The Cost of Shifting Supply Strategy: Balancing Cost, Risk, and Diversification in the EU's Solar PV Supply

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Energy Economics Group

Motivation

EU's Solar PV Expansion

- Fastest growing renewable sector in the EU
- 65 GW annual deployment
- Projected 700 GW global demand by 2030

Supply Chain Vulnerabilities

- 95% imports from China
- High supply concentration along the value chain
- Elevated geopolitical risk in producing countries

Key Challenge

How can the EU meet its 2030 solar PV demand while balancing:

- Cost efficiency
- Geopolitical risk in producing countries
- Supply diversification

Research Questions

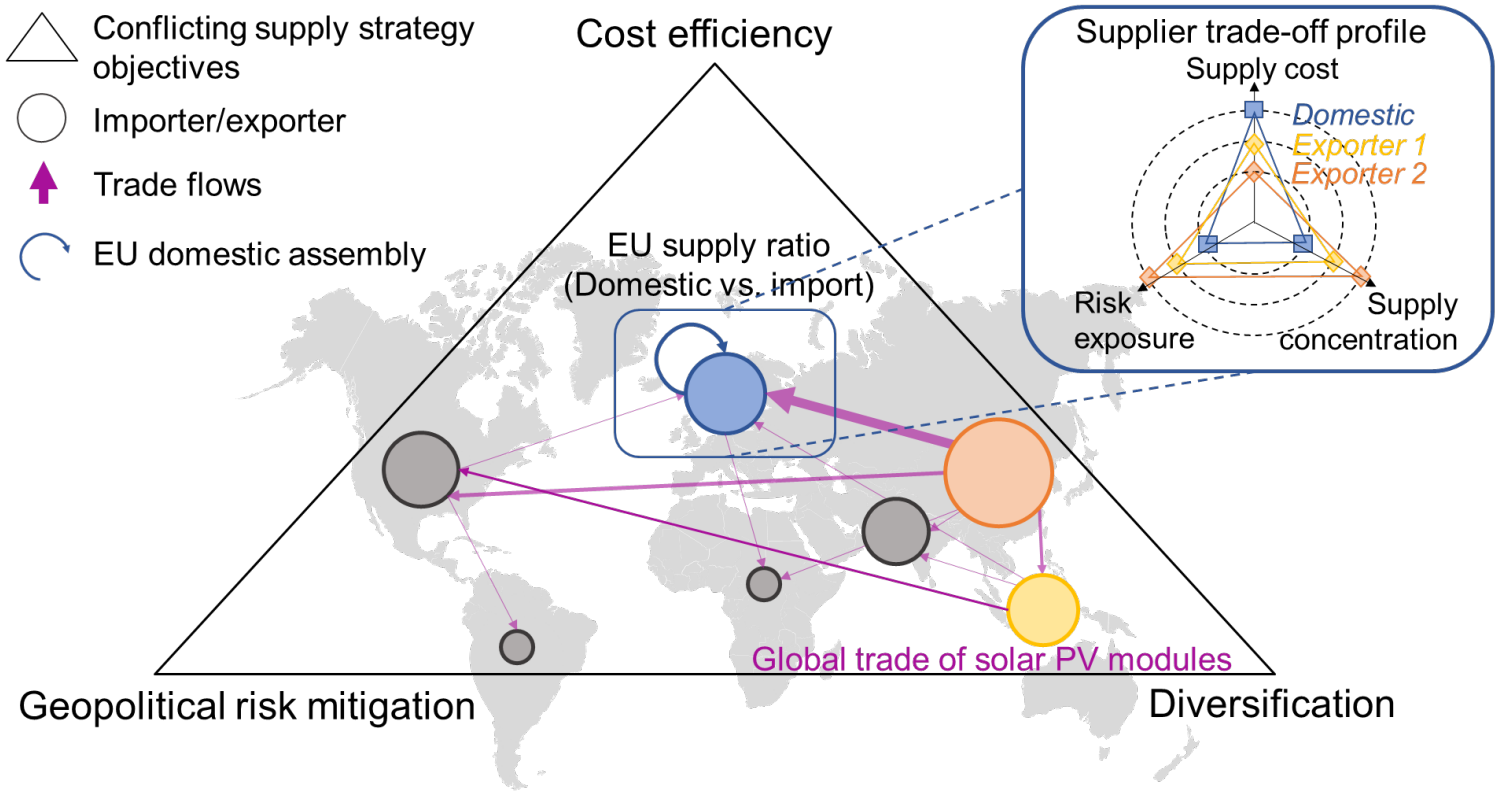
RQ1: Policy Pathways

Which policies enable the EU to meet its solar PV module demand in 2030 while enhancing import diversification, reducing geopolitical risk, and ensuring cost efficiency?

RQ2: Cost-Risk Trade-Off

What is the increase in supply cost (USD/kW) of solar PV modules when reducing the geopolitical risk and supply concentration for the EU?

Methodological Approach



- **Multi-Objective Linear Program (MOLP)** for global PV trade
- Simultaneously minimizes three conflicting objectives
- Country-specific strategic priorities via weighting factors
- Focus on EU domestic assembly and component-level imports

Optimization Framework

Objective Function:

$$\text{minimize} \sum_{i \in I} \left(\alpha_{1,i} c_i^{\text{SUP}} + \alpha_{2,i} g_i^{\text{RISK}} + \alpha_{3,i} s_i^{\text{CONC}} \right)$$

Three Objectives:

1. Supply cost (c^{SUP})
2. Geopolitical risk (g^{RISK})
3. Supply concentration (s^{CONC})

Key Features:

- Utopia-Nadir normalization
- Country-specific weights $(\alpha_{1,i}, \alpha_{2,i}, \alpha_{3,i})$
- WGI-based risk metric
- HHI for concentration

Geopolitical Risk & Supply Concentration

Geopolitical Risk:

- Based on World Governance Indicator (WGI)
- Scaled 0-10 (10 = high risk)
- Weighted by production share and import quantity

$$g_{e,i}^{\text{MOD}} = G_e^{\text{WGI}} \cdot P_e^{\text{MOD}} \cdot q_{e,i}^{\text{IMP}}$$

Supply Concentration:

- Herfindahl-Hirschman Index (HHI)
- Sum of squared supply shares
- Higher values = more concentrated

$$s_i^{\text{CONC}} = \sum_{e \in E} \left(s_{e,i}^{\text{MOD}}\right)^2$$

Data and Scenarios

Data:

- Key regions: China, EU, India, Malaysia, North America, Thailand, Vietnam, South Korea
- Characterized by demand, production capacity and cost parameters for 2030

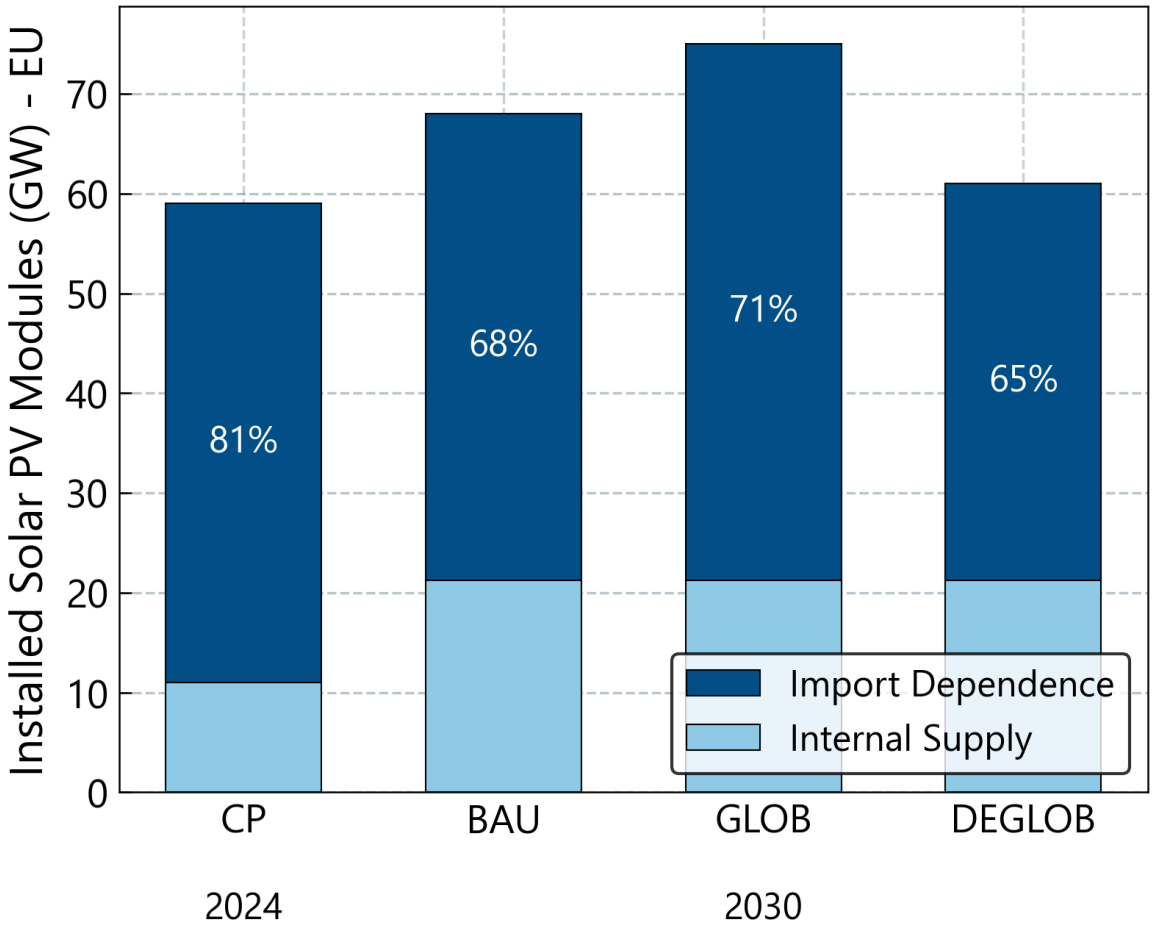
Scenarios for 2030:

- **BAU:** Continuation of existing policies, moderate tariffs (3%), 85% utilization rate, announced strategic priorities
- **GLOB:** Liberalized cost-driven market, reduced Chinese costs (-10%), 100% utilization, cost focus
- **DEGLOB:** Policy-driven reshoring, high tariffs (15%), domestic premiums, risk mitigation and diversification focus

Model Validation:

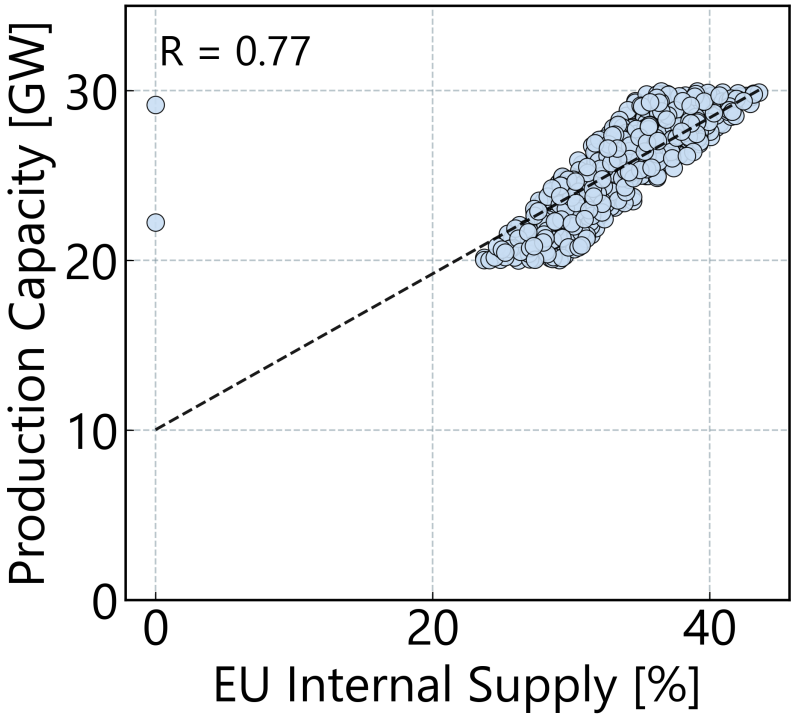
- Calibration to 2024 to reproduce observed trade flows and cost levels
- Monte Carlo simulation (N=500) to assess robustness under parameter uncertainty

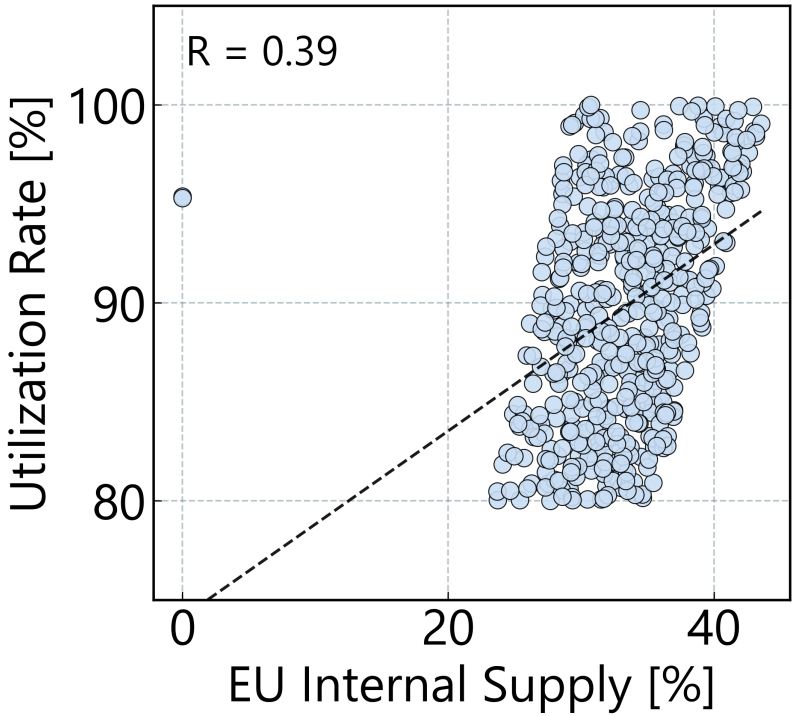
EU's Supply Composition



- Import dependence **decreases** from 81% (2024) to 65-71% (2030)
- Driven by higher production capacity (25 GW) and utilization (85%)
- DEGLOB achieves highest internal supply (35%)

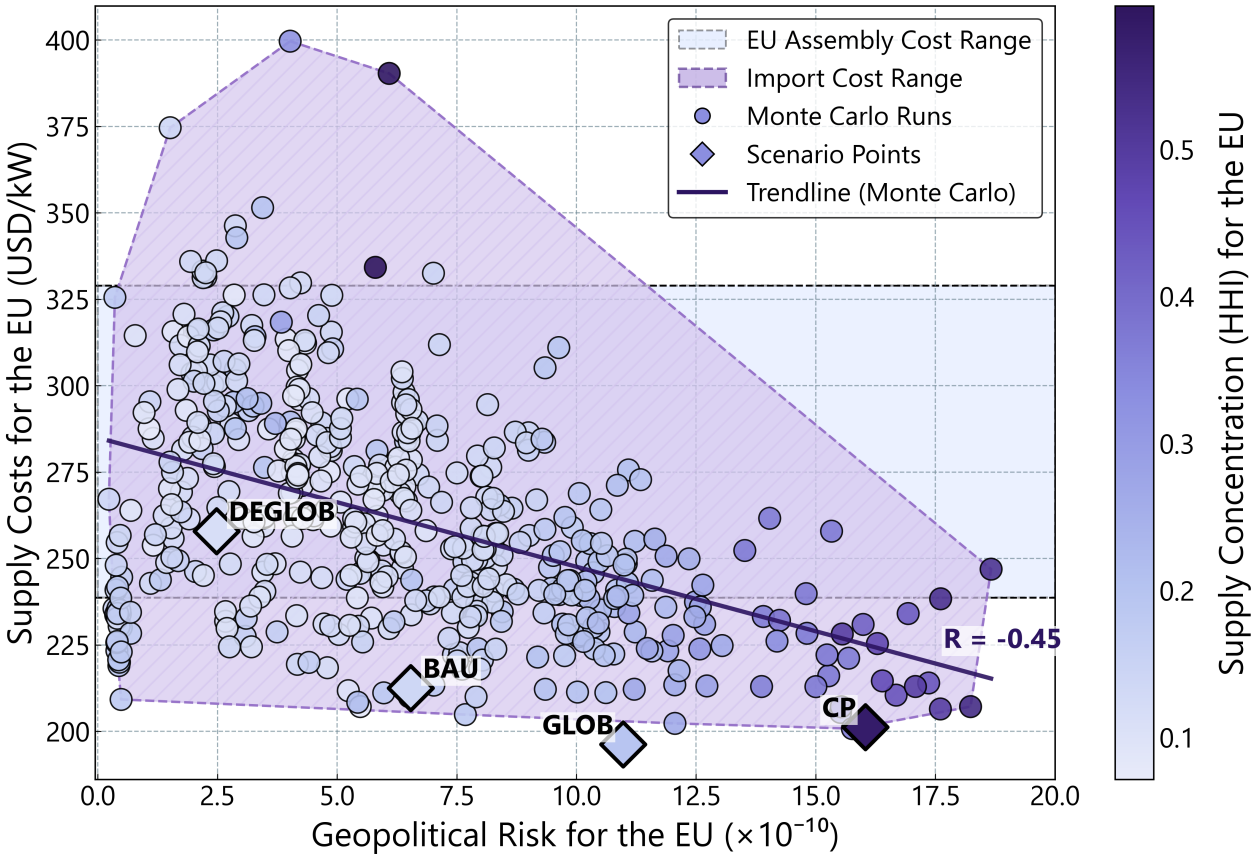
Key Drivers of EU's Internal Supply





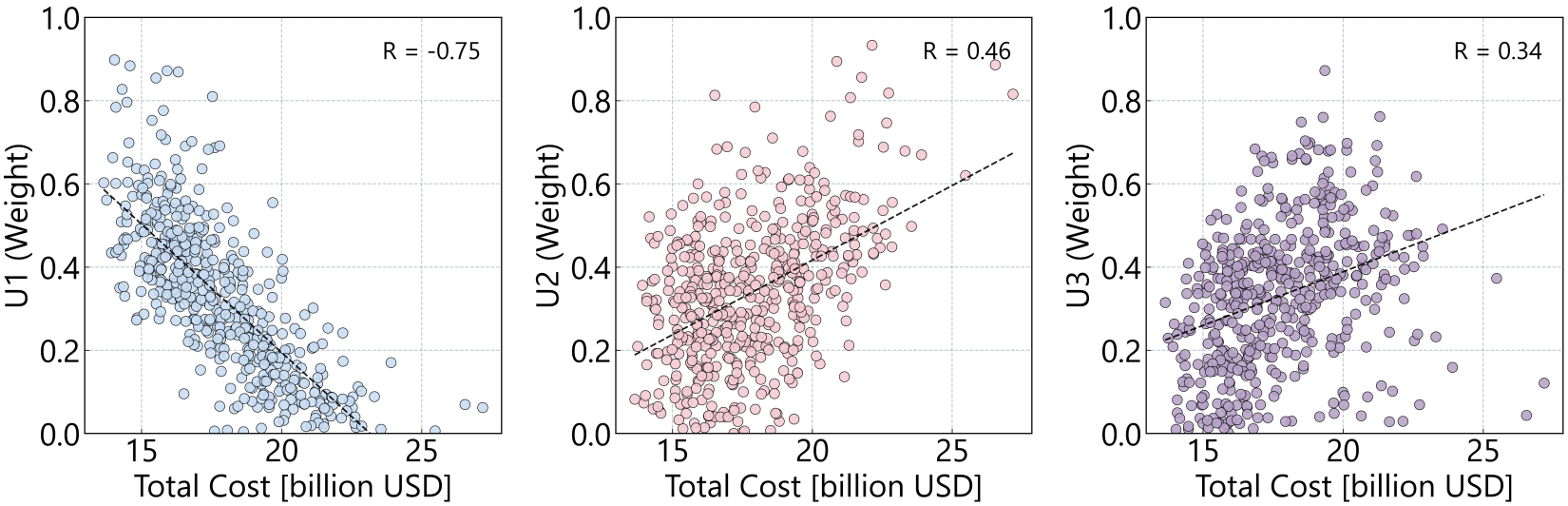
- Production capacity: positive correlation ($R = +0.77$)
- Utilization rate: positive correlation ($R = +0.39$)
- Weak correlation: policy premium, trade tariff, assembly costs

Cost-Risk-Concentration Trade-Off



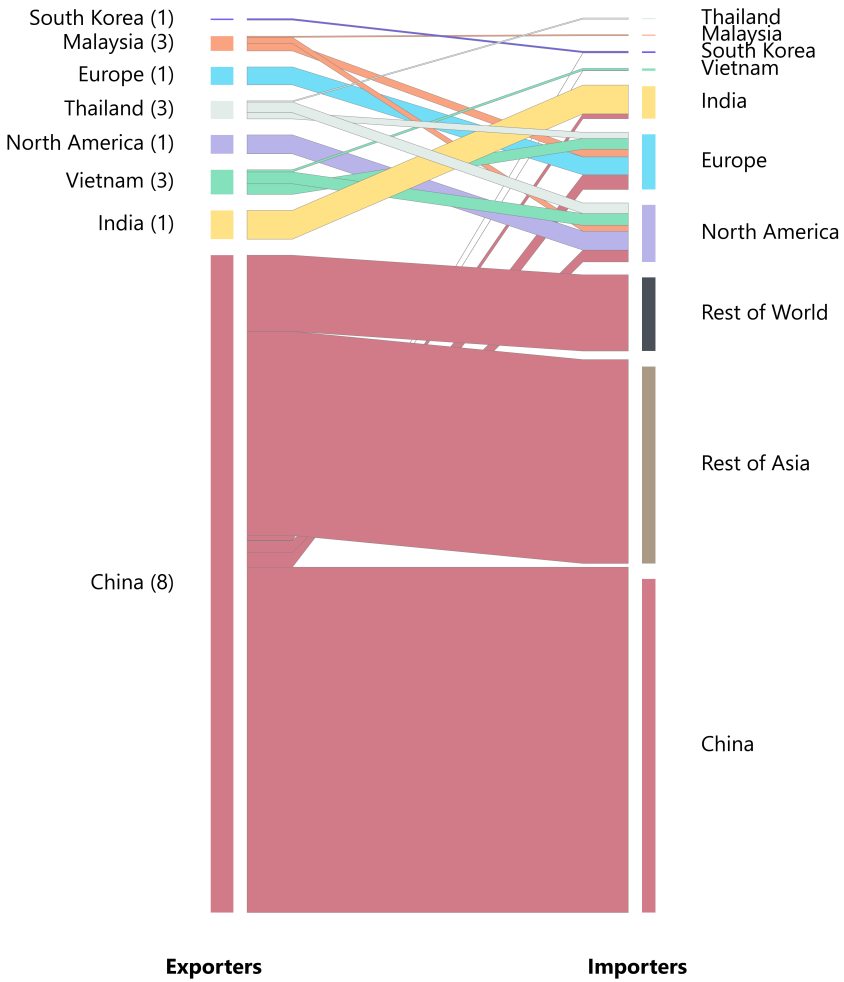
- Negative correlation ($R = -0.45$) between cost and risk reduction
- Additional costs: **50-200 USD/kW** for significant risk/concentration reduction
- BAU: Good balance (213 USD/kW, risk = 6.5, HHI = 0.14)

Impact of Strategic Weights on EU Costs



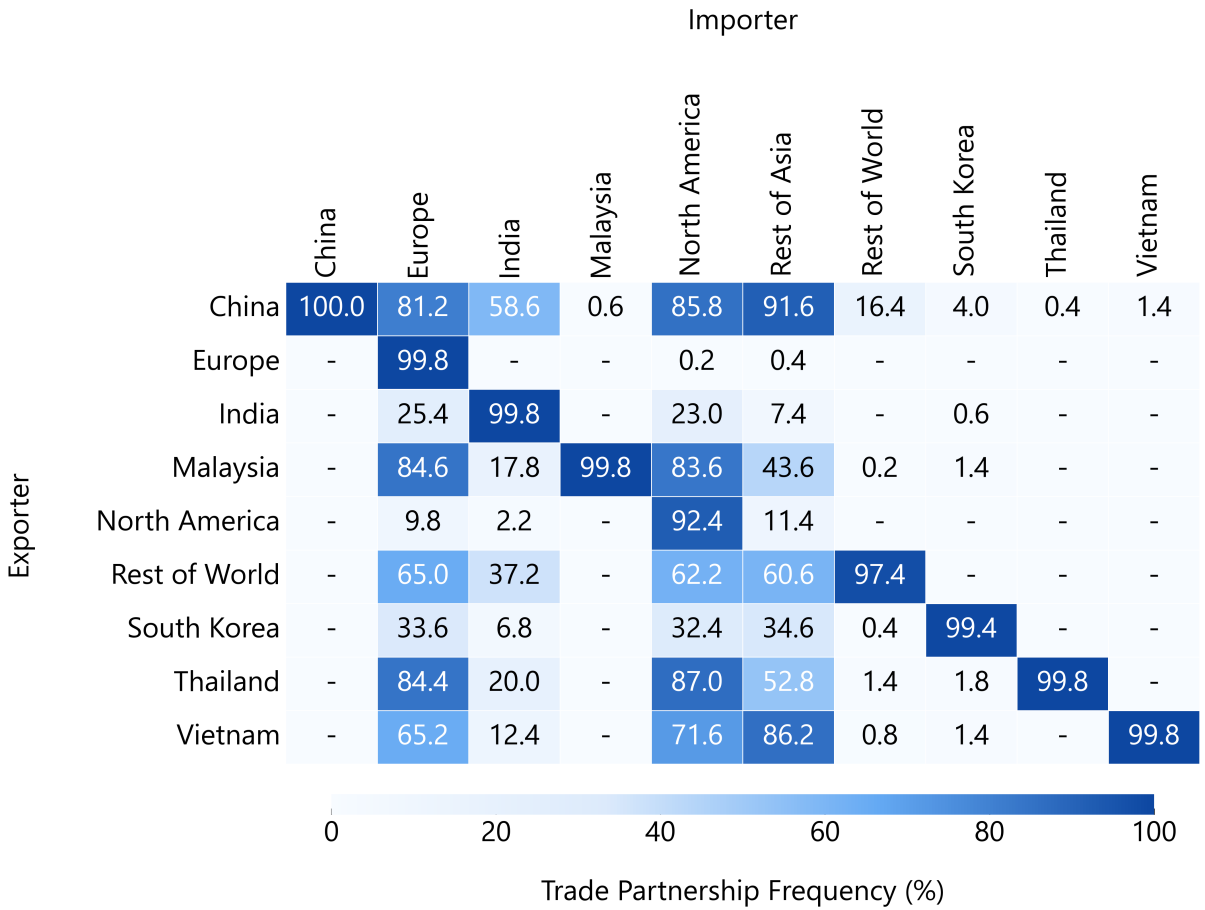
- Cost weight U_1: Strong negative correlation (R $= -0.75$)
- Risk weight U_2: Positive correlation (R $= +0.46$) - risk reduction is costly
- Diversification weight U_3: Weak positive correlation (R $= +0.34$)

Global Trade Patterns (BAU 2030)



- China remains dominant (84% market share)
- EU diversifies: Thailand, Vietnam, Malaysia emerging
- APAC suppliers gain relevance (11% combined)

Trade Partnership Frequency



Most frequent EU trading partners:

- Malaysia: 85% frequency, Thailand: 84% frequency, Vietnam: 65% frequency

Conclusions and Policy Implications

1. **Increase internal supply**
   - Results confirm that expanding local production capacity from 20 to 30 GW and achieving high utilization rates between 90 and 100% significantly increases internal supply from 20% to 40%
   - Secure reliable domestic market for EU-made modules
2. **Build new alliances**
   - Strengthen strategic partnerships with Malaysia, Thailand, Vietnam can diversify the EU's imports and reduce concentration risks
   - Coordinated agreements to secure stable quantities
3. **Spread the risk**
   - Define explicit benchmarks: HHI ≤ 0.15
   - Target: 41% reduction in geopolitical risk vs. 2024

Conclusions

Main Contributions:

- Multi-objective model for solar PV supply chains integrating cost, risk, and diversification
- Quantification of cost-risk-concentration trade-offs
- EU-focused supply structure with domestic assembly modeling

Future Research:

- Long-term time horizon with investment cycles
- Integration with energy system models
- Different module types and technological learning rates
- Detailed representation of entire supply chain stages

Thank you for your attention!

Questions?

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Backup: Model Validation

Calibration to 2024:

Indicator	Reference	Model	Diff. (%)
EU assembly cost (USD/kW)	299	294.4	−1.5
Component cost share (%)	75	74.6	−0.5
Domestic share (%)	15	18.7	+24.3
Import share (%)	85	81.4	−4.3
Share from China (%)	95	92.9	−2.2

Monte Carlo Simulation:

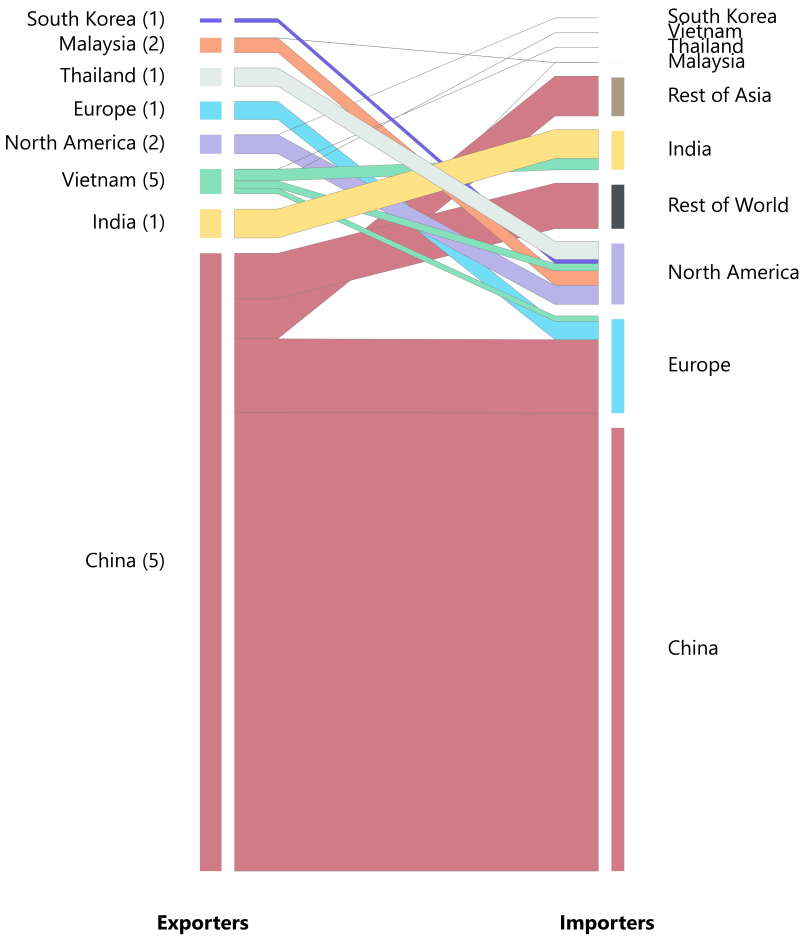
- N = 500 iterations
- Parameters: capacity, utilization, tariffs, assembly costs, objective weights
- Assesses robustness under uncertainty

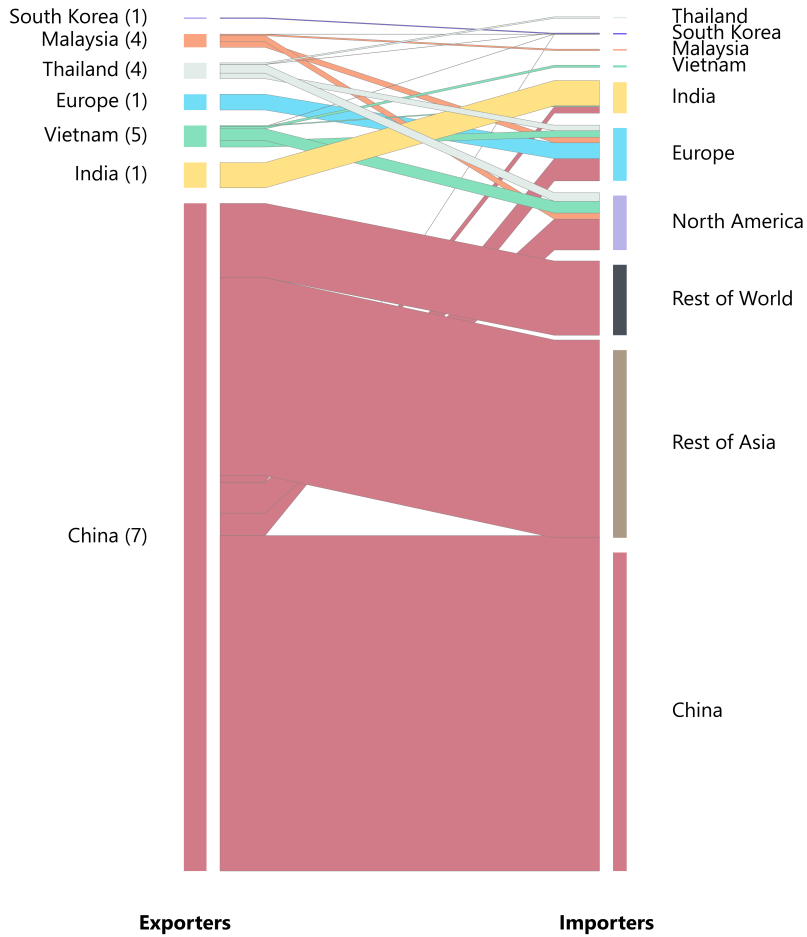
Backup: Monte Carlo Parameter Ranges

Parameter	Min	Max
Production capacity	0.8 × BAU	1.2 × BAU
Utilization rate	80%	100%
Trade tariffs	0%	50%
Policy premium	2%	15%
Assembly costs	0.8 × BAU	1.2 × BAU
Objective weights	Uniform [0,1]	Normalized to 1

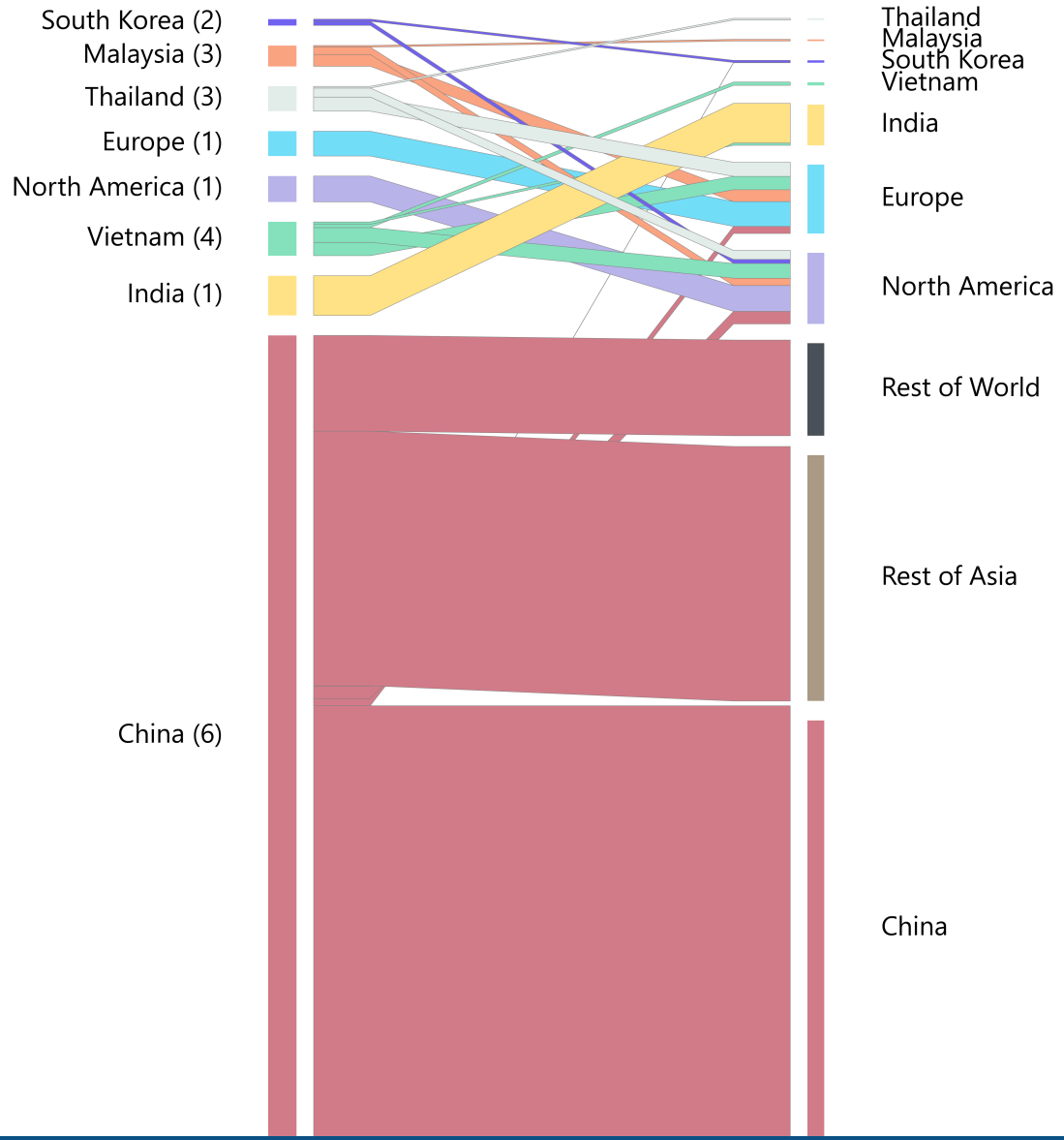
N = 500 iterations to assess robustness under parameter uncertainty

Backup: Global Trade Flows Comparison





Backup: Global Trade Flows (DEGLOB 2030)



Backup: Market Share by Region

Region	Market Share (%)		Internal Supply (%)	
	2024	2030	2024	2030
China	82.9	84.1	100.0	100.0
EU	2.4	2.3	18.6	31.3
India	3.9	3.7	71.4	85.4
Malaysia	2.0	1.9	90.0	100.0
Thailand	2.4	2.3	0.0	100.0
Vietnam	3.3	3.2	100.0	90.0

Backup: Cost-Risk-Concentration Metrics

Scenario	Cost (USD/kW)	Δ Cost (%)	Risk ($\times 10^{-10}$)	Δ Risk (%)
CP 2024	201.2	-	16.0	-
BAU 2030	212.5	+5.6	6.5	−59.4
GLOB 2030	196.2	−2.5	11.0	−31.3
DEGLOB 2030	257.9	+28.2	2.5	−84.4

Key Insight: Achieving geopolitical risk 41% below 2024 levels and HHI ≤ 0.15 requires additional expenditure of 50-200 USD/kW