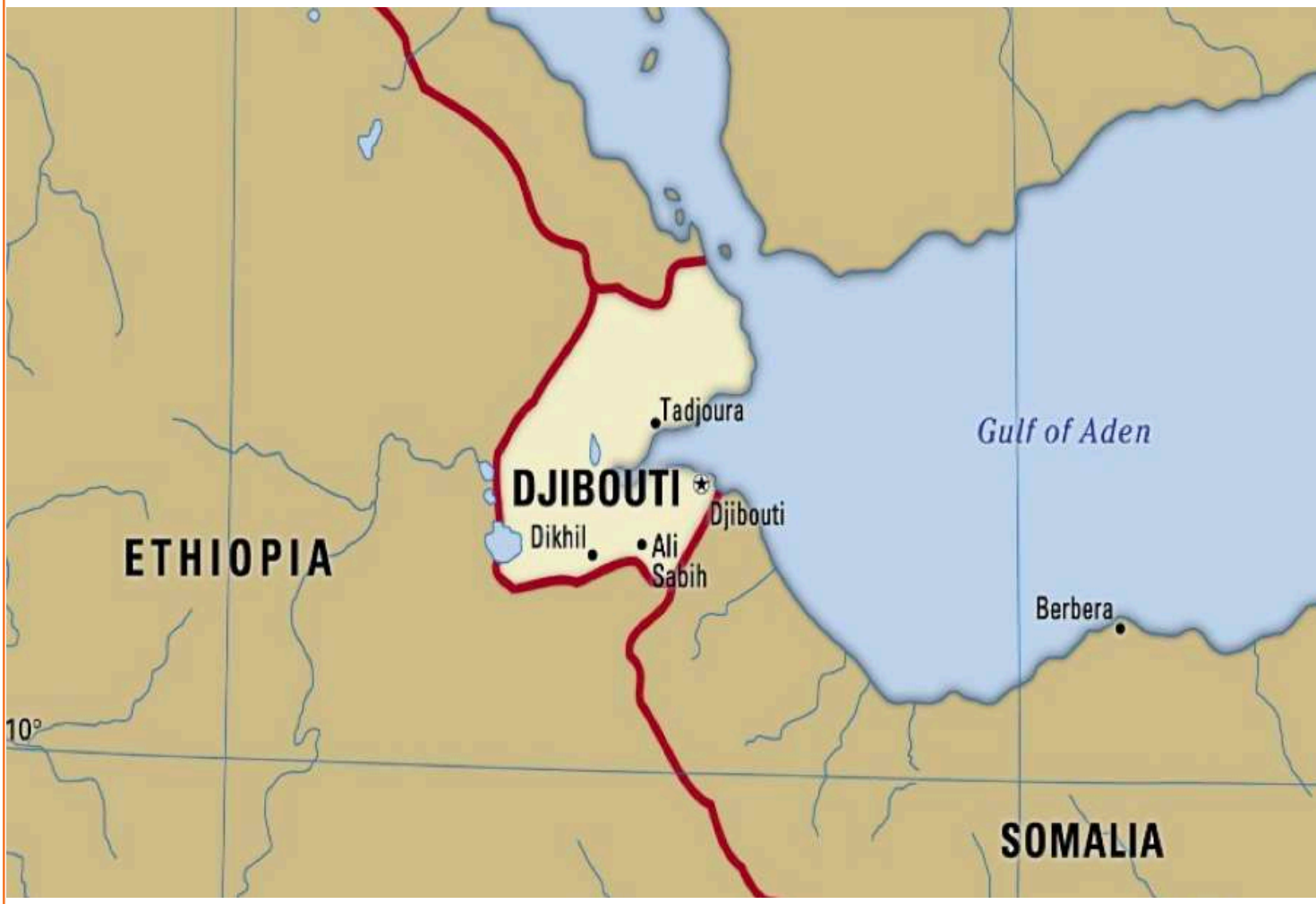


Image source: Brittanica Online

The electricity demand in Djibouti has been increasing at the rate of 10% each year since 2011, and the country's power ministry estimated that the total demand would reach 1,000 MW by the end of year 2030. The government has committed to reaching the goal of 100% electrification in the country by 2030. In addition, at the 2012 World Energy Forum at Doha, the President of Djibouti announced the government's intention of becoming the first country in Africa to be entirely reliant on green energy by year 2025. Subsequently, the government even established a roadmap to work towards achieving these goals.

With an estimated solar potential of more than 70 MWh per year, according to MERN, the potential for its development is substantial, both for on-grid and off-grid applications. One of the first projects approved towards the country's 100% RE goals was a 50MW solar power plant to be built at the Grand Bara desert. Slated to be built by Swiss company Green Enesys, the project was to be part of a bigger solar power complex of 300MW whose cost was estimated at €360 million. However, no progress was made even after three years of laying the foundation stone in 2016.

The government then decided to collaborate with France's Engie to build a USD 40 million (~€44.7 million) – 30MW solar power plant. This project was to be expanded to 100MW in the next phase, once production estimates were confirmed. Djibouti's [sovereign] financial arm, the FondsSouverain de Djibouti (FSD) has 20% stake in the project.

In parallel, the government has also been looking at other renewable energy options to help reach the goal of 100% green energy. A USD 160 million - 60MW Goubet wind power plant was to be built by Spanish company Siemens-Gamesa and was expected to be completed by end of 2022. A USD 150 million – 35MW - 40MW biomass plant was also being planned in collaboration with US investors, CREC Energy. Djibouti also has an estimated potential of 500 - 1,000 MW geothermal energy which was being explored by Kenyan companies, along with Djibouti's Red Sea Drilling Company.

In 2019, it was also estimated that the country may have vast pockets of pure hydrogen in its subsoils, which could be exploited. France has planned to invest USD 5 billion every year in Djibouti to develop this alternative fuel. A delegation from the University of Paris is already based in Djibouti to explore the possibility of harnessing this energy source.

While the roadmap to achieve its goals has faced obstacles, support of strong partnerships, Djibouti is on its way to substantially increase its share of renewable energy.

Researchers Develop Innovative Bio-Battery Using Phase Change Materials for Efficient Heat Storage

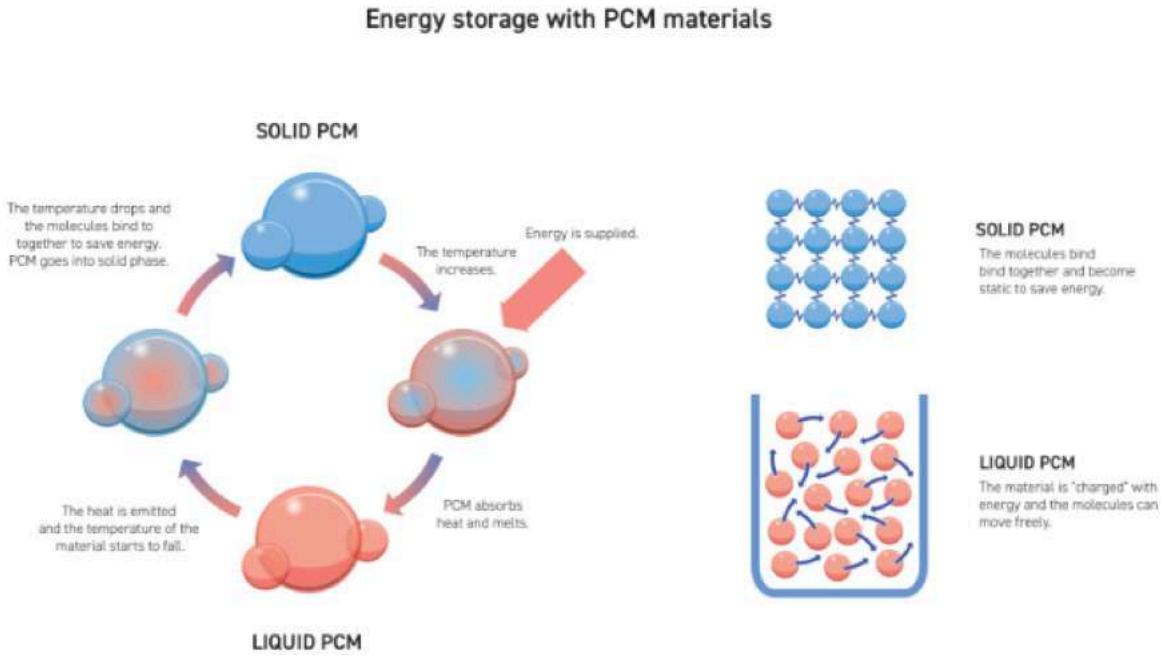
A team of researchers from SINTEF, a prominent Norwegian research organization, have successfully created a groundbreaking "bio-battery" by harnessing the potential of phase change materials (PCM). The bio-battery, built and tested at a Zero Emissions Building in Trondheim, Norway, combines PCM materials with heat pumps to store and utilize heat effectively and is set to be installed in a pilot project by the end of 2023

The ZEB laboratory operated by NTNU and SINTEF in Trondheim. Energy from the laboratory's solar panels is stored as heat in their innovation- the bio-battery. This energy is then used to heat the building when the weather is cold, and the sun isn't shining.
Photo and caption courtesy of SINTEF

Phase change materials (PCM) have long been recognized by researchers for their remarkable ability to absorb or release substantial amounts of latent heat during a change in physical state. Leveraging this unique characteristic, a team of researchers from SINTEF, a leading Norwegian research organization, has achieved a significant breakthrough in energy storage technology. Their groundbreaking creation, known as a "bio-battery," combines PCM materials with heat pumps to store and utilize heat efficiently.

The development of this innovative bio-battery took place at a Zero Emissions Building (ZEB) located in Trondheim, Norway, and involved collaborative efforts between SINTEF and the Norwegian University of Science and Technology (NTNU). The system was specifically designed to make use of the energy generated by the building's 180kWp solar installation, employing a heat pump to channel the energy into the bio-battery.

Enclosed within a silver-colored container, the bio-battery contains three tons of liquid bio wax derived from vegetable oil. This bio wax remains in a crystalline state when the temperature is below 37°C, transforming into a liquid form at higher temperatures. The change in state influences the bonding between the molecules of the bio wax, leading to an increase in their kinetic energy. As the temperature drops, the wax transitions back to its solid state, effectively converting the stored kinetic energy into heat, which is then dissipated.



To capture the heat generated during this phase change process, the bio-battery utilizes 24 "cushion-plates" surrounded by water. Acting as an energy carrier, the water extracts heat from the storage system. The heated water is then directed to the building's radiators and ventilation system, supplying warm air throughout the premises. Remarkably, the researchers estimate that the battery has a heat storage capacity of 200kW, capable of providing heating for the building during the coldest period of the year for three to four days. Additionally, the bio-battery boasts an impressive lifespan of 25 years and requires minimal maintenance.

The researchers strategically charge the bio-battery before the coldest parts of the day, allowing them to avoid consuming electricity from the grid during peak demand periods in the city of Trondheim. By leveraging the data obtained during the first year of operations, the team has been able to optimize the system further. As part of their future plans, the researchers aim to install pilot bio-battery systems in various industrial equipment manufacturing companies by the end of 2023, showcasing the potential and practicality of this innovative energy storage solution.

In conclusion, the successful development of the bio-battery utilizing phase change materials opens up new possibilities for efficient heat storage and utilization. With its impressive heat storage capacity and long lifespan, this technology has the potential to revolutionize the way buildings are heated, offering a sustainable and cost-effective solution for the future.

2.

Circularity: Solar PV, Battery And Waste Management

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2. Circularity: Solar PV, Battery And Waste Management

A Sustainable Recycling Technology Module For Solar PV Panels

Reduce, Reuse and Recycle are the fundamentals of sustainable development. This applies to Renewable Energy plants as well. Keeping in mind the three Rs, ROSI Solar has come up with a recycling technology for PV panels in France.

By the year 2050, an estimated 80 million metric tons of solar panels might retire: materials in solar PV panels taken offline can progressively grow in value and be worth an estimated USD 2.0 billion by 2050. Attempts have been made to refurbish and sell end-of-life panels for reuse to try and make the most of the available PV modules. Subject to the power output, these resold panels may fetch a third of the price of a comparable new solar PV module and can serve end-users for a few additional years. At the end of such efforts, it will be necessary to forward the PV models for materials recovery and environmentally conscious disposal of residues.

ROSI Solar, a Grenoble (France) based PV recycling company was launched in 2017, through the Linksium incubator[1]. The company's pyrolysis technology allows the recovery of ultra-pure silicon and other metals like copper and silver, otherwise lose at the end-of-life of the solar panels. The novel technology has earned the support of the French environment and energy agency Ademe, the French national investment bank BPIFrance, French environmental services provider Veolia, and European Union programs. The recovery of such materials as silver and silicon is projected to make recycling financially viable. Early experience indicates that the offer of sale of ground glass 'cullet' might offer ROSI and other recyclers a relatively small market niche and might not contribute substantially to recycler revenues.

More recently, in July 2021, Soren, a non-profit eco-organization approved by the French public authorities for the collecting and processing of used photovoltaic panels, partnered with ROSI Solar to suitably process end-of-life photovoltaic (PV) modules. Envie 2E Aquitaine was selected to provide the logistics and pre-processing services. Together, the three companies work on building an industrial facility in La Mure en Matheysine in Isère, Matheysine, for the recycling of solar panels and recovery of valuable materials.

The plant was commissioned by the end of 2022 and was in a position to recycle 3,000 tons of solar panels per year, extracting about 3 tons of silver and 90 tons of silicon. The project received 4.8 million Euro from European Union[2]. Estimates suggested that to be profitable, ROSI Solar would have to recycle at least 2,000 to 3,000 tons of panels per year[3].

Before the commencement of the project, between the years 2015 and 2020, Soren had already collected 15,000 tons of end-of-life PV modules and had expected to collect 7,000 panels by the end of 2021 and expected to collect an additional 20,000 tons of PV modules by the end of the year 2025[3]. This enabled ROSI to immediately start work on the first industrial line with large-scale equipment, and by January 2022, the company had conducted several full-scale tests and was well on its way to creating an economically viable PV recycling and recovery centre[4].

ROSI develops the chemical process to extract high-purity silicon and silver from the retired PV modules. The silver so recovered can be put to multiple uses, while the silicon can find its way into new PV modules or EV batteries. However, the breakeven volumes for ROSI can be determined by the relatively volatile market prices for the recovered material, especially the prices for solar-grade silicon. Further, if solar modules are to replace silver with other materials, the business case for recycling may have to be reconsidered, subject to the market prices of such material. Overall, the energy source and the quantum of energy invested into manufacturing, recycling, transportation and other support activities set to determine the greenhouse gas emissions avoided using the PV module, relative to erstwhile mainstream power generation options.

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The pyrolysis furnace used by Rosi Solar.
Source: PV Magazine

Elsi – A State-Of-The-Art Solar Panel Recycling Plant

This is a case study about the Elsi module introduced in Germany. It expands the scope of sustainability through a solar panel recycling and reusing module.

Recently, there has been a rapid expansion in the deployment of photovoltaic (PV) systems throughout most parts of the world with installed capacity in Europe expanding at a very encouraging pace. As equipment from some of the early installations in Europe from over two decades ago, near the end of its useful life, all stakeholders concerned have been considering options for material recovery and environmentally benign disposal of the residual material. Given the technical life of solar energy systems and the volume of installations in the early years of the millennium, the scale of the task involving disposing of obsolete and damaged solar panels is estimated to surge in the early 2030s. To address this problem, in 2016, the European Union funded the ELSi project that explores the possibilities for Industrial scale recovery and reuse of all materials from end-of-life silicon-based photovoltaic modules. The project was implemented over 24 months and cost an estimated €3.25 million, of which the EU provided a grant of €2.5 million [1].

ELSi focuses on silicon recovery from end-of-life ("EOL") modules and commissioned a pilot facility in Knittingen, Germany. Three major companies working on this project are Geltz Umwelt-Technologie, Variata, and Revatech. Before receiving grant funding from the EU, these companies had worked on developing a patented technology to recover about 95% of silicon, high-purity glass, aluminium, copper, silver, gold, tin and lead from end-of-life modules. For the ELSi, the three companies worked with Solartys, the industrial association, and Fraunhofer as RTD partners to demonstrate the technology involving mechanical and electrolytic-based processes at an industrially relevant scale (1000 mt/a).

PV recycling involves several processes including mechanical separation processes, chemical dissolution and electrically driven separation [2]. In addition to the technical process, the project also focuses on the logistics aspects of procurement, transportation, and outbound logistics. The project needs to ensure a steady supply of eol PV modules for the operation of the ELSi plants. Because of this, supply contracts are put in place, and various marketing and communication activities are carried out. It includes publications in user-oriented recycling and waste journals, presentations at various conferences and several web-based dissemination actions. The project owners focus on the commercialisation of the ELSi PV recycling system [3].

Solar recycling
Source: MS Tech, Pixel Squid, MIT Technology Review

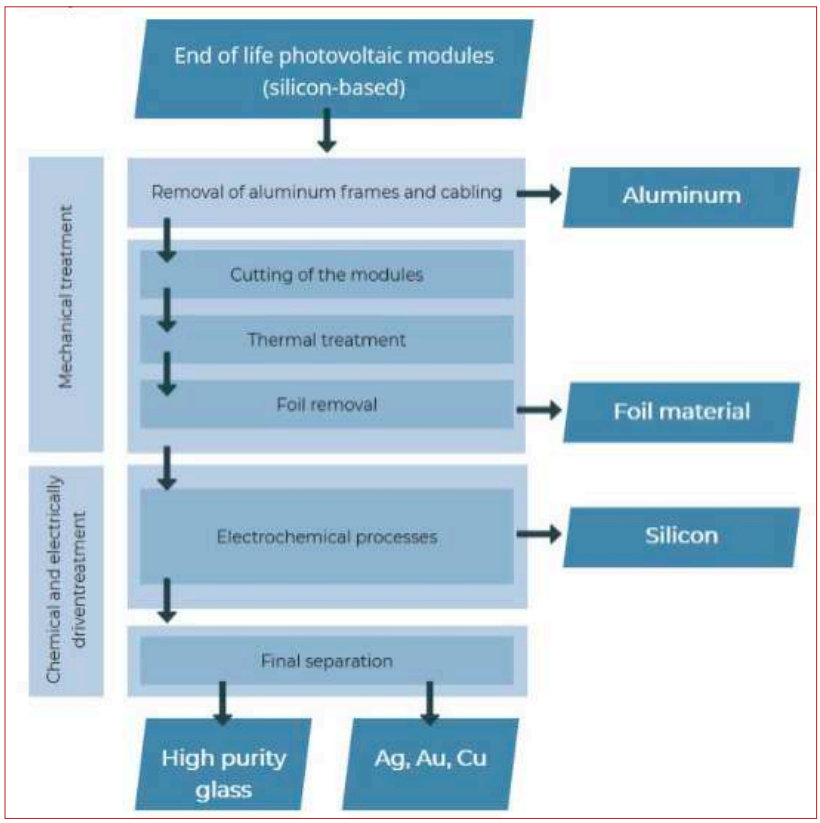

Figure 1: ELSi Pilot project for recycling Solar PV modules
Source: Geltz (2018) https://geltz.de/en/elsi-pv/

The new technology and operating parameters are tested extensively and optimised. As a result, the new industrial pilot facility can process up to 50,000 solar modules in a year. One cycle of the pyrolysis process at this facility can treat about one metric tonne of solar module waste. The project's recovery methods can yield over 95 per cent of recycled material [4]. The novel recycling technologies are expected to improve the economic viability of industries involved in the recycling and the consumption of raw materials. However, after the pilot project was completed, the commercial operation of the plant was delayed due to insufficient module feedstock and the low price of silicon which made material recovery from spent modules less attractive [5].

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An Innovative Solution - Solar Panels Based On Bio-Sourced Materials

2

Over the past three decades, Solar PV installations have grown at an unprecedented pace around the world, and installed capacity is expected to reach 4,500 GWp by the year 2050. There is a need to address the problems related to solar waste. The French Solar Energy Institute is one of the companies that have found a solution to this problem.

The volume of decommissioned PV modules is projected to grow in tandem with the growth in installation volumes albeit with a lag which would be equal to the useful life of the underlying technology option – shorter life spans for thin-film (a-Si) modules and relatively longer spans for crystalline silicon modules (c-Si). The International RE Agency (IRENA) estimates that by the year 2050, the mass of end-of-life PV modules (5.5-6 million tons) will be almost equal to the mass of new installations (6.7 million tons)[2].

Mainstream solar modules are typically made of glass, aluminium, silicon, lead, copper, silver and several other metals. The silicon in solar panels is normally combined with metals like cadmium and lead, and this raises the difficulty in recovering material for potential reuse. Some of the constituent materials are known to be hazardous and can have adverse impacts if they leech into the soil or the groundwater. Several institutions and companies around the world have been working on finding a solution to address the problem of managing solar waste. The French Solar Energy Institute (INES) is one of them.

In June 2022, INES announced the development of new PV modules made from thermoplastics and natural fibres. The front side of the panel is made with fibreglass polymer, while the rear side is made from a composite based on thermoplastics in which a weaving of two fibres – flax and basalt – has been integrated. This provides the required mechanical strength to the panel and increases resistance to humidity while lowering the module's weight to under-5kg per square meter of module area.

The material employed is eminently recyclable: the thermoplastic can easily melt and separate the layers, as opposed to the challenges faced in extracting material from a mainstream PV module. The scientists working on the design claim that the use of such material has reduced the carbon footprint by 75g of CO_2 per watt, which amounts to a 10% reduction compared to a mainstream module of the same power rating. Another advantage of the module is that the material employed is naturally black, which eliminates the need for an additional 'back sheet.' The basalt-free face of the module has a natural linen colour, which can be aesthetically interesting for architects in terms of façade integration (building-integrated PV –"BIPV").

Further, INES claims that manufacturers can adopt this technology without additional investments. Most manufacturers use the Heterojunction technology (HJT), in which a crystalline silicon cell is laminated between two layers of thin-film silicon. This energy-intensive lamination process lasts 30-35 minutes, with operating temperatures between 150°C and 160°C. However, the INES technology requires to operate at 200°C – 250°C: the HJT technology can not handle such temperatures. To overcome this problem, INES collaborated with Roctool, the French induction thermos-compression specialist. Together, the agencies developed "a module with a rear face made of polypropylene-type thermoplastic composite to which recycled carbon fibres" were integrated. Roctool's induction thermos-compression process makes it possible to heat the front and rear plates quickly without having to reach 200°C at the core of the HTJ cells. This process reduces the cycle time to just a few minutes, using less energy compared to the conventional method. Another problem faced by most manufacturers is the supply of solar glass. INES addresses this problem by re-using 2.8mm tempered glass from old modules. All in all, the new technology helps manufacturers produce parts of different shapes and sizes while integrating lighter, more durable and environmentally friendly materials[2].

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Recycled Solar Panels - An Economic Solution For Manufacturing PV Panels

The increasing use of solar panels also imposes a threat to the environment when it comes to the waste generated. Many studies have now shown and researched a recycling process for these panels that will create better and more efficient solar panels.

The global Solar PV market has grown at unprecedented rates since the turn of the millennium. The Solar PV panels are estimated to operate for 10 – 30 years subject to the technology option and operating conditions. The decommissioned panels may pose a sizable environmental problem at the end of their useful lives. Simultaneously, the end-of-life (EoL) PV modules also present a wonderful opportunity for material recovery. The International Renewable Energy Agency (IRENA) has estimated that the raw materials that can be recovered from solar PV panels can cumulatively yield a value of up to USD 450 million (€426.26 million), and approximately 60 million new panels can be manufactured from the recovered raw material [1].

As of mid-2022, experts from around the globe had been experimenting with several approaches for material recovery and were working towards improving process efficiencies. Many researchers were waiting for volumes of EoL PV modules to grow sizable enough for them to test their recycling technologies at a viable scale.

Processing and purifying silicon from decommissioned panels has been a major challenge since such recovery is an energy-intensive process. Moreover, solar panels made from recycled silicon exhibit significantly decreased conversion efficiency, and can not compete with solar panels made from new silicon. A team of scientists from the Key Laboratory of Urban Pollutant Conversion at the Chinese Academy of Sciences has been working on developing a recycling process that will be less energy-intensive and will produce silicon wafers that can result in high-efficiency cells. The scientists have based their technology on a process previously used by wafer manufacturers to produce black silicon wafers with reduced reflectivity [2].

The team uses a commercial multi-crystalline silicon (mc-Si) module that includes an Aluminum frame, tempered glass, two Ethylene-Vinyl Acetate layers, p-type 156mm2 silicon cells, copper ribbons, and a back sheet. The silicon cell consists of the silver electrode, anti-reflection coating, n-type silicon, p-type silicon, aluminium back surface field, aluminium-silicon alloy, and aluminium electrode. The process first mechanically separates the aluminium frame from the solar panel and recovers the silicon cells non-destructively through a special method developed by the team. This method involves immersing the sub-assembly in various chemical solutions, metal-assisted chemical etching (MACE), rinsing with ultra-pure water, and drying by nitrogen. The recovered silicon wafers have a favourable thickness of 165 µm, a resistivity range of 1.02–2.28 Ωcm, and a carrier lifetime of 1.12–2.47 µs, along with ultralow reflectivity compared to commercial silicon wafers. It makes the wafers a viable and preferred option for high-efficient photovoltaic module production.

An economic assessment by the team shows that the recovery technology presents a lower production cost than that of a comparable conventional recovery process or the price of silicon wafers from an industrial production process [3].

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2 Upcycling Silicon Waste From End-Of-Life Solar Panels For Thermo-Electric Application

This case study is about the technique developed by scientists in Singapore to upcycle and reuse the silicon from EoL PV panels. This study explains the metrics and processes involved.

Over the median year, Singapore received solar irradiance of about 1,580Wh/m2/year. It is about 50% more than the solar radiation in several other temperate zone countries, making solar PV one of the more promising sources of clean energy in Singapore. Realising this potential, the government proposed the deployment of 2.0 GW in solar capacity by 2030[1]. Grid-connected PV installations in the country grew from 59.3MW in 2015 to 443.6MW by March 2021[1]. However, the increase in installation volumes also concerns the disposal of end-of-life solar panels in the years to come. Several researchers across countries have tried to find ways to recycle, reuse or repurpose EoL solar panels in one way or another. Silver and Copper from the PV panels are usually extracted and reused because of their high value relative to their weight. However, silicon which makes up the bulk of contemporary solar panels is likely to go into landfills owing to the low value realisation from material recovery. It is because most silicon-based technologies are sensitive to impurities, and it is uneconomical to purify silicon from EoL panels[1].

In March 2022, a group of scientists from Singapore developed a new technique to reuse silicon from EoL photovoltaics in thermoelectric devices that converts heat into electricity. The scientists claim that the thermoelectric devices are 'tolerant to defects and impurities, making them suitable products for recycled silicon from EoL PV panels: 15.6 cm x 15.6 cm solar cells provided by Singaporean manufacturer Green Research Scientific.

Polycrystalline silicon is pulverised using ball milling for an hour in an argon atmosphere to prevent oxidisation and ensure homogeneity. Then the mixed powders are consolidated using a spark-plasma sintering process at 1,150°C for five minutes and pelletised into ingots. During the park plasma sintering process, the silicon is doped with germanium and phosphorus, which improves the 'power conversion and cooling efficiency of applicable thermoelectric technologies' and increases overall chemical stability during long-term, high-temperature operations. At the time of publishing the results from the tests, the team acknowledged that it was difficult to estimate the cost of their technology since it depended on several external factors such as scale, throughput, market prices for the material recovered, labour costs, etc. However, the team found that the energy harvested per dollar was more 'attractive' compared to conventional thermo-electric technologies that mainly rely on heavy elements[1].

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Reusing Discarded Solar Panels As Building Materials - A Case From India

Renewable energy accounts for only 12.3% of total energy in India. However, there are continuous efforts to increase the manufacturing and installation of solar PV panels. Many projects have also been started to reuse discarded panels for further production. This a case study about such projects that have started in India.

India has set itself an ambitious target of installing around 430GW of renewable energy capacity by 2030, of which 280GW is expected to come from solar PV installations alone [1]. In pursuit of such targets, the Government of India formulates and implements several policies and offers customised incentives directed at accelerating the pace of solar PV installations in the country. However, notwithstanding the incentives for capacity addition, the country lacks a concrete policy framework or implementation mechanism to tackle the problem of end-of-life solar (EoL) power plant components. It is estimated that the country will generate around 1.8 million tons of solar PV waste by the year-2050.

In 2007, a group of scientists from the Indian Institute of Science (IISc), Bangalore, embarked on a project to repurpose discarded End-of-Life (EoL) solar panels into building material [2]. Among others, the engineers considered employing the depleted panels as curtain walls and partitions within the building.

In 2018, the team wanted to extend the thermal testing facility to try and extend the life of depleted solar PV modules but did not have the necessary resources. Consequently, the team decided to use the modules to substitute cement and bricks in ongoing construction work on campus. In addition to serving as curtain walls, the modules were expected to bear some of the superimposed structural loads. Eventually, around 60% of the then-upcoming building was made from EoL solar modules, within a structure that also carried Mangalore [clay] tiles for roofing, tin sheets and packaging wood. The building was commissioned in May 2022 and was slated to serve as a site for new research. At the time, the team discovered that some of the PV panels could generate 30-40% of the name-plate capacity, and the power from such depleted panels could potentially power equipment used within the building.

As of 2022, the team was testing the climate resilience of the building: structural changes to the panels due to peak summer temperatures in tropical regions, structural stability against wind, rain, and hail etc. The indoor air quality was also tested since there was a risk of micro-plastics and toxic metals like tin, silver and others leaching out of the PV modules [3].

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An Automated Method For Solar Module Recycling Facility

Many plants have been set up in France to recover and reuse the materials from solar panels. In 2021, Soren and Envie took over the task of managing solar waste in France. This is a study about the recovery facility set up by them.

In tandem with rapidly declining prices and increasing conversion efficiencies, large volumes of Solar PV were deployed in the 1990s and early 2000s. Given that PV modules have an estimated useful life of about 20-25 years, some of the early installations have reached the end-of-their useful lives by the early 2020s. This gave rise to a problem of large-scale waste that needed to be managed appropriately while ensuring that most of the panels did not end up in landfills. Since PV modules contain heavy metals like tin and lead, disposing of such metals represents a matter of environmental concern. On the other hand, the presence of metals like silver and gold in these modules provides a valuable opportunity for materials recovery. However, most mainstream recycling processes employed during the 2020s can recover only a tiny portion of the material.

In 2021, the French authorities handed Soren and Envie 2E Aquitaine the responsibility of collecting, handling and managing solar waste. The companies collaborated to launch a new solar waste management and materials recovery facility in Saint-Loubès, France [1]. The plant uses a hot blade delamination process that helps recover up to 95% of the materials used in solar modules. The technology is provided by Japan's NPC Incorporated. The €2 million plant at Saint-Loubès employs 25 people and can process 4,000 tons of panels per year. The French consortium started work on three such facilities in February 2021. The first two facilities began operations in June 2021, and the third was started in October 2021.

The process involves an automatic solar panel disassembly line that separates the glass from the polymer layer containing the cells using a heated blade. Unlike traditional methods, this method separates the flat glass layer from the layer containing other metals without crushing the glass. This process makes it easier to recycle or recuse the glass pane [2].

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French Solar Recycling Facility
Source: PV Magazine

FRELP By The Sun - Industrial Plant Concept For End-Of-Life Pv Panel Recycling By Tialpi, Italy

To develop an Extended product responsibility of the producer for PV modules, the European Union funded a project called FRELP by the Sun - Full Recovery End of Life Photovoltaic by the Sun. This is a case study about the FRELP by the Sun initiative by Tialpi in Italy.

In 2012, the European Union became the first governing body in the world to develop a policy for recycling End of Life (EoL) PV modules, through Extended Producer Responsibility (EPR) directive, according to which a producer's responsibility for a product is extended to the post-consumer stage of product's life cycle [1]. The directive of the European Union requires Member States (MS) to take necessary measures to ensure that systems are set up for the collection and recycling of packaging waste. To help MS achieve this objective, the European Union funded several recycling projects. One such project was the 'Full Recovery End of Life Photovoltaic by the Sun' or 'FRELP by the Sun' project, initiated by the Italian company Sasil srl, to attempt complete recovery of EoL photovoltaic panels. The project had to be abandoned in 2015 due to insufficient availability of modules.

In 2019, Sasil Srl formed another company called Tapil Srl and resumed the project in collaboration with glass maker Stazione Sperimentale del Vetro di Murano (SSV) and the consortium PV Cycle. The project aimed to achieve 100% valorisation of the recovered materials, converting them to secondary raw materials or getting them End of Waste certified. The project is developed in four phases. Phase one of the project is slated to set up an automated experimental industrial plant to recover components such as aluminium, copper, glass and metal silicon mat. Phase two is to focus on the enhancement of the technology to separate the silicon from the plastic support. Phase three focuses on acid leaching treatment for enhancing metallic silicon. Phase four is projected to develop differentiated electrolysis treatment for the recovery of copper and silver and neutralisation of treatment of acidic waters [1].

Tapil Srl started work on phase one of the project in 2021, and launched the project in 2022 at the company's facility in Mottalciata, in Biella, Italy [2]. The automated experimental plant processes around 30 panels per hour. The aluminium frame detaches from the panel in the first stage and removes the back sheet containing the electrical connectors. The next stage separates the glass sized between 2 mm and 10 mm from the panel sandwich. The final step consists of an offline machine that is 'manually fed cabling at up to 150kg/hour to treat and extract copper with 99% purity and plastics that can be used for extrusion.'

According to the company, the entire process is 'environmentally compatible' as it does not result in greenhouse gas emissions and does not use water. The recovered aluminium can be melted and used in various industries such as automotive and construction. At the same time, high-quality extra-clear glass can be utilised in the container-glass and flat-extra-clear glass industries. According to the process specialists, the whole process has a low energy consumption of about 1kW per panel, requires only two workers and is subject to certain process volumes. The line enjoyed a payback period of about two years. Tapil srl is focusing on the next three phases of the FRELP project that were in various stages of implementation as of mid-2022.

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A 10-Second Recycling Process For PV Modules By Flaxres

It is estimated that electricity generation from solar PV avoids up to 90% of harmful greenhouse gas emissions compared to conventional electricity generation from fossil fuels. A German company, FLaxers, started a Recycling process for PV modules that just takes 10 seconds. This is a case study about mobile recycling units in Germany.

De-commissioned end-of-life solar panels, can represent a large amount of waste needing scientific disposal, failing which such waste can potentially leave an adverse environmental impact in its wake. Flaxres, a German company, estimated that by 2030, approximately 400,000 tons of solar PV modules could end up in landfills. The company began working on possible solutions to tackle this problem. The research team at Flaxres developed a unique process to recycle PV modules: the process separates different grades of glass and valuable metals in the modules by utilising low-energy light pulses[1]. In 2017, the company secured 'Booster Funding' from EIT RawMaterials to scale up the innovation and launch a pilot project to test the recycling technology. EIT RawMaterials is a part of the European Institute of Innovation and Technology, a body of the European Union that has been tasked with securing a sustainable raw materials supply by driving innovation, education, and entrepreneurship across European industrial ecosystems[2]. Flaxres is one of the 60 companies identified by EIT RawMaterials to receive part of the EUR 9.8 million funding.

Flaxres set up a pilot facility in Dresden, Germany, where its proprietary technology for recycling photovoltaic modules is scaled up into an industrial process with a potential recycling capacity to recycle 1,000 tons of end-of-life modules per year. In 2022, the company completed a mass test with 7.5 tonnes of photovoltaic modules in the pilot production equipment named 'FLAXTHOR™.' The team can extract 200kg of silicon, 4kg of silver, and 4.9 tonnes of glass of the highest quality from the PV modules. The average cycle time to process a single module is 10 seconds. The process uses less than 1kWh per module and did not involve any chemical processing[3]. The FLAXTHOR plants can process both crystalline and thin-film modules and modules with damaged glass panes.

With the experience gained from the pilot plant, the company realised that having a stationary plant might be counter-productive, given that large volumes of end-of-life modules might have to be transported back to such centralised locations for disposal. The company wants to develop mobile equipment that can fit into a shipping container and be rented to customers[4]. Flaxres has decided to begin construction of "FLAXTHOR" plants in 2024 and make them available to customers in 2025.

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A Convenient Solution For Solar Panel Recycling In Taiwan

In 2023, 10,000 metric tonnes of PV waste are anticipated in Taiwan and by 2035, they could even reach 100,000 metric tonnes. Following this, many companies have come up with solar panel recycling processes and projects. This is a case study about the PV module designed by the URE and ITRI in Taiwan for easy recycling.

A traditional PV module uses thermoset ethylene-vinyl acetate (EVA) or polyolefin (PO) as encapsulants to provide adhesion between solar cells. These encapsulants form a tight bond between the cells that complicates the separation process during PV recycling.

United Renewable Energy Co. Ltd., a Taiwanese solar PV manufacturer, and Industrial Technology Research Institute, formed a consortium to work on a new PV module design that will be easy to recycle. In 2022, the team of researchers from the consortium succeeded in developing a PV module, from which 96% of the materials including all of the solar cells and the encapsulation glass could be recovered easily. The new design uses a 'thermoset EVA/PO and thermoplastic elastomer (TPE) bi-layered compound' as an encapsulation material that serves as a buffer, protecting the cells from cracking during the dismantling process. The TPE has a lower melting point compared to the EVA/PO. The team uses a low-temperate thermal process to gradually decompose the bi-layer film. According to the researchers, the improved process recovered glass and silicon cells as a whole [as opposed to recovering material as pellets as seen in the traditional process], allowing the silver to extract from the solar wafers [1].

According to the team, the high purity of the recovered silicon wafers significantly increases the material value, reducing the need for new raw materials. The new design significantly increases the end-of-life value of the retired PV modules roughly from USD18.0 million (€17.58 million) to USD74.0 million (€72.28 million) per GW, creating a 'new circular economy model for the solar industry.' It is further estimated that the carbon emissions associated with PV production can be reduced by 50% by using recycled material from process [2].

The French Alternative Energies and Atomic Energy Commission (CEA) tested and proved the viability of the Proof of Concept (PoC) of the new design. The new technology complied with the IEC 61215 and IEC 61730 tests for safety and reliability. The team also received TÜV Rheinland's certification for the new design's safety and reliability. The technology is expected to obtain Taiwan's Voluntary Product Certification (VPC) in the first quarter of 2023 [2].

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An Agreement By The EU Council For Improving The Circularity Of Batteries

Battery demand is projected to grow at 25%, reaching 2,600 GWh in capacity in 2030. Therefore, the EU council along with the European Parliament, have proposed an agreement for proper waste disposal of these batteries.

Between 2010 and 2018, battery demand for mobility and application in mobile phones, computers and other end-use gadgets and household devices grew by an estimated 30 per cent per annum to reach 180GWh in 2018. Among others, electric mobility is projected to drive the dramatic growth in battery demand [1]. By June 2022, the European Commission (EC) observed the need for a new regulatory framework for managing the 800,000 tonnes of automotive batteries, 190,000 tonnes of industrial batteries and 160,000 tonnes of consumer batteries each year. Scientific recycling of batteries provide valuable input materials for other processes and new batteries alike and simultaneously prevent contamination of soils and water bodies. Batteries are slated to be produced with the lowest possible environmental impact, using material obtained in full respect of human rights as well as social and ecological standards. Regulations were therefore mooted to reduce the environmental and social impact of all batteries throughout their respective life cycles.

In December 2022, the EU Council and the European Parliament reached an agreement on a proposal to strengthen the sustainability of batteries throughout their life cycle from design to waste treatment. The new regulation was slated to apply to all batteries: portable, electric vehicle batteries – including cars, electric bikes, e-mopeds and e-scooters – industrial batteries, batteries used in vehicles and machinery for starting/lighting/ignition and was to replace the batteries directive of 2006. The regulation is projected to complete existing legislative provisions relating to waste management. The new regulation, yet to be formally adopted by the institutions by December 2022, provides specifications for end-of-life requirements including collection targets and mandates, and benchmarks for materials recovery as listed below, and extended the producers' responsibility in this regard [2].

Targets for producers to collect waste portable batteries:	63% by the end of 2027; 73% by the end of 2030
Collection objective for waste batteries for light means of transport (e-bikes, mopeds, scooters etc.):	51% by the end of 2028; 61% by the end of 2031
The target for lithium recovery from waste batteries:	50% by 2027; 80% in 2031
Mandatory minimum levels of recycled content for industrial, SLI batteries and EV batteries were initially set at:	16% for cobalt; 85% for lead; 6% for lithium; 6% for nickel.

Obligation for batteries to hold recycled content documentation

- **Recycling efficiency target for nickel-cadmium batteries** of 80% by 2025, for other waste batteries of 50% by 2025.
- **Portable batteries incorporated into appliances should be removable and replaceable by the end-user**, leaving sufficient time for operators to adapt the design of their products to this requirement (42 months after entry into force of the regulation). Light means of transport batteries will be replaceable by an independent professional.
- **Labelling and information requirements**, other things on the battery's components and recycled content, an electronic "battery passport" and a QR code.

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Ultra-Thin Solar Cells to Turn Any Surface Into A Power Source

This is a case study about ultra-thin, lightweight and highly durable solar cell modules. These modules prove to be more efficient than conventional ones and can be readily deployed in rural regions.

By 2022, photovoltaics had emerged as a technology with a broad range of applications ranging from power plants to wearable devices, internet-of-thing devices, and on-skin/in-tissue diagnostic tools. These applications were made possible due to advancements in manufacturing technology such as slot-die coating, ink-jet printing, spray-coating, and screen-printing, which enabled manufacturers to process photovoltaics onto ultra-thin glass substrates. However, glass being a brittle substrate, proved difficult to slit and trim, limiting the potential of photovoltaic applications.

A team of engineers from Massachusetts Institute of Technology (MIT), USA, developed large-area, ultra-thin organic photovoltaic (PV) modules, which can be transferred onto lightweight and high-strength composite fabrics [1]. This process of Integrating ultra-thin modules onto composite fabrics lends mechanical resilience to the fabrics, which allows these fabric-PV systems to maintain their performance even after 500 roll-up cycles. The resulting fabric-PV systems are ~50 microns thin, weigh under 1 gram over the module area (corresponding to an area density of 105 g m−2), and have a specific power of 370 W kg[1]. According to the team, the panels are one hundredth the weight of conventional solar panels but can generate 18 times more power per kilogram weight of panel [2].

The team further believes that the new 'flexible solar cells' are more durable and offer an interesting solution for 'deployment in remote locations or for emergency assistance in the event of a power outage.'

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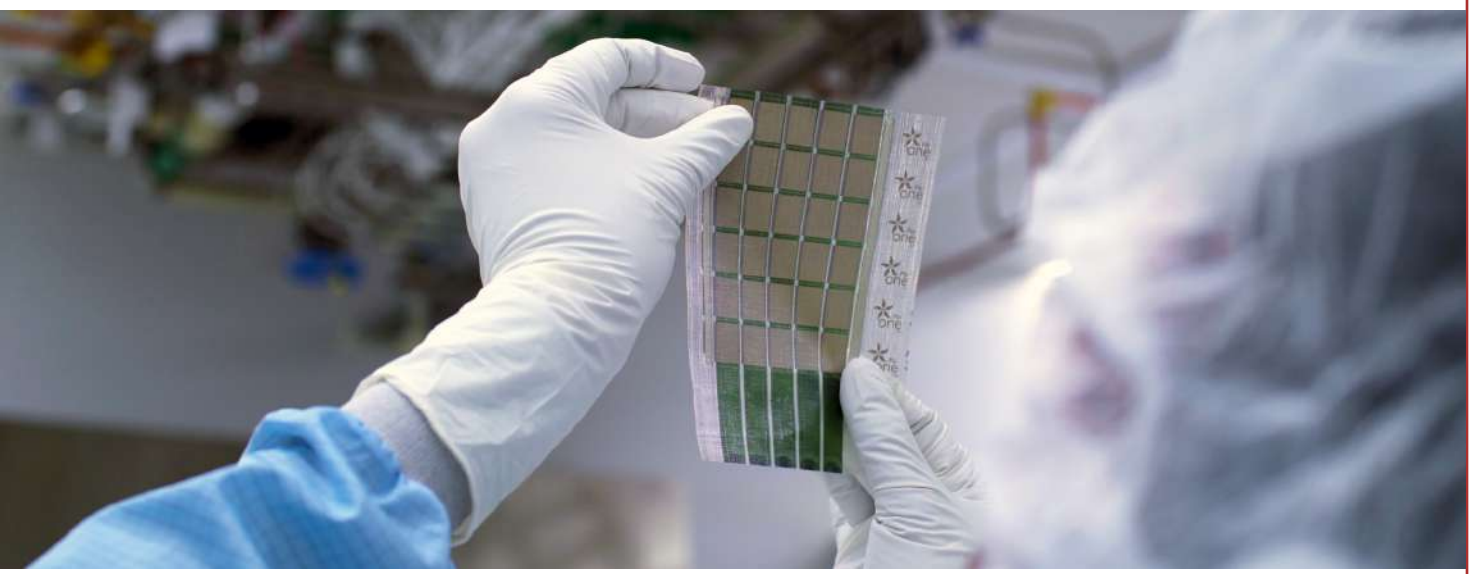

Ultra think solar modules
Source: MIT News

WAGA Power Pack - Recycling and Reusing Computer Battery

This is a case study about the Waga Power Packs, that recycle old batteries to make new ones. These new batteries are more efficient and sustainable.

The WAGA Power Pack consists of recycled laptop batteries and is designed to provide reliable and affordable power for electric bikes, solar lights, drill machines and other end-use applications. The power pack is slated to divert spent batteries to bridge deficits in the electricity supplied by the utility grid networks in Tanzania. The WAGA power pack is projected to extend the lives of batteries, to have a positive impact on the economy, on the safety of disposing batteries from outdated laptop computers, and consequently to leave a favourable impact on the environment. Between 2019 and 2020, the company worked with 15 battery supply partners and 26 battery collectors reuse-use over 3,100 lithium-ion batteries.

The UK Royal Academy of Engineering shortlisted engineer Gibson Kawago for the innovation and is nominated for the year-2023 Africa Prize for Engineering Innovation.

The Power Packs are designed with strengths of 12, 24 and 48 Volts for various applications. The sets of batteries are then fused with nickel strips and connected to battery management systems. Sensors are included to monitor performance and detect changes in temperature, current and voltage. The pack is enclosed in an aluminium case with ports that can connect to inverters, lamps and the like. The pack also includes a state-of-charge indicator and can go from deep discharge to full chargearge in about three hours: subject to the loads connected, the Pack can supply power for up to 13 hours on the run. The battery management system is also connected to a mobile phone application enabling users to monitor battery pack performance from mobile devices [1].

The WAGA Power Pack is made with batteries bought from informal waste collectors in five regions of Tanzania. The old batteries are charged, and tested after specified time intervals and the charge retention is compared against manufacturer specifications. Batteries that compare well against standards are selected for inclusion within the WAGA Power Pack. Batteries that have corroded or those where the voltage has dropped are sent to electrochemical recycling.

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Gibson Kawago using old laptop batteries to make new ones
Source: MIT News

3.

Scaling Solar Application For Agriculture Use

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3. Scaling Solar Application For Agriculture Use

Agri-Voltaics in Arid Regions - India

The Central Arid Zone Research Institute (CAZRI) under the Indian Council of Agricultural Research (ICAR) launched the one-acre/105kWp pilot Agrivoltaics project in Jodhpur, Rajasthan in year 2017. In addition to powering the drip-irrigation system, the PV system was designed to contribute to the rainwater collection system in a water-scarce region. Crops such as brinjal (aubergine/egg plant), cluster beans, coriander, okra (lady finger), bottle-gourd, pulses including green gram and split black gram, and sesame showed improved output under the array. Notwithstanding the energy generation and the secondary benefits from the shade provided by the solar PV array, the rainwater collection potential offered by the installation was considered significant in value. This plant was followed by the 666m2/25kWp project in Bhuj, in Gujarat at a site facing similar climatic conditions. Two such sites (1.0MWp/4.50 acre each) were then set up in Jamnagar and Kutch districts of Gujarat, on unused land within the boundaries of thermal power plants.

It was observed that the "Agrivoltaics system" was effective in increasing the yield of horticulture and pulse product – plants that grew within about 1.5 meter in height. The system was believed to be half-way to a solar-powered green house, with added benefits of natural ventilation, reuse of water, and most significantly, lower costs of production. Shading effects reduced evaporation and resulted in higher yields, while preventing soil erosion, providing shade for livestock and improved pollinator habitats. Such land use strategies could potentially benefit large numbers of farmers across ISA member countries [1].

Under certain circumstances bifacial arrays could be particularly attractive for agrivoltaic applications. As of December of year 2021, some 20 research projects employing a variety of panel configurations were underway in various parts of India to establish combinations of specific methods, crops and weather conditions that could maximize farm output, and hence, might enhance farmer welfare [2].

Installed agri-voltaic system at ICAR-CAZRI, Jodhpur, India
Source: https://www.researchgate.net/figure/Installed-agri-voltaic-system-at-ICAR-CAZRI-Jodhpur-India_fig2_352061905

AI Assisted PV Array For Grape Farming

Sun'Agri, a subsidiary of French Solar developer Sun'R, installed a viticulture agrivoltaic system in wine-growing area of Piolenc, France, (https://sunagri.fr/en/project/piolencs-experimental-plot/) as part of a program to test the performance of 'agri-voltaics systems' in specific crop cultures. The 84kWp plant comprises 280 solar modules placed at a height of 4.2m above the ground, providing partial shelter for the vines. Of the 1000 m^2 of vineyard area, about 600m^2 was covered by the solar array. The remaining area was used as a "control plot" to test the incremental impact of the solar array on resource use and on grape production. The modules could be operated in real time using artificial intelligence (AI), which determined the ideal tilt of the panels, responding to the sunshine and water requirements of viticulture (grape growing). In the event of extreme climatic conditions like drought, heatwave, hail, frost, heavy rain etc, the AI system could serve to adjust the panels to protect the crops. The early stage results from the project were reportedly very promising. The water requirement of the vines was reduced by 13-34%, while the grapes so produced had 13% more anthocyanins and 9-14% more acidity. The program was scheduled to move from demonstration phase to commercial phase later in year 2022.

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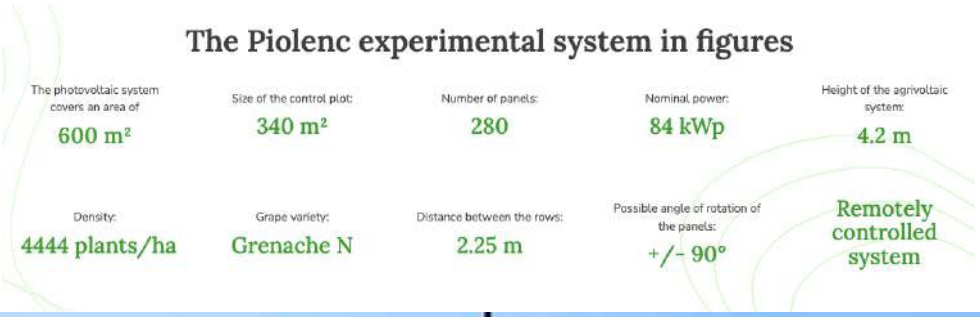

AI Assisted Solar Array Facility in Piolenc
Source: sunagri.fr

Japan's solar powered Farms - Chiba Ecological Energy

Japan aims to be a carbon neutral country by 2050, with 36%-38% of its energy mix coming from renewable sources, of which solar would account for 14%-16%. According to Institute of Sustainable Energy Policies in Tokyo, 8.9% of the country's power in 2020 came from solar installations. Due to the country's mountainous terrain, Japan has limited land for large solar plants. The Japanese government is actively exploring installations on rooftops, railway lines, airports and more recently agricultural land. It has been estimated that if solar panels are installed on roughly 5% of Japan's arable land, it could cater to 20% of the country's electricity demand [1].

Chiba Ecological Energy Inc. (https://www.chiba-eco.com/) is an environment and energy venture company, working at the forefront of agriculture-related solar power generation or "agri-voltaics" in Japan. The company's one hectare (~2.5 acre) demonstration farm in East Tokyo grew potato, ginger and eggplant (bringal/aubergine). The site is almost completely covered by the 2,826 solar modules that are mounted on a scaffolding 3-4 meters above these crops. The PV power plant can generate 830,000 kWh per year: enough to power 168 typical Japanese households [2]. All the machinery used on this farm excluding the tractor and a hand-pushed tiller, is electric, and such machinery is charged by solar panels installed above a small shed. All surplus energy generated by the solar panels is sold to the utility to generate additional revenue for the farm. The farm reportedly earned Yen 3.0 million (21,892 Euro) from the sale of agricultural produce, and an additional 24.0 million yen (174,202 Euro) from the sale of surplus solar energy [3].

Even as Chiba Ecological Energy Inc. had demonstrated the success of agri-voltaics, the practice of elevating PV installations had not been widely adopted in Japan. According to Japan's Ministry of Agriculture, Forestry and Fisheries, out of the country's 4.40 million hectares of land, a total of only 742 hectares were approved for agrivoltaic use between 2013 and 2019. Japan's elderly farming population believed that agri-voltaics was a distraction from the business of growing crops. Many of them were without successors to take over their business and were therefore unwilling to make investments into solar power plants. A few others were hesitant to adopt agri-voltaics as they believed that the practice ruined aesthetics, or believed that it was more cumbersome to manoeuvre farm equipment around the poles that held the arrays. Ministry rules relating to food security, farm land use and productivity might also be a deterrent for a few farmers [3].

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Solar Chickens – Geneva Peeps

Geneva Peeps an http://www.genevapeeps.org/ "egg cooperative" raising and taking care of egg-laying chickens/ hens, was launched in the month of May 2014, in Geneva, New York, USA. The land parcel employed for the egg-farm was categorized as an industrial zone plot which allowed for the construction of a solar PV farm, while, rather ironically, a special use permit was required for raising hen for egg production. By year 2015, 44kWp of solar PV capacity was installed at the cooperative farm.

Cooperative members let the hens out into the yard in the mornings, put the hens back in the evening, and collectively ensured feeding, hydration and safety of the livestock. The poultry farm itself was built under PV arrays. Additionally, the 180 egg-laying hens on the farm spent time underneath the ground mounted PV arrays and were protected by the PV installation from sun, rain and hawks and other air borne predators. This farm was as much about combining poultry farming, rainwater harvesting and energy generation as it was about demonstrating the benefits of combining such uses for the available land.

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Co-operative solar PV farm
Source: unknown

Agrivoltaics At Cochin International Airport

The Cochin International Airport ("CIAL":https://cial.aero/) in the southern Indian state of Kerala, built as a public-private partnership (PPP) project, commenced commercial operations in year 1999. In year 2012, CIAL Infrastructures Limited ("CIL":https://www.cialinfra.in/), a subsidiary company was instituted to work on power and other infrastructure sectors. As part of the airport's vision to shift to cleaner energy, CIL/CIAL commissioned a 100kWp pilot solar PV power project in February 2013. In year 2015, CIAL commissioned a 12.0 MWp solar PV plant on the 52 acre (210,437 sq.m.) vacant plot near its cargo complex.[1] Cochin International Airport thus became the world's first airport to fully operate on solar power[1].

Following observations that the land set aside for the PV power plant was being underutilized, an effort was made to start organic farming in the vacant areas surrounding the plant and between the solar arrays. In December 2015 such vegetable farming was undertaken[2] on an area of approximately 58 cents (approximately 2,347 sqm)[2]. Following the encouraging outcomes with the pilot initiative, farming activity was progressively extended to exploit most of the vacant land area within the boundaries of the solar plant. The organic farm consisted mainly of creepers and climbers like pumpkins, ash gourds, and tomatoes, as well as short rotation, short plants like okra and ginger. These vegetables were grown over mulching sheets between the solar arrays, and the plants were supported with drip irrigation systems[3]. The water used for the panels was also used to irrigate the vegetables and it also helped keep the land moist, thereby minimizing soil erosion and dust build-up on the solar arrays. The crops also served to modify the micro-climates beneath the PV arrays, through reducing the ambient temperature, and contributed to increased efficiency of power generation from the PV plant. Vegetable cultivation also dampened weed growth underneath the PV arrays.

CIAL Infrastructures Limited produced about 40,000 kg of vegetables during year 2016 and an estimated 80,000 kg of vegetables during year 2017. The airport employed about 8,000 persons and the vegetables were sold to the staff on priority; surplus stock was made available for sale to passengers. The airport stood fourth in the country in terms of international traffic and seventh in total traffic and had handled ten million passengers in 2017-18. The company had reported total revenues of INR 150,657,000 (Euro 2.14 million) in year-ending March 2017; revenues from vegetable sales would thus constitute some 0.5%–1.0% of total revenues generated[3].

In recognition of such initiatives, in year 2018, CIAL was awarded the Champion of Earth Prize, the highest environmental honour instituted by the United Nations.[4] However, the floods in August 2018 that left a severe impact on large part of the state of Kerala, left the PV farm submerged for several days, and the entire vegetable produce from the season was lost. Recovering from the deluge, the farm was replanted in September and the vegetables were successfully harvested and brought to market in the months that followed[4].

By year 2021, CIAL achieved another milestone in sustainable development by scaling the airport's agri-voltaic farming to 20 acres (80,937 sq. m.), the largest initiative of its kind in the country. The airport officials envisioned multiple additive and synergistic benefits, including reduced plant drought stress, greater food production, and reduced PV panel heat stress from the agri-voltaic program[5]. The overall program was also expected to help avoid 0.9 million metric tons in CO2 emissions over 25 years, and to result in annual cost savings of INR 400 million (approx Euro 4.40 million) to the airport. By November 2021, CIAL had installed a total of 40MWp in solar PV generation capacity and was producing an average of 160,000 kWh of electricity per day, consuming 130,000 kWh per day and exporting the remaining to the state utility for distribution to other consumers[5].

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Cochin Airport Agrivoltaic Project
Source: The New Indian Express

Bee Guardian Certification - UK

Research by the United Nations estimate that upto USD 577 billion worth in annual global food production1 relied on pollination by insects, birds and other animals including the likes of bees, humming birds and bats. Bees are known to play an especially vital role among such pollinator species. In the United States alone, more than half of native bee species have seen their numbers drop sharply since year 2005, with almost 25 percent now at risk of extinction. This decline could be attributed to climate change, pesticide use and parasites besides shrinking habitats and the conversion of natural landscapes such as scrublands and wetlands for agricultural use [1].

"Bee Guardian" status is conferred by the Bee Guardian Foundation to individuals, companies, universities and schools or other institutions or agencies working towards protecting bee populations. Bees were known to be under enormous pressure in Britain – alongside other wildlife species – and hence, the creation of new habitats was vital. Ecotricity (https://www.ecotricity.co.uk/) believed in the need to turn farmland back over to nature to restore the balance. In 2011, the Gloucestershire-based green energy company, Ecotricity became one of the earliest "bee guardian" businesses in the United Kingdom (UK) for its work to promote natural habitats[2]. Ecotricity was conferred the award for its proposals to create a 'bee haven' at its 20,000-panel solar farm in Lincolnshire, UK. The "Sun Park" was planted with native wildflower seeds to encourage bees and insects to the site. The company vowed to maintain the solar farm's wild flowers over the forthcoming 25 year period.

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2000 pollinator species
Source: https://www.fao.org/news/story/en/item/384726/icode/

Solar Arm - Agrivoltaics in Slovakia

During the first half of calendar year 2022, Sun Powered Systems, s.r.o., a Slovakian organisation had developed an automated solar system for agricultural applications such as soil preparation and crop growing. The system was connected to movable equipment located beneath the photovoltaic panels, and was designed for linear movement, in combination with simultaneous circular movement of the arm itself cumulatively yielding spiral patterns with a widths of 30 cm or 60 cm. The rotating arm was driven by a motor powered by the photovoltaic panels fastened to the structure. The photovoltaic arm, additionally, provided off-grid power supply for vegetable processing and for the preparation of ready to use vegetable products or for packaging, thus making the arm ideal for locations that were not connected to the utility power supply network or to the local grid.

The system was equipped with an AC asynchronous motor with a rotational speed of 1500 rpm and a power capacity of 750 W for motion[1]. The machine could be equipped with commercially available solar modules of small size, along with LiFePo batteries and frequency regulators. It could easily be installed and could be used to remove weeds between defined lines in one cycle. The machine was non-invasive to the soil and did not impact soil density as might be the case with heavier machines.

The system was provided in a range of sizes. The smallest variant was equipped with a six meter-long arm and a PV array of 1 kWp in capacity to cover a cultivated area of 104 m². The largest variant was equipped with an 18-meter-long arm and a PV array capacity of 2.40 kWp, and was designed to cover a cultivated area of 994 m². By June 2022, the 18 m variant retailed for about €24,000. Sun Powered Systems proposed to assemble the unit in Slovakia and then to market it to other European countries including France, Italy and Spain where the policy framework might have been favourable[2].

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Solar arm for agrivoltaics
Source: PV Magazine

Semi-Transparent Solar Panels on Greenhouses

In year 2020, a group of researchers from University of Greenwich, UK, undertook an experimental study to grow spinach and basil under tinted semi-transparent solar panels. The semi-transparent solar panels allowed the plants and the solar panels to selectively harness different portions of the electromagnetic spectrum. The tinted semi-transparent solar panels absorbed preferentially blue and green light, leaving the solar radiation falling on the plants to be relatively red-enriched permitting more efficient photosynthesis. The basil crop was grown during the summer/spring seasons for 71 days and the spinach crop was grown during the autumn/winter seasons for 111 days. The tinted semi-transparent solar panel used for basil crop generated approximately 27.8 kWh/ m2, and for spinach the generation was around 17.6 kWh/m2. Based on the feed-in-tariff data present during the time of the experiment, it was estimated that the agrivoltaic set up would earn the farmers an additional 2.5% in revenue in case of basil, and additional 35% in case of spinach. Consequently, the gross revenue accruing from the sale of produce and electricity increased by 18% in case of basil and 113% in case of spinach.[1]

The University then expanded this project to grow strawberries at the Hugh Lowe Farms Ltd. at Kent, in partnership with Polysolar Ltd., to supply the semi-transparent solar panels. The trial had received government funding of 250,000 UK Sterling pound (~€292,752). At this site, vertical semi-transparent photovoltaic panels were affixed to the sides of the glasshouse, allowing some light through the sides, as well as through the roof. In the next phase, the trial was extended to flexible panels attached to the side of "polytunnels." The study was expected to conclude in the spring of 2023, and a subsequent stage of research was to follow to prove the replication potential for the technology[2].

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Semi transparent solar cells for greenhouses
Source: Digital Trends

Solar Farms - Bare Honey Beekeepers

The concept and practice of co-locating solar PV farms and pollinators – honey bees at apiaries and wild pollinators alike – is increasingly becoming popular in different parts of the globe. These practices found early acceptance amongst US pollinator, solar, and agricultural groups and such groups came together to support the establishment of the country's first state-wide standard for vegetation on solar farms in year 2016 in the US state of Minnesota.

In the state of Minnesota alone, about 4,000 acres of ground-based solar arrays had been installed, primarily on land previously engaged for agricultural production. This conversion of land use had faced significant resistance from local residents who did not prefer to see the installation of the traditional gravel and steel covered arrays within their own communities. Hence the need to come up with multiple uses of the same farmland arose, in attempting to preserve the traditional character of the farms. This practice of placing beehives on or near solar fields – that emerged as a result of these efforts to preserve the character of the traditional landscapes – is commonly referred to as agri-solar-beekeeping. This business model creates multi-stacking of benefits by using the land for multiple purposes simultaneously.

Beekeepers worked with solar energy developers, first on developing such pollinator oases within the solar PV farms, and then on collecting 'Solar Honey' from hives placed near the solar arrays. These solar arrays had been planted with flowering habitat that has been scientifically designed to provide a regenerative refuge for pollinators, thereby reclaiming native habitat previously considered lost to industrialized agriculture. The initial cost of planting the farm area was to be offset [in the long term] by lower than routine maintenance costs given that there was no requirement for mowing the grass or managing gravel erosion. As the solar panels harvested clean energy, the plants surrounding them utilised the very same solar energy to feed honeybees and other native pollinators as well as to capture and filter storm water while maintaining topsoil at the farm. When the lands surrounding these arrays were used for farming of pollinator-dependent crop, the benefits delivered spilled over to the nearby apple orchards, berry, squash, pumpkin and melon farms. Meanwhile, the beekeepers harvested and sold the solar-grown honey to local grocery shops, fine dining restaurants, distilleries, and breweries. Agri-solar-beekeeping, therefore, created new economic opportunities for local beekeepers and for the community as a whole in the form of energy generation tax payments.

The most common practice involved the placement of the hives just outside the fence of the solar field for both liability and insurance reasons. Thereby, the beekeeper attempted to ensure adequate space for the hives and also provided for the movement of equipment. The responsibility of managing the pollinator species was outlined in the contract as well, but was typically the responsibility of a vegetation management service contracted with the project developer. Solar-based beekeeping groups focused on giving back to the environment through the pollination of plots of pollinator habitat. Working with the non-profit organisations like Fresh Energy (Centre for Pollinators) in the United States, solar energy developers worked on expanding the practice of planting flowering habitat on their solar farms. For instance, in order to achieve pollination goals, a vegetation management calendar was required to accommodate bloom seasons to ensure that the bees had access to the diversity of species at the site.

The US state of Minnesota required all ground-mounted installations to complete a solar pollinator scorecard during the planning stage and to complete one such card every three years after commissioning. This helped ensure that the quality of pollinator habitat at the site was reported to the Minnesota Board of Water and Soil Resources. The scorecard was part of Minnesota's Habitat Friendly Solar Program, a result of state policy that required verification of adhering to the standards set by the Board of Water and Soil Resources [1].

Connexus Energy, the largest customer-owned power company in Minnesota initially incorporated pollinator habitat at its 1.2-acre solar array site, called "SolarWise garden," in Ramsey, Minnesota, soon after the passage of the law in year 2016. In April 2017, the company partnered with local beekeepers Bolton Bees, and became the first U.S. solar farm to host a commercial bee operation with the installation of 15 hives. This was followed by two more solar array sites of about 40 acres each. Bolton Bees in St. Paul, harvested 3600 lb of "solar honey" from the three sites within a few months. The name "solar honey" has since been trademarked by Bolton Bees, and the company licensed the name to other beekeepers, food producers, and energy companies that strictly followed certain production standards. Bolton Bees also proposed to install apiaries at other solar projects in Minnesota, and in other states like Wisconsin, Iowa, and Illinois [2].

Chiara and Travis Bolton with their bees near a solar array site.
Source:https://www.smithsonianmag.com/innovation/solar-power-and-honey-bees-180964743/

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Solar Powered Vegetable Cart

In many developing economies, push carts carrying fruits and vegetables for sale offer residents an alternative to purchasing from supermarkets or small permanent shops. However, the produce on the carts is often exposed to unfavourable weather conditions like excessive heat, dust and pollution, or rain, while being carted around. Such exposure frequently resulted in potentially avoidable post-harvest losses of horticultural produce. These post-harvest losses could be minimised if the push carts were to be equipped with temperature and humidity management systems providing protection to the produce from ambient heat, dust and pollution.

This motivated the invention of a solar power operated tricycle-cart for fresh fruits and vegetables that helped ensure that the fruits and vegetables were stored under hygienic and cooled conditions in transit. The invention ensured that consumers received fresh produce while vendors minimised wastage in such transit from the farm to the consumer. The cart was a joint development of the Indian Council for Agricultural Research (ICAR) and Indian Institute for Horticulture Research (IIHR) and was launched in the year-2017 [1].

The fruit and vegetable chamber was fitted with glass doors that protected the contents from dust, moisture and insects. The chamber measured 1.5 x 1.0 x 1.0 m and was made up of aluminium frames and fittings. The entire chamber was mounted on a tricycle frame that was driven with the help of a 48V, 750 W DC geared motor, avoltage controller and 24 Ah Lithium ion battery. The 100 Wp/12V Solar PV module installed on the top of the cart generated electricity to cool the chamber through two forced air direct current fans (12 V, 0.7 A, 8.4 W each) and to power LED bulbs at night. A 12 V/7 Ah battery was also used to store solar power during the day and to run the system during cloudy days and at night-times. The chamber had a fine-misting system installed within it employing a 30 W DC misting diaphragm pump to maintain humidity within the chamber to thereby contributing to keeping the produce fresh. The chamber was designed to hold 8 plastic crates which could store 10-15 kg of produce and two specially designed high humidity boxes to safely store leafy vegetables. In all, the chamber could hold approximately 80-120 kg of fruits and vegetables and could keep the produce fresh for an additional 36 – 48 hours. This was projected to fetch the vendors better prices for their stock in trade. The cart was projected to retail for less than INR 30,000 (~€400) a unit [2].

As a pilot test, 10 carts were rented out to vendors in the summer season for a nominal rate of Rs.200 per month (~€2.75) to test the efficacy of the design. The feedback received from the vendors was positive: ICAR- IIHR then proposed to license the technology and help the urban poor achieve better income and an improved standard of living by employing the solar powered tricycle cart [3].

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Floating Solar and Aquaculture in China

The UN - Food and Agriculture Organization (FAO) had projected that aquaculture could play an important role in global food security in the years to come. In 2018, global harvest of fish from aquaculture amounted to 114.5 million metric tons, with an estimated first-sale value of USD 160.2 billion (€152.3 billion). China has been at the forefront of "capture fisheries" and of aquaculture production. The country alone accounted for 57.8% of the global harvest in year 2018 [1]. With installed Renewable Energy capacity of 1,020,234MW by year-end 2021, of which installed solar PV capacity[2] alone was 306,973 MW, China was also a global leader in renewable energy production.

In December 2021, Chinese power transmission and distribution equipment provider, Chint Solar, combined the country's experience in both aquaculture and solar power generation, to build the country's biggest "large-scale single-unit aquaculture-PV complementary solar plant"[3]. The 550 MW aquaculture-PV farm was located at Wenzhou in China's Zhejiang province, a city with subtropical maritime monsoon climate. The facility was spread across 4.7 square km and utilized 1.4 million units of glass-glass mono-Si photovoltaic (PV) modules with a power output of 450 Wp each, provided by Astroenergy, a subsidiary of Chint Solar.

Kstar, an inverter manufacturer provided its GSM3125C-MV35 inverter to the plant, which was best suited for the high temperature, high humidity, and high salt fog area of Wenzhou. This inverter with high anti-corrosion protection level, was chosen with due considerations for the plant's long-term operational stability. The facility was connected to the network of State Grid Corporation of China[4]. It was estimated that the plant would generate 650 million kWh of power annually, save 235,000 tons of coal, and to reduce carbon emissions by 648,000 tons[5].

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Agrovoltaics for Broccoli Production

In 2022, researchers at Chonnam National University, South Korea experimented with deploying ground mounted solar PV modules in farming, an Agrivoltaics (AV) system – in the lesser studied field of brassica crop cultivation (cabbage or mustard family of crops, with end-product derived from the stem or stalk of the plant). Such a system was likely to be beneficial in places with abundant sunlight, but limited land availability, and where production of such crops having high market demand was limited due to land and other resource constraints.

Broccoli was chosen for cultivation because it was in great demand and had low light saturation points (about 11klx), implying it might grow better in the shade. Five weeks after germination of the broccoli seeds, the seedlings were hardened and raised at the greenhouse facility at the University where the ambient temperature ranging between 18 and 30°C [2]. The plants were then transplanted to the testing site in Naju of the Jeollanam Province, South Korea. The AV system comprised bifacial solar panels tilted at 30° angle, and mounted at 3m height above the ground to allow for movement below. The control group comprised plants grown under similar climatic conditions nearby, which were under no influence of solar PV modules.

The spacing between the panels ensured that some plants grew under the shade of the PV array for most part of the day, and most others received direct sunlight and partial shading during certain times of the day; parameters relating to the microclimate and the soil were monitored, both for the control plots and the test area [1,2]. Broccoli grown in the test area was similar in appearance to the control group product but was greener, perhaps due to the lower exposure to direct sunlight. Although crop yield declined by 13% overall and the harvest was delayed due to unavoidable location-specific conditions, the higher unit-price realization and the electricity generation from the PV array were able to more than compensate for marginally lower productivity (due to diverting some land from broccoli to solar PV).

The average power generation per day was 127kWh from 4.2 average sunshine hours on a plot of land that measured 324m^2. The annual economic benefits were estimated to be 10.4 times more compared to the benefits delivered by growing broccoli alone. This model was a believed to be good demonstration of efficient use of available land, that could be eventually be replicated in high altitudes for premium crops having good market demand, thereby securing farmers' livelihoods through multiple-use of the available land parcels [2].

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Solar Dryers in Zimbabwe

Zimbabwe faced severe food insecurity in the past decade, due to prolonged droughts, deterioration in economic conditions, climate shocks, and more recently the Covid-19 pandemic. According to a joint report by the European Union, Food and Agricultural Organization, UNICEF, USAID, OCHA and WFP, circa year 2021, nearly 4.3 million rural Zimbabweans were in need of urgent humanitarian aid. It was also estimated that fewer than 20% of the children between 6-23 months received minimally adequate diet, which compromised their life-long quality of life, and around one in four children under five-years of age was stunted, and such children were at a risk of impaired physical and cognitive growth[1].

Simultaneously, even as the country experienced acute food shortages, piles of food in the country's vegetable markets were wasted due to inadequate and inappropriate storage and lack of avenues for preservation. Even though it was difficult to quantify the exact amount of such wastage, the FAO acknowledged that the numbers were quite high [2]. Several NGOs and support groups had been working with farmers to extend the shelf life of food by using techniques such as solar drying.

Zimbabwe Solar Dryers (https://www.zimsolar.org/) designed a unique solar drier – 2.40m to 9.60m in length – to ensure quick and efficient drying of fruits and vegetables. The design incorporated a fan powered by a solar panel that circulated warm air over trays of agricultural produce to expel moisture from the drying chamber. The smallest commercial drier sold by the company had a drying area of 3.58 sq m, a 30 Wp solar PV panel, and cost USD 1,170 (~€1,153.4), while the largest had a drying area of 19.15 sq m, a 60 Wp solar PV panel and cost USD 4,025 (€3,967.87). These driers could be used for drying mangoes, bananas, tomatoes, apples and leafy vegetables. While mangoes took around 2 days to dry, leafy vegetables could be dried within a few hours.[3]

Zimsolar used its social media pages to promote the products. The cost of the product varied according to the dimensions as given in Table 1.

Table 1: Cost of Zimbabwe Solar Dryers

NAME	DIMENSIONS	COST
Home Dehydrator	ONE Section: 0.8 x 0.6 x 0.16: Plywood	USD 150 (€ 147)
Economy	2.08 x 0.87m X 0.16m. With 30W PV panel, fan, Heat collector surface area 1.8sq.m. 3 trays with a drying area of 0.48sq.m each and a total of 1.37sq.m.	USD 1,170(€ 698.2)
Commercial 1	2.4 x 1.2 x 0.16 m With 30W PV panel, fan, 2 doors, 3 drying trays & 2 pairs steel legs. Drying area 2.48 sq. m With Jumbo Trays 4.96 sq m.	USD 1400 (€ 1321)
Commercial 2	TWO Sections (A and B) 4.8 x 1.2 x 0.16 m With 40W PV panel, fan, 2 doors, 6 drying trays & 3 pairs steel legs. Drying area 4.845 sq.m With Jumbo Trays 9.69 sq.m.	USD 2400 (€ 2365.93)

NAME	DIMENSIONS	COST
Commercial 3	Sections (A, B and C) 7.2 x 1.2 x 0.16 With 55W PV panel, fan, 2 doors, 9 drying trays & 4 pairs steel legs. Drying area 7.21 sq.m With Jumbo Trays 14.41 sq m.	USD 3270 (€ 3223.58)
Commercial 4	FOUR Sections (A, B, B and C) 9.6 x 1.2 x 0.16 m With 60W PV panel, fan, 2 doors, 9 drying trays & 4 pairs steel legs. Drying area 9.575 sq.m With Jumbo Trays 19.15sq m.	USD 4025 (€ 3,967.87)

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Image Source: unknown

Agrivoltaic Rotating Canopy

France's national energy plan of 2020 set targets of[1] 20.GW of renewable energy (RE) capacity to be installed by year 2023 and 44.0 GW in RE capacity by year 2028. Aligned with such aggressive targets, TSE (https://tse.energy/), a leading solar installation company, announced the development of the largest agrivoltaic demonstrator project in France. The project involved 10 pilot sites of six hectares each, at different locations across the country. The first agricultural project of 2.40MW in capacity and spread over 3 hectares of land was commissioned in September 2022 in northeastern France [2].The company had developed an agrivoltaic rotating canopy, the configuration of which allowed large agricultural machinery, including ones with sprayers and spreaders, to move under the panels. It was particularly suitable for cereal farms that grew rapeseed, maize, barley, and vegetable protein, as well as sheep and cattle farms. TES had invested around €12 million of its own equity into the project and hoped to replicate the project and to deploy 1.0GW of the technology by year 2025.

The agrivoltaic canopy consisting of bifacial solar modules mounted on four-post structures, measuring 27m x 12m was installed at a height of 5.5m above ground level. However, since each span of 27m had to support 10-12 PV modules, the large span of 27.0m between two supporting posts was a challenge in terms of mechanics as well as of aerodynamics. The company solved this problem by using pre-drawn cables of 30mm diameter, to mount the rotating modules, similar to the ones used on cable cars. The use of such cables also reduced the amount of steel in the structure and consequently the carbon footprint of the installation. The agrivoltaic canopy had over 400 sensors that regulated the movement of trackers to orient the panels along the east-west axis of the sun, and to orient the array based on the weather forecast.

By optimizing the tracking algorithm, TSE hoped to increase production by 10% to 20% compared to a conventional, fixed ground-mounted PV plant. In addition, the canopy could withstand wind speeds of up to 260kmph. Each row of panels could be controlled independently, and would automatically align at a safety position at a different inclination from the next, in order to "break the wind and avoid the suction effect. " The design was developed by a team from the R&D center in BourgoinJallieu [3].

The canopy provided shade to the crops in summer, reduced evapo-transpiration, and risk of spring frost, thereby contributing to the yield as well. The array also sheltered livestock during events of unfavorable weather. Irrigation systems could be integrated with the with canopy for water management, and the rotating panels that provided shade to the crops could optimize distribution and help save up to 30% water relative to the business-as-usual scenario. The company had selected plots based on innovation capacity, cultivation/breeding practices and few other relevant criteria and had planned to run the pilot studies for a duration of 9 years on each plot. TSE had entered into a 40-year emphyteutic lease, with the land owners, with payment of compensation shared between owner and operator. Such an arrangement ensured that the operators of the farm could conduct experiments while avoiding illiquidity related risks during periods of low yields [4].

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Vertical Agrivoltaic System

To make the most efficient use of the PV modules, conventional fixed solar PV arrays are installed at a "tilt angle" determined by the latitude of the site. However, it may not always be possible to install panels at the optimum tilt angle in all locations due to prevailing site conditions, including the likes of topographic constraints of the land. Sub optimal installations might still produce sufficient energy to balance the grid. In September 2019, Next2Sun GmbH (https://www.next2sun.de/en/homepage/), a German company, began construction of a 4.10 MW Agro-photovoltaic vertical, open space plant, on a 14 hectare plot in Aasen, a district of Donaueschingen: 5,800 frame elements and around 11,000 bifacial solar modules were installed for the project with an East-West orientation. The total investment for the project was estimated to be €3.2 million, and was financed by Solverde Bürgerkraftwerke Energiegenossenschaft eG. The plant was commissioned in early 2020 and the Bürgersolarkraftwerke Donaueschingen-Aasen GmbH was the designated operator [1].

Scientists from the Leipzig University of Applied Sciences, Germany, ran simulations to assess if such vertical bifacial PV systems could generate sufficient electricity during periods of high demand, and if these systems could also serve the ongoing agricultural activities at the site. Researchers also tested the impact of the west-east orientation of the system against north-south orientation of the PV systems. The EnergyPLAN simulation model developed by Aalborg University, Denmark was used to "simulate the operation of national energy systems on an hourly basis, including the electricity, heating, cooling, industry, and transport sectors [2]."

In the simulated model, four systems were compared: vertical west-east oriented PV system (v-EW), vertical north-south oriented PV system (v-NS), conventional ground-mounted system with 20 degree tilt (i-S) and combined profile: 25% i-S, 50% v-EW, 25% v-NS. Only two parameters were varied across the setting: one was the share of the installed power of the different PV systems, and second, integration of large-scale electricity storage. The results of the simulation are as presented in Table 1. While the conventional system generated the maximum annual power of 1020 kWh, vertical solar panels with east-west orientation produced[3] a maximum annual power of 999kWh.

SOLAR SYSTEM	CONVENTIONAL i-s	VERTICAL v-EW	VERTICAL v-NS	MIXED 25/50/25 C
Slope	20°	90°	90°	Mixed
Azimuth	0°	-90° to 90°	0° to 180°	Mixed
Yearly yield (kWh/kWp)	1020	999	926	986
Summer day yield (Wh/Wp)	6.3	7.5	4.6	6.6
Winter day yield (Wh/Wp)	2.2	1.7	4.0	2.4

The scientists also noted that the bifacial panels were more expensive compared to conventional solar panels. In addition, providing 8.0m – 12.0m of module row distance to avoid shading on the other panels and the agricultural crops meant that the cost of wiring increased. Though a complete cost comparison was not provided, researchers were of the opinion that the vertical solar systems would be costlier compared to conventional systems. However, the implementation of vertical solar systems could "shift solar yield into hours of higher electricity demand and more electricity supply in the winter months, thus reducing solar curtailment."The simulation also found that integrating a storage system of 1.0TWh with 1.0TWh capacity vertical solar system plant could enable CO_2 savings of up to 2.10 mt per annum when 70% of the capacity was oriented vertical-east-west and the remaining 30% capacity was inclined and south-facing.

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Sunfarming's Unique Agrivoltaic Programs In Africa

Sunfarming GmbH (https://sunfarming.de/), a German company introduced two concepts in Africa for sharing agrivoltaic expertise: the Food and Energy (F&E), and Food, Education, Energy Development (FEED) initiatives. The company had partnered with South Africa's North-West University, Potchefstroom campus in year 2014 to implement the F&E conceptual project. As part of the agri-PV project, bi-facial glass-glass modules were installed at distances of 3.0m between rows: the height was maintained at 1.0m at its lowest point, and 2.4m at the highest. The modules were integrated with an irrigation system to water the plants. The setting was ideal for growing vegetables like tomato, cucumber, peppers, cabbage, salad, spinach, etc, and berries like raspberries, strawberries, and wine grapes, as well as herbs. The space under the panels could also be used to house farm animals like bees, sheep, poultry, etc. Though the F&E plant began as a research initiative, it was expanded into a training center in 2016, to certify students and local farmers to grow healthy food, while generating carbon-neutral solar energy for the North-West University. More the plant itself, the F&E program was known for the socio economic changes it promoted.

In 2019 when cyclone Idai hit Mozambique, the F&E project produced nearly 10 tons of vegetables, amounting to 200,000 meals consisting of pre-cooked maize porridge blended with medicinal herbs, which was sent as humanitarian aid to the cyclone hit areas. With the experience gained from the F&E project at South Africa, Sunfarming set up a MW-scale plant at a refugee camp in Osmanyie, Turkey, securing the refugees fruits, vegetables, herbs, and chicken ("solar chicken").

The company planned to establish F&E plants at other locations in South Africa, Madagascar, Sri Lanka and Latin America. The same year, SUNCybernetics, a subsidiary company, was established to train interested candidates in installation and maintenance of PV systems that were safe, standard-compliant, and easy-to-operate and maintain. The training was called the PV Green Card training, and was endorsed by the South African Photovoltaic Industry Association (SAPVIA). According to an independent assessment, the training program trained up to 50 people and created up to 24 jobs per year.

Sunfarming started a "Healthy school meal" program, which distributed meals to schools in rural areas, areas of high unemployment, and low-socioeconomic status. The meal consisted of maize porridge, mixed with ginger, turmeric, and African wormwood, all grown at the F&E plant at the University. The meal was rich in vitamins, minerals and proteins, that helped boost the immune system of the children and supported their healthy development. As of 2021, the company estimated that nearly 52,000 people had benefitted from the healthy meal program, 360 locals received vegetable gardening starter kits, and 72 of them received entrepreneurship training to start their own small agricultural businesses.

The company started a second "Healthy school meal" program in June 2021, which planned to distribute 28.5 million portions of vitality porridge to 40 schools with around 12,000 children and their 60,000 family members until 2023. Sunfarming collaborated with the schools to grow gardens on school premises, so that they could cook food for the children. Sunfarming's F&E program also empowered women in the area, and as per company estimates nearly 90% of the women who attended the training began growing vegetable gardens at their homes, and 20% of all people trained eventually got a job on farm or went on to start their own businesses [1].

FEED was an offshoot of the F&E program, which focuses on directing donations received towards projects related to prevention of hunger, development of consciousness about the importance of healthy, well-balanced food, certified instruction programs and the creation of jobs for the local people [2].

Company website: https://sunfarming.de/ ; CEO: Ms. Edith Brasche; Phone: +49 03362/88 59 120; Fax: +49 3362/88 59 130 ; Email: info@sunfarming.de

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Agrivoltaics - A Way Of Adding Value To Low Yield Crops

In 2016, the European Union reformed EU's framework for energy policy, introducing directives related to "Renewable Energy Communities" (REC) and "Citizens' Energy communities" (CEC). Under the REC model, citizens become "prosumers," producing and consuming energy As part of the REC directive, Italy launched several initiatives to promote citizen participation. The prosumers were categorized as self-consumption collectives and energy communities. "Self-consumption collectives are groups of consumers that are located in the same building or building complex while energy communities are larger entities that can also include businesses or public organizations located in the proximity area of the power generator." The tariff for Energy communities was set at €0.11/kWh and for self-consumption collectives € 0.10/kWh for 20 years[2].

In 2021, Enel-X (https://www.enelx.com/it/it), an Italian energy company, extended REC to agriculture. In collaboration with regional bank Banca Agricola Popolare di Ragusa (BapR), Enel-X launched Italy's first "Agricultural energy community," also known as "Agricultural self-consumption community. " The financing to the energy community was promoted by the La MediterraneaSocietàConsortile Agricola, an agricultural consortium [3].

The project was open to SMEs in the agricultural sector, occupying an area of 60 hectares in Ragusa, Italy. It involved the construction of a 200kW photovoltaic system with a technological platform for the management of the energy community. It was estimated that the photovoltaic system would generate 300MWh per annum, and would feed more than 240MWh into the grid, to be 100% shared among the companies that were part of the business condominium. The energy sharing system allowed the community members to avail Italy's 20 year incentive, while significantly reducing their own greenhouse gas emissions; the structure delivered economic and environmental benefits for the entire territory. Enel-X estimated that the project would avoid the emission of 121 tons of CO2 per year. [4]

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AI In Agrivoltaics For Vineyards In Europe

For a few years leading up to 2022, interest in Agrivoltaics was growing rapidly as governments around the world made commitments towards "net-zero" greenhouse gas emissions (GHG) targets. Several vineyards in Spain and France were looking at adopting agrivoltaics for the benefits such installations offered.

Iberdola (https://www.iberdrola.com), a Spanish energy company, deployed a 40kW solar array in two vineyards belonging to Gonzalez Byass and Emperor Group in Guadamur, Spain. The array had sensors and trackers controlled by AI algorithms, that adjusted the position of the array to optimize exposure to the sun. The sensors also collected information relating to soil humidity, wind conditions, thickness of the vine trunk and other parameters. Electricity generated by the solar array was to be used by the wineries located in the vicinity. The project was to run for a duration of one year, and if found beneficial, the results were to be used as evidence to justify implementation of similar projects in the area.

In France, Total Energies (https://totalenergies.com/) and Ombrea (https://www.ombrea.fr/) implemented their first agrivoltaic project at the Rivals wine estate in Aude, in southern France. The project extended over an area of 3,000 square meters, and had an installed capacity of 85.6kW. The Total and Ombrea project was also monitored by AI algorithms, based on meteorological and agronomic data collected through sensors. The project also involved participation from the French Institute of Wine and Vine (IFV), SudExpé and the Aude Chamber of Agriculture, all of whom helped monitor plant physiology and photosynthetic activity. The project was slated to analyze plant growth, water requirements, and temperature variations for five years, and had hoped to be in a position to offer value-added solutions to other projects in the future[1].

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Solar panels in agrivoltaic regenerative wine cultivation
Source: CleanTechnica, Iberdrola

SHRIMPS Project – Germany Vietnam Partnership

In 2018, a consortium of diverse partners consisting of Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, the German research institute – Fraunhofer Institute for Solar Energy Systems (ISE), and Nong Lam University in Ho Chi Minh City, the Vietnamese Institute of Energy, a major Vietnamese shrimp production company, and Bac Lieu's Department of Agriculture and Rural Development, decided to launch a pilot project to explore the possibility of combing aquaculture and solar photovoltaics. The "Solar-Aquaculture Habitats as Resource-Efficient and Integrated Multilayer Production Systems" or "SHRIMPS" project, installed solar modules on the roofs of shrimp greenhouses at a pilot plant in An Gian and Bac Lieu provinces.[1]

The project was implemented in three phases: the first phase was conducted under lab conditions to develop the concept and the most promising production technique; in phase two the pilot plants were installed in An Gian and Bac Lieu provinces; phase three involved monitoring the plants to develop best practices[2]. The Bac Lieu facility was a 1.0MW plant integrated with the on-land shrimp greenhouse, which reduced an estimated 15,000 metric ton of CO_2 each year, and cut water consumption by 75 percent compared to that of a conventional shrimp farm. The proposed An Gian facility was a 400-kW capacity installed above a freshwater basin where pangasius, a type of fish, was bred. The solar arrays were to be elevated above the surface of the water, which reduced water loss through evaporation while also protecting the fish from predatory birds. The power generated by the plant was to be consumed by the aquaculture facilities itself [3]. The pilot projects were to be completed by end of 2022, demonstrating the effective use of farming land, and the efficient use of freshwater for aquaculture.

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Sketch of the planned shrimp photovoltaic greenhouse in Bac Lieu
Image Source - Fraunhofer.de.

Oorja – Farming as a Service

Since the early 1950s until as recent as 2020, nearly 85% of farmers in India remained small landholders and used diesel-based energy sources for agricultural activities such as irrigation, milling, and storage. Owing to the fragmented land-holding and the limited scales of their operations, the small and marginal farmers could not afford to invest in clean energy on their own. Oorja Development Solutions Limited (https://www.oorjasolutions.org/) a Delhi-based "Farming as a Service" company, offered irrigation, milling and cooling services to smallholder farmers on a pay-per-use basis. The company financed and installed decentralized solar energy systems at the farm level with no upfront cost charged to the intended end-users[1].

The company raised finance - typically blended capital – comprising of grants, soft funding and commercial funding – to invest in community-scale agri-infrastructure. Potential project sites were then identified based on farmers' energy needs within a given area. Small groups were formed of interested farmers, and a nominal membership fee was charged at the time of constituting each group. Oorja then procured equipment from reputed domestic suppliers and completed civil works at site, installed, tested and commissioned solar PV systems to meet the estimated energy needs. A member from the local community was hired as the operator of the project asset and was trained to deliver irrigation, milling or cooling services and to maintain a sales register. Customers paid the operator based on their consumption of the end-use service which was itself priced at affordable rates: for instance, irrigation services were charged on per-liter basis, measured by a flow-meter; cooling and storage services were provided at the farm or market gate on a per-crate-per-day basis; milling was provided on-farm at a per-kg rate. Oorja had committed to operate and maintain the solar PV systems.

Since the company's inception in 2016, through to year 2022, the company had installed 297 kWp of solar PV capacity across several sites, had touched more than 12,000 lives, contributed to increasing farmers' agricultural income by 29% per year, and had avoided the emission of an estimated 775 tons of CO_2.[2]

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OORJA Solutions
Source: www.oorjasolutions.org/

Agrivoltaics for Noah's Ark – Photovoltaic Rice Landscapes

The Po river valley in North Italy has been a major agricultural region of the country. The intensive agriculture in the region had negatively affected the soil fertility and had left an adverse impact on other environmental parameters in the region. Piero Manzoni and Giuseppe Natta, two environmentalists launched the NeoruralHub project (https://www.neoruralehub.com/) in 2018, with a proposed goal of restoring 400 hectares in the Po valley – where paddy was the main crop – back to the conditions that were present before such intensive agriculture was launched. Over the next few years, the team from NeoruralHub worked on several activities that increased biodiversity in the region, increased soil fertility, and decreased the use of insecticides.

In 2022, NeoruralHub organized an agrivoltaics design competition called "The Agrivoltaics for Noah's Ark. " The competition was organized in collaboration with Italian Network for Sustainable Agrivoltaics (www.agrivoltaicosostenibile.com) – a network launched by Italian National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA), and ETA Florence Renewable Energies. The concept for competition was developed by Alessandra Scognamiglio, who was the Coordinator of the Sustainable Agrivoltaics Task Force at ENEA. The participants of the competition had to create an agrivoltaic system with an approximate size range of 1.0MWp to 3.0 MWp on a total area of 8 hectares, where rice could still be cultivated after the agri-voltaic installation. The proposed agrivoltaic system had to be integrated as a part of the landscape, with food, electricity and aesthetic appeal sharing the same piece of land. The competition was open to architects, landscape architects, agronomists, engineers, energy experts and artists. The winning team was to be given the opportunity to further the design at NeoruralHub[1]. The second and third place winners were to be given cash prizes.

The winners of the competition were announced in September 2022. The group "StudioAlami" of which Fabiano Spano was the group leader, won the first place in the competition[2]. The team took inspiration from the fact that agricultural land was made up of several grids. They developed the agrivoltaic system canopy in the form of a grid. The average size of the cell of the grid module was 17m x 37.5 m and was "determined by the optimization of the agricultural operations on the soil and by the admissible span of the structural system"[3]. The team submitted two configurations of the grid system. 'Configuration A' provided for 3.0MWp capacity, with 76 arrays divided among 19 sub-fields. This version had a homogeneous distribution of the PV panels on the whole plot. Configuration B had a capacity of 2.75MWp, made up of 57 arrays divided among 19 sub-fields. This version provided a more differentiated landscape effect, recalling the pattern of the agricultural fields [3].

Both configurations covered a low percentage of land (~21%) and the module distribution was in perfect proportion with the rice field light requirements. Lightweight tensile material was used for support structure, with distance between support pillars being approximately 37.5m. The cost of the entire canopy was estimated at € 3,481[4].

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Agrivoltaics - Sheep Grazing At Solar Farms

The land chosen for siting a solar farm often overlaps with the land required for raising livestock, referred to as "pasture land" or "common property resources" in some jurisdictions. Solar PV plants were routinely built on large flat parcels of land, devoid of tall vegetation (so as to ensure shadow-free spaces), and land that enjoyed adequate amount of sunshine throughout the year. A study by the University of Arizona based on a detailed investigation of incoming sunlight, air temperature, and relative humidity found that incumbent croplands were also land parcels with the greatest solar PV power potential [1]. This led to the trend of leasing agricultural land out to solar producers especially in situations were returns on the incumbent use of the land were lower than the rentals from the solar farm.

However, such land conversion to solar farms negatively impacted agricultural production. Such transformations led to a growing interest in dual use opportunities of land to combine agriculture and solar power generation at the same sites, more popularly known as Agri-Voltaics. Agri-voltaic practices helped find common ground, particularly in areas where residents and governments were concerned about losing cropland. The PV plant helped provide additional use for the land as opposed to entirely converting farmland to alternative uses. Agri-voltaic solar capacity increased exponentially from about 5.0 Megawatts to 2,900 Megawatts between 2012 and 2020 [2].

A novel method in agri-voltaics involved a partnership between the farmers and the solar producers to use sheep for grazing between the solar panels. The solar producers paid the farmers to bring their sheep over to their site of operations to allow the sheep to graze on the weeds and other plants that might otherwise have blocked out the sunlight from reaching the panels. It was a win-win situation for all involved as the sheep were fed organically, the land owners were compensated financially, and the vegetation on the solar plant sites was managed effectively without using polluting mowers and weeders or the use of harmful herbicides [3].

In the U.K, the Building Research Establishment (BRE under the European Union) published the 'Agricultural Good Practice Guidance for Solar Farms' (in the year 2014), which described the experience and principles of good practice for the management of small livestock in solar farms which included the use of sheep on such farms[4]. Studies conducted across many states in the United States have concluded that sheep were a superior choice compared to cows, horses and goats on a solar farm. The cows and horses were too big to roam between the panels, and the goats chewed indiscriminately on both vegetation and wires. Sheep ate most kinds of vegetation, which helped control the plants' growth in the solar farms. Additionally, the panels provided shade for the sheep and grass and helped prevent the soil from drying out. The phased deployment of sheep through multiple sections of the property enabled pasture regrowth resulting in improved health of the groundcover.

A study funded by the National Renewable Energy Laboratory found that native vegetation grazed by sheep helped in carbon capture and improved soil quality by increasing the cycling of nutrients, carbon and water. Also, the synergies of grazing and leaving the ground undisturbed could improve a farm's soil during its use as a solar site, according to a study by the Institute for Energy and Environmental Research, based on solar projects on three Maryland farms [5].

A similar study by the Oregon State University (U.S.) in the years 2019-2020 on the use of sheep-lamb grazing and solar energy production on the same site revealed that even though the lambs gained almost the same amount of weight across the land used for solar and typical farming, there were significant differences in the daily water consumption of lambs (at the solar farms) in the late spring period and it led to 38% less forage in the solar farms [6].

A four-year-old project conducted in New South Wales, Australia, had reportedly produced better quality wool in increased quantities, with wool cuts being in the top 5 % in the district[7]. The solar panels also helped keep the drought-prone area green as the water from condensation on the solar panels (in the mornings) helped maintain the vegetation, enabling year-round grazing. As of mid-2022, several studies were still underway in Australia to optimise land use for agriculture and renewable energy generation.

The challenges of solar grazing included the transportation of sheep to solar farms and the lack of awareness of solar grazing opportunities. Todd Schmit, an associate professor of agribusiness at Cornell University, received funding from Cornell University and the U.S. Department of Agriculture (USDA) to help expand the solar-sheep practice by forming either a cooperative for business or a producer-owned organisation. The USD 500,000 project "A New Dawn for Shepherds: Grazing Sheep Under Utility-Scale Solar Arrays" was to be spread over three years in the state of New York, U.S.A. It involved partnering with various farmers, the American Solar Grazing Association (ASGA) – a

non-profit organisation that connects sheep farmers with solar producers – and solar industry professionals. The solar operators preferred dealing with a single entity rather than several farms and farmers. Hence, the organization aimed to be a point of contact between them and the shepherds and also assist the sheep owners with contract negotiations, marketing, planning, deliveries, and logistics. Such cooperative initiatives were expected to drive further investment into the sheep-growing sector.

Solar grazing also helped generate additional value for local communities as well. The ASGA estimated that solar farm operators paid land owners between USD250 – USD750 per year to graze an acre of a solar installation [8]. The additional income allowed farmers to expand their flocks, producing wool, dairy foods and meat. The USDA estimated that more than 50% of the lamb consumed in the U.S. was imported from New Zealand and Australia. An increase in the local production of lamb could reduce the carbon expended while transporting meat from distant markets and encourage more local economic activity in rural areas. As the United States has considerable potential for solar grazing, sheep rearing could be a new growth sector and positively impact local economies.

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Italy's Agrivoltaic Policy

In June 2022, a working group co-ordinated by the Ministry of Ecological Transition of Italy published the guidelines for the Design, Construction and Operation of Agro-voltaic Plants in the country. This guideline document was created in coordination with the Council for Agricultural Research and Analysis of Agricultural Economics (CREA), GestoredeiServiziEnergetici S.p.A. (GSE), the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA: https://www.enea.it/en/enea/about-us) and Research on the Energy System S.p.A. (RSE)[1]. From the date of publication, developers and Renewable Energy Supply (RES) plant owners were expected to consider the principles outlined in the document for their plants to be classified as agro-voltaic and to qualify for the benefits and incentives associated with such classification. The document provided precise definitions of agro-voltaic systems that separated agro-voltaics from "advanced agro-voltaics" [2].

In the month following the launch of the guidelines, the European Commission approved Italy's recommendation to launch a €1.2 billion support scheme for solar PV use in agricultural activities within the country. The proposed scheme was expected to support investments for deploying solar PV panels in the agrarian sector under its €191.5 billion Recovery and Resilience Facility (RRF)[3]. The scheme aimed to cover up to 90% of the project's investment cost, and such assistance was to be based on the installed capacity and was to be provided till the end of June 2026.

The solar scheme was proposed to cover agriculture, breeding and agro-industrial activities, and support companies involved in such activities to invest in solar panels. The scheme was expected to fast-track the adoption of renewable energy by farmers and food processing companies, helping the country achieve its climate objectives. It was also aimed to support the economic development of rural areas in Italy and thereby increase the competitiveness of such areas. The scheme was also slated to contribute to the European Union's (EU) strategic objectives relating to the EU Green Deal by encouraging the switch to renewable fuels. The initial assessment of the scheme revealed that it was most likely to incentivise end users who wouldn't have otherwise opted for a transition to solar PV and to co-locating solar PV arrays on their farms [3].

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Italy's Agrivoltaic Policy-Agrivoltaico
Source: Laterza Italia

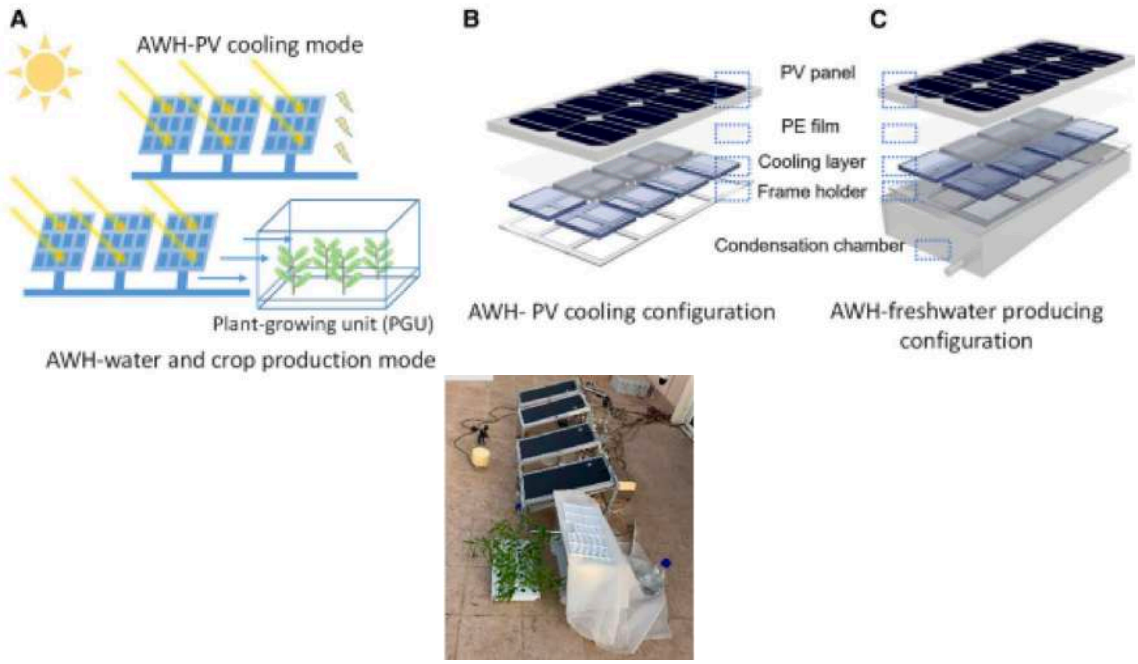
WEC2P, Saudi Arabia

In 2021, the report from the Intergovernmental Panel on Climate Change (IPCC) estimated that in recent years nearly four billion people around the world experienced severe water scarcity for at least one month each year. Further, according to the IPCC, water stress and drought conditions were expected to worsen over the course of the 21st century, impacting agricultural activities and food security of the world[1]. In view of such projections, a group of scientists from King Abdullah University of Science and Technology (KACST: http://www.kacst.edu.sa/), Saudi Arabia, embarked on research work to develop technology that could help tackle water and food insecurity in arid locations. The scientists succeeded in developing a "self-sustained, integrated water-electricity-crop co-production system (WEC2P)" that could produce electricity, fresh water, and crops in arid regions.

The team tested the WEC2P system for a period of three months in Thuwal, Saudi Arabia during the summer of year 2021. The system consisted of solar panels of dimension 60cm x 30 cm, with each panel made up of 12cm x 12cm PV cells. The panels were subjected to a seven day pre-test, to establish the average efficiency of the modules. Of the four PV modules subjected to pre-test, one was used as a spare module, one was unmodified, while two of the PV modules were coated with a 0.04mm thick Poly Ethylene (PE) film and attached to hydrogel modules. The hydrogel was synthesized by the team by dissolving Acrylamide, N,N'-methylenebis (MBAA), N,N,N',N'-tetramethylethylenediamine (TEMED), and calcium chloride in varying proportions in one liter of deionized water, and exposing it to a Nitrogen atmosphere. The solution was then transferred to 12 cm × 12 cm × 0.8 cm containers to settle at room temperatures, and then freeze dried [2].

The PV and the hydrogel modules were secured in place with a poly-methyl methacrylate (PMMA) plate and spring bolts. The assembled module was called Atmospheric-water-harvesting (AWH) – PV module. The team wanted to determine if the hydrogel in the AWH-PV module would cool the PV modules and would consequently increase their efficiency. One of the AWH-PV modules was also attached to an aluminum alloy condensation chamber that was connected to a two liter capacity water collection bottle through a cotton wick. The condensation chamber was opened at 7pm for the atmospheric water absorption process and was closed at 7:00 a.m. the next day to proceed with the water condensation process.

The two AWH-PV modules and the unmodified PV module were set out in the field with a 22° angle to the ground and facing to the south. Each PV panel was independently connected with a Maximum Power Point Tracking (MPPT) system and a 12-V lead-acid battery. The array's power generation performance was monitored and recorded by coulomb meters. Environmental conditions, including ambient temperature, relative humidity, solar irradiance and wind speed, were measured in real-time between 7am to 7pm, and recorded through a computer-controlled data collection system. The water collected from the AWH-PV module with the water collection unit was used to grow 60 water spinach (Ipomoea aquatica) seedlings, which were later transferred to plant growing units (PGU).



Agrivoltaico pergola agricola ombreggiante fotovoltaica, Laterza Italia

The results of the experiment showed that the temperature of the AWH-PV modules was ~1°C - 3°C lower than that of the unmodified PV panel, which resulted in higher power generation from the modules. The accumulated electricity generation by "AWH-water and crop production mode," AWH cooling, and unmodified module was 1,519.2 Wh (527.5 Wh/m2/day), 1,638.2 Wh (568.8 Wh/m2/day), and 1,497.9 Wh (520.1 Wh/m2/day), respectively. The electricity generation increment for "AWH-water production mode" and AWH cooling was 1.4% and 9.4% compared with the unmodified PV panel. The average AWH water production rate was about ~0.6 l/m2/day. The quality of the produced water was analyzed by total organic carbon-total nitrogen (TOC-TN) analyzer and inductively coupled plasma optical emission spectroscopy (ICP-OES). The ion content and TOC-TN concentration of the produced water fulfilled the World Health Organization (WHO) drinking water standard. Of the 60 seedlings planted, 57 survived, giving a 95% survival rate for the plants. Due to the size constraint of the PGU, the "plant growing" part of the test had to be stopped on day 16 when the foliage of the tallest plants reached the PGU ceiling when the average stem height was around 18 cm.

According to the researchers, to scale up this model, the hydrogel component had to be improved to enable it to absorb more water from air, compared to what was observed during the experimental stage,[3].

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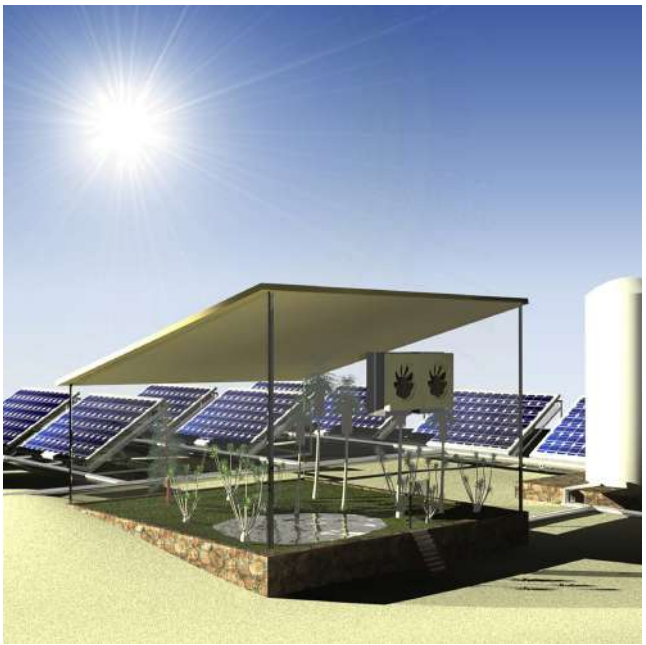

Self sustained water electricity crop production system at King Abdullah University, Saudi Arabia

BayWa R.E., Shepherd partnerships – USA and Mexico

BayWa r.e. (https://www.baywa-re.com/en/), a German company with international presence, had been experimenting with agrivoltaics by growing strawberry, apple and red currants under solar panels. However, high costs quoted for mowing the solar power facility in Texas, USA led the company to experiment with agrivoltaic operations involving livestock like sheep. The company's 270 MW solar power facility in Texas was spread over 1,700 acres of land, and had to be mowed at least twice a year. The company received a quote of USD 275,000 to mow the land each time by the local mowing company, which amounted to roughly 2% of the earnings by the plant. In addition, the plant lost 1,035 modules per year to projectile debris, thrown by mowers as they traversed the rocky fields. That damage totaled approximately USD 306,000 in procurement and repair work[1].

BayWa decided to experiment with sheep to manage the vegetation at two plant locations, one each in Texas and in Mexico. The company had some experience with combining sheep farming with solar plants, having set up two solar farms on decommissioned airfields in France, and converting the land to pasture for sheep grazing[2]. The company procured a flock of 700 sheep, and paid a shepherd to manage them, and also split the profits from selling mutton with the shepherd. The sheep grazed on 5-8 acres land per day. Through the year, around seven sheep were lost to predators, but the numbers were maintained through lambing. Moreover, the sheep had damaged just two solar panels as compared to the 1,035 panels by the mechanical mowers. Overall, the company was able to save USD 413,774 by using sheep as compared to the cost of mowing.

Based on the year-long study the company concluded that about 900 sheep would be required to maintain the area of 1,700 acres; and four people to move the sheep around the solar farm area. The herd needed 600 to 1,200 gallons of water per day, for which BayWa had to construct water distribution lines from local ponds and lakes. Dogs had to be employed keep predators away. The company also realized that lambing was risky and needed intensive management with veterinary intervention. Late in year 2022, BayWa decided to outsource the management of the sheep, and commenced discussions with local sheep owners to outsource shepherding and lambing operations.

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BayWa r.e.'s solar sheep farm
Source - unknown

Semi-Transparent Solar Module With Nano-Particles

In October 2022, researchers from the School of Photovoltaic and Renewable Energy Engineering University of New South Wales, Australia, had partnered with Tindo Solar (https://www.tindosolar.com.au/), Australia's only solar panel manufacturer, to develop a novel line of semi-transparent modules that could be retailed commercially. These modules were fitted with special nanoparticles tuned to capture various parts of the light spectrum. The partnership aimed to create a commercial product line for ground-mounted field locations or greenhouses that could significantly boost energy production and agricultural yields [1].

The semi-transparent module concept was an alternative to the traditional agrivoltaic system where the solar PV cells were enclosed in glass casing. In European countries and in Japan, where agri-voltaics are now commonplace, the panels were arranged such that there was enough space between the modules that allowed the light to reach the crops. Such systems were called 'shaded' agri-voltaics [2].

The novelty of the concept involved siting of the silicon photo voltaic cells within a transparent – or semi-transparent – material embedded with specially tuned nanoparticles. Such nanoparticles allowed parts of the light spectrum essential for crops to pass through while redirecting other parts of the light spectrum to hit the back-end of the bifacial modules, increasing the total energy yield.

The initial demonstration of the UNSW concept resulted in an increase in the total energy yield by as much as 20% compared to the traditional agri-voltaic system. The system was expected to benefit the crops by providing protection from the harsh sun and extreme weather and by improving water management through lower evaporation. The microenvironment created under the panels was slated to provide the crops with higher humidity, and the cooler temperatures were to achieve more efficient functioning of the solar panels.

Further research by the agencies involved was to focus on selecting crops based on the incumbent light conditions at specific sites. A proposed commercial line of various module options, in which nanoparticles had been tuned to the specific parts of the spectrum to suit different crops was also to be developed. Such agrivoltaic solutions were also expected to ease tensions between farmers and the renewable energy industry and win community support for siting solar and wind farms on arable land [2].

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Semi-transparent solar panels for agricultural needs Saudi Arabia

Agrivoltaico T2.1 – Sun Tracking Mounting Structure

RemTec (https://www.remtec.energy/en), an Italian company, had over 10 years of agrivoltaic experience, and had developed several patented mono and bi-axial agrivoltaic technologies. In 2022, the company developed a rotating mounting structure for agrivoltaics, designed to produce a "dynamic, controlled shadow on the ground," and was reportedly ideal for flat surfaces with a maximum slope of 3%.

The rotating structure had two vertical poles, 14m apart, which could be equipped with a single-axis or double-axis tracking systems. The height of the structure was 6.0m above ground level, which allowed for the routine operation of farm equipment under the array. The structure had a horizontal steel profile that could host four smaller profiles mounted perpendicular to the horizontal axis. Both, the smaller profiles and the horizontal profile could rotate around their respective axes[1]. Each of the four profiles could host up to six bifacial panels, with the entire horizontal profile adding up to 24 modules. The distance between the rows of solar panels could vary from 12 m to 18 m. Each horizontal structure could host between 13 kW and 17 kW of solar modules, aggregating to approximately 600 kWp and 800 kWp per hectare.

The "Agrivoltaico T2.1" rotating mounting structure was equipped with a control system that helped rotate the panels to control the shadow on the ground, which was critical during the flowering phase of the crops being grown on the plot. The company had tested the system with more than 15 types of crops including maize, wheat, rice, tomato, pumpkin, tea etc., and had found promising results [2].

The company announced plans to work with Portuguese energy company Galp on a pilot plant at a vineyard in Lisbon; the vineyard pilot was expected to be commissioned by the end of year 2023. Simultaneously, RemTec was also reportedly testing mono-axial tracker systems for higher gradients.

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RemTec's sun-tracking solar mounting structures
Source - unknown

Giant Agrivoltaic Project in China - Turning Desert Into Oasis

The Binhe New District on the eastern banks of the Yellow River in Ningxia, China, used to be a harsh desert in the years leading to 2014. Baofeng Group (http://www.baofeng.com), a Chinese internet and information service provider, began managing 107 square kilometer of land in the district, and started growing alfalfa, a perennial flowering plant to improve the soil quality. By 2016, the soil quality had improved substantially prompting the company to remove the alfalfa and construct an 'agri-voltaic' plant in its place. The first phase of the power plant had a capacity of 640 MW, which relied on 13,000 Huawei smart string inverters, and the PV power plant was connected to the grid under China's feed-in program for solar energy in 2016. The company began growing goji berries under the solar panels. The solar panels were installed at a height of 2.90m above-ground level, which was sufficient for cultivation of the goji berries. Such elevation also ensured optimal operation and maintenance activities under the arrays[1].

Huawei (https://www.huawei.com/), a partner company for the project, reported that as of year 2020, the PV power plant had generated 4.31 billion kWh of electricity and had displaced 2.047 million tons of CO2 emissions that might have otherwise been emitted. Such emission reduction was estimated to be equivalent to planting 89.01 million trees. The solar panels helped reduce evaporation of water from the soil by 30-40% compared to an exposed parcel of land, and had increased vegetation coverage by 86% compared to the vegetation cover in 2014. The PV power plant had also created over 80,000 jobs which covered activities such as cleaning the solar panels, and weeding, pruning, fertilizing, and picking in the goji fields[2].

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Elevated Agri-voltaics in France - Application of the Land Equivalent Ratio

One of the core concepts of solar dual-use or agri-voltaic systems involved an elevated mounting structure that carried the solar PV modules. The elevation of these "full" solar dual-use systems (that focused equally on agricultural production and solar energy generation) usually was 3.0 to 5.0 meters to allow for extensive or intensive, mechanized farming methods (including the use of harvesters/tractors) beneath the solar modules. Such solar dual-use applications called for a less dense area coverage of the solar modules than roof-mounted or conventional ground-mounted PV systems. Such a lower PV installation density allowed a higher proportion of the irradiation to reach the plants below. The space between the module rows differed from project to project and was a vital parameter of the dual-use setup. Such spacing was also determined by the shading tolerance of the crops and plants grown underneath the panels. Pilot projects and scientific test sites had experimented with differing shading ratios created by differing configurations of solar modules.

The PV modules could be fixed on the mounting structure or single or double-axis (2D or 3D) tracked (thus, the tilt angle of the PV modules could be adjusted). Single-axis tracked solar systems were generally found more in regions closer to the equator (that experienced short sunrises and sunsets), double-axis tracked systems were found more in areas further away from the equator. The dynamic control of the module tilt angle in tracked systems could be utilized to increase the solar yield of the system (more kWh generated per kWp installed). It would also allow more sunlight to reach the crops or to create a more stable shading effect (that would benefit soil humidity and micro-climate on the ground).

The first ever reported pilot project of an elevated agri-photovoltaic system was developed in France in the year 2010, where lettuce was grown under the PV system. The prototype occupied an area of 820 m2 and was located in Montpellier. The system consisted of rows of PV panels 44.8 m in length and was mounted 4.0 m above the ground. The supporting pillars were set 6.4 m apart, situated in North-South and East-West directions. The individual panels consisting of mono-crystalline cells were opaque, 1.58 m long and 0.808 m wide (JT185Wc) and were sourced from Jetion Solar Holdings Limited, Jiangsu, China (https://www.jetionsolar.com/).

The French research team Duprez et al. developed a model for radiation intensity within a solar PV field that included boundary effects [1]. The team also estimated the influence of shade on crop yield using existing models from agroforestry (interspersing crop areas with trees) and applied the concept of Land Equivalent Ratio (LER). The LER concept was developed initially to quantify yields of mixed agricultural systems, like the combination of different crops, or trees and crops, to the variety of PV with crops.

The study suggested that the agrivoltaic systems could be optimized by specific arrangements of PV panels and by plant breeding to determine the best utilization of an available parcel of land, thereby combining food production and electricity production. This study also led to further research studies on integrated designs of agrivoltaic systems to optimize food and energy production in a given economic context.

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Mobile Solar-Powered Pumps for Horticulture in Tanzania

Parts of rural Tanzania enjoyed two rainfall seasons each year and were endowed with weather patterns that might be considered conducive for agriculture. Yet, weather-related uncertainties and droughts in the years leading up to 2020 exposed farmers to great risks. Farmers cultivating small plots of relatively dry land struggled to irrigate such plots for most parts of the year. Such farmers depended on open wells and manual labour to irrigate their fields.

Under these circumstances, E-LICO Foundation, a local Renewable Energy organization developed a mobile solar-powered pump to help vulnerable farmers. ELICO's operations had been supported by the European Commission, the Mott Foundation, Shine and Selco Foundation. The mobile pump effectively provided pumping services to the farmers and to stockists and traders and matched the fees charged with the cash-flow patterns of the beneficiaries. The solar PV array was mounted on a two-wheeled handcart fitted with an electric pump to lift water from the source and to distribute it efficiently[1]. To maximize the productivity of the pump itself, farmer-beneficiaries working on drylands get to use the pump more frequently than farmers working in relatively wet lands.

The ability to move the pump across several farms was considered a key attribute to the design and to making more efficient use of the project asset. The mobile pump helped save physical effort and time for the small-holder farmers who were now able to engage in other productive activities. In addition, the yield output from the solar irrigated small farms is reported to have grown by substantial margins, on occasion by 100% or more and the earning from such produce is reported to have grown by higher proportions. Each beneficiary was mandated to contribute 5,000 Kenyan Shilling (~USD 2.0) per month towards maintenance of the mobile pump. This contribution was saved in a group bank account.

The relatively large pumps were priced at about USD 1,450 (~3.50 million Kenyan Shillings, ~1,450) and the Irrigation Department had been offering loans to farmers' groups to help with procuring the equipment. The groups were required to repay USD 518 (~1.20 million Kenyan Shillings, ~518) each year. The additional incomes from employing the pumps were believed to be sufficiently encouraging to motivate the farmers to procure the pump and to service the debt. ELICO had proposed to scale-up the numbers of pumps and the geographic coverage of the demonstration phase. Such scale-up also sought to train local solar trolley fabricators to fabricate mobile solutions within their respective regions.[2]

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Solar PV-Powered Milk-Chilling by Cooperatives in Uganda

Notwithstanding the large cattle populations, several African countries relied on dairy imports to meet domestic needs, frequently owing to poor herd management, low-quality of feed, small scale of operations and poor productivity, and above-all lack of refrigeration infrastructure. In Uganda, for instance, many of the milk collection centres were off the hydro-electric grid network. Cooling milk slowed down bacterial growth and reduced spoilage, thereby raising farmers' incomes and providing safe milk for consumers[1]. Expensive diesel generators were deployed but when the generators broke-down, the cooperatives had no further back-up options and large quantities of milk turned sour.

Heifer International (https://www.heifer.org/) partnered with Energy for Impact (https://energy4impact.org/) and Carbon Trust (https://www.carbontrust.com/) through the "Powering Renewable Energy Opportunities" (PREO) program to launch a pilot initiative to connect five off-grid milk collection centres in Kiboga District with solar PV systems. This Euro 1 million program was projected to increase efficiency and to reduce wastage and the first three plants aggregating 106kWp were to be commissioned by March 2023. The scale-up phase of the project was projected to run through to year 2024. Surplus electricity was to power cottage industries including food storage units, among others.

The solar powered cooler was an ice based system: the solar energy was used to produce ice-blocks which were then filled into an extra vessel in the middle of the insulated churns. The arrangement enabled milk to be cooled for up to 12 hours, preventing microbial activity. Such possibilities for preservation helped farmers milk their cattle twice daily and helped the cooperative earn higher prices for the safer and healthier milk supplied.

The first unit of 40.50 kWp capacity was installed at the Dwaniro Livestock Dairy Cooperative. The installation was projected to lower carbon emissions by about 90% relative to a diesel generator based benchmark. The cooperative/s entered into a power purchase agreement and paid for the power actually consumed each month. This helped align the cash-flow patterns from milk sales with the expenses on power consumption. Ownership of the power plant asset was to be transferred to the dairy cooperative after a period of 8 years, and following such transfer, the cooperative was responsible for the operations and maintenance of the plant[2]. Among other contributions, Heifer International intervened on equipment and installation quality, related aspects of pasture conservation, water conservation, access to finance for the cooperatives.

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Solar PV for Vertical Farming

Vertical farming is a method of farming where plants are stacked on vertical shelves, generally in indoor controlled environments. Modern techniques like hydroponics and aeroponics are used to irrigate the plants, while LED lights replace sunshine. It is estimated that a vertical farm the size of a supermarket, roughly around 3,500 square meter could hold as many plants as 700 acres of farmland.[1] In addition, the controlled conditions within an indoor vertical farm, could provide yields throughout the year independent of the season on the outside. Vertical farming could provide a promising solution to help address significant food insecurity in countries like Sudan.

However, vertical farms have high start-up costs and are energy intensive. A team of researchers from the University of Arizona therefore studied the possibility of using solar energy to power vertical farming in Sudan. The study considered three types of vertical farms: warehouse vertical farm, modular/shipping container vertical farm, and a greenhouse vertical farm.

The team worked with the local grocery store, Al-Anfal Supermarket in Sudan's capital city of Khartoum, to grow the store's annual demand of 66,000 kg of yellow potato and 79,200 heads of rocket arugula, using solar vertical farms. The results of the study are as shown in Table 1. Of the three types of farms, the greenhouse vertical farm was most profitable with an estimated annual profit of USD 179,447 and a break even period of 1.1 years. The study showed that, although solar powered vertical farms incurred significant capital and operational investments, they were able to meet the annual demands of the local grocery store Al-Anfal Supermarket, and demonstrated reasonable promise of profitability.[2]

Table 1:Estimated annual profit and break even period for the three types of vertical farms

TYPE OF VERTICAL FARM	ESTIMATED ANNUAL PROFIT (USD)	BREAK-EVEN PERIOD (YEARS)
Warehouse farm	166,924	1.3
Modular/shipping container farm	164,691	1.3
Greenhouse farm	179,447	1.1

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PV-Driven Aerator for Shrimp Farming

Indonesia has all the conducive conditions for shrimp farming: large numbers of islands with a cumulative coastline of about 54,000km, with abundant human resources, and a supportive tropical climate. However, according to certain independent estimates, as of year 2022, Indonesia had achieved just 50% of the country's potential in terms of shrimp farming.[1] It was believed that with the right investment in science, technology, and good management practices, Indonesia had the potential to become the world's biggest shrimp exporter.

In view of such beliefs, several agencies were engaged in developing new technologies that could help Indonesia's shrimp farming. One such technological innovation was the PV driven aerator developed specifically for use in shrimp farms, by researchers from the Institut Teknologi Sepuluh Nopember (ITS: https://www.its.ac.id/) in Indonesia. The process of aeration was very important in shrimp farming, to increase the amount of dissolved oxygen in the water. Aeration was also energy intensive. The PV aerator developed by the team aimed to reduce the farm's dependence on the utility grid.

The aerator consisted of a 200W solar panel fixed on top of the aerator frame. It had an eight-leaf windmill connected to a DC motor, for paddling water and restoring oxygen levels in the shrimp farms. The entire set up was fixed on a buoy with a box panel containing the electronic circuits and a battery. The team successfully tested the aerator at a white shrimp pond at GunungAnyarTambak Village, Surabaya, Indonesia. The scientists planned on using the aerator with Internet of Things (IoT) technologies, to enable shrimp farmers to operate the aerator using their mobile phones.[2]

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Image Source: unknown

PV-Driven Aerator For Shrimp Farming - Thailand

Since ancient times aquaculture has been a part Thailand's way of life. The presence of huge flood plains, natural lakes, brackish water areas along coastlines, etc., made the country suitable for aquaculture practices to flourish. In the past few decades, shrimp farming has expanded significantly in the coastal regions of Thailand. The country's shrimp farmers have shown considerable interest in new ideas and in the application of advanced technologies, with enthusiasm to learn and apply the same to their shrimp farms[1]. Such enthusiasm for shrimp farming has resulted in several new innovations in the country that have been directed towards improving the efficiency of shrimp farms.

One such innovation was the PV driven aerator with storage developed by Chaowanan Jamroen, a scientist from the King Mongkut's University of Technology North Bangkok in Thailand (https://www.kmutnb.ac.th). Aeration systems were usually integrated with the aquaculture farms, to increase the dissolved oxygen levels in water. However, aeration was highly energy intensive, and difficult to integrate in remote areas of developing countries like Thailand, due to limited coverage of utility electricity grids. In such areas, stand alone solar aerators like the one developed by the Jamroen were projected to be more beneficial.

The system consisted of a floating platform assembled using four high-density polyethylene floats, held together by a galvanized steel frame that also supported both a 100-rpm paddle wheel aerator and solar-plus-storage system. The system was assumed to have a power requirement of 200 W, and a monitoring system with a power demand of 5 W. This floating platform had a weight capacity of around 100 kg, which was a crucial factor that restricted the size of the solar generator coupled to storage. It was estimated that the day-aeration would need a 450 W PV system and 60 Ah battery, and night aeration setting would need 535 W PV system and 150 Ah storage system. A year-long simulation was conducted with the system to determine its reliability in providing continuous power supply for aeration[2].

The calculated cost of the proposed optimal floating solar-plus-storage system was USD 8,810 for the day-aeration scenario and USD 11,400 for the night aeration scenario. The PV aerators were cheaper relative to systems powered by diesel generators, which cost about USD 16,000 for comparable application.

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Image source: unkown

Mibet Mounting Structure for Agrivoltaics in Japan

Xiamen Mibet New Energy Company Limited (https://www.mbt-energy.com/), specialized in research, development, manufacture and distribution of solar PV mounting system solutions. The company's PV mounting systems were reportedly sold in over 100 countries and regions. Among others, the company produced and sold mounting systems and accessories for ground-mounted PV plant for rooftop installations, for floating solar PV projects and for carports, with and without tracking systems. The company was particular about the structural strength, stability and corrosion resistance and consequently of the longevity of the mounting structures and brackets supplied.

The Japanese solar PV market was known for stringent requirements and expectations for product quality. Several PV agri-voltaic projects had been successively built and commissioned in Shizuoka Prefecture, Aichi Prefecture, Yamanashi Prefecture, Fukushima Prefecture[1]. The Mibet mounting structure was capable of adjusting to the sun-light requirements of different crops while optimizing power generation and crop output at a given field. The overhead solar arrays could block some part of the UV light and could reflect the blue-violet light needed for insect propagation. This helped minimize insect pests and plant diseases, while leading to reduced use of pesticides and to improvement in quality and quantity of crops. While helping the crop output, the overhead PV arrays minimized the need for land-use conversion, generated power for local use, while lowering transmission losses for the utility and improving the utilization rate of available energy in the country.

The Mibet Agri-PV system installed in Japan adopted aluminum alloy and large span structures to allow for the routine operation of agriculture machinery. The structural elements were designed to support large-span overhead structures and the super-imposed loads. In January 2023, the company commissioned Japan's biggest agri-voltaic installation, a 4.0 MW project in Fukushima prefecture[2]. The 68,000 square-meter installation on abandoned land in Fukushima was built 2.5 meter above the ground, projected to generate some 3.70 million kWh of electricity per year. The electricity generated was to be exported to the utility grid at a specified feed-in-tariff. The tilt angle of the Mibet mounting system was set at 30 degrees and the structure was designed to withstand 80 meters per second. The main body of the Agri PV system was built with a 3.50 meter wide structure so as to facilitate the routine operation of agricultural machinery at the site. The site was adopted to grow seven types of grapes.

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Fruitvoltaics in Austria, Germany, Netherlands

BayWa RE (https://www.baywa-re.com/), a multinational company with presence in over 30 countries, was a leading renewable energy developer in the 21st century. For several decades, the company had been working with agricultural communities to offer customized solutions for location-specific challenges in agriculture[1]. After successfully working on setting up several biomass plants, the company focused its attention towards agrivoltaics, to combine the benefits of solar PV energy with agriculture. Among others, the company built agrivoltaic pilot projects in Europe, with a focus on fruits, to research on the right variables that could improve crops, and to produce optimum amounts of energy. "Fruitvoltaic projects" as they were called, were set up in Austria, Germany, and Netherlands. The projects were funded by the Dutch government, the federal state of Styria in Austria, and the federal state of Baden-Württemberg in Germany. BayWa RE's subsidiary companies helped with the implementation[2].

- In the Netherlands, the subsidiary GroenLeven (https://groenleven.nl/), built two agrivoltaic research facilities in the villages of Enspijk and Randwijkwith capacities 105 kWp and 125 kWp respectively. The project at Enspijk grew cherries and was monitored by a team from the Fruit Tech Campus of GroenLeven. The Randwijk project grew pear, and was monitored by the Wageningen University & Research (https://www.wur.nl/).
- The subsidiary Ecowind (https://www.ecowind.at/) helped set up an agrivoltaic project in Austria together with the Haidegg research facility (https://www.haidegg.at/) in Graz. Stonefruit and pomefruit were grown with a solar PV structure of 340 kWp capacity.
- In Oedheim, Germany, MKG GÖBEL (https://www.mkg-goebel.de/) grew raspberry under a rainproof solar PV structure with a 115 kWp capacity. The panels used had a light transmittance of approximately 70%. The research institute for Viticulture and Fruit growing in Weinsberg (https://lvwo.landwirtschaft-bw.de/) monitored the quality of the fruit below the PV modules.

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Fruit-voltaic PV
Source: Baywa r.e

Floating PV Plant Across Two Adjacent Ponds: the Netherlands

In January 2021, Spanish floating PV project specialist Isigenere (https://www.isifloating.com/en/solar-flotante-isifloating-by-isigenere-english/), commissioned a 338.0kW – 846 modules of 400Wp each – floating array built on the surfaces of two adjacent ponds in the Netherlands. The floating PV project in Rilland village of Zeeland province in the Netherlands was spread across one pond meant for irrigation and a second water body that served as a reservoir to fight fires. The plant had employed a special mounting system that avoided contact between the solar PV modules and the sides of the water bodies[1]. The Isigenere – Isifloating 4.0 floating structure was specially designed to optimize energy generation from PV arrays. The installation employed special anchors and moorings that allowed for vertical movement of the structure in keeping with changes in water levels, and yet, the anchors and moorings allowed for the PV system to maintain stability and to maintain a horizontal plane[2].

The floating solar plant was projected to reduce evaporation of water and algal blooms, while also supplying a significant portion of the power consumed by Limagrain (https://www.limagrain.nl/), specializing in breeding and marketing of seeds for livestock farming, and green seeds and green manures for arable farming.

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Insignere
Source: PV Magazzine

Sun'Agri Agrivoltaic Algorithms For Optimizing Solar Louvres And Plant Well-being

The agriculture sector the world over faced many challenges in terms of meeting demand while also catering to changing societal expectations, shrinking areas under cultivation, weak scale economies, low margins, climate change and the associated uncertainties, natural disasters, generational changes and the like. French agri-voltaic specialist Sun'Agri (https://sunagri.fr/en/) had undertaken extensive research to develop an agri-voltaic system that optimized the well-being of plants while also maximizing the energy output from positioning of solar louvres. "Dynamic agri-voltaics" was an agricultural innovation involving the construction of a system of solar louvers overhead the crops that protected yields and served to combat water, heat and solar stress in the plants. The sunlight management strategy adapted to the needs of the crop being cultivated and the company routinely compared performance against a 'control' farm which did not house the louvres[1].

Sun'Agri commissioned a 2,500 sqm facility in September 2020 in Granges-sur-Lot, in the Lot-et-Garonne region of France. One year after commissioning the facility the company revealed higher yields under the 'test' AV facility, relative to a 'control' greenhouse which was not fitted with solar PV modules. The test facility yielded in excess of 800 kg of vegetables relative to a reference greenhouse output of about 500kg: the eggplant harvested under the PV arrays had higher biomass, consistent with better plant development. In addition to adapting to climate change, offering resilience in the face of other challenges that farmers might be routinely faced with, the agri-voltaic array helped optimize agricultural production as well.

The micro-meteorological sensors placed at different heights measured air temperature, humidity, wind and radiation in the greenhouse. The Photo-synthetically Active Radiation (PAR) sensors helped estimate the needs of the plant. This data helped the farmers optimize meteorological conditions best suited for the plants. "Plant sensors" observed the water status, functioning, stress and other features of the plant. The plants were also faced with less stress from pests[2]. Subject to the plants' needs and given the weather conditions at the site, the energy output could be optimized based on the farmers' objectives, intra-day weather forecasts and plant growth patterns.

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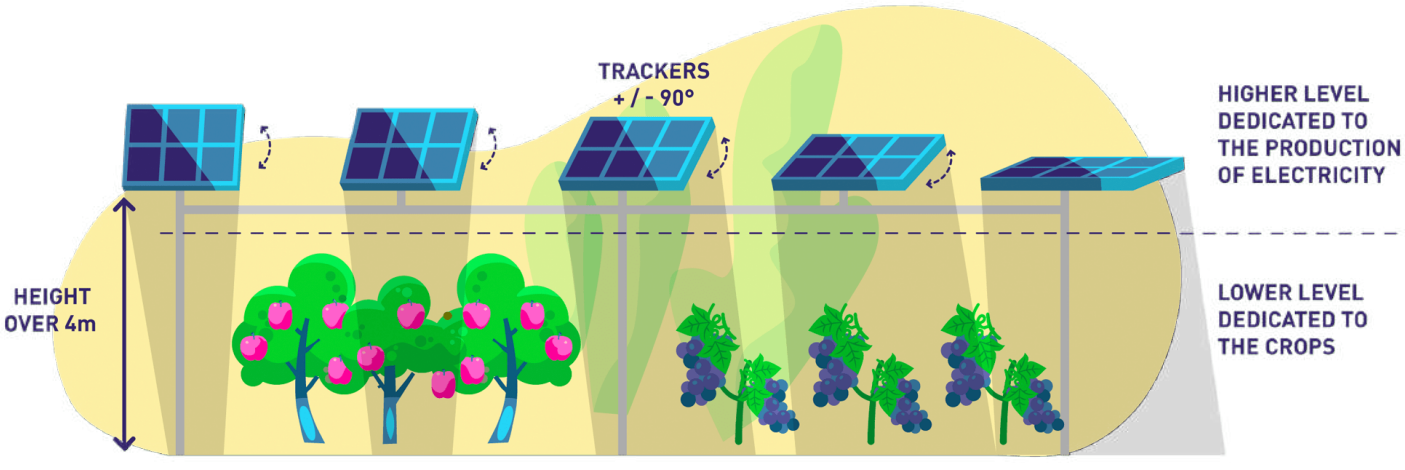

Sun Agri algorithm for Agrivoltaic

Project REGACE - Crop Responsive PV Trackers - Supported By EU

The Triangle Research and Development Center (https://trd-center.org/) had been exploring innovative low cost agrivoltaic solutions since 2017. Trisolar (https://www.trisolar.net/), an Israeli company, was launched as a spinoff to commercialize and market the solutions identified by the TRD Center[1]. On the strength of five years of research and testing, the company launched a 'plug-and-play' crop-responsive solar PV tracking system for agrivoltaic projects and greenhouses in 2022. The system consisted of a tracking structure, motor, controller and the specially designed bifacial solar panels. These solar panels were smaller and lighter than standard PV modules and custom-designed as per specifications provided by Trisolar. The modules were semi-transparent, with a transparent back-sheet and with spaces between cells. The agri-voltaic arrays were pre-assembled, to enable quick and easy deployment at greenhouses, requiring just about one fifth of the labor needed for conventional solar PV installations[2].

The tracking system optimized the distribution of light within the greenhouse while also maximizing the electrical output of the PV system. The company conducted a trial under Mediterranean climatic conditions and observed that the electricity output was 20% higher relative to a comparable fixed installation in a greenhouse. The company planned to conduct further studies of the system at various locations including at greenhouses in universities and research institutes in Germany, Austria, Greece, and Israel, and at operating farms in Germany and Italy. Since this was a substantial undertaking, the company formed a consortium of 12 research institutes and commercial organizations, and launched project "Regace."[3]

Project Regace received €5.30 million from the European Union through the Horizon Europe Research and Innovation Programme[4]. Apart from the solar tracking system, the project had also intended to undertake research and to develop various carbon dioxide (CO_2) enrichment methods to increase crop yields, including "bottled CO_2 enrichment, CO_2 enrichment using CO_2 bags, and using agricultural offcuts, compost, or manure to increase CO_2 levels inside the greenhouse." These techniques were projected to expand agrivoltaics usage to areas with less sunshine and low light conditions.

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Solar Polytunnel

Organic Photovoltaic (OPV) solar cells are a type of photovoltaic technology that uses conductive organic polymers for light absorption and for charge-transport to produce electricity from sunlight by exploiting the photovoltaic effect. In comparison to silicon based PV modules which were in wide circulation during the 2010s and the early 2020s, OPVs were lightweight, inexpensive to fabricate, flexible, and were known to cause lower adverse impacts on the environment. Since OPVs could be produced in various colors or could be used in transparent OPV devices, this technology was particularly appealing to the building-integrated PV segment[1].

In 2021, a team of scientists from Triangle Research and Development Center (https://trd-center.org/) Israel researched on the possibility of using OPVs for agrivoltaics, particularly on top of a polyethylene covered greenhouse high tunnel in a Mediterranean climate[2]. Polyethylene greenhouses were used to grow large quantities of fruits and vegetables that required more heat during the winter months. These greenhouses were harder to shade than those covered with glass. OPVs used polyethylene encapsulation materials which were lightweight and flexible and could be used to replace the polyethylene on the greenhouse tunnels. Specifically chosen colored OPVs could be used to transmit specific light spectrum needed for plant growth, and use the other parts of the light spectrum to generate electricity.

The team used solar modules with PBTZT-stat-BDTT-8 organic cells, and with physical dimensions of 1,000 mm x 800mm x 0.6 mm. Each module had an energy conversion efficiency of 3.3%, and could generate a nominal power of 14 W. Since the modules had a light transmittance rate of 23%, the team covered only 35% of the greenhouse roof with these solar modules to ensure that requisite light reached the plants below. The team tested the performance of these OPV systems for six months against that of a conventional solar module system. The researchers found that the OPV system had a combined output of 105Wh on sunny days with power conversion efficiency of 0.65%. On cloudy days, the PCE was 0.86% with a combined output of 81Wh. OPVs had a lower module temperature compared to silicon modules, but had greater degradation due to the mechanical stress caused by movements of the tunnel sheeting due to wind.[3]

The team found that the efficiency of the OPV modules used in these greenhouses was around 3%, which was low compared to the 17% achieved under laboratory conditions. The researchers concluded that more efficient modules would have to be used to enhance the economic viability of OPV modules. The team also observed that large scale production of OPVs might help make the product more attractive relative to contemporary mainstream alternatives.

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Solar Powered Insect Traps to Boost Organic Farming

In recent decades, mainstream farming practices have included the use of toxic chemical fertilizers and pesticides, which were known to be harmful to the soil, the consumer, and to the farmers themselves. Long term use of such chemicals posed the risk of permanent soil degradation which would render such soil unusable and clearly such practices were unsustainable. Since the early 21st century, organic farming techniques were being promoted more aggressively by several stakeholders concerned, to counter the ill effects of mainstream farming and to try and restore soil fertility. Solar insect traps were one of the many innovations that were introduced to try and reduce the use of chemical pesticides in large scale farming.

A research group from Thailand developed a Solar Energy-Based Insect Pests Trap which included an ultraviolet light emitting diode tube. The team tested the trap's effectiveness in luring different insect varieties. The trap was made from a steel structure of 150cm height, with a 20W solar panel of dimension 45 x 45cm at the top. The panel had a tilt angle of 10-15 degrees. The base of the trap had steel plates which were used to mount the trap on the ground. A clear acrylic square box with 150 LED bulbs was used as an "insect tempt." A wire mesh of electronic mosquito trap was attached to one side of the box. The trap also included 5 Amp battery charger, 12V 14Ah Sealed Lead Acid Calcium battery, and a light sensor switch circuit.

The energy from the solar panel was stored in the battery, which was then used to run the LED insect trap. During the nights, the light sensor switch circuit turned the system off, and allowed the plant- friendly insects to fly around. The set up was successful in trapping insects such as such as Cocinellidae, Nephotettixnigropictrs, adult cotton leaf worm, leaf minor fly, Rhinoceros beetle, and BrontispalongissimaGestro, which were common pests in Thailand[1]. By 2022, there were several variants of the solar energy based insect pests traps available in the market, and most models used solar panels in the 3W to 10W range. One trap was sufficient for an area of approximately one acre[2].

The Housing Development Finance Corporation Limited ("HDFC") Group, launched a Holistic Rural Development Program (HRDP) as part of its corporate social responsibility program[3]. Promoting organic farming and the use of alternate energy sources like solarPV were two of the several initiatives undertaken as part of HRDP. In 2020-21, as part of the HRDP initiative, HDFC distributed solar-powered insect traps in 10 villages in Yelburga taluk of Koppal district, Karnataka, India[4]. These insect traps were an eco-friendly alternative to chemical pesticides, reduced costs for farmers and helped produce better quality crops. Each trap cost in the vicinity of INR 5,400 (€ 60). The farmers reported that these solar insect traps reduced the use of chemical pesticides by almost half. Apart from the savings on pesticide cost, the farmers also saved on the labor costs which they might have incurred for spraying pesticides. Following the success with such pilot installations, the HRDP project installed 178 solar insect traps in adjoining areas.

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Renewable Energy To Power Irrigation In The Atacama Desert

The Atacama Desert in Chile is one of the hottest and driest regions on earth, endowed with solar irradiation comparable with the highest levels recorded anywhere on earth. However, the region had also been intermittently fed by melting glaciers from the Andes mountains which enriched the desert floor: the nutrient rich soil was found ideal for fruit growing[1]. In 2011, Subsole (https://www.subsole.com/), one of Chile's largest fruit exporters, decided to expand operations in the desert region fed by the glaciers. The company partnered with German company Kraftwerk Renewable Power Solutions (https://kraftwerk-rps.com/en/) to harness solar energy to power water pumps[2].

Subsole built a 300 kWp solar photovoltaic plant in the Copiapó valley to power its irrigation systems. The pumps would extract water from deep underground during the day, and used such water to irrigate the farms during the nights to try and minimize evaporation. The company also implemented a solar cooling technology, improved irrigation and water storage methods, and efficient energy and water management systems. Subsole was the first company from Chile's fruit industry to use solar energy for irrigation purposes. Subsole obtained a loan of USD 32.0 million (~€ 24.5 million) and received technical assistance from the Inter-American Development Bank (IDB: https://www.iadb.org/) for this project. The IADB loan offered a 10-year-tenure with a 30-month grace period on principal repayment, providing Subsole with the long-term funds to finance its expansion plan[3].

With the success of the first project, the company installed solar PV plants in seven different fruit-growing and processing sites. Six of these projects were installed in Subsole's table grape facilities in the Copiapó Valley, with a cumulative annual energy generation of 1,087,023 kWh. In 2021, Subsole was acquired by Frutura (https://www.fruturaproduce.com/), a USA, California-based company; the acquirer was equally committed to the renewable energy projects[4]. Under Frutura's leadership, the seventh plant was commissioned in 2022 on the rooftop of Subsole's largest fruit processing plant at Isla de Maipo, with an annual generation capacity of 1,000,000 kWh. Together these projects contributed to the generation of clean and renewable energy, reduced emissions and lowered costs for the company.

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Vertical Agrivoltaic Pilot Projects

In August 2022, the French energy major Total Energies (https://totalenergies.com/) and agrivoltaics specialist-InVivo (https://www.invivo-group.com/en) announced a 111kW pilot project to study the impact of agrivoltaics on agricultural yield as well as to document and develop a repository of benefits related to carbon storage, biodiversity, and water quality[1]. The pilot project was designed to study the combinations of vertical structures, bifacial photovoltaic panels, and the optimization of the ground surface to maximize the energy production as well as crop yields. According to a Germany-based study [2] published in August 2022, vertical installations allowed for increased agricultural activity integration relative to elevated ground-mounted structures, and without significant loss in energy yields. The vertical installations were found to have helped shift the solar yield into hours of higher energy demand and to increased energy production during the winter months reducing solar curtailment [3].

- The 237kW Le Channay plant was made up of vertical bifacial photovoltaic panels with 12 meters of spacing between the modules, and the crops included wheat and aromatic herbs. The location was subject to varied climatic challenges such as frost, wind, and drought. Total Energies, teamed up with agronomy consultancy Agrosolutions, Dijon Céréales, and Next2Sun and analyzed the contribution of the agrivoltaics on a plot with declining yield. Such analysis recorded an increase in yield of 1 quintal per hectare for wheat compared to previous harvests and 2 quintals for lentils during the summer harvest of 2022 [3]. The wheat protein levels were found to have increased by 2% which could be attributed to protection against high winds provided by the modules (by reducing average wind speeds by 14 km/hour).

- The Rivals plant (87 kW) was developed along with Sudexpe, IFV, InVivo, and Ombrea, and installed above pomegranate trees and vines.

- The Valpuiseaux plant was designed with Agrosolutions, Agrinovex and Next2SunNS and featured vertical bifacial modules. Total Energies hoped to continue the study of the effects of agrivoltaics and had more than 140 such projects in various developmental stages.

- The initial results published by the Total – InVivo pilot in January 2023 showed an increase in agricultural yields on field crops and a reduction in water stress. The published results related to the initial harvests from three agrivoltaic pilot studies located in the French municipalities of Channay (Côte-d'Or), Rivals (Aude), and Valpuiseaux.

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SokoFresh – Solar Cold Store Facility for Farmers

Like most smallholder farmers around the world, poor logistics and unpredictable demand were some of the post-harvest woes of the farmers in Kenya. It was estimated that Kenyan farmers lost as much as 50% of their quality produce due to unorganized and unreliable supply chains[1]. Solutions like cold storage facilities, and links to a wider pool of prospective buyers were inaccessible or unaffordable for most farmers. SokoFresh (https://sokofresh.co.ke/), a Kenyan company incorporated in 2019, set up "first-mile" post harvest management operations, to address key gaps in aggregation, cold-chain access, logistics, and market linkage.

The company provided solar powered cold storage facilities with a maximum capacity of five tonnes. The storage unit was mobile, and could store banana, avocado, French beans and flowers. The unit had solar panels of 2.5 - 3.0 kW and used thermal storage plates instead of batteries, which stored energy for over 30 hours.[2] These units were manufactured and supplied by Ecozen Solutions (https://www.ecozensolutions.com/) from India.

SokoFresh provided cold storage facilities under two business models. First was a "pay-as-you-store" model, where farmers could use the cold storage units on a cost-per-kg basis. Under this model, the company also provided harvesting and handling teams along with market linkage services. SokoFresh would pay the farmers as soon as the produce reached the cold storage, and arranged for onward sale of the produce. The second model leased cold rooms to aggregators such as farmer cooperatives, wholesalers, and exporters. SokoFresh offered training and technical support to these customers[3].

The company won the prestigious Ashden award in 2022. As of February 2023, SokoFresh had impacted and estimated 8,000 smallholder farmers, 97% of whom had an increased income of 20% upon using the company's services.[4]

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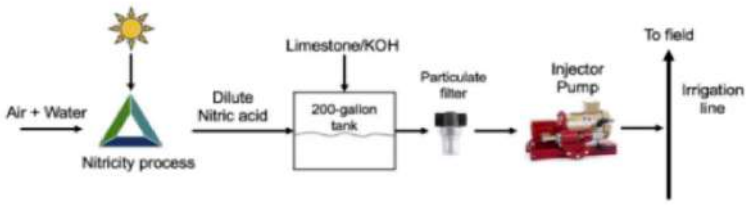
Nitricity Solar Fertilizer – Pulling Fertilizer Out Of Thin Air

Nitrogen is one of the most important macronutrients required for plant growth. It is also a component of the chlorophyll molecule, which enables the plant to capture energy from the sun for photosynthesis, driving grain yield. Farmers use ammonia and other nitrogen-based fertilizers to get a higher crop yield. As of 2017, it was estimated that more than 20 kg of ammonia was produced and used globally as fertilizer every year on average per person. Further, 3-5% of the world's natural gas was used for producing hydrogen feedstock for ammonia production, and 1% of the global energy use went into ammonia production[1].

In 2021, Nitricity (https://www.nitricity.co/), a US based company, set up year-long pilot project to use solar energy to extract nitrogen directly from air and use it as a fertilizer. The company installed a 16 panel ground-mounted array at a farm in Fresno, California, with a maximum power of 2.4kW. The array was connected to 200 gallon tank, where the nitrogen from air was captured and converted to nitric acid. The tank was connected to a sub-surface irrigation system used to fertigate a tomato crop. The volume and quantity of tomatoes produced on the plot of land fertigated using Nitricity's system were similar to the tomatoes on the control plot that received a standard, industrially produced nitrogen fertilizer[2].

Further, Nitricity's process avoided the production of CO2 normally seen as a part of industrial ammonia production. The process also eliminated the need for transportation. The company signed a USD 5.0 million deal with a wheat producer to conduct the next stage of trial.[3]



Nitricity's fertigation system

Source: Weaver John F (2022) "Pulling fertilizer out of thin air with solar power," PV Magazine, 18 January, https://pv-magazine-usa.com/2022/01/18/pulling-fertilizer-out-of-thin-air-with-solar-power/, last accessed 23 February 2023)

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Impact Of Single-Axis Agrivoltaics Systems On Non-Irrigated Grassland

The growing population, especially within developing countries has led to heightened competition for available land between the agriculture and energy sectors in general and between agriculture and solar energy in particular. Access to large tracts of contiguous land for solar farms is becoming increasingly difficult. The land related challenges could be ameliorated using the concept of agrivoltaics or co-developing the same area of land for both solar PV power as well as for conventional agriculture.

By 2023, several countries around the world have begun to implement agrivoltaic systems on their farm lands. Several researchers were working on the impact of environmental factors such as rain and temperature on such agrivoltaic lands and the output. Jack's Solar Garden (https://www.jackssolargarden.com/) was one of the largest commercially active research sites for agrivoltaics in the USA. The site received nearly 1,000 visitors every year; visitors have sought to learn about and experience the microclimates created under solar panels[1].

In 2022, Jack's Solar Garden worked with a team of scientists from the Colorado State University (https://www.colostate.edu/), USA, to investigate the functioning of agrivoltaic systems mounted on single axis trackers, the redistribution of rainfall and light, and the consequent impact of such redistribution on the non-irrigated grasslands. Jack's Solar Garden had 3,200 solar panels of 380W each that were mounted on single-axis trackers that tracked the sun from East to West. One third of these panels were at a height of two meters from the ground, and the remaining were installed at 1.8 m above the ground.

The team found that consequent to the agri-voltaic installation, two to five times the normal precipitation could be focused at one location, depending on the orientation of the panel at the time. Colorado had a semi-arid climate, with heavier rainfalls and higher temperatures [of about 35°C] in the afternoons. Since the panels faced west at the time of day, the west-ward edge of the array received higher rain water compared to the east-ward edge of the array. The researchers expected the westward edge to show more vegetation compared to the east, but found that the east-ward edge of the array showed higher plant growth. Moisture sensors placed on the land below indicated that a narrow strip of 40cm to 60 cm from the drip-edges benefitted the most from increased soil moisture. The growth of vegetation was also influenced by the ambient temperature of the region, with best yields seen at temperatures below 30°C. Further, the shade from the solar panels increased photosynthesis from the plants under the panels[2].

The team hoped that these studies would help increase productivity of land during periods of scanty rainfall and drought, and also to help restore land that might have been degraded by overgrazing, unsustainable agriculture practices, and water scarcity.

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Abellon Solar Agrivoltaic Project in India

According to certain independent estimates, the total energy consumption of the agricultural sector in India was close to eight percent of the total energy consumed in the country, and this proportion was expected to increase with the passage of time as agriculture operations were progressively mechanized[1]. Agrivoltaics – the installation of [elevated] PV arrays on farm land – was expected to provide a solution that would help meet the growing demand. By 2021, 15 Agrivoltaic pilot projects of varying capacities were tested by various stakeholders across the country and across a range of agro-climatic conditions. The largest among them at the time was a 3.0MW Agrivoltaic plant installed by Abellon Solar (http://www.abellonsolar.com/), in Aravali district, Gujarat.

The team from Abellon Solar installed conventional ground mounted polycrystalline PV panels of capacities 230W, 240W, and 280W in the region, over an area of 7.08 ha of land. Henna plants encircled the solar plant as secondary wind braking barrier. The plant's electricity output was 423 kWp/ha. The electricity generated was supplied to the state's grid under the Gujarat Solar Policy, with a FiT of 0.23 USD/kWp [2].

The semi-arid Aravali district was located in the foothills of Aravalli mountain range, experienced temperature that ranged 15°C and 45°C over the average year, and received 690mm of annual rainfall. The soil in this region was rocky, porous, and was known for low water retention which made it less suitable for cultivation of cereal crops. In addition to the henna, the team decided to grow vegetables such as bottle-gourd and okra, fruits like watermelon and spices like turmeric, ginger, and chilli peppers in the space under the solar arrays. The modules had to be manually cleaned and the water used for cleaning the modules, also irrigated the plants under modules. The project produced 24–34 tones/hectare/yr of agriculture produce by reusing 7.80 million liters of water per year and captured 250 tons of CO2 in the vegetables. The project also provided employment to 215 people from four villages including 156 women[3].

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Abellon Solar, Gujurat

PV Potential for Water Pumping

Water scarcity in Africa was predicted to reach dangerously high levels by 2025, when approximately 230 million Africans were projected to face water shortages, and up to 460 million people were projected to live in water-stressed areas across the continent[1]. According to the World Bank, well-managed water resources – both surface and underground resources – could help supply Africa's present and future needs[2]. Governments in Africa hoped that solar powered pumps with innovative monitoring technologies could help address issues surrounding water conservation and equitable access. For instance, Morocco had installed more than 100,000 solar pumps by 2020, while Egypt implemented several desert irrigation programs involving solar technology[3]. With several countries across Africa expressing interest in PV Water Pumping Systems (PVWPS), scientists from universities in France, the United Kingdom, and the United States, worked to develop a mathematical model to simulate the potential PVWPS systems for various locations in Africa.

The team developed the model using sub-hourly irradiance data rather than monthly averages (https://doi.org/10.5281/zenodo.7520120), which enabled the system to offer more precise estimates and to predict critical days of the year for which the volume of pumped water may be very low. With such information at hand, the residents impacted by low output could try and plan accordingly and plan their consumption patterns. The team used the irradiance data of the year 2020 for the study. The system also used realistic geological constraints on the depth of pumping. The researchers investigated the amount of groundwater that could be pumped by optimally tilted PV systems of 100 W, 1,000 W, and 3,000 W sizes: 1,000 W was the average size of a PVWPS for domestic water access, and 3,000 W was the typical array size for irrigation[4].

The team found that the larger PV systems did not always pump the design-specified volume of water. The 3,000 W system did not yield higher pumped water volumes in 27% of the locations, due to a phenomenon known as "groundwater drawdown," when the groundwater level dropped due to intensive water pumping, forcing the system to stop pumping. For instance, in Ivory Coast, the average daily pumped volume for a typical 1,000 W system was 15.9 cubic meters and only 5.2 cubic meters for the median 3,000 W system. The best potential for a 1,000 W PVWPS system was in Central Africa, with an average daily pumped volume of 100 cubic meters. The team also found that PVWPS served people better than hand-pumps for locations where groundwater was deeper than 50m. The team hoped that the model would help identify target areas for large-scale PV pumping programs [4].

The most important part of the code is available at the following link: https://doi.org/10.5281/zenodo.7520120. The available code helps compute the pumped volume from the irradiance on the photovoltaic modules, using the developed model.
For queries contact simon.meunier@centralesupelec.fr.

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For queries: simon.meunier@centralesupelec.fr.

Integrated Aquaculture Recirculation System (IARS) Supported by Solar Energy, Camarones Town

In 2018, Chile produced 3.7 million tonnes of fish valued at USD 11,544.1 million: 91% of this value came from aquaculture and 9% from fisheries[1]. Given such performance, in year 2019, Chile was one of the top 10 aquaculture producers in the world[2]. Appreciating the importance of the sector to Chile's economy, Chilean Solar Research Center, sought to investigate the possible uses of solar energy in aquaculture. The organization decided to implement a pilot project at a freshwater fish farm in Camarones valley[3].

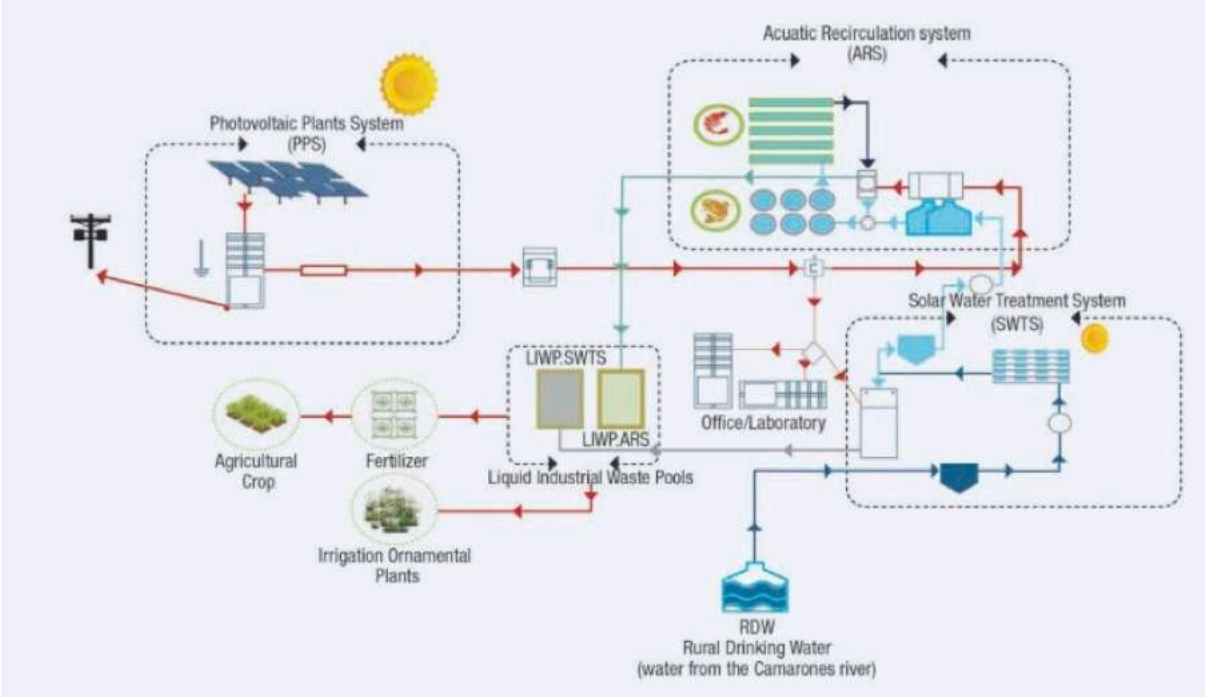
Camarones Valley was a village in the Arica and Parinacota Region, Chile, located 1,000m above sea level. This village was characterized by arid weather conditions, with almost zero annual rainfall, an average temperature of 18 °C, and solar radiation of 2,957 kWh m^2 per year. The Camarones River traversed through the valley had water with dissolved solids, arsenic, and boron, in quantities of 1500 mg L−1, 1 mg L−1, and 10 mg L−1, respectively. The dissolved arsenic levels were 100 times the levels recommended by the World Health Organizationfor products from aquaculture. Since fish was very sensitive to dissolved arsenic, the level of dissolved arsenic in these waters had to be reduced for successful fish farming. In addition, aquaculture ponds needed a recirculation system to be implemented to prevent a build-up of unionized ammonia in the water.[4]

Over a period of three years from 2018 to 2020, the pilot project involved implementing an Integrated Aquaculture Recirculation System (IARS) at a fish farm. The farm mainly produced rainbow trout and river shrimp. There were three main components to the IARS:

Component 1: A solar water treatment plant – the plant had a water pre-treatment system, where organic material (leaves, branches, among others), garbage, and other foreign bodies that could block the system's pipes, was extracted and removed. The water then passed through cylindrical and parabolic concentrating solar collector, composed of 16 numbers of 5 cm x 150 cm interconnected glass pipes placed parallel to each other. Through this plant, it was possible to reduce arsenic concentrations to within 0.03 and 0.05 mg per liter, removing 95% of the arsenic present in the natural waters of the Camarones River.

Component 2: Aquaculture Recirculation System – it was a terrestrial aquaculture recirculation system, where the water was partially reused for the simultaneous farming of shrimp (20 tanks) and trout (6 tanks). This system also had two accumulation tanks, placed at a height of 2.0 m to take advantage of the water fall by gravity. The arsenic-free water from the solar water treatment plant was to flow through these accumulation tanks into the fish tanks, and the flow from a height simulated the river current, and helped with oxygenation of the fish tanks.

Component 3: Photovoltaic Plant – a plant consisting of 80 polycrystalline silicon PV modules of 295W each was installed, [at 19°0'37.11'' S, 69°51'25.88'' W], and at an elevation of 719 m above sea level, a tilt of 7°. The plant could generate 2,620 kWh of electricity while the daily consumption of the fish farm was 1,355 kWh per day. The plant could sell the excess to the local electricity company under law 20.571 regarding the distributed generation or net billing of the Chilean Ministry of Energy. A back-up generator was also installed for emergencies. The schematic layout of the PV plant and Recirculation project is presented.



Integrated Aquaculture Recirculation System (IARS)
Source: Cornejo-Ponce Lorena et al (2020) "Integrated Aquaculture Recirculation System (IARS) Supported by Solar Energy as a Circular Economy Alternative for Resilient Communities in Arid/Semi-Arid Zones in Southern South America: A Case Study in the Camarones Town," Water, 12(12), 3469; https://doi.org/10.3390/w12123469, last accessed 3 March 2023

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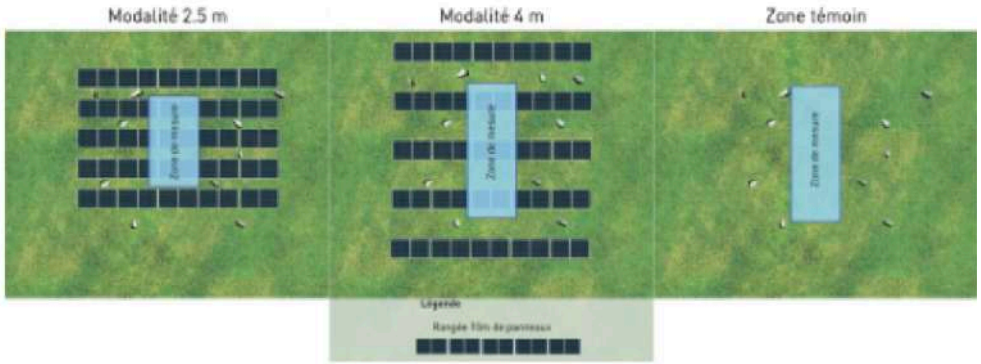
Agrivoltaics for Fodder

In 2021, French energy company Valeco (https://www.groupevaleco.com/), launched a pilot agrivoltaic project to study the impact of solar panels on quantity and quality of fodder growth, and the behavior of suckler sheep in an agrivoltaic environment[1]. The project was undertaken in partnership with the Charolles Ovine Pole, made up of the Charolles Agricultural High School (EPLEFPA of FontainesSud Bourgogne: https://www.epl-fontaines.fr/les-centres/lycee-de-charolles) and the Saône-et-Loire Chamber of Agriculture (https://chambres-agriculture.fr/).

The pilot installation consisted of three zones. In the first zone, the module rows were placed at a distance of 2.5m from each other, in the second zone, the distance between rows was set at 4.0m, and the third zone was designated a control zone with no arrays. Based on a year-long observation, the team from Valeco noticed that the shade from the panels protected the meadow from extreme weather conditions, and "smoothened the annual curve of grass growth." Both the quality and quantity of fodder under the panels was better compared to the control zone. It was also seen that the grass growth was more in winter and summer, than in the spring season. In addition, the grass under the panels had "little or no ears" which made it more digestible for the animals, while allowing them to maintain good nutritional quality for longer. The sheep also took advantage of the protection offered by the panels in summer when they sought shelter from the sun's heat or from rain[2].

The pilot also revealed that there was better distribution of rainfall under the panels than in the control zone. Valeco planned to explore the configurations in greater detail, with different row configurations, and crop variety.



Source: Deboutte Gwenaelle (2023) "Agrivoltaism: Valeco publishes results on fodder production in connection with sheep farming," PV Magazine, 9 March, https://www.pv-magazine.fr/2023/03/09/agrivoltaisme-valeco-publie-des-resultats-sur-la-production-fourragere-en-lien-avec-lelevage-ovin/, last accessed 14 March 2023.

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PV Potential for Water Pumping

Water scarcity in Africa was predicted to reach dangerously high levels by 2025, when approximately 230 million Africans facing were projected to face water shortages, and up to 460 million people were projected to live in water-stressed areas[1] across the continent[1]. According to the World Bank, well-managed water resources – both surface and underground resources – could help supply Africa's present and future needs[2]. Governments in Africa hoped that solar powered pumps with innovative monitoring technologies could help address issues surrounding water conservation and equitable access. For instance, Morocco had installed more than 100,000 solar pumps by year 2020, while Egypt implemented several desert irrigation programs involving solar technology[3]. With several countries across Africa expressing interest in PV water pumping systems (PVWPS), scientists from universities in France, the United Kingdom, and the United States, worked to develop a mathematical model to simulate the potential PVWPS systems for various locations in Africa.

The team developed the model using sub-hourly irradiance data rather than monthly averages (https://doi.org/10.5281/zenodo.7520120), which enabled the system to offer more precise estimates and to predict critical days of the year for which the volume of pumped water may be very low. With such information at hand, the residents impacted by low output could try and plan accordingly and plan their consumption patterns. The team used the irradiance data of the year 2020 for the study. The system also used realistic geological constraints on the depth of pumping. The researchers investigated the amount of groundwater that could be pumped by optimally tilted PV systems of 100 W, 1,000 W, and 3,000 W sizes: 1,000 W was the average size of a PVWPS for domestic water access, and 3,000 W was the typical array size for irrigation[4].

The team found that the larger PV systems did not always pump the design-specified volume of water. The 3,000 W system did not yield higher pumped water volumes in 27% of the locations, due to a phenomenon known as "groundwater drawdown," when the groundwater level dropped due to intensive water pumping, forcing the system to stop pumping. For instance, in Ivory Coast, the average daily pumped volume for a typical 1,000 W system was 15.9 cubic meters and only 5.2 cubic meters for the median 3,000 W system. The best potential for a 1,000 W PVWPS system was in Central Africa, with an average daily pumped volume of 100 cubic meters. The team also found that PVWPS served people better than hand-pumps for locations where groundwater was deeper than 50m. The team hoped that the model would help identify target areas for large-scale PV pumping programs [4].

The most important part of the code is available at the following link: https://doi.org/10.5281/zenodo.7520120. The available code helps compute the pumped volume from the irradiance on the photovoltaic modules, using the developed model.
For queries contact simon.meunier@centralesupelec.fr.

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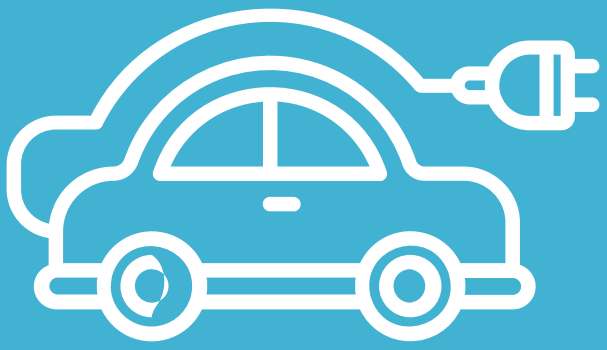

4.

Scaling Solar E-Mobility And Storage

4

SCALING SOLAR E-MOBILITY AND STORAGE

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4. Scaling Solar E-Mobility And Storage

World's First Never Charge Solar Vehicle - A Futuristic Vehicle

Electric Vehicles are a sustainable solution to vehicles on fuel, and they are on a boom these days. Many car companies have now started introducing a range under the EV category. Such an initiative of electric cars was also done back in 2007 by Aptera Motors in the USA and was much ahead of its time. This is a study of Aptera's journey in the EV and solar-powered automobile industry.

Aptera Motors was founded in 2006 by Steve Fambro and Chris Anthony to build an "ultra-efficient and futuristic" electric car. The car they developed had three wheels, was relatively light in weight, and was fitted with solar panels on the top. The company received USD 2.75 million (2.61 million euros) from Google's philanthropic arm and resources from the business incubator "Idealab." In September 2008, the company hired a new executive team, including a new CEO, Paul Wilbur. By the end of 2008, about 4,000 customers had paid deposits of USD 500 each to book an Aptera [1]. However, the company faced many challenges before the car was launched.

A few months after the new executive team took over, the US Department of Energy (DoE) rejected the company's application for the Advanced Technology Vehicles Manufacturing (ATVM) loan programme since the programme did not define any vehicle with fewer than four wheels as a car. The new CEO decided to redesign the Aptera 2e to adhere to all the safety standards of a 4-wheeler in hopes that the DoE would reconsider the company's application. Simultaneously, the company decided to work on designing a 4-wheeler (4e). However, the company had to wait for nearly a year, until December 2009, for the DoE to change its definition of a car and categorise three-wheelers as cars. The three-wheeler car still had to adhere to the National Highway Traffic Safety Administration safety standards, which specified the deployment of multiple airbags and various crash tests and imposed other such requirements.

The company resubmitted its application to the DoE in January 2010 for the 2e and the 4e designs. By January 2010, the company had still not heard from the DoE and decided to focus only on the 4e technology, believing that the 4e had a better chance of getting DoE approval. In September 2011, the DoE issued a conditional letter of commitment for a USD 150 million (143 million Euro) loan, provided Aptera was able to raise USD 80 million (76 million Euro) through other sources. However, the company was unable to raise the required funding and hence did not receive the loan from ATVM. The stakeholders then decided to close the company in December 2011 and auction off all its assets. A Chinese automaker, Zhejiang Jonway, won most of Aptera's assets, including intellectual property, equipment, and the vehicles in stock. Zhejiang Jonway announced that it would launch a gas version of the car in 2013 under an independent company called Aptera USA [2]. However, it is unclear if Aptera USA was ever incorporated or if such a variant was launched.

In 2019, with the auto industry looking to go green, solar-powered cars were more real and viable. In the intervening period, electric batteries, solar cells and module prices had fallen sharply and tremendous progress had been achieved in mobile communication technology. In addition to this, advancements in computer simulation speeded up the design process. The founders Anthony and Fambro decided that the time was appropriate to try and bring their original solar-powered electric vehicle to the market. Moreover, the Chinese company had not filed to take over Aptera's IP, which enabled the original owners to get back to their car design easily. The new design used solar panels that were twice as efficient as the ones used in the original design, and the new edition had a range of 45 miles per day. The car with a 700Wp solar array and 100kWh battery pack could seat two passengers and offered a 1000-mile range. Additional solar arrays could be provided to Aptera's hood and rear hatch for up to 38km of additional free solar charging per day [3]. The company called the new design "the world's first never-charge solar vehicle." The new car also had a touchscreen dashboard and "in-wheel motor" to save space [4].

The company learnt from experience and decided to focus on multiple sources of funding rather than wait for ATVM loan approval. Aptera raised USD 200,000 (190126 Euro) from crowdfunding site WeFunder, USD 4.0 million (3.8 Euro) from series-A private funding, and another USD 50 million (47.5 million Euro) after filing with the Securities and Exchange Commission with a public-private mix [5]. By December 2020, the company began taking preorders. The lower-end model of the car was priced at USD26,000(~24,714 Euro), and the higher-end model was USD 50,000 (~47,531 Euro). The first batch of 330 planned vehicles got booked within 24 hours of the launch of the booking window, and an additional 7,500 people put down deposits for the car in the following days.

The car's futuristic design and long-range, combined with the rapid acceleration from rest to 60mph in 3.5 seconds and the projected top speed of 110mph seemed to have drawn potential consumers. The Aptera product is also positioned as a delivery vehicle or a postal service vehicle, which does not travel very far but spends a lot of time idling, and hence could be charged easily[6]. The company estimated that by the end of year-2022, about 10,000 units could be sold at margins of about 35%. The company has also projected that relative to a business-as-usual baseline, each such car could curtail the emission of 14,000 pounds of CO2, subject to certain assumptions relating to use patterns.

Source: Photo by Hahn Jane (2021) "*It looks like batmobile, works on solar energy, and could be the future of cars*," Washington Post, February 25, https://www.washingtonpost.com/climate-solutions/interactive/2021/solar-car/, last accessed June 10, 2022

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Second-Life Battery - A More Sustainable Solution To The Lithium-Ion Batteries

Lithium-ion batteries are predominantly used in mobile phones and electric vehicles (EVs). Second-life batteries used for this purpose are said to be more environmental friendly than first-life batteries. Many companies thus came up with battery storage systems.

In tandem with the rapid global deployment of Renewable Energy capacity in general, and solar PV capacity in particular, lithium-ion battery technology has evolved rapidly and as of year-2022, was among the dominant storage options used to help electricity grids ensure a reliable supply of renewable energy [1]. It is estimated that 6.7 million pure EVs were operational worldwide as of June 2022, and this number is expected to rise to 34.7 million by 2030.

Partially degraded lithium-ion batteries are considered unsuited for EVs but could be used for stationary applications as a part of a battery energy storage system for about ten years. Providing a second life to such batteries is projected to save an additional 450 tonnes of CO2e per MWh relative to using first-life lithium-ion batteries [2]. Given the business opportunity presented by second-life batteries, several companies entered the market to repurpose used electric vehicle batteries in commercial battery storage systems for mobile and stationary applications alike.

Connected Energy, a second-life battery storage company headquartered in the UK, developed an E-STOR energy storage system that enables thousands of batteries at various levels of degradation to be aggregated, controlled, and reused as part of a single energy storage system. The company has set up sixteen operational systems across Europe, including Belgium, Germany, the Netherlands, and the UK. The company's largest unit is installed at Cranfield University in Bedfordshire, England. The system worked in tandem with the state's grid, solar farms, and air source heat pump to reduce reliance on the gas combined-heat-and-power (CHP) system. In 2022, the company received a total funding of USD 18.4 million (€ 17.43 million) from the Hinduja Group, Caterpillar Venture Capital, Mercuria, Our Crowd, and Volvo Energy. With this funding, the company plans to scale operations and meet energy storage demand across locations. The company also plans to develop a large-scale M-STOR system with a capacity of 20 MW–40 MW and to set up supply links with multiple OEMs to provide long-term operational services to customers [3].

At about the same time, and independent of Connected Energy, Nunam, which means "future" in Sanskrit, an Indo-German start-up based in Bangalore, India, experimented with old mobile phone batteries and retired laptop batteries, which were to be converted into new mobile energy storage and charging station battery packs. These refurbished battery packs, about the size of a car battery, weighed 2kg and were distributed to vegetable vendors as a part of a pilot project. The battery is large enough to support an LED light for 6 hours, and vegetable vendors used it to light up their stands at night [4].

In 2020, German Car maker Audi AG's foundation, Audi Environmental Foundation announced support for the battery start-up Nunam, though the parties involved did not disclose details of the funding support provided for the battery-reuse operations of Nunam [5]. As a part of such collaboration, Nunam would deploy Audi's e-tron's depleted batteries in e-rickshaws. The startup developed three prototypes in collaboration with the training team at Audi, and these e-rickshaws running on refurbished battery packs were scheduled to commence service on Indian roads under a pilot project in early 2023. Simultaneously, Nunam also developed a solar-powered EV charging station to charge the e-rickshaw batteries [6].

NUNAM deploys Audi e-tron's used batteries in e-rickshaws
Source: Energy News, ET EnergyWorld

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Solar Powered Bus in Australia

As of 2019, the transport sector alone was responsible for 18.9% of total carbon emissions in Australia: widespread utilization of electric vehicles (EVs) was believed to be one of the more effective ways to help lower emissions from the transportation sector. The Australian government had, therefore, offered support for replacing the fleet of buses in the country with more environmentally friendly options.

ABB Electrification (https://new.abb.com/about/our-businesses/electrification), a Swiss conglomerate experienced in e-mobility worked with public transport service provider Transdev Australasia (https://www.transdev.com.au/) and Australian bus body manufacturer Volgren (http://volgren.com.au/) to develop a charging solution that would enable zero-emission transportation along the bus routes. The buses were manufactured at Volgren's factory in Dandenong, near Melbourne, in turn, sourcing component parts from about one hundred suppliers. The chassis and the 348 kW lithium phosphate battery were sourced from Chinese company BYD.

ABB and Transdev worked together to provide an integrated grid-to-plug solution to enable the transition to an all-electric fleet. ABB provided this support with the high-power chargers that were part of the company's portfolio of digital solutions. The chargers provided the advantages of cloud-connectivity that allowed network operators to monitor round-the-clock availability of the charging infrastructure and to monitor and manage charging operations remotely and in real time: ultimately aimed to maximize charger availability. ABB provided EV charging stations and critical EV charging infrastructure components, such as substations, energy storage systems and eco-friendly switchgear. The technologies were modular and the EV charging stations could be scaled up in the future to meet growing demand [1].

The electric bus thus produced was fully powered by 'harvested' solar energy from the 250 solar panels installed at Transdev's Capalaba depot: the system was designed to generate more than 159,000 kWh annually. The bus was part of a 12-month trial starting in late 2020, estimated to cost AUD 3.30 million (funded by Transdev), to study the feasibility of such electric options as a replacement for the existing fossil fuel-powered and hybrid vehicles[2]. It was estimated that the energy harvested from the PV system at the depot would be sufficient to operate up to three electric vehicles from the Capalaba depot.

The initial trials reported performance comparable to similarly-sized diesel powered buses. The replacement of fossil fuel powered buses with zero-emission buses in Brisbane was slated to reap significant benefits for commuters, for fleet operators, for the health sector as well as for the environment. The switch to electric buses in Brisbane was designed to help accelerate the introduction of emission-free transportation across the country by creating an environmentally friendly bus fleet supported by a standardized, fast, efficient and reliable charging system.

As buses followed fixed schedules and routes, drive range limitations were not critical. The anchoring decision was the bus charging strategy, as efficient recharging had a direct impact on bus operating costs. Various aspects of the Capalaba depot were evaluated prior to submitting a charging proposal, including analyses of vehicle specifications, the numbers of vehicles being considered at the time and for the future, among other things. ABB deployed the e-bus-ready Terra 124 dual-outlet fast-charging stations that could provide a single 120 kW charge – or simultaneously charge two buses at 60 kW within five hours – and up to a 300 km range per charge.

In year 2021, Transdev Australasia launched Australia's first 100% sustainably powered full-sized electric bus on the roads in Queensland State. The state appeared to be a logical choice for introducing solar-powered buses, as Queensland enjoyed an average of 280 days of sunshine per year. Transdev had significant experience in the operation of zero emissions electric and hydrogen powered fleet, with more than 1,400 vehicles in operation globally[3]. The company had contributed about 100 buses to Transdev Australasia's fleet[4].

The 39-seater e-bus, [with the capacity to transport 61 passengers in all] had been plying throughout Brisbane and the Redlands, since early 2021, under a two-year partnership with the Queensland Government[5]. It was part of Brisbane's free "City-Loop" service and came with features such as USB charging ports and signs that informed passengers of the distance to the upcoming stop[6].

Solar-powered bus in Australia
Source: unkown

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VIPV Kit- A Vehicle Integrated Solar Kit

The transport sector has been a significant source of greenhouse gas (GHG) emissions across countries for several decades due to the widespread use of internal combustion engine (ICE) vehicles and fossil fuels to power such vehicles. With a view to curtailing emissions, countries have started focusing on transitioning from ICE vehicles to electric vehicles. First to curtail the combustion of fossil fuels and second lower emissions through using cleaner sources of generation to power such electric vehicles.

Among others, Vehicle-Integrated Photovoltaics (VIPV) technologies that integrate PV modules with vehicles are believed to possess the potential to power electric vehicles sustainably and thereby avoid GHG emissions that might otherwise emanate from fossil fuel use. In recent years, several companies have developed VIPV solutions for specific applications.

The French Alternative Energies and Atomic Commission (Commissariat à lénergie atomique et aux énergies alternatives) developed a VIPV kit that can be used with any electric vehicle to recharge the onboard batteries. The VIPV kit, which includes a 145Wp PV panel, could be deployed on the roof of the vehicle using a magnetic rear panel and connected to the vehicle's traction battery. It is estimated that the kit could increase the range of the vehicle by 800km per year and could reduce the frequency of charging of the EV by 14%. It also has a battery and a micro-inverter that could be used to export the stored energy to the grid when the battery is fully charged (vehicle-to-grid or "V2G").

The kit is tested on the Renault Zoé model and the range of the vehicle increases by an average of 4km per day on sunny days. Since the kit is non-intrusive, it could be adapted to work alongside all or most EV models.

VPIPV kit, Solar Innova
Source: unknown

Driv'eco Parasol – A 100% Autonomous Charging Station

Corsica is considered an ideal market to test electric vehicles and ancillary infrastructure, given that the size of the island was comparable with the range of most electric car models. Corsica Sole, a solar energy company received a total investment of €2,317,528 from the European Regional Development Fund, of which €959,339 was a specific contribution to the "Corsica operational program" to be implemented over the time 2007-2013. The Corsica operational program involves installing 70 solar-powered charging stations across the island [1].

Corsica Sole established DRIV'ECO in 2010 to focus exclusively on solar mobility solutions[2]. DRIV'ECO worked in collaboration with the French Atomic Energy Commission (CEA) to develop the concept of a solar charging station that guarantees 100% [solar-powered] charging 24 hours a day throughout the year. PARASOL, as the charging station is named, could produce, store, and distribute electricity. The stations are powered by 88 solar panels installed on the parasol's 150-square-metre roof. PARASOL could charge up to eight cars at a time and is compatible with all types of electric and hybrid rechargeable vehicles at the time in Corsica. Excess energy is stored in batteries to enable car charging during the night and during unfavourable weather conditions. Surplus energy from the network of charging stations could also be fed into the electricity grid.

PARASOL charging stations are also interconnected through a smart grid, designed in partnership with CEA-Tech and the National Institute of Solar Energy (INES), that controls charging to make consumption and production simultaneously possible. When energy at one of the PARASOL stations is insufficient to charge a vehicle, the station in deficit could request energy produced and stored at another PARASOL station on the network. Intelligent and real-time energy management is thus made possible. The first PARASOL was put into service on March 14, 2016, in Bastia, and the second was inaugurated on May 11, 2016, in Ajaccio. It is possible to cross Corsica on electric cars operating exclusively on solar energy, with more such installations on the island.

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Driv'eco Parasol
Source: unkown

Vehicle To Home (V2H) Systems By Panasonic

Interest in identifying alternatives to nuclear energy in general and RE applications, including Vehicle-to-Home (V2H) systems particularly, grew in Japan after the Fukushima disaster in 2011. A "V2H-capable" vehicle—the battery, in essence—connected to a solar PV-equipped home could enable the fully off-grid operation to power the home or other isolated load as a convenient, safe, and powerful backup generator[1]. In 2022 Panasonic Corporation Electric Works company of Japan introduced a V2H system branded the "Eneplat."

The Eneplat system is integrated with Panasonic's "AiSEG2" device, which connects various home appliances in a solar PV-equipped house. The AiSEG2 device combines data relating to weather, solar irradiation, and the home's diurnal power usage forecasts to manage the charging and discharging of storage batteries within the vehicles. The Eneplat integrates the AiSEG2 system has a rated output of 6.0 kW and could be charged with a maximum PV power output of 9 kW[2]. The system measures1,250 mm x 420 mm x 210 mm, weighs around 60 kg and fits into a limited-space parking lot[3]. The system is priced at JPY 1.76 million (€12,410).

The company claims that the system increases the "self-consumption rate of homes with rooftop PV and storage from about 50% to approximately 90%" of demand. The company plans to install the V2H power storage system in detached houses in Fujisawa Sustainable Smart Town in 2023.

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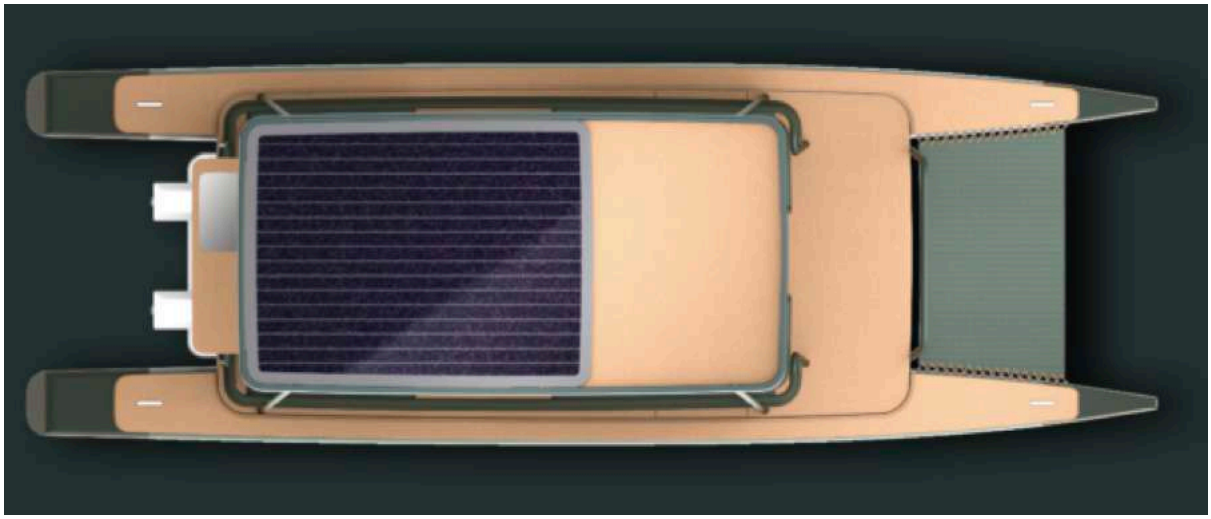
V2H Systems - Panasonic

A Solar PV Integrated Camper Boat

The POL Lux catamaran boat designed and built in Sweden is equipped with dual electric motors and a solar PV array integrated canopy. The PV array alone can drive the onboard motors to propel the 8-foot wide and 25-foot long boat, with a maximum of 13 passengers on board, at about 4 knots (7.4 km per hour) [1].

On a full charge, the 18kWh battery – powered by the PV array as well as charged from sources at the harbour – can drive the craft to travel for about 70 miles (112 km) at a maximum speed of 13 miles per hour (21 km per hour) and a cruising speed of 8 miles per hour (~12.9 km per hour). The quiet dual motors offer a more serene exploration experience for the passengers onboard. The modular components allow for multiple configurations and flexible use of the available space.

The "logical Scandinavian design" conceived by naval architect Gustav Larsson is supported by the zero-emissions electric drive, the modular deck, and a deployable tent for overnight stays. The solar PV integrated camper is positioned as an alternative to kayaking or canoe camping and as an overnight explorer, river-cruising day boat, daytime picnic party boat or even as a short-distance cargo vessel [2]. POL has priced the boat at USD 135,000 (~€ 135,000), and by December 2022, the company had commenced accepting waitlist applications from potential customers.



Solar electric camper catamaran
Image source - PV magazine International

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Vehicle to Grid (V2G) Trials By Octopus Energy In UK

Since the early 1990s, technologists have been researching the possibility of vehicle-to-grid (V2G) systems, where electric vehicles (EVs) could export the stored energy back to the grid through a bi-directional charging system. Such energy exports could help operate the loads connected to the grid [1]. Over the years, and after several attempts, several automotive manufacturers succeeded in developing "smart" bi-directional charging systems that made V2G a reality. EVs with V2G systems could help balance the grid loads by charging at night when demand is low and then by sending the power back to the grid when demand is high. Given its potential, several automotive manufacturers, like Nissan, Hyundai, Volkswagen, etc., have committed to including V2G technology in their new electric car models, further emphasising the potential of the technology.

In 2022, Octopus Energy, a UK-based energy supplier, conducted a trial with V2G technology. The trial tested the National Grid ESO's Balancing Mechanism, which was used to balance Great Britain's electricity system in real time. Twenty electric cars from participating customers were charged and discharged during the trial. The test demonstrated that EVs could receive a direct signal from the ESO and could contribute to "balancing the system."

Based on the results of the trial, the company estimated that "an hour of a million electric cars exporting to the grid could generate the same amount of power as 5,500 onshore wind turbines." Further, when these results were extrapolated across a whole year, it was seen that EV owners could realise a profit of around £62 million (€70 million) in one year. It is therefore concluded that in the future, consumers could play a direct role in balancing the national transmission system through their electric vehicles [2].

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Octopus energy V2G
Source: Future transport news

Carbon Fiber PV Module For Boats - A More Efficient Solution

In 2017, Rick Retzlaff, a mechanical engineer and university professor from Canada, went on a month-long trip on a solar-powered boat called the Puget Sound. Even though the trip was successful, the professor found that the solar solutions available for boats were flat, heavy, and inflexible. Flexible solar panels on the market were too fragile and had to be pasted onto boats. Further, such flexible modules presented the risk of coming undone during long journeys.

Drawing on his experience with working on aerospace composites and battery electric powered systems, Prof. Retzlaff developed a carbon fibre panel that was lightweight yet structurally rigid. He teamed up with other experts to launch the company- LightLeaf Solar[1]. LightLeaf Solar panels use monocrystalline solar cells supplied by SunPower-Maxeon, which were more efficient compared to conventional solar cells available at the time[2].

Each LightLeaf solar panel, called "SeaLeaf," has a rigid carbon-fibre foam foundation in place of the glass employed on mainstream panels. The SeaLeaf incorporates 32 SunPower-Maxeon GIII Premium ME3 monocrystalline solar cells rated at 25.1% efficiency. The SeaLeaf module measures 1,073 mm x 575 mm, has a thickness of 9 mm and weighs 2.5 kg each. It is curved and includes two quick-release clamps that are 50 cm apart. The 110-watt SeaLeaf module can be attached to the one-inch rail of a boat and could rotate 180 degrees to track the sun. These panels can be mounted onto the boat during travel and removed when parked. Each panel costs USD 650 (~€ 610) and is offered with a three-year workmanship warranty and a five-year power output warranty[3].

LightLeaf Solar has also developed detachable, mobile, lightweight solar panels for other applications: "DropLeaf" for large trailers (USD 625),"uLeaf" (USD 505) for long off-grid stays and other rugged outdoor use,"gLeaf" (USD 40) for other projects like the lid of a storage box, the roof of a micro camper etc[4].

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Source: unknown

Solar Carports - Solar Arrays On Parking Lot Canopies

In 2022, it was estimated that the USA alone had as many as 2 billion parking spots, and each one was at least 18 feet x 8 feet in measurement [1]. It meant that each parking spot could hold six 480W Qcell solar modules, adding up to an installed capacity of 2.88 kW per parking spot. It followed, therefore, that even if 25% of these parking lots were covered with solar arrays, the total installed generation capacity could aggregate 1.44 TW, generating 1.89 PWh of electricity each year. This was close to 50% of the USA's electricity consumption of 4 PWh in 2022.

Several states in the USA have introduced incentives for installing solar carports. These incentives help offset as much as one dollar per watt of additional costs of steel mounting structures, installation, and grid connection compared to a typical commercial rooftop installation. In 2022, it was estimated that California needed 110 MW of new solar installations to meet the state's 100% clean energy target by 2045. The "SB 49 bill" submitted to the state's legislation is expected to help facilitate the installation of solar carports in California through the employment of tax incentives and thereby help the state achieve the clean-energy mandate. Expecting to take advantage of such incentives, two companies, namely, DSD Renewables and Black Bear Energy, partnered to mount solar arrays on parking canopies.

By February 2023, the two companies had completed their first project on vehicle canopies at the Wilderness Lakes campground in southern California. The site had more than 500 RV campsites and other facilities. The project installed 3,500 solar panels with a total capacity of 1.50 MW. The facility is expected to generate 2.4 million kWh of energy per year and is projected to meet approximately 50% of the total energy used at the campground [2]. With the success of this project, the companies may expect to install PV - carports at other locations in California and beyond.

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Solar Carports
Source: PV Magazine

5.

Solar PV For Green Hydrogen

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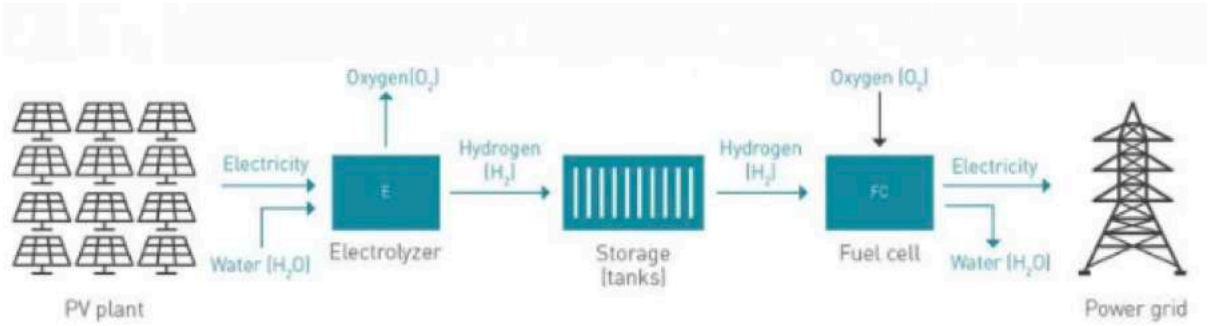
5. Solar PV For Green Hydrogen

'The Centrale Electrique De L'ouestguyanais (CEOG)' Renewable Power Plant In French Guiana

In 2018, Hydrogène de France (HDF), a pioneer in hydrogen energy, began work on a USD 90.0 million (~€ 84.0 million) hydrogen power plant near Saint-Laurent-du-Maroni in northwestern French Guiana. The project, The Centrale Electrique de l'Ouest Guyanais (CEOG), was located on a 140-hectare plot on hilltops, thereby avoiding the biodiversity-rich lowland forests. The solar PV – Hydrogen (PV-H2) project involves three stages: development, construction and operation. During the development phase, among other things, HDF works with local consultants to conduct topographic studies, environmental impact assessments and other relevant studies. At the time, construction was scheduled to begin in 2019, and operations were slated to commence in 2020[1]. However, the construction of the plant was delayed owing to the global pandemic and other related travel disruptions.

The construction of the plant began in 2021, and the PV – H2 project was to be commissioned by the year-2023 or year-2024, subject to potential disruptions in supply chains or other potential causes of delay. The project is based on HDF Energy's proprietary power-to-power 'Renewable' power plant technology. When completed, the plant would consist of a 55MWp solar park, a 16 MW electrolyser, two 1.5MW fuel cell systems, and a 40 MWh long-term hydrogen-based storage station. The plant is designed to generate 860 tons of green hydrogen per year. To put this in perspective, the plant is expected to cover the needs of around 10,000 local households in Saint-Laurent-du Maroni as well as the needs of the nearby municipality of Mana. HDF plans to replicate the project in about 20 countries: Mexico, Caribbean island nations, Southern Africa, Indonesia, Australia and others[2].



Source: CEOG https://www.ceog.fr/principe-de-fonctionnement, translated version obtained from Power, https://www.powermag.com/pioneering-10-mw-baseload-hydrogen-power-plant-breaks-ground-in-french-guiana/

Though the project costs were initially estimated at USD 90 million (84 million euros), the revised project costs were estimated to be USD 200 million (~170 million euros). While the European Investment Bank (EIB) offered a loan of €25 million to the project, the remaining is funded by five development and commercial banks like BNP Paribas, Agence Française de Développement, CréditIndustrielet Commercial, Bpifrance and SMBC Bank International PLC.

The project involves a complex combination of hybrid financing that includes equity bridge loans, tax credit bridge loans, long-term senior debt, and debt service credit facilities. The project also benefits from subsidies provided by Agence De La Transition Ecologique (ADEME)[3]. The funding is provided to CEOG S.A.S, a special purpose vehicle dedicated to building and operating the project owned by Hydrogène de France (10% equity), SociétéAnonyme de Raffinerie des Antilles ("SARA") (30% equity) and Meridiam EI (60% equity). While HDF is

providing engineering and technological services, Meridiam is the lead project developer and is responsible for developing the project over the long term. SARA is a fuel distribution company which might be involved in the distribution of hydrogen, once the project is completed. HDF Energy has signed a 25-year power purchase agreement with French utility EDF to sell power produced at CEOG [4]

CEOG is based on HDF Energy's proprietary power-to-power Renewstable power plant
Source: powermag.com

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Japan's Fukushima Hydrogen Energy Research Field (FH2R) Project

Japan has made considerable progress in the context of Hydrogen production. Such progress is achieved on the back of favourable government policy support and of the people's acceptance of hydrogen in the domestic energy mix. One of the significant and interesting projects is the Fukushima Hydrogen Energy Research Field project.

In 2015 – as the 'Paris Agreement' was adopted globally – the Japanese government compiled a 'Strategic Roadmap for Hydrogen and Fuel Cells.' In 2017, the government followed this by formulating a Basic Hydrogen Strategy with a vision of realising a 'hydrogen-based society' to be achieved by the year 2050. As part of this strategy, Japan decided to invest in the power-to-gas ('P2G') technology that stores electricity generated from renewable energy (RE) sources in the form of hydrogen. Improvement of water electrolysis technology is necessary for the commercial viability of P2G technology. Towards this end, Japan sought to establish the technology for lowering the unit cost of water electrolysis systems to 50,000 Yen (436 Euro)/kW by 2030. The country also has a target of reducing the cost of hydrogen production to 30 Yen (0.28 Euro)/Nm^3 by the year 2030 and further to 20 Yen (0.18 Euro)/Nm^3 by the year 2050. To commercialise P2G systems by 2032, a demonstration project is set up within the Fukushima Prefecture.

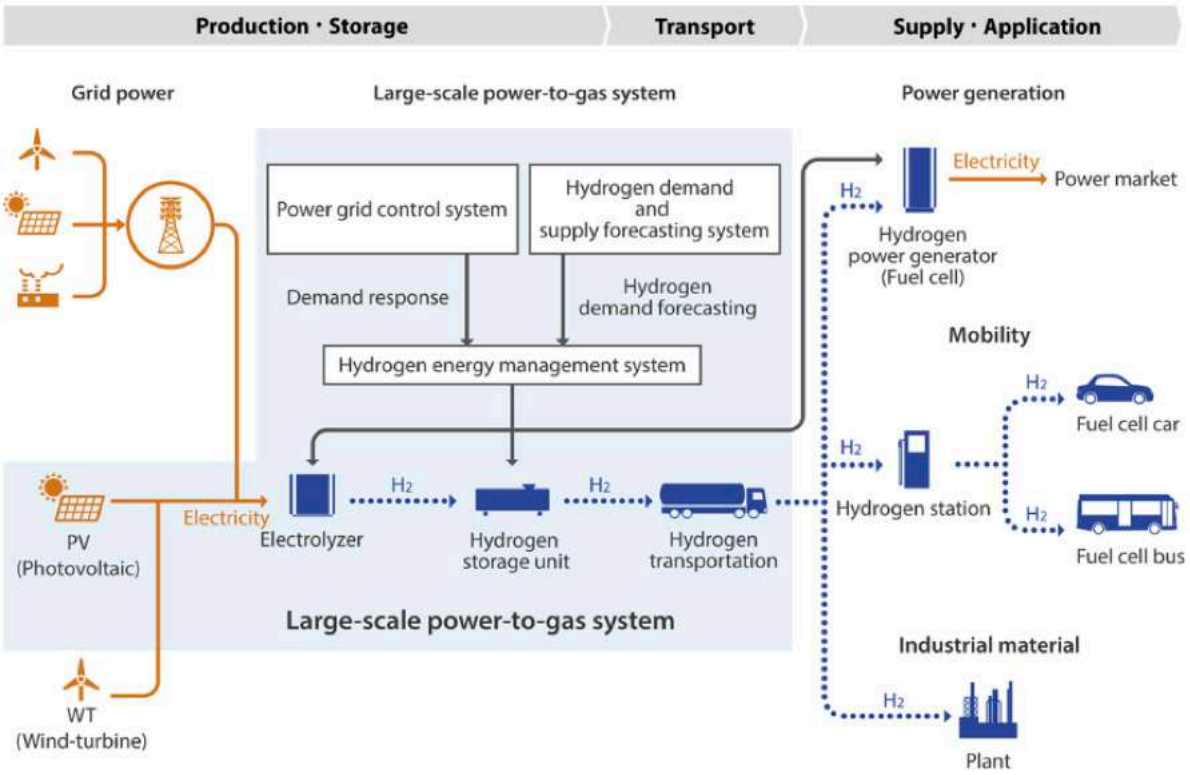
The Fukushima Hydrogen Energy Research Field (FH2R) Project

The construction of the Fukushima Hydrogen Energy Research Field (FH2R) project commenced in July 2018 on a 180,000 m^2 site in Namie town, Tanashio Area, Tanashio Industrial Complex in Namie-cho, Fukushima Prefecture. Toshiba Energy Systems & Solutions Corporation (Toshiba ESS), Tohoku Electric Power Co., Inc., and Iwatani Corporation were chosen through a tender for implementing this project and to work in partnership with the government's New Energy and Industrial Technology Development Organization (NEDO).

In March 2020, the FH2R began operation. At the time, at 10 MW the 'field' hosted the world's largest alkaline electrolyser, powered predominantly by a 20MWp solar PV power plant constructed specifically for the purpose and backed by power from the utility grid network. It can produce 1,200 Nm^3 of hydrogen per hour. To put this in perspective, the annual hydrogen production from this plant can power 150 households or 560 Fuel Cell Vehicles (FCV). Project costs are estimated at 20 billion Yen (177 million Euro). Figure 1 provides an overview of the FH2R system.

Assessment of Viability

According to a 2017 International Energy Agency (IEA) report, for hydrogen production to be financially viable, the price of electricity has to be lower than USD30 (28 Euro) per MWh. Additionally, to be competitive, the electrolyser plants need to benefit from high-capacity utilisation. A 20MWp plant like the FH2R whose electricity is priced at around USD60 (56 Euro) per MWh and whose capacity utilisation is estimated at 50%, is likely to produce hydrogen at a cost of approximately USD3.40 (3.2 Euro) per kg that is 240% higher than the base price for hydrogen. Estimates suggest that the first costs of building hydrogen electrolyzer plants would need to decline by half to enhance the viability of hydrogen production. The viability of H_2 production from using solar PV can also be enhanced by further converting the H_2 into Ammonia (NH^3) in situations where the prevailing prices for NH3 might be consistent with recovering the costs of producing and supplying ammonia.



Overview of the FH2R system

Source: Toshiba (2020),"The world´s largest-class hydrogen production, Fukushima Hydrogen Energy Research Field (FH2R) now is completed at Namie town in Fukushima," March 7, https://www.global.toshiba/ww/news/energy/2020/03/news-20200307-01.html?utm_source=www&utm_medium=web&utm_campaign=since202202ess, last accessed 26 May 2022

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The Moolawatana Renewable Hydrogen Project in South Australia

In May 2021, South Australia-based company Kallis Energy Investment announced a proposal to build a 6.0 GW renewable hydrogen project on 100,000 hectares of land in Moolawatana. The Moolawatana Renewable Hydrogen Project proposes to combine solar and wind farms, each with up to 3.0 GW of capacity, to be used to power electrolysers producing renewable green hydrogen. The stakeholders have decided not to connect the project to the grid, thereby avoiding congestion and the resulting grid connection issues that have plagued numerous large-scale projects in the region [1]. The plant is expected to meet 40 per cent of the state's goal of 500% renewables by 2050. The proposal includes the construction of a dedicated pipeline to facilities near Port Bonython on South Australia's Spencer Gulf for processing green hydrogen into ammonia that can then be exported, mainly to Japanese and Korean markets [2]. However, barely six months after the project was announced, it was shelved based on the findings of an environmental assessment. The environment and permitting risks around water supply and desalination were too high to continue with the project [3]. A spokesperson stated,"Not all projects work, and developers must determine fatal flaws as early as possible in the project timeline and communicate this to stakeholders."

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The Toyota Ecopark Hydrogen Demonstration Centre in Australia

Renewable energy sources are becoming dominant in the automobile industry. Toyota has come up with a model hydrogen demonstration project to power more and more Australian vehicles with renewable sources.

The Toyota Ecopark Hydrogen Demonstration project in Victoria, Australia, is constructed to transform Toyota Australia's decommissioned car manufacturing plant in Altona into a 'renewable energy hub.' The project's construction began in 2019 and became fully operational in November 2021. It aims to produce hydrogen from renewable sources for both stationary and transport energy uses. The total project cost is estimated to be AUD 8.1 million (€5.44 million) of which AUD 3.07 million (€2.06 million) is contributed by the Australian Renewable Energy Agency (ARENA) and AUD 4.30 million (€2.89 million) funded by Toyota Motor Corporation Australia Ltd.

The plant is powered by an on-site 87kilowatt (kW) solar PV installation, designed to work in conjunction with an existing 500kW PV array and with grid back-up if such support is required. At the Altona Hydrogen demonstration project, the 250kW electrolyser can produce at least 60 kg of hydrogen per day. Surplus solar energy is stored in batteries and used to supply (renewable) electricity to the Altona facilities [1]. There are provisions for fueling hydrogen to water-emitting-zero-CO2-fuel-cell vehicles like the Toyota Mirai Fuel Cell Electric Vehicle (FCEV). Such vehicles can be fuelled within minutes and offer drivers a 550km range [2]

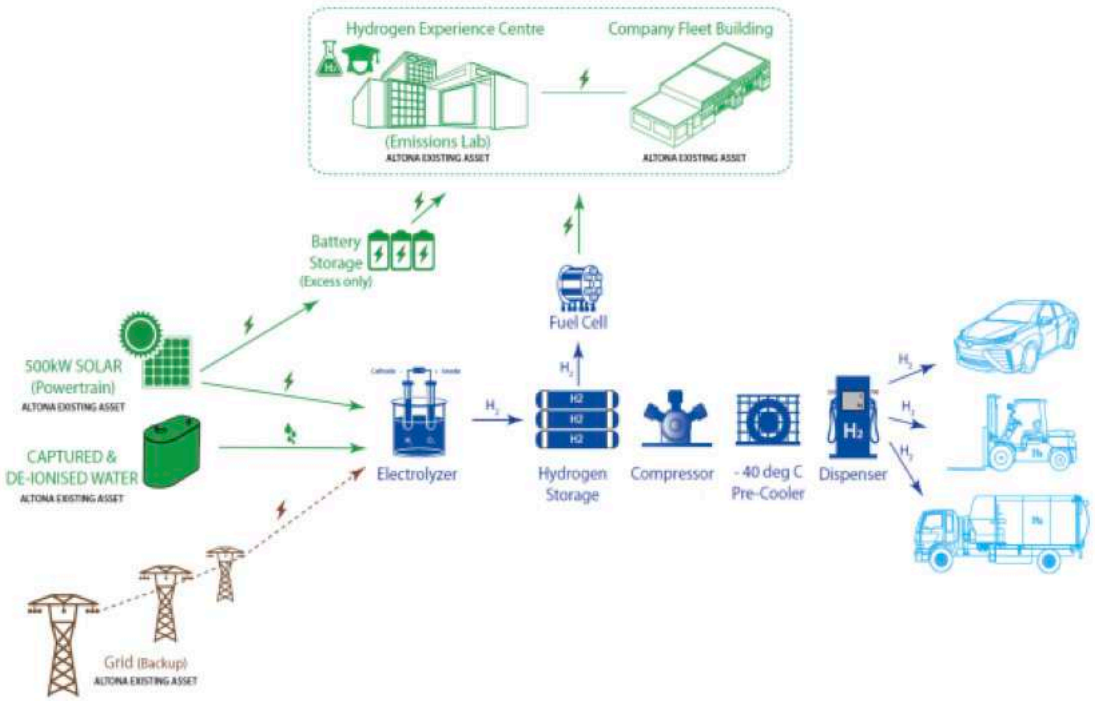

Figure 1: Graphical representation of Toyota Hydrogen Centre

Source: D'Souza Troy (2018),"Toyota Australia – Fuel Cell Project," ARENA and Toyota Motor Corporation Australia Limited, slide 8, https://arena.gov.au/assets/2019/12/toyota-australia-fuel-cell-project.pdf

The Toyota Australia Hydrogen Center includes two key areas: Hydrogen Demonstration Plant and Hydrogen Experience Centre. The Hydrogen Demonstration Plant focuses on the demonstration of hydrogen production using renewable energy, promoting the use of solar energy with battery storage, and intends to demonstrate a functional model of the 'hydrogen society' from stationary power to a refuelling station. The 'Hydrogen Experience Centre' intends to serve as an education centre to promote hydrogen and to create general awareness.

Implementation of this project provides various insights into Australia's Hydrogen programme. It reveals the low level of awareness relating to hydrogen infrastructure, safety requirements, and challenges in operating refuelling stations. Policies, standards and guidelines for hydrogen-based technologies are yet to be formulated. The government agencies are yet to define the list of documents to be submitted for project approval; the aspects of projects that require approval are yet to be defined. It is believed, this low level of awareness can affect the approval processes, leading to delays in implementing Hydrogen projects in the country. In all, the Toyota Australia Hydrogen Center offers two major lessons to future hydrogen projects in the country and elsewhere: (i) project schedules need to allow time for the agencies concerned to review, query and review documentation again (multiple iterations) and that (ii) early engagement with stakeholders and sharing of detailed information is crucial.[3]

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The Green Hydrogen Project At The Mohammed Bin Rashid Al Maktoum Solar Park In Dubai

In November 2021, the UAE announced an ambitious Hydrogen Leadership Roadmap that would contribute to the country's emissions reduction objective of 'net-zero by 2050' and helped establish the UAE as a competitive hydrogen exporter. UAE has been an early mover in the low and no - carbon industries and the country's leadership aims to leverage the experience thus gained to develop various projects at various stages of the clean hydrogen value chain. The Roadmap outlines five critical enablers to support the low-carbon hydrogen businesses in the country: 'a clear regulatory framework backed by policies, incentives, standards and certifications; best-in-class technology through value-add partnerships and the vibrant and robust UAE domestic research and development structure; access to existing and new government-to-government relationships to accelerate the growth of a domestic ecosystem; readily available land and infrastructure resources to support domestic production; and green financing within the UAE and in international capital markets.' UAE aimes to capture 25% of the global market share by 2030 for low-carbon hydrogen with seven main projects that are already underway in various stages [1].

The same year, the country's first green-hydrogen project was launched at the Mohammed bin Rashid Al Maktoum Solar Park in Dubai. The project is implemented in collaboration with Dubai Electricity and Water Authority (DEWA), Expo 2020 Dubai and Siemens Energy. It is the first solar PV-powered green hydrogen-producing facility in the Middle East and North Africa (MENA) region. Through this project, DEWA aimed to demonstrates the production of green hydrogen from solar power, its storage, and re-electrification. It is also envisioned that the plant will act as a platform to test various applications of green hydrogen, including mobility and industrial uses [2]. The plant has been in the test phase for two years before the launch. The green-hydrogen facility is powered by the 1,013 MW Mohammed bin Rashid Al Maktoum Solar Park and produces 20.5kg of hydrogen per hour [3].

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Europe's Largest Green Hydrogen Plant For Industrial Use In Spain

With a 170-year history of operations in the energy sector, Iberdrola is among Spain's oldest energy companies. In contemporary times, Iberdrola ranked among the world's biggest electricity utilities when measured in market capitalisation [1].

In 2020, Iberdrola allied with Fertiberia, a fertiliser company, to begin construction of Europe's [then] largest green hydrogen plant at Puertollano, Spain. The green hydrogen produced at the plant is used by Fertiberia to produce ammonia. Fertiberia already has an ammonia plant at Puertollano, with a production capacity of over 200,000 t/year [2].

The Puertollano plant was inaugurated in May 2022. The €150 million plant includes a 100 MWp solar PV plant, a 5MW Lithium-ion battery, a storage capacity of 20MWh battery storage system, and a 20MW electrolytic hydrogen production system. The plant is estimated to produce 1,080 tons of green hydrogen per annum, avoid 39,000 tons of CO2 per year and generate 1,000 jobs for the local community. The solar PV plant comprises bifacial modules – which allow higher energy production compared to conventional solar PV modules – generating an annual output of about 156,000 MWh [3]. Nel Hydrogen Electrolyser, a European company, is selected as the preferred supplier for the construction of the plant's hydrogen production system. Nel's Proton PEM electrolyser is deployed at the Puertollano facility. Elecnor, a Basque-based company is chosen to supply the electrical assembly required by the plant, including electrical panels, cabinets, conduits etc, while Construcciones Electromecánicas Consonni supplies the medium-voltage equipment for the project [4].

Further, Iberdrola and Fertiberia plan to invest €1.8 billion into the green hydrogen project in three phases between 2023 and 2027. The first phase is designed to enlarge the capacity of the hydrogen production plant in Puertollano from 20MW to 40MW. Three other projects are to be launched between 2023-2027, which will be carried out at the Fertiberia plant in Ciudad Real and the Palos de la Frontera plant in Huelva. Iberdrola and Fertiberia initiative plan to achieve 830MW of electrolysis capacity with these projects, accounting for 20% of Spain's national target of 4.0 GW by 2030. This initiative is expected to generate 4,000 skilled jobs through 500 suppliers. The two companies have sought investment support from the European Recovery Fund for the implementation of these three phases [5].

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The Hydrogen Valley Partnership In The European Union

In November 2018, the European Union set itself an ambitious target of becoming the first climate-neutral economy by 2050. The European Union works on building an alliance among nations both within and outside the EU. The European Hydrogen Valleys Partnership is one of the outcomes of such an endeavour.

In the communication to the European Parliament titled 'A Clean Planet for All', the European Commission acknowledged that climate change is a global threat that cannot be tackled by Europe alone but requires cooperation with partner countries and committed to work with neighbouring economies. Hydrogen valley can be defined as a geographical area – a city, a region, an island or an industrial cluster – where several hydrogen applications are combined into an integrated hydrogen ecosystem that consumes a significant amount of hydrogen, improving the economics behind the project. The scope is to [ideally] cover the entire hydrogen value chain from production through storage and distribution to end-use.

The European Hydrogen Valleys Partnership also focuses on Fuel cells and hydrogen (FCH) technologies, since such technologies have the potential to play a crucial role in this energy transition process. The main objectives of the partnership include:

1. Developing technological readiness and commercial availability of FCH applications,
2. Overcoming lack of access to information and expertise in the field of hydrogen,
3. Facilitating match-making and co-investing among potential regions,
4. Strengthening the value chain, green hydrogen production, and being an active stakeholder in the EU policy-making on hydrogen.

The Hydrogen Valley Platform, a global information-sharing platform is set up by the Fuel Cells and Hydrogen Joint Undertaking as part of the Hydrogen Valley Partnership initiative, along with the Mission Innovation IC8 Member States.

As of September 2022, the Hydrogen Valley platform included the details of 36 hydrogen valleys from 21 countries in Europe, Asia, the Americas, and Australia, which are in different stages of implementation. The platform (i) helps these projects through matchmaking with financial investors, (ii) shares information on the challenges and barriers normally experienced by hydrogen valleys, and (iii) lists a few best practices which can be applied.

The Hydrogen Valley Platform provides comprehensive data on the hydrogen valleys around the world and such data is available in the public domain. The challenges faced, success factors and the best practices shared on the platform are slated to help other projects avoid pitfalls while benefiting from the experience with similar initiatives. **Table 1** presents the common barriers experienced by the projects listed on the platform. Lack of hydrogen experience among permitting authorities, and securing funding for hydrogen production are two of the most common barriers to Hydrogen Valley projects, while **Table 2** provides the success factors.

Key Learning: Some of the best practices followed by successful projects listed on the Hydrogen Valley Platform and practices that might be worthy of being followed include:

- Choose decision makers in the project with backgrounds and experience in financing renewable energy projects.
- Build up contracts that involve off-takers and counterparts that de-risk the commercial structure of the project; without such contracts, bankability cannot be achieved, and private funding will be difficult.
- Capital can be invested into the project before securing off-take commitments.
- Engage with different entities early on in the project.
- Connect with several local and regional players who could potentially become valuable long-term partners. Building a growing network along the value chain very early on and investing in the collaboration of stakeholders helps in the long run.
- It would be counterproductive to encourage a high degree of "competition" among regional hydrogen players in an early market phase. Instead, a sense of broad and cooperative thinking should be in focus to help get larger and more integrated projects off the ground.

Table 1: List of barriers to project development experienced by projects listed on the Hydrogen Valley Platform

PROJECT DEVELOPMENT: PREPARATORY PHASE	
FACTOR	**NO. OF PROJECTS (AND %)**
Technological readiness/technological performance	13 (40.63%)
Regulatory provisions	15 (46.88%)
Permitting and authorization procedures	8 (25.00%)
Political backing and buy-in	7 (21.88%)
Funding	17 (53.13%)
Experienced staff	9 (28.13%)
Local Public acceptance	6 (18.75%)
Project's business case	12 (37.5%)
Stakeholder cooperation	6 (18.75%)
Risk sharing mechanism between project partners	8 (25.00%)
Project governance model	3 (9.38%)
Others	2 (6.25%)
PROJECT DEVELOPMENT: FINANCE	
Securing public financial support	15 (60.00%)
Securing private investors	10 (40.00%)
Building a financial model	5 (20.00%)
Securing customer commitments to de-risk the financial model	14 (56.00%)
Others	2 (8.00%)

Source: Hydrogen Valley Platform, https://h2v.eu/analysis/barriers/project_development/preparation, last accessed August 28, 2022

Table 2: Key success factors for project development (n= 29)

FACTOR	NO. OF PROJECTS (AND %)
Business model/business case development	21 (72%)
Funding	19 (66%)
Partnering	17 (59%)
Political backing and buy-in	16 (55%)
Stakeholder cooperation	14 (48%)
Experienced staff	14 (48%)
Project governance model	12 (41%)
Technological readiness/ technological performance	11 (38%)
Local public acceptance	10 (34%)
Risk-sharing mechanisms between project partners	9 (31%)
Permitting and authorisation procedures	8 (28%)
Regulatory provisions	6 (21%)

Source: Weichenhain, Uwe (2021) "Hydrogen Valleys: Insights into the emerging hydrogen economies around the world," European Union, https://h2v.eu/analysis/reports, last accessed August 28, 2022.

Table 3: List of barriers to project development experienced by projects listed on the Hydrogen Valley Platform (n=25)

REGULATORY BARRIERS	
BARRIER/ISSUE	**EXPERIENCED BY NO. OF PROJECTS**
Lack of H2 experience with permitting authorities	16 (51.61%)
Taxes/levies/duties on electricity from RES.	15 (48.39%)
Missing or inadequate permitting procedures	13 (41.94%)
Missing/too strict safety regulation in the context of H2 deployment	10 (32.26%)
Others	9 (29.03%)
Regulatory provisions	6 (21%)

Source: Weichenhain, Uwe (2021) "Hydrogen Valleys: Insights into the emerging hydrogen economies around the world," European Union, https://h2v.eu/analysis/reports, last accessed August 28, 2022

GRHYD - A Power-To-Gas Demonstration Project In Le Petit Village, France

One of the main challenges to the adoption of hydrogen as a fuel is the transportation of hydrogen from the point of production to the point of use. Several European countries like France, the Netherlands, and Spain have undertaken pilot studies to understand various challenges. The GRHYD project by Engie, a French utility company, was one such project.

Various projects have been carried out relating to hydrogen handling, with a focus on repurposing existing natural gas pipelines to transport either pure hydrogen or Hythane, a product formed by blending hydrogen with natural gas. The project GRHYD was launched in 2014, it was the first Power-to-Gas (P2G) demonstrator project in France, located in the 'Le Petit Village' district in Cappelle-la-Grande. The project also tested blending hydrogen with natural gas that would be used to meet the heating, cooking, and domestic hot water requirements of the village, and aimed to reduce GHG emissions by 20% by 2020[1].

The project is coordinated by Engie and a consortium of 11 partners with AREVA, ADEME and others and budgeted at € 15 million[2]. The first two years of the project were devoted to studying the technical aspects and sociological impacts of the project. The next five years are dedicated to the demonstration phase of the project, where surplus renewable energy is used to produce hydrogen that is then blended with natural gas and used for transportation and residential purposes. The plant uses a proton exchange membrane (PEM) which can generate ten normal cubic meters of hydrogen per hour, and a 5kg metal hydride storage tank[3].

Infrastructure at a bus fueling station is adapted to handle Hythane, which has 6% hydrogen content that progressively increases to 20% hydrogen. A fleet of 50 buses was run with this fuel over five years during this pilot study and the results from the pilot were analyzed in detail. On the residential demonstration end, initially, about 100 houses in the Capelle la Grande district were supplied with natural gas with variable hydrogen content below 20% by volume, in keeping with the prescriptions of the safety standards applicable. Towards the end of the project, the number of houses receiving such blended fuel increased to 200. Surplus hydrogen is stored to meet future needs[4].

The results of this demonstration project make it possible to understand the nature of installations required for electrolysis, storage and injection of hydrogen, models of transport, and optimum fuel blends.

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The Largest Project Of Underground Salt Cavern Storage For Green Hydrogen

Green hydrogen is being projected as the 'fuel of the future', with the ability to decarbonise a range of 'hard to abate' sectors like transportation, chemical, steel plants etc. However, the storage and transportation of hydrogen is more challenging than storing and transporting fossil fuels. It may result in the slow uptake of green hydrogen. As of 2022, hydrogen was most commonly stored as a gas or liquid in tanks for small-scale mobile and stationary applications. According to a report by the International Energy Agency, compressed hydrogen (at 700 bar pressure) has only 15% of the energy density of gasoline. This implies that 'storing the equivalent amount of energy at a vehicle refuelling station would require nearly seven times the space'. Therefore, to store hydrogen for large-scale inter-continental value chains, alternate methods of storage have to be explored. The usage of salt caverns, depleted natural gas or oil reservoirs and aquifers are being tested for large-scale and long-term hydrogen storage at several locations globally.

One such experimental project is being tested by Aces Delta, a joint venture between Mitsubishi Power Americas and Magnum Development LLC, in Utah, USA. In August 2022, Aces Delta began construction on a 300GWh capacity underground storage. The US Department of Energy ('US-DoE') has guaranteed a loan of USD 504.4 million (~€504.4 million) for project. The engineering, procurement, and construction management ('EPC') of the project is awarded to WSP USA (https://www.wsp.com/), a specialist engineering company. The project consists of repurposing two large salt caverns with capacities of 150 GWh, to store hydrogen generated by an adjacent 840 MW 'hydrogen-capable' gas turbine combined cycle power plant. This is equivalent to 11,000 metric tons of hydrogen or 40,000MW of lithium-ion batteries. This stored green hydrogen is expected to serve as an energy reserve that can be released to produce fuel for electric power generation as required. At the time, this project was considered to be the largest green hydrogen underground storage project.

Green Hysland Project - A Part Of The Clean Energy For EU Island Initiative

The European Union has set itself a target of installing at least 40GW electrolyser capacity that can produce 10 million tons of green hydrogen by the year 2030. Because of such ambitions, the European Commission decided to fund various hydrogen demonstration projects in Europe. In 2020, Green Hysland was the first project in the Southern European region that was selected by the Fuel Cells and Hydrogen Joint Undertaking of the European Commission for creating a green hydrogen ecosystem in the Balearic Islands. The solar energy generated on the island of Mallorca was to be diverted to Green Hyland, where the plant would produce 300 tons of green hydrogen per year,[1] Solar PV capacity of 16MWp was utilized for the project alongside the electrolyzer of 7.5MW capacity[2].

The project received a € 10 million grant from FCH JU, which spread over a six-year time frame between 2020 and 2025 [3]. Green Hysland is also supported by the Spanish government as it is part of Spain's Hydrogen Roadmap, which has an overall budget of €8.9 billion for 4.0GW capacity by the year 2030. The project is coordinated by Enagas and supported by a consortium of 30 companies like Acciona, CEMEX, Redexis etc. It is estimated that the project will reduce 20,700 tons of CO2 in the Mallorcan region between 2021 and 2025. The project aims to serve as a model for replication by five other island territories: Tenerife in Spain, Madeira in Portugal, Aran in Ireland, Ameland in the Netherlands and the Greek islands. The European Union hopes that the experience from this project will serve the 'Clean Energy for EU Islands' initiative.[4]

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The Use Of Artificial Intelligence Of Things (AIOT) For Hydrogen Transition

Many experts consider digital technology as one of the critical elements that can accelerate the industry's transition to green hydrogen. Artificial Intelligence of Things (AIoT) in particular, can help optimise and automate systems through enhanced data management and analytics.

Five ways to expedite the transition include:

- Digital twin analysis: Digital twins are virtual replicas of real-world systems. Multiple scenarios could be modelled using digital twins, by varying factors such as demand volatility, weather conditions, infrastructure, etc. Such models can help optimize capital expenditure by 10-15%, reduce investor risk by 30-50%, and also help in marginal changes to operational expenditure.
- Monitoring and control: The key performance indicators (KPIs) for a hydrogen plant are energy consumption, electrolyzer and other equipment performance, production rates, and purity of the hydrogen produced. Intelligent alarms and sensors working with AIOT can help monitor and control these KPIs and minimize losses. Asset health monitoring, rapid anomaly detection, remote control of assets, etc. are some of the other services offered by AIoT.
- End-to-end traceability: AIoT can help ensure end-to-end traceability along the entire life cycle of the green hydrogen, from cradle to grave. This could help speed up and narrow down the root cause in case of any issues.
- Guarantee of Origin (GoO) certification: In many countries, a GoO certificate is mandatory to monetize green hydrogen. "AIoT-monitored installations can leverage near real-time data to automate input to GoO issuers – this avoids manual processing, offers more confidence and reliability, and increases future-proofing as more and more certification evolves towards real-time and automation."
- Advanced analytics: AIoT can provide near real-time data and plant-level analytics along with recommendations to maximize yield. Such information would be useful for business management, investors and bankers to make strategic decisions [1].

Because of such benefits offered by AIoT, several companies have been working on integrating AIoT for Power to Hydrogen projects: one such company is Mind Tree, India. Mind Tree partnered with engineering major Larson & Toubro to implement a remote monitoring and controlling solution at L&T's hydrogen plant in Gujarat, India. Mind Tree's IoT analytics platform 'Insights NxT' is used to develop the solution which remotely controls all services at the plant. The IT solution helps optimise resource utilisation, thereby reducing the energy and operational costs of the plant. The IoT's predictive and preventive data analytics capabilities provide 'real-time insights into plant performance' to support decision-making and reduce the carbon footprint of plant[2].

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Gas Turbines - A Project To Use Existing Infrastructure For Green Hydrogen

In the years leading to 2022 governments and industries around the world were looking to tap into the potential of 'green Hydrogen' as a clean, secure, and affordable fuel that could help decarbonise a range of 'hard-to-abate' sectors – including long-haul transport, chemicals, iron and steel and the like. While some efforts focused on reducing the cost of green hydrogen production, others had been working on determining the possibility of using the existing infrastructure for the use of hydrogen.

In countries like UK and Spain, utilities like National Grid, Scottish Gas Network and others are engaged in testing the use of 'Hyblend' – a hydrogen–natural gas blend of various proportions – for use as a fuel in industrial plants and homes. Testing has shown that upto 20% hydrogen can be blended safely with natural gas and can be supplied through existing transportation and storage infrastructure. However, at higher proportions, hydrogen-induced 'embrittlement' could weaken existing pipelines, increasing the risk of leakages, particularly in high-pressure pipelines [1].

Apart from the pipelines, the use of hydrogen to fuel present-day gas turbines, and the use for several applications in aircraft, trains, ships, generators, pumps, etc., is being investigated. General Electric, with decades of experience with gas turbines, has been experimenting with the use of hydrogen since the 1990s. After experimenting with more than 100 turbines and 8 million hours of testing, the company has come up with several design upgrades for existing gas turbines to operate safely with a 50/50 blend of hydrogen and natural gas. The company's 7HA and 9HA models are capable of burning as much as a 50/50 hydrogen/natural gas blend when using the DLN2.6e combustor [2]. According to the company, the required modifications to configure a gas turbine to operate on hydrogen blends depend on the existing configuration of the gas turbine and the balance of the plant, as well as the desired proportion of hydrogen in the fuel mix.

Apart from GE, several independent researchers are also experimenting with gas turbine designs to assess the possibility of using 100% hydrogen sometime in the future. In 2022, a team of researchers from the University of Stavanger in Norway claimed to have developed a 100 per cent hydrogen-burning gas turbine to run a micro gas power plant. The team claimed that its gas turbine helped produce heat, electricity and hot water for hydronic heating. According to the research team, the efficiency of the turbine was less compared to the ones that run on natural gas. However, the big gain is that, the existing infrastructure can be utilised with certain adaptations, bringing about dramatic cost savings relative to building entirely new infrastructure. Eventually, the team concludes that conversion kits can be produced, which will enable plants to keep the existing turbine equipment while moving to zero-emission fuel sources like green Hydrogen [3]. However, for the kits and modifications to become economically viable relative to using natural gas in existing turbines, the price of green hydrogen fuel has to come down substantially.

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Desert Bloom - A Cost-Effective Hydrogen Project In Australia

In 2021, Australia's Northern Territory government authorised Aqua Aerem, a 'water-from-air' technology company to develop a USD 10.75 billion (10.05 billion Euro), 10 GW hydrogen project. The Desert Bloom Hydrogen project can produce green hydrogen at less than USD 2/kg (1.88 Euro/kg) by 2027. When fully operational, the facility can generate approximately 410,000 metric tonnes of hydrogen per year. The 'Desert Bloom' is designed to utilise the water capture technology powered by off-grid solar. According to Gerard Reiter, Aqua Aerem's chief executive officer, the project is 'transformative' as it has managed to overcome water supply and solar/electrolysis integration problems that have thus far held global renewable hydrogen production back. Further, this project created almost 1,000 jobs during the construction phase and 120 permanent jobs for running and maintenance of plant [1].

Aqua Aerem is backed by Singapore's Sanguine Impact Investment, which is providing The capital for the project. In addition to this, Japan's Osaka Gas has agreed with Aqua Aerem to contribute to the overall development of the project which will comprise the construction of a plant, engineering and technical support, negotiating with equipment manufacturers, and finding customers for the produced hydrogen [2].

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The Masshylia Project In France

In 2021, two major French groups, Total Energies and Engie, signed an agreement to design, develop, build and operate the Masshylia project. Located at Châteauneuf-les-Martigues in the Provence-Alpes-Côte d'Azur South region, the plant will have a 40MW electrolyser powered by a 100 MW solar plant. After completion, the project is slated to generate 15 tonnes of green hydrogen per day. The construction of the project began in 2022, and the project is expected to be commissioned by the year 2024.

The facility will initially supply 5 tonnes of green hydrogen per day to meet the needs of the biofuel production process at Total's La Mède bio-refinery and to avoid 15,000 tonnes of CO2 emissions per year. Later the facility is likely to be expanded to serve the needs of the industries surrounding Fos-sur-Mer (Marseille) and local transport and service projects (road, sea and rail). The project has applied for subsidies from the French (AMI) and European authorities (IPCEI, Innovation Fund) [1].

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Uniper's Underground Hydrogen Storage Facility In Germany

The impending climate crisis and Russia's war against Ukraine during most of the 2022 exerted pressure on governments of European countries, compelling policy-makers to accelerate the energy transition and to diversify away from Russian gas supplies in particular. Hydrogen was considered one of the key alternatives to help with the energy transition. While many companies were engaged in making the hydrogen production process more viable, it was the storage and transportation of hydrogen that proved challenging in the short term.

Uniper Energy Storage operates natural gas storage facilities in Germany, Austria and the United Kingdom, with a working gas capacity of over 7.5 billion cubic meters[1]. In July 2022, Uniper SE, a German company, received €2.375 million from the German Government for a pilot project at a natural gas storage site in Krummhoern, North Germany. Apart from this, the company planned to invest an additional € 10.0 million into the project. The facility is expected to be capable of storing up to 250,000 cubic meters of hydrogen. The company plans to sink an existing natural gas well into a new cavern to create an industrial-scale hydrogen storage facility[2]. The natural gas storage facility, which has not been in use since 2017, already has the infrastructure needed to handle gaseous fuels. The pilot project aims to examine the equipment and materials for compatibility with storing hydrogen. The experience and data gained from the pilot project are projected to help future projects that intend to use existing infrastructure. The facility is to commence operation by the year 2024.

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The European Hydrogen Bank - Providing Green Hydrogen For Industrial Use

As part of achieving the sustainable development goals by 2030, the European Union has initiated many projects for renewable energy plants and reuse and recycling. One of the prominent green fuels needed for these projects is Hydrogen. The European Hydrogen Bank is one such step towards storing and maintaining hydrogen.

Energy prices reached an all-time high in Europe and other places in 2022, forcing energy-intensive industries to look for alternative sources and technologies. These industries were ready to transition to green hydrogen if such fuel was available in adequate quantities and on schedule. To scale up green hydrogen production to the required levels, private investment of €330 billion to €400 billion is needed, translating into a supply of 20 million tons of green hydrogen by the year 2030. However, two key investment risks prevented green hydrogen suppliers from advancing beyond demonstration projects and to go forth and deploy green hydrogen at an industrial scale. First is the market risk, given that green hydrogen has to compete with other cheaper – even if not so clean – fuels like grey hydrogen, natural gas, coal etc., preventing off-takers from entering into contracts that would lock them into paying higher prices for prolonged periods in time. Second is the "first-mover" risk, where early market participants have to invest heavily in technology whose cost is expected to drop in the long term, possibly turning the early adopters uncompetitive.

According to a study conducted by Rocky Mountain Institute (RMI), USA, the cumulative market risk is likely to increase as higher volumes of green hydrogen are used in the EU; it is also believed that rising carbon prices would drive fossil fuel costs above costs of green hydrogen by about the year 2030. On the contrary, if fossil fuel prices are renormalised to lower levels by as early as 2024, the gap between green hydrogen and standard fuel costs will expand, and cumulative market risk will increase. The report suggests that if the EU invests early into green hydrogen assets while the fossil fuel prices are high, the EU can save billions by offsetting the market risk. To offset first-mover risk, investors keen on investing in new technologies will need assurances and support from the government that they will receive support to sustain in business when the technology matures. RMI estimates that off-setting first-mover risk will cost between €3.5 billion to €5.0 billion in payments to producers per year until the end of 2027. Risk-sharing mechanisms and public subsidies will be needed to manage these risks effectively [1].

Because of the benefits that green hydrogen offers and in a bid to offset risks, in October 2022, the European Commission announced the launch of a European Hydrogen Bank that would accelerate green hydrogen market development in the European Union. The bank is expected to mobilise initial funding of €3 billion to create market certainty and to support further funding as required [2].

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The Green Hydrogen Corridor Between North And South Europe

Rotterdam in the Netherlands is considered the most important energy port in Europe since it handles nearly 13% of Europe's energy supplies. As part of Port Rotterdam's energy transition plans, and with the support of the Dutch government, the port authorities have developed the necessary infrastructure and facilities for the import of green hydrogen. With the help of several private companies, the authorities plan to build a hydrogen pipeline network that will connect the industrial centres in Netherlands, Belgium, and Germany. They have proposed to supply North Europe with 4.6 million tons of green hydrogen by 2030[1].

As part of its ambitious plan, port Rotterdam signed a Memorandum of Understanding (MoU) with Spanish energy company Cepsa to establish a green hydrogen corridor between southern and northern Europe. Cepsa plans to export hydrogen produced at its San Roque Energy Park near the Bay of Algeciras through hydrogen carriers such as ammonia or methanol. The hydrogen corridor between Spain's leading port at Algeciras and port Rotterdam is expected to be ready by 2027. It is estimated that by 2050 some 20 million tons of hydrogen will flow through the port, of which only 2 million tons will be produced locally. This project will help decarbonise the industries in Europe and contribute to European Union's RePower EU strategy[2].

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The Solhyd Project - Hydrogen-Producing Rooftop Solar Panels

Solar PV and hydrogen are often hailed as the energy sources which can address the world's energy challenges. In this regard, scientists in Belgium have initiated a project called the Solhyd Project that makes hydrogen panels to generate electricity.

In 2011, a team of researchers from KU Leuven, a university in Belgium, began researching possibilities of developing solar-hydrogen panels that will make hydrogen accessible to "anyone, anywhere." The scientists launched the "Solhyd project" to specifically work on this concept[1]. In November 2022, the team succeeded in developing a hydrogen panel that uses incident sunlight to convert water vapour captured from the air into hydrogen gas.

A mainstream commercially available solar PV panel at the time converted approximately 18 and 20% of the solar radiation into electricity when operating on the field. The researchers at KU Leuven avoided conversion losses by designing a solar panel of 1.6 m^2 that converted 15% of the harnessed solar energy directly into hydrogen[2]. The researchers claim that the panel can produce 250 litres of hydrogen per day. The team estimates that 20 hydrogen panels with a heat pump can meet the electricity and heating requirements of a well-insulated house for the entire winter season in Leuven, Belgium.

The hydrogen panels are compatible with most solar panels available on the market, and the Solhyd panel can be mounted onto conventional PV mounting structures. The solar panels are connected to the hydrogen panels through a network of tubes. It has a membrane for capturing water from the air, and the electricity from the solar panel helps extract Hydrogen from the captured water. In keeping with safety concerns, the hydrogen so produced is collected centrally in a separate chamber and compressed for storage. This hydrogen can be used in a wide range of applications, including for mobility.

The Solhyd project moved to a 350 square-meter pilot production space close to the town of Leuven after successfully testing the hydrogen panels under lab conditions. The team plans to start by producing a few dozen hydrogen panels for small-scale pilot projects and then to scale up production to 5,000 panels per year by 2026.[3]

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HEVO - A Miniaturized, Lightweight, And Mass-Producible PEM Electrolyzer

This is a case study about the photoelectric hydrogen generator, HEVO, that is used to make solar generators. These generators have proven to improve efficiency and considerably reduce the logistic and transportation costs for households and industries.

High capex costs associated with producing hydrogen and the volatility in the price of the hydrogen so produced have historically made commercial production of green hydrogen uncompetitive relative to conventional hydrogen derived from hydrocarbons. In 2018, Portuguese energy company Fusion Fuel commenced work on finding a way to produce green hydrogen efficiently, and hence, cost-effectively. While the industry was focusing on large electrolysers to improve efficiency, researchers at Fusion Fuel focused on optimising the miniaturised and decentralised design, and the form factor of the Polymer Electrolyte Membrane (PEM) electrolyzer.

By 2020, the company developed a photoelectric hydrogen generator referred to as, 'The HEVO', a miniaturized, lightweight, and "mass-producible" PEM electrolyzer. HEVOs are paired with a high-efficiency concentrated photovoltaic (CPV) panel to make a HEVO-Solar generator. The CPV panel concentrates solar radiation of 1,400xonto III-V multi-junction solar cells, yielding a solar-to-electric conversion efficiency of about 40%. This improves the efficiency of the electrochemical reaction and reduces the levelized cost of green hydrogen [1]. Further, the "wasted" thermal energy from the CPV can be used to pre-heat the feed water, thereby reducing the electrical load required to electrolyze water by approximately 10%. During nights, the HEVO generator can use power from the grid or from other alternative sources to double the annual output. The team claims that at a location with 2,100 kWh/m^2/year of direct normal irradiance—Southern Portugal—each HEVO-Solar generator could produce one metric ton of green hydrogen per year using only solar power. In addition to this, because of the small size of the HEVO generator, it can be co-located at the customers' end, thereby avoiding expensive transportation and logistics costs.

In 2022, Fusion Fuel successfully connected its first green-hydrogen plant, the H2Évora, to the grid at Évora, Portugal. The plant featured 15 HEVO-generators with a generation capacity of an estimated 15 tons of green hydrogen per year [2]. Canadian company Ballard Power supplied the plant with a 200-kilowatt FCwave fuel cell module that helped convert hydrogen into electricity that can be fed into the electric grid during periods of peak demand.

Fusion Fuel received an estimated €10 million grant under Component 14 (C-14) of the Portuguese Recovery and Resilience Plan to develop a 6.6 MW HEVO-Industria green hydrogen project in Sines, Portugal. The company estimates the overall project cost at about €25 million. The project when completed, will have 300 HEVO-generators in all, producing approximately 764 tons of green hydrogen per year. The generated hydrogen can be used for mobility and industrial applications in Sines itself or can be supplied through the existing natural gas grid [3].

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The World's First 100% Hydrogen-Combusting Residential Water Heater

On November 2021 in Nagoya, a 100-year old Japanese company, Rinnai Corporation, launched the Rinnai Innovation Manifesto 2050 ("RIM 2050"), outlining the company's commitment to carbon neutrality and proposing the development of energy-efficient household appliances that can operate in a post-fossil-fuel world. Following such commitments in June 2022, Rinnai Corporation reportedly launched the world's first 100% hydrogen-combusting residential water heater.

The company has previously developed a gas-based water heater that could operate with a 20% hydrogen or methane blend. The company's 'tankless' water heater design was then successfully tested with 30% hydrogen or methane blending. The 100% hydrogen-fired water heater is built on the back of such accumulated experience with the company's fluid control technologies. The clean-fuel-powered water heater design is slated to avoid carbon emissions and is also intended to avoid explosion risk and combustion stability [1].

The hydrogen-based water heater is deployed in demonstration projects in South Australia and Victoria in Australia, where hydrogen is proposed as the main residential energy source. The company proposes to gain experience from such demonstration and to improve upon the reliability of the technology, before commencing large-scale commercial production [2]. By introducing hydrogen-fired water heaters, Rinnai Corporation helps households enjoy the convenience of rapid gas-heated hot water while leaving a lower carbon footprint. The technology thus offers households and businesses in Australia, Japan and elsewhere options for mapping the optimal pathway to net-zero emissions [3].

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6.
Affordable Finance at Scale

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6. Affordable Finance at Scale

Azuri PAYG – An Affordable Solar Solution in Africa

According to Renewable Capacity Statistics in 2021, Africa has the potential of 40% of the globe's solar power generation. However, most households in African countries cannot afford to install solar systems due to financial obligations. This case study is about Azuri Technologies which is seeking to provide an innovative solution through an affordable pay as you go system for solar.

In 2012, Azuri Technologies, a UK-based company, came up with an innovative pay-as-you-go (PAYG) solution to make solar energy accessible to people in 11 African countries (Tanzania, Kenya, Ethiopia, Uganda, Sierra Leone, Malawi, Zimbabwe, South Africa, Rwanda, Togo, and Ghana). At the time, limited electricity supplies on the African continent had forced people to resort to kerosene lamps, candles and other means for illumination and other routine uses.

According to the African Progress Panel, as of 2017, nearly 620 million Africans – most of them in rural areas – did not have access to electricity or reliable supplies when connected: this amounted to nearly two-thirds of the population on the continent. Further, according to the World Health Organization (WHO), about one in four clinics and hospitals across 11 African countries do not have access to power supplies, while a large proportion of the others received supplies from ill-maintained or inadequately-fueled generators. Such energy shortage has proven to be a significant barrier to the development of the continent and is believed to have adversely affected health and education-related outcomes. According to the World Bank, if the African countries have access to continuous and reliable electricity supply, they will grow at least two percentage points [per year] faster than the observed rate of growth for the year-20171.

Most residents in rural Africa cannot afford a basic USD 70 (~ €67) solar system to illuminate their houses: average earnings per day is around USD 2.0 – 3.0 (~ €1.92-2.87). Residents spend about USD 4.0 - 7.0 (~€3.83-6.70) each week on kerosene and phone charging and thus have limited savings. Azuri's pay-as-you-go solution offers an alternative solution, where the user needs to pay a small one-time installation fee for the solar home system and follow this up with purchasing a scratch card or use an integrated mobile money service to top-up the unit in the spirit of pre-paid energy service. These top-up purchases cost approximately USD 1-2 (€0.96-1.92) per week, which is 50% lower than the weekly expense on kerosene and phone charging. These regular 'top-ups' pay off the cost of the solar system: after about 18 months, the customer owns the system and can use the energy at no further cost.

The upfront costs and top-ups vary according to the country of installation and of course, the size and configuration of the system acquired. For instance, in Kenya, it costs 4,999 Kenyan shillings (40.73 Euro) and the top-ups are around 149 Kenyan shillings (1.21 Euro). Upon paying the installation fee, along with the solar panel and batteries, customers receive LED lights, mobile phone chargers, and a radio/MP3 player. Azuri's solar home systems have in-built analytic and AI technology designed to profile consumption patterns of individual customers and manage power supplies to optimize system performance. Azuri has also offered a 24 inch television with a satellite connection running on ten Watts of power in some parts. In Kenya, the company has tied up with satellite TV provider Zuku, providing access to nearly 50 channels for customers.

Azuri claims to have supported the supply of solar home systems to more than 150,000 households. According to an independent survey conducted in 2017, of the 85% of Azuri's customers who had been using kerosene before the installation of the solar home system, a mere 17% continued to use kerosene. The survey further shows that their customers had saved USD 70 (~67 euros) per annum on average. Azuri customers reportedly spent the savings on school fees, food and water, and launching or expanding their business. The solar home systems have provided 28.5 million hours of clean light and 9.5 million hours of mobile phone charging, avoiding 3,504 tonnes of CO2 emissions since the company's inception.

Azuri continues to help villagers across different countries in Africa. In 2021, the company also ventured into solar irrigation projects in several villages. The company's website (https://www.azuri-group.com/) lists various success stories on educational, business and gender-related outcomes.

REBFF - A Blended Finance Model for Renewable Energy in Nepal

Natural resources are abundant in Nepal, providing an opportunity to become an economy based on renewable energy. The government of Nepal taking advantage of this blessing initiated the Renewable Energy Blended Finance Facility that aims to build a market-led renewable energy financing system. This case study is about the REBEFF initiative that focuses on developing and enhancing Renewable Energy systems in Nepal.

Nepal has been facing an energy crisis due to the country's dependence on coal and imported petroleum for power generation. At the time when the Austria-Nepal Renewable Energy Blended Finance Facility (REBFF) was conceptualised and launched, installed generation capacity in the country stood at 856MW, which meant that about 3.5 million people were yet to be connected to, and served by, the utility grid[1]. Routine applications like cooking and lighting are affected by insufficient energy supply.

As of 2019, power generation from RE sources was 1% of the total power generation, whereas access to electricity from RE sources was estimated at 10%. The Government of Nepal aims to enhance the contribution of power generated from renewable sources to about 10% and to increase the access to power from RE sources to 30% of the population over a 20-year horizon[2]. The Government has started to explore the possibility of financing renewable energy projects through blended finance mechanisms to minimise dependence on donor funding.

SNV of the Netherlands, The Renewable Energy and Efficiency Partnership (REEEP) and NMB Bank Private Limited collaborated to build a market-led renewable energy financing system with support from the Austrian Federal Ministry of Sustainability and Tourism. This facility is referred to as the Austria-Nepal Renewable Energy Blended Finance Facility ('REBFF') and was to be implemented for three years between October 2019 and July 2022. REBFF sought to establish a credit guarantee facility to promote and encourage RE financing in Nepal (including solar PV options), with the support of NMB Bank Limited and the Alternative Energy Promotion Centre (APEC). The €1.0m Credit Guarantee Fund was designed to compensate financial intermediaries for up to 25% first loss limited to €142,000.[4]

Involving intermediaries to lend for such ventures, the fund aimed at encouraging private investments in cleaner generation and distribution. The guarantee facility covered a part of the first loss faced by intermediaries from lending to finance such RE projects implemented: such compensation was limited to a ceiling of €1,42,000. Although the REBFF was established in October 2019, the creditworthiness criteria of the prospective projects[5] that might qualify for lending were mentioned in detail in the handbook 'Scaling up of Commercial Lending in Renewable Energy Projects', brought out by SNV Netherlands Development Organisation in August 2021. As proposed, the Credit Guarantee Fund was initiated to finance RE projects through wholesale lending to micro-finance institutions (MFI) or directly to communities. Banks and financial institutions are projected to gain adequate experience through access to the Credit Guarantee Fund and to continue working on funding the acquisition and use of RE assets in Nepal. This initiative is also slated to design and implement capacity development programs to encourage the deployment and utilization of RE options in Nepal.

The consequences of implementing the guarantee facility and the resulting market development outcomes are yet to be reported even though the original tenure of the project was to end in July 2022.

Renewable energy comunita - Energetiche Europee

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An Innovative Community Model To Scale Rooftop Solar In Italy

This case study talks about the initiative by the European Union to promote the use of solar power energy by introducing a community model. This model involves citizens, making them the consumers as well as the producers. The government aims to utilise energy efficiently through the functioning of these Renewable Energy Communities.

In 2016, the European Union (EU) adopted eight legislative acts which reformed the EU's framework for energy policy. 'Renewable Energy Communities' (REC) and 'Citizens' Energy Communities (CEC) are two important directives under the reformed framework. Under the REC model, citizens become 'Prosumers', producing as well as consuming energy. The 'Energy Communities' formed by these prosumers, create innovative forms of aggregation and governance in the area to generate benefits for individuals and the community. Under the new paradigm, the energy flow between the buildings (private, public or corporate) and the grid should be bidirectional.[1]

Italy launched several initiatives to promote citizen participation as part of the REC directive. The Italian government offered an income tax break or the 'super bonus' as it was called, to participating citizens, to undertake the required building renovations and energy re-qualification projects, till end-2022. In addition, the government set the maximum price of PV systems at €2,400 per kW and €1,000 per kWh for storage systems.[2] Further, the prosumers are categorised as self-consumption collectives and energy communities, defined as 'groups of consumers located in the same building or complex, while energy communities are larger entities that can also include businesses or public organisations located in the proximity area of the power generator.'

The tariff is €0.11/kWh for 'Energy Communities' and at € 0.10 /kWh for self-consumption collectives applicable for 20 years. This scheme is open to RE systems not exceeding 200 kW in size; surplus power can be integrated into the grid but without any remuneration. Through this approach, the government hopes to encourage the deployment of batteries to promote [time-shifted] self-consumption and to discourage the export of surplus energy.[3]

Italy's first energy community for solar power sharing was established in 2021 at Magliano Alpi. Due to a low building density in the region, the REC could connect only seven members, of which three were public buildings. The municipality in Magliano planned to connect to five neighbouring REC in the future, creating a CEC4. As of 2021, several other REC projects are in the pipeline. In 2016, the European Union (EU) adopted eight legislative acts which reformed the EU's framework for energy policy. 'Renewable Energy Communities' (REC) and 'Citizens' Energy Communities (CEC) are two important directives under the reformed framework. Under the REC model, citizens become 'Prosumers', producing as well as consuming energy. The 'Energy Communities' formed by these prosumers, create innovative forms of aggregation and governance in the area to generate benefits for individuals and the community. Under the new paradigm, the energy flow between the buildings (private, public or corporate) and the grid should be bidirectional.[1]

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The 60MW Solar PV project In Monte Plata - A Path To Regional Empowerment

The following case study is about the 60MW Solar PV model in Monte Plata that helps to positively change the dimensions of solar energy in the Dominican Republic. The main focus of this project is to establish Solar PV plants in the region. This project has not only proved beneficial in terms of Renewable Energy but also generated employment thereby empowering the communities.

The electricity generation mix in the Dominican Republic is dominated by fossil fuels, entailing, among others, a substantial dependence on coal. As most of these fuels are imported, such fuel use imposes a disproportionate financial burden on the economy. This outflow of foreign currency and the technical and commercial losses suffered by the country's electricity distribution networks left the power sector weak, which in turn proved to be a constraint on economic growth in the country[1].

As of 2015, the output from Renewable Energy (RE) sources (including hydropower) accounted for 12% of the total generation[2]. It means that the government spent about USD 4.0 billion annually on fossil fuel imports for the years leading up to 2016[3], which at the time represented about 6% of the nation's GDP. Cleaner technology like Solar PV presents options to help reduce dependence on imported fuels while lowering costs and simultaneously curtailing potential damage to the environment as well. Policymakers considered this option seriously and moved in the direction of exploiting solar PV technology to try and augment energy supplies while cutting back on fossil fuel imports.

The 60 MW grid-connects Solar PV park is proposed in the Monte Plata region to increase the RE mix in the overall generation mix. When the first 30.0MWp plant was installed in the year-2016, it was the largest Solar PV plant among all Caribbean countries. Initially, the second phase was scheduled to be commissioned in 2017 but implementation was delayed due to permitting processes and later by the COVID-19 pandemic. The second 30 MWp plant was scheduled for commissioning by the end of the year-2022.

Electronic JRC of the Dominican Republic initiated the project with General Energy Solutions, a Taiwanese-owned company acting as a Special Purpose Vehicle. The project is built, operated and maintained by Soventix GmbH, a German Company. The project is supported by the Foundation Myclimate – The Climate Protection Partnership from Switzerland and Uno Wind Service GmbH from Germany. Total investment in the project for the first 30MW phase was estimated to be USD 110 million (€ 99.8 million). [4,5]

As per Project Design Document[6] (UNFCCC/CDM Project 8530: 60MW Solar PV – Monte Plata), which had assumed that the entire 60.0 MWp plant would be operational. It was estimated that upon commissioning [in 2017], for each year starting in year-2018 the project would avoid the emission of 58,509 t CO2e. However, the implementation and commissioning of the second phase [of 30 MW capacity] was delayed. Notwithstanding the delay and considering just 50% of the operational plant, the emission reductions projected for the year 2020 stood at 29,254 t CO2e relative to a fossil-fuel-heavy baseline. Yet, the plant reported avoiding the emission of 31,309 t CO2e since the plant generated 6.24% more electricity than initially estimated.[7]

The emission reduction crediting period for the project as registered was from 31-May-15 to 30-May-25: given the actual performance, a total of 15,209 CERs were issued for the project between 01 January 2013 and 31 December 2020[8]; the Gold Standard registry reported that 108,264 CERs were issued as of 16-Mar-21[9].

The employment generated during the initial phase of the project was estimated to be 261, and around 50 people were to be employed routinely for operations and maintenance (O&M)[10]. In addition to generating cleaner electricity, saving on foreign currency and creating employment, the project empowers remote communities, and above all, the initiative demonstrates the collaboration among stakeholders from multiple countries in designing, building and operating viable PV projects in emerging markets[11].

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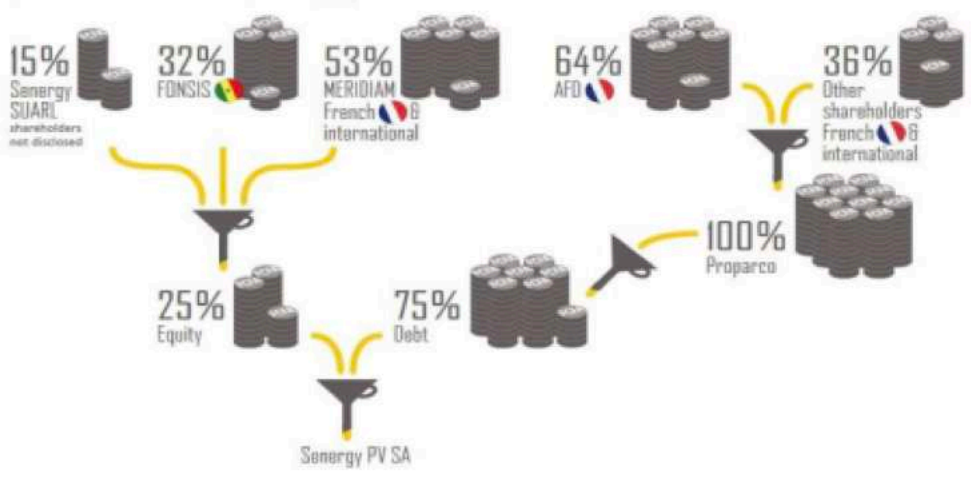
The Santhiou-Mékhé, Senegal Solar Plant - An Innovative Initiative

The Senegal solar plant initiated and facilitated in parts of Africa has proved to bring about a significant change in the African region. It has led to fewer emissions of greenhouse gases and better use of the available resources. These plants' guarantee is a plus point for investors in the project.

In the years leading up to 2010, Senegal recognised the need to augment energy supplies through aggressive generation capacity addition. Since then, policymakers have actively pursued reform policies in the energy sector with a strong focus on promoting renewable energy (RE). It led to the adoption of a Renewable Energy Law in 2010. Senegal had committed to increasing the installed RE capacity to 20% of the total installed capacity by 2017.

By 2016, Senegal reported 650MW of installed electricity generation capacity; 33% of the population had access to electricity. Imported liquid fuel-based thermal sources provided About 90 per cent of this capacity. The country was subject to frequent droughts and the resulting water scarcity meant that the utility was unable to meet demand. City grids were also overloaded due to demand growth from rapid rural-urban migration in many parts of the country. The electricity demand had been growing at a rate of about 6.2 % per annum. Due to Senegal's heavy reliance on thermal power plants, the costs of production and consequently end-user electricity tariffs remained among the highest in the region. This situation provided a favourable benchmark for solar power to compete with the generation mix in the country.

In pursuit of the self-defined RE targets and partial fulfilment of the commitments made under the CoP 21 pledges, the Santhiou-Mékhé 30 MWp solar plant located near Méouane in the Thies region, is commissioned to meet the immediate energy needs in the country. The project was originally developed in February 2015 by the Senegalese-born American Sam Wébé whose company Senergy SUARL partnered with Senegal's Fonds Souverain d'Investissement Strategique (FONSIS- created to promote the role of the state as an investor) and the private investment company Meridiam. The total cost of the project was estimated at €43.2 million. The cost estimate also included developing the infrastructure to connect the plant to the utility grid network on behalf of the Senegalese public purchaser SENELEC (Senegal National Electric Agency). The utility has executed a power purchase agreement for 25 years at a competitive starting price of 0.10 EUR/kWh and an escalation leading to an average price of 0.12 EUR/ kWh over the lifetime of the project.



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Senegal was the second African country to join the International Finance Corporation's Scaling Solar program in January 2016. The IFC organised competitive reverse auctions for solar and also provided financing and guarantees for investors. In the same year, Proparco, a development financial institution owned by the French Development Agency (AFD) and private parties to promote investments in Africa, Asia, Latin America, and the Middle- East, announced the grant of a €34.5 million loan (~75% of project cost) to Senegal-based renewable energy company Senergy PV SA for the development of a solar PV power plant. Proparco remained the fundamental financier of the project and the only lender for the project loan term of 18 years.

The equity component (25% of total investment) of the project is financed by French investment firm Proparco (53% of the equity), the project developer Senergy PV SA (15% of the equity) and Senegal's Sovereign Fund for Strategic Investment (FONSIS) (32% of the project equity)[1]. Solairedirect is appointed as the EPC contractor for the project and contracted to offer the O&M services required for it. Schneider Electric supplies the inverters and transformers.

The project involves the local population throughout the construction period by organising public consensus-building meetings and forming a monitoring committee that assists the developer in recruiting local labour for construction and plant operations. The EPC firm, Solairedirect and the numerous subcontractors employed approximately 350 people during the construction phase and 150 from the surrounding villages. The plant was completed with 92,160 modules of 320 W each and spread over 64 hectares. It was commissioned in June 2017 and completed in a single phase for €41.15 million[2].

The average annual power generation from the project is estimated at 50,004 MWh. During the six months from January to June of the calendar year 2018, the plant exported 25,807 MWh to the grid, which quantum was aligned with the estimated output. The plant provided electricity equivalent to the annual consumption of 226,500 inhabitants. It brought about positive consequences on their health and educational outcomes at prices more competitive than those offered by thermal power plants operating in the country. In addition to the immediate social benefits, the solar PV project helps mitigate greenhouse gas emissions projected within the CDM application. The Santhiou Mékhé project is registered as a Gold Standard CDM project.

MONITORING PERIOD	ACTUAL PRODUCTION (IN MWH)	ACTUAL EMISSION REDUCTION ACHIEVED(IN TCO2E)
01/05/2017 – 30/06/2018 The project was commissioned on 28 July 2017	42,655	28,993
01/07/2018 – 30/09/2019	62,175	42,259
01/10/2019 – 30/09/2020	49,845	33,879

Source: Monitoring report form for CDM project activity, CDM: Grid-connected Solar PV project in Méouane (unfccc. int), last accessed 28 June 2022

This project responded magnificently to the objectives of the state that is, to increase the production of electricity through the promotion of renewable energies in general and solar PV in particular. The PV project helped Senegal become the leading West African country concerning grid-connected non-hydro RE development. The five-year period from the first application to the commissioning of the solar power plants witnessed a series of legal measures as well as the creation of a dedicated department within Senelec. The government's provision of sovereign guarantees to minimise the off-taker risk might be considered a decisive factor that facilitated the project's achieving financial closure. The agreed-upon power purchase agreement (PPA) tariff was at the level of Senegal's than the average variable cost of generation and thus guaranteed long-term tariff stability for investors.

The Santhiou-Mékhé project provides Senegal with energy security and helps conserve scarce foreign exchange earnings. The project also helps reduce emissions by producing electricity without adding to the country's greenhouse gas emissions. Above all, the project serves to demonstrate Senegal's attractiveness as an investment destination, especially for investments in the solar PV sector.[3]

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An Off-grid Solar Access Project For Underserved Regions

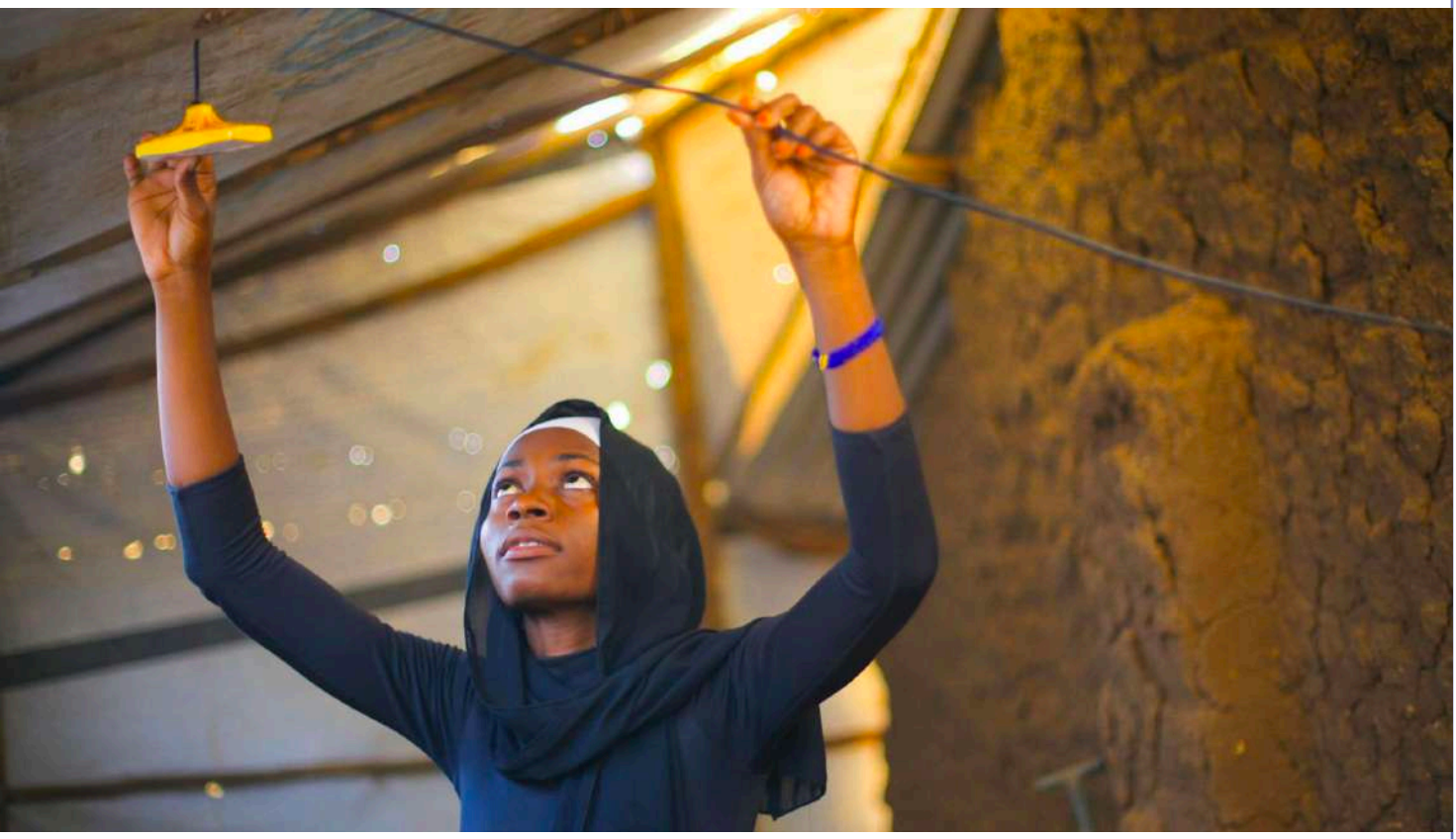
According to official reports, almost 90 per cent of the electricity requirement in Kenya is sourced from Renewable energy sources as of 2022. The Kenyan government has started an off-grid solar project to further develop RE power generation and reach the sources to rural communities and the urban poor.

As of 2019, about 5.5 million Kenyan households are connected to the utility grid, and an estimated 4.0 million households are yet to receive access to electricity supplies. Kenya targeted achieving grid connectivity for about 3.0 million new users, while the rest would be served through off-grid solutions. The Government of Kenya has developed a plan for innovative power generation from RE sources and effective distribution towards achieving Kenya's Vision 2030 of augmenting energy supplies to rural communities and for the urban poor. It can be accomplished by providing rural households, small businesses, and community and public facilities in remote locations with solar mini-grid, stand-alone systems, water pumps and household systems.

The Kenya Off-grid Solar Access Programme ('K-OSAP'), a project registered with the UNFCCC – Clean Development Mechanism (CDM), aims to operate within 14 counties in Kenya that are not served by the national grid; the underserved counties collectively constitute 72% of the total population[1]. Under the K-OSAP, two types of Component Project Activities ('CPA') are proposed to be implemented: (i) CPA01: Stand-alone solar home systems for households under the CDM Methodology and (ii) CPA02: Solar mini-grids and standalone solar systems for community facilities, and solar water pumps for community facilities under the CDM Methodology[2]. According to the Programme of Activities ('PoA') of CDM, project number 10515, registered on 22 November 2019, each component project activity – pumping, mini-grid and home systems – would achieve emission reductions of up to 20,000 tCO2e each year[3]. The K-OSAP was to be implemented by the Rural Electrification and Renewable Energy Corporation ('REREC'), the Ministry of Energy ('MoE') and the Kenya Power and Lighting Company ('KPLC'). Some counties expected to benefit from this programme were West Pokot, Marsabit, Wajir, and a few other counties in Northeast and Northern Kenya.

The total project cost[4] is estimated at USD 155 million. The K-OSAP is largely financed by the World Bank[5] and K-OSAP service providers are backed by two types of funding: result-based funding ('RBF') and debt from SunFunder (www.sunfunder.com), a debt financing service provider for solar projects and climate-conscious initiatives in underserved parts of Africa and Asia. The K-OSAP, being categorised as a CDM-registered project, is required to adhere to monitoring requirements to claim the issue of emission reduction certificates (CER), and the carbon credit rights are to be transferred to the Rural Electrification Authority ('REA')[6] in Kenya.

The International Renewable Energy Agency (IRENA) reported aggregate installed solar PV capacity in Kenya (grid-connected and off-grid combined) at 106MW in 2019, 106MW in 2020 and 147MW in 2021. Of this total volume, off-grid installations were estimated at 49.393MW at year-end 2019 (shortly after the registration of the CDM-registered project discussed herein), 49.477 MW in the year 2020 (reported as unofficial estimates) and 49.477 MW in the year 2021 (IRENA estimates). As a result of these reports, and while the implementing agencies are still required to submit monitoring reports, it has been impossible to link specific accomplishments to the expenditures and pledges made for the current project.



Standalone Solar Systems for Households – Results-Based Financing (RBF) Facility
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Nexamp's Economical French Road Solar Project in Illinois

This case study is about the model by Nexamp in Illinois for providing renewable energy solutions. It has set up a clean energy model and helps consumers to save about 10-20% on their utility bills. This model is a step towards the state's target of achieving 100% cleaner energy by 2050.

Community-owned Solar PV has been one of several approaches adopted to encourage the deployment of cleaner energy capacity while accumulating resources and serving to spread risks among members of the community. One such initiative is the 'French Road' solar PV Project, a 2.80 MWp community solar installation in Illinois, USA, comprising 7,000 solar modules and sized to supply an estimated 400 homes in the community.

Nexamp, a Burlington, Illinois-based company, has installed the solar power plant and has committed to exporting cleaner energy to the local grid. The power plant contributes to reducing greenhouse gas emissions to about 3.0 million tonnes each year, relative to a fossil-fuel-based counterfactual[1]. The project is designed and built to meet the energy requirements of various consumer categories like apartment dwellers, homeowners, businesses, and community organisations. The joint–ownership model enables the participation of the very consumers through leasing or purchasing project capacity equivalent to a maximum of 120% of their respective monthly electricity usage. Such consumers then receive credit on their monthly electricity bills in proportion to the energy produced by the individual consumer's share of the installation[2].

The project design also provides the landowner to avail a share of the revenue while extending requisite support for the installation of the project. This model appears convenient to consumers who seek to benefit from the solar energy generated by the project but otherwise face constraints in accommodating the plant on their respective rooftops. Nexamp claimed that the model helps households save between 10% and 20% on their electricity bills[3].

Illinois passed the Climate and Equitable Jobs Act (SB 2408) in September 2021. The enactment charted the path to achieving the state's cleaner energy goals and set a target of supplying the state with 100% cleaner energy by the year 2050. The law also provided for actions that could expedite the energy transition in the state. This enactment was followed by the approval of permits for about 250 MW capacity of new community solar projects in Illinois alone[4].

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An Affordable Credit-based Solar Water Heater Programme For Households

The Tunisian government has started a program, 'Prosol', that provides financing options like loans and subsidies for households to use solar water heaters. This program has helped the Government to reduce CO2e emissions and abide by sustainable development norms. This article briefly studies the Prosol programme in Tunisia.

Prosol, the Tunisian Solar Programme, was launched in the year 2005, jointly by the Tunisian Ministry of Industry, Energy, and Small and Middle Size Enterprises and the National Agency for Energy Conservation of Tunisia, with support from the United Nations Environment Programme (UNEP) and the Italian Ministry of Environment, Land, and Sea.

The 'Prosol' program focused on transitioning from using fossil fuels for heating water to using solar water heaters ('SWH') among households in Tunisia. Prosol is designed to provide effective financing backup and to overcome market barriers by using an interest buy-down subsidy as an affordable end-user credit mechanism. Out of the 14% interest charged by the financial institutions engaged in lending for the purchase of solar water heaters, UNEP paid 7.0% interest on behalf of the borrowers. This interest subsidy was financed by almost USD 1.0m as a part of UNEP's Mediterranean Renewable Energies Programme ('MEDREP'). Simultaneously, the Tunisian Government paid for 20% of the cost of each solar water heater to provide a capital subsidy to make the purchase more affordable.

Each customer availing of this facility can repay the loan to buy a solar water heater over five years through the electricity bill. Subsidised LPG supply in Tunisia is routinely employed to heat water using 'gas geysers'. The program seeks to shift public attention and promote a switch from using subsidised LPG to solar thermal water heaters. Owing to the Prosol program, during the year 2005 alone, an estimated 7,200 SWH were reportedly installed in the country[1].

Following the effective and reportedly successful implementation of the Prosol program, in January 2007, the Tunisian National Agency for Energy Conservation ('ANME') launched a solar thermal program named "Prosol 2 – Residential[2]. This program aims at installing 30,000 solar water heaters each year and is registered with the UNFCCC – Clean Development Mechanism to validate and internalise the environmental benefits. This program is designed to encourage households to avail loans for installing solar water heaters ('SWH').

Towards the end, ANME acted as the Coordinating and Managing Entity (CME) and agreed with the Tunisian Electricity and Gas Company ('STEG') and Attijari Bank, Tunisia to facilitate such off-take[3]. ANME acts as the intermediary between the households that seek to install solar water heaters and the suppliers/installers of the SWH. Attijari Bank offers loans to households for the purchase of SWH, and STEG permits this loan to reimburse the electricity bill over five years. In addition, the Tunisian Government also grants a capital subsidy for purchasing the SWH.

Cumulatively 103,427 SWH were installed in Tunisia by the end of 2011. The baseline emission reductions are estimated at 104,600.8 tCO2e. The program is reported to have achieved 90,510 tCO2e in emission reductions. It was later seen that by the end of 2015, about 270,000 SWH were installed, which helped mitigate 700,000 tonnes of CO2e.

The Prosol 2 – Residential Program was applauded for the cooperation secured from a range of stakeholders involved, including the Tunisian Government, from the financial intermediaries – with banks providing an estimated USD 71.0 million in loans and private financial institutions providing USD 224 million in funding, and from the end-users who purchased the solar water heaters. In addition to invigorating the water heater industry, the Program is believed to have created about 3,500 direct employment opportunities[4]. Given this record of performance, in 2017, the National Subsidy Scheme 'Prosol' was extended till 2020, and the ANME invited banks to bid for loan disbursement programmes till 2020. STEG has also allocated a budget of about TND 120 million for continued implementation of the program[5].

PROSOL: Financing Solar Water Heating in Tunisia
Source: https://www.inno4sd.net/prosol-financing-solar-water-heating-in-tunisia-454

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Solar Powered Water Heater Project For Dairy Farmers In Costa Rica

Similar to households and organisations, dairy farms too have a considerable amount of energy consumption. A company, Enertiva, has come up with a solar solution for these dairy farmers. This project aims to provide better and improved solar water heaters as well as credit for buying these.

Dairy farmers in Costa Rica milk the cows on the farms and sell the milk to milk-purchasing cooperative Dos Pinos (https://www.cooperativadospinos.com/). The cows are milked twice per day and milk is kept in refrigerated tanks. Dos Pinos collects the milk from the tanks on alternate days. After each use, the milking equipment and the tank have to be cleansed with cold water, detergent and ultimately with hot water raised to 50°C to sterilise all parts of the system. The hot water wash is necessary since Dos Pinos is particular about the bacterial content in milk; they usually reject milk with high bacterial content.

A typical 60-cow dairy needs about 450kWh of energy per month on average, for heating water through to 50°C, translating into a cost of about € 125 per month for the farmer. Heating water constitutes a significant expense for a dairy farmer – but it is necessary because failing to use hot water to sterilise the system will lead to rejection and a substantial loss for the farmer.

In 2009, Enertiva (https://enertiva.com/), a Costa Rican solar solutions company, partnered with Dos Pinos to develop specialised solar water heaters to meet the needs of dairy farmers. The company modified its solar water heaters to include a control system that would monitor the water temperature, turning on a heating or a cooling element to maintain the water temperature at the pre-set level. Farmers can set the controls to suit the schedule for milking and milk collection. The modified unit consists of 20 tubes and a 200-litre tank, has a life of 20 years, and cost about €1,250. Enervita provides a five-year guarantee on the system. The only maintenance needed is to wash the outer surfaces of the collector tubes monthly, to prevent dust and debris from blocking sunlight. Dos Pinos provides loans to the farmers at 14% interest to buy these modified solar water heaters.

By 2017, Enertiva had installed 378 solar water heaters in 337 dairy farms, of which 312 were in Costa Rica, 15 in Guatemala, and 10 in Panama. Farmers were able to save between USD 120 to USD 300 per month, and also repay their loans within 12 months. Enervita estimated that 700 tons of CO2 are saved per year since the year 2009.

The solar water heater is a cost-effective and pragmatic solution for the farmers. In 2015, Enervita won the prestigious Ashden Award for the solar water heater project[1].

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Remitenergy– A Financial Model Of Remittance Payments For Clean Energy

People in underdeveloped nations have very little access and exposure to sustainable energy solutions. Remitenergy is a project in Haiti that aims to bridge this gap. This case study is about this project that provides remittance payment facilities for workers to purchase solar energy products.

In the early years of the present century, Haiti was among the poorer nations in the world, with a mere 12.5% of the country's population having access to electricity. Haiti's economy relies heavily on remittances sent home by Haitian immigrants in the USA. Remittances contribute to nearly 26% of the country's GDP, amounting to USD 1.5 billion (~€1.1 billion). Inter-American Development Bank and Clinton Haiti Fund collaborated with Arc Finance to develop a unique financial model tapping into these inward remittances to provide Haitians with a sustainable energy solution.

'Remitenergy', as the project is called, enables migrant Haitian workers living in Miami to direct a part of their remittance payments towards the purchase of solar energy products. The payments happen through a remittance agent affiliated with FoodExpress, a Haitian-owned remittance company. Money Transfer Organization SagoExpress, with 56 stores across Haiti, is responsible for purchasing solar products at wholesale prices from a local distribution partner. It is also responsible for delivering the product with the appropriate warranty to the respective families.

The project was launched in April 2012, with an implementation period of two years. Over the two years, 5,000 solar lanterns with and without mobile phone charging ports and mini solar home systems have been sold. The pilot successfully presents remittances as a viable means of financing cleaner energy. The model is considered self-sustaining and continues to operate beyond the initial test period.

The project reported that by 2016, over 82,000 cleaner energy products were retailed, benefiting approximately 410,000 persons and leading to a 30 per cent reduction in household energy-related expenses of the beneficiaries. In all 165kW of clean energy capacity was deployed, and this reduced about 7,000 tons of greenhouse gas emissions[1]. As of 2021, the project continued to pave the way for energy access in Haiti.

The model is replicated in Bolivia, where migrant workers living in Spain contribute to purchasing solar water heaters. Feasibility studies are also conducted for replicating the model within countries in Central Asia[2], where inward remittances play a significant role in the economy.

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An Ingenious Project Of Energy Communities For Clean Energy In Portugal

As of 2023, hydro and wind energy contribute a significant part to power generation in Portugal. The country also aims to install solar power plants for greater use of renewable energy sources for power generation. Cleanwatts is one such project that facilitates clean energy through communities and works in around 100 villages

Cleanwatts, a Portuguese clean energy technology company, launched the CemAldeias ('100-villages') project, designed to create Renewable Energy Communities (RECs) in Portugal to fight energy poverty in the country. In August 2021, CleanWatts inaugurated its first community in Miranda do Douro, a small rural village close to Potugal's border with Spain. The community has more than 100 members, including Santa Casa da Misericórdia, a well-known charitable institution in Portugal, housing nursing homes, and a kindergarten.

As part of the project, 73kWp of PV capacity is installed on the rooftops of community members, providing the REC with an energy autonomy of 33% (90 MWh/year) and reducing the release of an estimated 19 tons of carbon dioxide emissions in the first year of its operation alone. eRedes, a power distribution company under Portugal's national electricity utility Energias de Portugal (EDP), helps analyse the production and consumption profiles of community members and distributes the surplus energy to balance generation and consumption. The energy markets platform 'Kiplowas' is used to aggregate small and medium energy loads[1].

Cleanwatts raised €67,000 through crowd-lending on the GoParity Platform for the RE Communities launched in the villages of Castelões and Soutelinho da Raia. A total of 171kWp of solar PV capacity is installed, projected to produce about 140MWh of clean energy per year, on average. Participants in the Energy Communities do not have to make any investments or change their contracts with the incumbent energy supplier. During sunlight hours, customers substitute a portion of the energy they consume from a local energy supplier with green energy from the rooftop solar installation. Cleanwatts also conducted training programs through its digital energy management tools – *Kisense, Kiome and Kiplo* Energy Communities – which trained the Energy Communities on monitoring the generation and consumption of energy, identifying additional opportunities for saving on energy efficiency measures and other related topics[2].

By the end of 2021, Cleanwatt had launched six Energy Communities in Portugal, with an installed capacity of around 530 kW, allowing for savings of more than €30,000 per year. Another 18 Energy REC proposals are in the process of achieving financial closure or in the installation phase and it is expected that participants will save about €185,000 per year. Cleanwatts plans to reach the goal of powering 100 communities by the end of 2022, involving an investment of about €20 million and deploying a production capacity of 17.5 MW while serving over 1,500 members[3].

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BGFA - The Financing Model For Sustainable Energy In Rural Regions Of Africa

This is a case study about Beyond The Grid Fund in Zambia, Africa, which provides off-grid solar solutions to households and businesses. The Project helps in the sustainable financing of resources and their energy generation.

Large proportions of the rural populations of Sub-Saharan African countries have no access to electricity networks. Widely dispersed populations and challenging geography make it expensive for governments and utilities to reach such areas through the grid network. Several companies and non-governmental organisations are engaged in providing off-grid energy solutions in underdeveloped African regions through mini-grids and solar home systems (SHS). Yet, such companies face several challenges in scaling up their business ventures, given the high overhead costs relative to the revenues from systems or services, leaving vast expanses without access to electricity. Beyond Grid Fund Africa (BGFA) aims to incentivise the private sector to reach the 'last mile' and to bring clean, affordable, off-grid energy access to rural people[1].

A pilot project was launched in Zambia in 2016, called Beyond the Grid Fund for Zambia (BGFZ) intending to connect at least 190,000 households to provide clean, affordable, reliable off-grid energy access by 2021. The Swedish International Development Cooperation Agency contributed €48.0 million to the BGFZ project, and it was implemented by Austria and Vienna-based Renewable Energy and Energy Efficiency Partnership.

The project calls for proposals from off-grid energy companies to compete for funding and provided incentives to four energy service companies to enter the market. Financing is offered to the companies on a 'per-connection' basis. The fund also focuses on capacity building, technical assistance to local energy authorities, general stakeholder outreach and developing market intelligence.

A national Off-Grid Energy Task Force is formed in Zambia, led by the Ministry of Energy working in collaboration with the Office of the Vice President, while REEEP provides secretarial services. The Task Force facilitates the implementation of 'VAT exemption' for LED lights, the drafting of a new national mini-grid policy in Zambia and the initiation of discussions to improve the affordability of off-grid energy solutions. Data from the BGFZ companies are gathered and analysed through the custom-built Energy Data and Intelligence System for Off-Grid Networks (Edison). Edison connects to the contracted energy provider companies' internal systems and provides live information on energy service subscriptions sold, payments, upgrades and warranty events, among other data points[2].

In recognition of its efforts, BGFZ was awarded the 2019 Ashden Award for Innovative Finance and a 2019 UN Global Climate Action Award. The data collected from the pilot project in Zambia was used for similar implementation in other African countries. As of 2022, the BGFA program was at different stages of implementation in the Democratic Republic of Congo (BGFA4), Uganda (BGFA3), Mozambique (BGFA2), and Burkina Faso, Liberia and Zambia ("BGFA1"). In addition to the contribution from Sweden, these follow-on projects also received funding from Denmark, USA, Germany, Norway and several other donor countries[3].

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Bhutan's First Grid-Connected Solar Power Plant

Growing concerns about Bhutan's rising energy demands while maintaining its carbon negative status led the country to pursue further renewable energy alternatives. Their efforts led to the deployment of their first hybrid energy project, using both wind and solar energy to generate power.

With more than 70% of the Kingdom's land area under forest cover, Bhutan has been a 'carbon negative' country for several decades of the last century. A majority of the country's electricity needs are met by hydro-power with relatively minor imports from neighbouring countries like India. However, events like Glacial Lake Over-Flows (GLOFs) and flash floods have increased the volatility of hydro-power generation and threatened the country's energy security. Moreover, projected economic growth threatened the carbon-negative status of the country.

The Kingdom, therefore, was looking at tapping other energy sources like solar PV and wind generation. Bhutan's Department of Renewable Energy (DRE), at the time under the Ministry of Economic Affairs, received a grant of USD 210,000 (~€ 210,000) from the government of Japan – through the support of UNDP – for implementing a pilot hybrid project designed to harness both solar and wind energy.

Initiation of the pilot project took place in August 2021. It included a 600kW wind turbine plant and a 180kW solar plant at Ruebisa, Wangdue. Between 27 August and 31 August 2021, the hybrid project generated 2.76MWh of energy [1]. It is the country's first grid-connected solar power plant. Before this, solar power was only used for solar lamps in remote, off-grid areas of the country.

The wind-PV hybrid project engaged ten engineers from the Bhutan Power Corporation (BPC), who carried out the design, construction, installation, and grid integration work. The solar plant consists of 464 solar modules and is expected to produce 263,000 units of energy per year, which is approximately equal to the electricity demand of 90 Bhutanese households. The pilot project design and the operating hybrid plant are expected to serve as 'learning material' for Bhutan's renewable energy students and pave the path for further work in the sector[2].

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The Pay-As-You Drive 'e-Moto' Solution For Sustainable Development

Nowadays, E-motor vehicles are replacing traditional ones running on petrol and diesel. It helps reduce carbon emissions and attains environmental sustainability. This case study is about the e-motor initiative that is by Ampersand Solar with Bboxx.

Rwanda-headquartered Ampersand Solar build battery packs and electric motorcycles (also known as 'e-motos' or 'e-bodas') that offer a lower life-cycle cost relative to petrol taxi motorbikes. Such cost reductions are made possible by the company's proprietary battery pack, a network of battery swap stations and a software back-end that manages the energy system in real time. During the calendar year 2022, Ampersand served 620 motorcycles that covered a total of two million kilometres a month in Kenya and Rwanda.

After testing prototype models through 2018, Ampersand commissioned three battery swap stations and 20 e-moto taxis in 2019. It then grew its network to 5 swap stations and the fleet to 200 vehicles in 2020. The company's efforts are supported by FONERWA, USAID, Shell Foundation, Total Energies, and UK Aid [1].

By October 2022, Ampersand partnered with Bboxx to finance electric taxi motorcycles for drivers in Rwanda. Bboxx is already engaged in providing clean energy, clean cooking, smartphones and loans for communities in Africa. The partnership represents Bboxx's entry into mobility solutions. It requires Ampersand to provide the hardware – the e-motos and the battery swaps. The mobile payments are managed using Bboxx's 'Pulse', a fully integrated operating system that streamlines Bboxx's business operations [2].

The Motorcycle project provides an opportunity for employment of the youths while the lower running costs promise healthy incomes. The Pay-as-you-go and Pay-as-you-earn models are well-established for the incumbent motorcycles, and bike owners could pay per day or weekly for up to 24 months for a motorcycle [3]. The incumbent motorcycles are responsible for a sizable proportion of CO2 emissions in the country. The project intends to help Rwanda meet year-2030 climate targets. The business model is proven, and the partnership seeks to replace a large proportion of the estimated 5.0 million petrol taxi motorbikes that operate across East Africa.

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An Affordable Financing Option For a Rooftop Solar PV Project For a Bottling Plant

Many projects have been developed in Africa to support Sustainable financing. The initiative by Spark Energy Services is one such example. This project aims to increase the use of solar PV and reduce electricity generation costs for a bottling plant in Kenya. This is a case study about how the service provides affordable financing options.

Camco is an Accredited Entity of the Green Climate Fund (GCF), regulated by the UK Financial Conduct Authority and operates as an impact fund manager investing in relatively low-risk but high-impact projects located within developing countries. Camco operates offices in Ghana, South Africa, Finland, New Zealand, Australia, Singapore, the UK, and Canada. Spark Energy Services was formed by Camco to finance energy efficiency and captive solar PV projects within the commercial and industrial sector in Africa and managed from offices in Ghana/Accra, South Africa/Johannesburg, and Kenya/Nairobi.

Spark Energy Services has a financing agreement with Safi Power which provides 100% financing upfront to Safi Power for installing a 400kWp rooftop PV power plant in Mombasa, Kenya. Safi Power of Kenya installs and commissions the rooftop captive solar PV installation at Coastal Bottlers in Mombasa to supply reliable, cleaner and more affordable power for the company's bottling operations. The PV project commissioned in October 2022 slates to power the PET line sized to fill 26,000 bottles per hour.

Spark Energy funds the project. The project expects to generate approximately 600 MWh of energy on average per annum. It is anticipated that this will displace about 8,000 tonnes of GHG emissions relative to an assumed business as usual for the country's utility grid network. In addition, it is expected that the installation will lower the company's electricity costs by about 25% relative to the amounts paid to the utility for the same levels of electricity consumed [1].

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Uliastai - Mongolia's First Utility-Scale Power Plant

Uliastai is a solar PV power plant project in Mongolia that uses an advanced battery and energy system to produce clean energy. This project has an expansive scope and covers most of the households in the Zavkhan Province. This study briefly understands the financing of the project.

The '5.0 MW Uliastai' solar PV power plant in Mongolia is combined with a 3.60 MWh battery energy storage system (BESS) and advanced energy management systems to serve the rural areas in Zavkhan province. Commissioned in November 2022, the Uliastai project is the first utility-scale power plant and battery system deployed in the country. The project adopts a Sodium–Sulfur battery ('Na-S') that offers a 15-year operating life, provides improved fire safety and is slated to perform well in Mongolia's harsh winters. The battery system is designed to accept peak generation during the day and to supply the peak evening-time demand in the country [1].

The hybrid PV – BESS system is projected to supply 8.80 million kWh and 1.30 million kWh of charged–discharged energy. An estimated 8,000 households comprising some 48,000 consumers are projected to benefit from the energy supplied by the power plant. Relative to a projected business as usual (BAU) baseline, the power plant is estimated to avoid the emission of 223,813 tons of CO_2 over a 25-year horizon.

The project is implemented by Japanese plant engineering specialist JGC Holdings, NGK Insulators and local general contractor MCS International (construction, operations and maintenance). NGK Insulators manage battery supply, and MCS International manage construction, operations and maintenance. Given the specific nature of the baseline and the projected climate benefits, the USD 7.95 million project is funded by debt from the ADB alongside USD 6.0 million grant co-financing from the Strategic Climate Fund and the Japan Fund for the Joint Crediting Mechanism (JFJCM) [2]. The carbon reduction from the project is to be credited to Japan's achievement of carbon reductions, achieved through avoiding emissions in a developing country [3].

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An Affordable Financing Option For A Rooftop Solar PV Project For A Bottling Plant

This is a case study of the decentralised renewable energy service provided by First Electric in Nigeria. It is deployed as an energy-as-a-service model and seeks to lower electronic costs.

Around 30% of the population is estimated to be without electricity by 2030 in Nigeria, given the inertial rates of expansion of grid networks. It represents missing deadlines determined by Nigeria's Energy Transition Plan. The purchase of solar PV hardware and equipment for the productive use of such energy is out of reach for the median citizens in the country. Households and small and medium enterprises (SME) with energy demand in the 1 – 10kW range are most likely to be left out of the grid as well as by decentralised RE systems coverage. Further, the end-users in this segment also seek to work towards lowering their electricity costs.

Outright ownership of PV equipment, however, involves investments of the order of USD 900 – USD 10,000. Energy service provider First Electric seeks to mitigate the impact of the high upfront costs by providing decentralised RE as a service.

Under the energy-as-a-service model, the solar energy solution provider continues to maintain ownership of the hardware and charges consumers for the energy consumed. This is facilitated by a GSM prepaid smart energy meter connected to the network, topped up by the end-users.

EnAccess, a funding agency for open-source innovation, helps develop a smart meter that can be deployed one unit at a time, even in urban areas that might otherwise nominally be covered by the utility grid [1]. After assembling the meter, its performance is validated to confirm its accuracy and consistency. Following such testing and calibration exercises, the smart meter is set in the market for customer validation. End-users are also in a position to monitor power consumption and remaining credit remotely through their mobile phones.

Given the early stage acceptance from the market, the favourable message spread across regions and the demand for energy-as-a-service grew rapidly. By December 2022, the RE utility reportedly had a waitlist of over 500 end-users seeking a PV system combined with a pre-paid GSM-enabled smart meter [2].

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A Crowdfunding Finance Model For Solar Projects

Financing remains a fundamental issue when it comes to renewable energy projects. Various innovative models have been developed to overcome this challenge, one of which is this crowdfunding finance model by a US based company. It works through a website where investors and entrepreneurs can register themselves and be part of the projects.

Unlike traditional and centralised power plant projects, Renewable Energy (RE) projects involve high upfront capital costs (and relatively low operating costs), and accordingly, project development led by the private sector seeks to finance such investments on non-recourse finance (project finance) terms. However, due to the long tenures of such funding, the inherent uncertainty of resource availability and counter-party risks involved, attracting the required quantum of investment on favourable terms continue to be a significant challenge for the RE sector. In keeping with market circumstances, several innovative financing instruments and processes have been devised and employed to address such challenges over the years. However, mobilising adequate funding on favourable terms continues to prove challenging, especially in emerging economies[1].

It is often seen that venture capitalists and institutional investors avoid making investments in RE projects due to the given risk-return parameters. Individual investors make minor contributions but such volumes are not noteworthy. Under these circumstances, mainstream financial agencies seek to direct the path of innovation and project development through their investment choices[2].

Raise Green, a US-based company, aims to solve the problem of directed funding on favourable terms through the crowdfunding platform called 'Originator Engine'. The platform caters to two categories of clients: the clients who want to build a clean energy project (on the demand side) and potential investors who seek to find such clean energy projects (on the supply side). It is built in collaboration with IBM technologies. According to the company, people often get tired of waiting for governments and large organisations to 'get their acts together' and want to take climate-responsible action themselves.

With the Originator Engine, one can become an investor in a clean energy project with as little as USD 50. Investors just have to register on the company's website, pick a project to invest and then watch the project grow and deliver returns. Entrepreneurs with project ideas also have to register on the company website: such entrepreneurs are guided through project design and implementation to convert ideas into business propositions and to receive funding for the same. The company's 'business in a box' solution helps project developers cut down on paperwork and eases the process of project development.

Raise Green has received more than 60 project ideas since the launch of the platform in 2020 but focused on ten projects to develop by the end of year 2021. For instance, two solar projects in New Haven, Connecticut, USA, were funded by the platform and managed to raise a total of USD 82,000 from 133 investors[3]. The company raised the minimum investment value to USD 100 and funded several projects subsequently.

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VPP- The Virtual Power Plant Operating System For Clean Energy In The US

This case study is about the Virtual power plant installed by Sunrun in the USA. It has proved successful in 2022 to generate power using cleaner energy resources. The project continues to benefit the customers by enhancing grid reliability and helping during peak demand hours.

In 2019, Sunrun (NASDAQ: RUN) was awarded a contract to operate a virtual power plant (VPP) comprising home solar PV systems and battery storage systems that would add capacity value to the utility grid network [1]. Sunrun aggregated thousands of home solar and battery storage systems to operate a virtual power plant (VPP) that helps reduce the peak demand on the utility grid network and minimize the use of 'peaker plants' in the New England area. Home PV installations require to compete against polluting centralised power plants representing a shift to cleaner and decentralised sources of generation.

The virtual power plant exported over 1.80 GWh during the summer of 2022 spanning June, July and August. Most significantly, the output from the virtual power plant helps meet demand during the time window between 13:00 and 17:00 hours each day, which overlaps with peak generation from the PV plant. Further, the power demand in the region was projected to rise in tandem with the heat wave forecast for July 2022, and the VPP is said to have helped the system operator keep actual wholesale system demand below such forecast estimates.

The virtual power plant model demonstrates the use of clean energy resources to address capacity constraints while enhancing grid reliability for the Independent System Operator – New England (ISO-NE). It was reportedly the first successful season in 2022 in the USA, where a residential VPP operated within the wholesale capacity market. Solar PV installations were projected to deliver similar benefits in the winter months when customers were expected to use space heating at a time when transportation was increasingly being electrified [2].

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