Energy transition vs. circular economy: How should solar energy grow?

Malte Ruben Vogt

12th of October 2023

Delft, NL

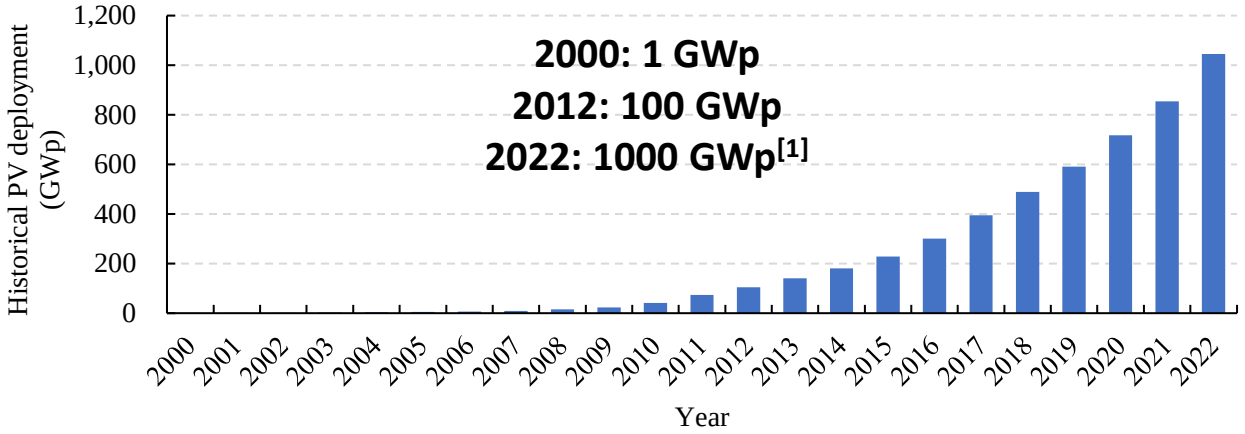
PVMD Delft University of Technology

TU Delft

“80% of worldwide PV installations have been deployed during the past 5 years”

Tsanakas et al. , *PiP* ,28:454-464 (2020)

Exponential growth in photovoltaics



Past decade:

- Average annual growth rate: 25%
- Price: -91%

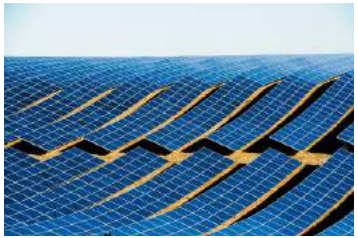
Today:

- 1 TWp cumulative global installed PV capacity
- PV is cheapest form of electricity in most countries

Solar cell
~5-10 Wp

PV module
~300-500 Wp

Rooftop system
~2-10 kWp

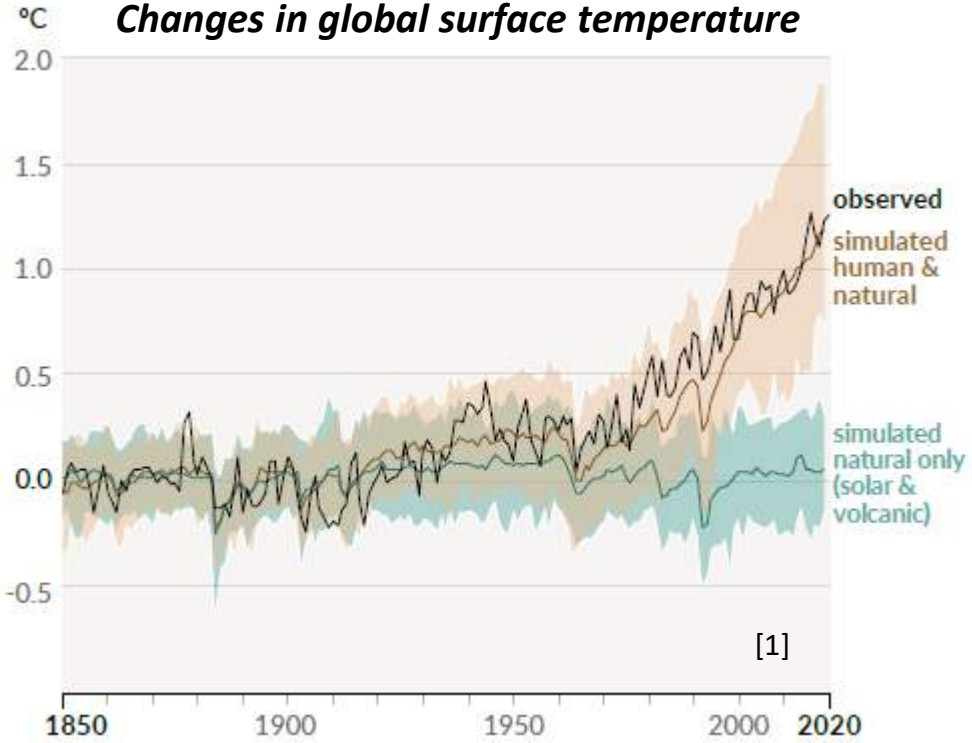


Solar farm
~1 MWp-2.8 GWp

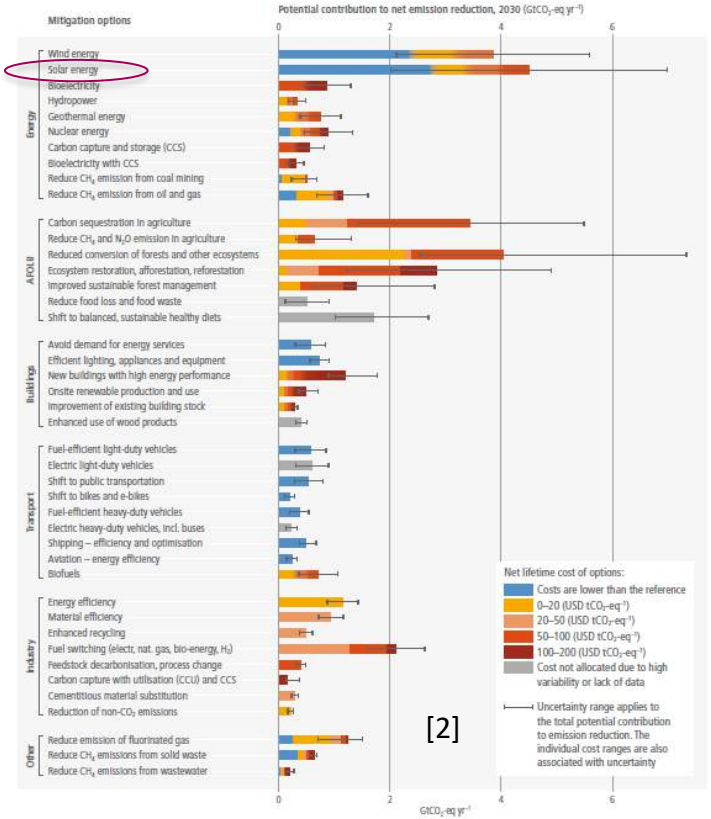
[1] Adapted from IRENA RENEWABLE CAPACITY STATISTICS (2023)

Why grow PV?

Changes in global surface temperature



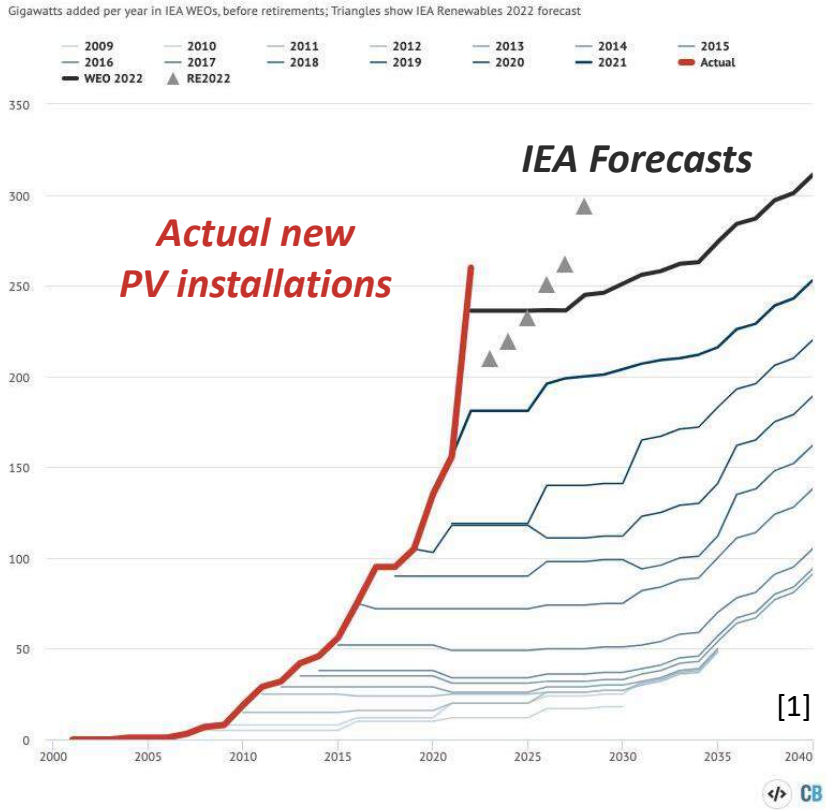
Climate change mitigation options



[1] IPCC AR6 WG I (2022)
[2] IPCC AR6 WG III (2022)

PV capacity growth projections past

Gigawatts(GWp) of PV added globally per year

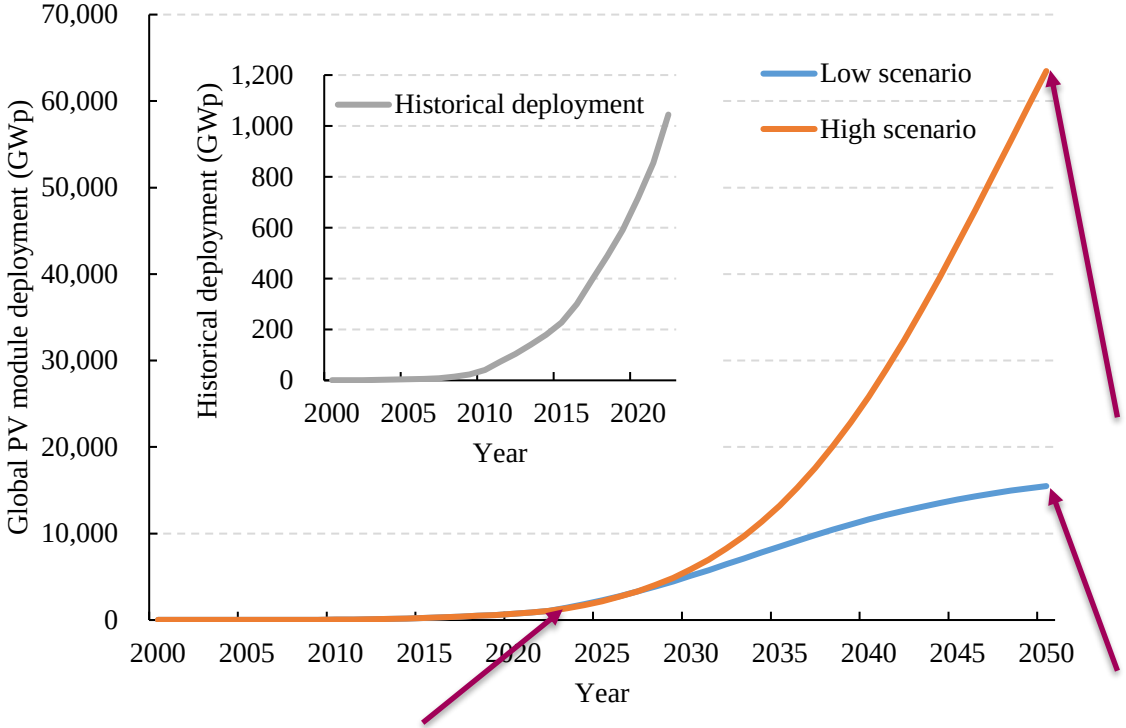


[1]

- Growth scenarios can be wrong!
- IEA is conservative on PV growth

[1] https://twitter.com/AukeHoekstra (2023) based on IEA projections

Global PV deployment size



1 TWp in 2022, supplying 4.5% of 29 PWh global electricity demand

- **Net zero emissions goal by 2050**

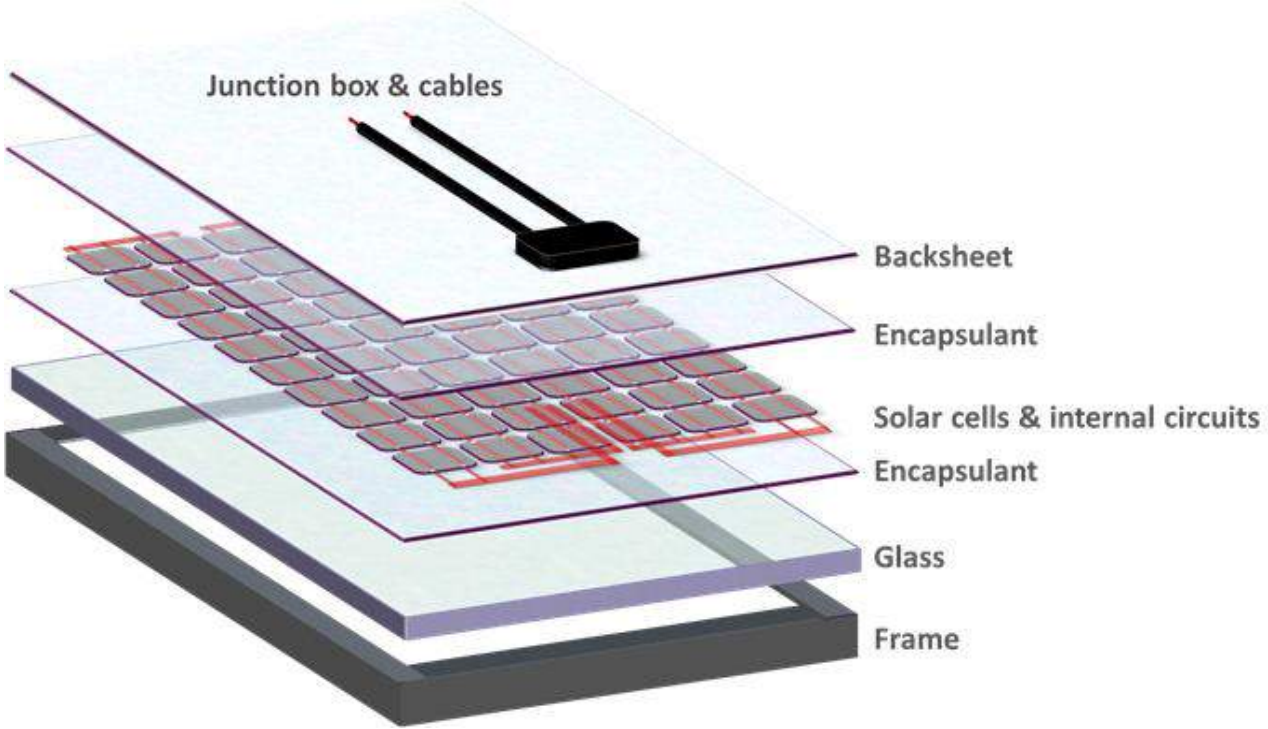
Broad electrification scenario [2] as High scenario:
63.4 TWp by 2050, supplying 69% of 150 PWh global electricity demand

IEA scenario[1] as Low scenario:
15.5 TWp by 2050, supplying 35% of 70 PWh global electricity demand

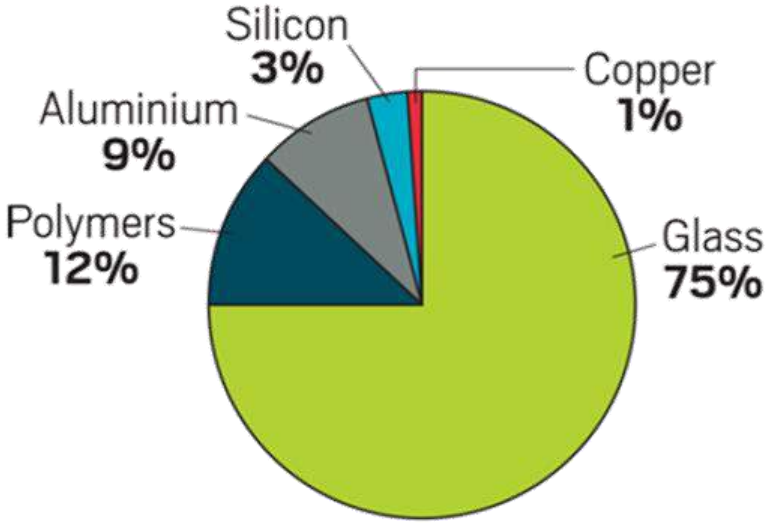
[1] IEA, *World energy outlook(WEO)*, (2021)
[2] D. Bogdanov et al., *Energy* **227**, 120467 (2021)

Critical material demand of PV

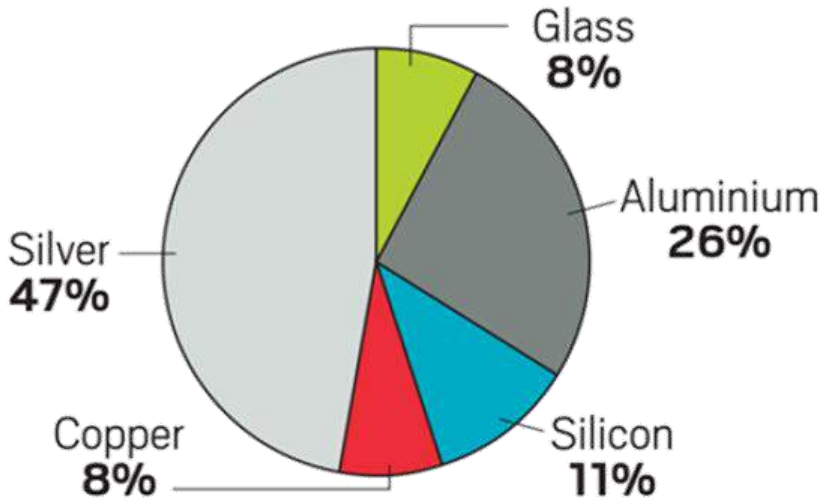
Crystalline silicon PV module



Materials in Si PV modules



Distribution of materials by mass

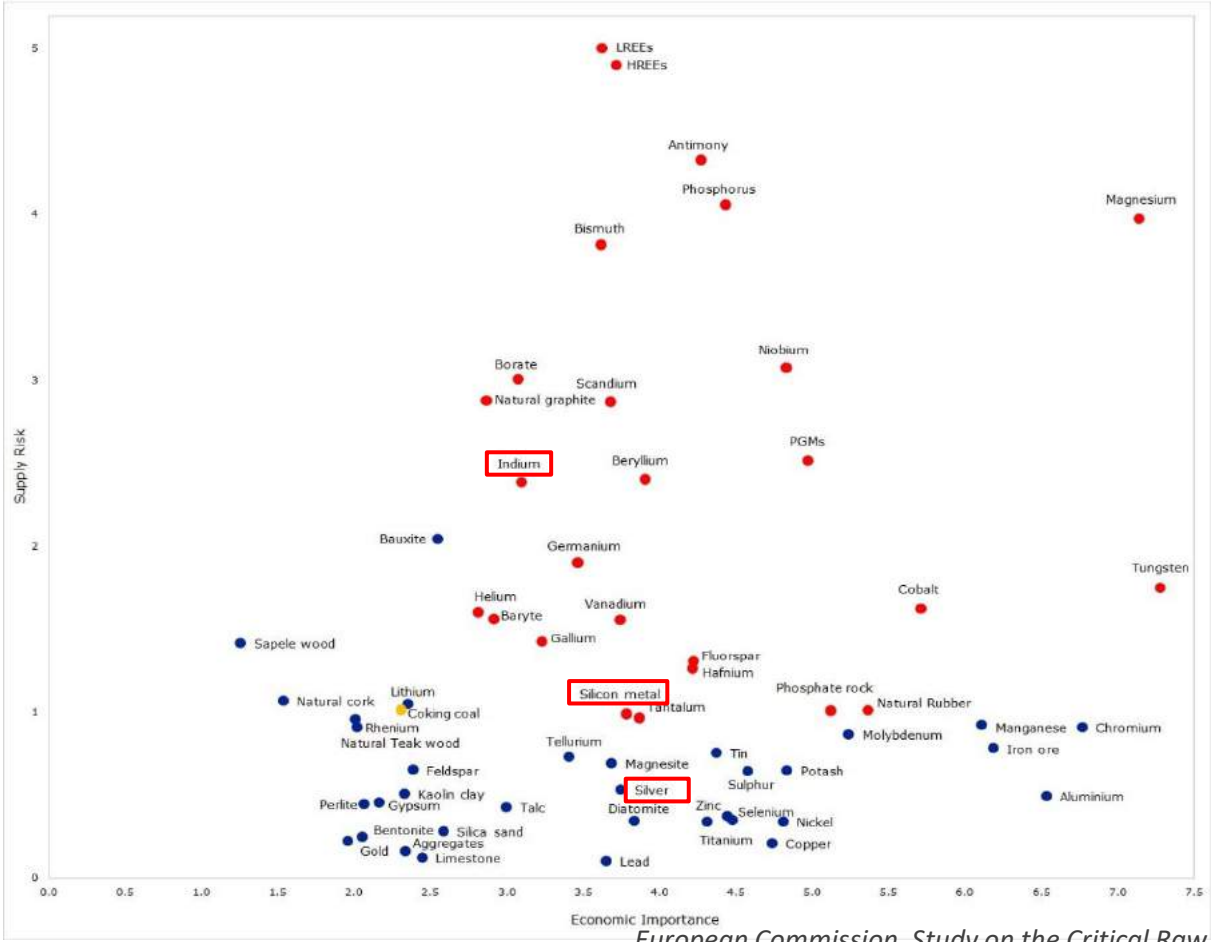


Distribution of materials by value

Source: Martin Bellman/Icarus. **Note:** Silver is less than 1% of the mass.

- **Glass and Al about 85% of the weight, but 30% of the material value**
- **Ag and Si about 4% of the weight, but 60% of the material value**

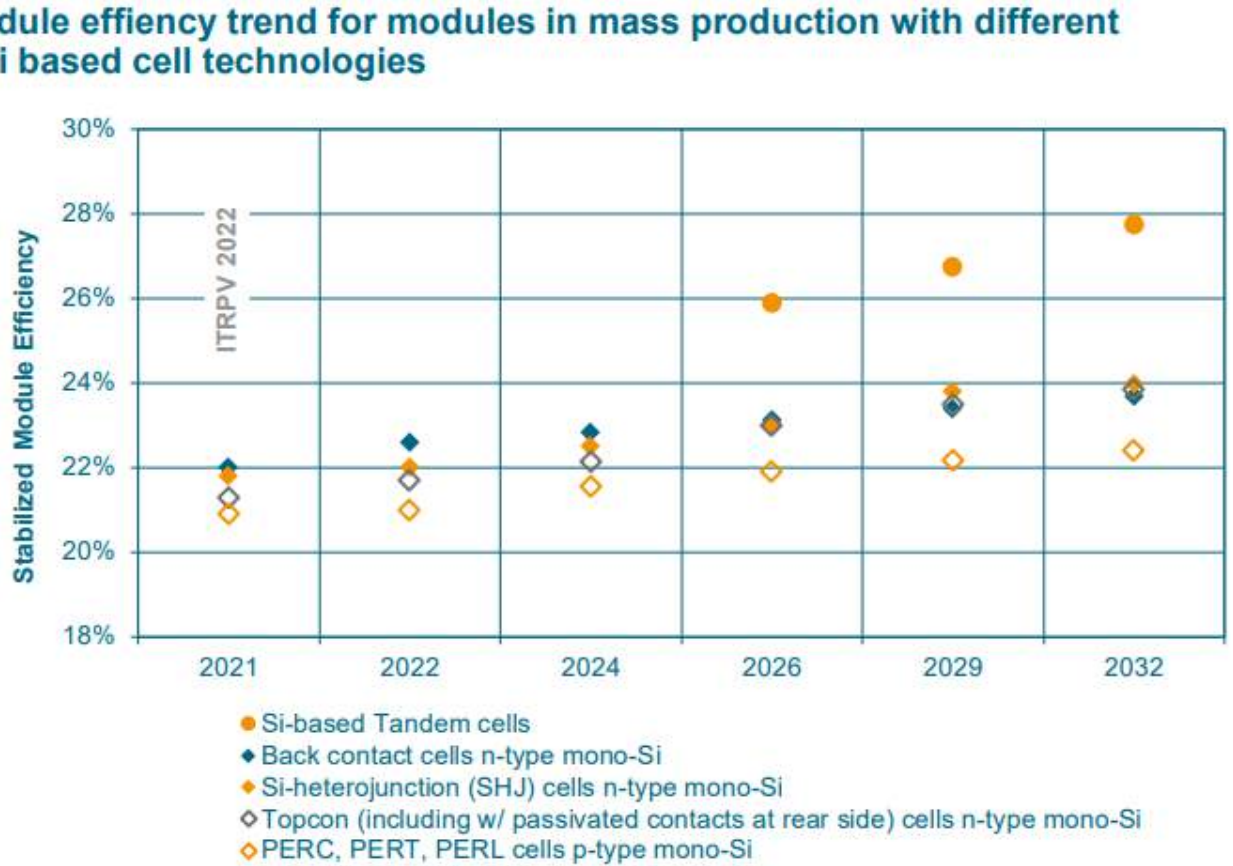
Critical materials



European Commission, Study on the Critical Raw Materials for the EU(2023)

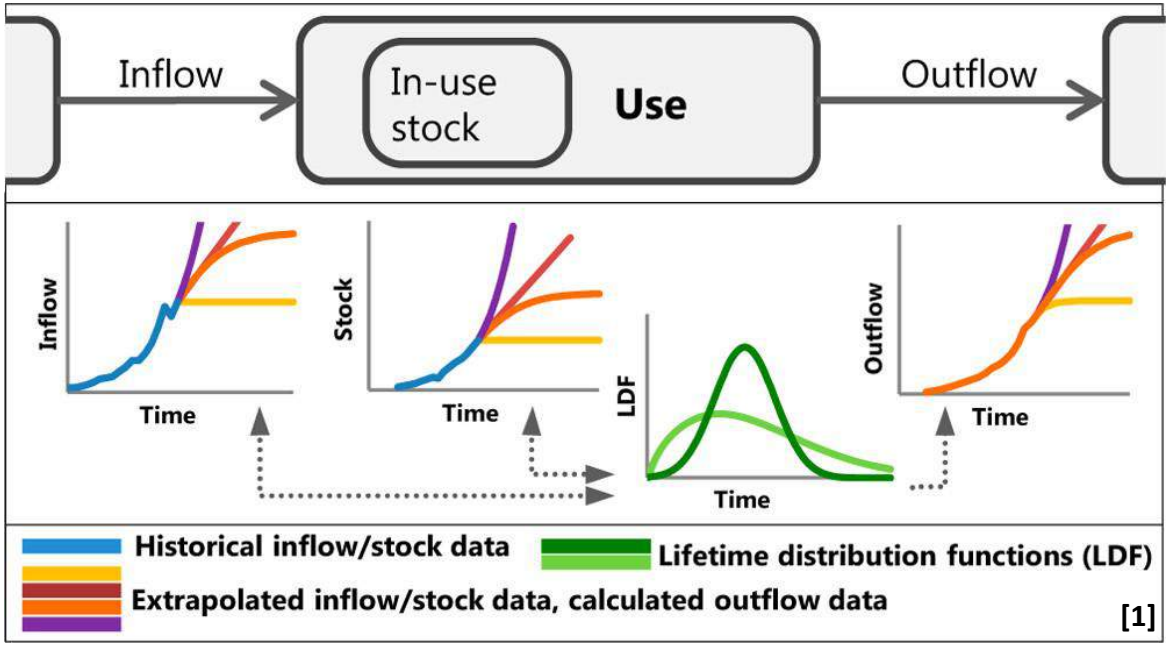
PV technology changes

- **Market share of PV technologies**
  - BSF (standard), PERC, Topcon, SHJ, XBC, Si-based tandem
- **Technology trends to reduce cost while increasing efficiency**



[1] International Technology Roadmap for Photovoltaic (ITRPV), 13th Edi., (2022)

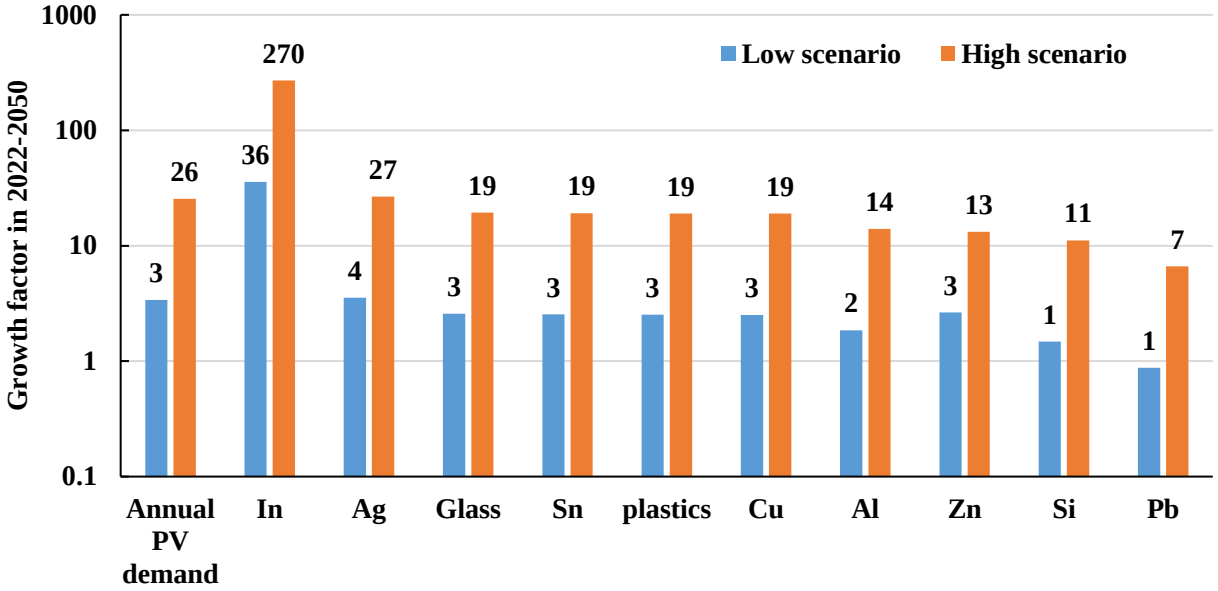
Dynamic material flow analysis model



- **Global PV deployment[2,3,4]**
- **PV technology changes**
- **PV lifetime[5]**
  - Utility PV systems: Average lifespan of 30 years
  - Residential PV systems: around 20 years, considering economic motivations

[1] E. Müller, et al., *Environ. Sci. Technol*. **48**, 2102-2113 (2014)
[2] International Technology Roadmap for Photovoltaic (ITRPV), 13th Edi., (2022)
[3] International Energy Agency (IEA), Net Zero by 2050, (2021)
[4] IEA, https://www.iea.org/reports/solar-pv, (2022)
[5] V. Tan et al., *Sustainability*. **14**, 5336 (2022)

PV material demand growth 2022->2050

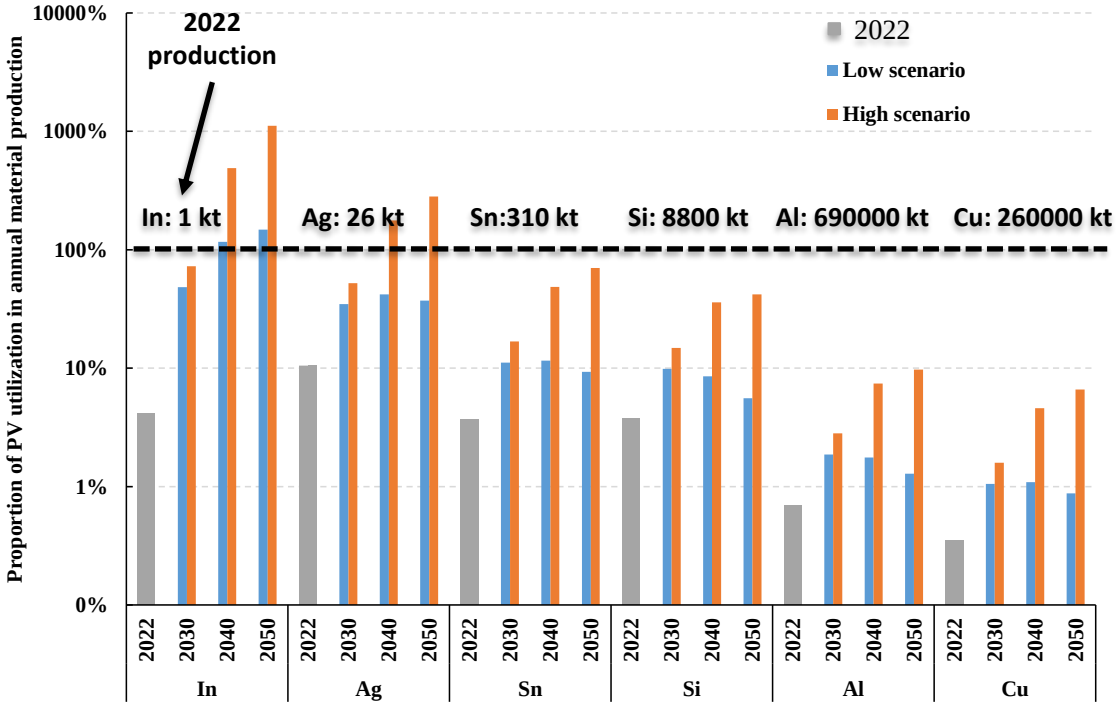


Dr. Chengjian Xu

- In and Ag growth factor higher than PV demand
- Relative decoupling for other materials

Chengjian Xu et al., to be published

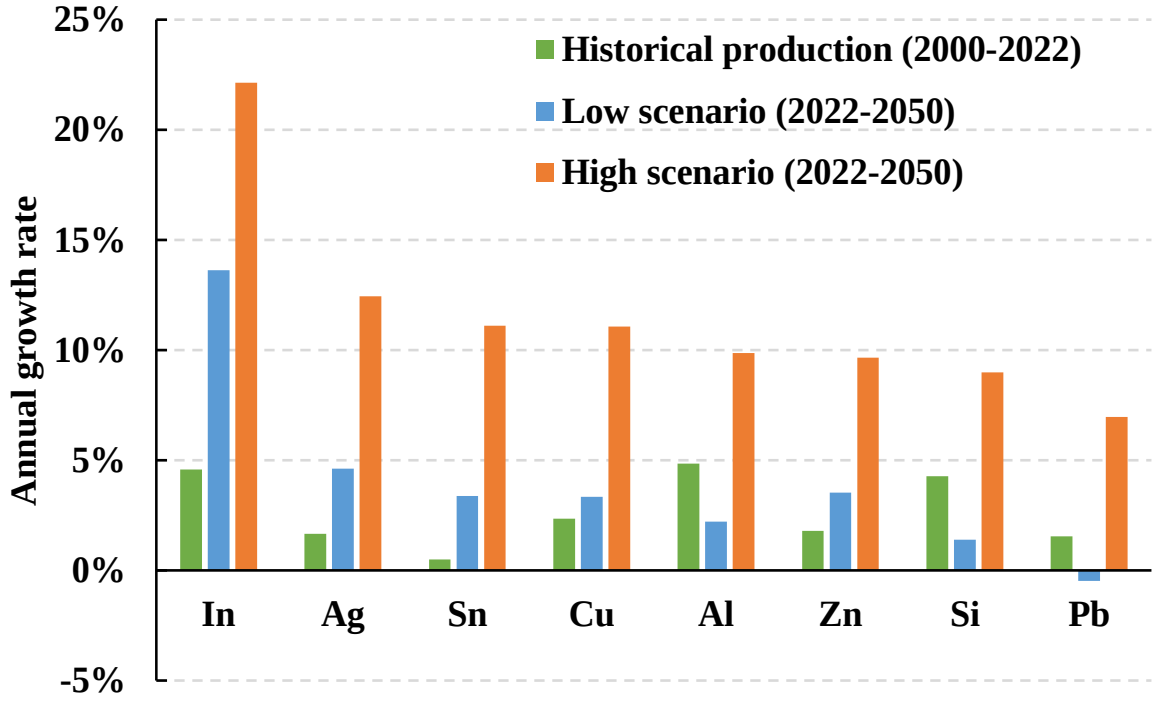
PV material demand



Dr. Chengjian Xu

Chengjian Xu et al., to be published

PV material demand vs historical production

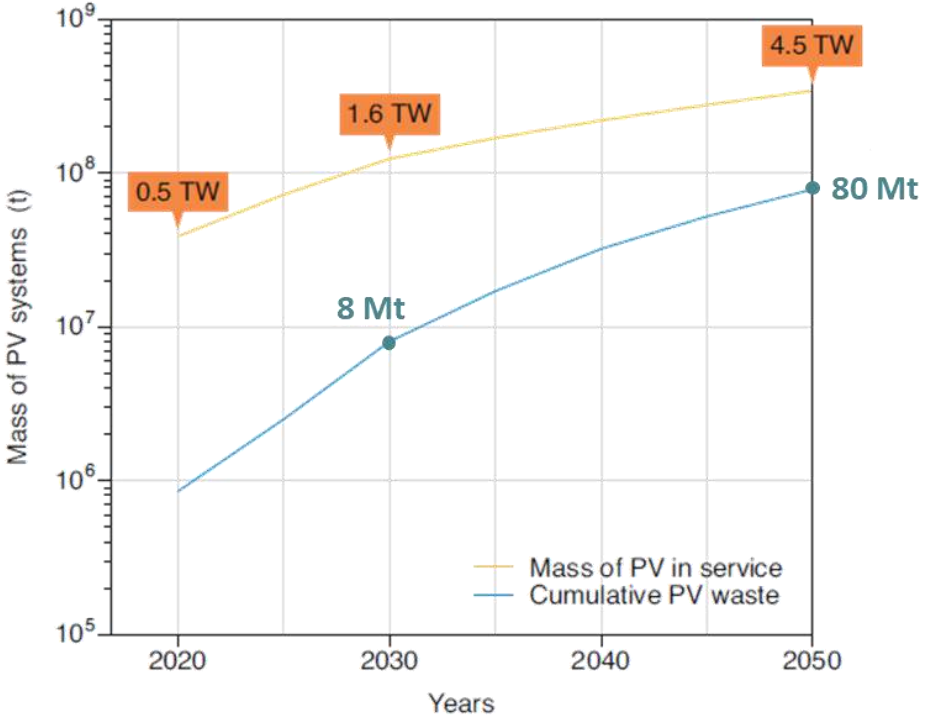


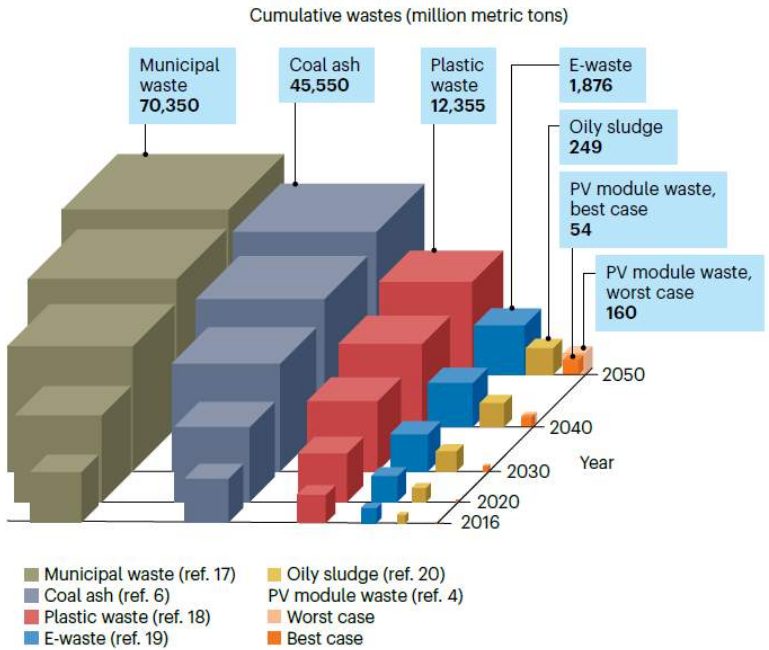
Dr. Chengjian Xu

Chengjian Xu et al., to be published

Current and future PV End-of-Life practices

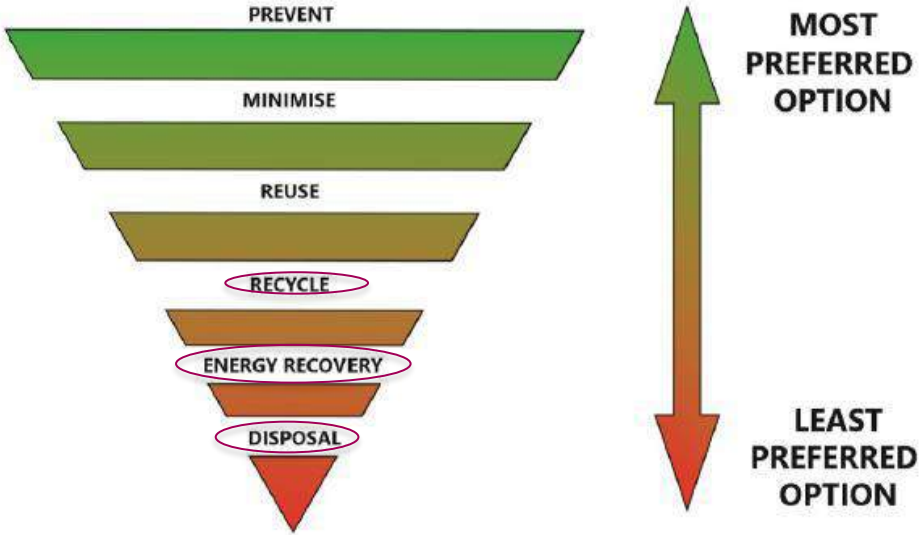
PV waste issue





[1] S. Weckend, et al., IEA PVPS Task 12, Subtask 1, 2016
[2] G.A. Heath, et al., Nat. Energy, 2020
[3] H. Mirletz et al., *Nat. phy.*,1376-1378 (2023)

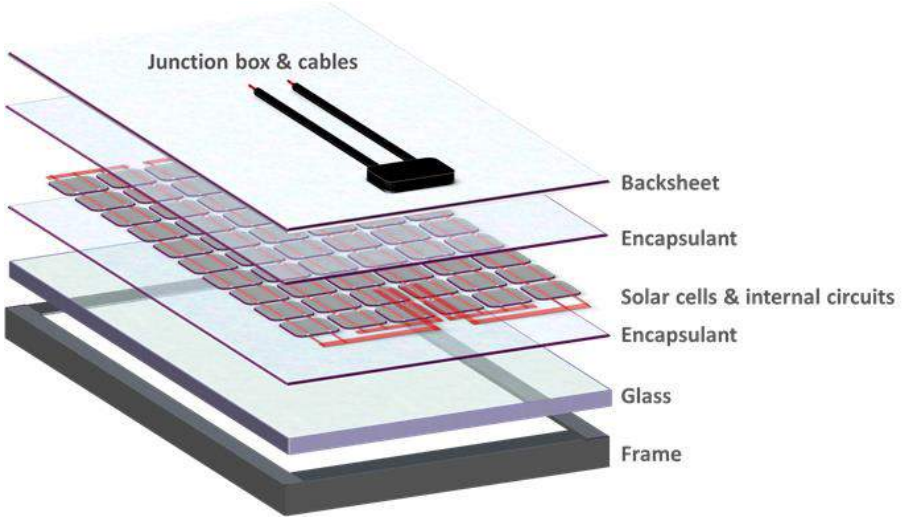
PV End of life today

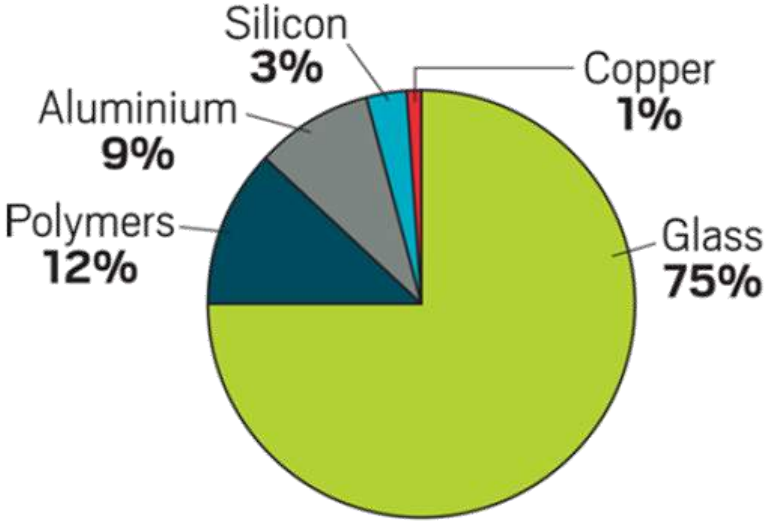


- EU: Waste from Electrical and Electronic Equipment (WEEE or e-waste)[1,2]
  - Collection rate >85%
  - Recycling rate >80%

[1] http://data.europa.eu/eli/dir/2012/19/2018-07-04 (2012)
[2] EN 50625
Figure: Source: NSW EPA The waste hierarchy

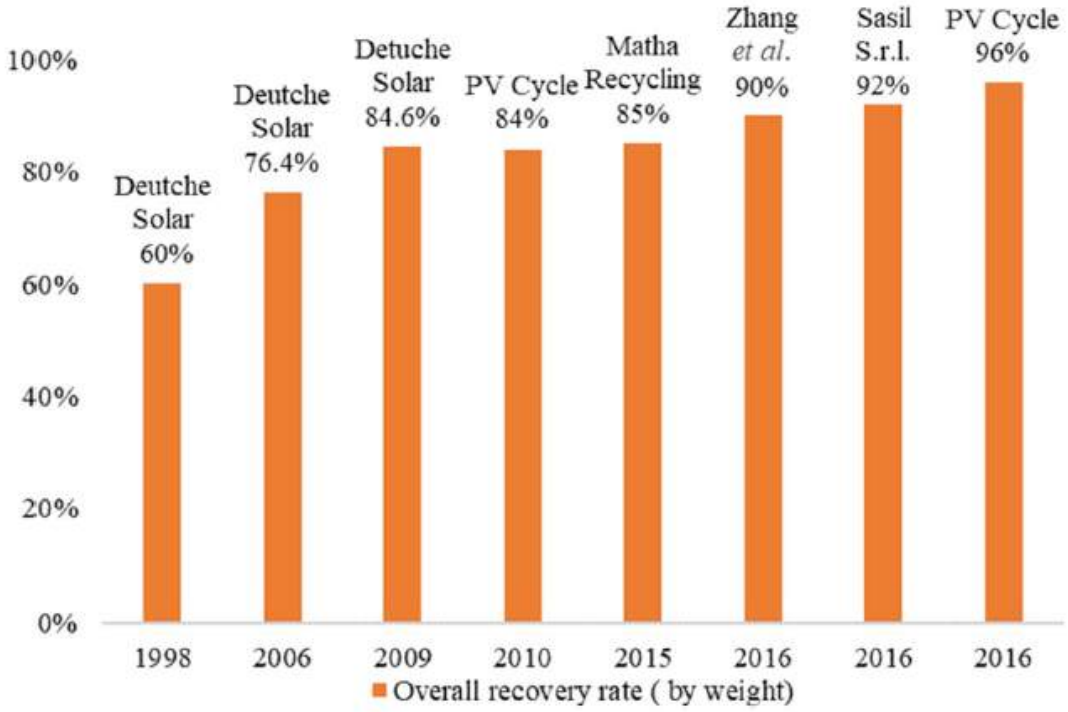
How would you fulfill the >80% recycling rate?





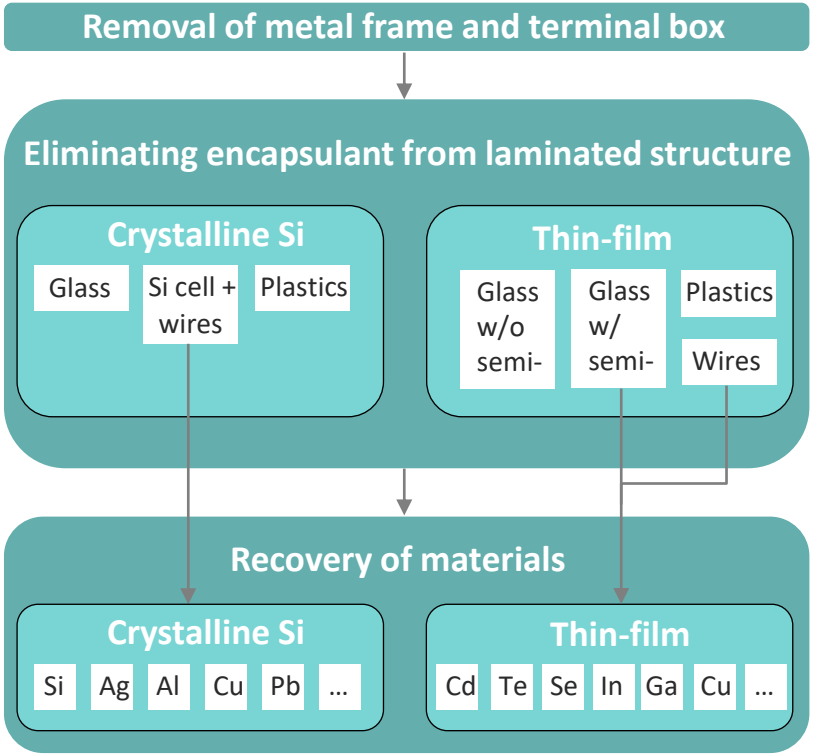
- **Remove aluminum frame and copper cable -> 10%**
- **Crush glass: Low level filer material -> 75%**

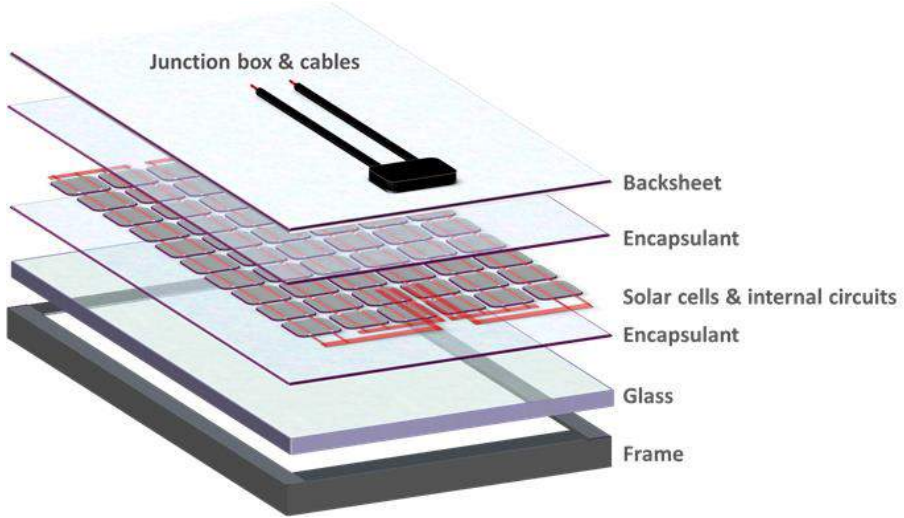
PV recycling rates



R. Deng, et al., Renew. Sust. Energ. Rev., 2019

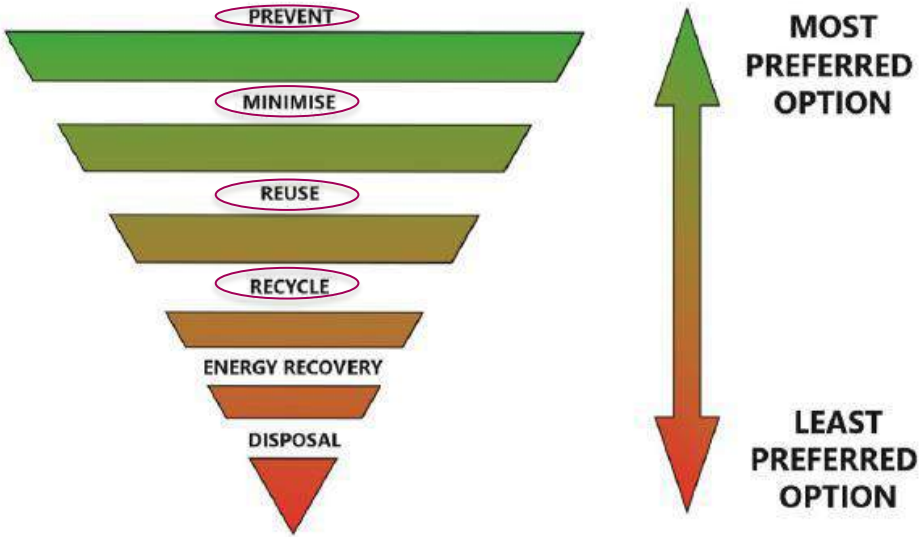
PV module recycling goal





S. Weckend, et al., IEA PVPS Task 12, Subtask 1, 2016

PV End of life future



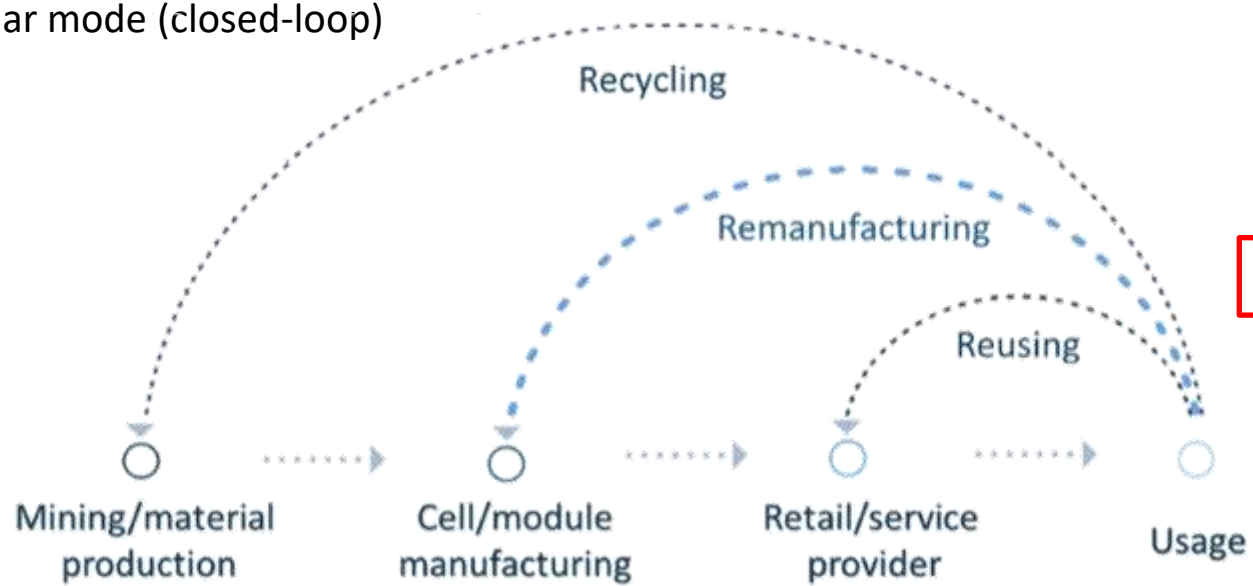
- Use less electricity
- Extend lifetime
- Increase efficiency
- Use less materials
- Reuse PV panels
- Recycle more efficiently

Figure: Source: NSW EPA The waste hierarchy

Circular PV

- Linear mode (open-loop)

- Circular mode (closed-loop)



Circular PV

R. Deng, et al., Prog. Photovolt.: Res. Appl., 2021

Wrap-up

1. Growth scenarios for PV
   - Installed PV will grow by a factor of 15-63

2. Critical materials and demand of PV
   - Silver reduction most critical for PV

3. Current and future PV End-of-Life practices
   - Remove aluminum frame and copper cable -> 10%
   - Crush glass: Low level filer material -> 75%
   - Circular PV futures
     - Reduce, Reuse, Recycle …

Thank you for your attention!

SOLAR URBAN
Delft University of Technology
Amsterdam Institute for Advanced Metropolitan Solutions

e-Refinery

TU Delft | AgTech Institute

TU Delft Climate Action Programme

PVMD funding

Rijksdienst voor Ondernemend Nederland
URBAN EUROPE
HORIZON 2020
cet Partnership
Horizon Europe
NWO
HyET Solar
Flexible light weight solar modules

Contact

m.r.vogt@tudelft.nl

Request your trial version of ASA7: **http://asa.ewi.tudelft.nl/**
PVMD web-lab: **www.tudelft.nl/dutchpvportal**
International PV Systems Summer School series: **www.tudelft.nl/pvsss**