Modular PV Design: Literature Review

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1

What is preventing this concept from being applied today?

Single module efficiency is *low*

Modular design itself causes complications

Energy storage not sufficient

How do we improve single module efficiency?

- **Increasing module size**
- **Making connectors more flexible and durable**

2

Research Is there published research on this concept?

1. **Majdi, A, Alqahtani, MD, Almakytah, A, Saleem, M. "Fundamental study related to the development of modular solar panel for improved durability and repairability". IET Renew Power Gener. 2021**

- Global solar panels are typically not repairable, leading to electronic waste.
- This research introduces a modular solar panel design with performance akin to traditional ones.
- The modular design was tested for power transfer, re-connection, and easy part replacement.
- It offers a repairable solution, with economic viability for real-world scenarios.

3

Research Cont.

2. **T. Stern and A. Reid, "Modular solar panels using components engineered for producibility," 2011 37th IEEE Photovoltaic Specialists Conference, Seattle, WA, USA**

- Innovative modular approach for spacecraft solar arrays using space-qualified materials and high-efficiency crystalline solar cells.
- Offers superior environmental resistance and facilitates a transition to repetitive production with standardized elements.
- Streamlined assembly with features that simplify positioning, covering, stringing, laydown, and wiring of solar cells into series-parallel strings.

4

Patents

Patents

- **Some design methods are already patented by Solar Square**

Similar Patents

- US20110290307A1 - Modular solar panel system
- US8276330B2 - Modular solar panel racking system
- US8410350B2 - Modular solar panels with heat exchange

5

Commercial Activity

Commercial activity #1

- Installed **55 solar tiles** on a 27-foot sailboat.
- Total output: **600W**, and took approx 2 hours.
- Installed in **three sections** connected in **parallel**.

6

Commercial Activity

Commercial activity #2

- **<u>“1” big panel</u>**
  - Comprises of *four pieces*.
- ***36 modular solar tiles*** per piece
- Combined power: 72V 360W per panel
- Application: Provides power to a remote off-grid house.

7

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1

Potential Energy Savings

Daily Energy Production (DEP)

= η x A x H x PR

where,

η = Efficiency

A = Panel Area (m^2)

H = Annual Avg. Solar Radiation ($kWh/m^2/day$)

PR = Performance Ratio (range from 0.5 to 0.9, default value = 0.75)

Annual Energy Production (AEP)

= DEP x 365 days

2

For 1 panel

LG NeON 2 vs SquareSolar

Specifications :-

η = 19 %

A = 1.71 m^2

STC Rating = 325 W

H = 6.5 $kWh/m^2/day$ (for Arizona)

PR = 0.75

Daily Energy Production

0.19 x 1.71 x 6.5 x 0.75 = ***1.584 kWh/day***

Annual Energy Production

1.584 x 365 days = ***578.16 kWh/yr***

Specifications :-

η = 21 %

A_{module} = 0.08428 m^2

A_{panel} = 0.08428 m^2 x 20 modules
= 1.68 m^2

STC Rating = 11 W

H = 6.5 $kWh/m^2/day$ (for Arizona)

PR = 0.75

Daily Energy Production

0.21 x 1.68 x 6.5 x 0.75 = ***1.72 kWh/day***

Annual Energy Production

1.72 x 365 days = ***627.8 kWh/yr***

3

For a Single Panel,

Annual Energy Savings = **627.8 kWh/yr** *(Energy generated by solar module itself and not from grid)*

The average household requires 20-25 panels.

Considering 20 Panels used in single installation -

Total Annual Energy Savings :

= 20 x 627.8 kWh = **12,556 kWh/yr**

4

Potential CO2 Savings

CO2 emissions savings (kg)

= -(electricity generated by PV panel in kWh x carbon intensity in kgCO2/kWh)

5

Potential CO2 Savings

EIA Carbon Intensity Level in Phoenix, Az (2022):

0.3138 kg/kWh

SquareSolar panels generate *12,556 kWh/year*

CO_2 emissions savings = -(energy savings x carbon intensity)

– (12,556 x 0.3138) = **-3,940 kg CO2/yr**

LG NeON 2 CO2 savings: *-3,628.53* kg/kWh

6

SquareSolar

Offers up to

8% more energy savings **&**

8% more CO_2 savings annually

than the "average" solar panel (LG NeON 2)

7

References

Specs for SquareSolar

https://www.squaresolarinc.com/

Specs for LG NeON 2

https://www.lg.com/us/business/solar/neon-2-series-solar-panels

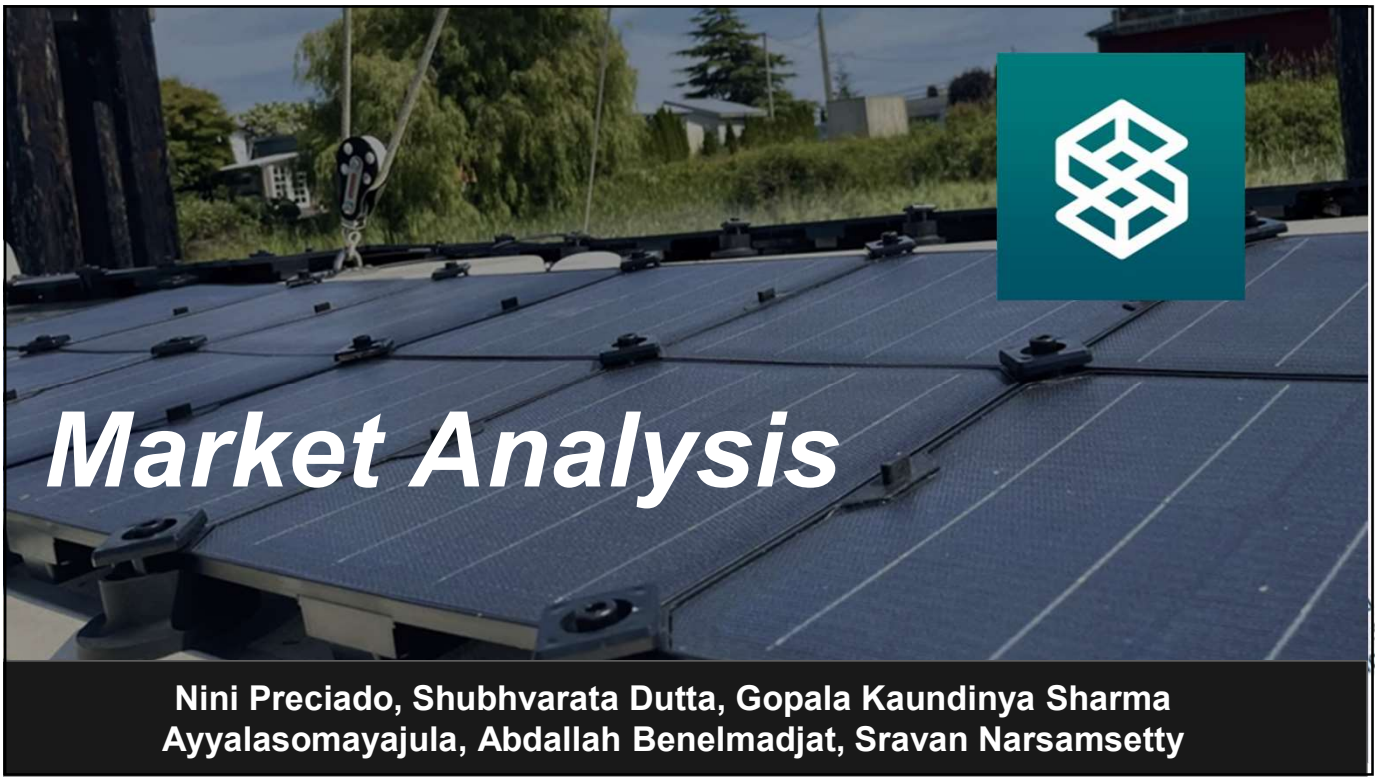
Average Energy Consumption in Phoenix, Az → How many solar panels do we need?

https://www.forbes.com/home-improvement/solar/cost-of-solar-panels

Carbon Intensity Levels in 2022:

https://www.eia.gov/electricity/state/arizona/

8



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Cost of installation

Single module Spec:-

- ***Power Rating:***

  Single Module = 11W

  Single Panel (with 20 modules) = 220W

- ***Cost = $1 - 1.4 / W (Taken average = $1.2/ W)***
- ***No Labour cost - as Self-installable***

Previously:-

1. ***We Stated that an Average household utilizes 20-25 panels.***

   Considering 20 Panels used in Single Installation And each panel consists of 20 Modules.

1. ***Total Annual Energy Savings = 12,556 kWh/yr***
2. ***Arizona Electricity Cost (Residential) = $0.1254/kWh***

2

Simple Payback

SPP = (Cost of Installation / Annual Energy Cost Savings)

3

Conv. Solar vs SquareSolar

Calculations :-

*Cost of Installation, CI = $ 7,500**

*Annual Energy Savings = 9,000 kWh/yr**

Annual Energy Cost Savings = 9,000 x $0.1254

= $1,128.6/yr

Simple Payback

=> ($7,500) / ($1,128.6/yr) = ***6.4 years***

**Resource:-* https://www.forbes.com/home-improvement/solar/cost-of-solar-panels/

Calculations :-

CI = No. of Panels x Module Cost x Power Rating of single Panel

= 20 x 1.2 x 220 = $ 5,280

Annual Energy Savings = 12,556 kWh/yr

Annual Energy Cost Savings = Energy Savings x Electricity Rate

= 12,556 x 0.1254

= $1,574.5/yr

Simple Payback

=> ($5,280) / ($1,574.5/yr) = ***3.3 years***

4

Estimated Market Size

5

Global - Market Size

TRENDS IN PHOTOVOLTAIC APPLICATIONS // 2022

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME WWW.IEA-PVPS.ORG

TOTAL BUSINESS VALUE IN PV SECTOR IN 2021

$190 BILLION USD

TOP 5 PV MARKETS IN 2021

CHINA	54.9 GW
EU	28.7 GW
USA	26.9 GW
INDIA	13.4 GW
JAPAN	6.6 GW

PV CONTRIBUTION TO ELECTRICITY DEMAND

5%

Share of PV in the global electricity demand in 2021

GLOBAL PV CAPACITY END OF 2021

ANNUAL INSTALLED CAPACITY IN 2021 (GW)

174GW

946GW 2021

772GW

GLOBAL PV CAPACITY END OF 2020 (GW)

Source :- annual report 2022 | iea-pvps

6

Added Competition to Existing Market

Benefits -

- Improved Durability and Robustness
- Easy to Replace & Repair compared to one-time use traditional Solar panels
- Lightweight and Self-installable means no Labor or transportation cost
- Effective in controlling and reducing system damage caused by environmental and man-made loadings such as hailstorms, thermal cycling, hotspots and mechanical damage, etc.
- Less cost to replace damaged components improving performance and repairability of system

Source:- https://ietresearch.onlinelibrary.wiley.com/doi/full/10.1049/rpg2.12079

7

References

- Average Energy Consumption in Phoenix, Az → How many solar panels do we need?

  https://www.forbes.com/home-improvement/solar/cost-of-solar-panels

- Market Analysis for Solar energy

  https://iea-pvps.org/annual-reports/

- Comparison - Modular Panels and Conventional Solar Panels

  https://ietresearch.onlinelibrary.wiley.com/doi/full/10.1049/rpg2.12079

- Market for Renewable Energy

  https://www.eia.gov/energyexplained/us-energy-facts/

8