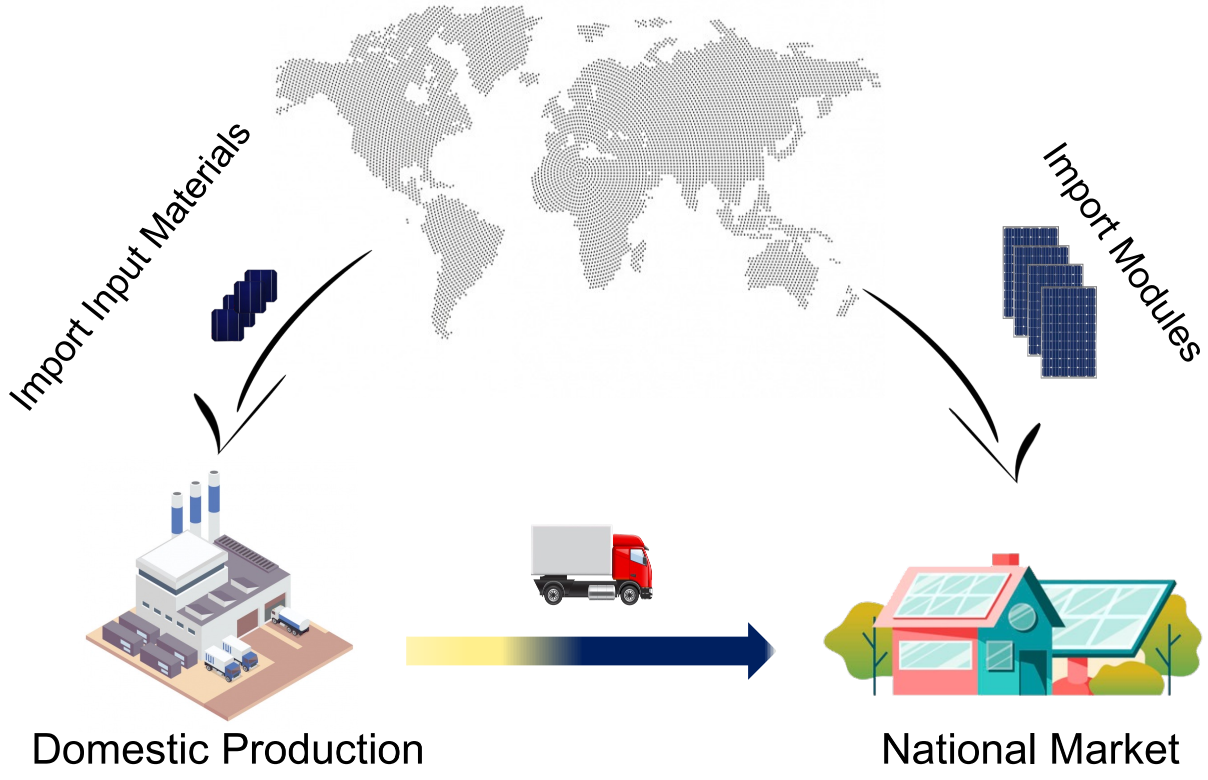
Economic, Environmental, and Social Implications of Localizing PV Module Assembly



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08 Mar 2024

Motivation:

Transition to more renewable energies – solar

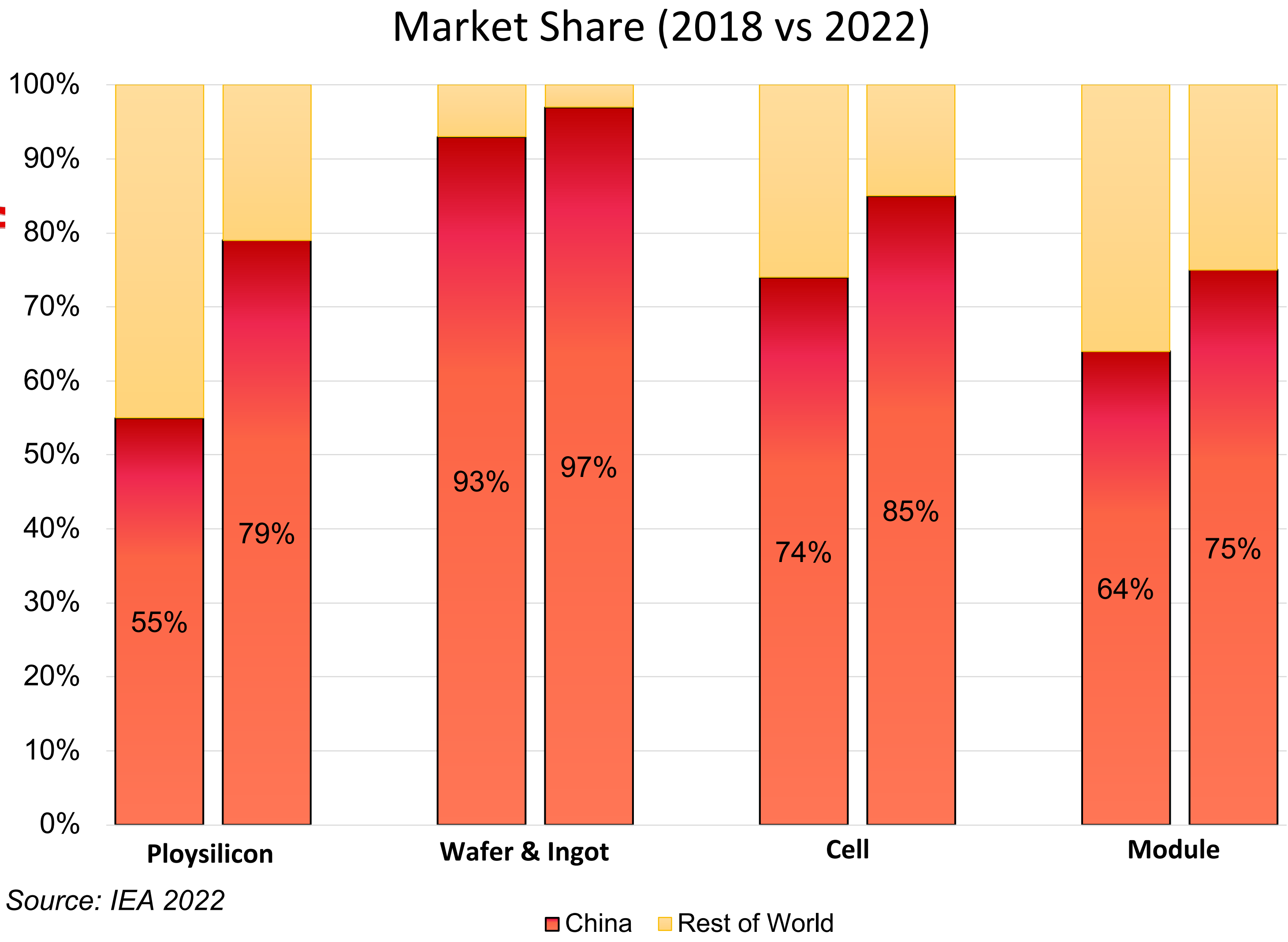
Local PV manufacturing supply chain

- Vulnerable PV supply chain
- Ethical supply chain
- Growing demand
- CapEx reduction
- Social impacts
- Environmental impacts

Motivation:

Transition to more renewable energies – solar

Local PV manufacturing supply chain



Source: IEA 2022

Motivation:

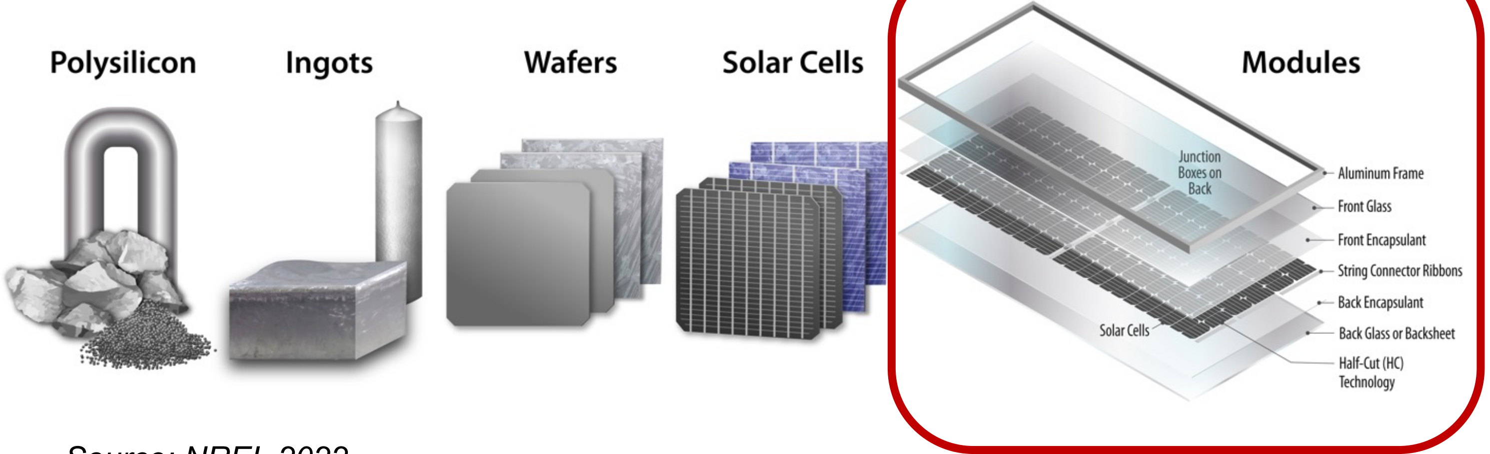
Transition to more renewable energies – solar

Local PV manufacturing supply chain

Module assembly supply chain

Vulnerable PV supply chain
Ethical supply chain
Growing demand
CapEx reduction
Social impacts
Environmental impacts

CapEx required
Risk of investment
Fresh start?!



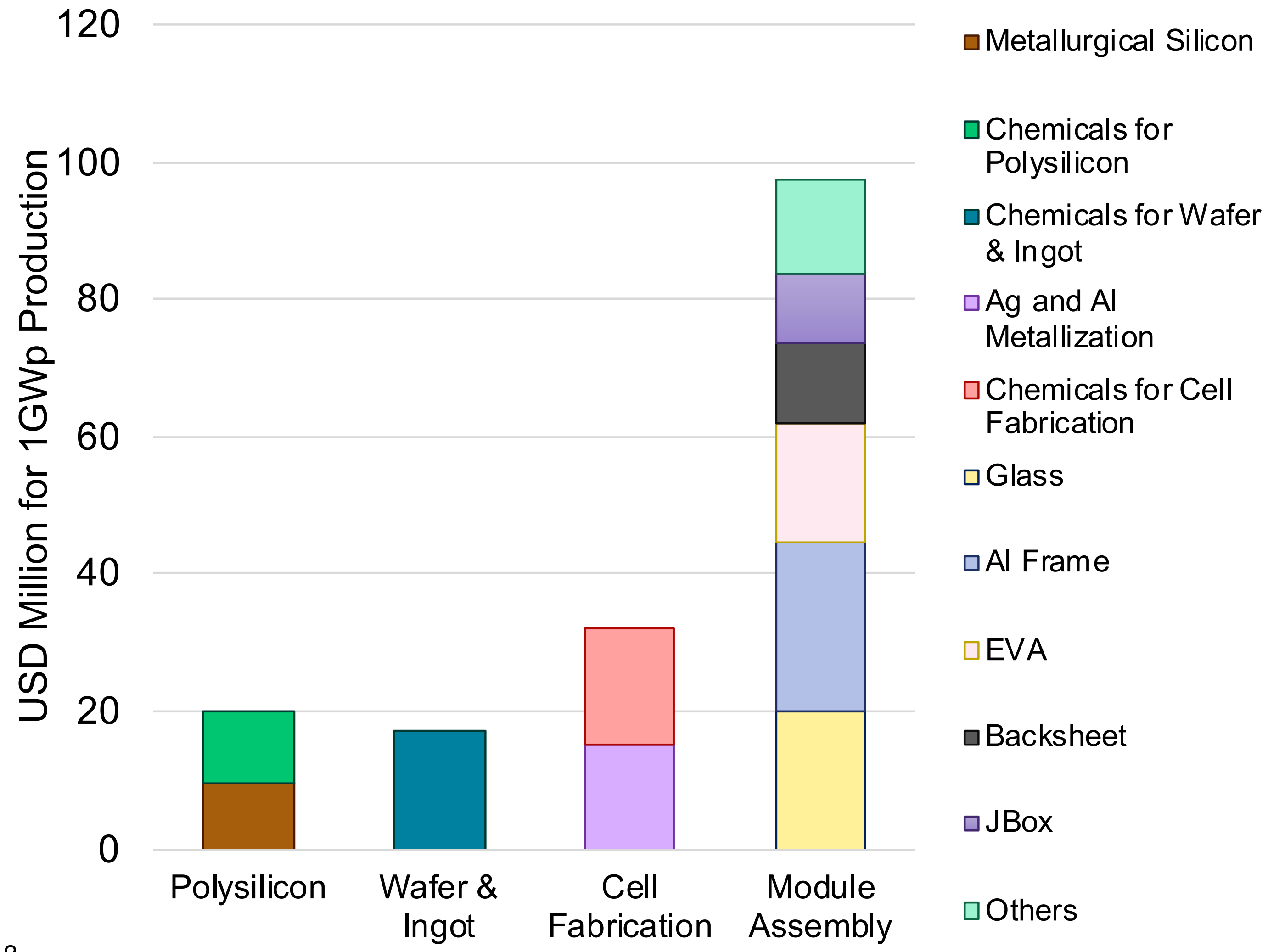
Source: NREL 2022

Economic Benefits:

Up-stream supply chain

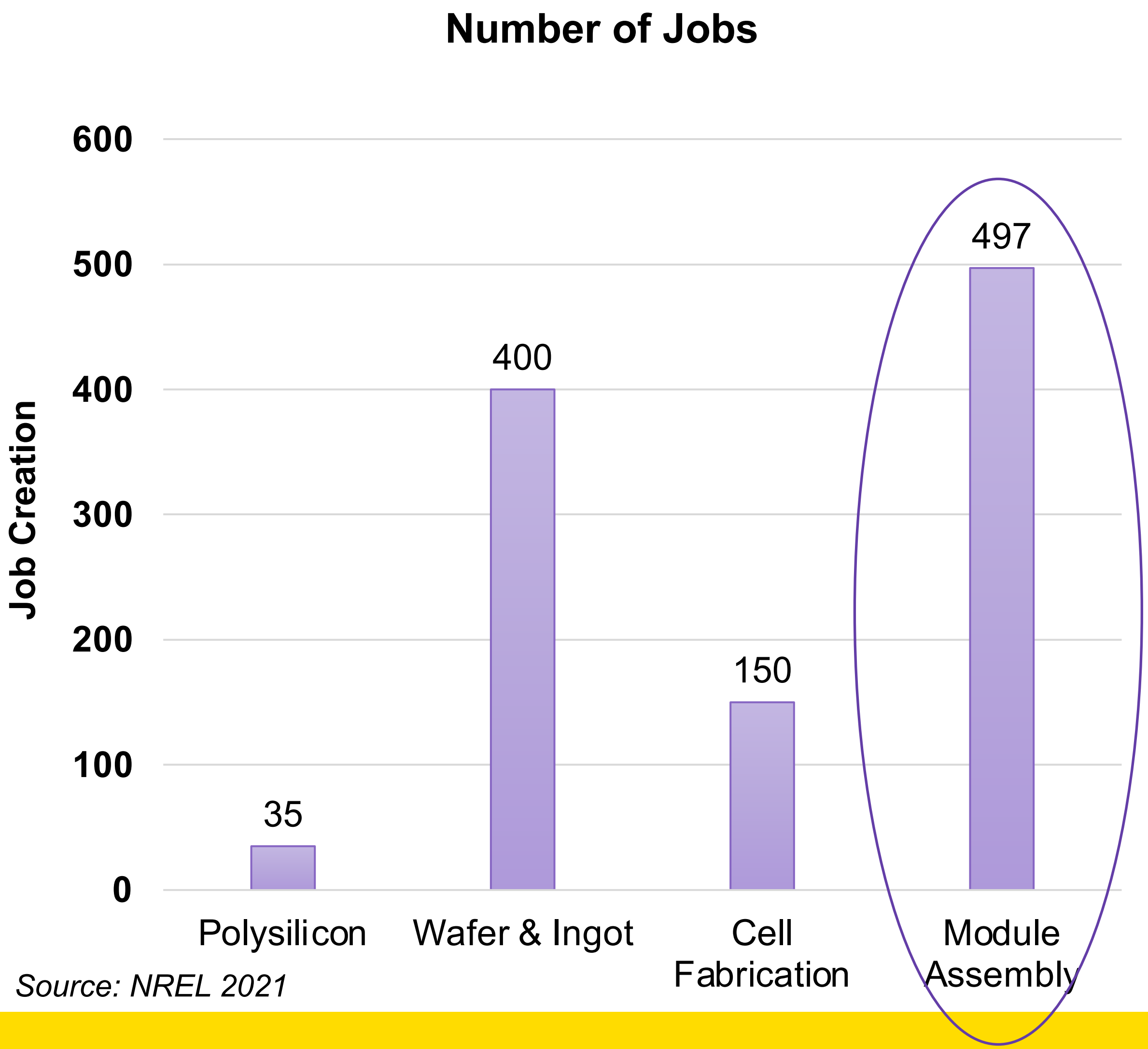
$100m/GWp

- Glass: $20m/GWp
- Aluminum: $24m/GWp

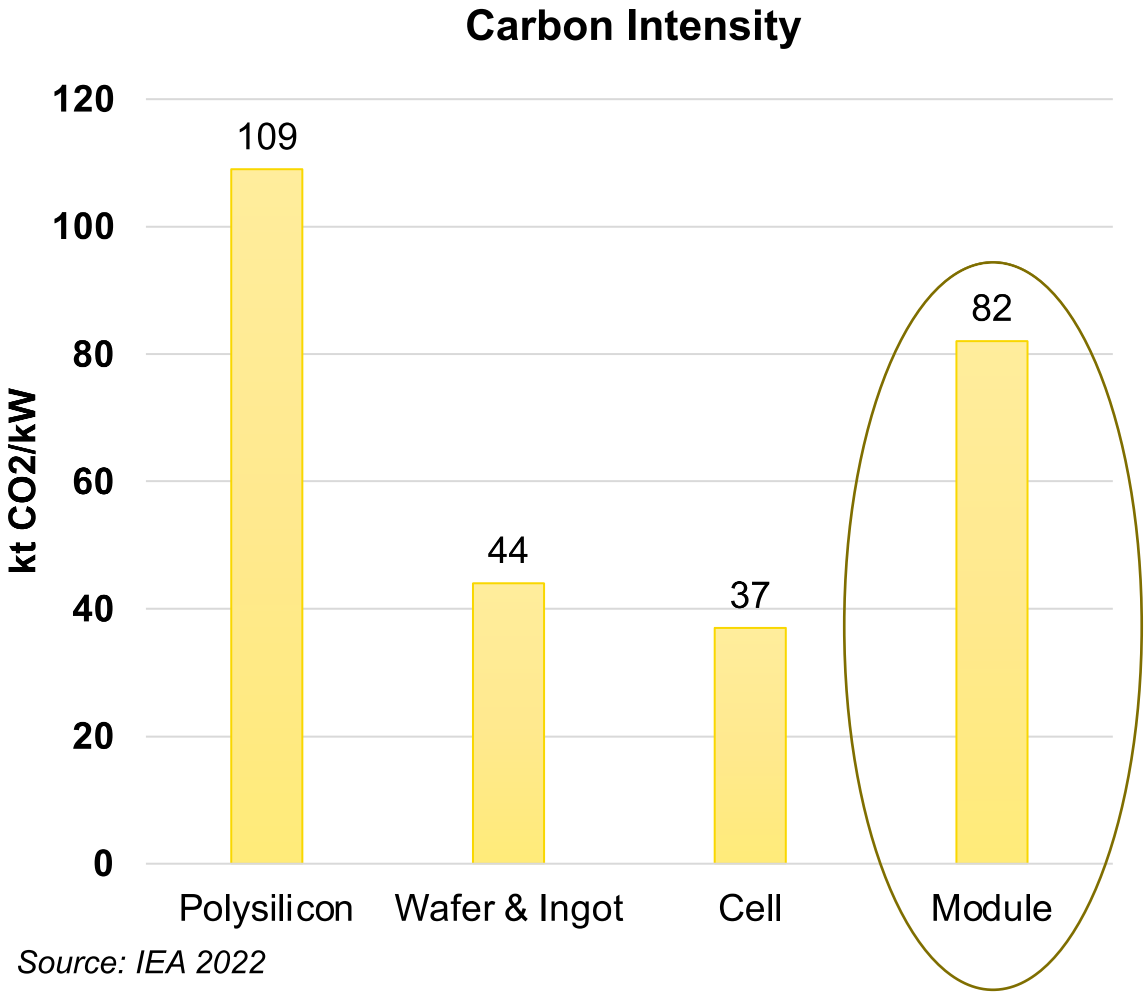


Source: NREL 2018

Social & Environmental Benefits:



Source: NREL 2021



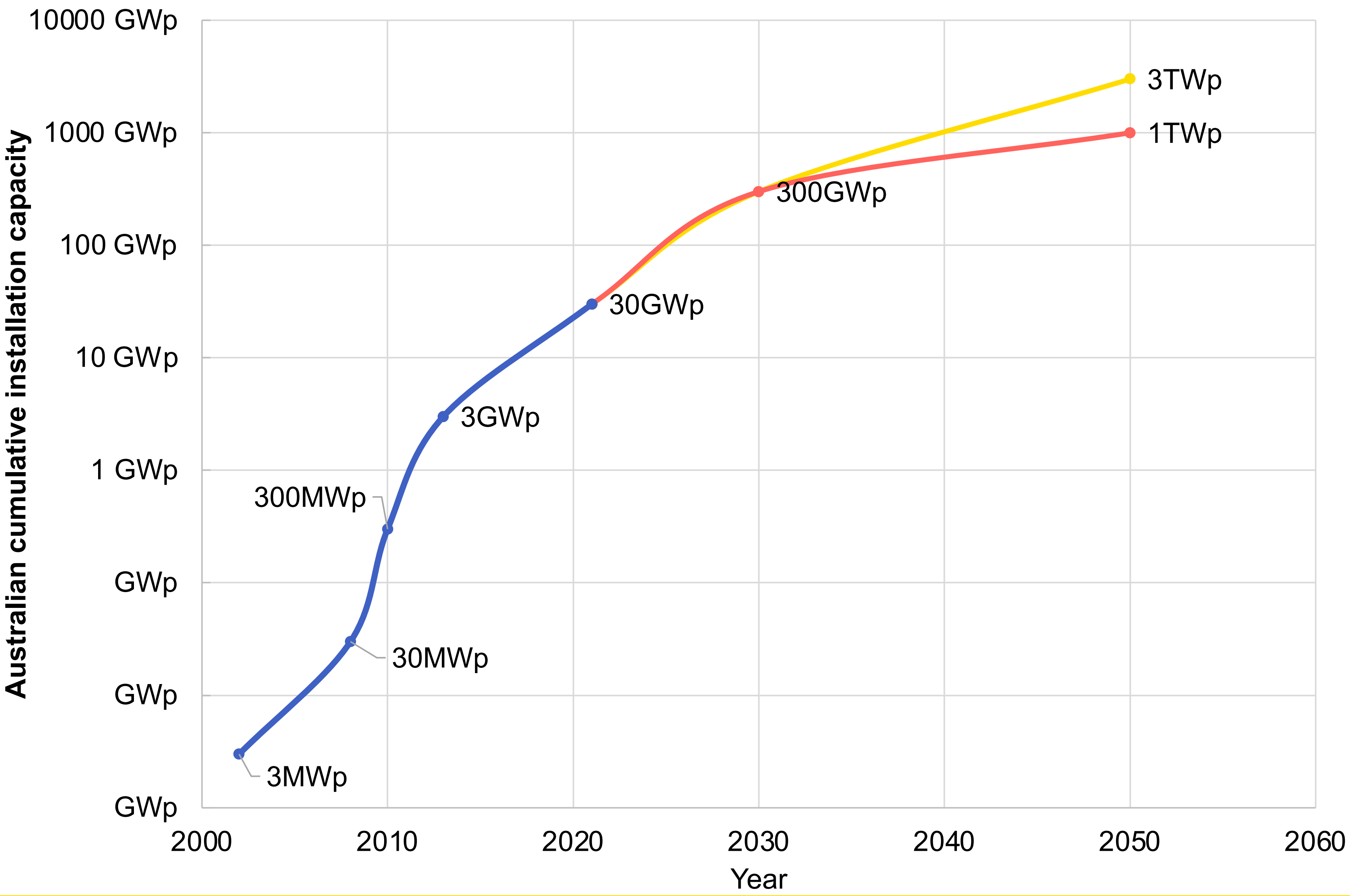
Source: IEA 2022

Market benefits:

Cumulative
module market

Potential value:
$3b by 2030

$100-300b by 2050



My PhD journey:

Economic optimization

- CapEx
- OpEx
- Trade expense
- Logistic expenses

Exploring policies

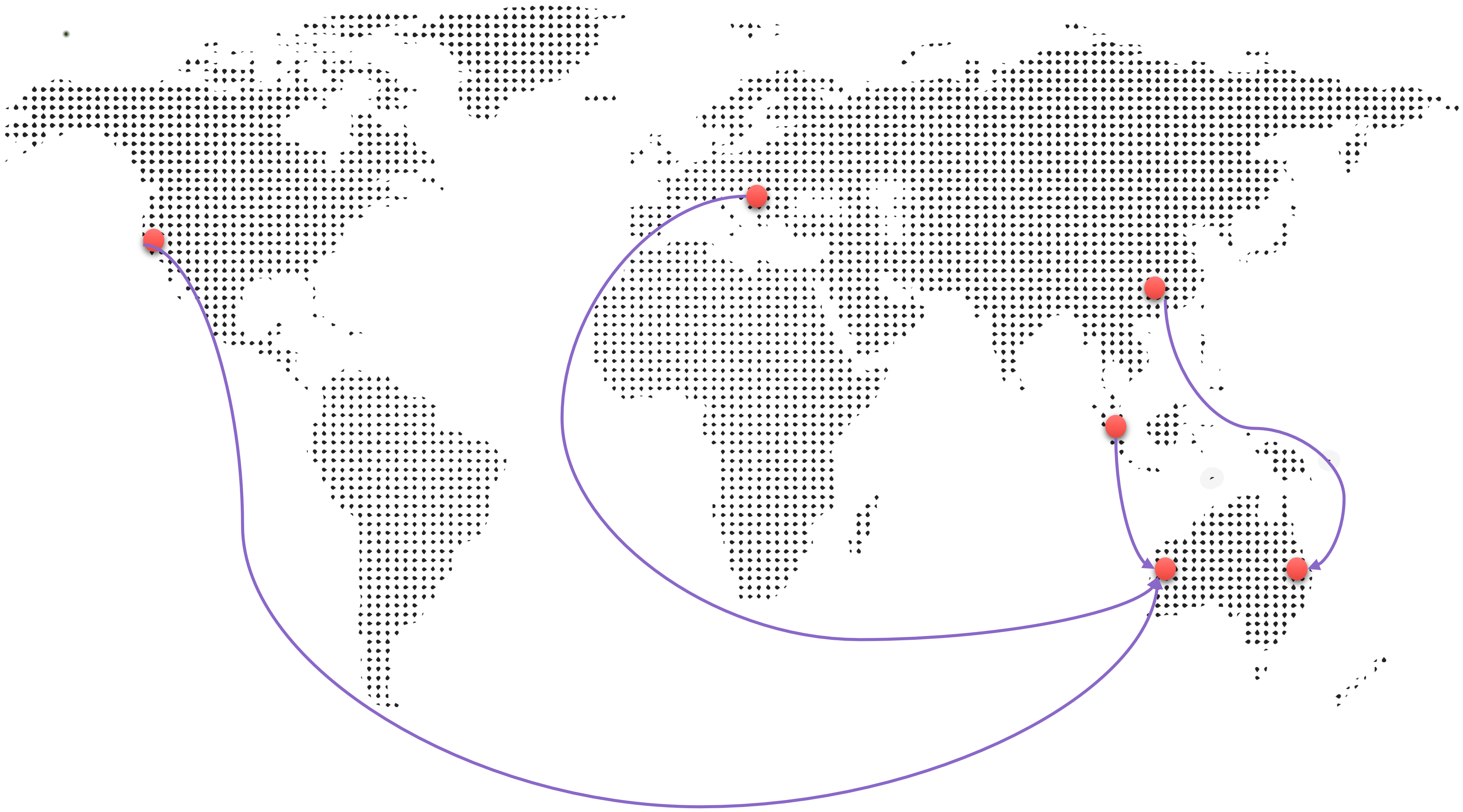
- Supportive
- Protective

Social and Environmental optimization

- Job creation
- Carbon footprint

Multiobjective optimization

- Socio-economic
- Eco-environment
- Economic, environmental and social



Logistic Fleet

$$Min\ Economic\ impact$$

Methodology:

$$MSP: Min \sum Cost$$

$$IRR = WACC$$

\+ Monte Carlo simulation

Assumptions:

Production capacity: 600MWp

144 half-cut mono c-Si P-type PERC bifacial

Module power: 545Wp

IRR = WACC of 14%

No debt funding

No export

To calculate the IRR, the factory is assumed to operate with the calculated costs and selling price for 7 years

$$Min\ Z = Depreciation\left(\frac{\$}{Wp}\right) + OpEx\left(\frac{\$}{Wp}\right) + Trade\left(\frac{\$}{Wp}\right) + Logistics\left(\frac{\$}{Wp}\right)$$

Import Costs

Logistic Costs

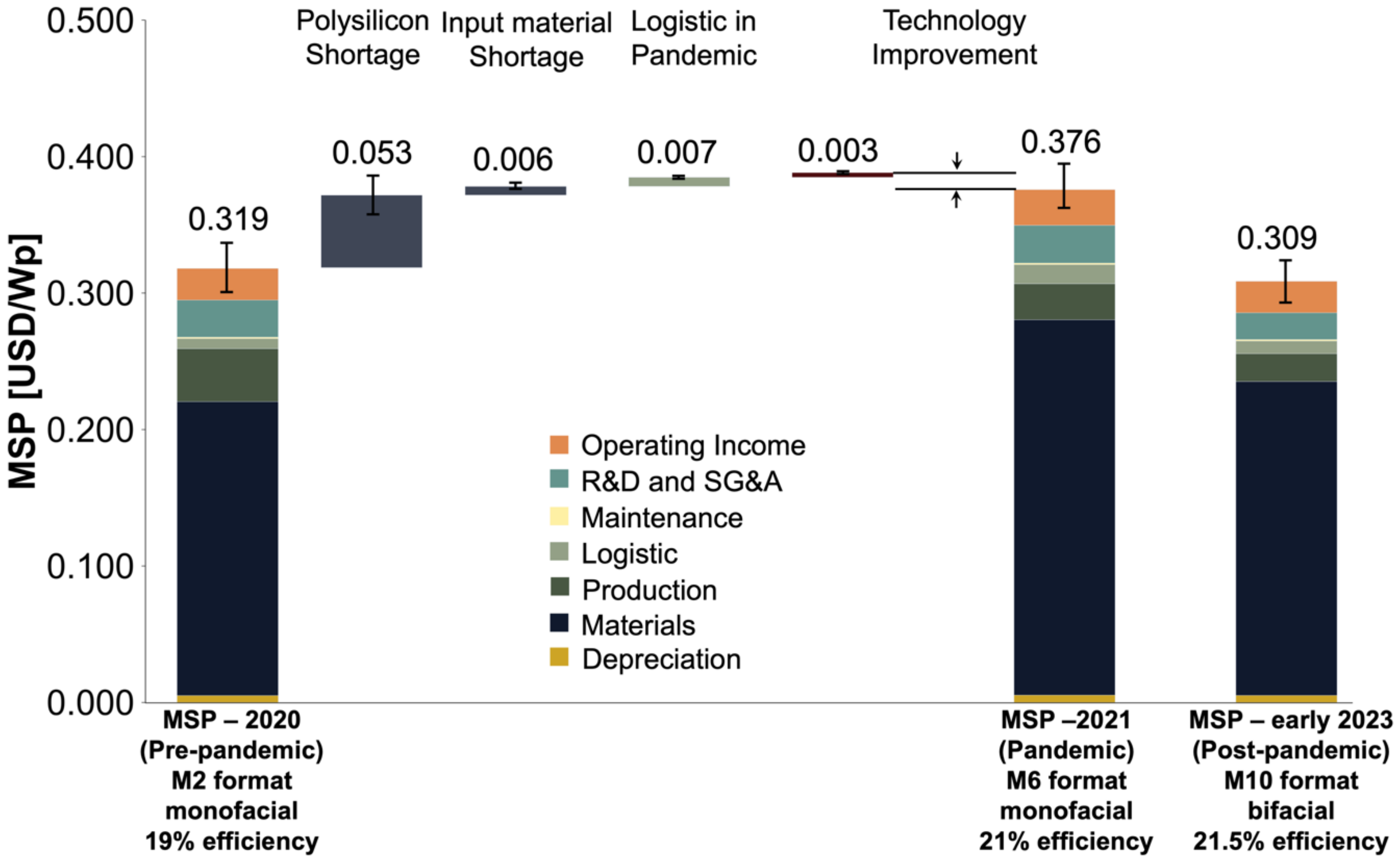
Production Costs

Investment Costs

Recent Supply Chain Disruptions – Polysilicon Shortages and the Pandemic

Production Cap: 600MWp/year

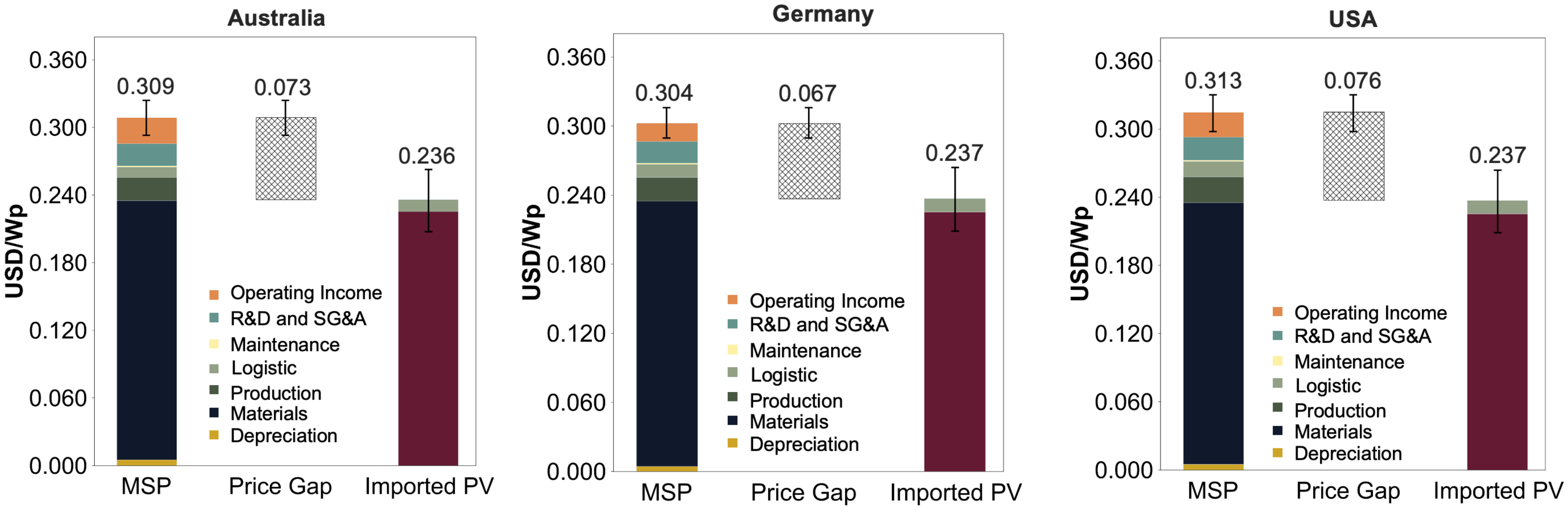
Location: NSW



Modelling the Price Gap - Without any government support or protection

Production Cap: 600MWp/year

Based on early 2023 cost data



Modelling the Price Gap – Economies of Scale

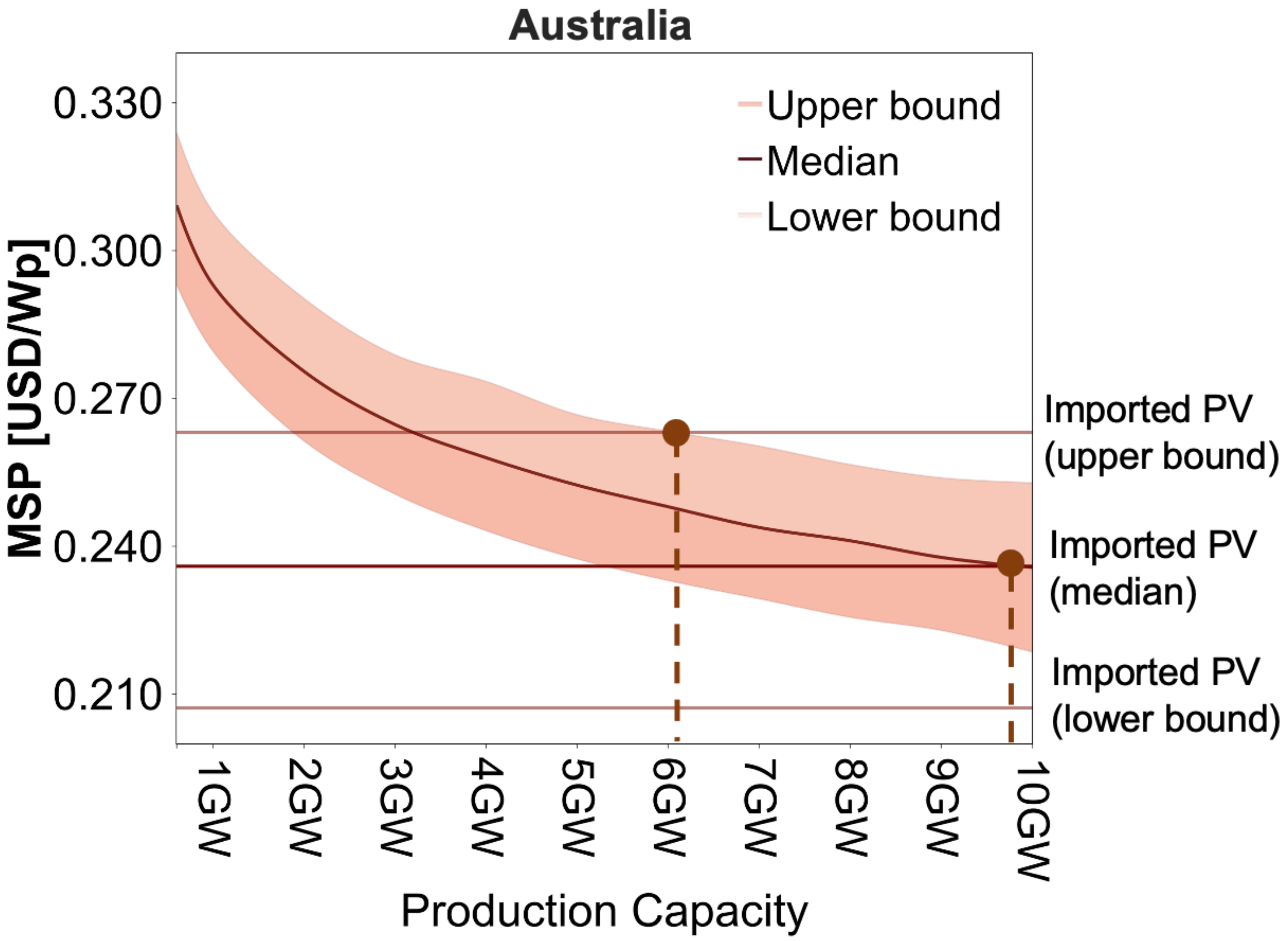
Competitive capacity

6 GWp at $0.26/Wp

Initial investment: **$390m**

10 GWp at $0.20/Wp

Initial investment: **$630m**



Policy options – history overview

A Review of Historical PV Manufacturing Policy Options:

- China
- Germany
- USA

		Policy	China	Germany	USA
Supportive	Capex	**Equipment incentives**	Various Forms of Local Support (1998 –)	Joint Task program (2005-2022) (45% of Equipment expenses in 2022)	Manufacturing Tax Credit (2009-2022): 30% of Equipment expenses
Supportive	Capex	**Land/building incentives**	Various Forms of Local Support (2004 –)	Joint Task program (2005-2022) (45% of land/building expenses in 2022)	Manufacturing Tax Credit (2009-2022): 30% of land/building expenses
Supportive	Capex	**Free/low interest loan**	China Development Bank (2004 –)	KfW Special Program(2005-2022) KfW Entrepreneur Loan(2005-2022)	Infrastructure Investment and Jobs Act The America COMPETES Act of 2022 Energy Policy Act (2005-2022)
Supportive	OpEx	**Cash out**	Various Forms of Local Support (2005 –)	No Specific Program (2009 –)	Inflation Reduction Act (2022 –)
Supportive	OpEx	**Labour incentives**	Rewarded PV scientists Free car and apartment	Recruitment Support, Training Support, 50-70% of the wage	No Specific Program (2009 –)
Supportive	OpEx	**Electricity incentives**	Various Forms of Local Support (2005 –)		
Supportive	OpEx	**Free/low interest loan**	China Development Bank (2004 –)	KfW Special Program(2005-2022) KfW Entrepreneur Loan(2005-2022)	Infrastructure Investment and Jobs Act and The America COMPETES Act of 2022 Energy Policy Act (2005-2022)
Supportive	OpEx	**Tax exemption**	Various Forms of Local Support (2007 –)		14% tax reduction (2018-2022)
Protective	Trade	**Import tariffs**	USA (polysilicon) (2014-2022): 53.6%-59.1% Korea (polysilicon) (2014-2022): 4.4%-113.8%	Al (2012-2022):14.6%-46.7% Glass (2012-2022):20.7%-92.5% PV cell & module (2012-2018):27.3%-76.4%	Section 201, Section 301, Section 232
Protective	Trade	**Trade barriers**			Import Quota (2022): 5GW Section 307: The Uyghur Forced Labour Prevention Act (UFLPA)

Policy options – history overview

A Review of Historical PV Manufacturing Policy Options:

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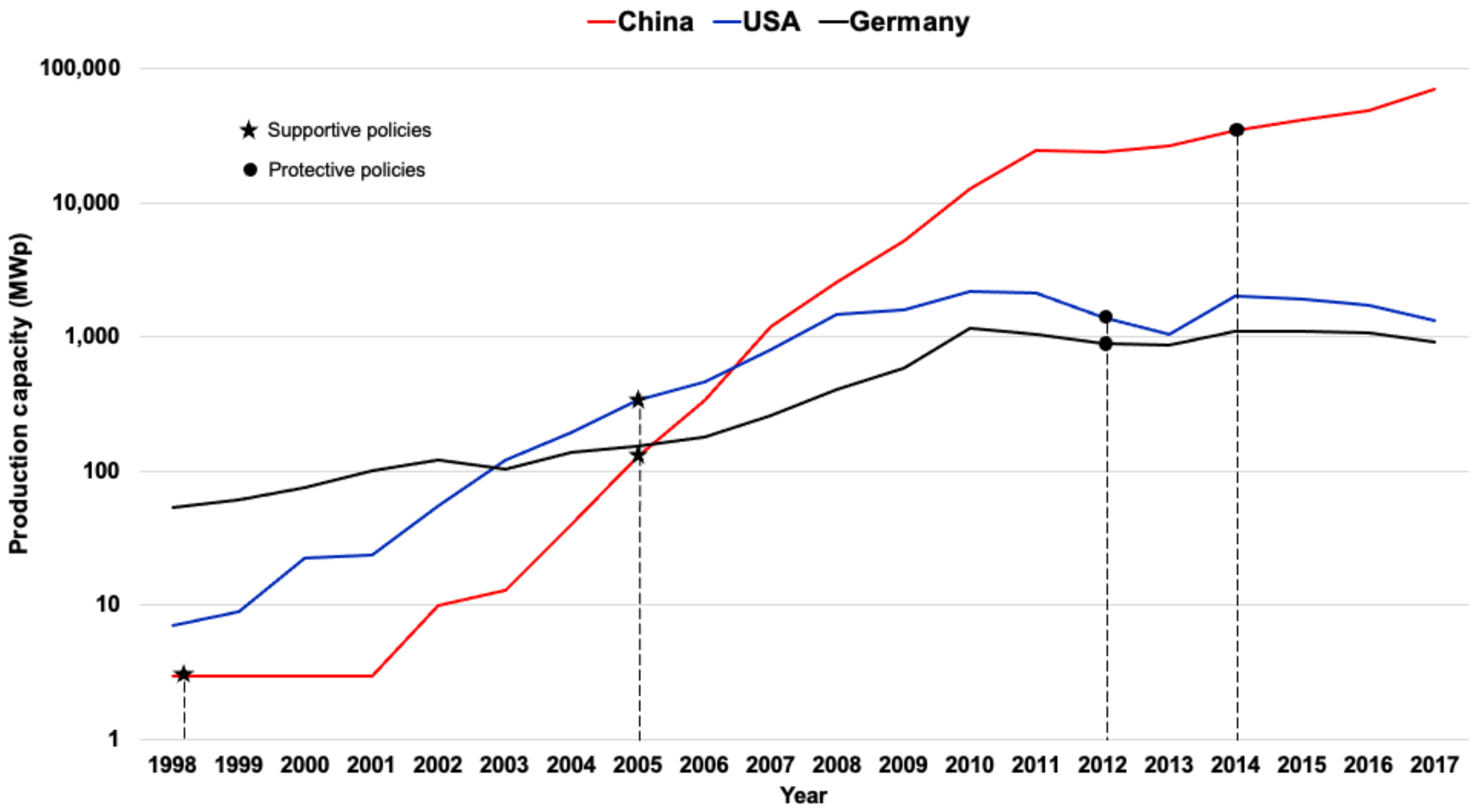
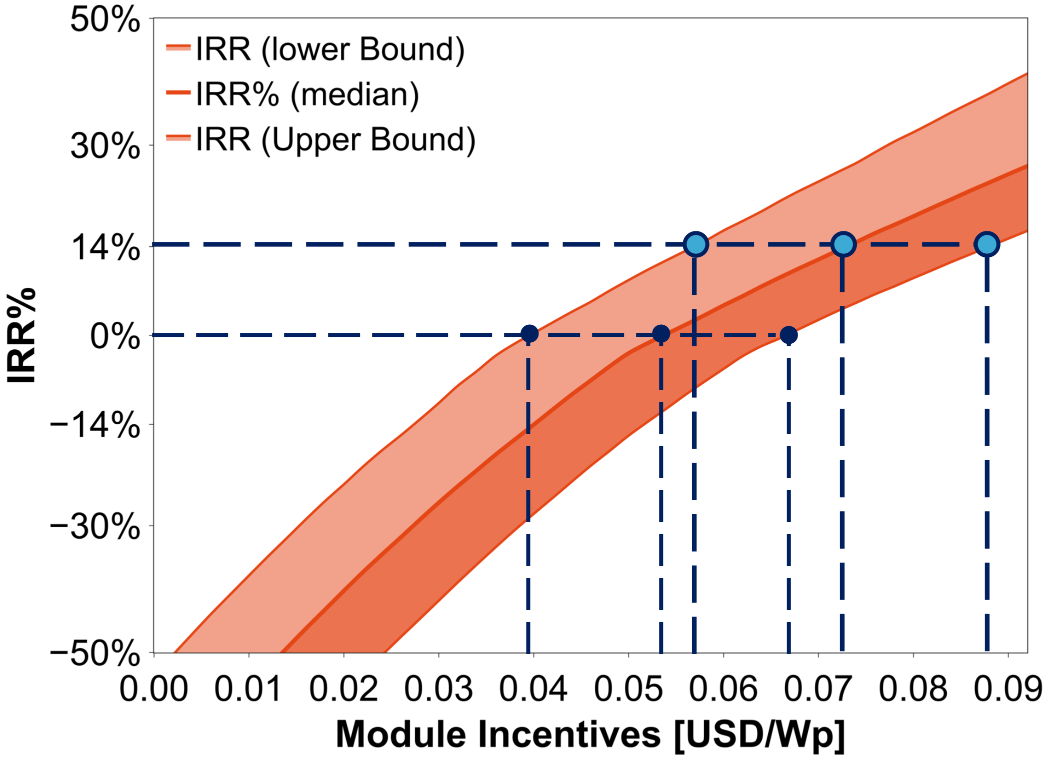
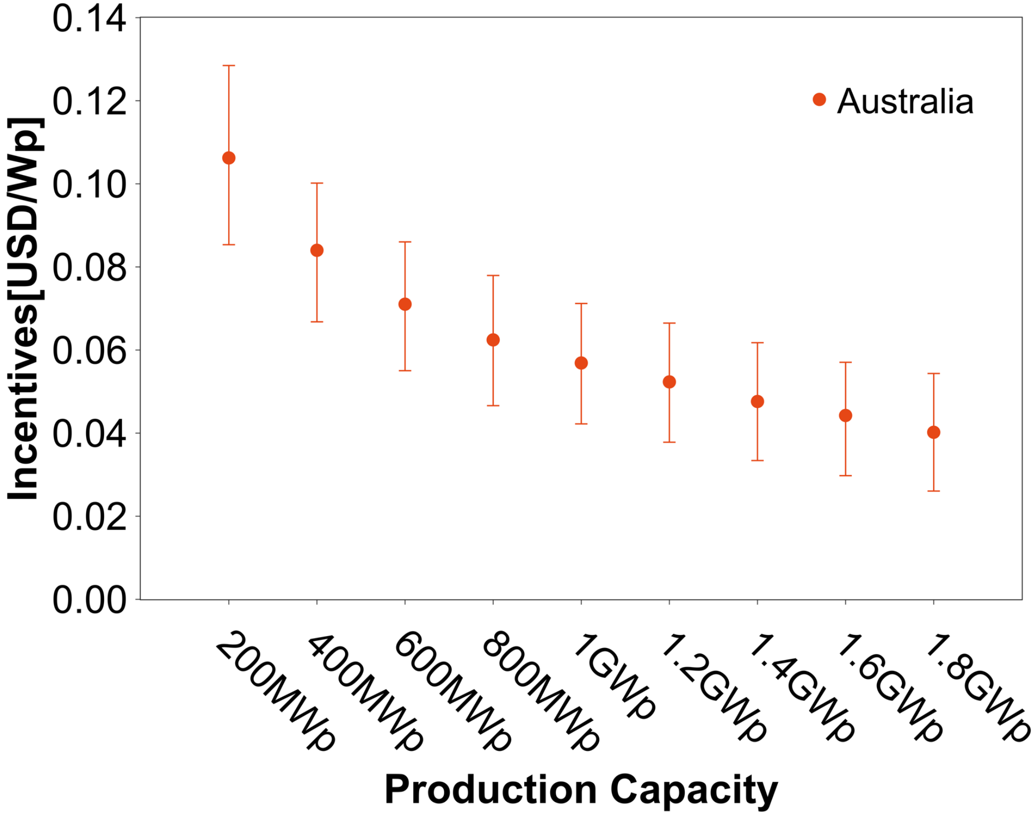


Modelling Supportive Policies – Option 1 production credit



Required incentives for 600MWp: $0.073/Wp

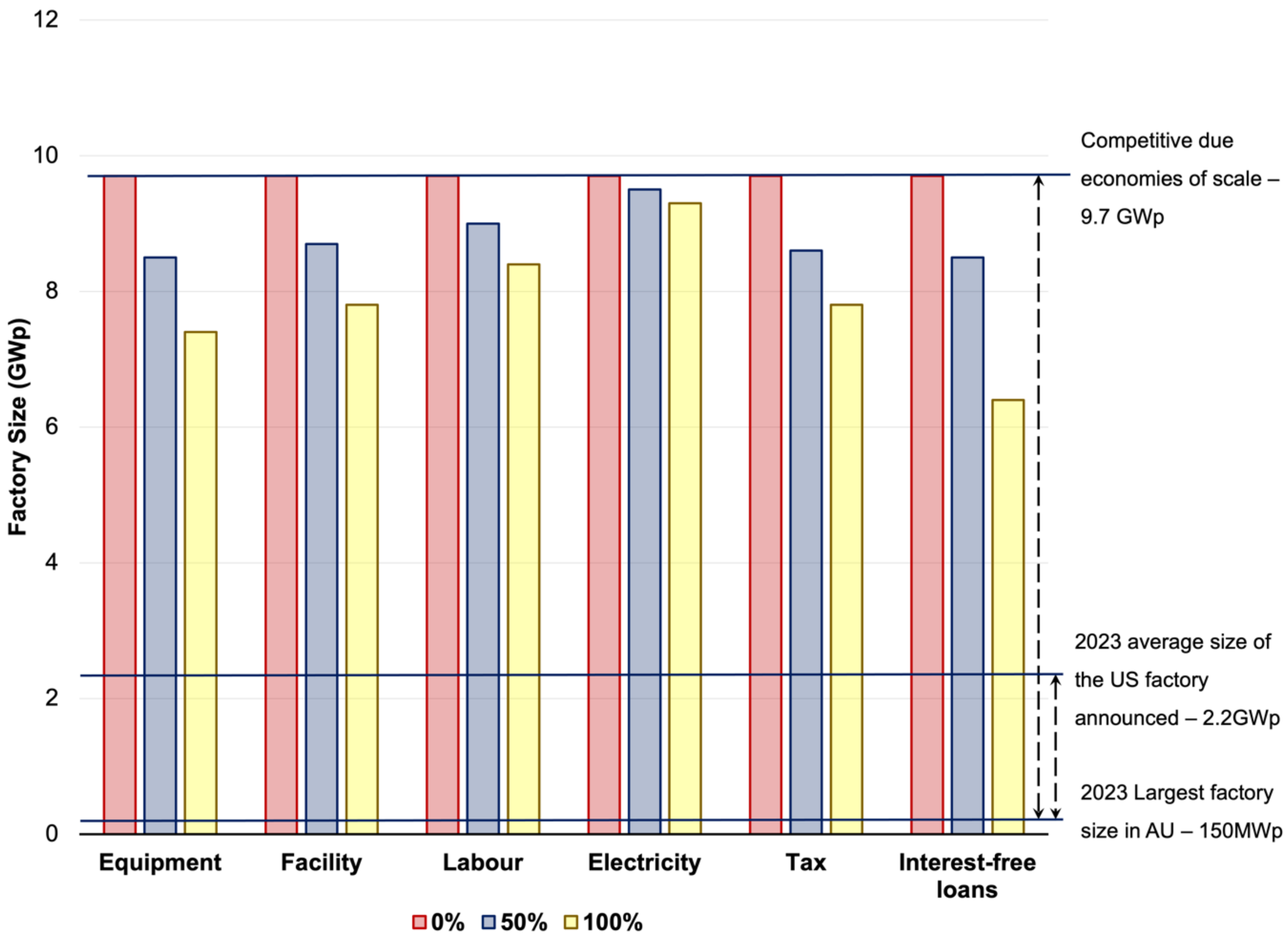


Required incentives for different production capacity

Modelling Supportive Policies – Comparing options

Largest factory: **Tindo (150MWp)**

Average size announced in the US: **2.2 GWp**

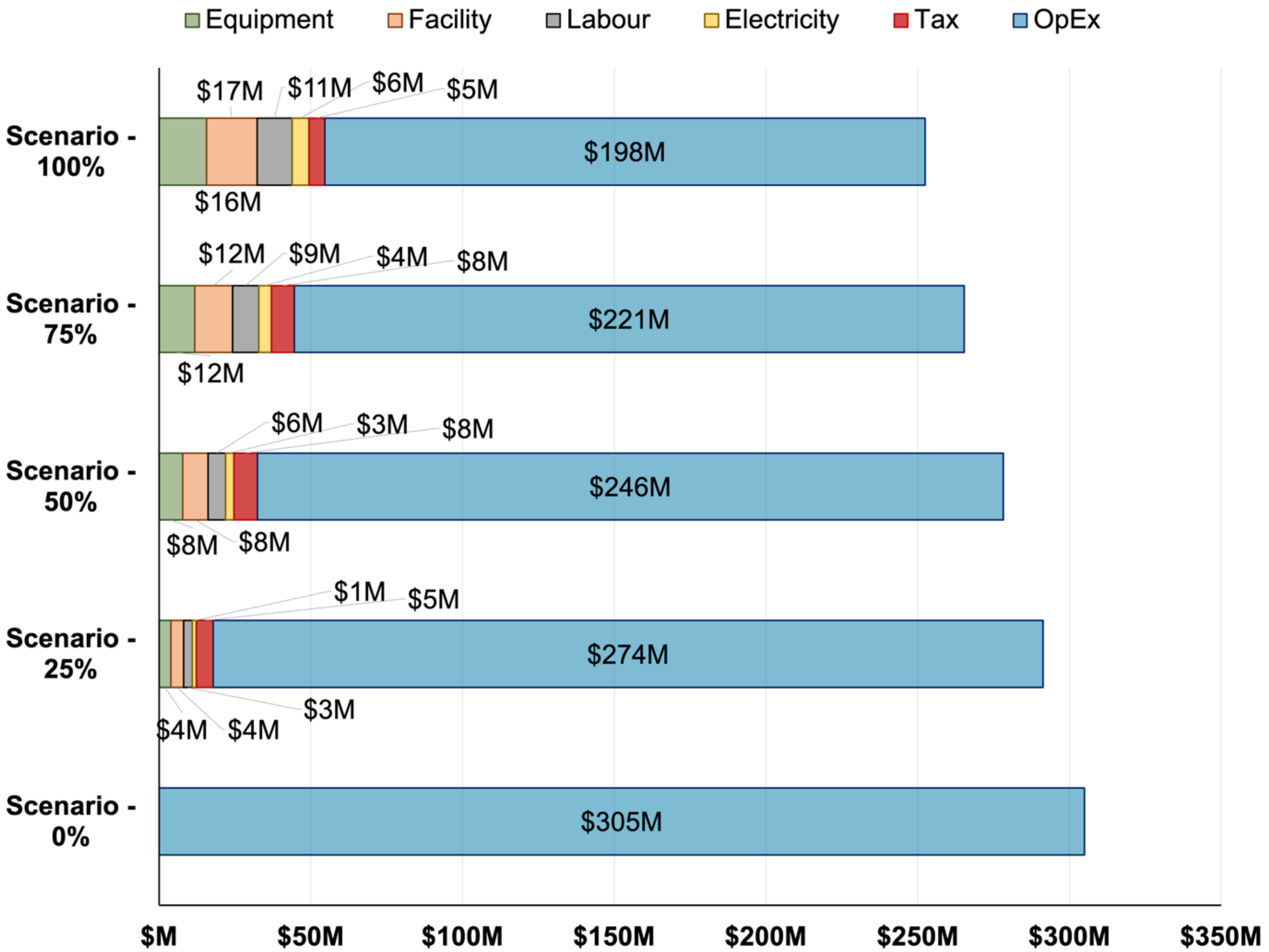


Modelling Supportive Policies – Combining options

Scenario – 100%= USD253m

Scenario – 50%= USD279m

Scenario – 0%= USD305m



Modelling Protective Policies

0% on input materials

32% on imported module

40% on glass

36% on imported module

Import Tariffs on input materials				MSP (Locally produced) (USD/Wp)	Price Gap (USD/Wp)	Required Tariff
Cell	Glass	Al	EVA			On module
0	0	0	0	0.309	0.073	32.2%
10.0%	0	0	0	0.325	0.089	39.6%
40.0%	0	0	0	0.374	0.137	58.1%
0	10.0%	0	0	0.311	0.075	33.2%
0	40.0%	0	0	0.317	0.081	36.1%
50.0%	50.0%	50.0%	50.0%	0.423	0.187	83.0%

Modelling Protective Policies

Policy	Suppliers	Input material cost	Logistic cost	MSP	Price change
100% by China →	***China***	0.230	0.0093	0.309	-
50% trade quota on China →	***China/Vietnam***	0.254	0.0103	0.335	+9%
trade embargo on China	***Vietnam***	0.278	0.0113	0.361	+17%
trade embargo on China	***Germany***	0.348	0.0112	0.434	+41%
trade embargo on China	***USA***	0.397	0.0115	0.486	+58%

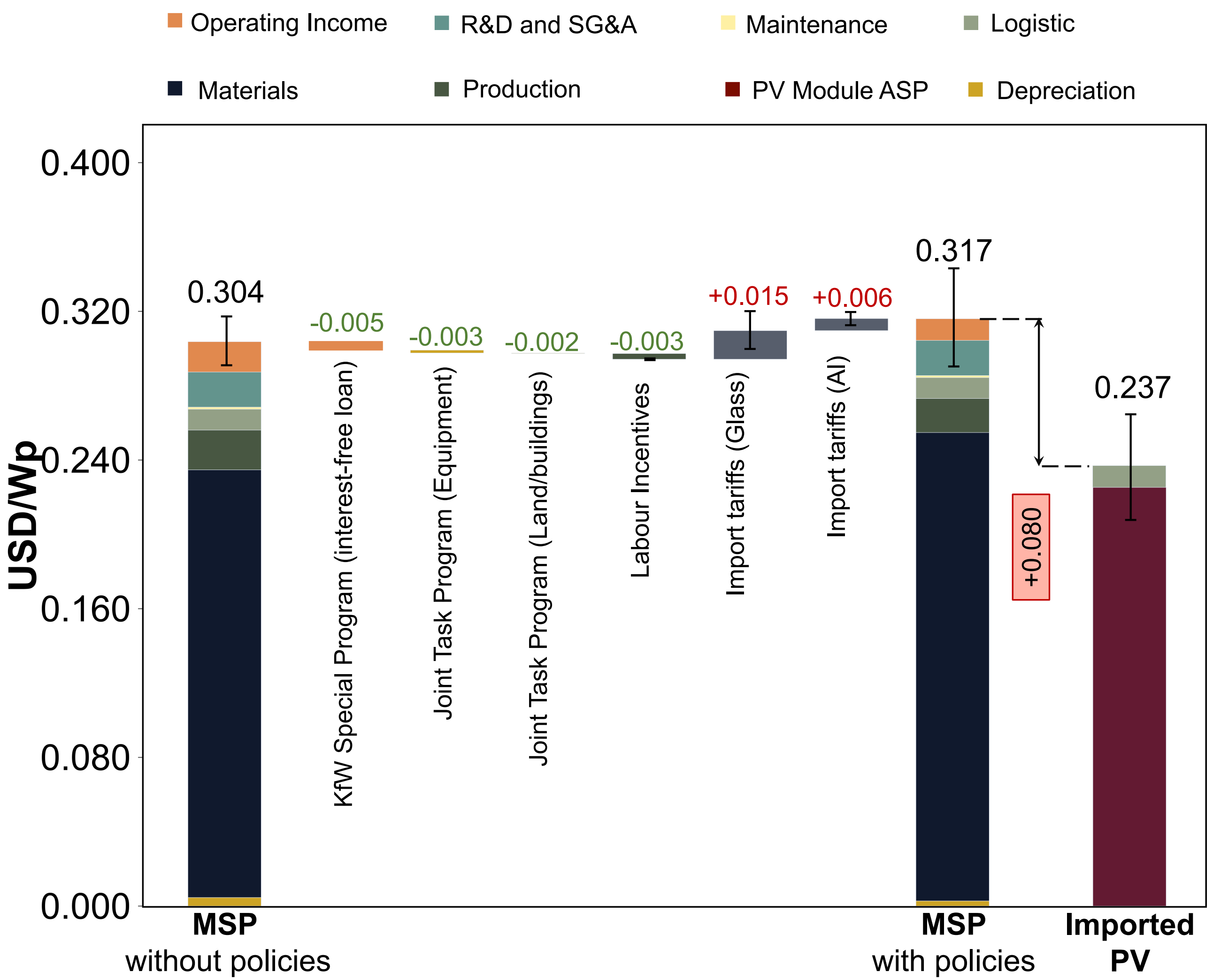
Case Study 1 – Existing German Policies

Tariffs on Glass: **20.7% – 92.5%**

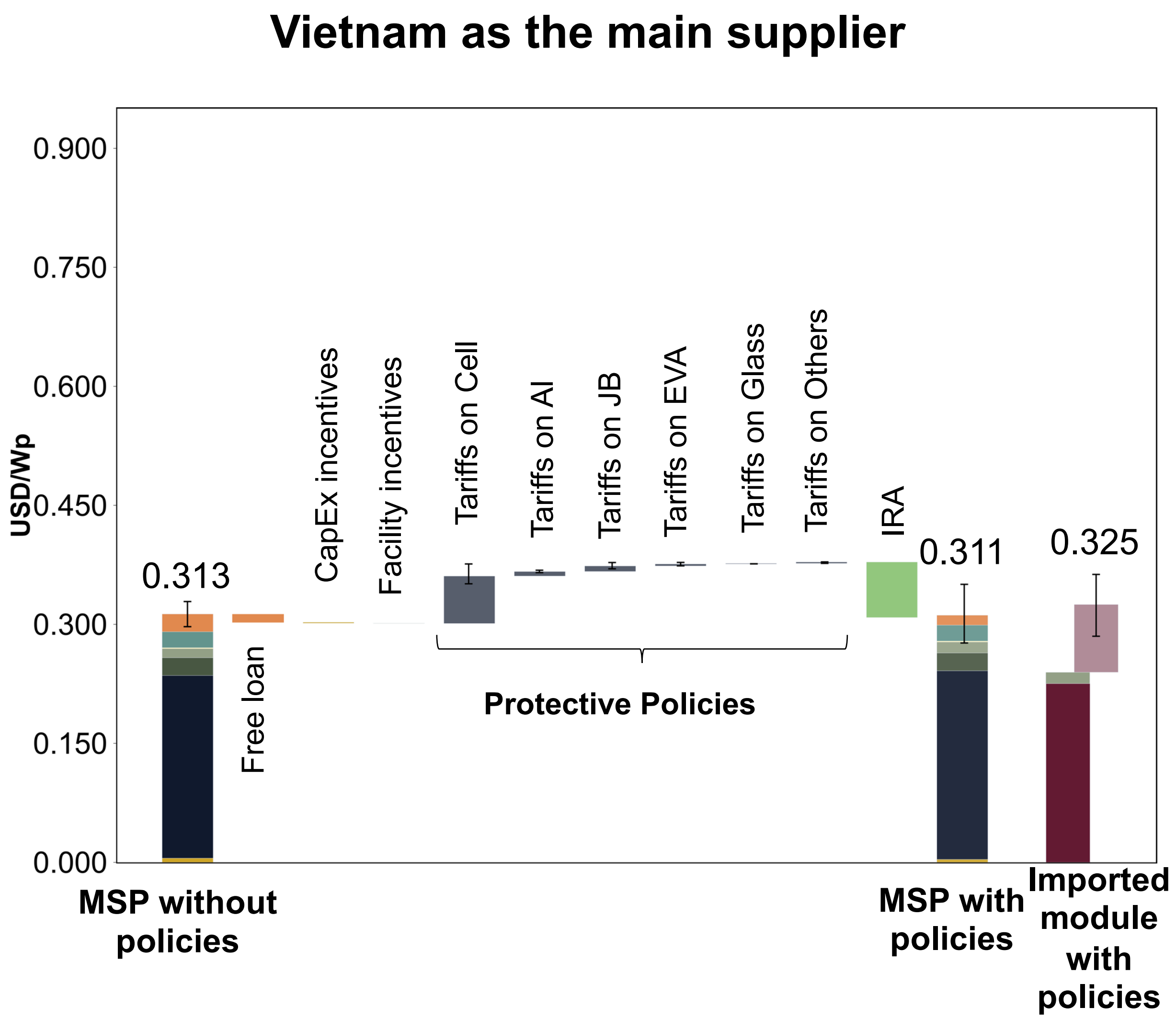
Tariffs on Al: **14.6% – 46.7%**

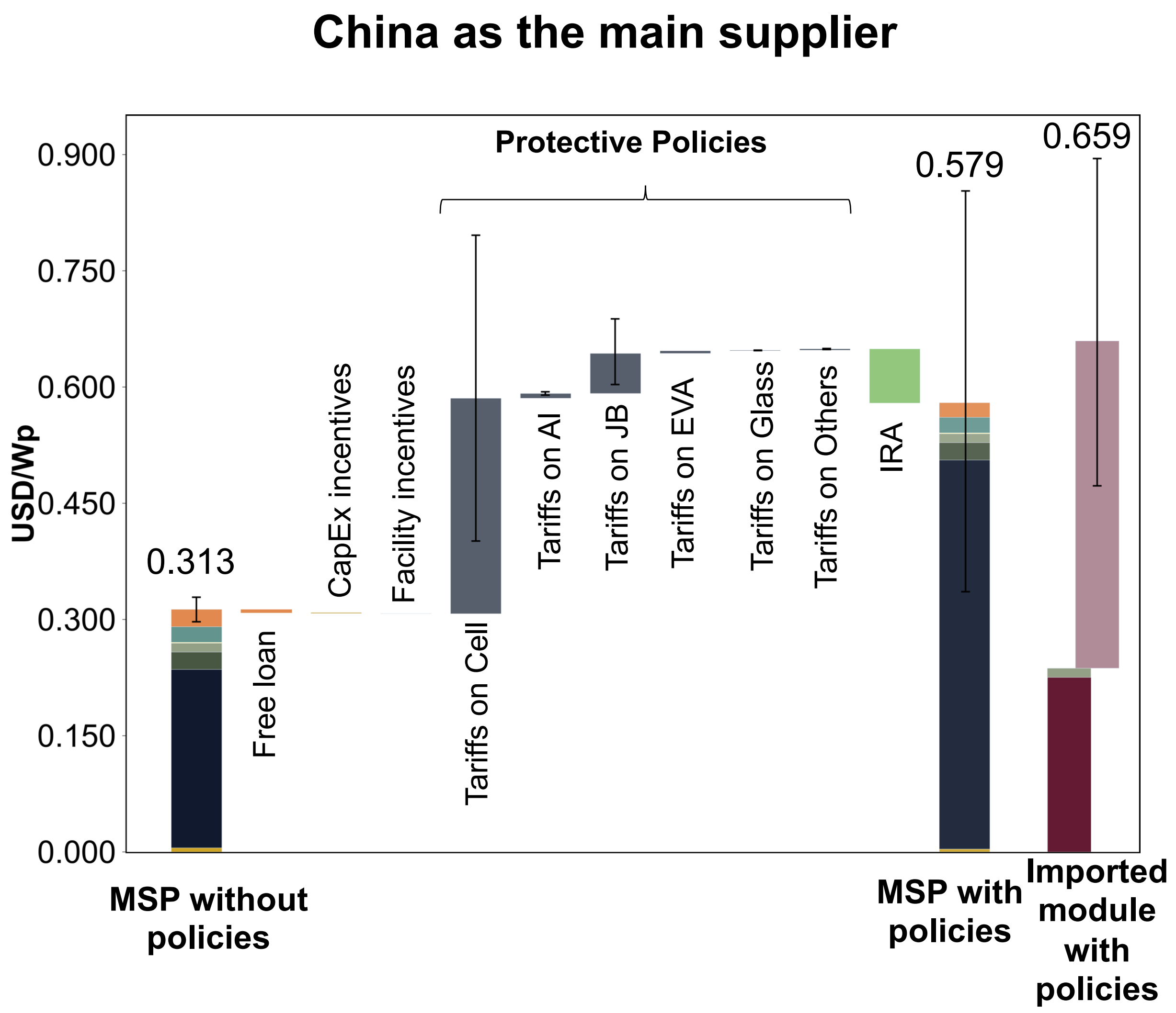
MSP without policies: **USD 0.304/ Wp**

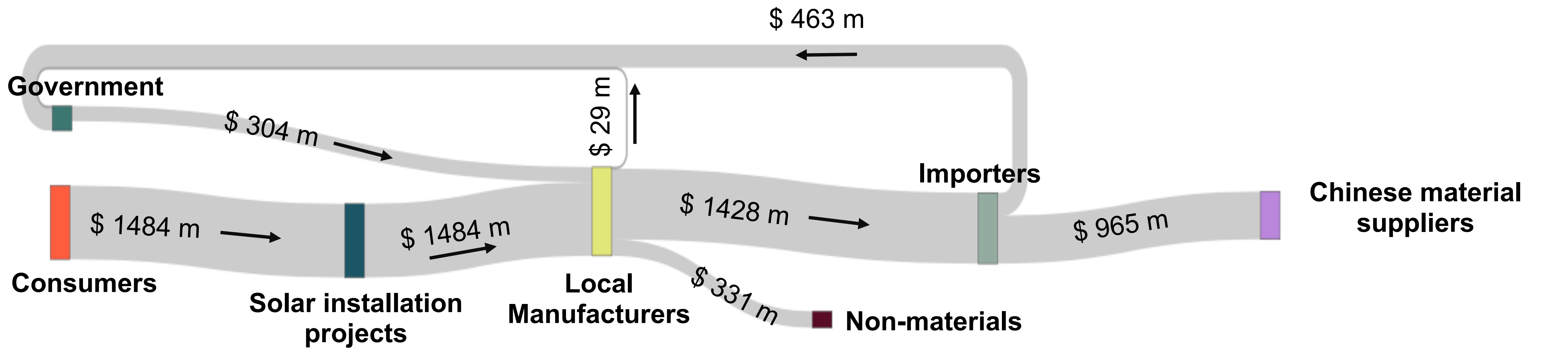
MSP with policies: **USD 0.317/ Wp**

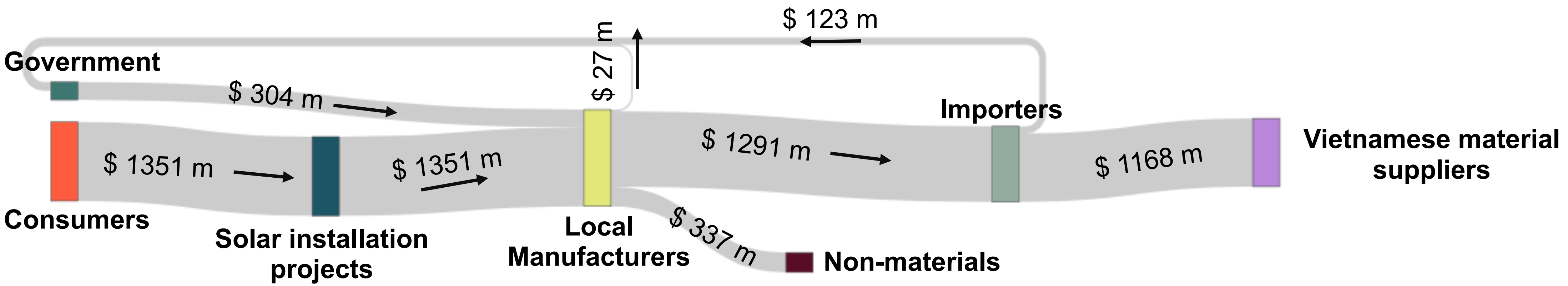


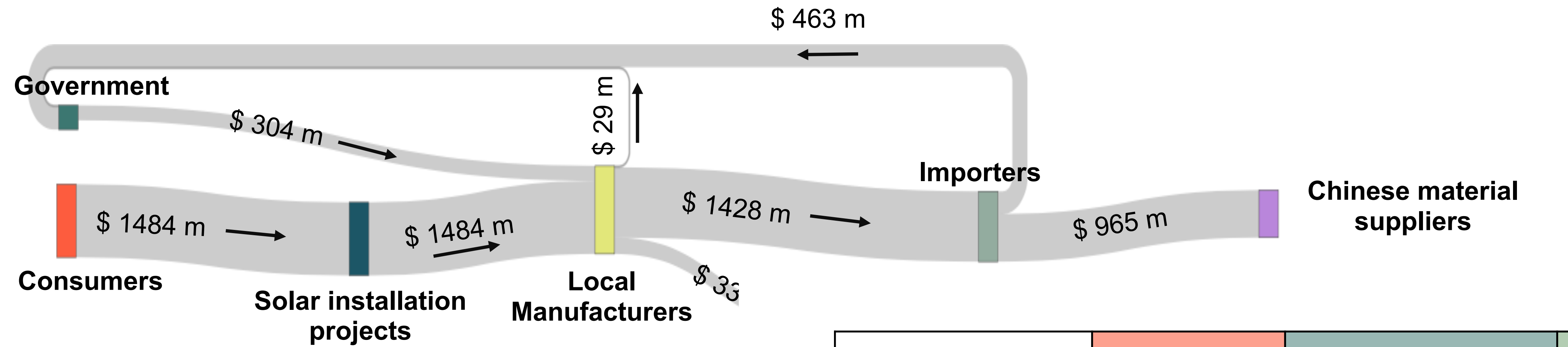
Case Study 2 – Existing US Policies



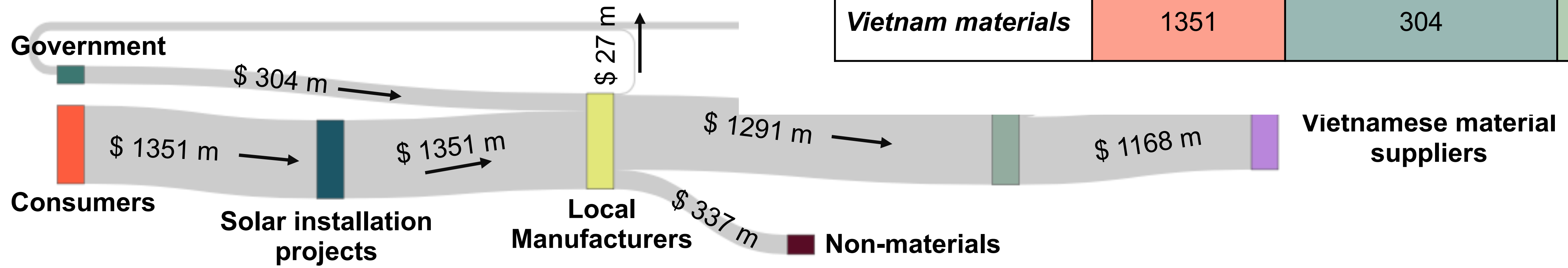



$ 463 m
Government
$ 304 m
$ 29 m
Importers
Chinese material suppliers
$ 1484 m
$ 1484 m
$ 1428 m
$ 965 m
Consumers
Solar installation projects
Local Manufacturers
$ 331 m
Non-materials


$ 123 m
$ 27 m
Government
$ 304 m
Importers
Vietnamese material suppliers
$ 1291 m
$ 1351 m
$ 1351 m
$ 1168 m
Consumers
Solar installation projects
Local Manufacturers
$ 337 m
Non-materials



Scenario	*Customers (USD million)*	*Government Support (USD million)*	*Collected Tariffs (USD million)*
Scenario – 100%	995	296	0
China materials	1484	304	463
Vietnam materials	1351	304	123



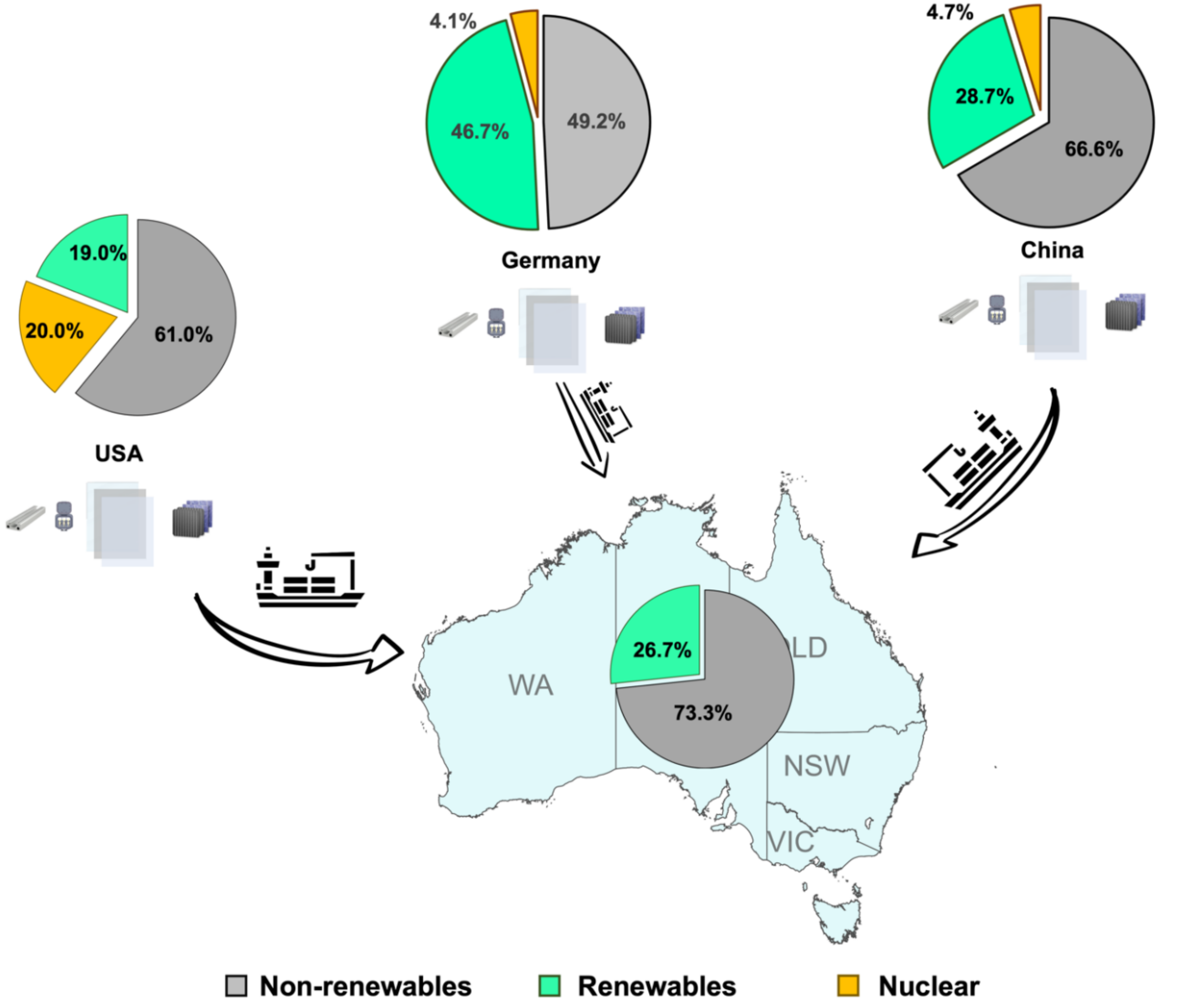
Eco-environment Optimization

Goal & Scope: assessing the carbon footprint of 1 kWp of module production

Life Cycle Inventory: Ecoinvent v3.8 and IEA PVPS

Life Cycle Impact Assessment: Global Warming Potential (GWP) 100-year assessment, expressed in kg CO_2

Interpretation: kg CO2 per kWp of produced or imported PV



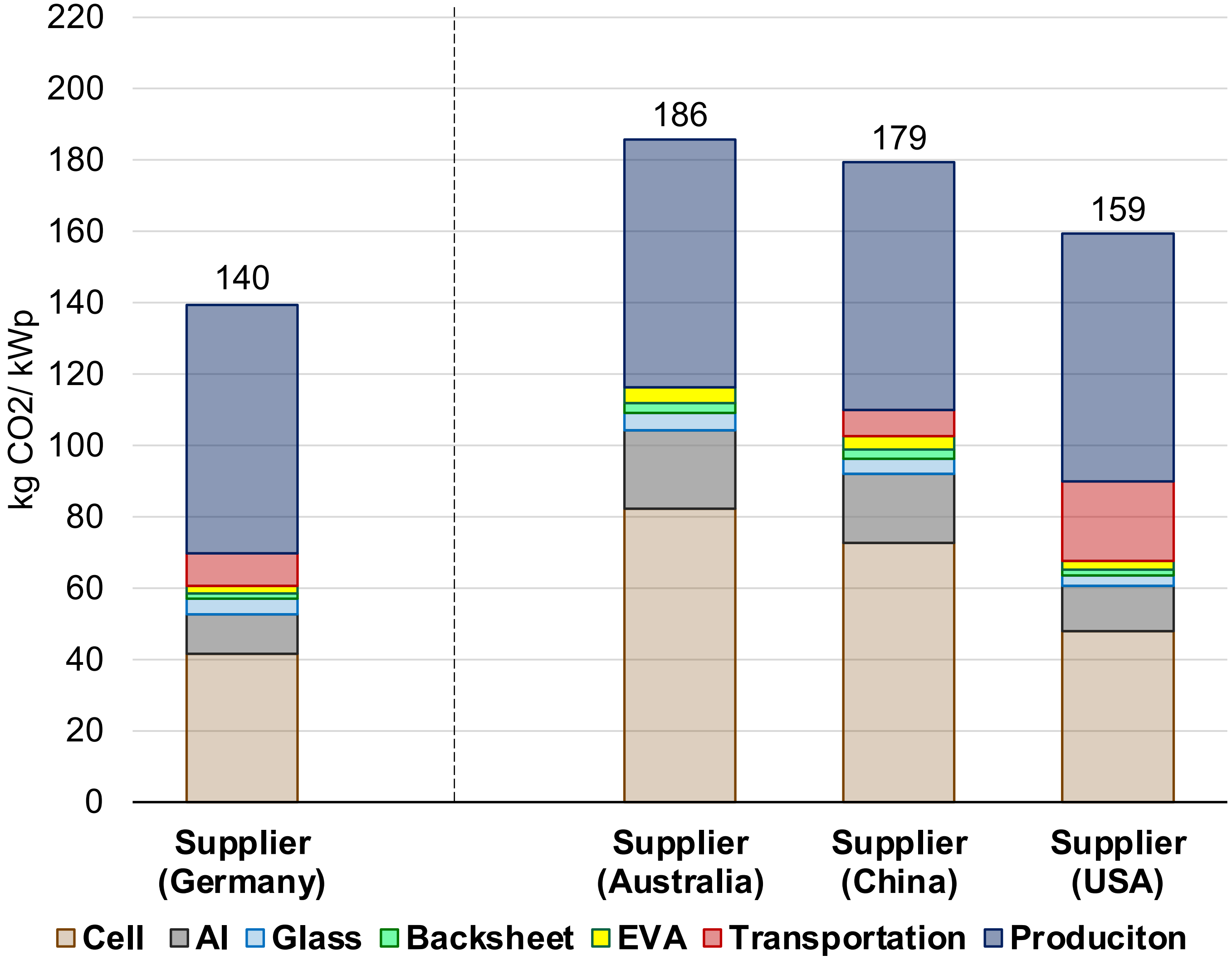
Eco-environment Optimization

Lowest emission:

Germany with 140 kg CO_2/kWp

Highest emission:

Australia with 186 kg CO_2/kWp



Eco-environment Optimization

$$Min \sum Costs$$

↕

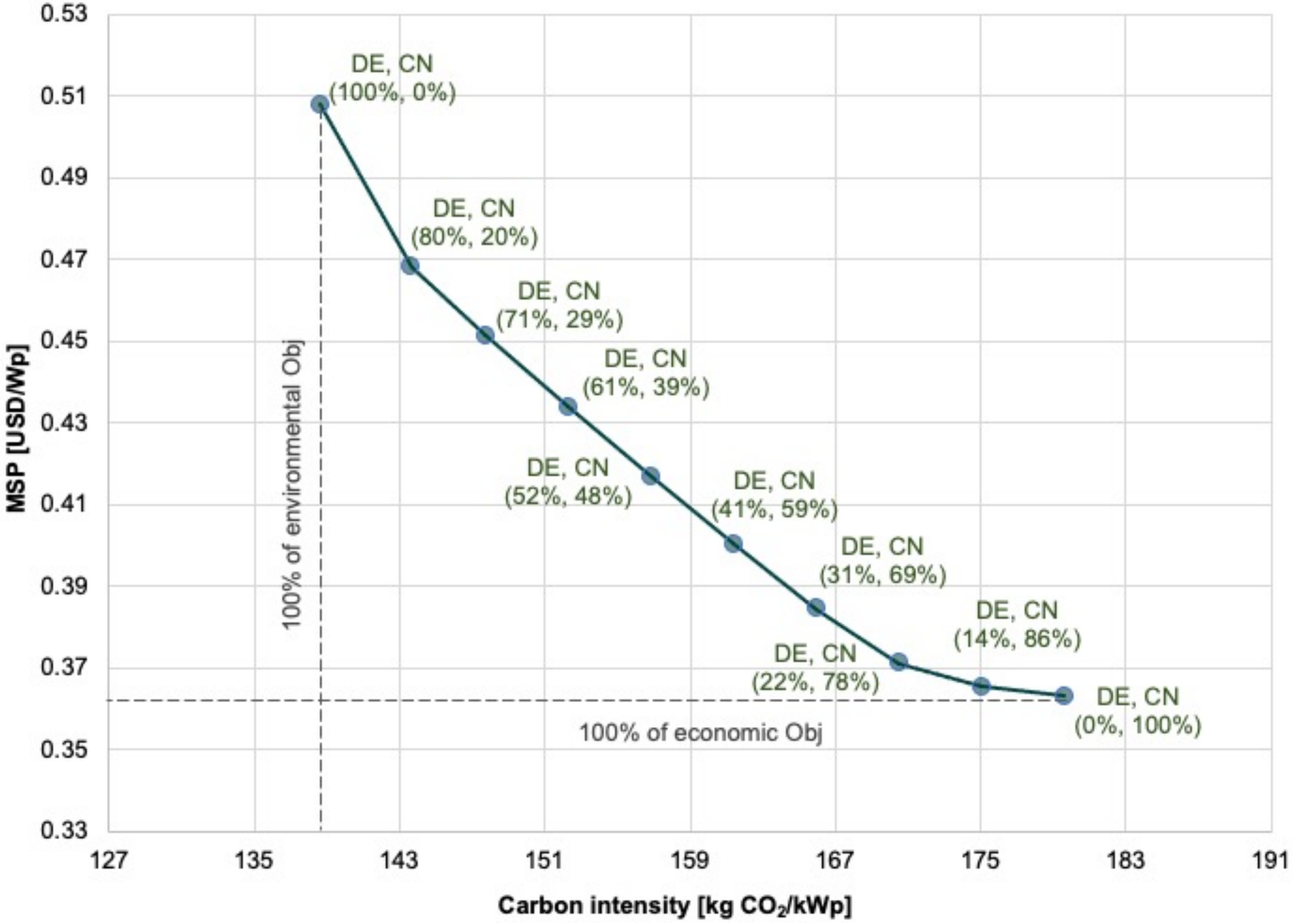
- Supplier
- International logistic
- National logistic

↕

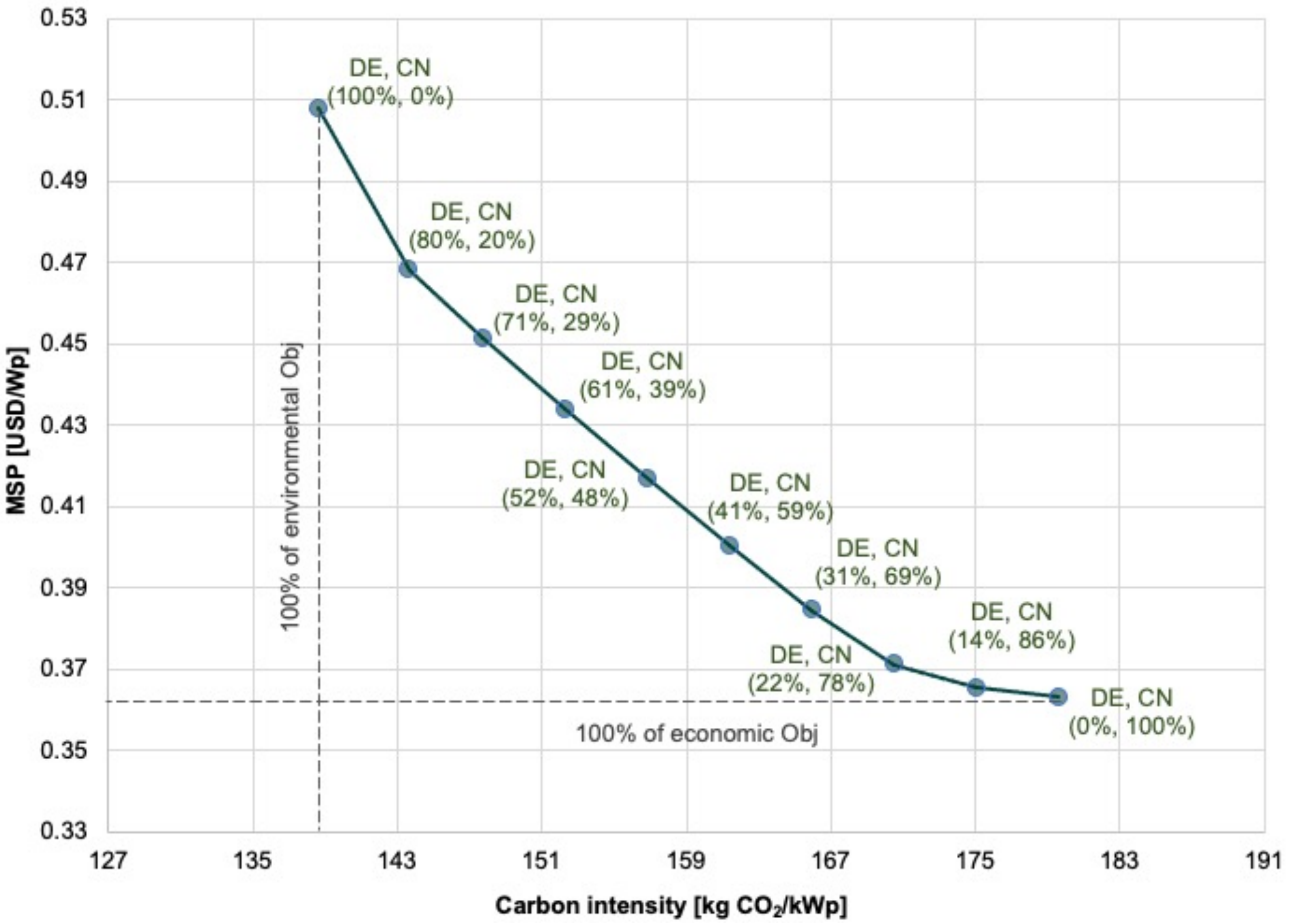
$$Min \sum emissions$$

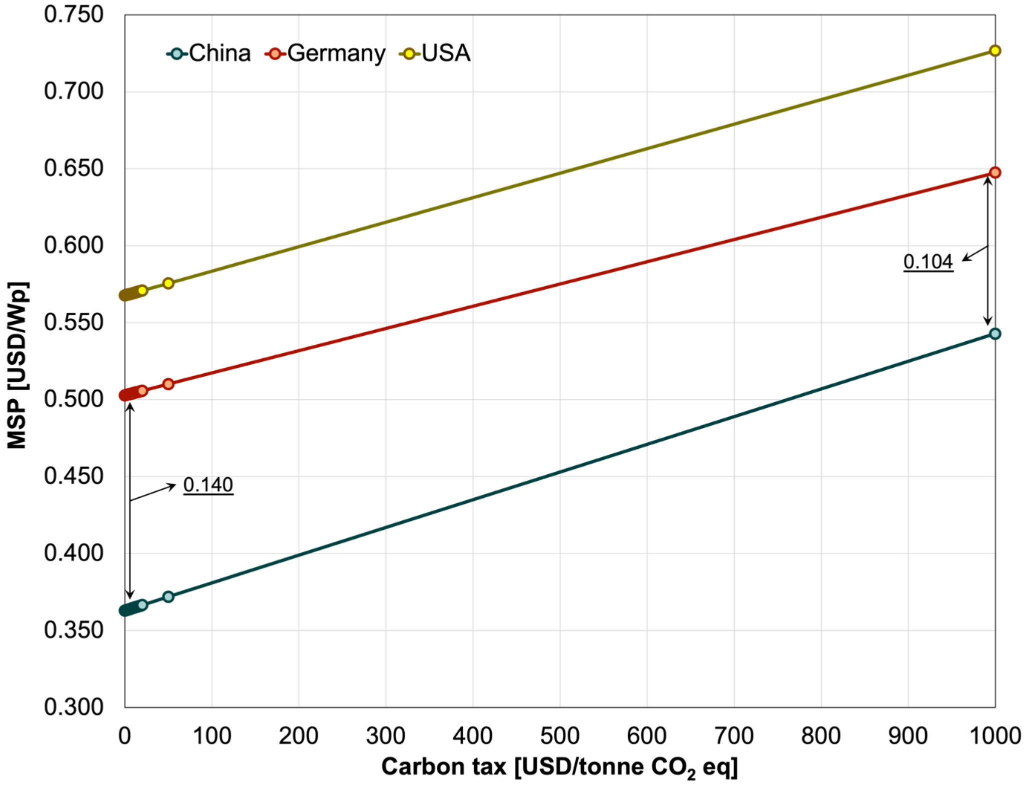
	Minimizing MSP	Minimizing CO_2 emission
Number of centres	1	1
Production capacity	600MWp	600MWp
Locations	Campbelltown (VIC)	Brimbank (VIC)
Suppliers of input materials	China	Germany
MSP (USD/Wp)	0.363	0.509
Total carbon intensity (kg CO_2/kWp)	179	140

Eco-environment Optimization



Eco-environment Optimization





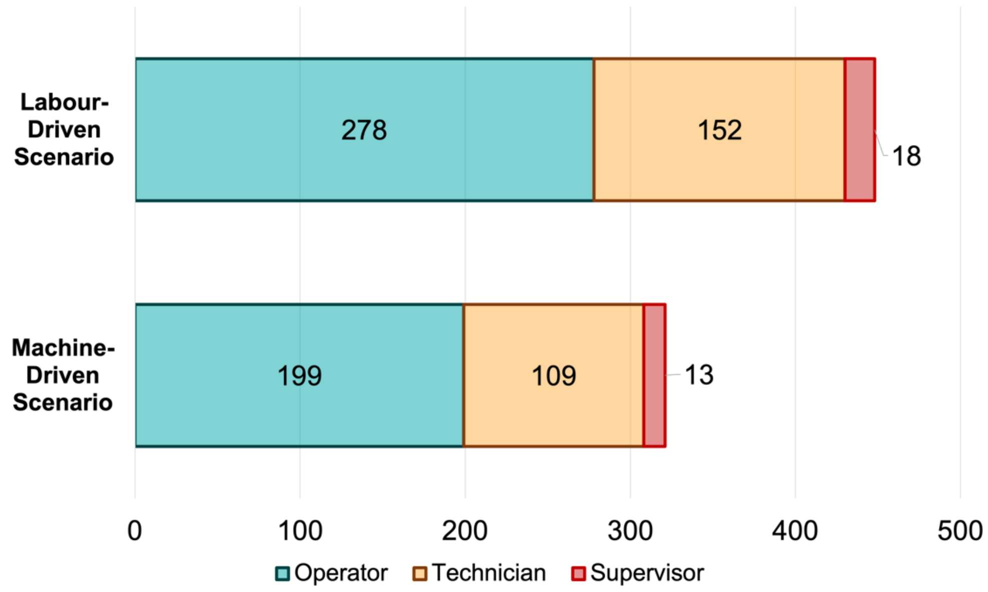
Various levels of carbon tax

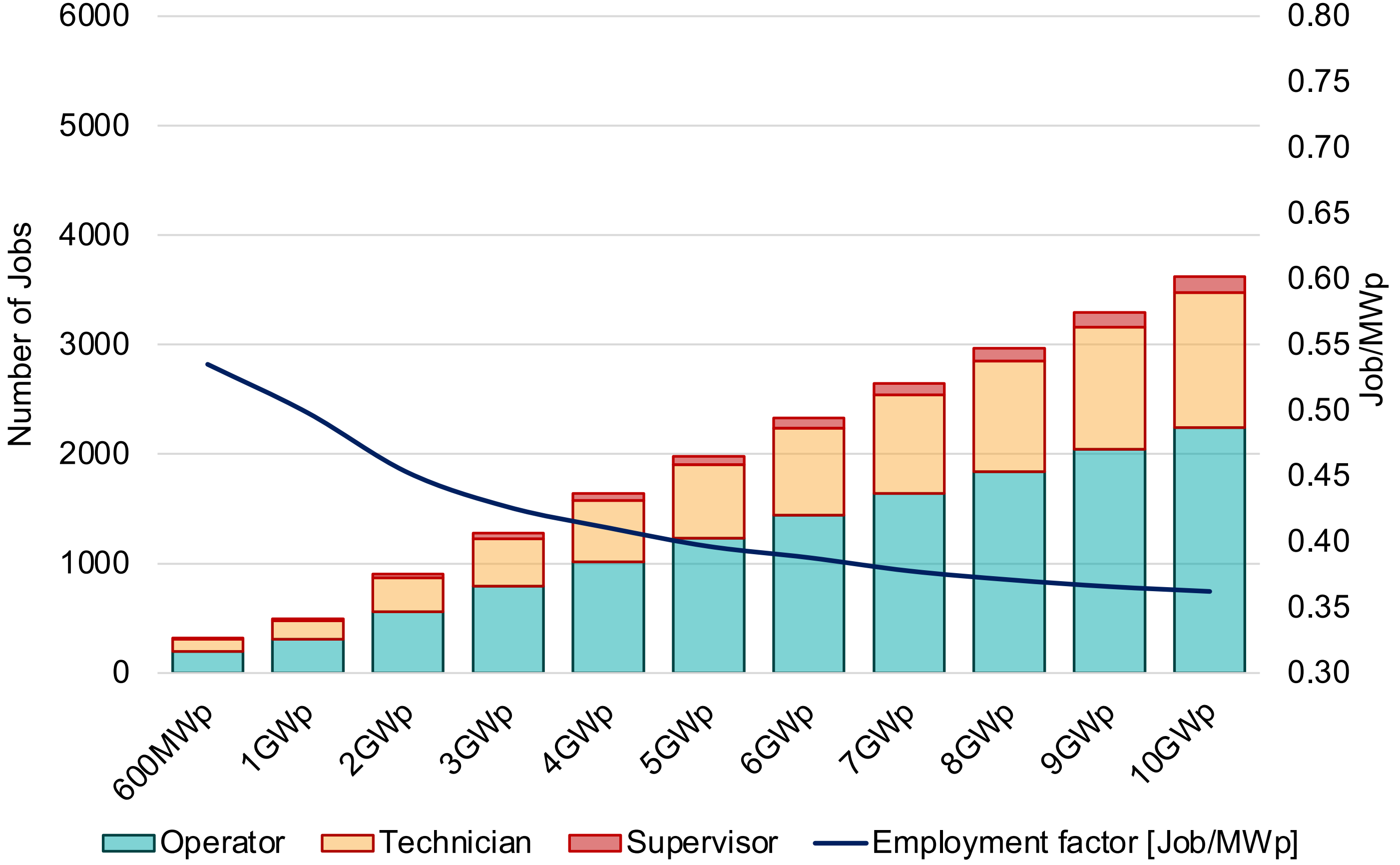
Socio-economic Optimization

- Labourers
- Drivers
- Administrative Workers
- …

- Electrical Engineers
- Electricians
- Mechanical Trades & Technicians
- Finance & Business Professionals
- …

- Executive & Senior Managers
- Operational & Asset Managers
- …





Socio-economic Optimization

$$Min \sum Costs$$

↕

$$\varphi^s = \left(\left(\frac{Cap_m^s}{Cap_m^{s-1}} \right)^{\beta} - 1 \right)$$

↕

$$Max \sum Jobs$$

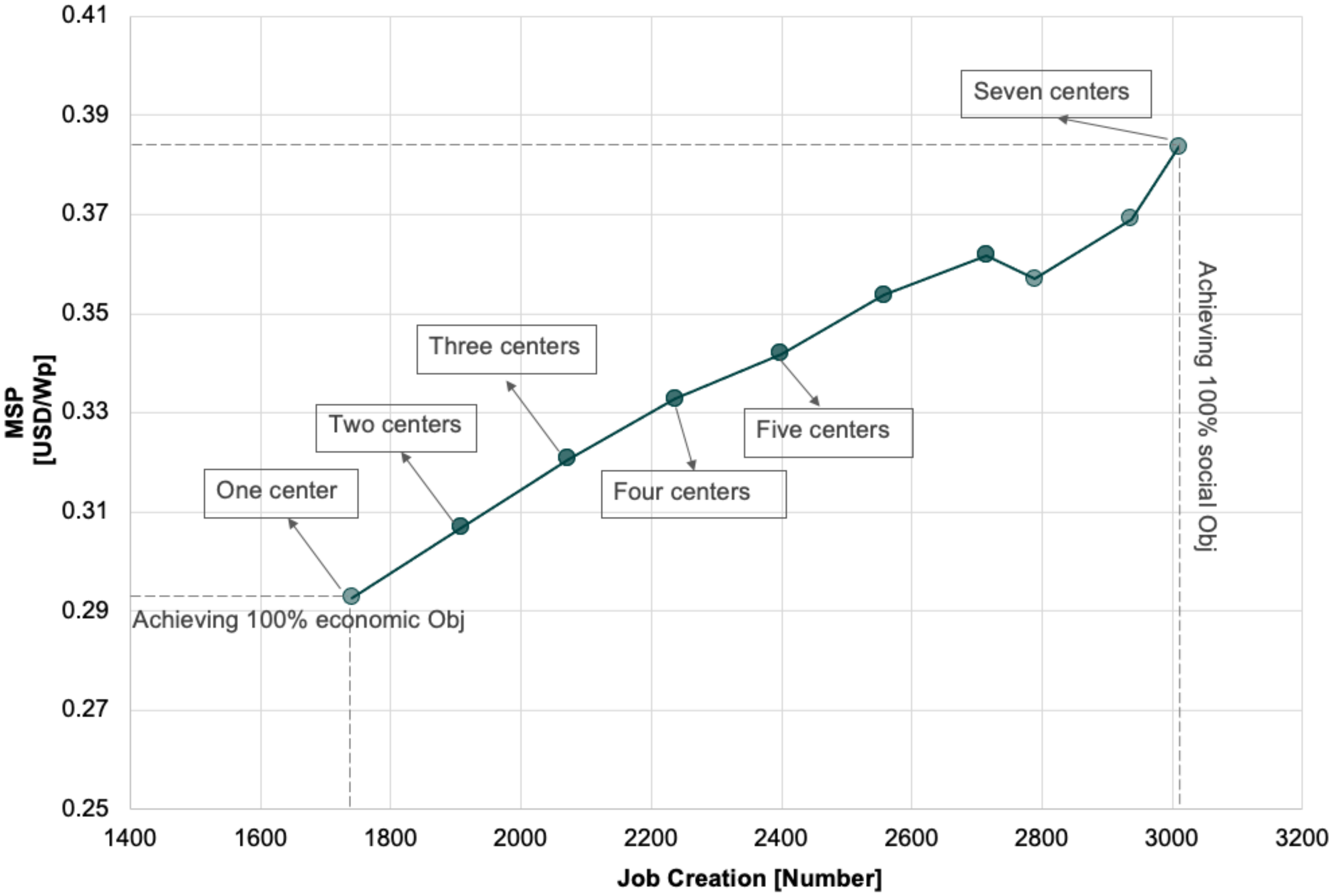
	Minimizing MSP	Maximizing social impact
Number of centres	1	7
Production capacity	4GWp	600MWp
Locations	Campbelltown (SA)	Newcastle (NSW), Blacktown (NSW), Parramatta (NSW), Logan (QLD), Ipswich (QLD), Onkaparinga (SA), Marion (SA)
MSP (USD/Wp)	0.292	0.383
Number of created jobs	1,751	3,011
Employment factor (Jobs/MWp)	0.44	0.75

Socio-economic Optimization

$$Min \sum Costs$$

$$\varphi^s = \left(\left(\frac{Cap_m^s}{Cap_m^{s-1}} \right)^{\beta} - 1 \right)$$

$$Max \sum Jobs$$



Multi-objective Optimization

$$Min \sum Costs$$

$$Max \sum Jobs$$

$$Min \sum emissions$$

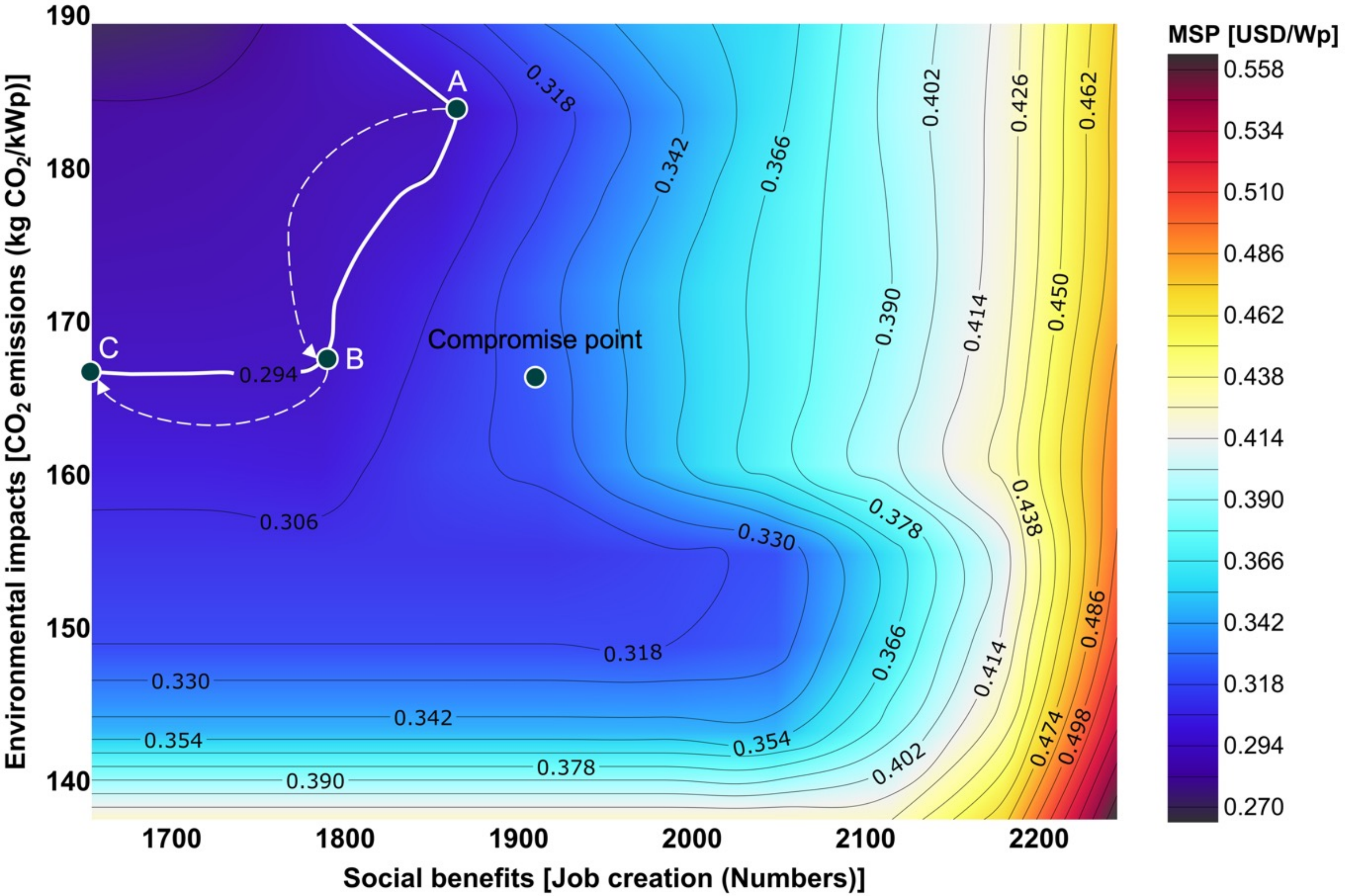
Compromise solution:

MSP (>80%): USD 0.324/Wp

Jobs (>80%): 1917

Emissions (>80%): 167 kg

CO_2 per kWp



What I left behind?

Extend the model to the whole supply chain?

Impact of various policies on different supply chain segments?

Impact of policies on deployment?

Which segment is more suited for Australia?

Opportunities on supplying input materials locally?

Limitation

Data availability – data quality and data span

Market dynamics

Quantifying intangible factors

Learning rate of new manufacturing establishments

Output & Impact

Papers:

Dehghanimadvar, M., Egan, R. and Chang, N.L., 2022. Economic assessment of local solar module assembly in a global market. *Cell Reports Physical Science*, *3*(2).

Chang, N.L., Dehghanimadvar, M. and Egan, R., 2022. The cost of risk mitigation—Diversifying the global solar PV supply chain. *Joule*, *6*(12), pp.2686-2688.

Dehghanimadvar, M., Egan, R. and Chang, N.L., 2024. Quantifying the costs of diversifying silicon PV module assembly with local economic policies. *Joule*.

Report:

Australia's Solar Manufacturing Opportunity. *APVI 2023*

Silicon to Solar Foundations for Solar PV Manufacturing in Australia. *APVI 2024*

Special thanks:

Renate Egan and Nathan Chang

Thank you!
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