Applicability and Manufacturing Capability

Next-gen PV in Indonesia



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Image source: https://katadata.co.id/ekonomi-hijau/energi-baru/66eb99dba8e89/harga-panel-surya-turun-66-peluang-negara-asean-dongkrak-industri-hijau

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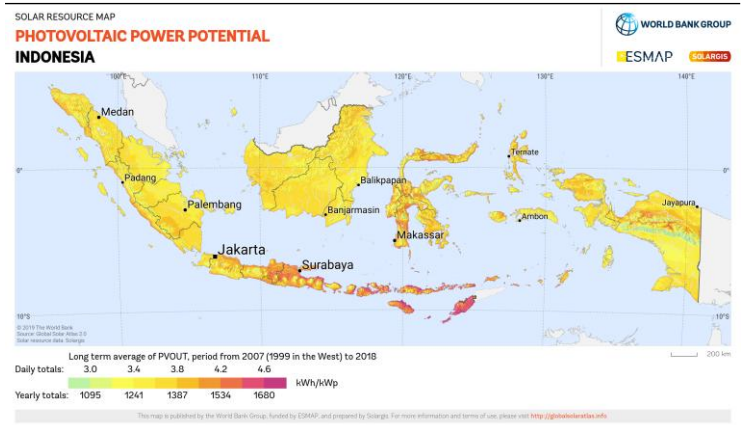
Solar is the renewable energy with the largest resource in Indonesia

Fortunately, it is also distributed and could enhance energy access

Electricity generation potential & installed capacities by type [GW]

	Geothermal	Hydro	Bioenergy	Solar PV	Onshore wind	Offshore wind	Marine	Coal	Gas	Diesel
Potential	24	95	57	3315	60	94	16			
Installed	2.7	7.5	3.1	1.1	0.15	0	0.5	61.0	25.2	6.1

Solar potential is distributed



Electrification: Remote villages and islands remain

> As of mid-2024, Indonesian electrification ratio reached 99.82%, with the gaps mainly in Papua, Nusa Tenggara, and Maluku

> However, the electrification ratio does not measure the quality of electricity access

Further takeaways

> Solar potential is abundant, more than the installed capacities even after accounting for its 16% capacity factor

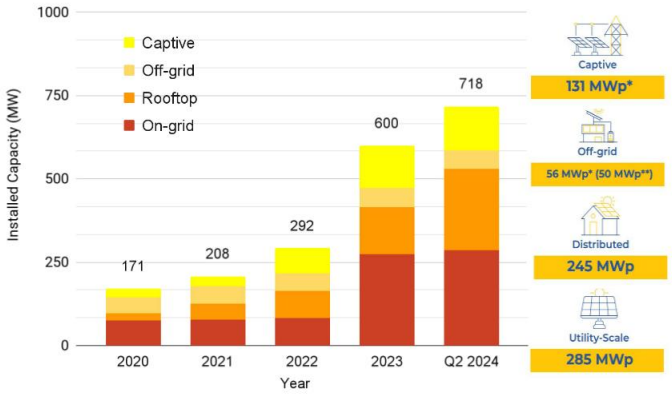
> Nusa Tenggara-East Java have the best solar potential, essential for local development

> The potential around demand centers in Java is also decent .

Sources: [Ministry of Mineral and Energy Resources (MEMR), IESR, Global Solar Atlas]

Solar energy is growing; historically slow but high in ambition

Solar Capacities & Potential [GW]

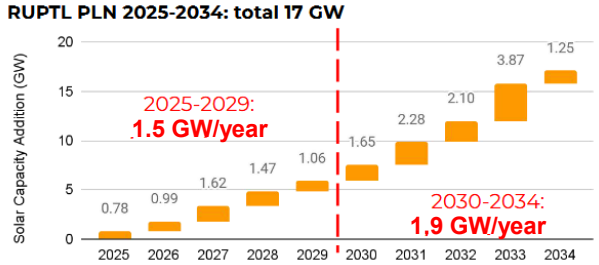


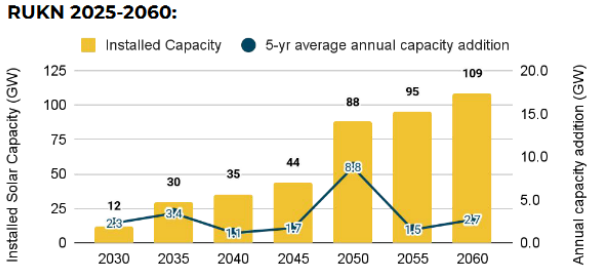
In **Jan 2026**, MEMR announced that installed capacity **had risen to 1.5 GW-peak**, with:

- 445 MW-p rooftop PV,
- 413 MW-p ground-mounted PV and
- 192 MW-p floating PV

> **Indonesia is behind in solar build out,** even compared to Vietnam (17 GW), Thailand (3 GW), Malaysia (2 GW), and Philippines (2 GW)

Government plans





> Indonesia plans to add 17 GW until 2034 and 109 GW until 2060,

> President announced the ambition of 100 GW across villages

Private solar projects

> Indonesia **will export 7.5GW to Singapore**

> **Captive PV projects** stand at **3.7 GW**

> **Rooftop solar PV projects amount to 2.4 GW**

Energy access projects

Rural grid extension for 780 thousand households

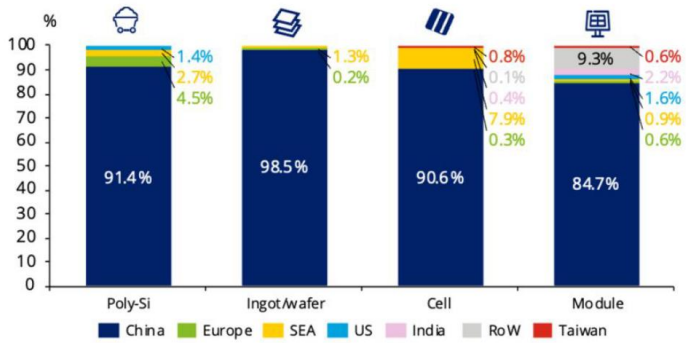
Increasing availability from several hours to full-day

Replacing diesel generators with PV+BESS

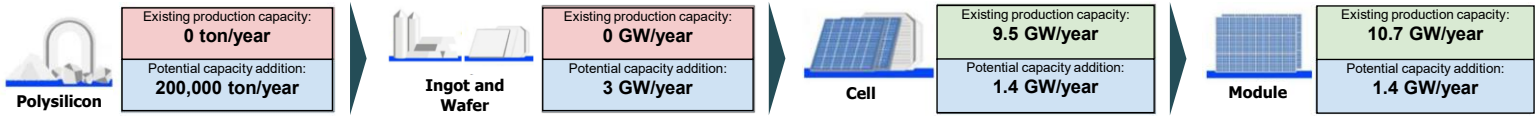
Source: Ministry of Mineral and Energy Resources (MEMR), IESR

Solar PV manufacturing is also growing, faster in its downstream than upstream

Global solar supply chain relies on China



Indonesian PV manufacturing status



- Lagging polysilicon refining and ingot processing industries
- Export potential to Western countries that avoid Xinjiang-produced polysilicon
- Energy intensive, need to be coupled with large renewable to avoid adding coal-fired power plant
- The projected plant is part of the conflicting Rempang Eco-park
- Large, newly opened, cell and module manufacturing capacities
- Majority for exports, rather for local installations
- Has produced tier-1 solar modules (Trina's plant)

Source: IEA, MEMR, IESR

There are various technologies of solar cell, each with own characteristics

Generations are based on when the cells started to be developed

1st Generation

- **98%** of produced module in 2024
- Quite high efficiency, around **24%**
- **Low cost** and **abundant materials**
- Stable, guaranteed power for **25-30 years**
- China's massive production capacity

2nd Generation

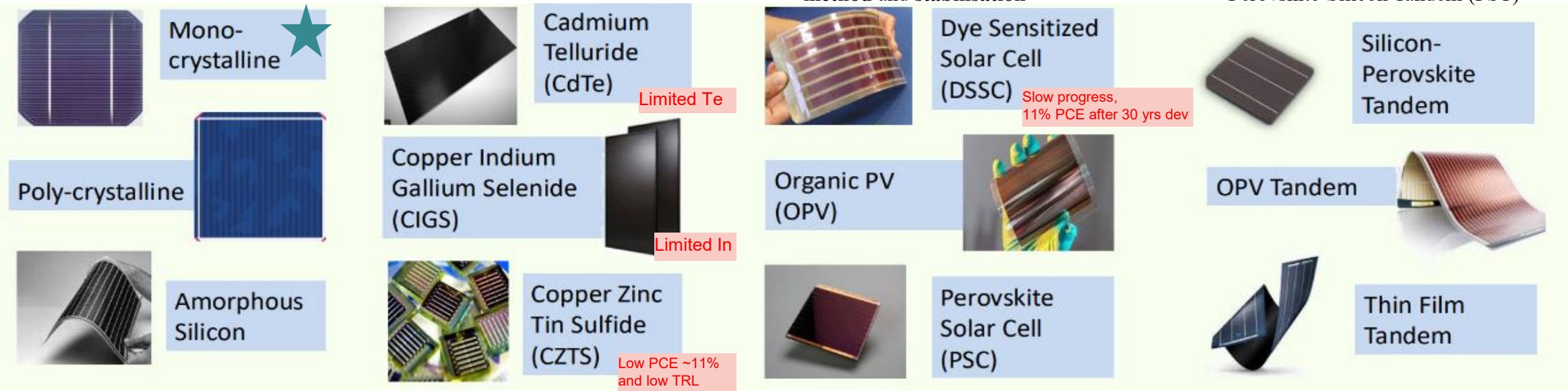
- **2%** of produced module in 2024
- **18%** efficiency for **CdTe** and **13%** for **CIGS**
- Bit **higher price** than c-Si
- Stable for **10-20 years**
- **Rare** and **toxic** key materials (Te, Cd, Se)
- **Less energy** for its manufacturing

3rd Generation

- **Mostly still in prototype**
- **20%** efficiency P**erovskite**, **14%** for **organic**
- **Low material use, low energy to produce**
- **Flexible, lightweight, and tunable** in **color and transparency**
- Need to find **scalable manufacturing method** and **stabilisation**

4th Generation

- **Tandemisation** to surpass the fundamental efficiency limit of single material cell (29% for Si)
- **Higher price** of the panel
- Mixed environmental impact: higher electricity yield offsets higher footprint
- Need better encapsulation for **stability**
- Mass manufacturing underway for Perovskite-Silicon Tandem (PST)



Source, Ludin, 2025, Blakesley, 2024; Priya & Stoiner 2025; Fraunhofer ISE

While silicon dominates the market, third gen cells offers several competitive advantages

	Characteristics	Monocrystalline Si	Organic	Perovskite
Most Important	**Panel efficiency**	**24%**	8-14%	20% (increasing), **28% in tandem with Si**
	Stability	**30 years**	5 years product, 20 years performance warranty	Months, still on-going research
	Levelized cost of electricity	**40-60 USD/MWh**	Uncertain, 80-130 USD/MWh	Uncertain, 20-70 USD/MWh; 30-42 USD/MWh for PST
	Product features	Rigid, opaque, bit heavy (12 kg/m^2), need mounting	**Tunable color, semitransparent, lightweight, flexible, easy installation**	**Tunable color, semitransparent, lightweight, flexible, easy installation**
	Materials	**Abundant silicon**	Sophisticated carbon-based compounds with small usage	Organic, lead, and halide. Toxic solvent and lead issues
	Manufacturing	Centralised, energy intensive, clean room	**Lower temp, roll-to-roll production**	**Like organic, solution or physical vapor deposition**
	Geopolitical	Production concentrated in China, forced labor in Xinjiang	**Distributed materials, still no production base**	**Distributed materials, still no production base**
	GHG emission	20-40 gCO_2/kWh	**8-20 gCO_2/kWh**	30-50 gCO_2/kWh

Source, Ludin, 2025; Fraunhofer ISE; Gan, 2025; Liu, 2025; Blakesley, 2024

Key takeaways

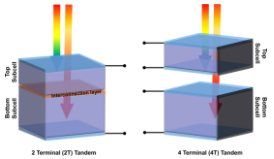
- **Silicon PV (monocrystalline) wins in the key characteristics -> market share**
- **Organic and Perovskite cells will fill niche applications** which Silicon is not suitable.
- **Perovskite-Silicon Tandem (PST) is promising contender for utility-scale applications**, thanks to high yield but subject to stability and manufacturing.
- **Ease of manufacturing** organic and perovskite cells enables **local manufacture** in low-middle income countries.

Several studies of general NGPV application, but limited for the Indonesian context

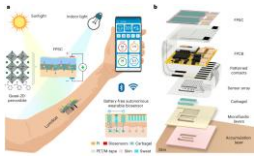
NGPV applications in general….



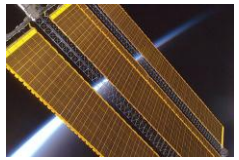
Building Integrated PV



Tandem PV



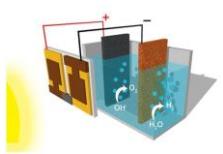
Wearable PV ->
Medical devices and sensors



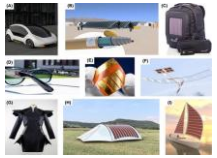
Space PV



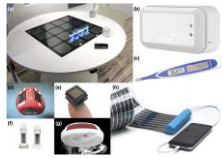
Agrivoltaics



Catalysis:
Water splitting to H_2 and CO_2 reduction



Flexible lightweight PV portable products



Indoor PV:
e.g for wireless devices

but which are appropriate for the Indonesian context?

Source: Riede, 2021; Min, 2023; Subudhi, 2023, Heliatek; 2025

Several studies discussed NGPV manufacturing, but hard to find a study for the Indonesian context

NGPV commercialisation and manufacturing studies….


PROGRESS REPORT

10th Anniversary Article

Organic Solar Cells—The Path to Commercial Success

Moritz Riede, Donato Spoltore, and Karl Leo*

Organic solar cells have the potential to become the cheapest form of electricity, beating even silicon photovoltaics. This article summarizes the state of the art in the field, highlighting research challenges, mainly the need for an efficiency increase as well as an improvement in long-term stability. It discusses possible current and future applications, such as building integrated photovoltaics or portable electronics. Finally, the environmental footprint of this renewable energy technology is evaluated, highlighting the potential to be the energy generation technology with the lowest carbon footprint of all.

1. Introduction

Energy Reports

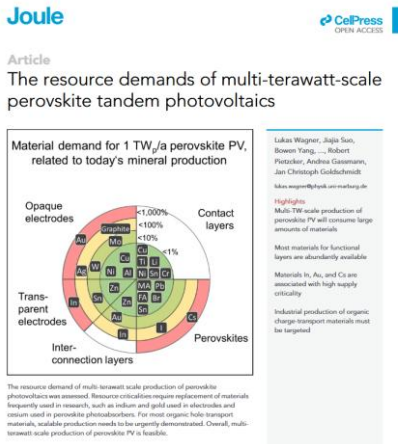
Major challenges for commercialization of perovskite solar cells: A critical review


Energy & Environmental Science

ROYAL SOCIETY OF CHEMISTRY

ANALYSIS

Local manufacturing of perovskite solar cells, a game-changer for low- and lower-middle income countries?†


Joule

CellPress

Article

The resource demands of multi-terawatt-scale perovskite tandem photovoltaics

Material demand for 1 TW_p/a perovskite PV, related to today's mineral production

Opaque electrodes

Contact layers

Trans-parent electrodes

Inter-connection layers

Perovskites

<100%

<10%

<1%

but very limited for the Indonesian context

Source: Riede, 2021; Seyisi, 2025; Roose, 2022; Wagner, 2024

Research Objectives and Methods



What are the prospective applications of NGPV technologies?

1. Scan all potential markets
2. Identify problem and opportunities
3. Assess task-technology fit



How promising is the applied NGPV for mass adoption?

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

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



How capable is Indonesia to locally manufacture the potentially widely used NGPV?

Evaluation across four influential aspects:

- **Business environment** using 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

Source: Ardichvili, 2003; Christensen, 2015; World Bank, 2025

Potential applications for Next-Gen PV in Indonesia

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

Source: Silalahi, 2021; Meitzner, 2021;Min, 2023; BPS, 2025, He, 2025 Note: In the capacity calculation, different applications have their own ground coverage ratios

Potential applications for Next-Gen PV in Indonesia

PV for buildings






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*

Source: Batista, 2025; Tang, 2024; REACH-PSM, 2024; Beynon, 2023 Note: In the capacity calculation, different applications have their own ground coverage ratios

Potential applications for Next-Gen PV in Indonesia

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*

Source: Mahalingam, 2025; Yamaguchi, 2023 Note: In the capacity calculation, different applications have their own ground coverage ratios

The prospective path to mass adoption

Implement in the easier application first to enable disruptive innovation



Near term

Vehicle-integrated PV and Portable PV



Medium term

Large scale applications using PST (reservoir, energy-intensive building, power plant, mining)

Shade-tolerant agrivoltaics



Long term

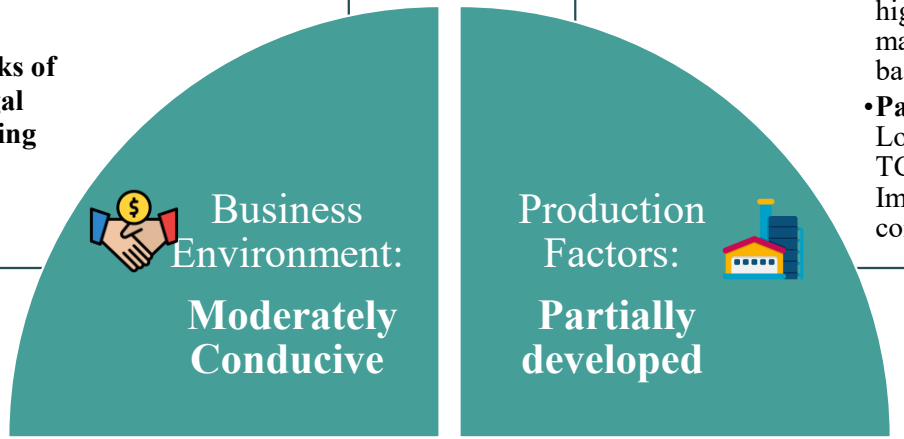
Shade-intolerant agrivoltaics

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

Indonesia has a partially emerging capability to manufacture NGPV

Evaluated for PST production, across four aspects important for solar PV manufacturing industry



- **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

Soruce: World Bank, 2024, Hausmann & HKS, 2025; USGS, 2025; MEMR, 2025; IEC, 2025; Katadata, 2022

Future Work and Recommendations

Future works on NGPV commercialisation



Primary quantitative market research



International collaboration and governmental supports



Continuous improvement in NGPV devices and manufacturing process

Recommendations for Indonesian local manufacturing



Improve governance in legal, welfare, finance, markets, and taxation systems.



Upgrade Indonesia's industrial base toward higher-complexity NGPV value chain industries, especially in materials.



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.

Thank you!