Applicability and Manufacturing Capability of Next Generation Solar Photovoltaics in Indonesia

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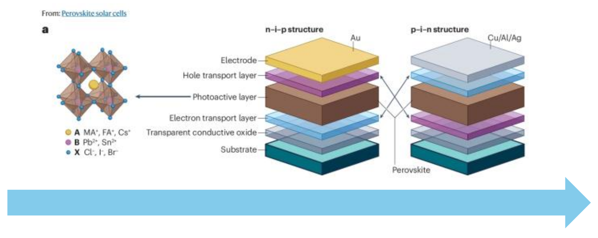
Background

Indonesia energy challenges:

- Rising energy demand
- Energy access gaps
- Climate risks



Next-gen PV (Perovskite and Organic) potentials:

- Higher electricity yield
- Tunable light absorption
- Relatively easier manufacturing

Indonesia energy solution traits:

- Affordable, inclusive, and low-carbon
- Enable green industrialisation

However, most research on NGPVs has focused on their **material advancements**, with little attention to their **context-specific applications, socioeconomic compatibility**, and **local manufacturing potential**

Research Objectives

1. What are the prospective applications of NGPV technologies in Indonesia, considering current and future energy needs?
2. Which NGPV architecture best suits these identified applications in Indonesia, considering both technical properties, cost-competitiveness, and environmental safety?
3. How promising are the pairs of application and NGPV architecture for widespread adoption in Indonesia?
4. To what extent is Indonesia capable of locally manufacturing the potentially widely used NGPV architecture?

Methodology

A. Perceiving prospective applications and the suitable NGPV architecture

1. Scan all potential markets, then filter and merge application sectors.
2. Identify problem (substitution- and integration-type) and opportunities
3. Assess task-technology fit, matching NGPV architectures properties with task characteristics

B. Evaluating the potential for mass adoption and devising a pathway to mass adoption

Create a pathway to mass adoption based on the Disruptive Innovation theory, with the following prioritisation criteria:

- Less hurdle in the module development
- Clear advantage over silicon PV
- Smaller-scale
- Aligned with the trajectory of government

C. Evaluating Indonesian manufacturing capability of the potentially widely used NGPV

Evaluation across four influential aspects:

- **Business environment** based on World Bank B-Ready and domestic political developments
- **Production factors** in terms of productive knowledge and material access
- **Demand alignment** in terms of market size, consumer acceptance and regulations
- **Environmental management** in terms of hazardous material in the production process and end-of-life

Results: Applications and Architectures

Area-covering applications

Agrivoltaics

Applications	**Shade-tolerant crops** (fruits and vegetables)	**Shade-intolerant crops** (paddy, corn, sugarcane)	**Reservoirs and Open pond**	**Mining**	**Ground-mounted power plant**
Potential cell type	spaced-opaque or existing semi-transparent OSC	Highly-transparent OSC	Perovskite-Silicon Tandem (PST)	Perovskite-Silicon Tandem (PST)	Perovskite-Silicon Tandem (PST)
Advantage over Silicon PV	Lightweight	Visible light transmittance	More electricity yield per weight	More electricity yield	More electricity yield
Challenges	Module stability, expensive flexible encapsulation	Module stability, expensive flexible encapsulation, balancing AVT and PCE	Scalability, stability to a lesser extent	Scalability, stability to a lesser extent	Scalability, stability to a lesser extent
Potential application area [km^2]	25,000	144,000	2,227 (reservoirs); 7,850 (open pond)	1,200	23,528
Projected module efficiency	8%	8%	33%	33%	33%
Potential Capacity [GWp]	1,000	5,760	147 (reservoirs); 518 (open pond)	158	5,435

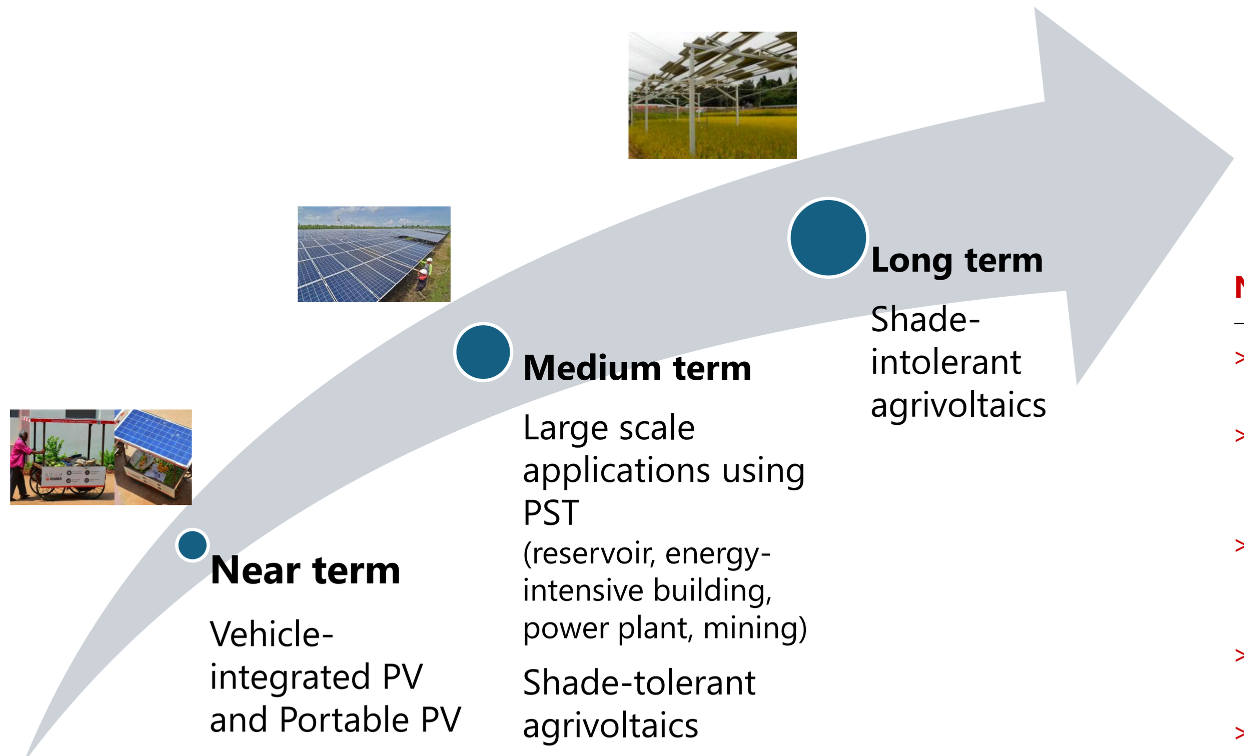
Applications for Building

Applications	**Factories and Data Centers**	**High End** (Building-integrated PV)	**Mid market** (Rooftop PV)	**Rural**
Potential cell type	Perovskite-Silicon Tandem (PST)	Semi-transparent flexible OSC or PSC	Singe-junction PSC or NFA bulk-heterojunction OSC	Single-junction triple-mesoscopic carbon PSC
Advantage over Silicon PV	More electricity yield	Transparency and flexibility for integration into façade	Potentially lower module cost??	Potentially lower module cost, easy to be produced locally
Challenges	Scalability, stability to a lesser extent	Module stability, balancing AVT and PCE, non-ideal façade alignment to sun	Scalability, stability	PCE, Scalability, stability
Potential application area [km^2]	*Need further research*	*Need further research*	8,248	*Need further research*
Projected module efficiency	33%	6-15%	20%	15-20%
Potential Capacity [GWp]	*Need further research*	*Need further research*	495	*Need further research*

Non-stationary Applications

Applications	**Vehicle-integrated**	**Portable solar kit**
Potential cell type	Bendable Perovskite-Silicon Tandem	Lightweight OSC
Advantage over Silicon PV	Surpassing PCE limitation, Flexibility	Flexibility and potentially lower module cost
Challenges	Scalability, stability to an even lesser extent	PCE, expensive flexible encapsulation
Potential application area [km^2]	72	*Need further research*
Projected module efficiency	28%	8-20%
Potential Capacity [GWp]	16	*Need further research*

Results: Pathway to Mass Adoption



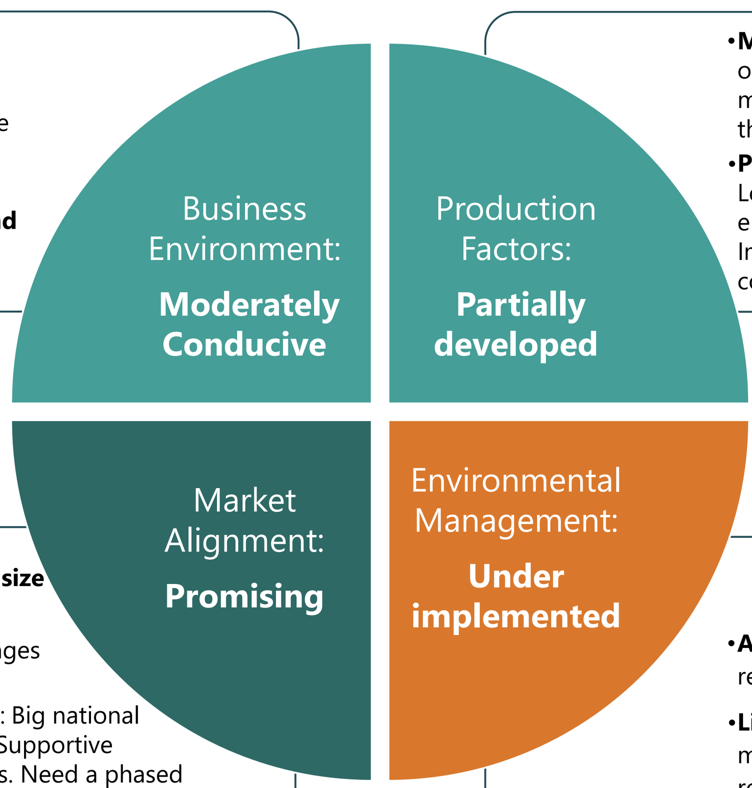
Not prospective applications

- > **Rural**: urgent but NGPV is not ready yet, clustered village favors mini-grid
- > **Mid-market building**: limited competitive advantage over silicon PV
- > **BIPV**: difficult transparency and flexibility needs, potentially not economical yield
- > **Wearables and indoor PV**: strong competition from battery
- > **Space PV**: far-fetched for Indonesia

Results: Manufacturing Capability

- **Moderate B-Ready pillars and topics scores**, compared to ASEAN countries
- Domestic political developments indicate **risks of unfair competition, reduced incentives, legal uncertainty,** with **weakened consumer buying power and investor confidence**

- **Moderate productive knowledge:** the lack of high-complexity industry like electronic manufacturing. Strength in basic metal for the balance-of system.
- **Partial material availability for PST:** Locally available lead, non-precious electrode, TCO/CTL raw metals, and glass. Import needed for the advanced organic compounds, Si ingot, flexible encapsulant



- **Large domestic and regional market size**
- **Cautiously receptive but poorly informed consumers.** Multiple challenges for personally using solar panel
- **Broadly supportive usage regulation**: Big national ambition, limited regional rooftop PV. Supportive standards. Available certification bodies. Need a phased LCR

- **Available prerequisite regulations:** regarding hazardous materials and waste
- **Limited implementation:** limited by monitoring capacity and absence of PV recycling infrastructure

Future Work

- Quantitative primary market research
- International collaboration and governmental supports
- Continuous improvement in NGPV devices and manufacturing process

Recommendation for Local Manufacturing

- **Improve governance** in legal, welfare, finance, markets, and taxation systems.
- **Upgrade Indonesia's industrial base** toward higher-complexity NGPV materials industries
- **Establish consistent, coordinated policies,** such as phased LCR targets, preferential contracts, financial incentives, and international collaboration, to build competitiveness.
- **Reallocate subsidies from fossil fuels to renewables,** while enhancing storage, grid, and flexibility,
- **Expand international collaboration** with leading institutions in NGPV.

Selected References

B. Roose et al., 'Local manufacturing of perovskite solar cells, a game-changer for low- and lower-middle income countries?', Energy Environ. Sci., vol. 15, no. 9, pp. 3571–3582, 2022, doi: 10.1039/d2ee01343f.

J. C. Blakesley *et al.*, 'Roadmap on established and emerging photovoltaics for sustainable energy conversion', *J. Phys. Energy*, vol. 6, no. 4, p. 041501, Oct. 2024, doi: 10.1088/2515-7655/ad7404.

J. Han et al., 'Perovskite solar cells', Nat. Rev. Methods Primer, vol. 5, no. 1, Jan. 2025, doi: 10.1038/s43586-024-00373-9.

Kementerian ESDM, Regulation No. 2: PLTS Atap yang terhubung pada jaringan tenaga listrik pemegang IUPTLU, 2024

L. Wagner et al., 'The resource demands of multi-terawatt-scale perovskite tandem photovoltaics', Joule, vol. 8, no. 4, pp. 1142–1160, Apr. 2024, doi: 10.1016/j.joule.2024.01.024.

M. Riede, D. Spoltore, and K. Leo, 'Organic Solar Cells—The Path to Commercial Success', Adv. Energy Mater., vol. 11, no. 1, Jan. 2021, doi: 10.1002/aenm.202002653.

World Bank, 'Business Ready', World Bank, 2024.