



June 6-8, 2023 | Chambéry, France & Online

Beyond silicon: thin-film tandem as an opportunity for photovoltaics supply chain diversification and faster power system decarbonization out to 2050

Alessandro Martulli, PhD Student, Hasselt University, Belgium

Co-authors:

Fabrizio Gota (KIT, Germany), Neethi Rajagopalan (VITO/DOW, Belgium), Toby Meyer (Solaronix, Switzerland), Cesar Ramirez Quiroz (FOM/Nice Solar, Denmark), Daniele Costa (VITO, Belgium), Ulrich Paetzold (KIT, Germany), Robert Malina (UHasselt, Belgium), Bart Vermang (UHasselt/IMEC, Belgium), Sebastien Lizin (UHasselt, Belgium)

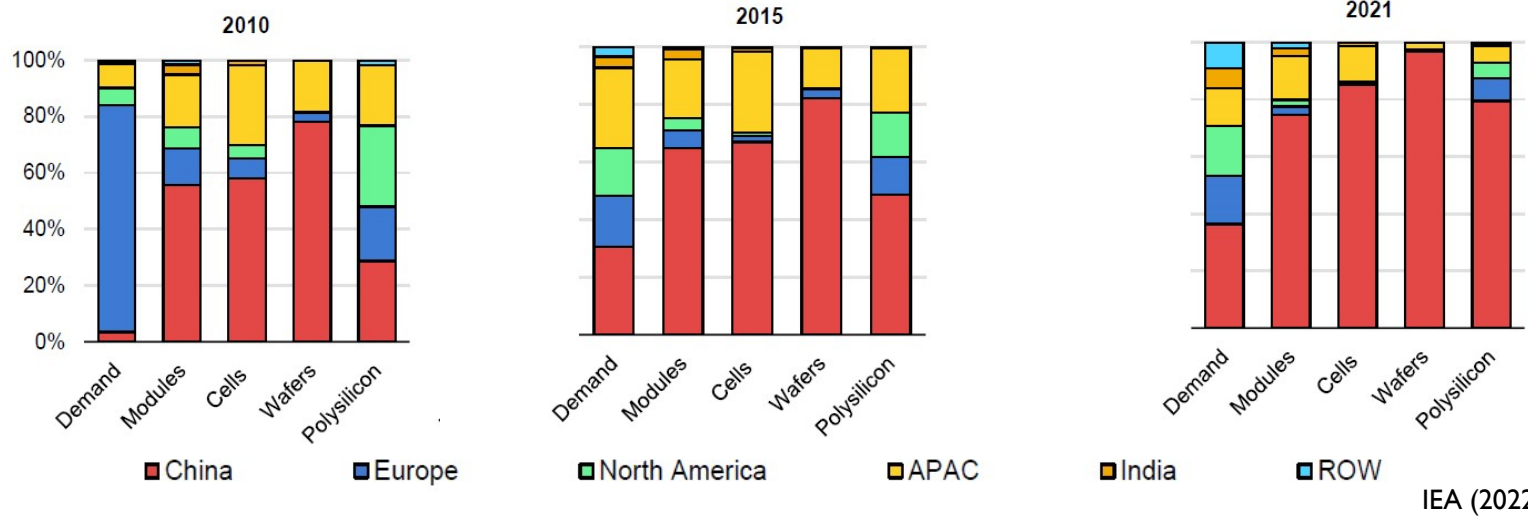


European Union's Horizon 2020 research and innovation programme, grant agreement N° 850937.



Background: Solar PV techs and supply chain

Silicon SJ (95% of market)	Thin-film SJ	Tandem (novel)
PERC	CIGS	Perovskite/CI(G)S
SHJ	CdTe	Perovskite/PERC
	Perovskite (novel)	Perovskite/SHJ



- Silicon: dominant PV technology
- China: dominant of silicon PV supply chain

Background: Pros and Cons of China concentration

PROS

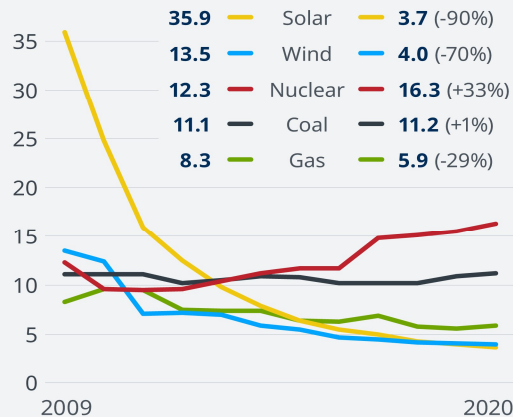
- About 90% solar cost decline
- Solar = most affordable source of electricity

CONS

- Market concentration
- Geographic concentration (China)
- Supply chain vulnerable to shocks
- Import dependency

Worldwide energy prices over the last decade

Generation costs in cents (US\$)



Source: WNIISR, Lazard

South China Morning Post

SUBSCRIBE



Business

China's 2022 heatwave

+ FOLLOW

China heatwave hits supply chain for lithium batteries and solar panels as Sichuan power cut impacts key producers

- Leading producers including GCL-Poly Energy Holdings, Tongwei Solar, Tianqi Lithium and Yahua Lithium are complying with a government-ordered shutdown

Bloomberg

Europe Edition

• Live Now | Markets | Economics | Industries | Technology | Politics | Wealth | Pursuits | Opinion | Businessweek | Equality | **Green**

Subscriber Only

Green

Polysilicon Makers Shares Soar After Blast at Chinese Plant

- Polysilicon prices could rise 17% on supply impact: Daiwa
- No. 4 producer GCL-Poly shuts Xinjiang plant after explosions

By Bloomberg News

July 21, 2020 at 4:46 AM GMT+2 Updated on July 21, 2020 at 5:40 PM GMT+2

LIVE ON BLOOMBERG
Watch Live TV
Listen to Live Radio

PV Supply chain diversification

- Solar PV crucial technology to reduce energy GHG intensity

Supply chain diversification needed

- Growing interest of EU and US policymakers to reduce dependence and stimulate domestic manufacturing
 - Inflation Reduction Act (US)
 - Green Deal Industrial Plan (EU)



Silicon SJ (95% of market)	Thin-film SJ	Tandem (novel)
PERC	CIGS	Perovskite/CIS
SHJ	CdTe	Perovskite/PERC
	Perovskite (novel)	Perovskite/SHJ

- Thin-film could be alternative to complement silicon supply
 - Thin film tandems (perovskite/CIS) show good performance (high-efficiency)
 - Thin film equipment suppliers location: Europe/US
 - Thin film R&D location: Europe/US

Can thin-film tandem PVs be competitive with silicon-based PVs (SJ and tandems)?

- Economic
- Environmental

1. Quantify costs and GHG emissions of PV technologies produced in:
 - EU
 - China
 - US
2. Determine whether thin-film tandems can be competitive with dominant silicon PVs made in China
3. Project the analysis to 2050

Economic and environmental indicators employed

- Module-level: analysis until PV module production

$$\text{Minimum sustainable price (MSP)} = \left[\frac{\text{USD\$}}{W} \right]$$

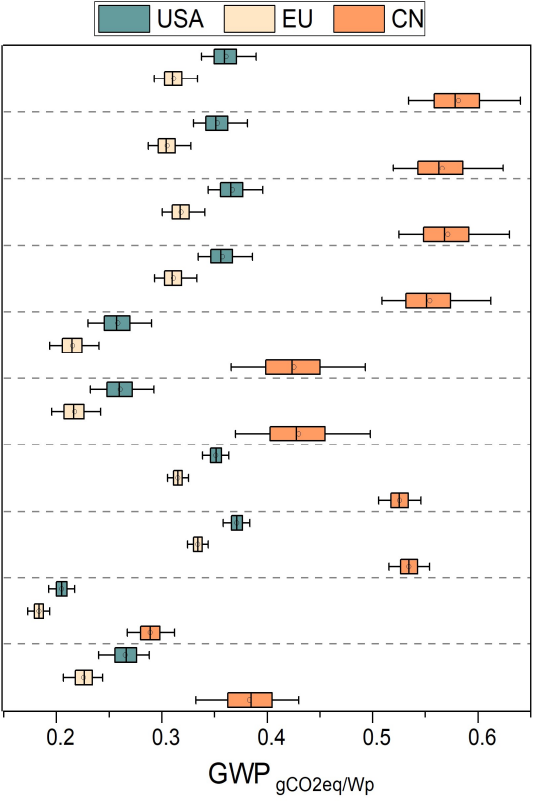
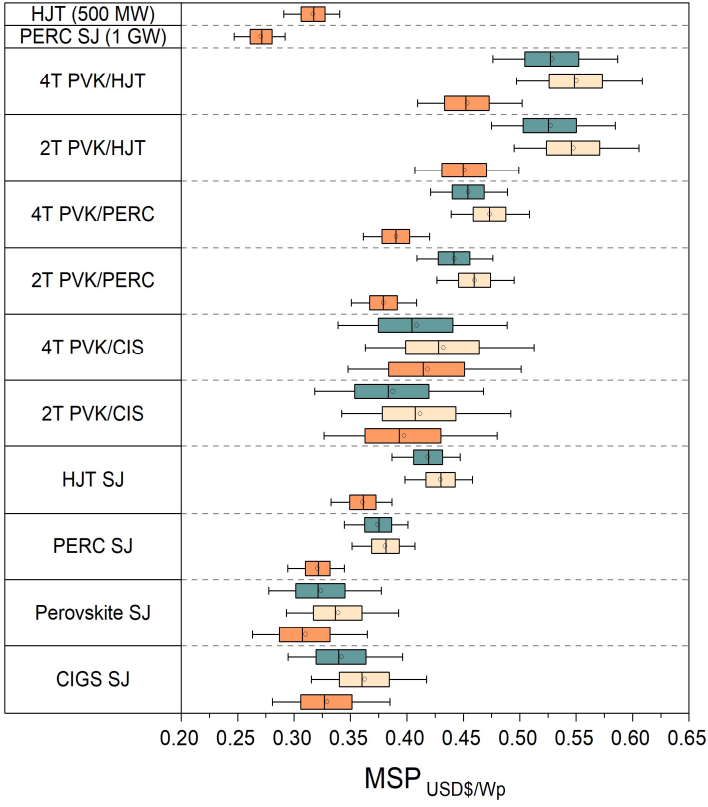
$$\text{Carbon footprint (GWP)} = \left[\frac{\text{kg CO}_2 \text{ eq}}{W} \right]$$

- System-level: deployment of PV modules in PV system to generate electricity
 - Supported by Energy Yield calculations: annual energy generated at three climatic locations

$$\text{Levelized cost of electricity (LCOE)} = \left[\frac{\text{USD\$}}{\text{kWh}} \right]$$

$$\text{Greenhouse gas emission factor (GEF)} = \left[\frac{\text{g CO}_2 \text{ eq}}{\text{kWh}} \right]$$

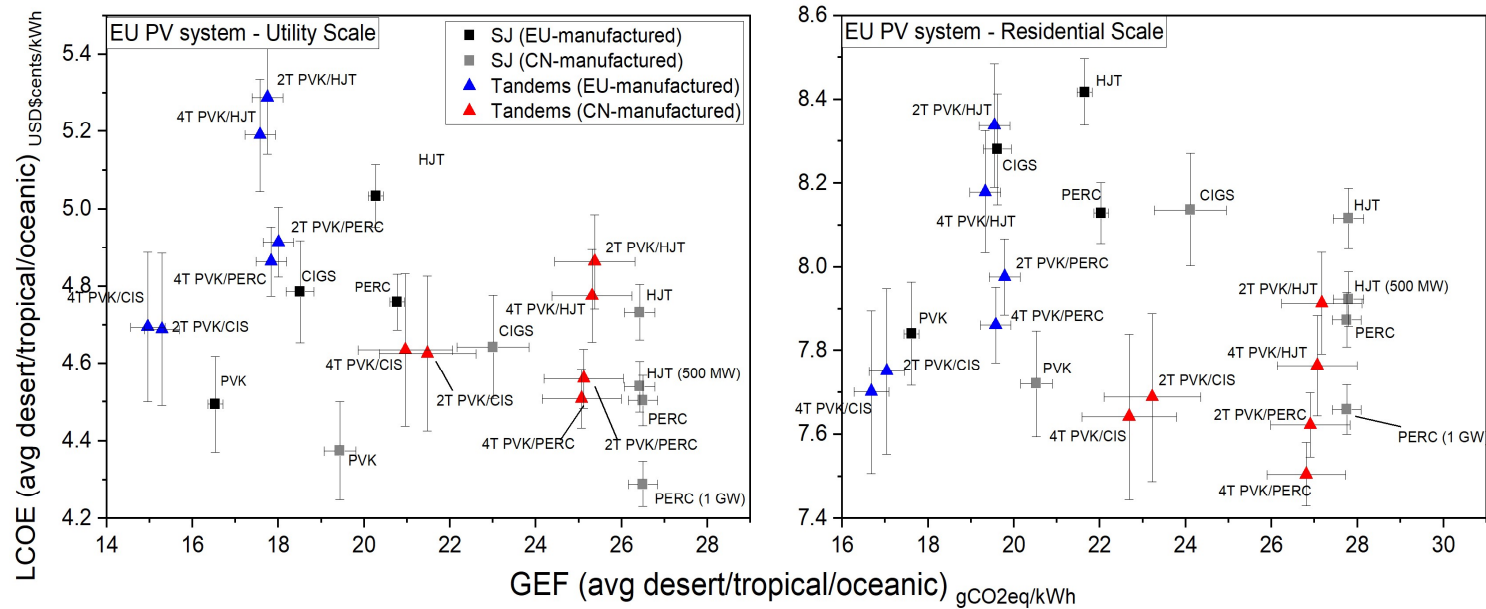
Results – Module level



Main considerations

- Contrasting results are found for MSP and GHG
- Large scale production of PERC (1 GW) – lowest costs
- Perovskite/CIS (thin-film tandems, made in EU/US) can reach similar costs to perovskite/PERC made in EU/US
- EU made perovskite/CIS have 22% probability to have lower costs than perovskite/PERC (China)
- US made perovskite/CIS have 34% probability to have lower costs than perovskite/PERC (China)
- Perovskite/CIS (EU) have approx. 60% less GHG than PERC and HJT SJ made in China
- Perovskite/CIS (US) have approx. 52% less GHG than PERC and HJT SJ made in China

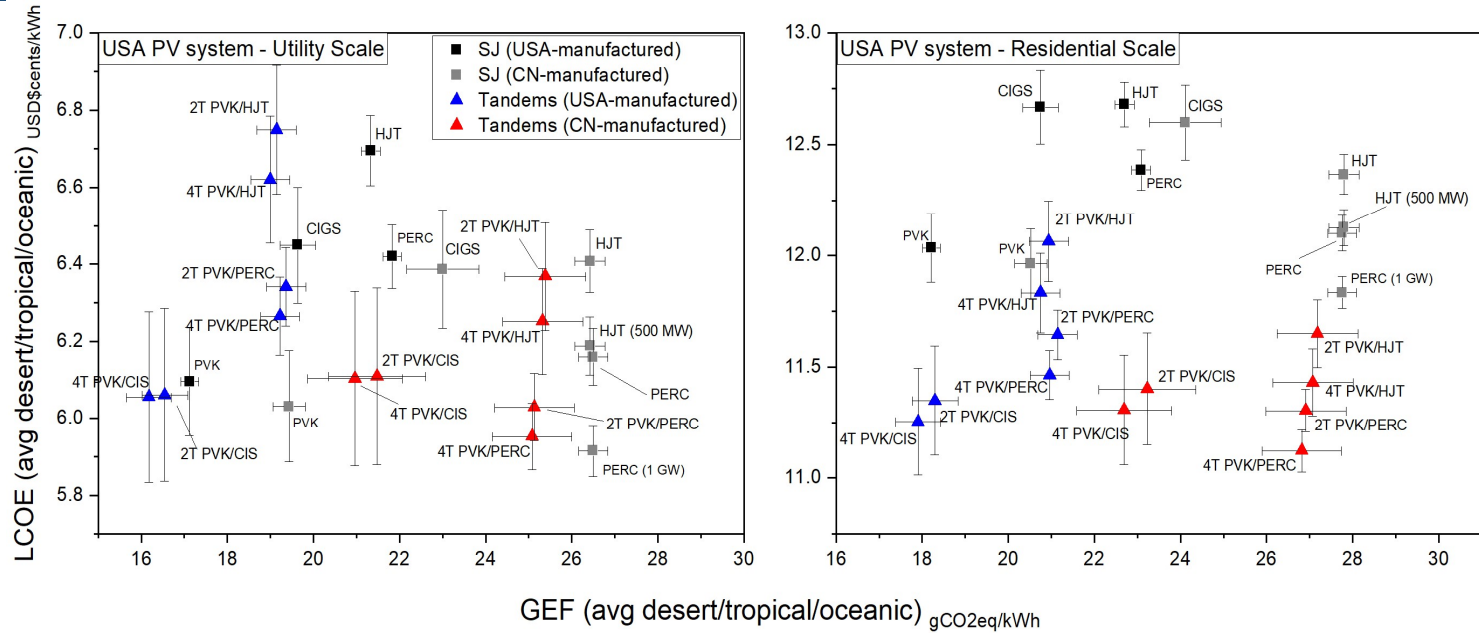
Results – System level



Main considerations

- Figure shows LCOE and GEF for PV modules made in EU (and installed in EU) and PV modules made in China (imported and installed in EU)
- Utility-scale power plants: EU manufactured technologies have higher LCOE
- Residential-scale: EU manufactured perovskite/CIS can be cost competitive with imported silicon PVs
- Perovskite/PERC (China) 2-4% lower cost per kWh than perovskite/CIS made in EU
- GHG emissions per kWh of perovskite/CIS are 37-40% lower than perovskite/PERC made in China

Results – System level



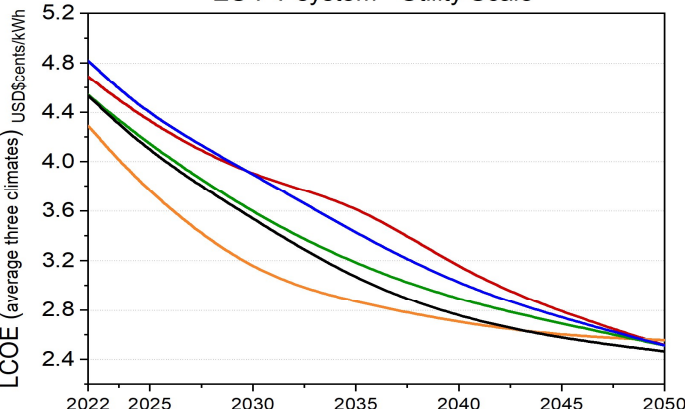
Main considerations

- Figure shows LCOE and GEF for PV modules made in US (and installed in US) and PV modules made in China (imported and installed in US)
- Similar findings as for the EU case (previous slide)
- Perovskite/PERC (China) 1-2% lower cost per kWh than perovskite/CIS made in EU
- GHG emissions per kWh of perovskite/CIS are 33-35% lower than perovskite/PERC made in China

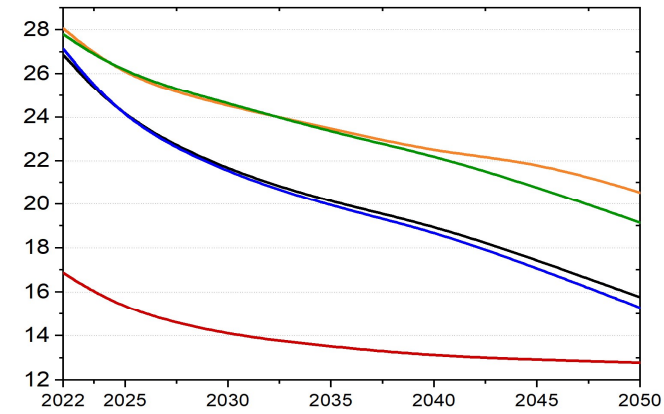
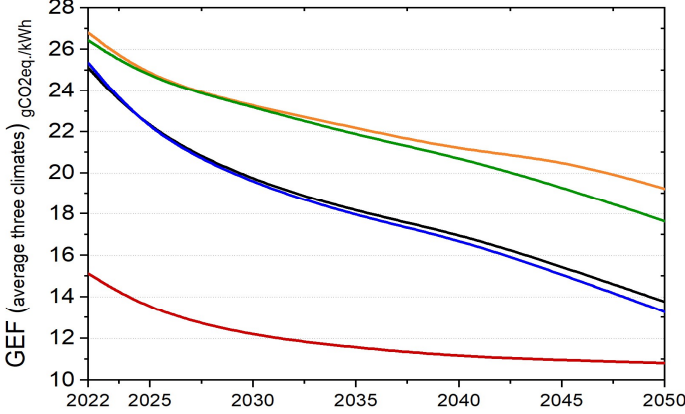
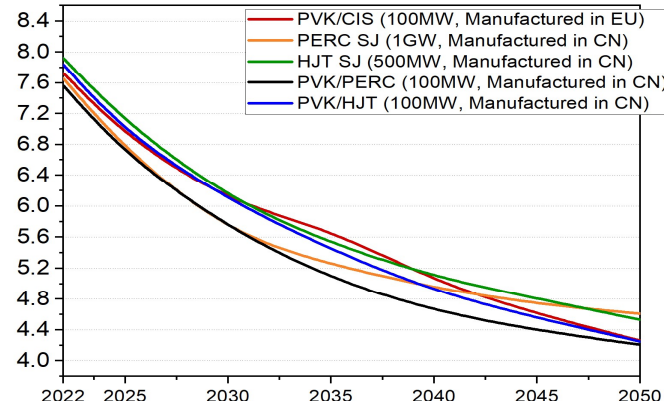


Results – out to 2050

EU PV system - Utility Scale



EU PV system - Residential Scale

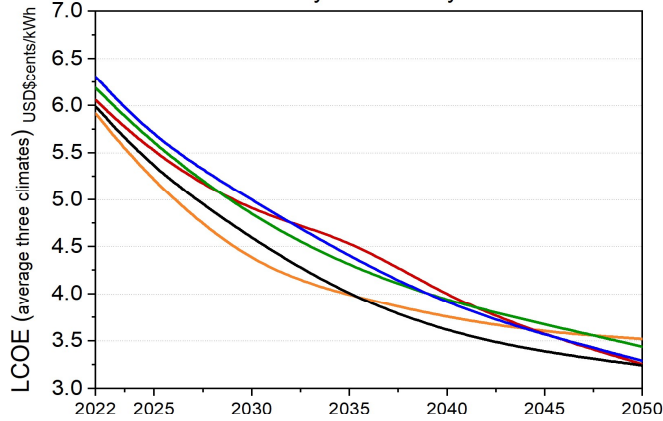


Main considerations

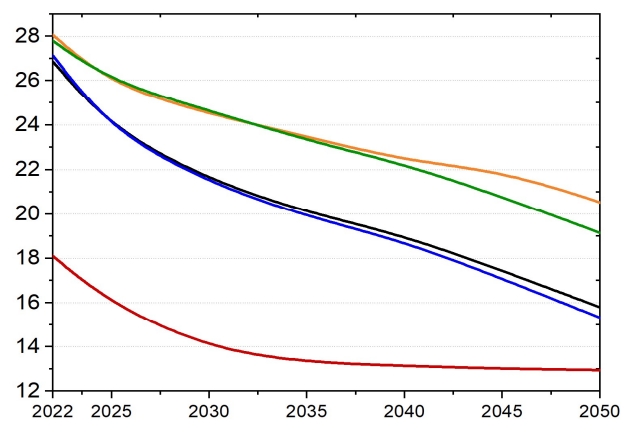
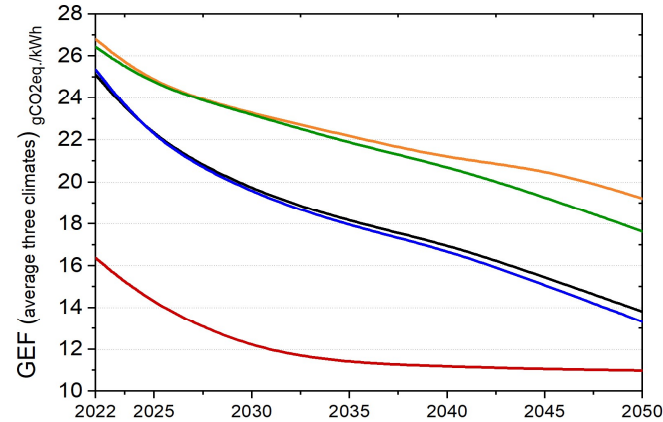
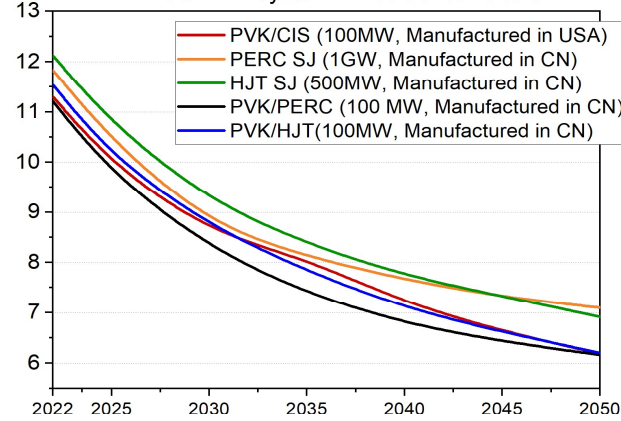
- Expected transitions towards low-carbon energy mix in China in the next decades
- Perovskite/CIS made in EU will still retain best GHG performance by 2050
- 19-21% lower than silicon tandems made in China and imported-installed in EU
- perovskite/CIS cost competitiveness with perovskite/silicon can be envisioned:
 - Provided increasing market shares
 - Provided increases in efficiency

Results – out to 2050

USA PV system - Utility Scale



USA PV system - Residential Scale



Main considerations

- Similar as EU scenario
- Perovskite/CIS made in US will still retain best GHG performance by 2050
- 18-20% lower than silicon tandems made in China and imported-installed in US
- perovskite/CIS cost competitiveness with perovskite/silicon can be envisioned:
 - Provided increasing market shares
 - Provided increases in efficiency

Conclusions

- In the following decades, additional PV manufacturing capacity will need to be installed to meet growing demand
 - Our findings support development of thin-film production capacity could complement this additional supply
 - Enable supply chain diversification
 - Faster power system decarbonization
1. Perovskite/CIS (EU) have one of the lowest GHG performances (as low as 0.21 kgCO₂eq./W)
 2. Minimum Sustainable Price can be competitive with perovskite/silicon made in China
 3. LCOE of perovskite/CIS made in EU or US can be competitive with perovskite/PERC or PERC PV imported from China
 4. GHG emissions per kWh of perovskite/CIS (EU or US) is between 33-40% lower than perovskite/PERC imported from China
 5. Out to 2050, cost competitiveness can be retained and GHG emission advantage can be up to 20%

Thank you for the attention.
Questions?