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

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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

Market Share (2018 vs 2022)

- Ploysilicon: 55% to 79%
- Wafer & Ingot: 93% to 97%
- Cell: 74% to 85%
- Module: 64% to 75%

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:

Number of Jobs

- Polysilicon: 35
- Wafer & Ingot: 400
- Cell Fabrication: 150
- Module Assembly: 497

Source: NREL 2021

Carbon Intensity

- Polysilicon: 109
- Wafer & Ingot: 44
- Cell: 37
- Module: 82

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
Methodology:

 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 Economic impact

 \[ \text{MSP: Min} \sum \text{Cost} \quad + \quad \text{Monte Carlo simulation} \]

 \[ IRR = WACC \]

 Min Z

 \[ = \text{Depreciation} \left( \frac{\$}{Wp} \right) + \text{OpEx} \left( \frac{\$}{Wp} \right) + \text{Trade} \left( \frac{\$}{Wp} \right) \]

 \[ + \text{Logistics} \left( \frac{\$}{Wp} \right) \]

 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
A Review of Historical PV Manufacturing Policy Options:

- **China**
  - Equipment incentives
  - Land/building incentives
  - Freeflow interest loan
  - Cash out
  - Labour incentives
  - Electricity incentives
  - Freeflow interest loan
  - Tax exemption
  - Import tariffs

- **Germany**
  - Various Forms of Local Support (1998 – )
  - Various Forms of Local Support (2004 – )
  - China Development Bank (2004 – )
  - Various Forms of Local Support (2005 – )
  - Various Forms of Local Support (2007 – )
  - China Development Bank (2004 – )
  - Various Forms of Local Support (1998 – )
  - Various Forms of Local Support (2004 – )
  - China Development Bank (2004 – )

- **USA**
  - Manufacturing Tax Credit (2009-2022): 30% of Equipment expenses
  - Infrastructure Investment and Jobs Act
  - The America COMPETES Act of 2022
  - Manufacturing Tax Credit (2009-2022): 30% of land/building expenses
  - Inflation Reduction Act (2022 – )
  - No Specific Program (2009 – )

**Supportive**

**Protective**

**Trade barriers**

**OpEx**

**Capex**

**Policy options – history overview**

**China**

**Germany**

**USA**

- **Trade barriers**
  - Import tariffs

- **OpEx**
  - Various Forms of Local Support (2007 – )
  - Various Forms of Local Support (2005 – )
  - Various Forms of Local Support (2004 – )

- **Capex**
  - Various Forms of Local Support (1998 – )
  - Various Forms of Local Support (2004 – )
A Review of Historical PV Manufacturing Policy Options:

• China
• Germany
• USA
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

<table>
<thead>
<tr>
<th></th>
<th>Import Tariffs on input materials</th>
<th>MSP (Locally produced) (USD/Wp)</th>
<th>Price Gap (USD/Wp)</th>
<th>Required Tariff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cell</td>
<td>Glass</td>
<td>Al</td>
<td>EVA</td>
</tr>
<tr>
<td></td>
<td>10.0%</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>40.0%</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>10.0%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>40.0%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>50.0%</td>
<td>50.0%</td>
<td>50.0%</td>
<td>50.0%</td>
</tr>
</tbody>
</table>
# Modelling Protective Policies

<table>
<thead>
<tr>
<th>Suppliers</th>
<th>Input material cost</th>
<th>Logistic cost</th>
<th>MSP</th>
<th>Price change</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>0.230</td>
<td>0.0093</td>
<td>0.309</td>
<td>-</td>
</tr>
<tr>
<td>China/Vietnam</td>
<td>0.254</td>
<td>0.0103</td>
<td>0.335</td>
<td>+9%</td>
</tr>
<tr>
<td>Vietnam</td>
<td>0.278</td>
<td>0.0113</td>
<td>0.361</td>
<td>+17%</td>
</tr>
<tr>
<td>Germany</td>
<td>0.348</td>
<td>0.0112</td>
<td>0.434</td>
<td>+41%</td>
</tr>
<tr>
<td>USA</td>
<td>0.397</td>
<td>0.0115</td>
<td>0.486</td>
<td>+58%</td>
</tr>
</tbody>
</table>

- 100% by China
- 50% trade quota on China
- Trade embargo on China

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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

Vietnam as the main supplier

China as the main supplier

MSP without policies
MSP with policies
Imported module with policies

Protective Policies

Tariffs on Cell
Tariffs on Al
Tariffs on EVA
Tariffs on Others
Tariffs on Glass
Tariffs on JB
IRA

Free loan
CapEx incentives
Facility incentives

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SPREE
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Customers (USD million)</th>
<th>Government Support (USD million)</th>
<th>Collected Tariffs (USD million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario – 100%</td>
<td>995</td>
<td>296</td>
<td>0</td>
</tr>
<tr>
<td>China materials</td>
<td>1484</td>
<td>304</td>
<td>463</td>
</tr>
<tr>
<td>Vietnam materials</td>
<td>1351</td>
<td>304</td>
<td>123</td>
</tr>
</tbody>
</table>

Consumers → Solar installation projects → Local Manufacturers → Importers → Chinese material suppliers

Consumers → Solar installation projects → Local Manufacturers → Non-materials → Vietnamese material suppliers
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 CO₂

**Interpretation:** kg CO₂ per kWp of produced or imported PV
Eco-environment Optimization

Lowest emission:
Germany with 140 kg CO₂/kWp

Highest emission:
Australia with 186 kg CO₂/kWp
Eco-environment Optimization

\[
\text{Min } \sum \text{Costs}
\]

\[
\text{Min } \sum \text{emissions}
\]

- Supplier
- International logistic
- National logistic

<table>
<thead>
<tr>
<th></th>
<th>Minimizing MSP</th>
<th>Minimizing CO₂ emission</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of centres</strong></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Production capacity</strong></td>
<td>600MWp</td>
<td>600MWp</td>
</tr>
<tr>
<td><strong>Locations</strong></td>
<td>Campbelltown (VIC)</td>
<td>Brimbank (VIC)</td>
</tr>
<tr>
<td><strong>Suppliers of input</strong></td>
<td>China</td>
<td>Germany</td>
</tr>
<tr>
<td><strong>materials</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MSP (USD/Wp)</strong></td>
<td>0.363</td>
<td>0.509</td>
</tr>
<tr>
<td><strong>Total carbon intensity</strong></td>
<td>179</td>
<td>140</td>
</tr>
<tr>
<td>(kg CO₂/kWp)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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
- ...  

Labour-Driven Scenario
- 278 Operators
- 152 Technicians
- 18 Supervisors

Machine-Driven Scenario
- 199 Operators
- 109 Technicians
- 13 Supervisors

Number of Jobs

Operator - Technician - Supervisor - Employment factor [Job/MWp]
Min $\sum Costs$

$\varphi^s = \left( \frac{Cap^s_m}{Cap^s_{m-1}} \right)^\beta - 1$

Max $\sum Jobs$

<table>
<thead>
<tr>
<th>Minimizing MSP</th>
<th>Maximizing social impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of centres</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Production capacity</strong></td>
<td>4GWp</td>
</tr>
<tr>
<td><strong>Locations</strong></td>
<td>Campbelltown (SA)</td>
</tr>
<tr>
<td><strong>MSP (USD/Wp)</strong></td>
<td>0.292</td>
</tr>
<tr>
<td><strong>Number of created jobs</strong></td>
<td>1,751</td>
</tr>
<tr>
<td><strong>Employment factor</strong> (Jobs/MWp)</td>
<td>0.44</td>
</tr>
</tbody>
</table>
Socio-economic Optimization

\[ \text{Min} \sum \text{Costs} \]

\[ \varphi^s = \left( \frac{\text{Cap}_{m}^s}{\text{Cap}_{m}^{s-1}} \right)^\beta - 1 \]

\[ \text{Max} \sum \text{Jobs} \]
Multi-objective Optimization

\[
\begin{align*}
\text{Min } & \sum \text{Costs} \\
\text{Max } & \sum \text{Jobs} \\
\text{Min } & \sum \text{emissions}
\end{align*}
\]

Compromise solution:
- MSP (>80%): USD 0.324/Wp
- Jobs (>80%): 1917
- Emissions (>80%): 167 kg
- CO₂ per kWp

\(0.294\)
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:


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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