THE COST OF OWNERSHIP AND MINIMUM SUSTAINABLE PRICE OF POLO BJ CELLS PRODUCED IN GERMANY

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DLR

Introduction

APOLON – Investor-oriented development of POLO technology for a PV production in Germany and Europe

- Goal: Strengthen European PV manufacturing competitiveness
- Focus : Polysilicon on oxide (POLO BJ & IBC) technologies
- Key assessments: Cost of Ownership (CoO), Minimum Sustainable Price (MSP), Levelized Cost of Electricity (LCOE)
- Benchmark (POLO) vs. PERC technology

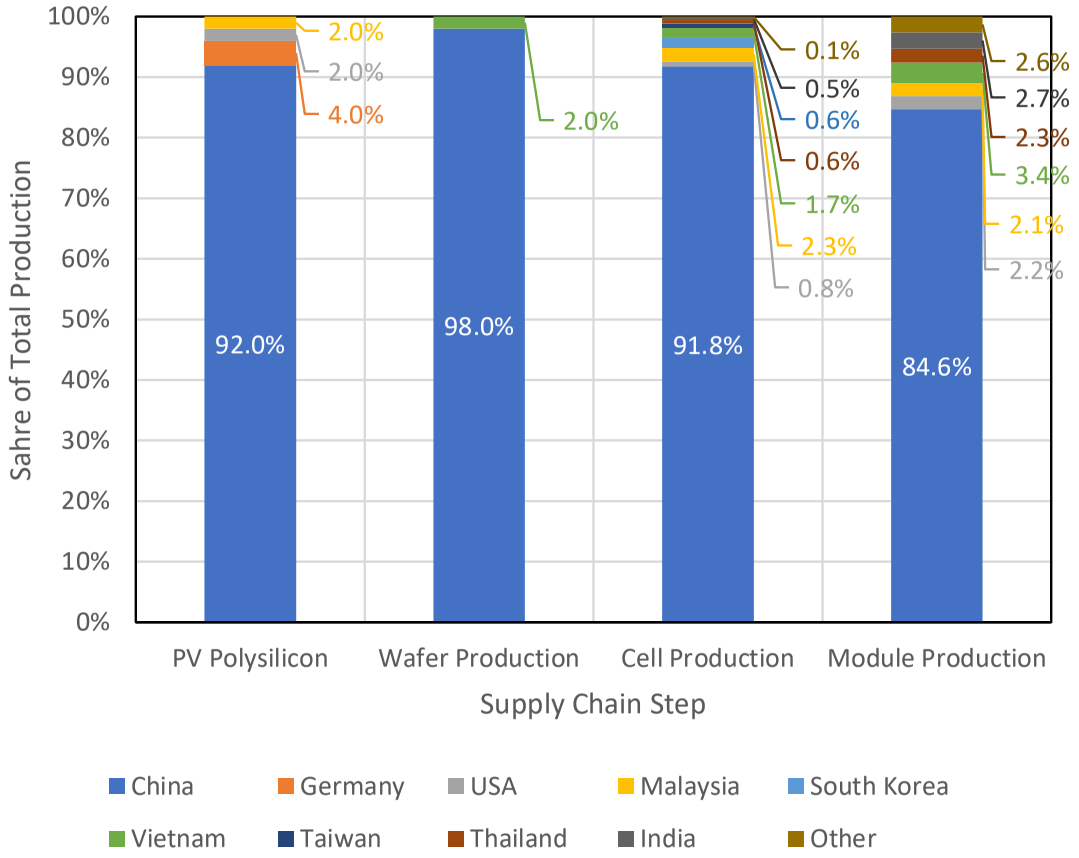
Funded by : BMWE

Federal Ministry for Economic Affairs and Energy

Project Partners: **ISFH, DLR, Centrotherm, LPKF**

China's Dominance in Global PV Supply Chains

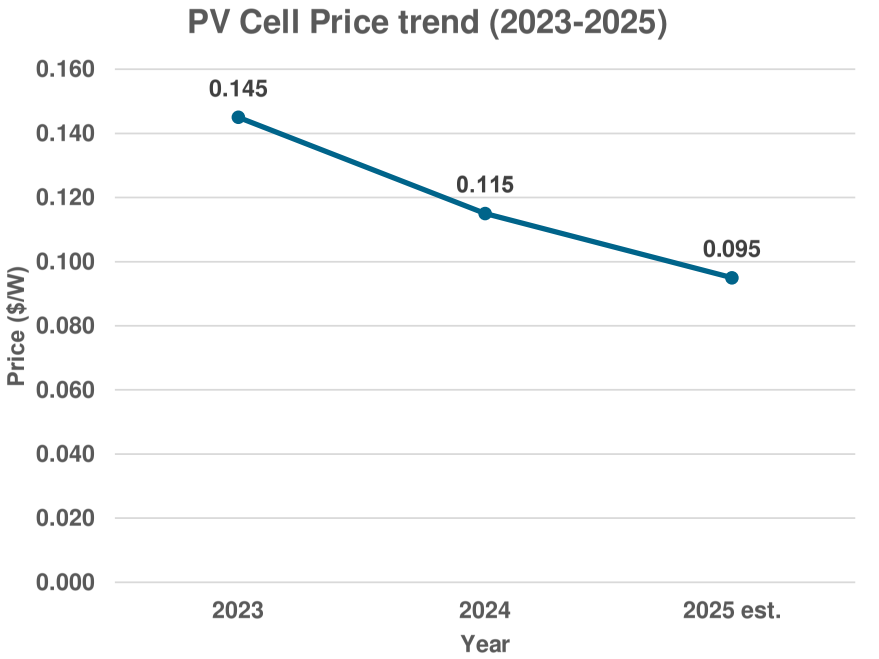
- **Why China so dominant?**
  - Cheaper electricity and labour costs
  - Large-scale factories → lower production costs
  - Heavy investment in new technologies (n-type TOPCon, HJT)
- **What this means for Europe?**
  - Global prices are set from China → increased entry barriers and difficulties for new EU manufacturers
  - Strong reliance on China → supply and competitiveness risks, similar to Europe's past challenges with fossil fuel dependence.



Source: Masson, G.; l'Epine, M.; Kaizuka, I.; Trends in Photovoltaic Applications 2024

PV Cell Price Trend (2023-2025)

- **Drivers of decline:**
  - Large-scale **overcapacity in China** (>500 GW cell capacity)
  - Rapid **Shift to n-type** technologies (TOPCon, HJT) improving efficiency
  - **Economies of scale** in production and supply chains
- **Implications for Europe:**
  - Local production costs: ~$0.20 - 0.25/W → nearly double import prices
  - Policy measures are necessary to compensate the price gap and support European PV competitiveness



Source: Fall 2024 Solar Industry Update; Winter 2025 Solar Industry Update; PV spot price

Key Cost Metrics

⚙️ Cost of Ownership (CoO)

- **Definition:** Manufacturing cost per watt (¢/Wp)
- **Covers:** Materials, energy, labor, consumables, depreciation, yield losses, overheads
- **Tells us:** How much it costs the factory to produce 1 W of cell capacity?

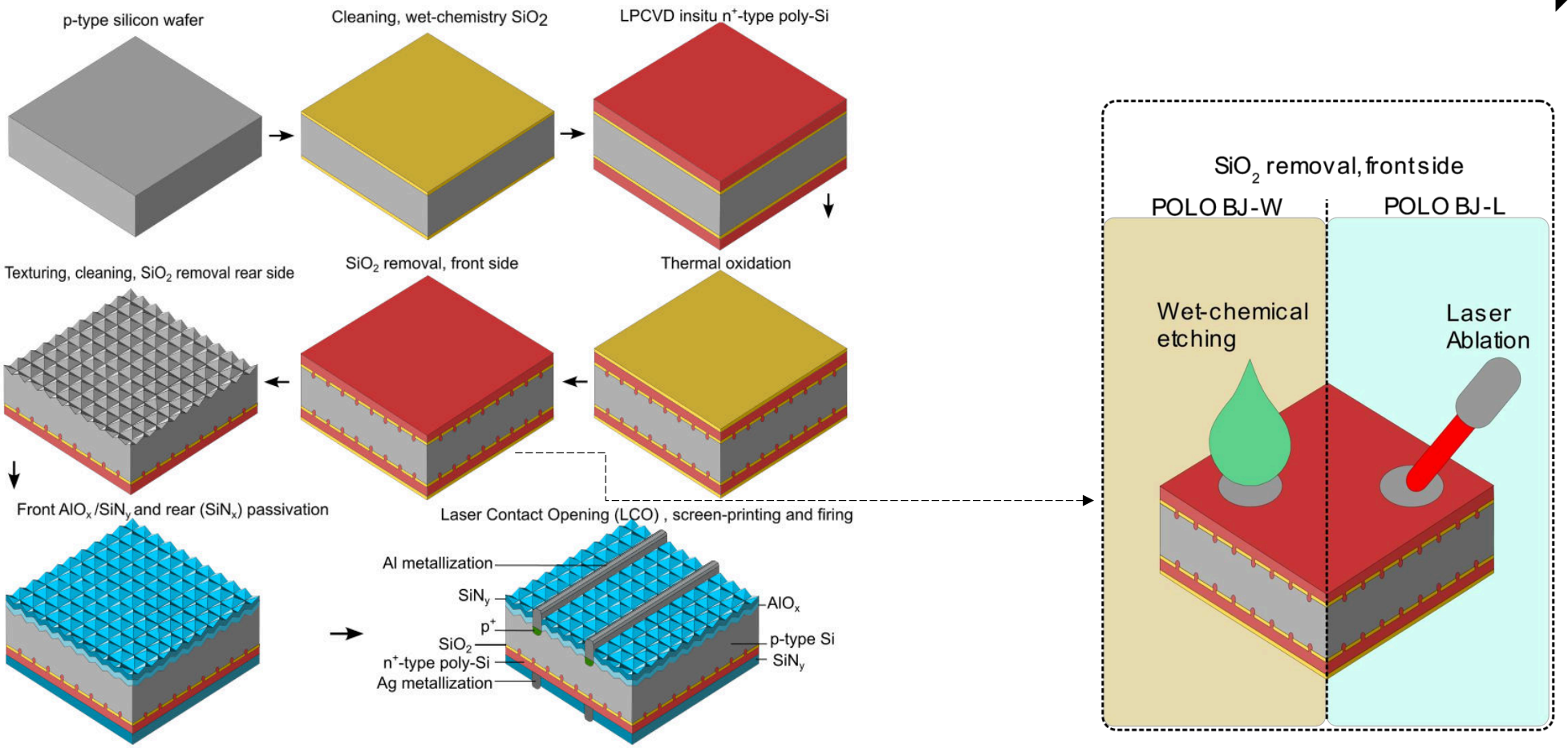
💵 Minimum Sustainable Price (MSP)

- **Definition:** Lowest selling price per watt (¢/Wp) that ensures financial sustainability
- **Covers:** CoO + financing (WACC), SG&A, taxes, profit margin
- **Tells us:** The price floor at which the factory can stay profitable long term

⚡ Levelized Cost of Electricity (LCOE)

- **Definition:** Average lifetime cost of electricity per kWh produced
- **Covers:** System CAPEX (modules + BOS), O&M, discount rate, lifetime generation
- **Tells us:** How much one kilowatt-hour of electricity costs over the system's lifetime?

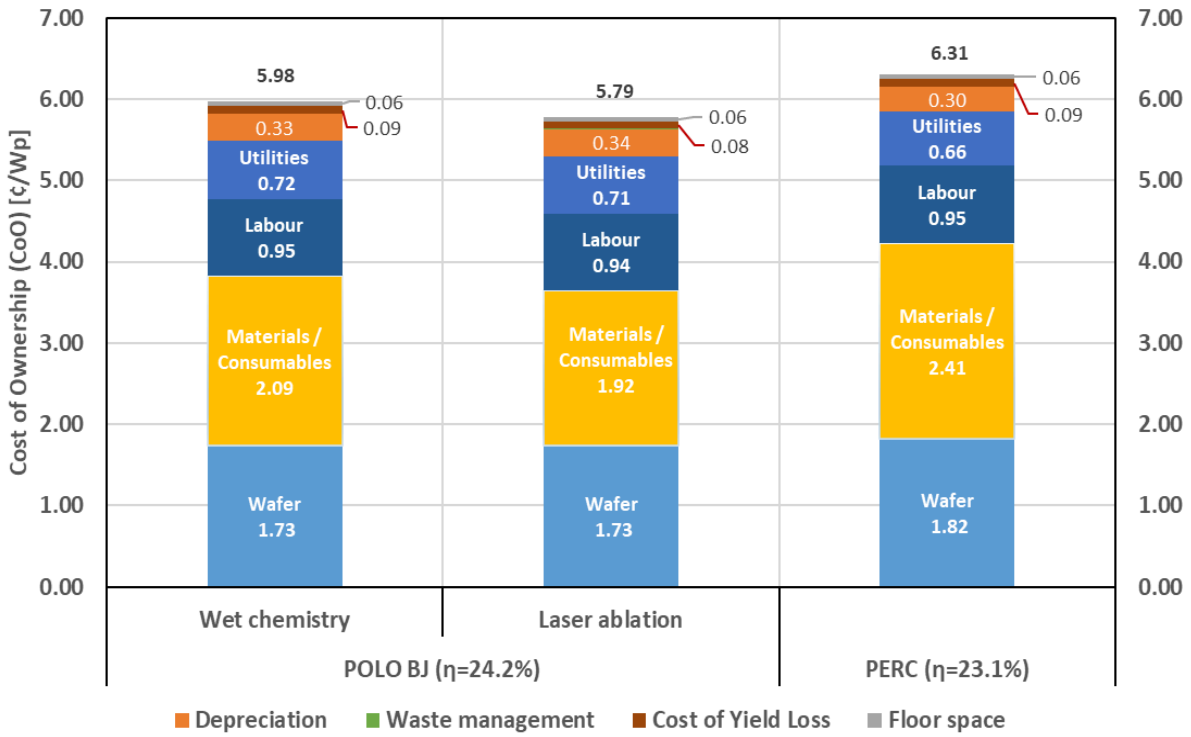
Considered Cell Concepts and Production Sequences



Source: Gomez Trillos, J.C. et al; 2025; The Cost of Ownership and Minimum Sustainable Price of POLO BJ Cells produced in Germany. [Manuscript submitted for publication]

Cost of Ownership (CoO)

- ‘POLO BJ-Laser’ achieves lower CoO than ‘POLO BJ-Wet’ chemistry, mainly due to reduced chemical usage.
- CoO for POLO BJ (η_{cell}=24.2%) is 8.2% lower than that of PERC (η_{cell}=23.1%), therefore highlighting the economic benefits of POLO BJ.
- Dominant cost factors:
  1. Materials & consumables
  2. Wafers
  3. Labour
  4. Utilities



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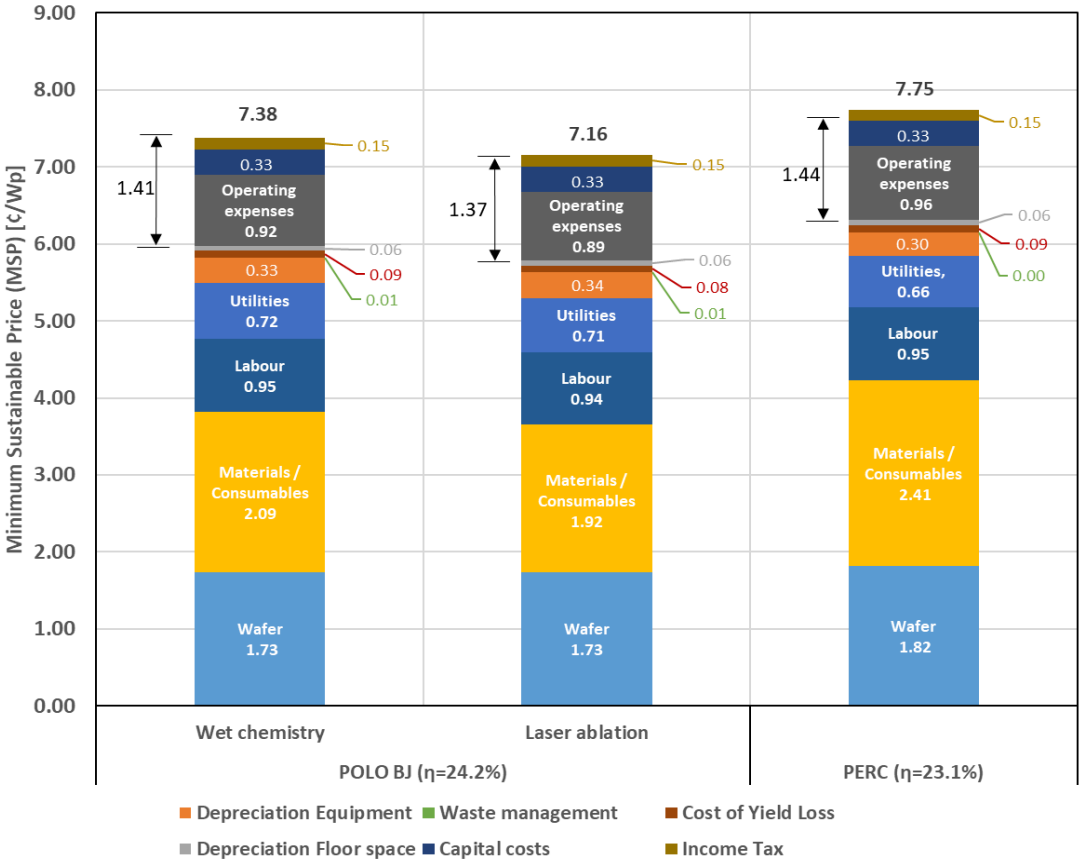
Minimum Sustainable Price (MSP)

- MSP of POLO BJ is up to 7.6% lower than PERC (24.2% vs 23.1% effeiciency)
- MSP per Wp driven by higher material costs for PERC and subsequently by the lower efficiency assumption made for this type of cell.
- MSP for POLO BJ is within the range of spot market price range for TOPCon (3.8-11.0 USD ct/Wp, August 2025)



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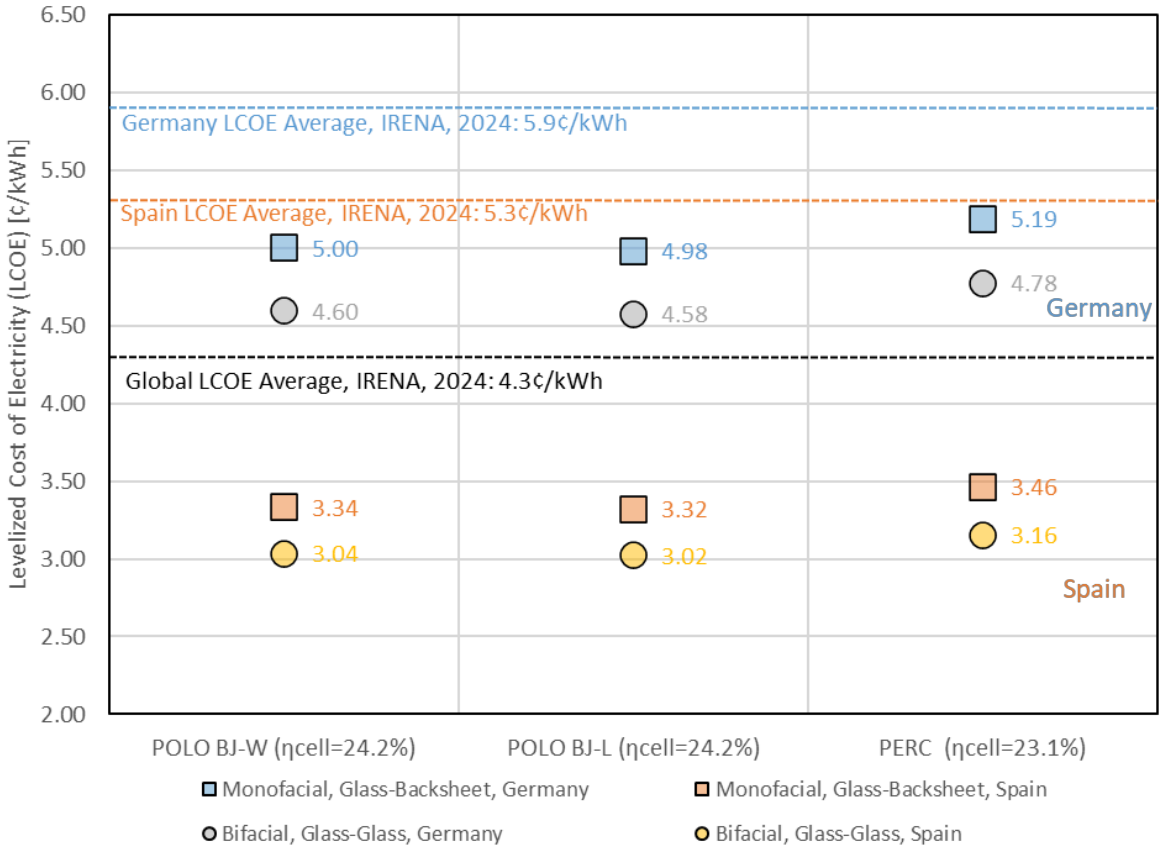
Levelized Cost of Electricity (LCOE)

- LCOE(bifacial) < LCOE (monofacial) due to higher electricity yield and despite higher module costs.
- LCOE (Germany) > LCOE (Spain) due to the higher solar resources in Spain.
- LCOE of POLO BJ is up to 0.14 ¢/kWh lower than PERC (Southern Europe, bifacial systems).
- LCOE of POLO BJ is competitive in both Germany and Southern Europe, aligning with reported global values



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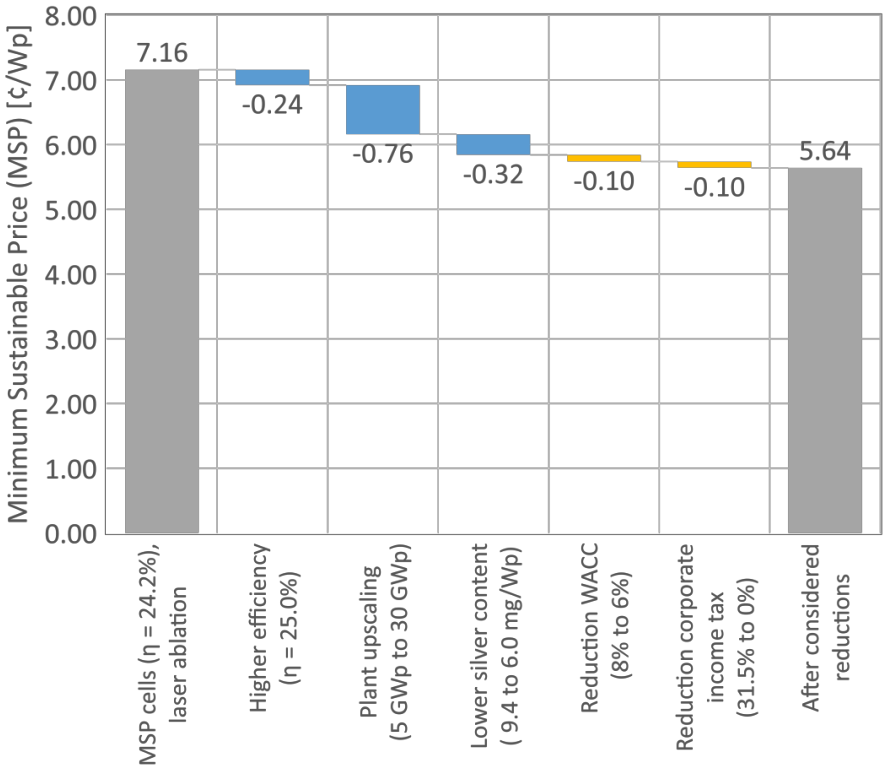
For Global and Germany'y LCOE average: IRENA; 2025; Renewable Power Generation Costs 2024. International Renewable Energy Agency, Abu Dhabi.

Pathways for the Reduction of the MSP

Considering a base MSP for POLO BJ – laser cells

- 0.24 ¢/Wp less MSP if efficiency = 25%.
- 0.76 ¢/Wp less MSP for upscaling the plant to 30GWp
- 0.32 ¢/Wp reduction in MSP by lowering Ag from 9 mg/Wp to 6 mg/Wp
- 0.20 c/Wp reduction in MSP through lower WACC (Weighted Average Cost of Capital) and income tax
- All these possibilities combined lead to a reduction of 1.52 ¢/Wp (21.2%$_{rel}$)



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Conclusion

🔑 Key Takeaways

- 💰 **Cost Advantage**
  → **POLO BJ** shows clear economic gains over PERC:
  - Up to 8% lower **CoO**
  - Up to 7–8% lower **MSP**
  - Competitive with **current TOPCon market prices**

- ⚡ **Efficiency and LCOE**
  → 24.2% efficiency assumed (vs 23.1% for PERC)
  → LCOE analysis: POLO BJ delivers **lower electricity costs**, especially in high-irradiance regions

- 🏭 **Upscaling Potential**
  → Combined improvements (efficiency, scaling, silver reduction, financing) can reduce
  - MSP ↓ >20% → ~5.6 ¢/Wp
  - 30 GW scaling + silver savings + 25% eff. + financing

- 🇪🇺 **European Relevance**
  → Local production still >30% costlier than China
  → Needs policy support & innovation to close gap

Impressum

Topic: **The Cost of Ownership and Minimum Sustainable Price of POLO BJ Cells produced in Germany**
Date: 2025-09-22
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Institute: DLR Institute of Networked Energy Systems (Oldenburg)

Annex

Methodology to Calculate CoO

Plant output	GWp/a

General inputs

Prices	*Unit*
Cell Efficiency	%
Cell area/format	cm^2
Wafers price	$/piece
Material	$/kg
Utilities	$/kWh
Consumables	$/piece
Labour	$/a*FTE
Floor space	$/a*$m^2$
Waste disposal	$/$m^3$
Depreciation time	a

Inputs step i

Item	*Unit*
Throughput tool	piece/h
Tool number	-
Productive time	h/a
Material	kg/wafer
Tool price	$
Tool footprint	m^2
Utilities	kW
Consumables	piece/a
Waste volume	m^3/h
Labour	FTE/shift
Yield loss	%

Results step i

CoO process i	USD
CoO per cell i	USD/piece
CoO per power unit i	USD/Wp
CoO per area unit i	USD/m^2

Aggregated results sequence

CoO	USD
CoO	USD/piece
CoO	USD/Wp
CoO	USD/m^2

Iterative process to calculate MSP

Methodology to Calculate MSP

$$B_{Gross\ income\ ,t} = B_t - C_{var,t} - D_{facility,t} + D_{tools,t}$$

$$C_{var,t} = C_{mat,t} + C_{utilities,t} + C_{waste,t} + C_{labour,t} + C_{yield\ loss,t}$$

$$B_{Operating\ income,t} = B_{Gross\ income,t} - C_{OPEX,t}$$

$$C_{OPEX} = f_{OPEX} * B_t$$

$$C_{tax,t} = B_{Operating\ income,t} * f_{income\ tax,t}$$

$$R_{cash\ flow,0} = C_{Investment,t} + \Delta NWC$$

$$R_{cash\ flow,t} = B_{Operating\ income,t} - C_{tax,t} + D_{facility,t} + D_{tools,t} + \Delta NWC + C_{Investment,t} + B_{salvage,t}$$

$$R_{NPV} = R_{cash\ flow,0} + \sum_{t=1}^{T} \frac{IR_{cash\ flow,t}}{(1+i)^t}$$

$$R_{NPV} = 0$$

$B_t = B_1 \quad \forall\, t > 0$

$C_{var,t} = C_{var,1} \quad \forall\, t > 0$

$C_{OPEX,t} = C_{OPEX,1} \quad \forall\, t > 0$

$C_{tax,t} = C_{tax,1} \quad \forall\, t > 0$