Investeren in de toekomst van een Europese zonne-energie maakindustrie

Om de Europese concurrentiekracht op lange termijn te waarborgen, stelt Mario Draghi in zijn recente rapport *The Future of European Competitiveness* dat een eigen maakindustrie voor essentiële energietechnologieën onmisbaar is. Dit gaat om kritieke technologieën die voor de energietransitie van strategisch belang zijn. Hiervoor wil Europa niet afhankelijk zijn van andere werelddelen. Maar om een maakindustrie op te bouwen voor duurzame energietechnologieën zoals zonnepanelen en batterijen, zijn forse investeringen nodig. Het Europese doel is om ten minste 40 procent van de benodigde technologieën binnen de Europese grenzen te produceren, met een resterende 60 procent ruimte voor import uit andere werelddelen, zoals Azië. Dit stelt Europa voor de uitdaging om zijn productiecapaciteit op te schalen, en daarvoor kapitaal te mobiliseren.

Uitdagingen voor opschaling en innovatie

De komende jaren zullen in het teken staan van het mobiliseren van investeringskapitaal voor deze transitie. Dit is geen geringe opgave. Ten eerste moet Europa een antwoord vinden op de vraag hoe het de opschaling van eigen productie efficiënt kan financieren, terwijl Europese productie momenteel duurder is dan bijvoorbeeld Aziatische import. Dit betekent dat de periode waarin de Europese industrie op gang komt en zichzelf moet bewijzen, slim gefinancierd moet worden om het kostennadeel van Europese productie te overbruggen. Ten tweede ligt de focus op het opschalen van toekomstgerichte technologieën. Het investeren in de bewezen technologieën van vandaag zal Europa lastiger een competitief voordeel brengen; we moeten inzetten op de technologie van morgen. Dit vraagt om innovatief financieringsbeleid dat risico’s op technologische ontwikkeling kan afdekken. De derde uitdaging ligt in het kennisniveau. Terwijl Europa in eerdere decennia een leidende positie had in de maakindustrie, is de kennis inmiddels grotendeels naar Azië verschoven, vooral op productiegebied. Dit betekent dat Europa enerzijds strategisch onafhankelijk wil worden, maar ook moet blijven samenwerken met landen zoals China om concurrerend te blijven.

De rol van overheid en strategische investeringen

Naast investeringskapitaal spelen andere factoren een cruciale rol in de ontwikkeling van de Europese maakindustrie voor zonne-energie, zoals de kosten van arbeid, energieprijzen en toegang tot kritieke grondstoffen. Overheidsfinanciering is hier van groot belang, omdat deze als hefboom kan werken om ook private investeringen aan te trekken. Via blended finance, waarbij publieke en private middelen worden gecombineerd, kan het kapitaal zo effectief mogelijk worden ingezet. Het rapport *Solar panel manufacturing cost comparison* van Roland Berger laat zien dat voor de gehele Europese Unie publiek bedrag van 27 miljard euro nodig is om de “oncompetitieve” periode te overbruggen. Dit bedrag zou een veelvoud aan private middelen kunnen mobiliseren, zeker wanneer het gepaard gaat met stimulerende instrumenten die het prijsonderscheid met Aziatische producten dempen. Vanuit de Nederlandse groeifondsaanvraag kan economische groei worden bereikt in machinebouw, zonnepaneel productie opschaling en de innovatie infrastructuur daaromheen.

Een gezamenlijke Europese aanpak

De opbouw van deze industrie vraagt ook om een strategische en tijdige start. Europa moet op het juiste moment klaarstaan met nieuwe technologieën om een voorsprong te nemen. Met BatteryNL en SolarNL heeft Nederland een goede uitgangspositie om zich ook binnen Europa sterk te positioneren. Maar de waardeketens van zonne-energie en batterijproductie zijn groter dan Nederland alleen; Europese samenwerking met landen als Frankrijk, Spanje, Italië en Duitsland is noodzakelijk om een robuust ecosysteem voor innovatieve technologieën te creëren.
Betaalbare batterijen en zonnepanelen zijn essentieel voor het behalen van de Europese CO_2-reductiedoelen, en daarom kunnen importheffingen averechts werken.

Slim concurreren én samenwerken

Het oplossen van de drie uitdagingen uit het rapport vormen de uitdaging van de Europese maakindustrie. (i) het kostennadeel is fundamenteel in arbeid, grondstoffen en energieprijs. Door arbeid in de nieuwe maakindustrie productiever te maken, kan Europa een competitief voordeel ontwikkelen in de productie en circulaire economie. Door te focussen op arbeids- en grondstof-besparende innovatie, kan Europa een competitief voordeel ontwikkelen in de productie en circulaire economie. Elektrificatie van het energiesysteem vormt in potentie een positieve feedbackloop. Door te investeren in flexibiliteit en slimme benutting van het elektriciteitsnet, kan Europa in potentie duurzame èn competitieve elektriciteit produceren. (ii) Toekomstgericht investeren en opschalen moet tegelijkertijd plaatsvinden. (iii) Innovaties in de maakindustrie richten zich op materiaalgebruik, introductie van nieuwe materialen, circulariteit en nieuwe productiemethodes.

Het Draghi rapport benadrukt dat klimaatactie en economische groei elkaar juist kunnen versterken. Zo zorgen we ervoor dat groene groei werkelijkheid wordt voor Nederland en Europa.

Solar panel manufacturing cost comparison

A comparison between China, Europe and the US

Amsterdam, October 2024

Contents

Appendix

A. Executive summary

This analysis determines the cost gap between solar panels manufactured in China, the EU, and the US, and provides an overview of policy measures

Background and approach of the project

Background

- With the Net Zero Industry Act (NZIA) the European commission aims to manufacture 40%1) of the equipment required to reach the European climate targets within Europe by 2030
- Currently, the vast majority of solar panels are being manufactured in China where production is cheap due to among others the low cost of utilities and labor
- Bringing (a share of) solar panel manufacturing to Europe implies overcoming the cost gap associated with manufacturing in Europe (price premium), doing so would strengthen European strategic autonomy and capitalize on current knowledge position

Project approach

The aim of the project is to determine the difference between the production cost and market price (price premium) of solar panels in China, the EU and the US and provide an overview of what policy measures could be used to overcome the cost gap. To solve this question the project assesses:

1. **High-level cost comparison of solar-PV manufacturing**
2. **Policy options to overcome the European cost gap**
3. **Value chain impact**

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1) Includes all components for the equipment across the value chain (e.g. modules made with chines cells do not count to the 40%)

The EU needs to act now and instate policies that overcome a EUR 12-27 bn cumulative cost gap, to establish a solar panel value chain in line with the NZIA

Executive summary (1/3) – Key messages

B **Cost comparison**

Completely manufacturing solar panels in Europe comes at a price premium of 20-25 EUR ct/Wp compared to manufacturing in China

C **Cumulative cost gap**

NZIA requires an EU solar manufacturing capacity of 22-37 GWp (40% of 56-93 GWp annual additions) which, requires overcoming a cumulative cost gap of EUR 12-27 bn

D **Minimal capacity**

At least 20-25 GWp EU manufacturing capacity is required to achieve economies of scale, this is in line with the 22-37 GWp needed for the NZIA and unlocks EUR 8-35 1) bn of investments withing Europe

E **Potential policies**

A decision needs to be made on a policy direction to support the solar panel manufacturing industry and selecting a direction is urgent as 2-3 years are required to start-up new manufacturing capacity

F **Value chain**

Increasing EU solar panel manufacturing will positively impact various stages of the value chain, from machinery manufacturing to technological innovation

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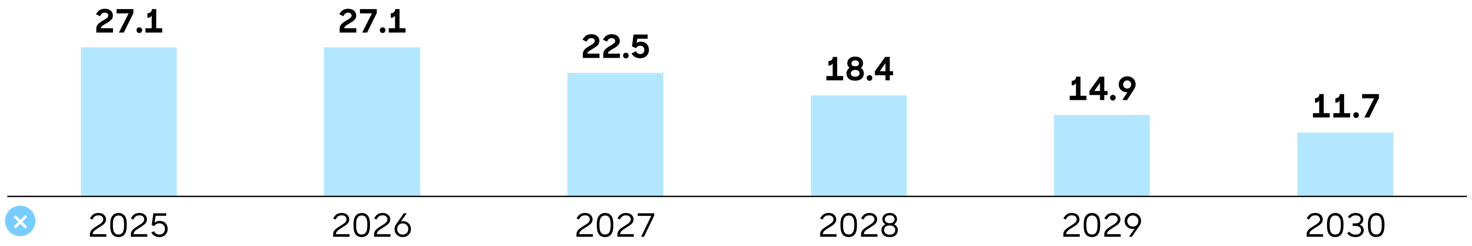
1) Including potential cost for setting up supporting industrial facilities

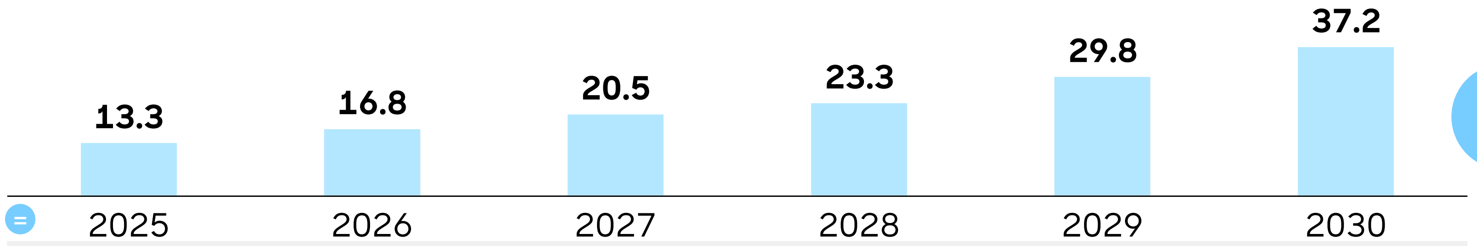
The cumulative cost gap has been determined based on a declining price premium as a result of innovation, scaling, and the EU solar power forecast

Executive summary (2/3) – Calculation of the cumulative cost gap

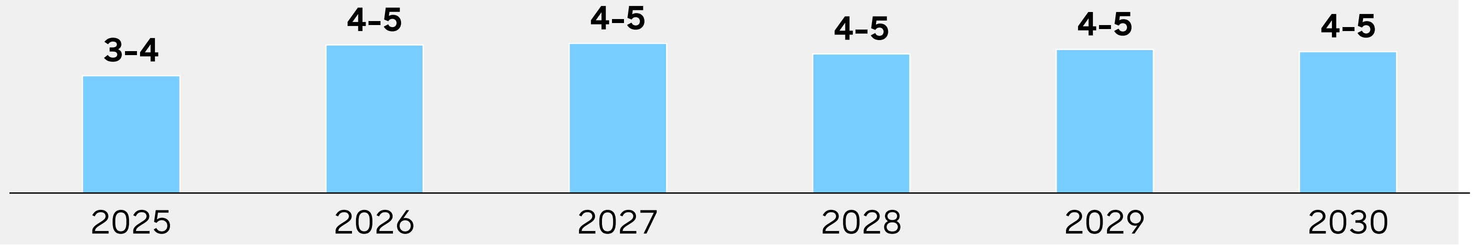
Price premium with market price [EUR ct/Wp]



EU solar panel manufacturing capacity¹⁾ [GW]



Cost gap [EUR bn]



Σ

18.4 EUR Ct/Wp
Average weighted cost gap

141 GW
Solar panels manufactured

EUR 26 bn
Cumulative cost gap

Methodology and comments

Market price :

- **Import price:** 38.6 EUR ct/Wp (EU cost level) –11.4 EUR ct/Wp (market price) = **27.2 EUR ct/Wp (2024)**
- **12% p.a. EU manufacturing cost decrease from 2027:** given that Europe can incorporate significant economies of scale already achieved in other parts of the world, a 12% p.a. decrease from 2027, in line with the historical average, is a reasonable estimate

Market volumes

- **SolarPower Europe:** 40% of 93 GWp/year = **37.2 GWp/year (2030)**

Over 2025-30 EUR 26 bn of incentives or subsidies to get EU manufactured panels equal to the market price

- Subsidies initially increase as production rises, but (partly) subsides as economies of scale are developed

1) Share of EU manufacturing capacity is based on average capacity among the processing steps

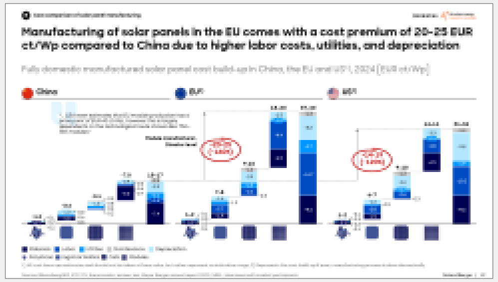
Source: BloombergNEF, ETIP PV, Het Financieele Dagblad, iea, MCPV, Meyer Burger annual report, NREL, Our World in Data, Interview with market participants

The EU government funding required to establish a European solar panel supply chain amount to EUR 0-27 bn depending on the policy direction

Executive summary (3/3) – Potential policy directions

European price premium & Cumulative cost gap

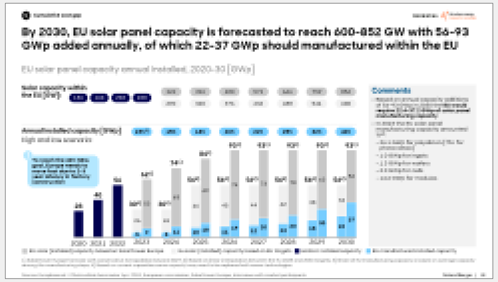
Solar panel production in the EU comes with a **price premium of EUR 22-25 ct/Wp**



Manufacturing of solar panels in the EU comes with a cost premium of 20-25 EUR ct/Wp compared to China due to higher labor costs, utilities, and depreciation

Fully domestic manufactured solar panel cost build-up in China, the EU and US, 2024 [EUR ct/Wp]

40% of production within the EU would imply **22-37 GWp production capacity**



By 2030, EU solar panel capacity is forecasted to reach 600-852 GW with 56-93 GWp added annually, of which 22-37 GWp should manufactured within the EU

EU solar panel capacity annual installed, 2020-30 [GWp]

Cumulative cost gap of EUR 12-27 bn

Potential policy directions and corresponding government funding [EUR bn]

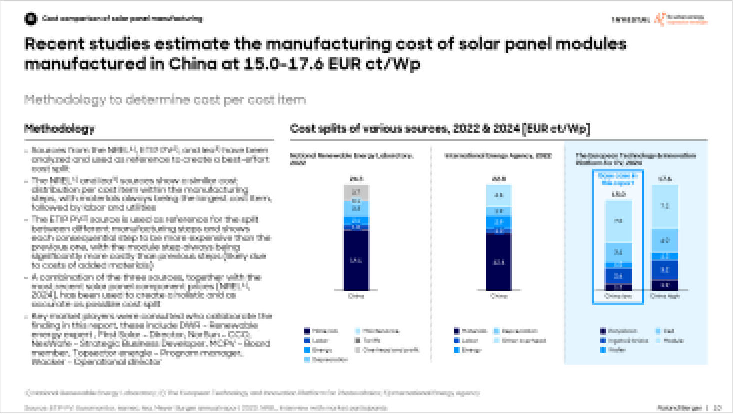
Build solar PV industry	15-27	• In this scenario, the focus is to develop the solar panel manufacturing industry without slowing the adoption of solar energy • The gov't pays for the cumulative cost gap • The gap is overcome with strong incentives and subsidies with no cost passed onto the market
Spread the burden	12-21	• In this scenario, the government supports the development of solar panel manufacturing industry, while passing on some of the costs to the solar projects, decelerating solar energy adoption • The gap is overcome with incentives, subsidies and tariffs on foreign manufactured panels
No cost to the EU	0	• In this scenario, the government creates an equal playing field but does not financially support the solar panel manufacturing industry • The gap is overcome with high tariffs combined with strict regulatory requirement, traceability of the value chain, and local content requirements

B. Cost comparison of solar panel manufacturing

The manufacturing cost of solar panels in the EU and US have been determined by multiplying each cost item relative to manufacturing cost in China

Methodology to determine the cost premium of solar panel manufacturing outside China

Determine cost level and split



Recent studies estimate the manufacturing cost of solar panel modules manufactured in China at 15.0-17.6 EUR ct/Wp

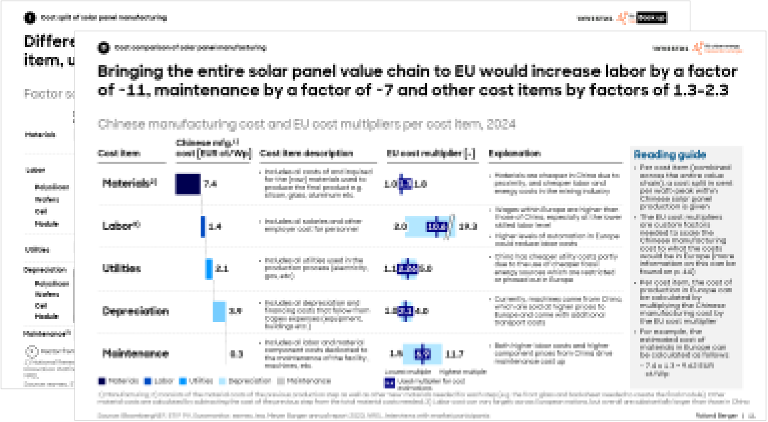
Methodology to determine cost per cost item

Methodology

Cost splits of various sources, 2022 & 2024 [EUR ct/Wp]

- Building on research from NREL1), ETIP PV2) and iea3) we split the market price (which reflect Chinese prices given the current distribution of production) into 5 key cost items: materials, labor, utilities, maintenance and depreciation/Capex
- In these analyses we assume the full production process is carried out in the respective country

cost item multipliers



Bringing the entire solar panel value chain to EU would increase labor by a factor of ~11, maintenance by a factor of ~7 and other cost items by factors of 1.3-2.3

Chinese manufacturing cost and EU cost multipliers per cost item, 2024

- With data from sources like Euromonitor, NREL1), ETIP PV2), iea3) and interviews, multipliers are determined which indicate the relative difference between cost items in China, the EU and the US
- By multiplying each key/sub cost item found for China with the multipliers, the region-specific cost splits per cost item are determined

Sources

- National Renewable Energy Association (NREL):
  - The Global Solar Photovoltaic Supply Chain and Bottom-UP Cost Model Results, 2024
  - Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing, 2018
- International Energy Agency (iea):
  - Special Report on Solar PV Global Supply Chains, 2022
- European Solar Manufacturing Council:
  - Das geopolitische Rennen um die Kontrolle über die PV-Herstellung, 2023
- The European Technology & Innovation Platform for Photovoltaics:
  - PV Manufacturing in Europe: Ensuring resilience through industry policy, 2024
- Euromonitor:
  - Wage per hour, 2023, Electricity price, 2023
- LONGi PV Solutions:
  - Bottom-up cost assessment, 2024
- Meyer Burger annual reports
- Interviews with DWR, First Solar, MCPV, NorSun and NexWafe, Topsector energie, and Wacker

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1) National Renewable Energy Laboratory; 2) The European Technology and Innovation Platform for Photovoltaics; 3) International Energy Agency

Source: BloombergNEF, ETIP PV, Euromonitor, iea, Meyer Burger annual reports, NREL, interviews with market participants

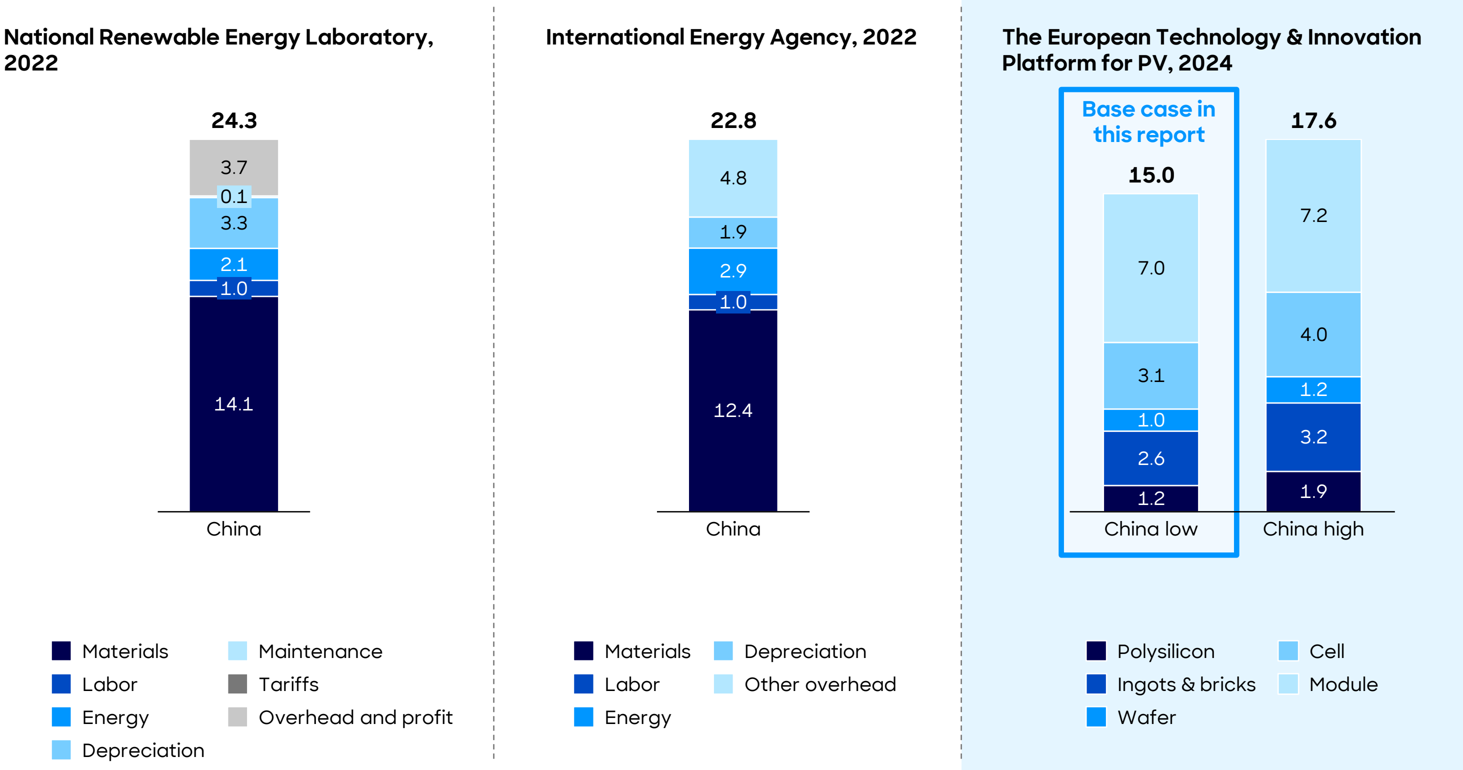
Recent studies estimate the manufacturing cost of solar panel modules manufactured in China at 15.0-17.6 EUR ct/Wp

Methodology to determine cost per cost item

Methodology

- Sources from the NREL[1], ETIP PV[2], and iea[3] have been analyzed and used as reference to create a best-effort cost split
- The NREL[1] and iea[3] sources show a similar cost distribution per cost item within the manufacturing steps, with materials always being the largest cost item, followed by labor and utilities
- The ETIP PV[2] source is used as reference for the split between different manufacturing steps and shows each consequential step to be more expensive than the previous one, with the module step always being significantly more costly than previous steps (likely due to costs of added materials)
- A combination of the three sources, together with the most recent solar panel component prices (NREL[1], 2024), has been used to create a holistic and as accurate as possible cost split
- Key market players were consulted who collaborate the finding in this report, these include DWR – Renewable energy expert , First Solar – Director, NorSun – CCO, NexWafe – Strategic Business Developer, MCPV – Board member, Topsector energie – Program manager, Wacker – Operational director

Cost splits of various sources, 2022 & 2024 [EUR ct/Wp]



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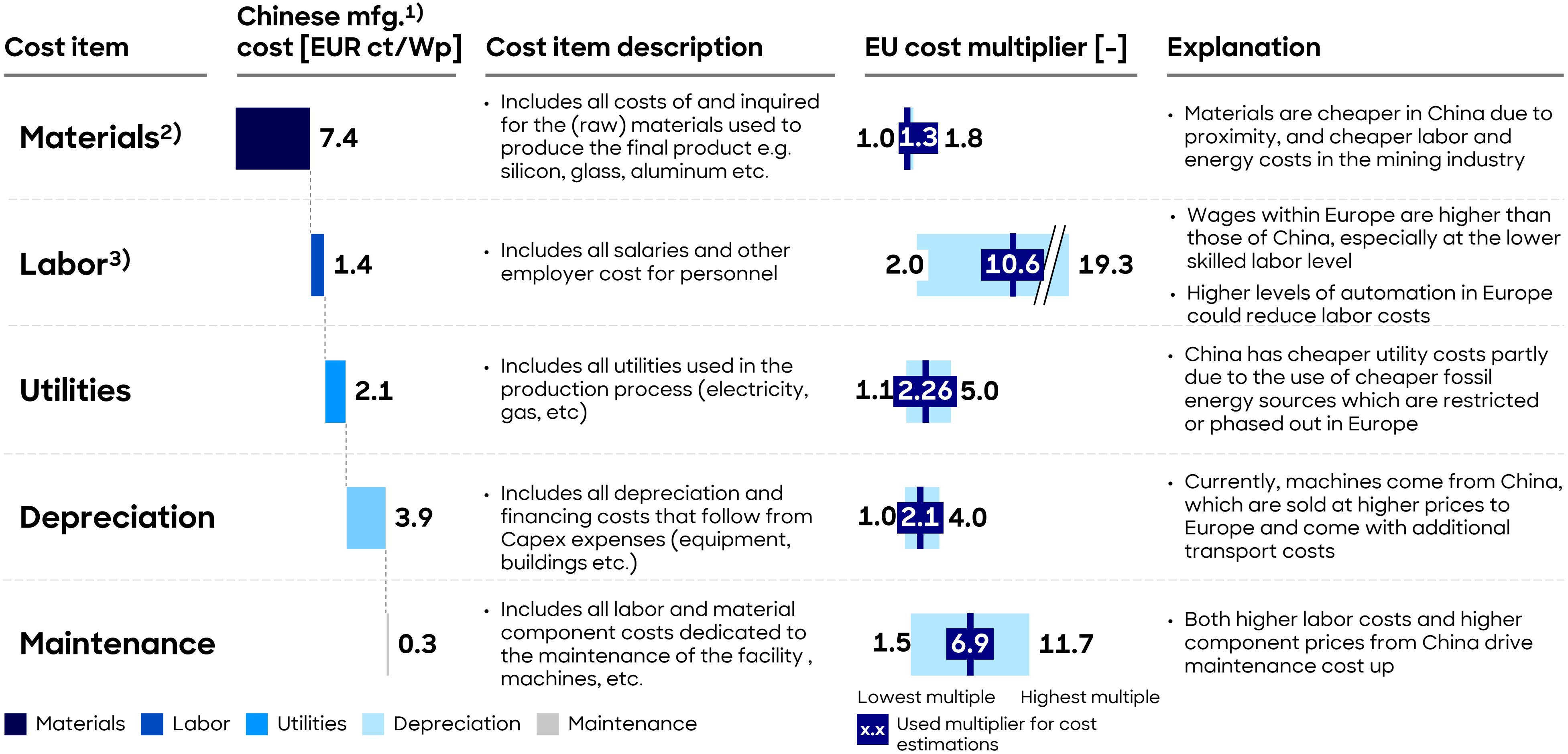
1) National Renewable Energy Laboratory; 2) The European Technology and Innovation Platform for Photovoltaics; 3) International Energy Agency

Source: ETIP PV, Euromonitor, esmec, iea, Meyer Burger annual report 2023, NREL, Interview with market participants

Bringing the entire solar panel value chain to EU would increase labor by a factor of ~11, maintenance by a factor of ~7 and other cost items by factors of 1.3-2.3

Chinese manufacturing cost and EU cost multipliers per cost item, 2024



Cost item	Chinese mfg.[1] cost [EUR ct/Wp]	Cost item description	EU cost multiplier [-]	Explanation
Materials[2]	7.4	Includes all costs of and inquired for the (raw) materials used to produce the final product e.g. silicon, glass, aluminum etc.	1.0 **1.3** 1.8	Materials are cheaper in China due to proximity, and cheaper labor and energy costs in the mining industry
Labor[3]	1.4	Includes all salaries and other employer cost for personnel	2.0 **10.6** 19.3	Wages within Europe are higher than those of China, especially at the lower skilled labor level Higher levels of automation in Europe could reduce labor costs
Utilities	2.1	Includes all utilities used in the production process (electricity, gas, etc)	1.1 **2.26** 5.0	China has cheaper utility costs partly due to the use of cheaper fossil energy sources which are restricted or phased out in Europe
Depreciation	3.9	Includes all depreciation and financing costs that follow from Capex expenses (equipment, buildings etc.)	1.0 **2.1** 4.0	Currently, machines come from China, which are sold at higher prices to Europe and come with additional transport costs
Maintenance	0.3	Includes all labor and material component costs dedicated to the maintenance of the facility , machines, etc.	1.5 **6.9** 11.7	Both higher labor costs and higher component prices from China drive maintenance cost up

Reading guide

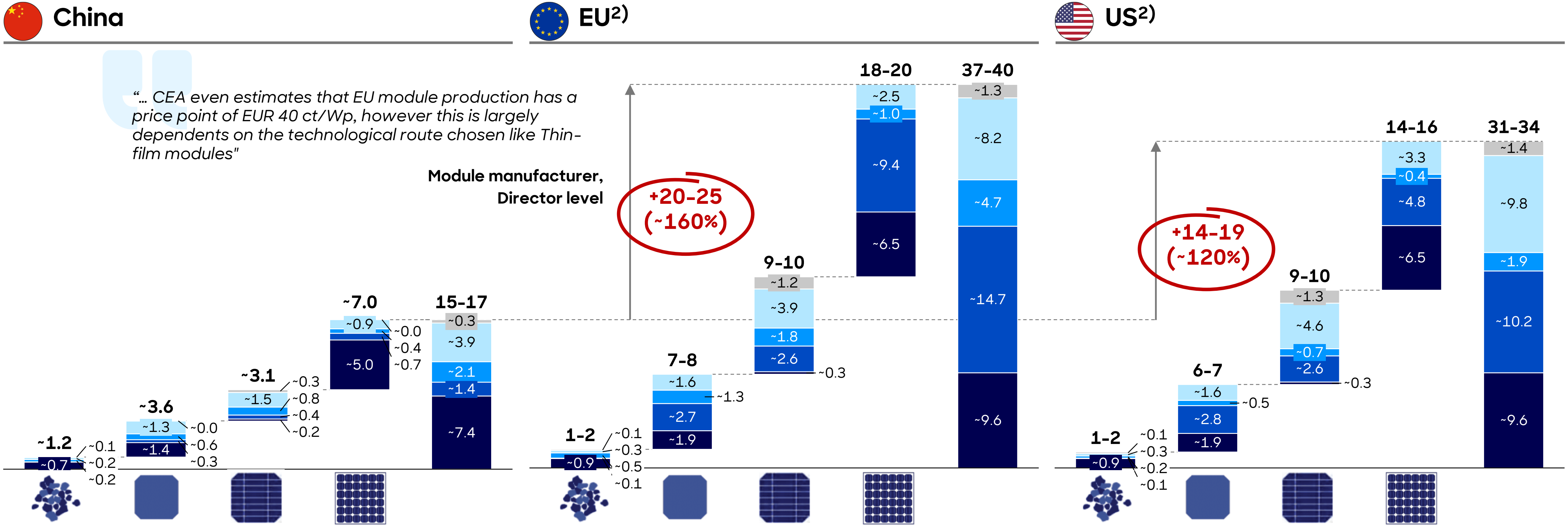
- Per cost item (combined across the entire value chain), a cost split in cent per watt-peak within Chinese solar panel production is given
- The EU cost multipliers are custom factors needed to scale the Chinese manufacturing cost to what the costs would be in Europe (more information on this can be found on p. 44)
- Per cost item, the cost of production in Europe can be calculated by multiplying the Chinese manufacturing cost by the EU cost multiplier
- For example, the estimated cost of materials in Europe can be calculated as follows:
  - 7.4 x 1.3 = 9.62 EUR ct/Wp

1) Manufacturing; 2) Consists of the material costs of the previous production step as well as other 'new' materials needed for each step (e.g. the front glass and backsheet needed to create the final module). Other material costs are calculated by subtracting the cost of the previous step from the total material costs needed; 3) Labor cost can vary largely across European nations, but overall are substantially larger than those in China

Source: BloombergNEF, ETIP PV, Euromonitor, esmec, iea, Meyer Burger annual report 2023, NREL, Interviews with market participants

Manufacturing of solar panels in the EU comes with a cost premium of 20-25 EUR ct/Wp compared to China due to higher labor costs, utilities, and depreciation

Fully domestic manufactured solar panel cost build-up in China, the EU and US1), 2024 [EUR ct/Wp]



> *"... CEA even estimates that EU module production has a price point of EUR 40 ct/Wp, however this is largely dependents on the technological route chosen like Thin-film modules"*
>
> **Module manufacturer, Director level**

■ Materials ■ Labor ■ Utilities ■ Maintenance ■ Depreciation

Polysilicon Ingots & Wafers Cells Modules

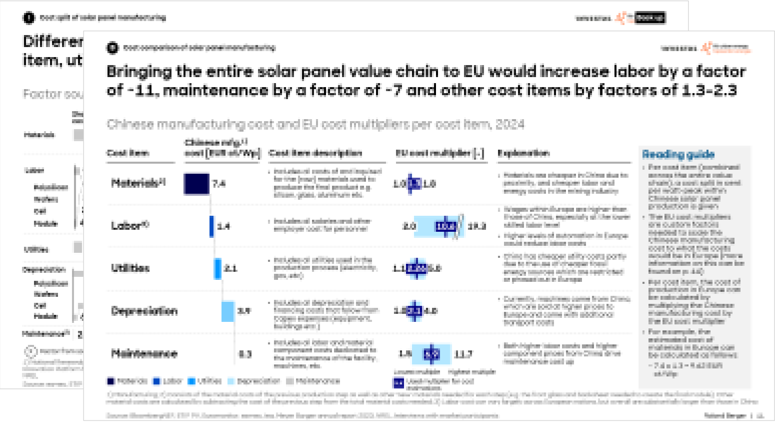
1) All cost items are estimates and should not be taken at face value, but rather represent an indicative range; 2) Represents the cost build-up if every manufacturing process is done domestically

Source: BloombergNEF, ETIP PV, Euromonitor, esmec, iea, Meyer Burger annual report 2023, NREL, Interviews with market participants

Completely manufacturing solar panels in Europe comes at a price premium of 20-25 EUR ct/Wp compared to manufacturing in China

Summary cost comparison of solar panel manufacturing

Cost item multipliers

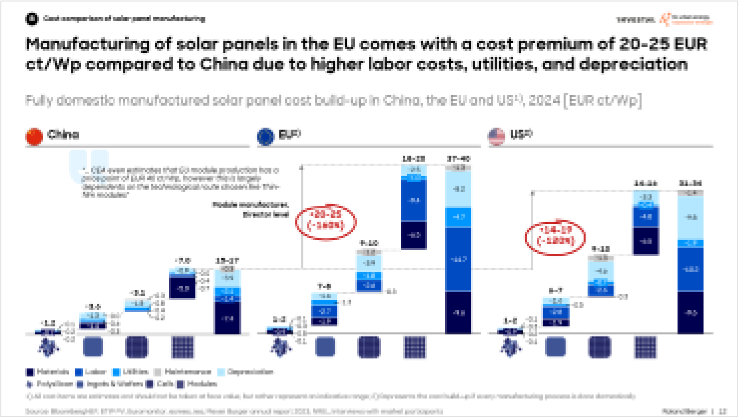


Bringing the entire solar panel value chain to EU would increase labor by a factor of ~11, maintenance by a factor of ~7 and other cost items by factors of 1.3-2.3

Chinese manufacturing cost and EU cost multipliers per cost item, 2024

- **To completely** (full value chain) **manufacture a solar panel in the EU** instead of China would increase:
  - **Labor** by a **factor 10.6**
  - **Maintenance** by **a factor 6.9**
  - **Utilities** by a **factor 2.26**
  - **Depreciation** by a **factor 2.1**
  - **Materials** by a **factor 1.3**

EU and US Price premiums



Manufacturing of solar panels in the EU comes with a cost premium of 20-25 EUR ct/Wp compared to China due to higher labor costs, utilities, and depreciation

Fully domestic manufactured solar panel cost build-up in China, the EU and US[1], 2024 [EUR ct/Wp]

- **China manufactures** solar panels **at 15-17 EUR ct/Wp**
- **If solar panels would completely be manufactured in Europe the cost would be 37-40 EUR ct/Wp, invoking** a **price premium of 20-25 EUR ct/Wp** (~160%) compared to China
- **If the US** completely **manufactures** solar panels domestically the cost would be **31-34 EUR ct/Wp, invoking** a **price premium of 14-19 EUR ct/Wp** (~120%)

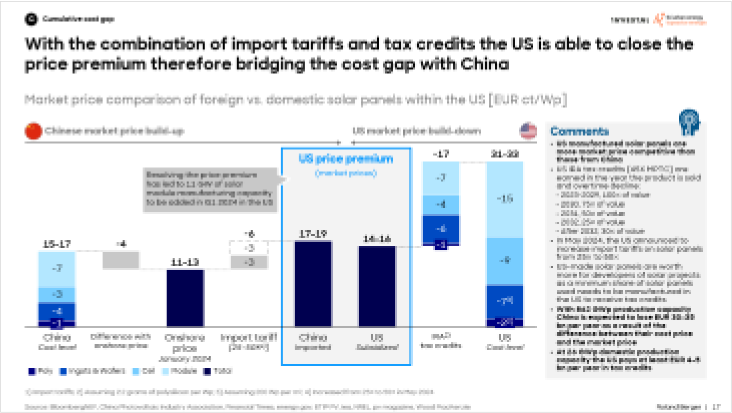
Source: BloombergNEF, ETIP PV, Euromonitor, esmec, iea, Meyer Burger annual reports, NREL, Interviews with market participants

C. Cumulative cost gap

The cumulative cost gap is determined by analyzing relevant price premium , US subsidies and assessing the market volume needed to reach the NZIA targets

Methodology to determine the cumulative cost gap

Relevant price difference

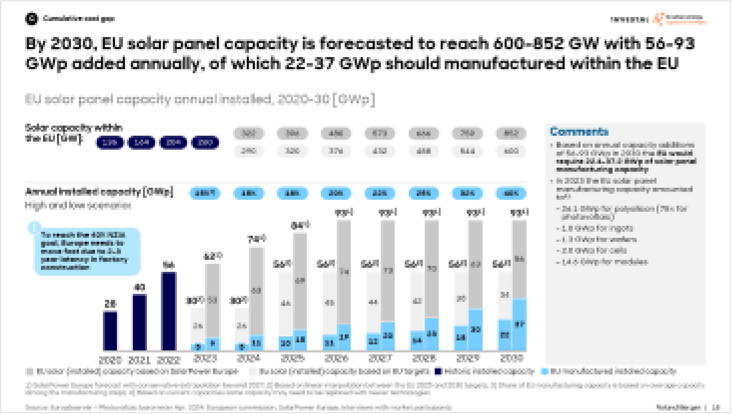


With the combination of import tariffs and tax credits the US is able to close the price premium therefore bridging the cost gap with China

Market price comparison of foreign vs. domestic solar panels within the US [EUR ct/Wp]

- By comparing the calculated cost level with the general market price of Chinese-made solar panels, and US import tariffs, an assessment is made of the market price differences (price premium) between imported solar panels from China and the price of US-manufactured solar panels

Market volume

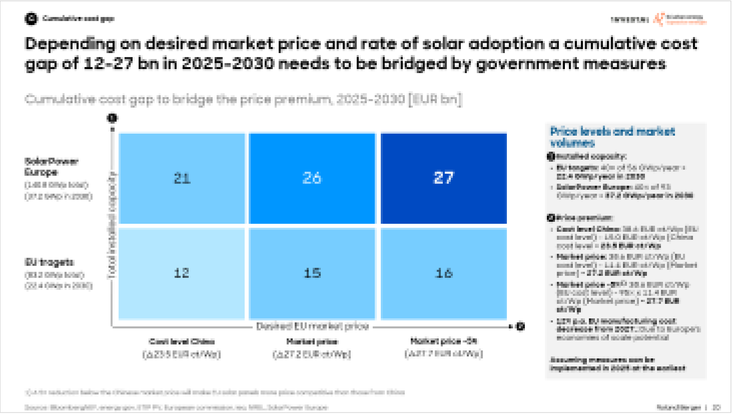


By 2030, EU solar panel capacity is forecasted to reach 600-852 GW with 56-93 GWp added annually, of which 22-37 GWp should manufactured within the EU

EU solar panel capacity annual installed, 2020-30 [GWp]

- The target GWp manufacturing capacity within the EU as dictated by EU targets are compared to the SolarPower Europe forecast
- The needed solar panel capacity is calculated by multiplying the annual capacity additions of the EU (EU targets and SolarPower Europe) with the share of EU manufactured solar panels

Cumulative cost gap



Depending on desired market price and rate of solar adoption a cumulative cost gap of 12-27 bn in 2025-2030 needs to be bridged by government measures

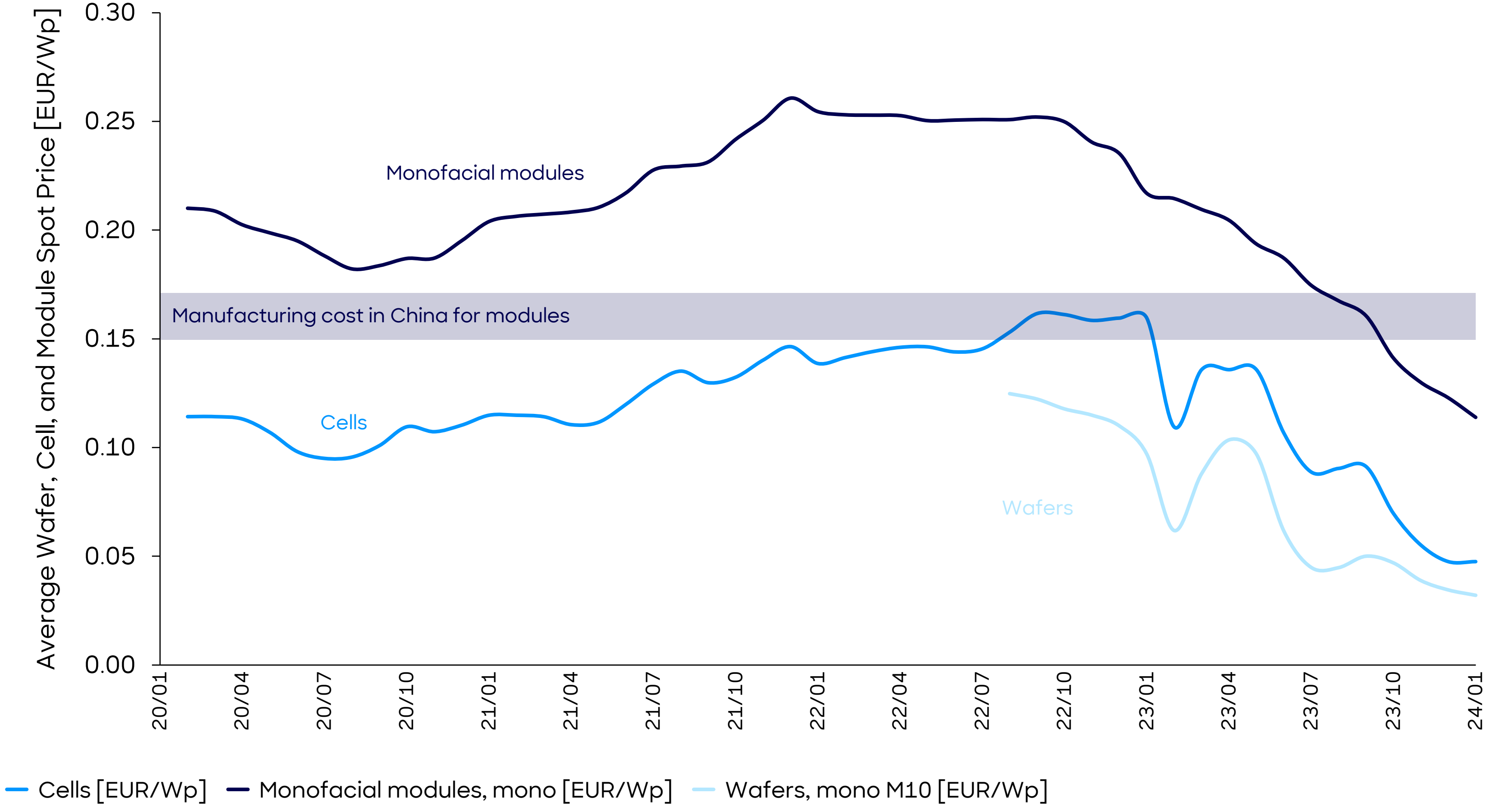
Cumulative cost gap to bridge the price premium, 2025-2030 [EUR bn]

- The cumulative cost gap is estimated based on the desired EU manufacturing capacity and price premium between the selected market prices and manufacturing costs
- Six possibilities for cumulative cost gap are identified, based on whether the EU targets or SolarPower Europe is considered, and depending on which price premium needs to be overcome

Source: BloombergNEF, ETIP PV, iea, NREL,

As of January 2024, global spot price for monofacial monocrystalline modules are ~0.11 EUR/Wp which is below the estimated Chinese manufacturing costs

Global spot prices of key solar panel components, January 2024 [EUR/Wp]



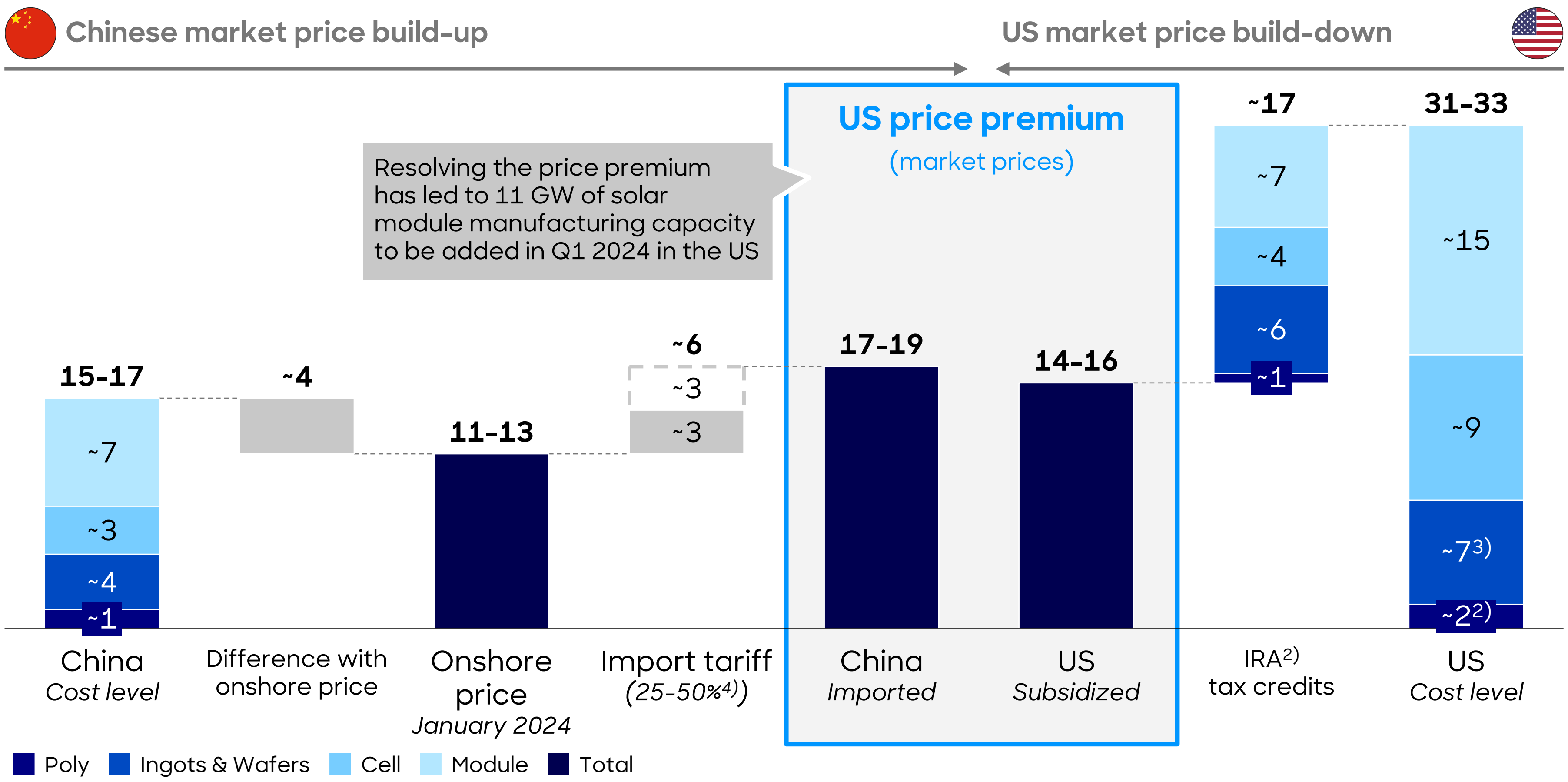
Comments

- Polysilicon prices fell 18% from October (10.53 USD/kg) to January (8.70 USD/kg), approaching their lowest level since 2020:
  - New polysilicon capacity scheduled to come online in 2024 exceeding the increase in expected demand, further increasing polysilicon overcapacity
- From October to January, prices also decreased for wafers (-27%) and cells (-33%)
- Module prices reached a record low, falling 22% between October and January to 0.11 USD/W_{dc}:
  - Decreasing supply chain costs increasing module manufacturing capacity
  - Large module inventories in Europe and intense competition suppressed demand and prices
- Chinese manufacturing costs are unlikely to decrease further as limited new (more efficient) factories are built in the foreseeable future, given net congestion issues and current overcapacity in China

Source: BloombergNEF, Het Financieele Dagblad, NREL, PV magazine, PV Tech, Solar Spot Price Index

With the combination of import tariffs and tax credits the US is able to close the price premium therefore bridging the cost gap with China

Market price comparison of foreign vs. domestic solar panels within the US [EUR ct/Wp]



Comments

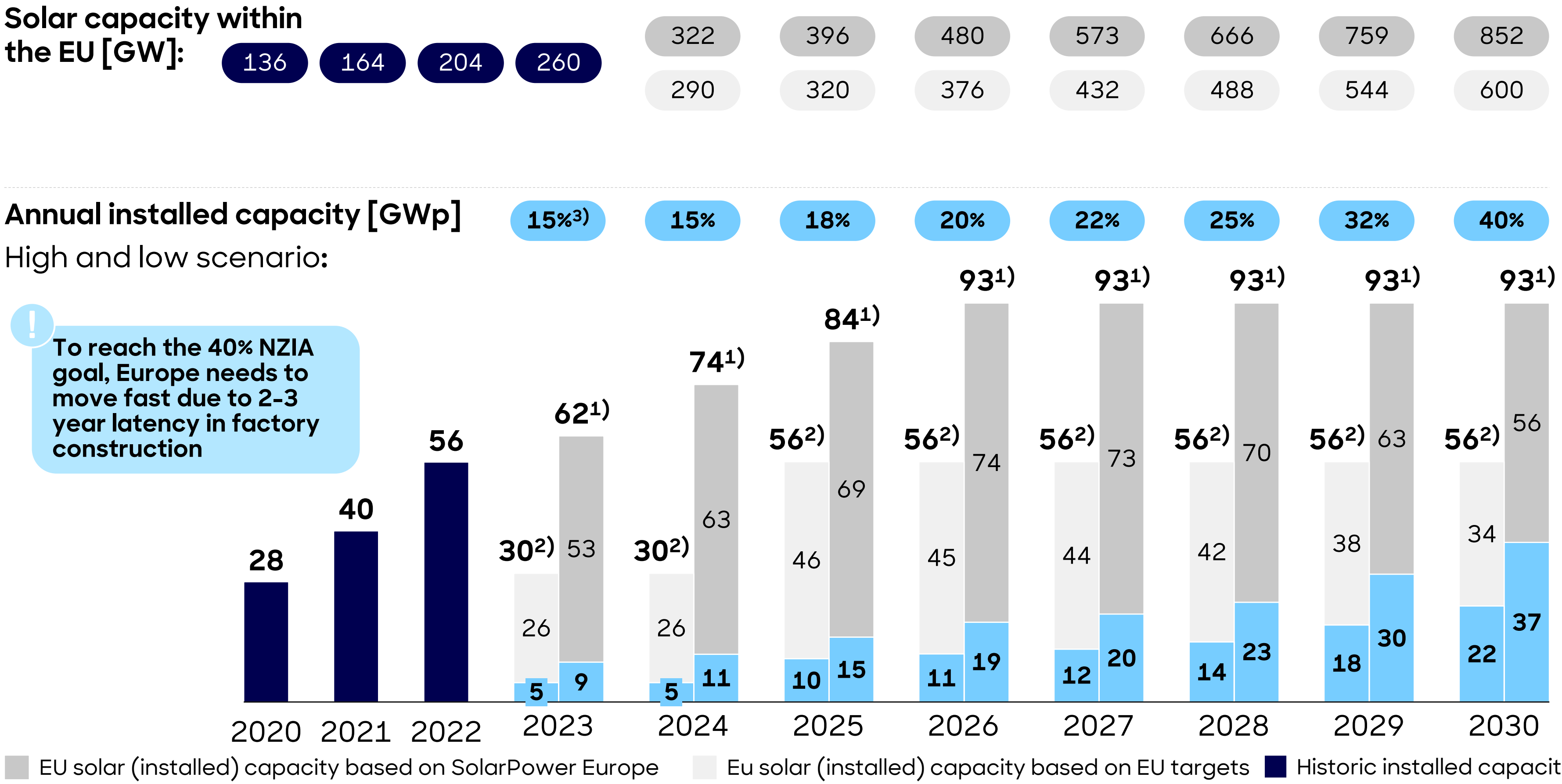
- **US manufactured solar panels are more market price competitive than those from China**
- US IRA tax credits (45X MPTC) are earned in the year the product is sold and overtime decline:
  - 2023-2029, 100% of value
  - 2030, 75% of value
  - 2031, 50% of value
  - 2032, 25% of value
  - After 2032, 30% of value
- In May 2024, the US announced to increase import tariffs on solar panels from 25% to 50%
- US-made solar panels are worth more for developers of solar projects as a minimum share of solar panels used needs to be manufactured in the US to receive tax credits
- **With 862 GWp production capacity China is expected to lose EUR 30-35 bn per year as a result of the difference between their cost price and the market price**
- **At 26 GWp domestic production capacity the US pays at least EUR 4-5 bn per year in tax credits**

1) Import tariffs; 2) Assuming 2.2 grams of polysilicon per Wp; 3) Assuming 200 Wp per m²; 4) Increased from 25% to 50% in May 2024

Source: BloombergNEF, China Photovoltaic Industry Association, Financial Times, energy.gov, ETIP PV, iea, NREL, pv magazine, Wood MacKenzie

By 2030, EU solar panel capacity is forecasted to reach 600-852 GW with 56-93 GWp added annually, of which 22-37 GWp should manufactured within the EU

EU solar panel capacity annual installed, 2020-30 [GWp]



To reach the 40% NZIA goal, Europe needs to move fast due to 2-3 year latency in factory construction

Comments

- Based on annual capacity additions of 56-93 GWp in 2030 the **EU would require 22.4-37.2 GWp of solar panel manufacturing capacity**
- In 2023 the EU solar panel manufacturing capacity amounted to4):
  - 26.1 GWp for polysilicon (75% for photovoltaic)
  - 1.0 GWp for ingots
  - 1.3 GWp for wafers
  - 2.0 GWp for cells
  - 14.6 GWp for modules

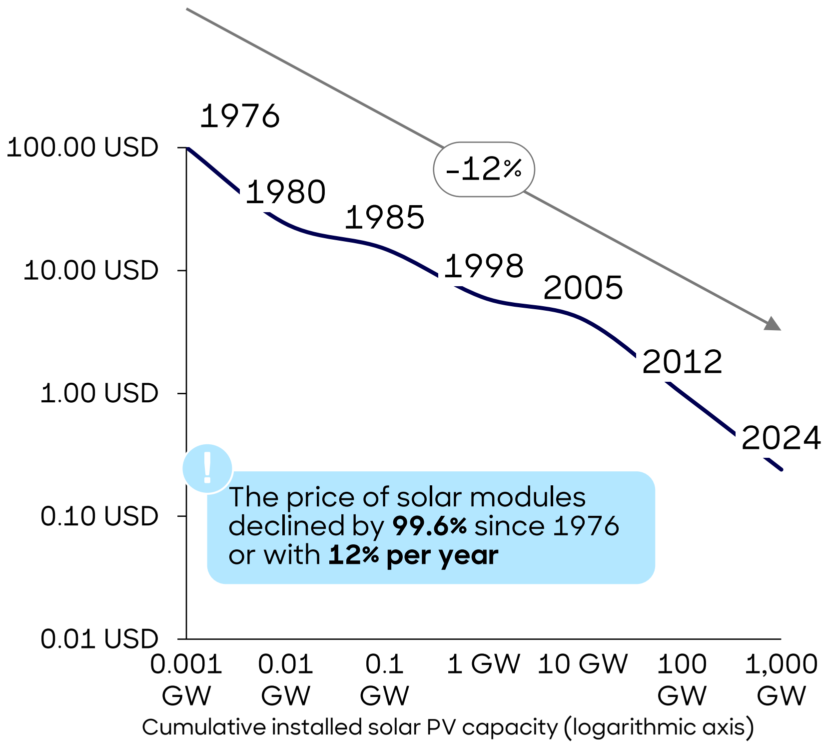
1) SolarPower Europe forecast with conservative extrapolation beyond 2027; 2) Based on linear interpolation between the EU 2025 and 2030 targets; 3) Share of EU manufacturing capacity is based on average capacity among the manufacturing steps; 4) Based on current capacities some capacity may need to be replaced with newer technologies

Source: Europbservér = Photovoltaic barometer Apr. 2024, European commission, SolarPower Europe, Interviews with market participants

Historically, the solar PV price declined at 12% p.a. – The EU is more expensive now but could see a similar rate of decline as economies of scale are achieved

Historical learning curve of solar panel technology and market insights

Solar PV cell price [USD/Wp] (logarithmic axis)



The price of solar modules declined by **99.6%** since 1976 or with **12% per year**

Market insights

> *“We assume selling price will decline by 20-25% until 2030, in line with industry analyst"*
>
> **Module manufacturer,**
> **Investors presentation Mrt. 2024**

> *“In China further price decreases are almost certainly ruled out, as its unlikely new [read more cost effective] factories will be developed "*
>
> **Het Financieele Dagblad,**
> **Newspaper article**

> *“We can cut cost by half getting close to the Chinese production levels, if we scale up to GW scale.. ..at maximum, our costs would be 10% above Chinese cost"*
>
> **Wafer manufacturer,**
> **Manager level**

> *“If China is strictly forced to comply with EU labor, environmental and sustainability criteria, the average price for Chinese modules will rise from 12 to 17 Ct/Wp"*
>
> **Module manufacturer,**
> **Director level**

Comments

Chinese manufacturing costs is now ~25% above market price, so further decline in market price by 2030 is not realistic

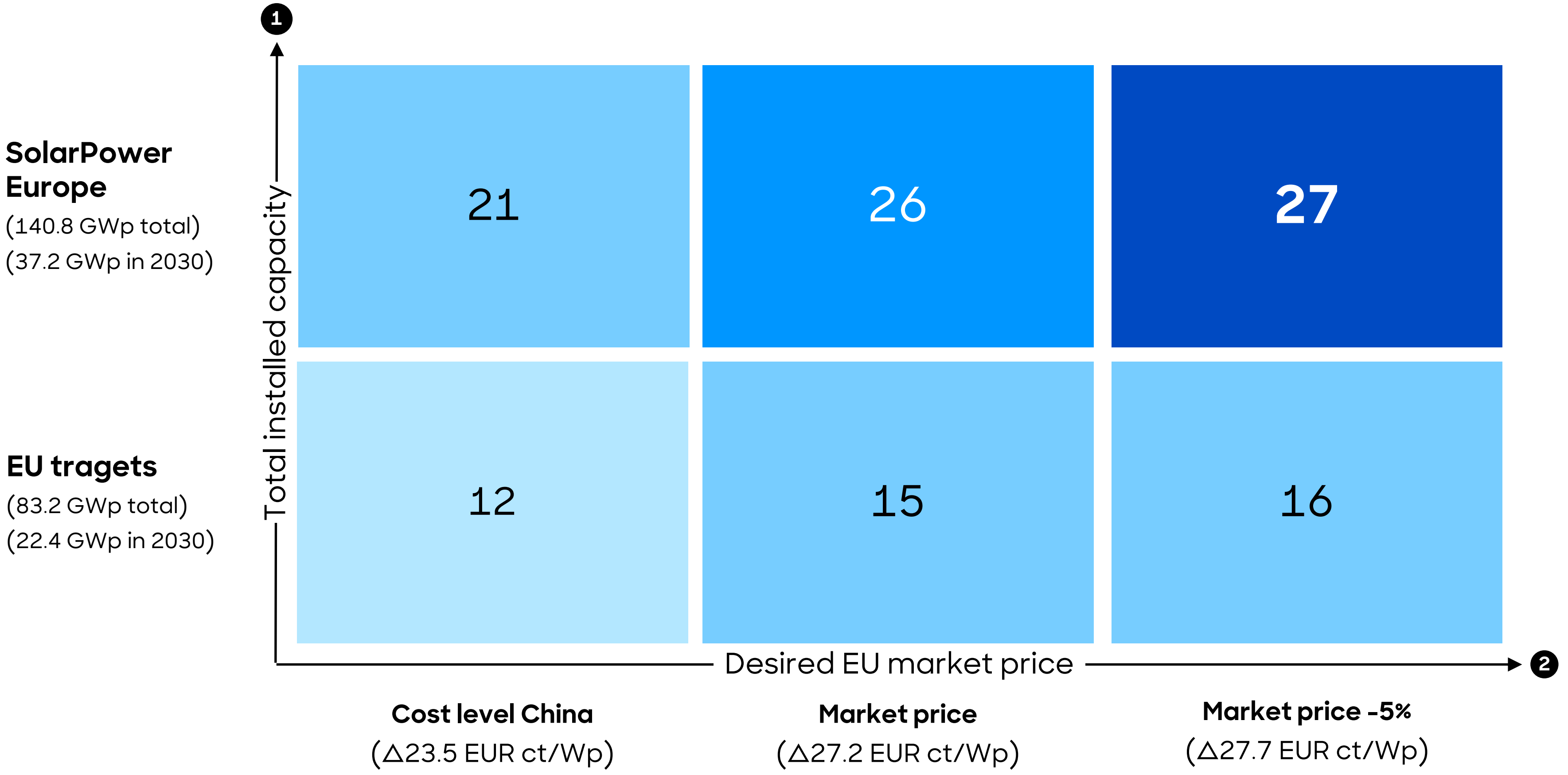
- **EU** has significant potential to reduce cost through **economies of scale** by:
  - – Building larger (more cost effective) factories
  - – Value chain effects (e.g transport costs, shorter delivery time, etc.) which would require cluster forming of the value chain
  - – Living factories are required to achieve economies of scale if only a Limited number of factories are built
- To achieve cost reduction governments, need to orchestrate the sector providing certainty and stability to both enterprises and investors

Expect 10-12% p.a. decline for EU solar manufacturing from 2027 onward, as larger and more efficient factories come online

Source: China Photovoltaic Industry Association, Het Financieele Dagblad, MCPV, Our World in Data, Interview with market participants

Depending on desired market price and rate of solar adoption a cumulative cost gap of 12-27 bn in 2025-2030 needs to be bridged by government measures

Cumulative cost gap to bridge the price premium, 2025-2030 [EUR bn]



	Cost level China (Δ23.5 EUR ct/Wp)	**Market price** (Δ27.2 EUR ct/Wp)	**Market price -5%** (Δ27.7 EUR ct/Wp)
SolarPower Europe (140.8 GWp total) (37.2 GWp in 2030)	21	26	**27**
EU tragets (83.2 GWp total) (22.4 GWp in 2030)	12	15	16

Price levels and market volumes

① **Installed capacity:**

- **EU targets:** 40% of 56 GWp/year = **22.4 GWp/year in 2030**
- **SolarPower Europe:** 40% of 93 GWp/year = **37.2 GWp/year in 2030**

② **Price premium:**

- **Cost level China:** 38.6 EUR ct/Wp (EU cost level) – 15.0 EUR ct/Wp (China cost level = **23.5 EUR ct/Wp**
- **Market price:** 38.6 EUR ct/Wp (EU cost level) – 11.4 EUR ct/Wp (Market price) = **27.2 EUR ct/Wp**
- **Market price -5%[1]:** 38.6 EUR ct/Wp (EU cost level) – 95% x 11.4 EUR ct/Wp (Market price) = **27.7 EUR ct/Wp**
- **12% p.a. EU manufacturing cost decrease from 2027.:** Due to Europe's economies of scale potential

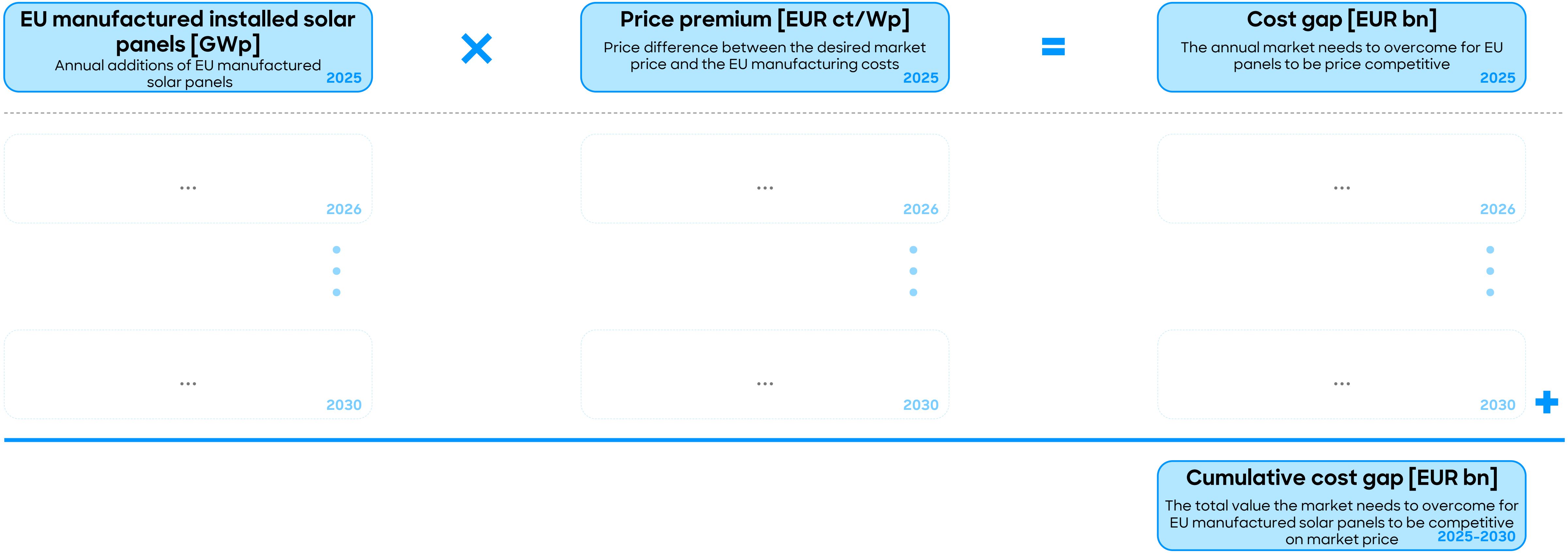
Assuming measures can be implemented in 2025 at the earliest

1) A 5% reduction below the Chinese market price will make EU solar panels more price competitive than those from China

Source: BloombergNEF, energy.gov, ETIP PV, European commission, iea, NREL, SolarPower Europe

Cumulative cost gap is the sum of all cost gaps – The cost gap is the multiple of the price premium and the annual addition of EU manufactured solar panels

Definitions and methodology for the cumulative cost gap



EU manufactured installed solar panels [GWp]
Annual additions of EU manufactured solar panels
2025

×

Price premium [EUR ct/Wp]
Price difference between the desired market price and the EU manufacturing costs
2025

=

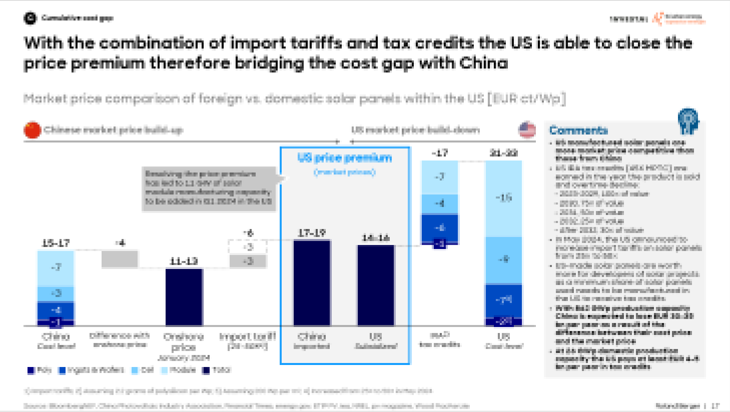
Cost gap [EUR bn]
The annual market needs to overcome for EU panels to be price competitive
2025

Cumulative cost gap [EUR bn]
The total value the market needs to overcome for EU manufactured solar panels to be competitive on market price
2025-2030

NZIA targets require an EU solar manufacturing capacity of 22-37 GWp which, requires overcoming a cumulative cost gap of EUR 12-27 bn

Summary cumulative cost gap

Relevant price difference

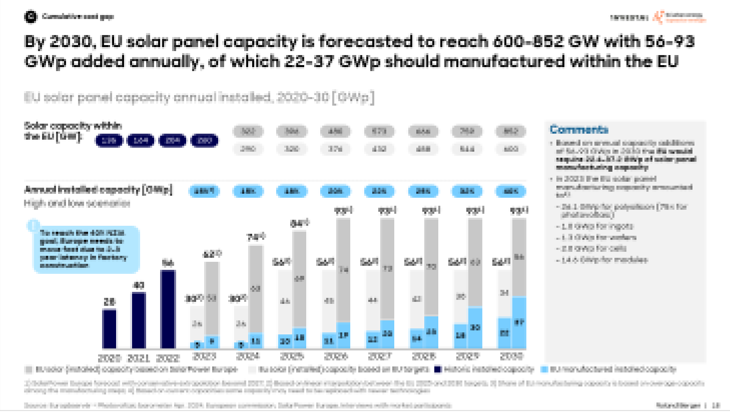


With the combination of import tariffs and tax credits the US is able to close the price premium therefore bridging the cost gap with China

Market price comparison of foreign vs. domestic solar panels within the US [EUR ct/Wp]

- **US overcame the price premium with** the combination of high **import tariffs (25-50%)** and strong **government incentives (US IRA tax credits (45X MPTC))**

Market volume

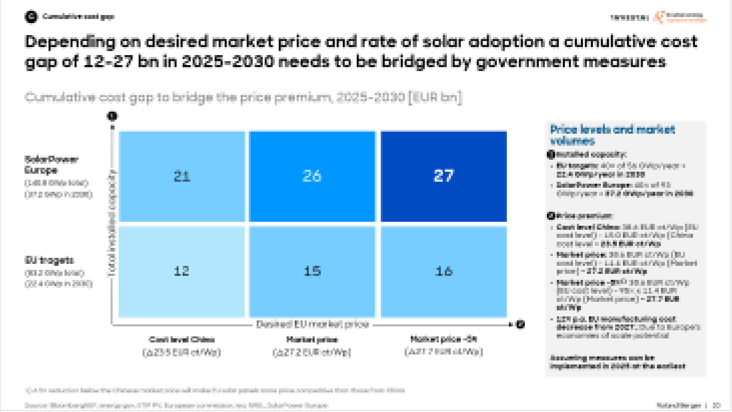


By 2030, EU solar panel capacity is forecasted to reach 600-852 GW with 56-93 GWp added annually, of which 22-37 GWp should manufactured within the EU

EU solar panel capacity annual installed, 2020-30 [GWp]

- Depending on the forecast **EU solar** capacity will **grow** to **600-852 GW in 2030**, which would translate to 56-93 GWp of annual additions
- **To achieve NZIA** at least **22-37 GWp p.a.** (~40%) of solar panels need to be **manufactured within the EU in 2030**

Cumulative cost gap



Depending on desired market price and rate of solar adoption a cumulative cost gap of 12-27 bn in 2025-2030 needs to be bridged by government measures

Cumulative cost gap to bridge the price premium, 2025-2030 [EUR bn]

	Cost level China	Market price	Market price -5%
SolarPower Europe	21	26	27
EU targets	12	15	16

- The **cumulative cost gap is between EUR 12-27 bn**, depending on the targeted market price and the volume of solar panels installed

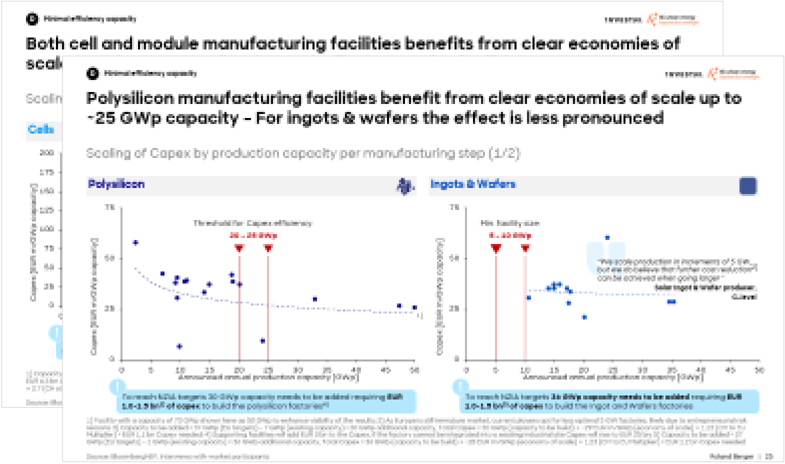
Source: BloombergNEF, ETIP PV, iea, NREL,

D. Minimal efficiency capacity

The minimum required European market capacity required for effective Capex utilization is determined by how Capex scales with manufacturing capacity

Methodology to determine the minimal efficient EU production capacity

Scaling of capex per manufacturing step



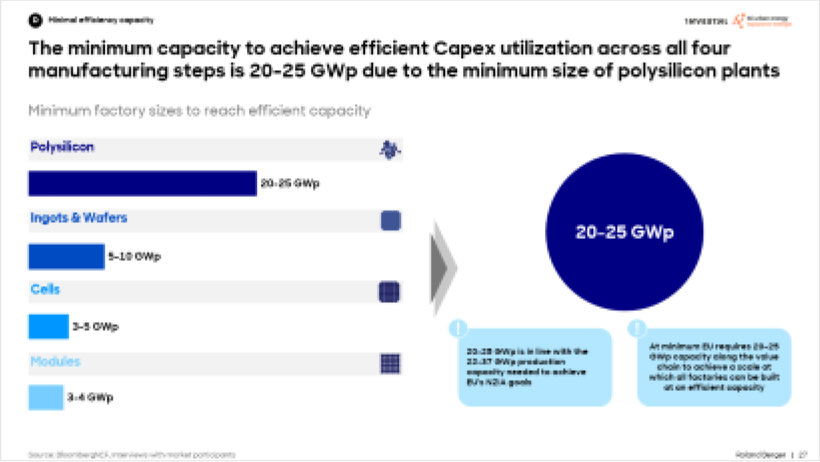
Both cell and module manufacturing facilities benefits from clear economies of scal

Polysilicon manufacturing facilities benefit from clear economies of scale up to ~25 GWp capacity – For ingots & wafers the effect is less pronounced

Scaling of Capex by production capacity per manufacturing step (1/2)

- For each manufacturing step, the Capex per GWp has been scaled with the capacity size of manufacturing facilities in China

Largest common requirement



The minimum capacity to achieve efficient Capex utilization across all four manufacturing steps is 20-25 GWp due to the minimum size of polysilicon plants

Minimum factory sizes to reach efficient capacity

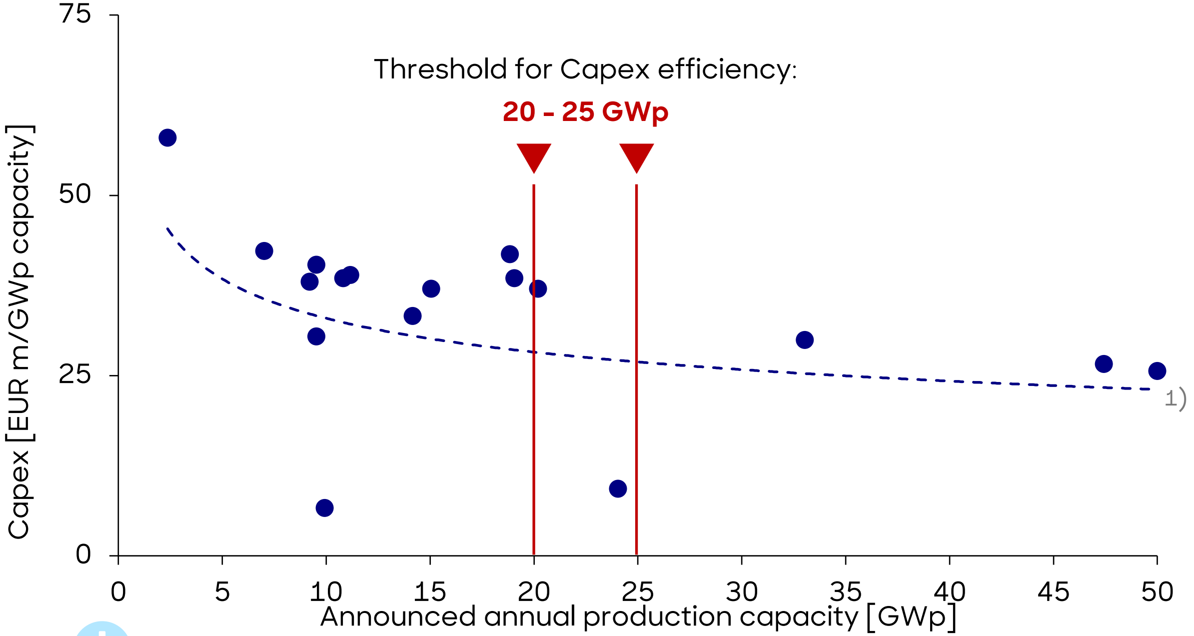
- By comparing the datapoints of the capex and manufacturing capacity scaling analysis for each process step, the minimum manufacturing capacity needed to be efficient is determined

Source: BloombergNEF, ETIP PV, iea, NREL, Interviews with market participants

Polysilicon manufacturing facilities benefit from clear economies of scale up to ~25 GWp capacity – For ingots & wafers the effect is less pronounced

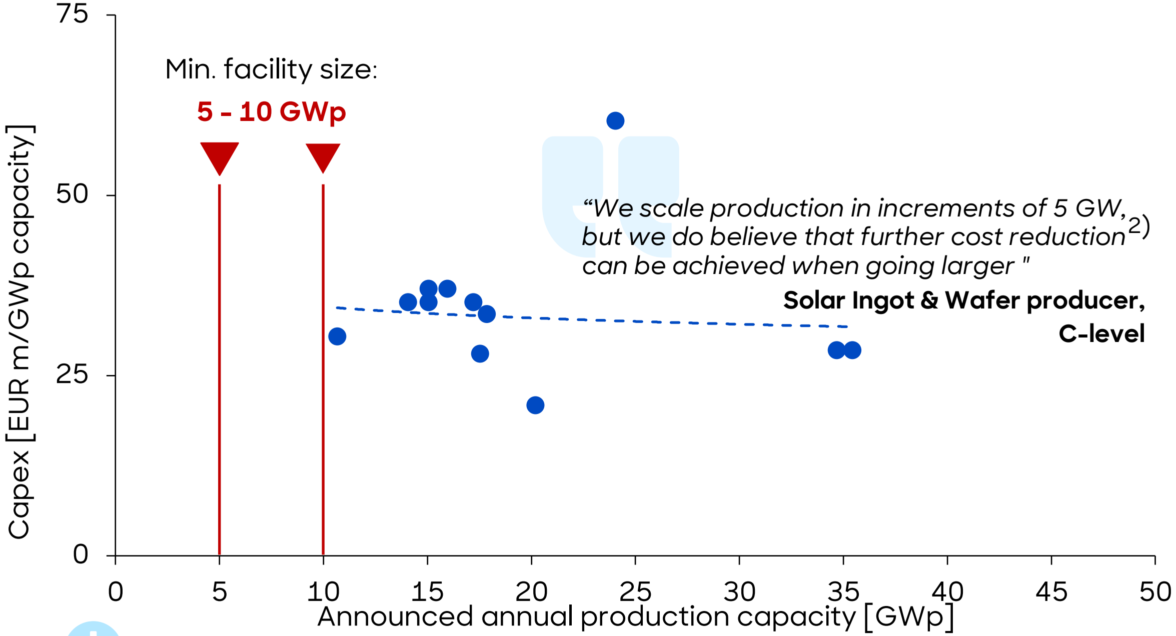
Scaling of Capex by production capacity per manufacturing step (1/2)

Polysilicon



To reach NZIA targets 30 GWp capacity needs to be added requiring **EUR 1.0-1.5 bn**3) **of capex** to build the polysilicon factories4)

Ingots & Wafers



> *"We scale production in increments of 5 GW, but we do believe that further cost reduction can be achieved when going larger "*2)
>
> **Solar Ingot & Wafer producer, C-level**

To reach NZIA targets **36 GWp capacity needs to be added** requiring **EUR 1.0-1.5 bn**5) **of capex** to build the Ingot and Wafers factories

---

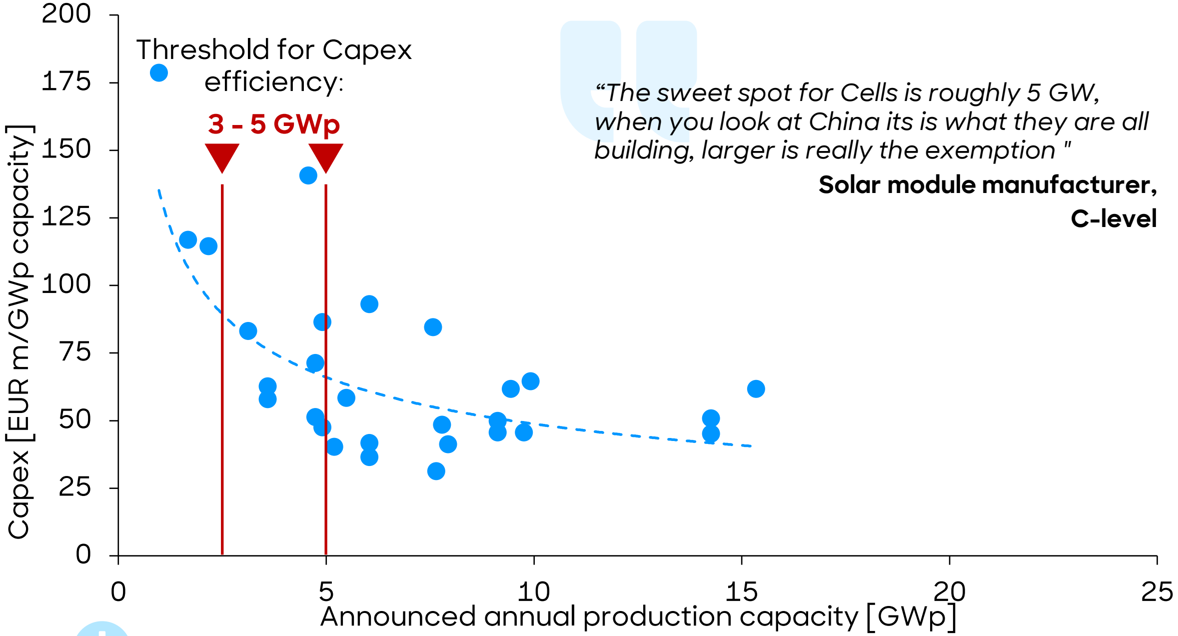
1) Facility with a capacity of 70 GWp shown here as 50 GWp to enhance visibility of the results; 2) As Europe is still immature market, current players opt for less optimal 5 GW factories, likely due to entrepreneurial risk reasons 3) Capacity to be added = 37 GWp (EU targets) – 7 GWp (existing capacity) = 30 GWp additional capacity, Total Capex = 30 GWp (capacity to be build) × ~29 EUR m/GWp (economy of scale) × 1.23 (CH to EU Multiplier) = EUR 1.1 bn Capex needed; 4) Supporting facilities will add EUR 3 bn to the Capex, if the factory cannot be integrated into a existing industrial site Capex will rise to EUR 25 bn; 5) Capacity to be added = 37 GWp (EU targets) – 1 GWp (existing capacity) = 36 GWp additional capacity, Total Capex = 36 GWp (capacity to be build) × ~28 EUR m/GWp (economy of scale) × 1.23 (CH to EU Multiplier) = EUR 1.2 bn Capex needed

Source: BloombergNEF, Interviews with market participants

Both cell and module manufacturing facilities benefits from clear economies of scale, yet they are smaller than polysilicon or wafer facilities, at 3-5 GWp

Scaling of Capex by production capacity per manufacturing step (2/2)

Cells

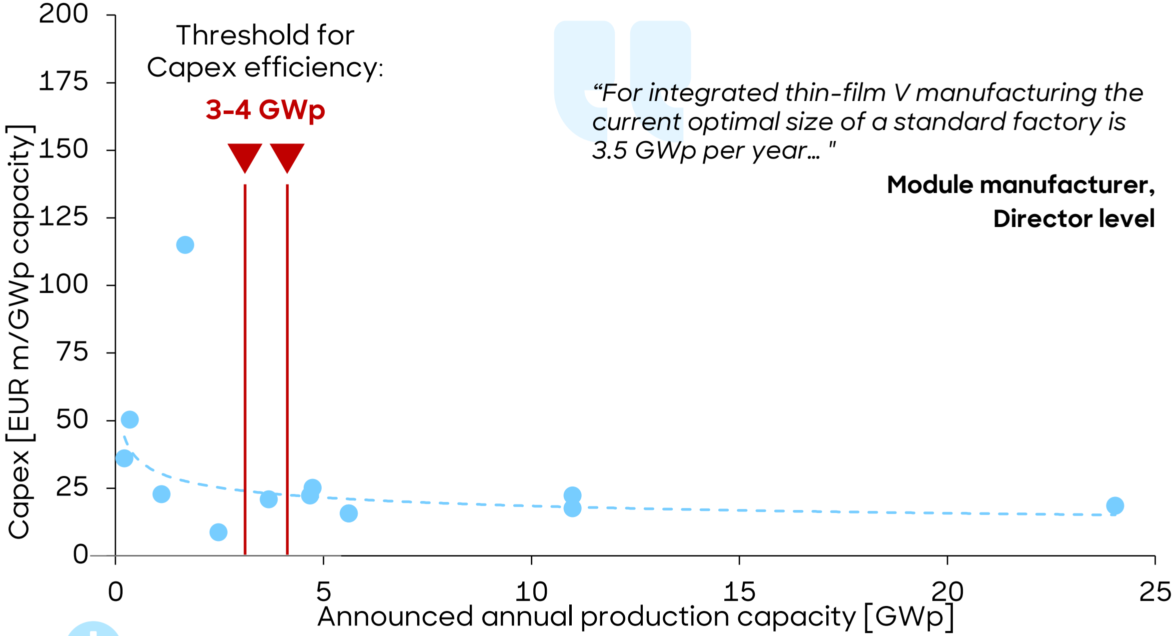


“The sweet spot for Cells is roughly 5 GW, when you look at China its is what they are all building, larger is really the exemption "

Solar module manufacturer, C-level

To reach NZIA **targets 35 GWp capacity needs to be added** requiring **EUR 5.0-7.5 bn$^{1)}$ of capex** to build the Polysilicon factories

Modules



“For integrated thin-film V manufacturing the current optimal size of a standard factory is 3.5 GWp per year… "

Module manufacturer, Director level

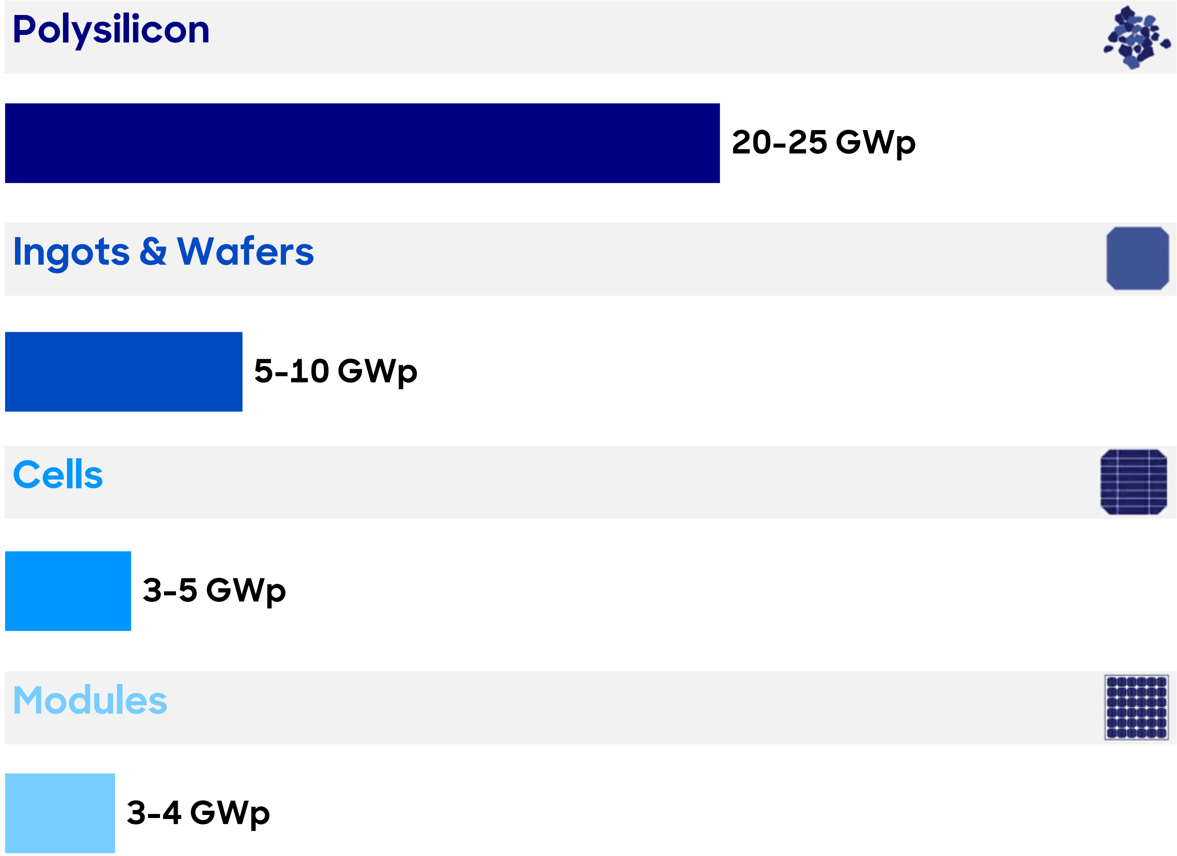
To reach NZIA targets **22 GWp capacity needs to be added** requiring **EUR 1.0-1.5 bn$^{2)}$ of capex** to build the Ingot and Wafers factories

1) Capacity to be added = 37 GWp (EU targets) – 2 GWp (existing capacity) = 35 GWp additional capacity, Total Capex = 35 GWp (capacity to be build) × ~67 EUR m/GWp (economy of scale) × 2.7 (CH ot EU Multiplier) = EUR 6.3 bn Capex needed; 2) Capacity to be added = 37 GWp (EU targets) – 15 GWp (existing capacity) = 22 GWp additional capacity, Total Capex = 22 GWp (capacity to be build) × ~22 EUR m/GWp (economy of scale) × 2.7 (CH ot EU Multiplier) = EUR 1.3 bn Capex needed

Source: BloombergNEF, Interviews with market participants

The minimum capacity to achieve efficient Capex utilization across all four manufacturing steps is 20-25 GWp due to the minimum size of polysilicon plants

Minimum factory sizes to reach efficient capacity



20-25 GWp

20-25 GWp is in line with the 22-37 GWp production capacity needed to achieve EU's NZIA goals

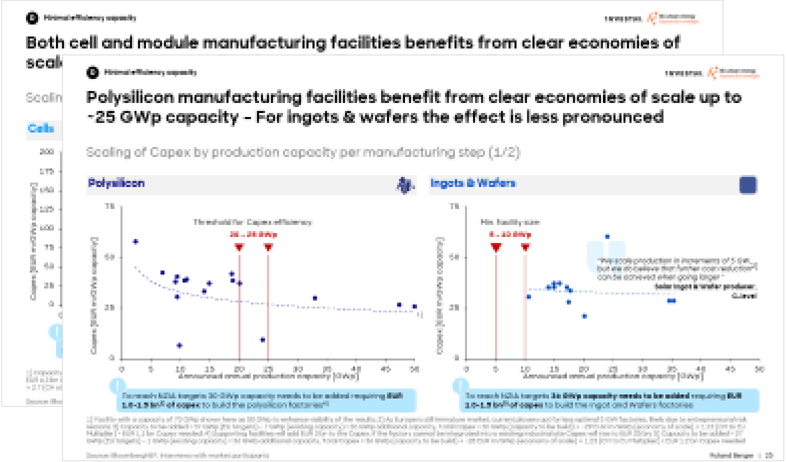
At minimum EU requires 20-25 GWp capacity along the value chain to achieve a scale at which all factories can be built at an efficient capacity

Source: BloombergNEF, Interviews with market participants

At least 20-25 GWp EU manufacturing capacity is required to achieve economies of scale – This is in line with the 22-37 GWp needed for the NZIA

Summary minimal efficient capacity

Scaling of capex per manufacturing step

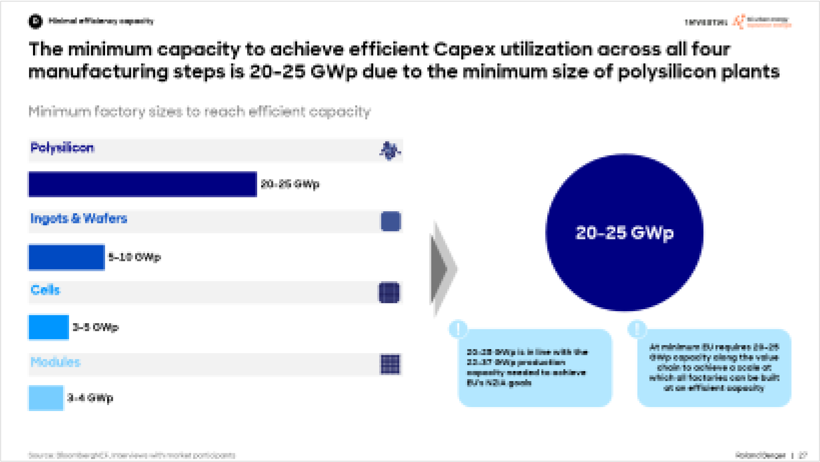

Both cell and module manufacturing facilities benefits from clear economies of scal

Polysilicon manufacturing facilities benefit from clear economies of scale up to ~25 GWp capacity – For ingots & wafers the effect is less pronounced

Scaling of Capex by production capacity per manufacturing step (1/2)

- For **each manufacturing step** a **minimal factory efficient capacity** exists at which **most economies of scale are achieved**, these are:
  - **20-25 GWp** for **Polysilicon** manufacturing
  - **5-10 GWp for Ingots & Wafers** manufacturing
  - **3-5 GWp** for **Cell** manufacturing
  - **3-4 GWp** for **Module** manufacturing

Largest common requirement


The minimum capacity to achieve efficient Capex utilization across all four manufacturing steps is 20-25 GWp due to the minimum size of polysilicon plants

Minimum factory sizes to reach efficient capacity

- To set up a **Capex efficient EU value chain at least a 20-25 GWp** of manufacturing capacity is needed
  - At this capacity, all manufacturing steps including Polysilicon can build Capex efficient factories

Source: BloombergNEF, ETIP PV, iea, NREL, Interviews with market participants

E. Potential policy measures

There are various potential policy measures which can be used to distribute the cost gap to either the gov't, solar projects or other market participants

Overview of potential policy measures and their financial impact on the gov't and projects

Financial impact on gov't ↑ / Financial impact on projects (and the energy transition) →	**Primarily negative**	**Limited**	**Primarily positive**
Primarily positive	**Import tariff** (trade barrier) **CBAM1)/EUFLR2)**		**Increase in energy tax, while exempting EU made renewable energy**
Limited	**Set minimal module prices** **Local content requirement**	**Traceability of value chain**	**Government financing**
Primarily negative		**Tax credits3)** **Capex/Opex subsidy**	**Contract-for-Difference** **Offtake guarantees** **Made-in-Europe project subsidies**

XXX Measures already in place or being implemented in the EU

Comments

Overview of (other) factors which should be **considered** when policy measures are selected:

- Financial impact on gov't (EU)
- Financial impact on projects (and the energy transition)
- Time to implement measure
- Geopolitical effects (e.g. trade barriers, trade war)
- Financial Impact on consumers and companies
- Whether measures can be implemented on national or only European level
- Certainty on the measure in time (i.e. for how long is it guaranteed to stay in effect)
- Share of Cumulative cost gap bridged

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1) Carbon Border Adjustment Mechanism (carbon border tax); 2) European Forced Labor Regulation (ban on products made using forced labor); 3) US IRA Inflation Reduction Act

Source: Bloomberg, energy.gov, ETIP-pv, European commission, RVO, Interviews with market participants

Next to the financial impact of the policy measures, other aspect should be considered too, like the impact on the energy transition or gov't budget

Impact overview of policy measures on various considerations

Measures	Financial impact on gov't	Financial impact on projects (and the energy transition)	Time to implement	Geopolitical effects (e.g. trade war)	Implementable at National or EU	Financial Impact on consumers and companies
Tariffs	Pos	Neg	Slow	Neg	EU	Neg
Raise energy taxes	Pos	Pos	Fast	Med	National	Neg
CBAM	Pos	Neg	n.a.	Neg	EU	Med
EUFLR	Pos	Neg	n.a.	Neg	EU	Med
Minimal module price	Med	Neg	Slow	Pos	EU	Neg
Traceability of value chain	Med	Med	Slow	Med	EU	Med
Gov't financing	Med	Pos	Fast	Med	National	Med
Local content requirement	Med	Neg	Fast	Med	National	Neg
Contract-for-difference	Neg	Pos	Slow	Med	National	Med
Tax credits	Neg	Med	n.a.	Med	National	Med
Offtake guarantees	Neg	Neg	Slow	Med	National	Med
Capex/Opex subsidies	Neg	Med	Fast	Med	National	Med
Made-in-Europe subsidies	Neg	Med	Fast	Med	National	Pos

Pos Primarily positive impact[1] **Med** Medium or limited impact[1] **Neg** Primarily negative impact[1]

1) High-level impact, but may vary depending on a range of factors

Source: Bloomberg, energy.gov, ETIP-pv, European commission, RVO, Interviews with market participants

To establish an EU solar manufacturing industry, governments need to act and introduce measures to bear the cumulative cost gap

Overview of possible policy directions, corresponding measures and cost to the EU

Rationale

Possible measures

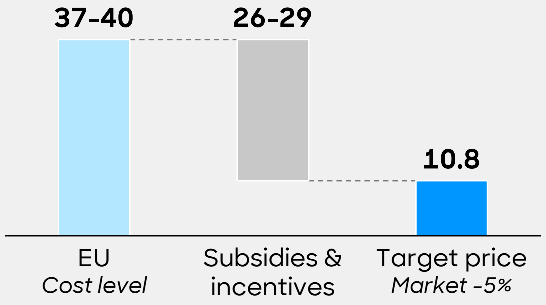
Bridging the price premium

Total costs for the EU

Build solar PV industry

Establish both a strong solar panel manufacturing industry in Europe and accelerate the adoption of solar energy. The cost gap needs to be overcome without raising the market price, hence the government must bear the full cost.

- Capex, Opex or project subsidies
- Contract-for-Differences/ offtake guarantees

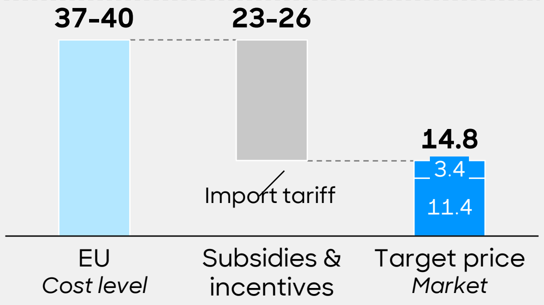


EUR 16-27 bn

Spread the burden

Establish solar panel manufacturing industry in Europe but not at all cost. Governments accept an increase in panel prices even if it (temporarily) decelerates the adoption of solar energy.

- Import tariffs (e.g. 30%)
- Capex, Opex or project subsidies
- Increase in energy taxes with exemptions or tax credits
- Government financing support

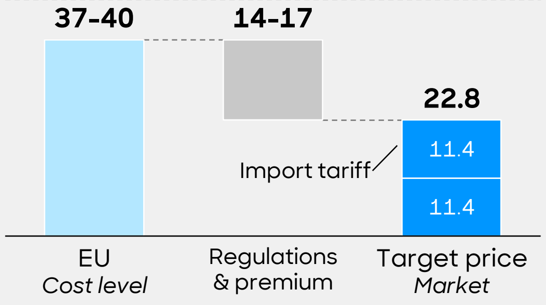


EUR 12-21 bn

Neutral to EU budget

Establish solar panel manufacturing industry by bringing foreign and European panels on par through measures that bare no cost to the government. Consequently, loss of speed in the energy transition is accepted.

- Import tariff (e.g. 100%)
- Traceability of value chain/Local content requirements
- CBAM, EUFLR and/or minimum Module price



EUR 0 bn

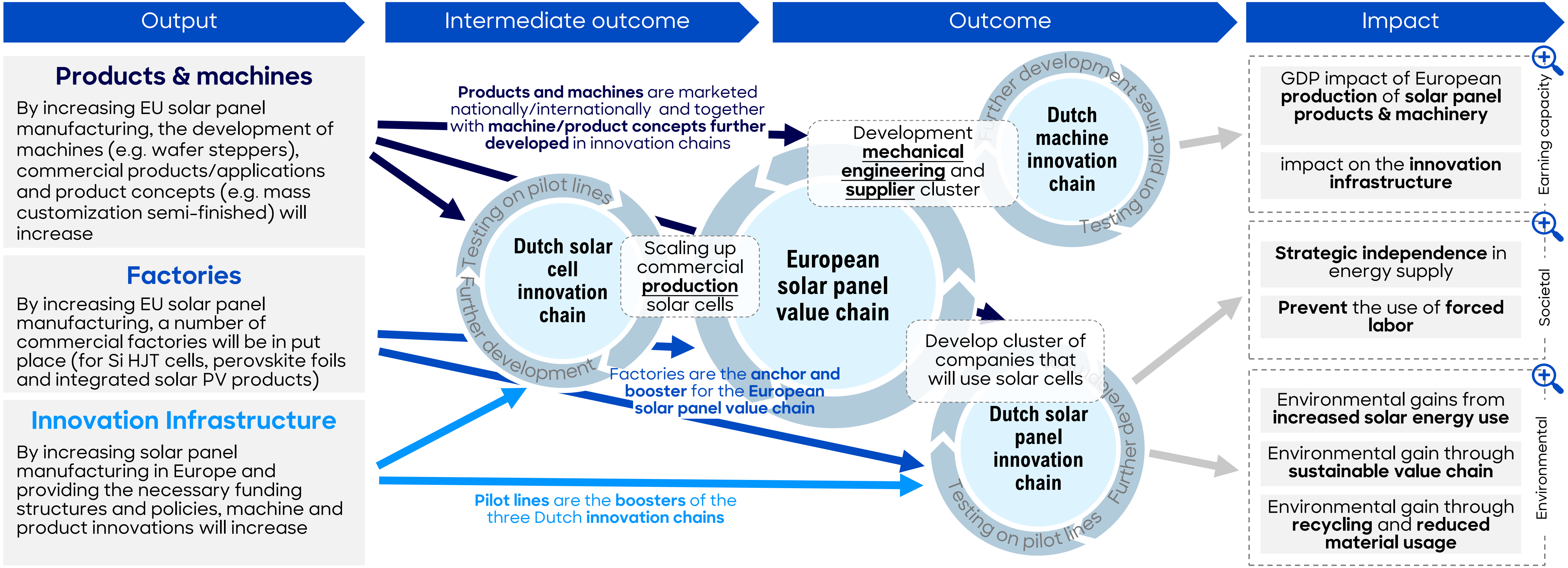
Source: BloombergNEF, energy.gov, ETIP PV, European commission, SolarPower Europe; NREL, iea

F. Value chain impact

Increasing EU PV manufacturing will also positively impact various other steps of the value chain, such as machine manufacturing and the (Dutch) innovation chain

Value chain impact

External influences: Development of international competition, insufficient development of the European solar panel value chain, lagging investment climate for tech spin-outs in the Netherlands and Europe



Output

Products & machines

By increasing EU solar panel manufacturing, the development of machines (e.g. wafer steppers), commercial products/applications and product concepts (e.g. mass customization semi-finished) will increase

Factories

By increasing EU solar panel manufacturing, a number of commercial factories will be in put place (for Si HJT cells, perovskite foils and integrated solar PV products)

Innovation Infrastructure

By increasing solar panel manufacturing in Europe and providing the necessary funding structures and policies, machine and product innovations will increase

Intermediate outcome

Products and machines are marketed nationally/internationally and together with **machine/product concepts further developed** in innovation chains

Factories are the **anchor and booster** for the **European solar panel value chain**

Pilot lines are the **boosters** of the three Dutch **innovation chains**

Outcome

Dutch solar cell innovation chain

Scaling up commercial **production** solar cells

European solar panel value chain

Development **mechanical engineering** and **supplier** cluster

Dutch machine innovation chain

Develop cluster of companies that will use solar cells

Dutch solar panel innovation chain

Impact

GDP impact of European **production** of **solar panel products & machinery**

impact on the **innovation infrastructure**

Strategic independence in energy supply

Prevent the use of **forced labor**

Environmental gains from **increased solar energy use**

Environmental gain through **sustainable value chain**

Environmental gain through **recycling** and **reduced material usage**

Source: Roland Berger

Increasing solar panel production in the EU will create opportunities in machinery manufacturing, solar panel production, and the innovation infrastructure

Zoom in – Earning capacity impact of solar panel production in the EU

GDP impact of production of machinery

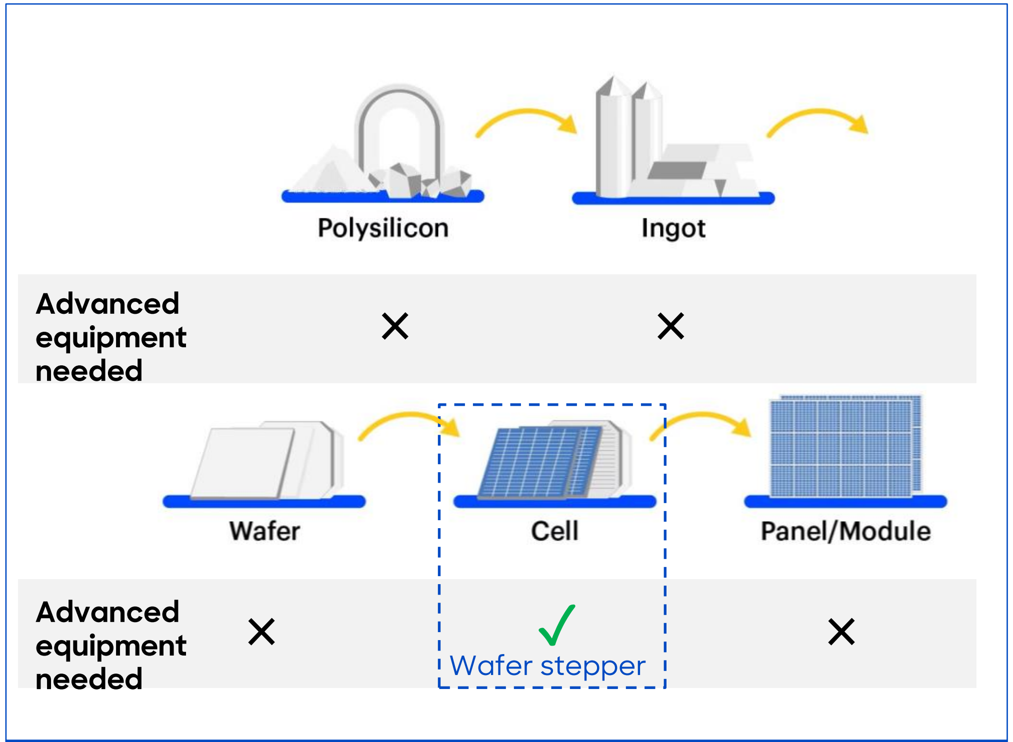
- By boosting European solar panel production, EU manufacturers such as ASML can capitalize on opportunities in the EU's solar panel industry by producing advanced equipment tailored for solar panel manufacturing

GDP impact of solar panel production

- In response to European policies, a GDP effect will follow from investments by companies setting up in solar panel production in Europe
- Furthermore, expanding production facilities in Europe will also positively affect job creation

Impact on innovation infrastructure

- Policies aimed at increasing European solar panel production will strenghten the innovation infrastructure
- Increasing solar panel production will further the development and production of concepts and innovations in machinery, integrated products, and materials



	Polysilicon	Ingot	Wafer	Cell	Panel/Module
Advanced equipment needed	✗	✗	✗	✓ Wafer stepper	✗

An advanced type of equipment needed in the cell production step are wafer steppers

Source: Roland Berger

Increasing EU solar panel production will improve energy independence, prevent the use of forced labor, and improve the sustainability of the value chain

Zoom in – Societal and environmental impact of solar panel production in the EU

Societal benefits

Independence in energy supply

- By subsidizing the production of solar energy in Europe **a European solar value chain is ensured**
- As such, Europe can better meet their own needs for solar energy and **become less dependent on foreign, especially Chinese, suppliers**
- By decreasing this dependence, the **security of Europe's energy supply** and its energy transition is ensured

Preventing the use of forced labor

- Reports estimate the number of **forced laborers** in China at **0.8-2.6 million people**, working in dire circumstances
- Forced labor in China mainly takes place in silicon production in the **Uyghur region of Xinjiang**
- The realization of a solidified EU solar power value chain means fewer solar products need to be imported from China and the associated **forced labor of an estimated 4,000 people is prevented**

Environmental gains through a more sustainable value chain

- The **production of solar panels** and their raw materials, and through the rest of the value chain, **releases CO_2**
- Currently, much of the value chain is still in China where **environmentally damaging solutions such as dirty-coal are still widely used**
- By realizing and using PV value chains in Europe they **can be made more sustainable**

Environmental gains through recycling and reduced material usage

- Producing solar panels in Europe will increase the ease of **recycling materials within their own value chains** at the end of the cycle
- Increasing EU production capacity will contribute to the development of a **future circular and low-material value chain**

Environmental gains

Source: Roland Berger

G. Key takeaways

With EUR 12-27 bn the support required is reasonable, but it should be done fast, at scale and with minimal impact on the energy transitions

Key takeaways

1. 〉 With EUR 12-27 bn needed over 2025-2030, the amount of support required to build a European solar PV manufacturing supply chain is reasonable
2. 〉 Acting fast can deliver long-term savings as local manufacturing costs are reduced before even larger volumes of solar panels need to be produced in the EU
3. 〉 To achieve efficient Capex utilization, scale (and clustering) of manufacturing capacity is required to become competitive
4. 〉 It should be ensured that the package of measures implemented to build the solar PV manufacturing industry in the EU has no (or minimal) impact on the speed of the energy transition
5. 〉 The recent investment uptake in solar PV manufacturing capacity in the US shows that building a new solar PV manufacturing supply chain can be done
6. 〉 Building such an industry now, creates the readiness for new technological steps such as back contacts, thinfilm and perovskite tandems

Appendix

I. Cost split of solar panel manufacturing

Accuracy of figures does not represent accuracy of the analysis

The Chinese manufacturing costs of solar panels amount to 15.0 EUR ct/Wp, with Materials being the largest cost item throughout the process (~49%)

Solar panel manufacturing cost per manufacturing step and cost item in **China** [EUR ct/Wp, % of total]

Cost item	Polysilicon	Ingots & Wafers	Cells	Modules	Total
Materials					
Previous production step		1.24 (8.2%)	4.85 (32.3%)	7.99 (53.2%)	
Other materials1)	0.72 (4.8%)	1.44 (9.6%)	0.202) (1.3%)	5.00 (33.3%)	**7.35 (48.9%)**
Labor	0.02 (0.1%)	0.30 (2.0%)	0.40 (2.7%)	0.67 (4.5%)	**1.39 (9.2%)**
Utilities	0.23 (1.5%)	0.59 (4.0%)	0.80 (5.3%)	0.44 (2.9%)	**2.07 (13.7%)**
Depreciation	0.21 (1.4%)	1.29 (8.6%)	1.47 (9.8%)	0.93 (6.2%)	**3.89 (25.9%)**
Maintenance	0.06 (0.4%)	0.00 (0.0%)	0.27 (1.8%)	0.00 (0.0%)	**0.33 (2.2%)**
Total	**1.24 (8.2%)**	**4.85 (32.3%)**	**7.99 (53.2%)**	**15.03 (100.0%)**	
Added value step	1.24 (8.2%)	3.61 (24.1%)	3.14 (20.9%)	7.04 (46.8%)	15.03 (100.0%)

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1) Other materials needed for each step are e.g. the front glass and backsheet needed to create the final module. Other material costs are calculated by subtracting the cost of the previous step from the total material costs needed; 2) To align the cost of materials from the previous production step, we manually added EUR 0.20 ct to account for additional material costs, as the initial calculations did not precisely match

Source: Roland Berger

The European manufacturing costs of solar panels amount to 38.6 EUR ct/Wp, with the labor cost item accounting for almost 38% of total costs

Solar panel manufacturing cost per manufacturing step and cost item in **the EU** [EUR ct/Wp, % of total]

Cost item	Polysilicon	Ingots & Wafers	Cells	Modules	Total
Materials					
Previous production step		1.89 (4.9%)	9.42 (24.4%)	19.22 (49.9%)	
Other materials1)	0.94 (2.4%)	1.87 (4.8%)	0.26 (0.7%)	6.50 (16.9%)	**9.56 (24.8%)**
Labor	0.05 (0.1%)	2.73 (7.1%)	2.59 (6.7%)	9.36 (24.3%)	**14.73 (38.2%)**
Utilities	0.52 (1.4%)	1.34 (3.5%)	1.81 (4.7%)	0.99 (2.6%)	**4.67 (12.1%)**
Depreciation	0.25 (0.7%)	1.59 (4.1%)	3.92 (10.2%)	2.48 (6.4%)	**8.24 (21.4%)**
Maintenance	0.12 (0.3%)	0.00 (0.0%)	1.22 (6.4%)	0.00 (0.0%)	**1.34 (3.5%)**
Total	**1.89 (4.9%)**	**9.42 (23.5%)**	**19.22 (49.9%)**	**38.55 (100.0%)**	
Added value step	1.89 (4.9%)	7.53 (19.5%)	9.80 (25.4%)	19.33 (50.1%)	38.55 (100.0%)

1) Other materials needed for each step are e.g. the front glass and backsheet needed to create the final module. Other material costs are calculated by subtracting the cost of the previous step from the total material costs needed

Source: Roland Berger

The United States' manufacturing costs of solar panels amount to 32.8 EUR ct/Wp, with the materials, labor and depreciation accounting each for 30%

Solar panel manufacturing cost per manufacturing step and cost item in **the US** [EUR ct/Wp, % of total]

Cost item	Polysilicon	Ingots & Wafers	Cells	Modules	Total
Materials					
Previous production step		2.20 (6.1%)	10.82 (30.1%)	20.97 (58.4%)	
Other materials1)	0.94 (2.9%)	1.87 (5.7%)	0.26 (0.8%)	6.50 (19.8%)	**9.56 (29.1%)**
Labor	0.06 (0.2%)	2.79 (8.5%)	2.62 (8.0%)	4.75 (14.5%)	**10.22 (31.1%)**
Utilities	0.21 (0.6%)	0.53 (1.6%)	0.72 (2.2%)	0.39 (1.1%)	**1.85 (5.7%)**
Depreciation	0.25 (1.7%)	1.59 (10.7%)	4.59 (12.3%)	3.33 (7.7%)	**9.75 (29.7%)**
Maintenance	0.14 (0.4%)	0.00 (0.0%)	1.29 (3.9%)	0.00 (0.0%)	**1.43 (4.4%)**
Total	**1.59 (4.9%)**	**8.37 (25.5%)**	**17.85 (54,4.4%)**	**32.82 (100.0%)**	
Added value step	1.59 (4.9%)	6.78 (20.7%)	9.48 (28.9%)	14.97 (45.6%)	32.82 (100.0%)

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1) Other materials needed for each step are e.g. the front glass and backsheet needed to create the final module. Other material costs are calculated by subtracting the cost of the previous step from the total material costs needed

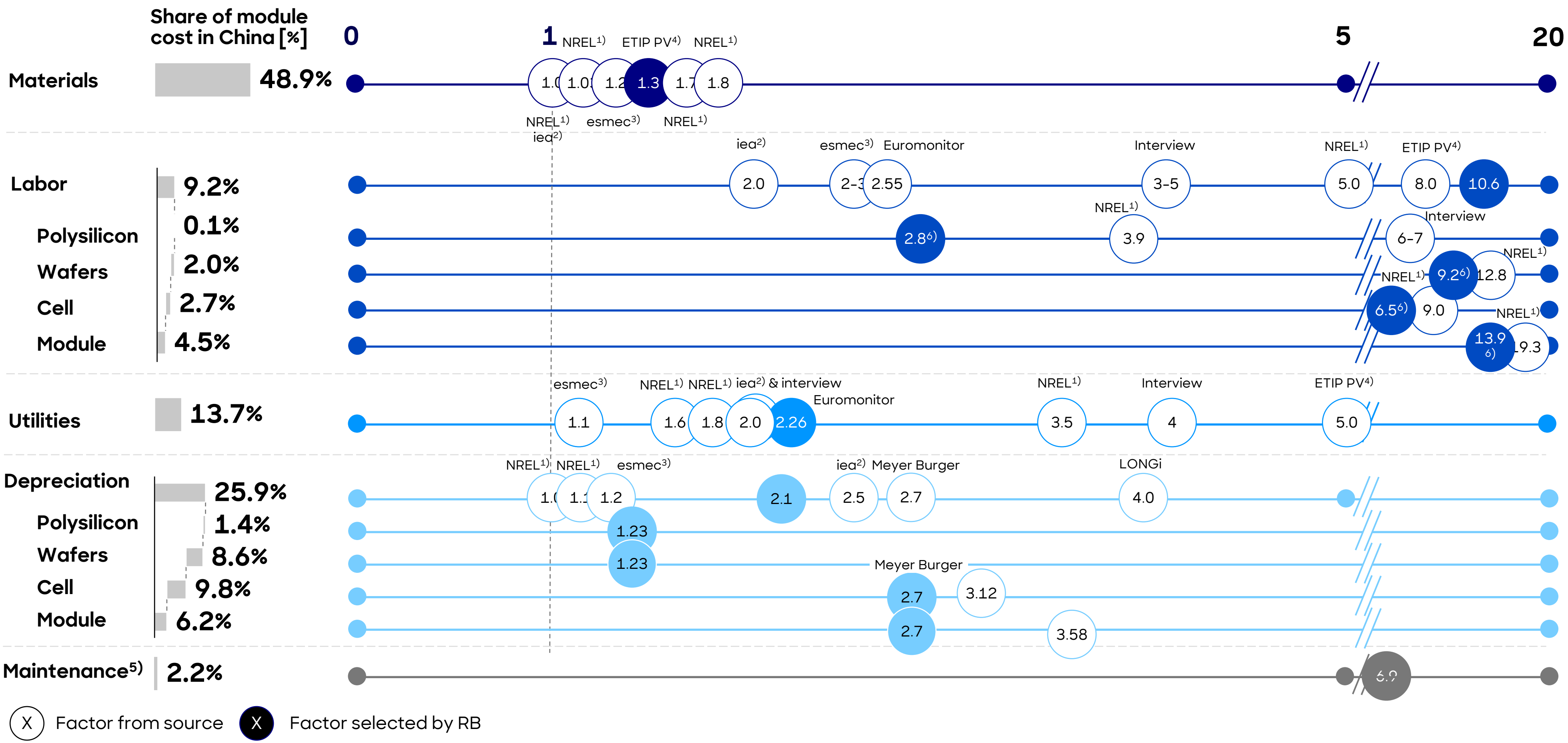
Source: Roland Berger

I Cost split of solar panel manufacturing

Back up

Different sources have been compared to create a custom factor for each cost item, utilities have the largest impact on the estimated EU manufacturing cost

Factor sources – **EU** compared to China



Reading guide

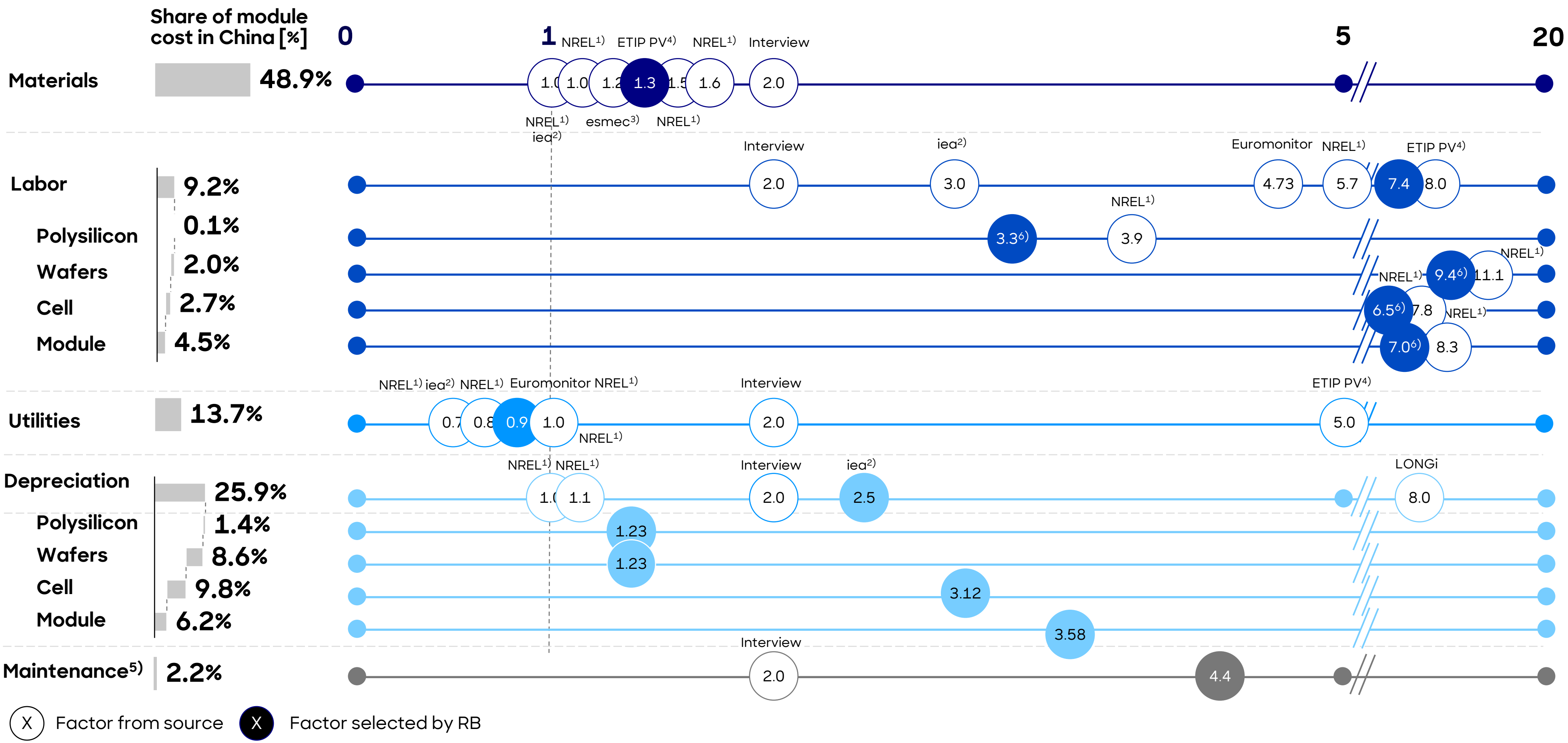
- The EU cost multipliers are factors needed to scale Chinese manufacturing cost to what the costs would be in Europe
- For each cost component of the four solar panel production steps, various sources have been compared to create a custom factor
- The factors are displayed on a scale from 0 to 20: a factor closer to 0 means that the cost of production in Europe is close to that in China, while a score closer to 20 indicates a significantly higher cost of production in Europe compared to China
- For example, to calculate cost of materials in Europe would be to multiply Chinese material costs by a factor of 1.3

1) National Renewable Energy Laboratory (sources used of overarching as well as individual production steps); 2) International Energy Agency; 3) European Solar Manufacturing Council; 4) The European Technology and Innovation Platform for Photovoltaics; 5) The factor for Maintenance is calculated using an average of labor and depreciation; 6) Average of production specific NREL factor and scaled overall labor factors of ETIP, and NREL

Source: esmec, ETIP PV, Euromonitor, iea, Meyer Burger annual report 2023, NREL, Interviews with market participants

Different sources have been compared to create a custom factor for each cost item, labor has the largest impact on the estimated US manufacturing cost

Factor sources – **US** compared to China



Reading guide

- The US cost multipliers are factors needed to scale Chinese manufacturing cost to what the costs would be in the US
- For each cost component of the four solar panel production steps, various sources have been compared to create a custom factor
- The factors are displayed on a scale from 0 to 20: a factor closer to 0 means that the cost of production in the US is close to that in China, while a score closer to 20 indicates a significantly higher cost of production in the US compared to China
- For example, to calculate cost of materials in the US would be to multiply Chinese material costs by a factor of 1.3

1) National Renewable Energy Laboratory (sources used of overarching as well as individual production steps); 2) International Energy Agency; 3) European Solar Manufacturing Council; 4) The European Technology and Innovation Platform for Photovoltaics; 5) The factor for Maintenance is calculated using an average of labor and depreciation; 6) Average of production specific NREL factor and scaled overall labor factors of ETIP, and NREL

Source: esmec, ETIP PV, NREL, Euromonitor, iea, Interviews with market participants

II. Overview of policy measures

The EU or countries within the EU could consider various policy measures to increase local solar panel manufacturing capacity

Overview of potential policy measures to overcome the price premium (1/7)

Policy measure	Financial impact on:		Description	Advantages	Disadvantages
	Gov't	Projects[1]			
Tax credits (US IRA[2])	↗	→	• Tax credits/tax relief is granted to companies manufacturing (parts for) solar panels • Comparable effect for solar manufacturers as Opex subsidies • Currently applied by the US at 0.07 USD/Wp for modules, 0.04 USD/Wp for cells, 12 USD/m² for wafers and 3.0 USD/kg for polysilicon	• Can be applied selectively (with different rates) for each production step • Provides manufacturers an opportunity to overcome the price premium on the marginal cost as compared to foreign suppliers • Often administratively easier to claim than subsidies	• Can be costly for the gov't to implement (lost tax revenue) • Doesn't reduce the risk exposure of solar panel manufacturers when they invest in new facilities (no guaranteed price or offtake)
Import tariff (trade barrier)	↘	↗	• Imposing an additional tax on the import of (parts for) solar panels when they are produced outside the EU or in specific countries • The US currently applies a 25-50% duty on solar cells and modules	• Can be applied selectively (with different rates) for each production step maximizing the effect • Inherently, brings a positive cashflow for the gov't which could be used to subsidize production in the EU • Can have positive effect on added value domestically by creating jobs and value chain effects	• Drives up the cost for solar energy project as it requires developers to source more expensive European panels • Often perceived as unfriendly by foreign nations and could trigger counter import tariffs (e.g. trade war)

↗ Increases cost or decreases revenue ↘ Decreases cost or increases revenue → No/minimal impact on cost or revenue

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1) Defined as projects using solar panels to generate and sell electricity; 2) Inflation Reduction Act

Source: Bloomberg, energy.gov, ETIP-pv, European commission, RVO, Interviews with market participants

The EU or countries within the EU could consider various policy measures to increase local solar panel manufacturing capacity

Overview of potential policy measures to overcome the price premium (2/7)

Policy measure	Financial impact on:		Description	Advantages	Disadvantages
	Gov't	Projects1)			
Opex subsidy	↗	→	• Gov't support to manufacturers of (parts for) solar panels for instance in the form of a subsidy per Wp produced or a fixed subsidy per year	• Can be applied selectively (with different rates) for each production step • Provides manufacturers an opportunity to overcome the price premium on the marginal cost as compared to foreign suppliers	• Might be subject to EU state aid regulation • Can be costly for the gov't to implement • Doesn't reduce the risk exposure of solar panel manufacturers when they invest in new facilities (no guaranteed price or offtake) • Likely not sufficient as standalone
CBAM (carbon border tax)	↘	↗	• European carbon tax on certain products or parts produced outside the EU but sold within the EU • Height of tax is based on the amount of CO_2 emissions as a result of the production of the product	• Currently solar PV is excluded from CBAM, in review phase (2027) it should be added • By design, covers all process steps of the solar panel manufacturing process	• Focused only on the CO_2 emissions and hence will never cover the entire price premium • To the extent solar panel manufacturers in the EU are covered by the ETS the effect on the price premium should be minimal

↗ Increases cost or decreases revenue ↘ Decreases cost or increases revenue → No/minimal impact on cost or revenue

1) Defined as projects using solar panels to generate and sell electricity

Source: Bloomberg, energy.gov, ETIP-pv, European commission, RVO, Interviews with market participants

The EU or countries within the EU could consider various policy measures to increase local solar panel manufacturing capacity

Overview of potential policy measures to overcome the price premium (3/7)

Policy measure	Financial impact on:		Description	Advantages	Disadvantages
	Gov't	Projects1)			
Local content requirement	→	↗	• Require solar energy project to use (at least) a share of solar panels or sourced in the EU or share of Capex spent within the EU • Local content requirements are common in oil & gas (globally) and in offshore wind (e.g. in UK, US, Poland)	• Relatively simple policy measure which can be easily enforced • Does not require any additional payments to/from the gov't, project developers and solar panel manufacturers • Could also focus on niches where EU currently has an edge keeping the Chinese manufacturers out, complementary regulations could boost the demand for these niches (e.g. EPBD IV)	• Drives up the cost for solar energy project as it requires developers to source more expensive panels produced in the EU • Focused mainly on module production, difficult to enforce earlier process steps • Might not achieve its goal when specified as a percentage of Capex as for instance inverters are already produced in the EU • Requires sufficient EU production capacity to be available
Capex subsidy	↗	→	• One-off subsidies by the gov't to manufacturers of (parts for) solar panels to stimulate investment in new factories	• Reduces the risk exposure for investors when investing in new facilities • Can be applied selectively (with different rates) for each production step	• Might be subject to EU state aid regulation • Can be costly for the gov't to implement • Doesn't provide manufacturers an opportunity to overcome the price premium on the marginal cost • Likely not sufficient as standalone

↗ Increases cost or decreases revenue ↘ Decreases cost or increases revenue → No/minimal impact on cost or revenue

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1) Defined as projects using solar panels to generate and sell electricity

Source: Bloomberg, energy.gov, ETIP-pv, European commission, RVO, Interviews with market participants

The EU or countries within the EU could consider various policy measures to increase local solar panel manufacturing capacity

Overview of potential policy measures to overcome the price premium (4/7)

Policy measure	Financial impact on:		Description	Advantages	Disadvantages
	Gov't	Projects[1]			
Contract-for-Difference (2-sided)	↗	↘	• Guarantees manufacturers a certain price for their products • If the market price is below the set price level the gov't pays the difference to manufacturers and (in a 2-sided form) if the market price is above the set price level the manufacturer pays the difference to the gov't • Often used within renewable energy such as the Dutch SDE++ scheme	• Fixes the price for solar panel manufacturers and hence greatly reduces revenue risk which improves bankability of investments • Can be applied selectively (with different rates) for each production step • Relatively easy to implement for polysilicon and wafers due to uniformity of the products	• It might be complicated to set fair, uniform, price levels due to differences in product quality (e.g. efficiency, degradation) • Can be costly for the gov't to implement and exact height of the cost can not be determined upfront • Requires a form of an auction (and hence heavy administrative process) to award the support • So far unproven measure
Traceability of value chain	→	→	• Implement measures to improve traceability of raw materials and parts use for solar panel manufacturing for instance by use of block-chain technology • The aim is to create an opportunity to market e.g. "forced-labor free" solar panels for which consumers might be willing to pay a premium	• May allow traceability across the entire supply chain and hence help in enforcement of other incentives • Creates additional value for customers and hence willingness to pay more • Could be an expansion of CSDD[2] and EUFLR[3]	• Additional willingness to pay by consumer is likely insufficient to bridge the cost premium • May be complicated to implement in a fraud resilient way • Might remain susceptible to loop holes (e.g. missing revers burden of proof)

↗ Increases cost or decreases revenue ↘ Decreases cost or increases revenue → No/minimal impact on cost or revenue

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1) Defined as projects using solar panels to generate and sell electricity 2) Corporate Sustainability Due Diligence (EU regulations); 3) European Forced Labor Regulation

Source: Bloomberg, energy.gov, ETIP-pv, European commission, RVO, Interviews with market participants

The EU or countries within the EU could consider various policy measures to increase local solar panel manufacturing capacity

Overview of potential policy measures to overcome the price premium (5/7)

Policy measure	Financial impact on:		Description	Advantages	Disadvantages
	Gov't	Projects1)			
Set minimal Module prices	→	↗	• The EU or EU nations set a fixed minimum price for solar panel modules (components) sold within their territory • Measure applies both to Chinese and European solar panels • Minimum price should be set at or above the European manufacturing cost (after any other support)	• No cost to the government • Provides security on minimal selling price, which reduces revenue risk thereby reduces financing cost	• Could provide additional profits to Chines solar panel manufacturers • Increases Capex for solar energy projects
EUFLR	↘	↗	• European ban on products or parts produced using any form or quantity of forced labor	• No additional work required as regulations is already being implemented • By design, covers all process steps of the solar panel manufacturing process	• Focused only on forced labor manufactured goods and hence will never cover the entire price premium • Requires strict and thorough audits for it to be properly implemented and prevent loopholes

↗ Increases cost or decreases revenue ↘ Decreases cost or increases revenue → No/minimal impact on cost or revenue

1) Defined as projects using solar panels to generate and sell electricity

Source: Bloomberg, energy.gov, ETIP-pv, European commission, RVO, Interviews with market participants

The EU or countries within the EU could consider various policy measures to increase local solar panel manufacturing capacity

Overview of potential policy measures to overcome the price premium (6/7)

	Financial impact on:				
Policy measure	Gov't	Projects[1]	**Description**	**Advantages**	**Disadvantages**
Offtake guarantees	↗	↘	• Government guarantees minimal offtake for Solar panel (or components of) manufactures i.e. if manufactures cannot offload goods to the market	• Decreases volume risk hence revenue risk, thereby reduces the financing cost for manufacturers	• Could impose significant cost to government • Could result in unutilized (structural) overproduction
Increased energy tax, with exemptions for EU made ren. Energy	↘	↘	• Increase in electricity tax, while exempting EU manufactured renewable energy	• Brings in additional income for the EU/national goverments • Encourages solar project to use EU manufacture product, to benefit form tax exemption	• Drives up energy cost for consumers and business • Policy not specific to the solar panel manufacturing industry

↗ Increases cost or decreases revenue ↘ Decreases cost or increases revenue → No/minimal impact on cost or revenue

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1) Defined as projects using solar panels to generate and sell electricity

Source: Bloomberg, energy.gov, ETIP-pv, European commission, RVO, Interviews with market participants

The EU or countries within the EU could consider various policy measures to increase local solar panel manufacturing capacity

Overview of potential policy measures to overcome the price premium (7/7)

	Financial impact on:				
Policy measure	Gov't	Projects[1]	**Description**	**Advantages**	**Disadvantages**
Government financing	→	↘	• Government provides financing for (components of) solar panel manufacturing at discounted market rates	• Minimal market interference • No direct cost to governments • Drives down cost of EU made solar panels	• Limits renewable investment opportunities for the financing market • Increase government debt
Made-in-Europe project subsidy	↗	↘	• Government provides subsidies to solar projects that utilize (a share of) European made solar panels	• Stimulates both solar projects and subsidizes the manufacturing industry, hence it increases demand and alleviates price pressure from foreign manufactures • Also supports REPowerEU, by accelerating the transition to renewable energy sources • Proven very effective in USA	• No control on how subsidies are distributed between project planners and manufacturers • Can come at great cost to the government • Doesn't directly reduce the risk exposure of solar panel manufacturers when they invest in new facilities (no guaranteed price or offtake) • Without sufficiently lenient zoning laws, the number of projects will remain constricted, limiting the effectiveness of the measure

↗ Increases cost or decreases revenue   ↘ Decreases cost or increases revenue   → No/minimal impact on cost or revenue

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[1] Defined as projects using solar panels to generate and sell electricity

Source: Bloomberg, energy.gov, ETIP-pv, European commission, RVO, Interviews with market participants

III. US Tax credits (IRA)

The energy provisions in the IRA have significant implications for the cost competitiveness of energy storage, hydrogen, and sustainable fuels

Key implications

The IRA results in lower cost renewable energy from wind and solar, which benefits downstream users of clean energy, but also accelerates the need for energy storage and other capacity/reliability solutions

The standalone storage ITC substantially reduces the cost of storage, and increased utility-scale storage deployment will provide capacity and firm renewables, but could also saturate ancillary service markets

Green hydrogen production costs will decline significantly, due to lower cost renewable energy, in addition to a large Production Credit – potentially accelerating the decarbonization of heavy industry and transport

E-fuels could reach parity by the end of the decade – new or expanded credits reduce the cost of renewable power, green hydrogen, and captured CO_2, which are inputs to e-fuels production

The IRA provides a broad set of tax credits that incentivize the deployment of a range of clean energy technologies, at utility-scale as well as for consumers

Key energy sectors impacted

Clean electricity

- ITC and PTC are effectively extended through 2035
- Starting in 2025, any zero-carbon generation qualifies, including nuclear and facilities using carbon capture

Energy storage

- Standalone battery storage qualifies for the Investment Tax Credit (30%+)
- Decreases storage costs by 20-30 USD/MWh
- Accelerates the timeline for parity with gas peakers

Carbon sequestration

- Increases the value of the tax credit for carbon capture
- Specifically incentivizes Direct Air Capture technologies

Clean fuels & hydrogen

- New tax credits for the production of hydrogen and transportation/aviation fuels
- Incentivizes green production pathways
- Could make e-fuels cost competitive by the end of the decade

Zero emission vehicles

- Federal EV tax credit, with domestic content requirements for battery components and minerals
- Clean Vehicle Refueling Infrastructure ITC for hydrogen refueling and EV charging

Homes and buildings

- Home energy efficiency tax credits, covering heat pumps, insulation, and retrofits
- Energy Efficient Commercial Buildings deduction, incentivizing energy efficiency projects

Source: H.R. 5376 – Inflation Reduction Act of 2022, NREL ATB, Roland Berger

The IRA also aims to support American jobs and communities, by incentivizing domestic manufacturing and the siting of projects in "energy communities"

Provisions benefiting domestic industries and communities

Domestic manufacturing

- **Advanced Energy Project Credit:**
  - Up to 30% investment tax credit for new domestic manufacturing facilities
  - Covers facilities that manufacture equipment or recycle materials necessary for a range of energy transition sectors
- **Advanced Manufacturing Production Credit:**
  - Production tax credit for domestic manufacturing of clean energy and storage components
  - Substantially subsidizes domestic production of solar and battery storage

Labor and communities

- **Prevailing wage and apprenticeship requirements**
  - IRA requires developers to pay local prevailing wages to workers, and to employ workers who are in qualified apprenticeship programs
- **Bonus provisions for siting projects within "energy communities"**
  - Increases the credit value for the ITC, PTC, Hydrogen, CCUS, Clean Fuels, and Advanced Energy Project credits
  - Qualifying locations:
    - Areas with high employment by the fossil fuel industry
    - Former coal plant communities

On top of the PTC/ITC which targets mostly project developers, manufacturing companies like HSM are eligible to tax credits through 45X or 48C

Deep-dive US tax credits

Most manufacturers apply for 45X !

	45X: Advanced Manufacturing Production Credit	48C: Advanced Energy Project Credit
Description	• **Traditional, uncapped program** • **Production tax credit:** – Value of credit is specific to each product or component • Credit will remain in effect through the end of 2029 – Credit value for each component **declines to 0% from 2030-2032**	• **Competitive program – capped at USD 10 bn** • **Investment tax credit:** – 6% base credit, 30% for projects meeting wage and labor requirements • **Program size:** – USD 10 bin, of which USD 4 bn is for projects sited in "Energy communities"
Eligible projects & technologies	**Solar:** • Solar-grade polysilicon 3.0 USD/kg • PV wafer 12.00 USD/m^2 • PV cells 0.04 USD/Wp • PV modules 0.07 USD/Wp **Wind:** • Blade 20,000 USD/MW • Nacelle 50,000 USD/MW • Tower 30,000 SUD/MW • Offshore platform1) 20-40,000 USD/MW **Storage:** • Battery cells 35,000 USD/MWh • Battery modules 10,000 USD/MWh **Inverters:** • Residential-scale 65,000 USD/MW • Commercial-scale 20,000 USD/MW • Utility-scale 15,000 USD/MW **Raw materials:** • Critical minerals 10% of costs	**Facilities that produce or recycle**: • Renewable generation equipment • Fuel cells • Energy storage (and components) • Grid modernization equipment • CCUS equipment • Equipment used for low carbon fuels and chemicals production • Energy efficiency hardware • xEV vehicles, components, charging **Projects that retrofit existing facilities** for emissions reduction, through: • Low/zero carbon process heat • Carbon capture, utilization & storage • Energy efficiency & waste reduction **Facilities that process or recycle**: • Critical minerals and materials (lithium and other energy-related raw materials)
Key requirements & stipulations	• **Individual credits are "stackable" for integrated components** – e.g. an entity that produces cells and assembles modules earns both credits • **Facilities taking the Advanced Energy Project Credit (48C) do not qualify**	• Requires the submission of an application, **subject to approval** • Sponsor has 2 years to provide evidence that the project meets requirements • Once certification is issued, **sponsor has 2 years to place project into service**

1) USD 20,000/MW for a fixed platform, USD 40,000/MW for a floating platform

Source: H.R. 5376 – Inflation Reduction Act of 2022

Roland
Berger