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Chapter- 8

A Brief Review on Solar Photovoltaic: A Key to Sustainable Development

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Abstract:

Taking urgent steps towards embracing green or renewable energy sources is essential to address the increasing energy demands and tackle the ongoing climate crisis. To advance society's sustainable development, switching to solar energy is crucial due to its abundant availability and reliable, nearly limitless source, making it the most attractive option for an eco-friendly power source. Solar cells or photovoltaic devices are durable and reliable and can convert sunlight directly into electricity efficiently without producing noise or pollution. The popularity of solar panels depends on their cost, availability of raw materials, and efficiency. Currently, studies are underway to discover novel materials for solar photovoltaic devices. The objective is to find a system with high efficiency, lower cost, and improved durability. Current data ensure the worldwide progression of the use of solar cells and the increasing rate of efficiency improvement due to extended research.

Introduction:

Energy enhances convenience and comfort in our daily lives. Because of the increasing population and industrialization, the global energy demand is rising constantly. The majority of requests are satisfied through the use of non-renewable energy sources such as fossil fuel and nuclear energy. Overuse of fossil fuels leads to the release of greenhouse gases, resulting in climate change. To safeguard our environment and reduce pollution caused by greenhouse gas emissions, the Kyoto Protocol agreement (Tucker, 1999; Kalogirou, 2009) was implemented. Fossil fuels have a dual impact, affecting both the environment and the finite nature of their sources. The quest for alternative energy sources has been ongoing to address the increasing global energy demands (Tucker, 1999; Nandwani, 1996). Renewable energy sources such as geothermal, solar, wind, tidal, biomass, and hydropower are widely recognized. Clean energy, also called non-carbon-emitting forms of energy, is crucial for environmental sustainability, aligning with SDG 7: Affordable and Clean Energy, which aims to ensure access to affordable, reliable, sustainable and modern energy for all.

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Solar energy is the most appealing option because of its abundant availability and reliable, nearly infinite source (Muhammad et al., 2019; Yadav et al., 2023; Gajbhiye et al., 2024; Singh et al., 2024). This technology contributes significantly to SDG 13: Climate Action by reducing greenhouse gas emissions and supporting global efforts to combat climate change (Mukherjee et al., 2022; Chatterjee et al., 2023).

Humans have been utilizing solar energy for a long time, dating back to the 7^{th} century B.C., when they used sunlight to start fires by reflecting the sun's rays onto reflective surfaces. In the 3rd century B.C., the Greeks and Romans utilized solar power by using mirrors to illuminate torches during religious rituals. In 1839, French scientist Edmond Becquerel observed that a cell with metallic electrodes generated increased electricity in the presence of light, leading to the first recognition of the photovoltaic effect and the creation of the PV cell. In 1954, Daryl Chapin, Calvin Fuller, and Gerald Pearson invented PV technology at Bell Labs. He created the first solar cell capable of absorbing and converting sufficient solar energy to power standard electrical devices. Thanks to technological advancements, we can now use solar energy to fuel satellites and spacecraft that orbit the Earth. These innovations support SDG 9: Industry, Innovation, and Infrastructure, which promotes inclusive and sustainable industrialization and fosters innovation.

By encouraging the use of solar photovoltaics as a critical source of renewable energy, we also contribute to SDG 12: Responsible Consumption and Production, which aims to ensure sustainable consumption and production patterns by reducing reliance on finite resources like fossil fuels and adopting cleaner, renewable alternatives.

Photovoltaic cell and Photovoltaic effect:

A solar cell, also called a photovoltaic cell, is an electronic device that seizes light energy (specifically solar energy) and converts it into electrical energy using the photovoltaic effect. This is essentially a semiconductor-based p-n junction diode. A semiconductor's electrical conductivity lies between a conductor and an insulator. Doping techniques involving intentionally injecting impurities into pure semiconductors can help enhance their conductivity. We obtain either a P-type or N-type semiconductor based on the type of doping element used (trivalent or pentavalent). Excess of negatively charged electrons serves as the majority charge carrier in N-type semiconductors. In contrast, an excess of positively charged holes, which are the absence of electrons, characterize P-type semiconductors. When these two types of semiconductors are combined (using the proper fabrication process), holes from the p-side and electrons from the n-side diffuse through the junction, creating a layer of negative and positive charges on the p-side and n-side, respectively, and forming a depletion layer as depicted in Figure 1. Because of the stationary charge in vicinity of the P-N junction, an electric field is created (from the N region to the P region) that prevents the continued movement of holes and electrons in average condition.

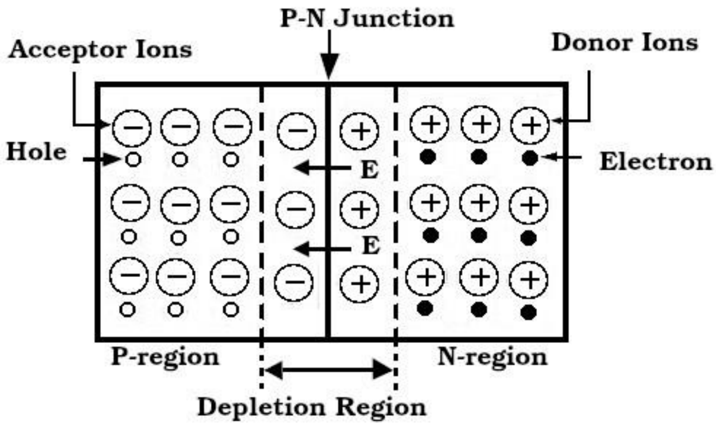

Figure 1. Schematic diagram of P-N junction diode with depletion region.

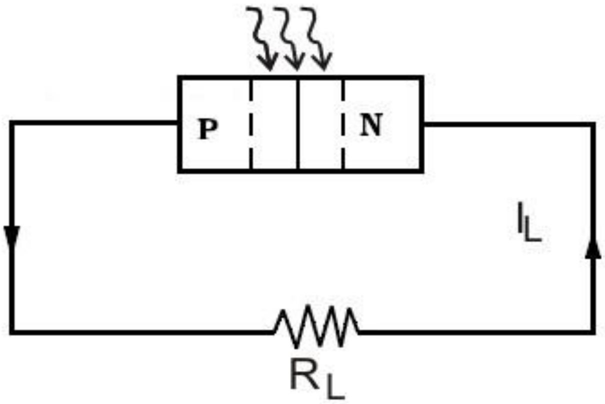

Figure 2. Schematic diagram of PV cell.

Now, suppose light with proper wavelength (for solar cells, sunlight) falls on the PN junction. In that case, the electron-hole pair is generated (Figure 2). If these mobile charge carriers reach the vicinity of the junction before they recombine, the electric field in the depletion region will push the hole in the P side and the electron in the N side. An accumulation of electrons and holes into N and P regions, respectively, generates an electromotive force. This accumulation continues till the electric field due to this accumulation is equal to the previous field generated due to diffusion.

Now, when the endpoints are connected through the load resistance (R_L), the current (I_L)will flow as long as light falls on the P-N junction, and this will act as a photovoltaic cell (PV) cell. The phenomenon is called the photovoltaic effect. When R_L=0, maximum current flows through the circuit, termed a short circuit current (I_{SC}). The open circuit voltage V_{OC} occurs if the circuit has the highest load. The typical open circuit voltage of a PV cell is approx 0.58 volts. Conversion efficiency, the most commonly used metric to assess photovoltaic technologies, is the ratio of electrical energy output to solar energy input. Efficiency results from various system components like short-circuit current, open-circuit voltage and fill factor, all of which are influenced by material properties and production flaws (Węgierek and Billewicz, 2011). The efficiency of a solar panel is calculated by dividing the power output by the total solar energy input.

The solar cell converts power at an efficiency of approximately 27%. Chapin et al. (1954) reported the first solar cell with 6% efficiency in 1954. The well-known Shockley-Queisser (SQ) limit establishes a maximum efficiency for commercially available technologies by considering the equilibrium between photogeneration and radiative recombination (Węgierek and Billewicz, 2013).

Practical structure of solar panel:

Most of the photovoltaic modules currently being used contain silicon solar cells. Silicon ranks as the Earth's second most abundant material, after oxygen. Silicon solar cells offer a lengthy lifespan, high efficiency, and affordable price. Module longevity is anticipated to be at least 25 years. It continues to produce more than 80% of its original power beyond this point. When exposed to sunlight, a typical solar cell generates a voltage of approximately 0.6V. Most applications require greater voltage than this. Solar cells are commonly linked in a series to create a photovoltaic module for proper voltage (Figure 3A), and these modules are then connected in parallel to achieve a higher current.

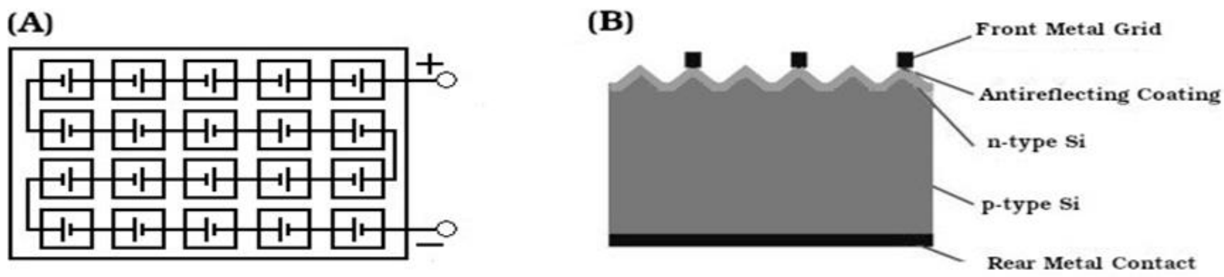

Figure 3. Schematic diagram of (A) a photovoltaic module and (B) a cross-section of a traditional silicon solar cell.

A silicon wafer of the p-type, measuring a few hundred micrometers in thickness and roughly 100 centimeters in size, is used to create a conventional silicon solar cell. The wafer, which forms the "base" of the cell, is weakly doped (about 1016 cm^{-3}). Silicon could be used as either a single- or multi-crystalline structure. Dopant diffusion forms an n-type layer on the wafer's surface, producing the required p-n junction. The n-type layer, also called the "emitter," is significantly thinner than the p-type base and more strongly about 1019 cm^{-3}). Figure 3B depicts a schematic cross-section of a silicon solar cell. The silicon wafer is usually texturized by chemical etching to reduce light reflection from its surface before the n-type emitter layer forms. To further improve light absorption, an antireflection coating can be applied to the surface after the n-type layer forms, made of sin_x or TiO_2, which can reduce reflections and act as passivation to keep charges from becoming trapped at the surface. To provide a back surface field that reduces surface recombination, the rear surface is more highly doped. After that, metal contacts are placed using a printing method, including screen-printing silver or aluminum. While the metal contact on the back of the cell can be continuous, as seen in Figure 3B, a grid-like metal pattern is printed on the front to restrict the quantity of light blocked.

Silicon solar cells can easily be damaged and corroded, so encapsulation steps are incorporated into manufacturing modules to offer adequate protection. The cells connected in series can be enclosed in a transparent polymer, like ethylene vinyl acetate (EVA), and then installed on a piece of glass, which serves as the top, see-through layer of the module. A further barricade against water and gases can be provided by adding another polymer layer, like polyvinyl fluoride, to the underside of the module.

Advancement of Photovoltaic cell:

Solar panels' popularity is influenced by cost, availability of raw materials, and efficiency. Various technologies are utilized in the production of photovoltaic cells, involving material adjustments to vary the photoelectric conversion efficiencies within the cell parts. Ideal material for solar cells will possess a band gap ranging from 1.1 to 1.7 eV and should have a direct band structure. Along these lines, it should also have high photovoltaic conversion efficiency and be readily available and safe for use (Hayat et al., 2019). Because of the development of several unconventional manufacturing techniques for fabricating operational solar cells, photovoltaic technologies can be categorized into four distinct generations (Luque and Hegedus, 2011; Almosni et al., 2018).

First generation: The initial photovoltaic cell technologies rely on mono crystalline (m-si) and polycrystalline silicon (p-si) as well as gallium arsenide (GaAs). Monocrystalline material is commonly utilized for its superior efficiency compared to multi-crystalline material. The estimated theoretical efficiency threshold for first-generation PV cells was around 29.4%, and a value close to this was achieved almost 20 years ago. The efficiency of crystalline silicon photovoltaic cells has increased by 20.1% since they were first developed, rising from 6% to a current record efficiency of 26.1% (Saga, 2010). Table 1 displays the contrast between initial photovoltaic cells (Sharma and Goyal, 2020).

Table 1. Comparison between first-generation photovoltaic cells (Sharma and Goyal, 2020).

Solar cells Based on	Band Gap (eV)	Efficiency (%)	Life span (years)	Advantages	Drawbacks
Monocrystalline silicon (m-si)	-1.1	15 - 24	25	High stability, high performance, long service life	High production cost, issues with absorption, increased sensitivity to temperature, loss of materials
Polycrystalline silicon (psi)	-1.7	10 - 18	14	Cost-effective, simple manufacturing procedure, reduced silicon wastage, more excellent absorption than m-si.	Lower efficiency, higher temperature sensitivity.

Gallium arsenide (GaAs)	-1.43	28 - 30	18	High stability, reduced sensitivity to temperature, and improved absorption compared to m-si	Extremely expensive

Second Generation: This category comprises the microcrystalline and amorphous silicon, copper indium gallium selenide (CIGS), and cadmium telluride/cadmium sulphide (CdTe/CdS). One important enhancement area required was decreasing the significant reliance on semiconductor materials. Regarding efficiency, CIGS holds a record value of 23.4%, which is on par with the top silicon cell efficiencies. They provide enhanced mechanical characteristics suitable for flexible uses, though this may result in decreased effectiveness. Table 2 compares second-generation photovoltaic cells relative to second-generation (Sharma and Goyal, 2020).

Table 2. Comparison between second-generation photovoltaic cells (Sharma and Goyal, 2020).

Solar cells Based on	Band Gap (eV)	Efficiency (%)	Life span (years)	Advantages	Drawbacks
Amorphous silicon (a-si)	-1.7	5 - 12	15	Cost-effective, non-toxic, abundant, high absorption coefficient.	Lower efficiency, challenges in choosing dopant materials, limited minority carrier lifetime.
Copper Indium Gallium Selenide (CIGS)	-1.7	20-23	12	Production requires a smaller amount of material.	Extremely expensive, prone to temperature variations, unstable, extremely unreliable
Cadmium telluride /cadmium sulphide (CdTe / CdS)	-1.45	15 - 16	18	High absorption rate, less material needed for manufacturing.	Lower efficiency, extreme toxicity of Cd, limited Te availability, higher temperature sensitivity.

Third generation: The third iteration of solar cells, which includes tandem, perovskite, dye-sensitized, organic, and new concepts, encompass a variety of strategies, from cost-effective but low-efficiency options (like dye-sensitized and organic solar cells) to pricey but high-efficiency choices (such as III-V multijunction cells) for uses spanning from buildings to space. The third-generation solar cells employ quantum dots, dye-sensitized solar cells, and organic polymers. Quantum dots are available in different sizes and can be customized in terms of their bandgap, which allows them to absorb light that is usually challenging to capture and to be combined with other semiconductors. Current silicon photovoltaic cell technology advancements focus on creating extra energy levels within the semiconductor's band structure. Current research efforts are focusing on enhancing the manufacturing technology and efficiency of third-generation solar cells. The most advanced and promising technology in photovoltaics is third-generation solar cells. Investigations on these are still ongoing. Table 3 displays the comparative analysis of third-generation solar cells (Sharma and Goyal, 2020; Peumans et al., 2003; Gao et al., 2020).

Table 3. Comparison between third-generation photovoltaic cells (Sharma and Goyal, 2020; Peumans et al., 2003; Gao et al., 2020).

Solar cells Based on	Efficiency (%)	Advantages	Drawbacks
dye-sensitized photovoltaic cells	5 - 20	Low production cost, lower operating temperature, efficiency in low light and wide-angle settings, robustness, and longer lifespan.	Issues regarding temperature control, and the presence of harmful and unstable substances.
Organic and polymeric photovoltaic cells	9 -11	Cost-effective processing, reduced weight, thermal stability, and flexibility,	Low efficiency.
Quantum dots	11 - 17	Low energy consumption and low production cost.	High levels of toxicity in nature, degradation
Perovskite	21	Low production cost and simplified structure, high efficiency, lightweight, and flexibility.	Unstable
Multi-junction solar cells	≥36	High performance	Complex, expensive

Fourth generation: Fourth-generation graphene-based solar cells have overcome the limitations of older generations thanks to technological advancements. The fourth-generation cell technologies are currently in the development stage. Fourth-gen photovoltaic cells, termed hybrid inorganic cells, blend the cost-effectiveness and adaptability of polymer thin films with the durability of organic nanostructures like metal nanoparticles, metal oxides, carbon nanotubes, graphene, and their derivatives. These tools, also known as "nano photovoltaics," maybe the bright future of photovoltaics (Wu et al., 2020). The fourth generation comprises inexpensive thin film, metal oxides, metal nanoparticles, graphene, carbon nanotubes, and graphene derivatives. Graphene provides numerous advantages for PV technology, including flexibility, stability, low resistivity, and photo-catalytic properties.

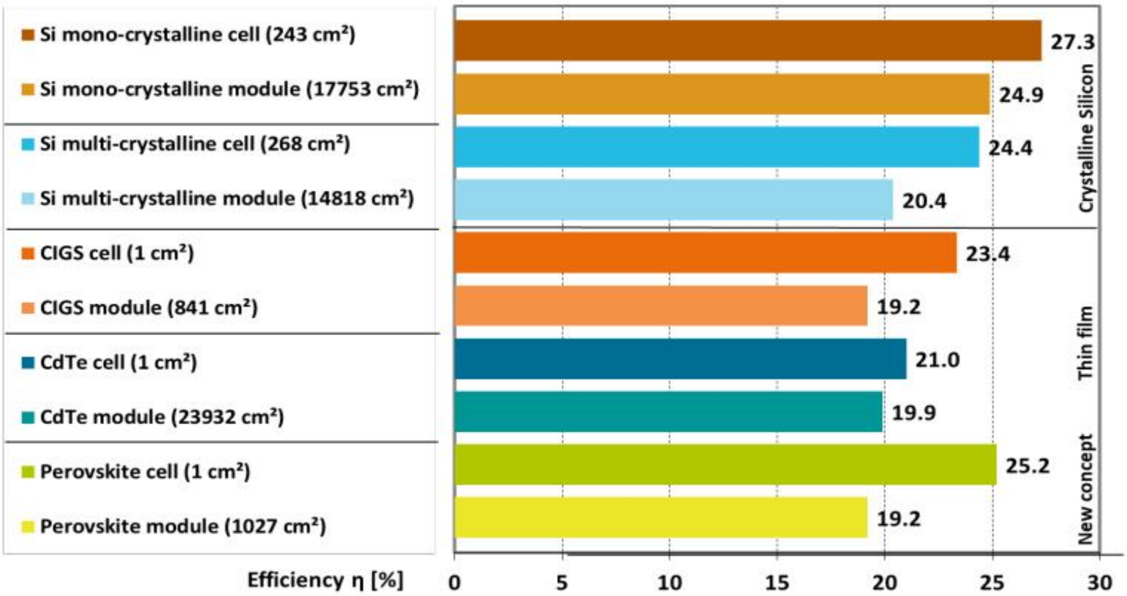

Figure 4. Efficiency Comparison of Technologies; Best Lab Cells vs. Best Lab Modules (Source: Data: (Green et al., 2024). Graph: PSE Projects GmbH 2024. Month & Year of data: 06/2024).

Based on the most recent data from the indicated source in the figure caption, Figure 4 illustrates the efficiency comparison between the best laboratory cells and the best laboratory modules based on technology. During recent years, the cell-to-module ratio (CTM) in mass production has seen improvement through decreased losses and increased utilization of potential gains from solar cell integration into modules.

Types of Photovoltaic Cells:

Thin-Film Photovoltaic: A thin-film solar cell is created by applying thin layers of PV material onto a substrate such as glass, plastic, or metal. Currently, two primary kinds of thin-film PV semiconductors are available for purchase: cadmium telluride and copper indium gallium selenide (CIGS). Both materials can be applied directly to the front or back of the module surface. CdTe, the second most prevalent photovoltaic material following silicon, can be manufactured into cells using affordable processes. Although this factor makes them a cheaper option, their efficiencies need to match up to those of silicon. CIGS cells possess ideal characteristics as a PV material and demonstrate high efficiencies in the laboratory setting. Yet, the intricacy of incorporating four elements complicates the shift from lab scale to mass production. CdTe and CIGS need more protection than silicon to ensure extended durability when utilized outdoors.

Perovskite Photovoltaic: Perovskite solar cells are a thin-film cell type named after its unique crystal structure. Perovskite cells consist of layers of materials that are applied through printing, coating, or vacuum deposition onto a base layer known as the substrate. Typically, they are simple to put together and can achieve efficiencies on par with crystalline silicon. Perovskite solar cell efficiencies in the lab have increased more rapidly than any other PV material, rising from 3% in 2009 to 25% in 2020. To be economically feasible, perovskite PV cells must last outdoors for 20 years, prompting scientists to improve their durability and create inexpensive manufacturing methods on a large scale.

Organic Photovoltaic: Organic photovoltaic (OPV) cells consist of carbon-rich compounds and can be customized to improve a specific PV cell function, like bandgap, transparency, or colour. OPV cells are currently half as efficient as crystalline silicon cells and have shorter lifetimes, but they may be cheaper to produce in large quantities. OPV can also be used with a range of supporting materials, including flexible plastics, which makes it versatile for many different purposes.

Quantum Dots: Quantum dot solar panels generate electricity by utilizing minuscule semiconductor particles known as quantum dots, which are only a few nanometres in size. Quantum dots offer a novel method for handling semiconductor materials, yet establishing an electrical link between them is challenging, resulting in lower efficiency levels. They can be applied to a surface through spin-coating, spraying, or roll-to-roll printing methods, similar to those utilized in newspaper printing. Quantum dots are available in different sizes and can have their bandgap adjusted, allowing them to absorb light that is hard to capture and be combined with other semiconductors, such as perovskites, to enhance the efficiency of a multijunction solar cell.

Multijunction Photovoltaic: An additional approach to enhance the efficiency of PV cells involves stacking various semiconductors to create multijunction photovoltaic systems. These cells consist of stacks of various semiconductor materials, unlike single-junction cells that contain just one semiconductor. Every layer possesses a distinct bandgap, enabling them to capture varying sections of the solar spectrum and utilize sunlight more efficiently than single-junction cells. A solar cell with two bandgaps is called a tandem solar cell, although all solar cells with multiple bandgaps are categorized as multijunction solar cells. Multijunction solar cells have shown efficiencies exceeding 45%; however, their production is expensive and complex, making them suitable only for space missions.

Concentration Photovoltaic: Concentration PV, or CPV, directs sunlight onto a solar cell through a mirror or lens. Focusing sunlight on a small area reduces the amount of PV material needed. PV materials show increased efficiency with higher light concentration, making CPV cells and modules achieve the highest efficiencies overall.

Applications:

There are various applications in diverse fields, like

- as a power source for the International Space Station, Earth-orbiting satellites, etc.
- as a power source in remote areas
- as an alternative energy source in the home, industrial sectors, etc.
- in vehicles, it acts as auxiliary power devices
- in devices like calculators, solar chargers, solar pumps, etc.
- In military uses.

Worldwide Progression Status and India Government Policy:

With the world recognizing the importance of sustainable energy solutions, governments around the globe are introducing different incentives to encourage the use of solar power. These incentives aim to promote investment, lower costs, and accelerate the implementation of solar power facilities. Figure 5 (source of data provided in figure caption) shows that annual production has grown by a factor of 13 in the last ten years. Around 95% of solar modules and their parts were sourced from Asia in 2023, mainly from China. China has an 80% share in module production and dominates over 95% of the market for specific components like ingots and wafers. Figure 6 shows a significant increase in grid connection over time. Presently, around 99.6% of the PV capacity that has been installed is linked to the grid. The percentage of off-grid systems has decreased by around half over the years, dropping from almost 1% in 2010 to 0.43% in 2023. Figure 7 guarantees the enhancement of various types of solar cell efficiencies over time due to progress in research and technology. By 2023, China held the top globally, with a 35.6 % share of solar energy consumption. During that time, the US was responsible for about 14.7% of global solar consumption, positioning it as the second biggest solar power consumer on a global scale. In India, there has also been a notable rise in the utilization of PV, making up around 7% of the total PV capacity worldwide. Figure 8 clearly illustrates the year-wise cumulative PV Installation, with the data source provided in the figure caption.

To promote sustainable development and the welfare of the people, the Ministry of New and Renewable Energy, Government of India, has launched the PM Surya Ghar: Muft Bijli Yojna. Rupees 75000 crore has been allocated to illuminate one crore homes by supplying up to 300 units of complimentary electricity. The Indian government is introducing the Production Linked Incentive (PLI) Scheme for the National Programme to boost efficient modules' solar PV manufacturing capacity, introduce advanced technology in India for producing high-efficiency modules, and encourage establishing integrated plants for improved quality control and competitiveness. The goal is to create a system for obtaining materials locally for solar manufacturing, increase employment and achieve technological independence.

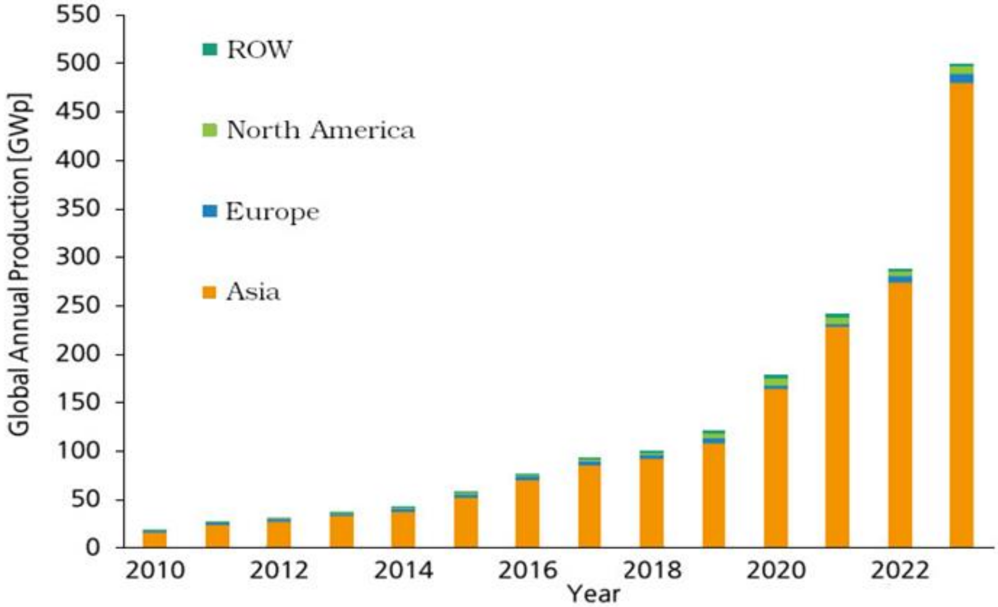

Figure 5. PV Module Production by Region (Source: Data: from 2010 to 2021 IHS Markit from 2022 estimates based on IEA and other sources. Graph: PSE Projects GmbH 2024. Month & Year of data: 04/2024).

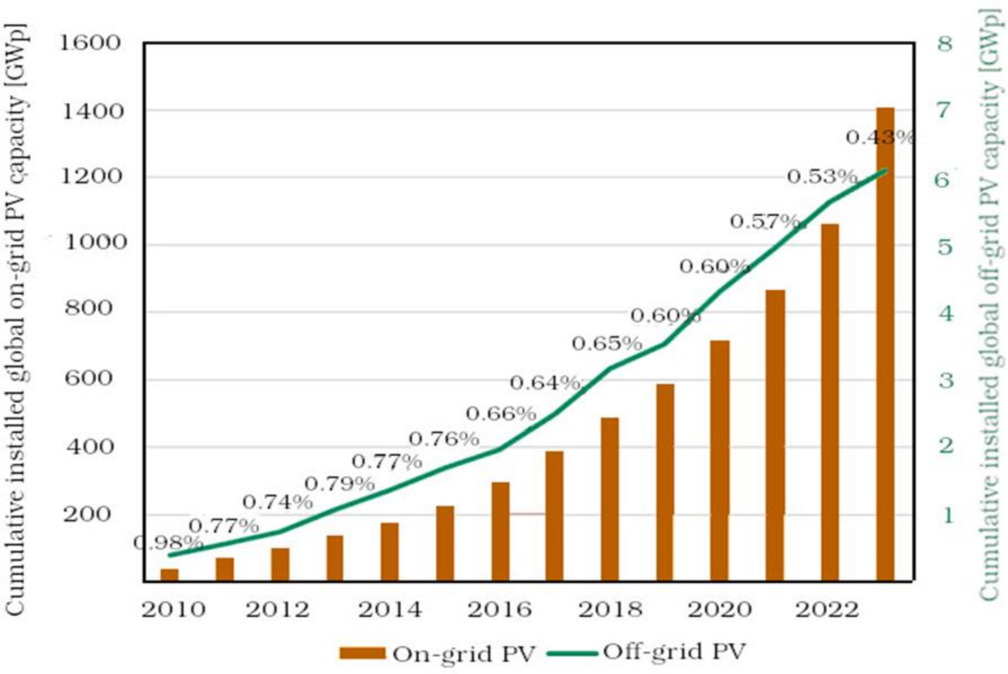

Figure 6. Global Cumulative PV Installation by on-grid & off-grid installation type (Source: Data: IRENA 2024. Graph: PSE Projects GmbH 2024. Month & Year of data: 04/2024).

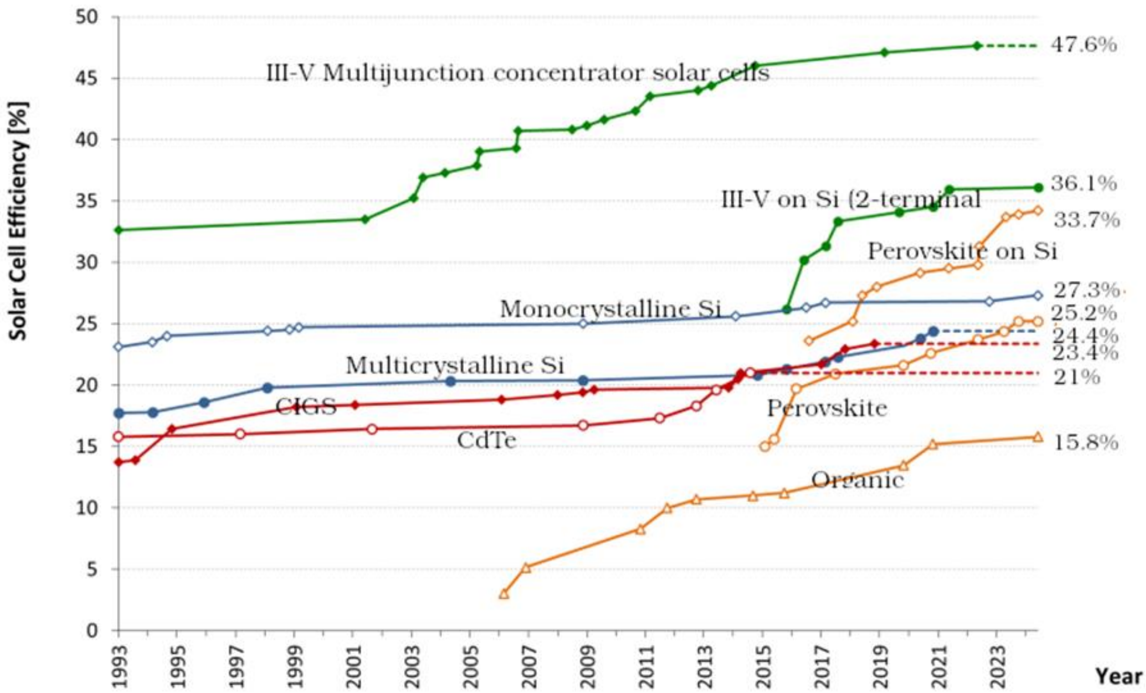

Figure 7. Development of Laboratory Solar Cell Efficiencies (Source: (Green et al., 2024), 1993-2024. Graph: Fraunhofer ISE 2024. Date of data: 06/2024).

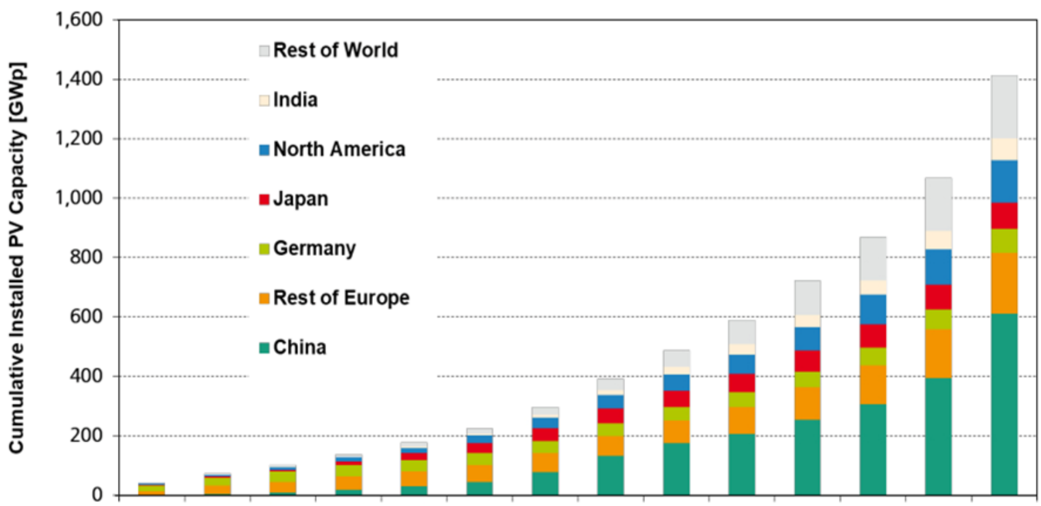

Figure 8. Global Cumulative PV Installation year-wise (Source: Data: IRENA 2024. Graph: PSE Projects GmbH 2024. Month & Year of data: April-2024).

Advantages and disadvantages of photovoltaic systems:

Advantages	disadvantages
• Renewable and Sustainable energy source • cost-effective in the long run • Flexible and highly reliable • Low maintenance cost • Long life span • Zero fuel consumption • safe in use • Energy independence	• Initial or startup cost is high • Weather dependent • Required external energy storage device • Constraints of sufficient space • Scarcity of materials • Difficulties in relocation • Recycling or disposal issues

Conclusion:

Photovoltaic (PV) is a simple and fashionable method of harnessing solar energy. Photovoltaic devices or solar cells can directly transform sunlight into electricity without creating noise or pollution or needing moving components, guaranteeing their long-lasting and dependable nature. This article explains how solar cells are based on the same principles and materials as the communications and computer industries and discusses how photovoltaic devices work and their various applications. Photovoltaic popularity relies on cost, raw material availability, and efficiency. Research is currently being conducted to find new materials for solar photovoltaic devices. The goal is to identify a system with high efficiency, reduced cost, and enhanced durability. Current data shows worldwide the continuously increasing rate of use of solar cells and the improvement of efficiency of solar cells. For the sustainable development of society, it is essential to transition to solar energy as a more environmentally friendly power source.

References:

Almosni, S., Delamarre, A., Jehl, Z., Suchet, D., Cojocaru, L., Giteau, M., Behaghel, B., Julian, A., Ibrahim, C., Tatry, L., Wang, H., Kubo, T., Uchida, S., Segawa, H., Miyashita, N., Tamaki, R., Shoji, Y., Yoshida, K., Ahsan, N., … Guillemoles, J.F. (2018). Material challenges for solar cells in the twenty-first century: Directions in emerging technologies. *Science and Technology of Advanced Materials*, *19*(1), 336–369. https://doi.org/10.1080/14686996.2018.1433439

Chapin, D. M., Fuller, C. S., & Pearson, G. L. (1954). A new silicon *p-n* junction photocell for converting solar radiation into electrical power. *Journal of Applied Physics*, *25*(5), 676–677. https://doi.org/10.1063/1.1721711

Chatterjee, S., Mukherjee, P., Saha, A., Sen, K., Das, R., & Sanyal, T. (2023). Utilizing climate physics: Advancing SDG 13 with integrated low carbon energy from diverse sources – a glimpse ahead. In *A Basic Overview of Environment and Sustainable Development [Volume 2]* (2nd ed., pp. 506–519). International Academic Publishing House (IAPH). https://doi.org/10.52756/boesd.2023.e02.031

Gajbhiye, M., Kalbande, V., Bankar, A., Baseshankar, M., & Fande, A. (2024). Experimental Investigation of Two-Pass Solar Dryer with V-Corrugated Absorber for Potato Slice Drying. *International Journal of Experimental Research and Review*, *43*(Spl Vol), 1–12. https://doi.org/10.52756/ijerr.2024.v43spl.001

Gao, H., Yang, R., & Zhang, Y. (2020). Improving radiation resistance of gainp/gainas/ge triple-junction solar cells using gain back-surface field in the middle subcell. *Materials*, *13*(8), 1958. https://doi.org/10.3390/ma13081958

Green, M. A., Dunlop, E. D., Yoshita, M., Kopidakis, N., Bothe, K., Siefer, G., Hinken, D., Rauer, M., Hohl-Ebinger, J., & Hao, X. (2024). Solar cell efficiency tables (Version 64). *Progress in Photovoltaics: Research and Applications*, *32*(7), 425–441. https://doi.org/10.1002/pip.3831

Hayat, M. B., Ali, D., Monyake, K. C., Alagha, L., & Ahmed, N. (2019). Solar energy-A look into power generation, challenges, and a solar-powered future. *International Journal of Energy Research*, *43*(3), 1049–1067. https://doi.org/10.1002/er.4252

Kalogirou, S. (2009). Thermal performance, economic and environmental life cycle analysis of thermosiphon solar water heaters. *Solar Energy*, *83*(1), 39–48. https://doi.org/10.1016/j.solener.2008.06.005

Luque López, A., & Hegedus, S. (Eds.). (2011). *Handbook of photovoltaic science and engineering* (2. ed., (fully rev. and updated)). Wiley.

Nandwani, S. S. (1996). Solar cookers—Cheap technology with high ecological benefits. *Ecological Economics*, *17*(2), 73–81. https://doi.org/10.1016/0921-8009(96)00021-3

Mukherjee, P., Saha, A., Sen, K., Erfani, H., Madhu, N.R., & Sanyal, T. (2022). Conservation and prospects of Indian Lacustrine fisheries to reach the Sustainable Developmental Goals (SDG 17). © International Academic Publishing House (IAPH), Dr. N. R. Madhu & Dr. B. K. Behera (eds.), *A* Basic Overview of Environment and Sustainable Development, pp. 98-116. ISBN: 978-81-957954-2-0. https://doi.org/10.52756/boesd.2022.e01.010

Peumans, P., Yakimov, A., & Forrest, S. R. (2003). Small molecular weight organic thin-film photodetectors and solar cells. *Journal of Applied Physics*, *93*(7), 3693–3723. https://doi.org/10.1063/1.1534621

Saga, T. (2010). Advances in crystalline silicon solar cell technology for industrial mass production. *NPG Asia Materials*, *2*(3), 96–102. https://doi.org/10.1038/asiamat.2010.82

Singh, M., Solanki, S., Agrawal, B., & Bhargava, R. (2024). Performance Evaluation and Cost Analysis of Photovoltaic Thermal (PVT) System Using the Triangular Shape of Absorber with Different Water-based Nanofluids as Coolants. *International Journal of Experimental Research and Review*, *39*(Spl Volume), 51-72. https://doi.org/10.52756/ijerr.2024.v39spl.004

Suman, Sharma, P., & Goyal, P. (2020). Evolution of PV technology from conventional to nano-materials. *Materials Today: Proceedings*, *28*, 1593–1597. https://doi.org/10.1016/j.matpr.2020.04.846

Tucker, M. (1999). Can solar cooking save the forests? *Ecological Economics*, *31*(1), 77–89. https://doi.org/10.1016/S0921-8009(99)00038-5

Węgierek, P., & Billewicz, P. (2011). Jump mechanism of electric conduction in n-type silicon implanted with ne $^{++}$ neon ions. *Acta Physica Polonica A*, *120*(1), 122–124. https://doi.org/10.12693/APhysPolA.120.122

Węgierek, P., & Billewicz, P. (2013). Research on mechanisms of electric conduction in the p-type silicon implanted with ne $^{+}$ ions. *Acta Physica Polonica A*, *123*(5), 948–951. https://doi.org/10.12693/APhysPolA.123.948

Wentzel, M., & Pouris, A. (2007). The development impact of solar cookers: A review of solar cooking impact research in South Africa. *Energy Policy*, *35*(3), 1909–1919. https://doi.org/10.1016/j.enpol.2006.06.002

Wu, C., Wang, K., Batmunkh, M., Bati, A. S. R., Yang, D., Jiang, Y., Hou, Y., Shapter, J. G., & Priya, S. (2020). Multifunctional nanostructured materials for next generation photovoltaics. *Nano Energy*, *70*, 104480. https://doi.org/10.1016/j.nanoen.2020.104480

Yadav, R., Gautam, A., & Pradeepa, P. (2023). Design, Performance and Economic evaluation of a 4kW Grid-interactive Solar PV Rooftop in Odisha using Pvsyst. *Int. J. Exp. Res. Rev.*, *31*(Spl Volume), 98-107. https://doi.org/10.52756/10.52756/ijerr.2023.v31spl.010

Ya'u Muhammad, J., Bello Waziri, A., Muhammad Shitu, A., Muhammad Ahmad, U., Hassan Muhammad, M., Alhaji, Y., Taofeek Olaniyi, A., & Abdulkadir Bala, A. (2019). Recent progressive status of materials for solar photovoltaic cell: A comprehensive review. *Science Journal of Energy Engineering*, *7*(4), 77. https://doi.org/10.11648/j.sjee.20190704.14

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