EU Clean Tech Industry

Key project results

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A. Executive summary

Executive summary: Introduction and as-is assessment

Executive summary & overall storyline (1/8)

1 **The European Union is setting itself ambitious goals**: Climate Neutrality by 2050 at the latest and independence of Russian fossil fuel imports before 2030, giving further acceleration to growth in Renewable Energy sources and related technologies.

With political attention shifting from setting the goal towards achieving the goal, it's time to investigate Europe's capabilities to reach set goals utilizing **Europe's existing green technology manufacturing footprint focusing on PV, Wind, Electrolyzer, Heat Pump and Battery**. Considering the latest developments in global supply chains (i.e.: short-term disruptions such as the Suez Canal blockage) as well as geopolitical developments (Russian war against the Ukraine), the notion to strengthen and focus on EU-built technology supply has gained traction. Becoming resilient against these forces has increasingly become a key objective of both public and private stakeholders.

Hence, the **project approach and structure** is focused on the identified overall project objective: **Setting, quantifying and implementing an optimized level of manufacturing resilience in the EU**. Four key elements are investigated accordingly: Focus technologies' status quo, European value chain coverage and potential, potential European supply scenarios, suitable policy levers as well as a corresponding competitive outlook.

2 **As-is assessments** with regards to the selected focus technologies yielded:

- For **PV**, focus is set on monocrystalline silicon as unique proxy due to high market share and efficiency advantages. Medium to high threat of new innovations stems from advanced TRL[1] of new generation Mono-Si cells (e.g., PERC, HJT, TOPCon). The share of EU manufacturing is at 2% for Wafers, 4% for Cells and 28% for Modules in '23
- For **Wind**, differentiation takes at generator-level: gearbox double-fed induction generator **(GB-DFIG) for onshore** and direct-drive permanent-magnet synchronous generator **(DD-PMSG) for offshore turbines. Varying degree of disruptive** threats come from TRLs of new generators and turbines. For **Wind Onshore**, share of European manufacturing is at 74% for Blades, 54% for Nacelle, 92% for Gearbox, >100% for Generator and 58% for Tower in 2023. For Wind Offshore, share of EU manufacturing is at 44% for Blades, and >100% for Nacelle, Generator and Tower in 2023
- For **Electrolyzer**, focus is on **Alkaline Water Electrolyzers (AWE) and Proton Exchange Membrane (PEM) Electrolyzers** due to high market share and lower technology readiness of alternatives SOE[2] and AEM[3]. **Low expected disruption** due to limited application field of SOE and low TRL of alternative solutions. The share of European manufacturing is at >100% for AWE and at 64% for PEM in 2023
- For **Heat Pump**, **Air-Source (ASHP)** used as proxy technology due to large market share of ATW (Air-to-Water) and ATA (Air-To-Air), comparable processes and costs of ATW and ATA. Low threat of disruption comes from mature competitive technologies with limited application areas or low TRL. The share of EU manufacturing is at 79% for Heat Pumps
- For **Battery**, Focus on **LFP (Lithium Iron Phosphate)** and **NMC (Lithium Nickel Manganese Cobalt Oxide)** cells due to high market share for BEVs and battery energy storage. Medium-level of disruption expected due to high TRL of competing technologies, particularly regarding the shift from cobalt to nickel-rich chemistries anticipated. The share of European Manufacturing is at 12% for LFP and at 50% for NMC

1) TRL = Technology Readiness Level; 2) SOE = Solid Oxide Electrolyzer; 3) AEM = Anion Exchange Membrane

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Executive summary: As-is assessment and European value chain coverage

Executive summary & overall storyline (2/8)

2 **As-is assessment** with regards to the identified deep dive topics showed…

- **Demand development**: Based on Agora EU Gas Exit Pathway scenario with time horizon until 2035 with annual deployments [2030] compared as-is supply capacities [2022] show need for capacity additions. Annual demand deployments go as follows: PV at 53 GW, Wind onshore at 26 GW, Wind offshore at 12 GW, Electrolyzer at 6 GW, Heat Pumps at 25 GW and Battery at 610 GWh in 2030
- **Geographic allocations**: **Country-focus** identified for **PV's** wafer production (FR) and cells (DE, IT), albeit less focus for modules, Electrolyzer production for AWE (DE, IT, DK) and PEM (DE, FR) production and Battery production in PL and HU. **Broad production set-up** identified for **Wind onshore/offshore** (with certain hubs) as well as **Heat Pumps**
- **As-is Unit Manufacturing Costs (UMC)**: **UMCs** are comprised of energy, labor, material and SG&A/overhead costs. Energy and labor deemed influenceable within the EU. **China is best in class for costs competitiveness** across all technologies except for PEM (EU/US). **EU** is among the **technology leaders for all technologies** except for batteries.
- **Time to market to scale up**: **Lead times** depict the time between announcements and commercial operation date (COD) - High relevance for considerations on investment risks, SC mgmt. and ramp-up. **Mining of raw materials** with longest lead times (20 yrs.). **Manufacturing sites** for clean technologies with lead times of **2-4 years**. After ramp-up, **1-4 years of finetuning and operational improvements** to be expected
- Qualitative risk assessment: **Key risks** are **economical, geopolitical, technological, geographic, and digital** including corresponding subcategories. The **assessment is based on four key categories**: 1) occurrence probability, 2) technology exposure, 3) impact of disruption and 4) mitigation opportunity. Focus technologies show a differing risk assessment with a more detailed quantification as part of the risk scoring completed within the scenario evaluation

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3 The **European Union's value chain coverage** is divided into the review of the raw material extraction and processing as well as the component's trade balance and manufacturing opportunities within the European Union.

- **The European Union established the list of Critical Raw Materials (CRM) in 2011** and has updated it ever since. Key assessment criteria include the 'Economic Importance' (EI) as well as the 'Supply Risk' (SR) for the EU. The result is a list of critical and critical + strategically important raw materials
- **22 raw materials** were identified as either critical or critical & strategic across the focus technologies. These materials are the basis for the 'relevant' raw materials assessed in the project. By applying five key analysis parameters (strategic/critical raw material, EU extraction, EU processing, material intensity and recycling rate), **3 additional materials were added to this list** as they either show high demand across all technologies or no EU-based sourcing is possible. In total, **25 raw materials were identified as relevant**

Executive summary: European value chain coverage and introduction to manufacturing resilience premium & scenarios

Executive summary & overall storyline (3/8)

3 With regards to **raw material extraction and processing:**

- In terms of **world supply** (extraction or processing), China is the clear leader holding majority stakes (50% and more) for 9 raw materials in extraction and 10 raw materials in processing as well as close to monopolies (90% and more) for 3 raw materials in processing. Other key players include Australia, Brazil, Russia and South Africa
- In terms of key **EU supply partners** (extraction or processing), there appears somewhat more diversification than expected given the concentrated world supply. However, key dependencies remain especially with regards to key materials such as Cobalt (Congo), PGMs (South Africa), REEs (China) and Lithium (Chile)

With regards to **components**, China stands out as key supplier across most technologies. Particularly important are PV cell imports where China currently captures roughly 90% of all imports to the EU

4 **Manufacturing resilience** is understood as **ability to mitigate risks to manufacturing supply of focus technologies to the European market**. These risks are derived, among other aspects, from the dependencies on imports into the EU and influenced by the (resulting) level of EU-based manufacturing supply vs. the total demanded annual deployments. The level of resilience is measured via a structured risk scoring (as part of the overall risk assessment), capturing the level of risk per technology along a set of key economical, geopolitical, technological, geographic and digital risks. The resulting risk scoring is used as targeted level of manufacturing resilience to counteract the identified key risks

Overall**, two outcomes are possible**: **Manufacturing resilience** is **already sufficient**, or **manufacturing resilience** is **not yet sufficient**. In the former case, investments and/or measures can be required to support and sustain a certain level of resilience and in the latter, investments are required to develop local infrastructure accordingly

From a quantitative point of view, the **resilience premium** captures the additional OPEX, CAPEX & reinvestments necessary to achieve the desired level of manufacturing resilience

5 **Supply scenarios** are the **basis for the evaluation of the resilience premium.**

A **base case (scenario 1)** depicts the development of the as-is manufacturing base along planned additions and identified key trends. **Scenario 2a/2b** minimizes risks, optimizes resilience and accounts for either cost competitiveness (‘**EU-optimized**’) or the countries’ own ambitions (‘**country-optimized**’). The targeted manufacturing resilience level is derived from above-mentioned risk assessment and is given as a %-share of volume.[1)] **Scenario 3 (NZIA[2)] case)** investigates the implementation of technology-specific NZIA targets[3)], however, without geographic differentiation

The resulting **scenarios** are evaluated based on **total costs derived in EUR** (total costs = CAPEX, OPEX and Reinvestments) discounted to 2023 values, **volume** (GW/GWh[3)] and market share) and **geographic allocations.** The comparison of the base case against the scenarios (2a/b and 3) gives the corresponding manufacturing resilience premium – Indicating the required investments to reach the before derived or given manufacturing resilience level

1) Resulting resilience levels are: PV: 55% for wafers, 50% for cells, 51% for modules; Wind onshore: 44% for blades, 46% for nacelle, 52% for gearbox, 53% for generator, 48% for tower; Wind offshore: 47% for blades, 46% for nacelle, 52% for generator, 47% for tower; Electrolyzer: 61% for AWE, 57% for PEM; Heat Pumps: 50% and Battery: 55% for LFP and 58% for NMC; 2) NZIA: Net Zero Industry Act; 3) PV: 45% EU demand share by 2030, Wind: 85%, Electrolyzer: 100%, Heat Pump: 60% and Battery: 90%; 3) GWh for Battery only

Executive summary: Overview scenarios

Executive summary & overall storyline (4/8)

6 The **base case** generates **total costs of EUR 691bn** for the **investment period 2023 to 2035**. This includes **OPEX at EUR 598bn**, **CAPEX** for new investments **at EUR 11bn** and **reinvestments at EUR 82bn**. Within this scenario, all (re-)investments are viewed as driven by the market dynamics with no additional, policy-driven supporting measures taken.

Included herein is the **overall manufacturing base load**: The **existing manufacturing base** as well as **planned additions** as communicated by the market participants. The **manufacturing base** is understood as the currently available EU-based manufacturing supply as per 2023. This base was either split by components (PV, Wind) or technology type (Heat Pump, Electrolyzer, Battery) throughout the analyses. **Planned additions** are understood as announcements made by existing/new players in the respective technology industries. These figures were reviewed and adjusted based on overall reliability of the source, expected completion deadline and overall expected implementation probability – Discounting ranges from 20% risk adjustment for immediate additions to up to 100% for, e.g., additions after 2030.

Trend-based additions are based on historic and future market developments, albeit at conservative level. Overall, a positive supply growth trend is assumed for PV, Electrolyzer, Heat Pump and Battery of 0.5% p.a. 2025-2030 and of 0.1% p.a. 2030-2035 thereafter. For Wind, a negative trend with regards to the as-is manufacturing capacity development is accounted for, leading to a market-driven decrease in supply of -1.0% p.a. 2025-2030 and -0.5% p.a. thereafter

Countries with strong overall manufacturing base load include Germany, followed by Spain, Hungary, Sweden and France

7 For **scenario 2a (EU-optimized)** **EUR 256bn in manufacturing resilience premium (RP) are added** compared to the base case, thereby raising the **total costs by c. 37% to EUR 947bn**. The **resilience premium divides into OPEX at EUR 182bn (71%), followed by CAPEX at EUR 42bn (17%) and reinvestments at EUR 32bn (12%)**.

At the core of the scenario is the allocation of the additional volume to the EU-27 countries. This is done by a scoring considering three key parameters: 1) the **overall cost competitiveness** (adjusted for characteristics of each technology), 2) the **strategic rationale** to optimize the surrounding conditions and, lastly, 3) the **energy supply capability** to ensure sufficient electricity is available for hosting additional manufacturing capacities. For each technology, **15 countries** are in scope for volume allocation – Countries with overall high allocation shares include Latvia, Bulgaria, Portugal, Croatia and Estonia.

From a **technology perspective**, key contributor to the manufacturing resilience premium is battery at 71% of total RP and PV at 21% of total RP.

8 For **scenario 2b (Country-optimized)** **EUR 286bn in RP are added** compared to the base case, thereby raising **the total costs by c. 41% to EUR 977bn**. The **resilience premium** divides **into OPEX at EUR 187bn (66%),** followed by **CAPEX at EUR 56bn (20%)** and **reinvestments at EUR 42bn (15%)**.

Similar as with scenario 2a, at the core of the scenario is the performed country allocation based on three key parameters: 1) the countries' **inherent climate ambitions**, 2) the countries' **economic power** and 3) the countries' **energy supply capability**. Within this scenario, all countries are subject to volume allocation. Countries with higher shares include Sweden, France, Germany and Denmark.

From a **technology perspective**, key contributor to the resilience premium is battery at 71% of total RP and PV at 21% of total RP.

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Executive summary: Overview scenarios & deep dive technologies

Executive summary & overall storyline (5/8)

9 For **scenario 3 (NZIA targets)** **EUR 576bn in manufacturing resilience premium are added** compared to the base case, thereby raising **the total costs by ca. 83% to EUR 1,267bn**. The **manufacturing resilience premium divides into OPEX at EUR 401bn (70%), followed by CAPEX at EUR 99bn (17%) and reinvestments at EUR 77bn (13%)**

From a **technology perspective**, key contributor to the resilience premium is battery at 75%, followed by Wind onshore at 9% and PV at 8% of the manufacturing resilience premium

10 From a **technology perspective**…

- For **PV**, the **base case of EUR 38bn** increases by **EUR 55bn in resilience premium (RP) for scenario 2a**, by **EUR 61bn in RP for scenario 2b** and **EUR 46bn in RP for scenario 3**
  – For scenarios 2a/b, the targeted resilience level of 50%-55% across the components results in a comparatively higher CAPEX than OPEX need: CAPEX rises by factor 9 compared to the doubling of OPEX. OPEX is, among others, potentially sensitive to changes in electricity prices, potentially warranting a cross-subsidization
  – For scenario 3, the targeted level of resilience is c. 10 ppts. lower than the desired level for scenarios 2a/b due to a lower targeted resilience level (at 45%). This results in comparably lower OPEX/CAPEX needs

- For **Wind onshore**, the **base case of EUR 185bn** increases by **EUR 9bn in resilience premium (RP) for scenarios 2a/b** and **EUR 49bn in RP for scenario 3**
  – As-is manufacturing resilience level set to decrease based on decrease in installed manufacturing base of 1-2 GW per component (cumulative c. 7 GW)
  – For scenarios 2a/b, the manufacturing resilience premium is mainly driven by OPEX as the installed base is mostly already above the targeted level of resilience (44-53%) – As a result, there are little to no additions needed to fulfill the European demand from a manufacturing resilience perspective
  – For scenario 3, CAPEX investments are required to reach the targeted level of manufacturing resilience of 85%

- For **Wind offshore**, the **base case of EUR 78bn** increases by **EUR 8bn in resilience premium (RP) for scenarios 2a/b** and **EUR 32bn in RP for scenario 3**
  – As-is manufacturing resilience level set to decrease based on decrease in installed manufacturing base of cumulative up to c. 2 GW until 2035
  – For scenarios 2a/b, the manufacturing resilience premium is mainly driven by OPEX as the installed base is mostly already above the targeted level of manufacturing resilience (46-52%) – As a result, there are little to no additions needed to fulfill the European demand from a manufacturing resilience perspective
  – For scenario 3, CAPEX investments are required to reach the targeted level of manufacturing resilience of 85%

Executive summary: Deep dive technologies

Executive summary & overall storyline (6/8)

10 From a **technology perspective**…

- For **Electrolyzer**, the **base case of EUR 14bn** increases by **EUR 1.5bn in manufacturing resilience premium (RP) for scenario 2a**, by **EUR 1.8bn in RP for scenario 2b** and by **EUR 6.2bn in RP for scenario 3**
  – For all scenarios, OPEX is driving the manufacturing resilience premium due to a limited need for additional investments given a strong supply growth forecast in the base case. Given the cost structure of Electrolyzer production, incentives and subsidies might be needed to support and shield the industry from fluctuations in labor costs
  – For scenarios 2a/b, moderate additions are required to meet the desired level of resilience with focus on PEM capacity expansions starting from 2030 onwards. For AWE, no additional investments are required due to the already strong production footprint given the demand development and targeted resilience levels
  – For scenario 3, the targeted level of manufacturing resilience (100% of demand in 2030) requires additional CAPEX investments for both PEM and AWE technologies

- For **Heat Pumps**, the **base case of EUR 73bn** increases by **EUR 2.1bn in resilience premium (RP) for scenario 2a**, by **EUR 2.5bn in RP for scenario 2b** and **EUR 9.0bn in RP for scenario 3**
  – For all scenarios,
    - OPEX is driving the manufacturing resilience premium due to a limited need for additional investments given a strong supply growth forecast in the base case
    - Share of reinvestments is comparably higher than in other technologies, which appears to be driven by overall high, existing capacities and fragmentation in the market
  – Scenario 2a/b: Due to already high supply levels of c. 80% of annual EU demand, minimal CAPEX investments are required starting after 2030 to maintain resilience level
  – For scenario 3, the targeted resilience level of 60% results in comparably higher CAPEX needs due to the required additions to the existing manufacturing base

- For **battery**, the **base case of EUR 303bn** increases by **EUR 182bn in manufacturing resilience premium (RP) for scenario 2a**, by **EUR 204bn in RP for scenario 2b** and **EUR 433bn in RP for scenario 3**
  – For scenarios 2a/b, the targeted level of manufacturing resilience (55/58%) across the two focus technologies LFP and NMC results in a comparatively higher CAPEX than OPEX rise: CAPEX is increasing by a factor 5 compared to the less than doubling of the OPEX. Investment amounts for LFP and NMC are similar in order to increase/uphold demand share with rising demand
  – For scenario 3, the desired manufacturing resilience level of c. 90% (of demand in 2030) further drives CAPEX needs compared to scenarios 2a/b

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Executive summary: Resilience premium and introduction financial incentives and subsidies

Executive summary & overall storyline (7/8)

11 **Resilience premium** is the starting point for the **development of policy levers** to foster the desired industrial developments. Based on the scenario results, the following key takeaways can support said creation:

- **OPEX** is key driver and biggest share of resilience premium across all technologies and scenarios. However, from a policy-perspective, one would not expect to see direct manufacturing cost subsidies, but rather indirect incentives and support mechanisms to tackle cost drivers across industries such as energy price guarantees and/or decreases in labor costs
- **CAPEX** for new investments are particularly important for PV and Battery technology footprints. Policies and funding incentives will likely focus on direct and indirect investment grants to support the desired build-up
- **Reinvestments** play a role across all technologies, as the existing (and added) manufacturing base must be maintained in order to continually meet demand. While new investments might take up the main share of financial support given, financial incentives to maintain existing production facilities are important to ensure continued economical competitiveness within and outside of Europe

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12 **Financial incentives and subsidies** are based on evaluated operational and investment expenditures. Comparing all technologies at EUR/kW-level, above stated trend can be asserted at scenario-level (scenarios 2a/b and 3)

- **PV and Battery** show comparably high EUR/kW requirements, substantiating the potential need for appropriate funding – Particularly given the strong growth cases across all scenarios
- **Wind onshore and offshore** show comparably high operational expenditure per kW, warranting a look into OPEX-focused incentives
- **Electrolyzer** (only PEM for scenarios 2a/b, additionally AWE for scenario 3) shows similar cost structure as Wind, suggesting an OPEX- over CAPEX focus with regards to subsidies
- Compared to all other technologies, **Heat Pump** show the highest EUR/kW in both operational and investment expenses across all scenarios

Executive summary: Policy levers and competitive outlook

Executive summary & overall storyline (8/8)

13 **Policy levers** include the focus areas legislation, infrastructure, innovation and international partnerships
- **Legislative levers** include creating a strong, but fair border for non-EU manufactured technologies (e.g.: via proof of origin for energy used in production processes and/or raw materials) and ensuring an agile local market with eased permitting procedures and a harmonized legislative framework at EU- and country-level
- **Infrastructure levers** include measures at raw material-level such as increase in EU-based material extraction, expansion of raw material processing and refining facilities, tapping into existing, but not yet explored materials and increase in recycling rates for key materials
- **Innovation levers** differentiate investments in supporting technologies and pre-components such as production processes (e.g.: Wafers) or Balsa-wood alternatives for Blades (Wind) as well support of establishing market entry level of new, high TRL technologies and launch of further R&D of medium TRL solutions with high potential
- **International partnerships** differentiate in three key areas of action:
  - **Imports – Raw material extraction & processing** with key focus to decrease the dependencies in sourcing from countries with high extraction/processing shares (i.e.: China) via the set-up of preferred supplier schemes, supplier diversification and enhanced trade relationships particularly for materials with small material intensities, but high impact on production including, REEs, PGMs, Titanium, Zirconium and Boron
  - **Imports – Components** with focus on diversification supply of key components for technology manufacturing, including permanent magnets, semiconductors and membranes
  - **Exports:** Strengthen partnerships and trade relations with existing key export destinations such as North America (US), Europe (UK, CH) and Asia

14 **Competitive outlook** is overall positive given the weight of political will to establish and nurture an economically beneficial technology environment. Key elements include
- **European cost competitiveness**: Reaching and/or maintaining cost competitiveness vs. Asian manufacturers (i.e.: China) given, e.g.: OPEX-focused subsidies are kept in place
- **European technology leadership**: Strong focus on innovation and European IP creation required to safeguard and expand Europe's technology leadership position
- **Learning curve and scaling effects**: Significant learning curve and scaling effect must be reached to support achieving a reasonable production size and to maintain 'right to play' globally
- **International partnerships for sourcing**: Focus on building new and foster existing relationships with key suppliers of high, medium and low material density materials
- **Powerhouse for skilled labor**: Raise in attractiveness of skilled labor profiles across all technologies in Europe to curb the exodus of needed specialists
- **Net zero targets and political motivation**: Raise in overall attractiveness of technologies via given political pathways will further nourish the influx in private investments

B. Key project results

The project structure is focused on the overall project objective: Setting, quantifying and implementing an optimized level of manufacturing resilience in the EU

Overall project structure

1 Technology status quo assessment

- Technology briefings for PV, Wind, Electrolyzer, Heat Pumps and Battery
- Demand & supply development (REPower, GEXIT)
- Overview on as-is Unit Manufacturing Costs (UMCs)
- EU-perspective on geographic allocation
- View on the required time to market to scale up
- Qualitative risk assessment

2 European value chain coverage & potential

- Identification and assessment of relevant raw materials
- View on world and key European raw material extraction and processing capacities
- View on key European opportunities for value chain coverage
- Selected view on EU trade balances

3 European supply scenarios

- Introduction to the scenario approach
- Key results across scenarios and technology deep dives
- Scenario methodology and overview on selected key inputs (risk scoring, country allocation keys and key assumptions)

4 Policies & competitive outlook

- Policy booklets with key policy levers including
  - Financial incentives & subsidies
  - Legislative levers
  - Infrastructure levers
  - R&D levers
  - International partnership levers
- Competitive outlook

Creating a resilient European-based Green Technology manu-facturing footprint

B.1 Technology assessment

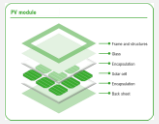
Technologies are either evaluated on component (PV, Wind) or technology type (ELY, Heat Pump, Battery) level – Disruptive forces driven by TRL of substitutes

Overview technology status quo assessment

Technology briefings

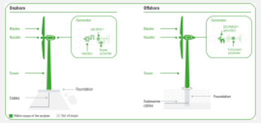
PV

- Focus on **monocrystalline silicon** as unique proxy due to high market share and efficiency advantages
- **Medium to high threat of new innovations** from **advanced TRL-level of new generation Mono-Si cells** (e.g., PERC, HJT, TOPCon)



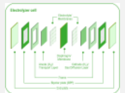
Wind (onshore/offshore)

- Focus on Gearbox double-fed induction generator **(GB-DFIG) for onshore** and Direct-drive permanent-magnet synchronous generator **(DD-PMSG) for offshore turbines**
- **Varying degree of disruptive threats** due to TRLs of new generators and turbines



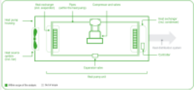
Electrolyzer

- Focus on **Alkaline water Electrolyzers (AWE) and Proton Exchange Membrane (PEM) Electrolyzers** due to high market share and lower technology readiness of alternatives SOE and AEM
- **Low expected disruption** due to limited application field of SOE and low TRL



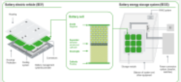
Heat Pump

- **Air-Source (ASHP)** used as proxy technology due to large market share of ATW (Air-to-Water) and ATA (Air-To-Air), comparable processes and costs of ATW and ATA
- **Low threat of disruptions** due to mature competitive technologies with limited application areas or low TRL



Battery

- Focus on **LFP** (Lithium Iron Phosphate) and **NMC** (Lithium Nickel Manganese Cobalt Oxide) cells due to high market share for BEVs and battery energy storage
- **Medium disruption** due to high TRL of competing technologies – Shift from cobalt to nickel-rich chemistries



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Deep dives

1. Demand & supply development
2. Geographic allocations (as-is)
3. As-is Unit manufacturing costs (UMCs)
4. Time to market to scale up
5. Qualitative risk assessment

Deep dives into demand/supply, geographic allocation, UMC and risks show a common denominator: China as key trade partner and cost leader across technologies

Overview technology status quo assessment

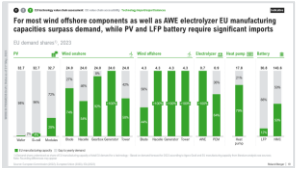
Technology briefings

PV	Wind (onshore/offshore)	Electrolyzer	Heat Pump	Battery

Deep dives

1 Demand & supply development

- Based **on Agora EU Gas Exit Pathway** scenario with time horizon **until 2035**
- Annual deployments [2030] compared as-is supply capacities [2023] show differing levels of Manufacturing supply vs. EU demand across technologies



2 Geographic allocations (as-is)

- **Country-focus** identified for
  - **PV's** wafer production (FR) and Cells (DE, IT), albeit less focus for modules
  - **Electrolyzer** production for AWE (DE, IT, DK) and PEM (DE, FR) production
  - **Battery** production in PL & HU
- **Broad production set-up** identified for **Wind onshore/ offshore** (with certain hubs) as well as **Heat Pumps**

3 As-is Unit manufacturing costs (UMCs)

- **UMCs** are comprised of energy, labor, material and SG&A/overhead costs
- Energy and labor deemed influenceable within the EU
- **China is best in class for costs competitiveness** across technologies except for PEM
- **EU** is among the **technology leaders for all technologies** except for batteries

4 Time to market to scale up

- **Lead times** depict the time between announcements and commercial operation date (COD) - High relevance for considerations on investment risks, SC mgmt. and ramp-up
- **Mining of raw materials** with longest lead times (20 yrs.)
- **Manufacturing sites** for clean technologies with lead times of 2-4 years
- After ramp-up, **1-4 years of finetuning and operational improvements** to be expected

4 Qualitative risk assessment

- **Key risks** are **economical, geopolitical, technological, geographic, and digital** incl. corresponding subcategories
- **Assessment based on four key categories** incl. occurrence probability, technology exposure, impact of disruption and mitigation opportunity
- Focus technologies with differing risk assessment – Further quantified in scenario evaluation

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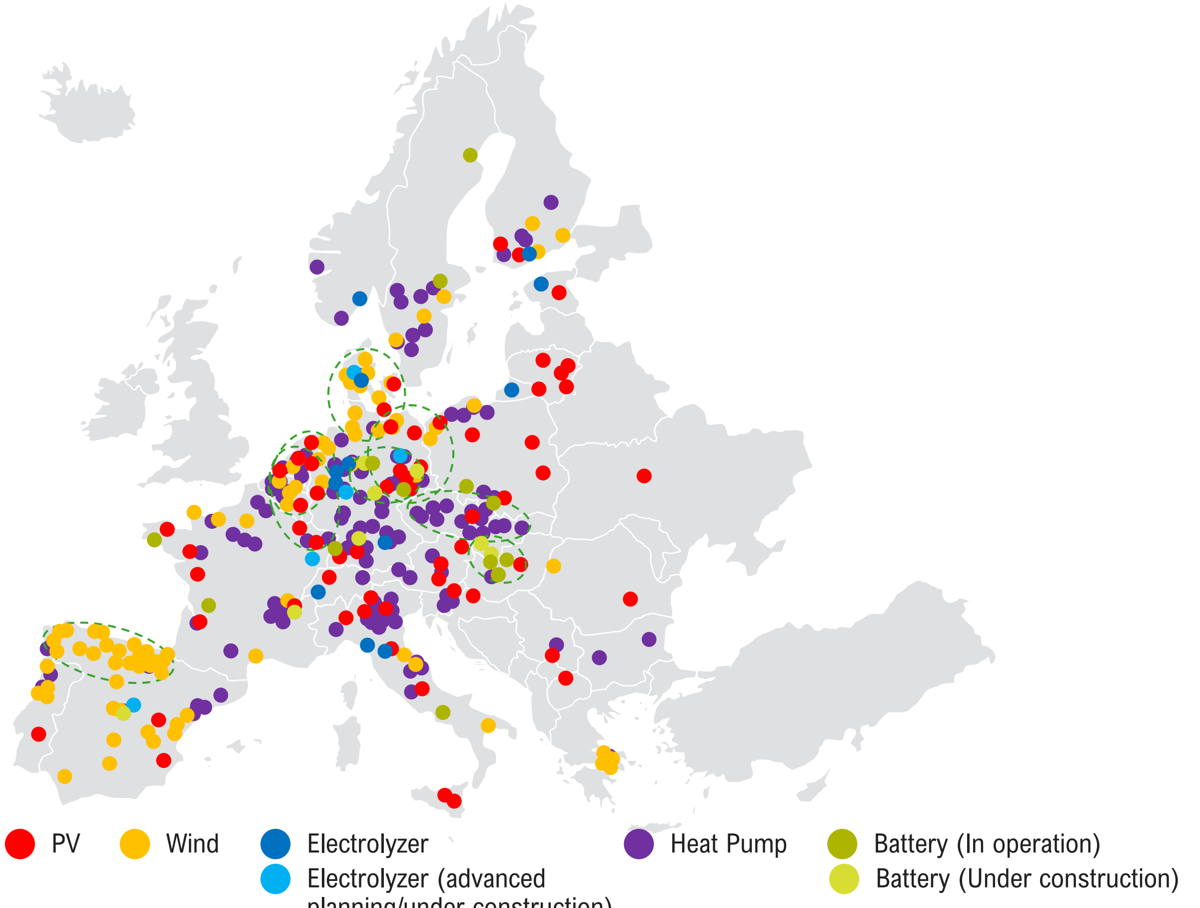
Manufacturing plants are concentrated in Middle Europe – Electrolyzer and Wind show highest global market shares, followed by Heat Pump manufacturer

Overview geographical concentration across all technologies – Component manufacturing



EU manufacturing capacities [2022]		Global market share ['22]	EU demand share[2)] ['23]
PV module [GW/y]	9	2%	28%
Solar cell [GW/y]	1	<1%	4%
Wind, onshore[1)] [GW/y]	13	16%	54%
Wind, offshore[1)] [GW/y]	2	23%	44%
Electrolyzer [GW/y]	2	26%	>100%
Heat Pump [GW/y]	14	16%	79%
Battery [GWh/y]	75	8%	43%

Europe shows **high global manufacturing shares** for **Electrolyzer and Wind** with up to c. 26% – The **Heat Pump** production is distributed across the **highest number of plants**

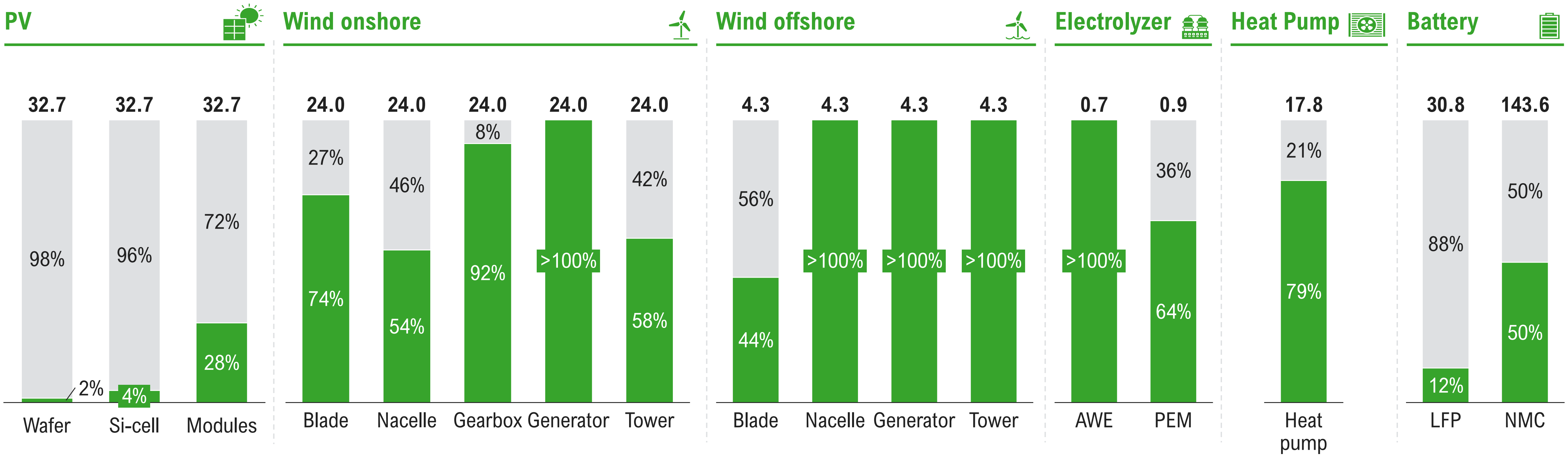
1) Capacity [GW/y] equals the minimum of manufacturing capacity of towers, nacelles and blades. Market share [%] is calculated as the weighted average share of the three categories based on their respective manufacturing capacity; 2) Demand share understood as share of EU manufacturing capacity of total EU demand for a technology – Based on demand forecast for 2023 according to Agora EU Gas Exit Pathway and EU manufacturing capacity from literature analysis

Source: IEA (2023), European Union (2023), European Commission (2022), Desk research

Indicative

For most Wind offshore components as well as AWE Electrolyzer EU manufacturing capacities surpass demand, while PV and LFP battery require significant imports

EU demand shares[1] [GW, 2023]



- **PV** with very limited production for wafers and cells – Modules at higher level
- **Wind onshore/offshore** with high market coverage and export potential to RoW
- **Electrolyzer** production captures total EU demand for AWE – PEM at lower level

- **Heat Pump production** at high level driven by smaller, fragmented set-ups
- **European battery production** is focused on NMC rather than LFP in line with the global market development (stronger focus on nickel-rich technologies)

EU manufacturing capacity | Gap to yearly demand

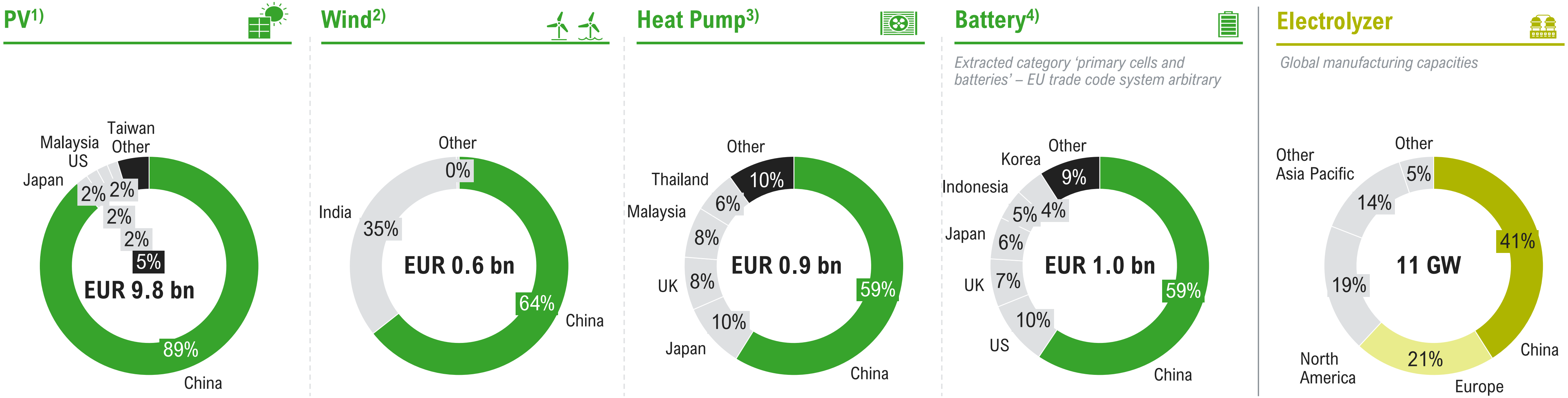
1) Demand share understood as share of EU manufacturing capacity of total EU demand for a technology – Based on demand forecast for 2023 according to Agora EU Gas Exit Pathway and EU manufacturing capacity from literature analysis see sources without adjustment for planned annual additions or trends | Note: Rounding differences may appear

Source: European Commission (2022), European Union (2023), IEA (2022)

Not exhaustive | Deviations possible

Imports range from EUR 0.6 bn to EUR 10 bn depending on technology – China acts as main and key sourcing partner across all technologies, albeit at varying levels

Imports across technologies [% | EUR bn, 2021]



- For **PV**, China is the dominant trading partner at c. 89% (EUR 8.7 bn) of all cells/modules sourced
- For **Wind**, key trading partners for Wind turbine imports are China (EUR 0.4bn) and India (EUR 0.2 bn)

- **Heat Pumps** are predominantly sourced from China
- For **Batteries**, key sourcing partners are China, the US and the UK as well as Japan

- **Electrolyzer** could not be quantified due to a lack of data available. Based on the world-production, potential key sourcing regions are China and NA
- Case evidence suggests a NA focus for imports

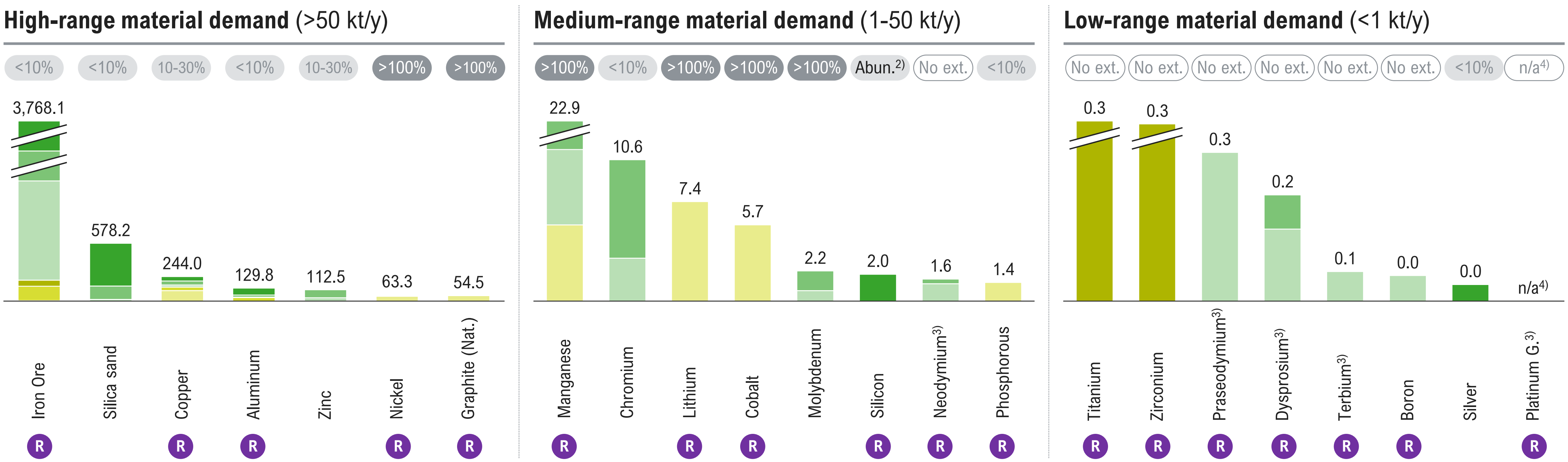
1) Combined Nomenclature (CN) position 854140, adjusted (Cells and Modules); 2) CN position 850231 (Generating sets, wind-powered) for wind turbines; 3) CN position 841861 (Heat Pumps); 4) CN positions 8506 ('Primary cells and primary batteries, electrical; parts thereof (excl. spent)') and corresponding subcategories 850650 (Lithium), 850610 (Manganese Dioxide), 850640 (Silver oxide cells and batteries (excl. spent), 850660 (Air-zinc cells and batteries (excl. spent) and others

Source: Eurostat (2021)

Indicative | Dependent on scope & product specifications as per manufacturer

EU raw material extraction shows most insufficiencies to cover the requirements of the as-is manufacturing base especially for Battery, Wind and Electrolyzer

Raw material demand for as-is manufacturing base, 2022[1)] [kt/y]



Most EU material insufficiencies for **Battery**, **Wind** and **Electrolyzer** – Thereof, extraction capacities are either not available or not enough given as-is demand

- **Manganese** and **Molybdenum** as well as **Rare Earth Elements** problematic for **Wind**, while for **Battery**, **Titanium** and **Zirconium** are affected
- For **Battery**, the EU extraction of **Nickel, Graphite, Manganese, Lithium and Cobalt** does not cover demand requirements

Solar PV | Wind onshore | Wind offshore | Electrolyzer | Heat pump | Battery | x% Share of EU extraction (last data set available, 2020) | No ext. No EU extraction | R Relevant material

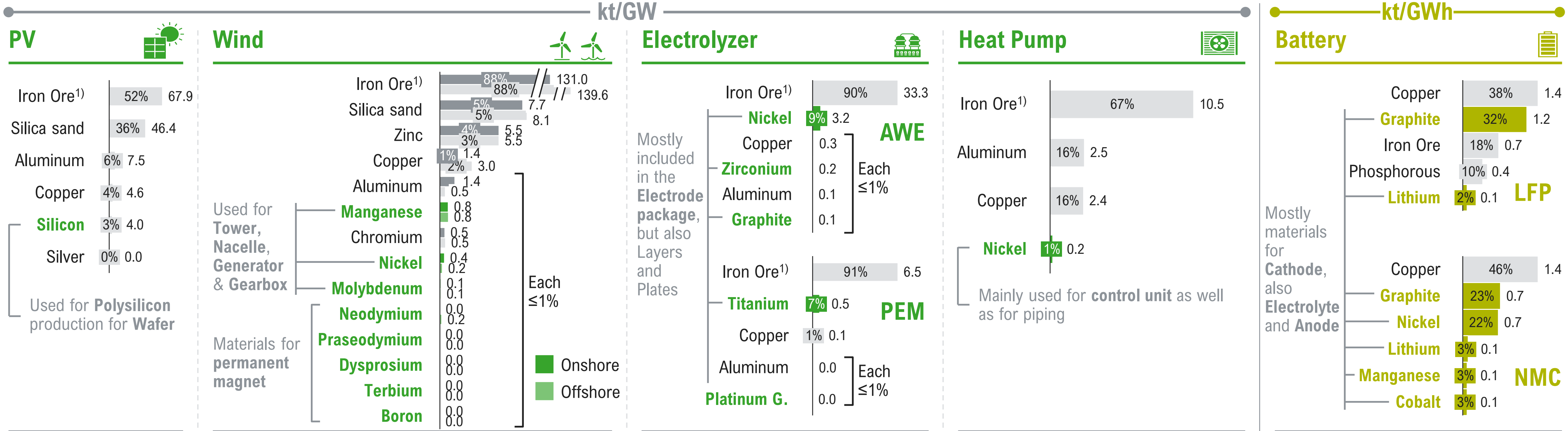
1) Projection of raw material demand based on the discussed raw material intensities from the raw material assessment to cover the as-is manufacturing base 2022; 2) Abundant supply available, quantitative estimates are not available; 3) Raw materials of the group Rare Earth Elements; 3) Includes Iridium, Palladium, Platinum, Rhodium, Ruthenium; 4) Missing data for quantification, import reliance identifiable

Source: European Commission (2023), U.S. Geological Survey (2022), World Mining Data (2021)

Indicative | Not exhaustive

Wind and Battery include most import reliant raw materials – For Wind, the permanent magnet is particularly affected by the import of Rare Earth Elements

Selected raw material intensities with focus on import reliance [kt/GW | kt/GWh]



PV
- EU extraction for most materials available
- Despite abundant Silicon reserves, pure form **Polysilicon** is highly import reliant

Wind
- **Permanent magnets** consist fully of import reliant materials (esp. REE2)) except for Iron Ore – High import dependence both on raw materials as well as on finished pre-components (magnets)
- Further 'at-risk' materials are used for all components except for blade production (balsa wood as pre-component)

Electrolyzer
- **Some of the main raw materials** of Electrolyzers besides Iron Ore are highly import reliant
- **Platinum Group Materials (PGMs)** and **Rare Earth Elements (REEs)** are important materials dependent on imports

Heat Pump
- Heat Pumps show **low reliance** on highly imported raw materials
- **Nickel** with insufficient EU extraction is used across multiple parts of the Heat Pump, mainly for the control unit

Battery
- Especially **NMC** is **significantly affected** by import reliant materials – Most used materials lack EU extraction
- For **LFP**, import reliance is also significant as key materials are concerned

EU extraction insufficient to cover demand of as-is manufacturing base or no extraction available

1) Including steel, iron cast and other iron; 2) Rare Earth Elements (REE)

Source: European Commission (2018, 2020, 2022), Energy Transitions Commission (2023), IEA (2023), Bareiß et al. (2019), Koj et al. (2017)

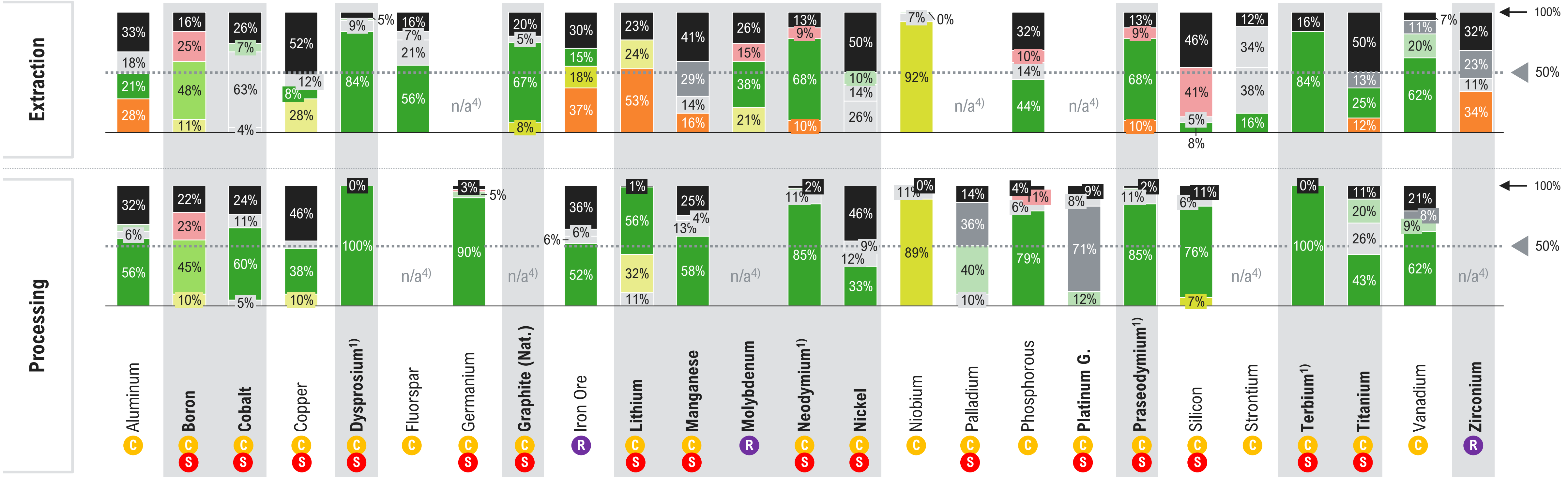
Final status as of June 7, 2023. Published in September 2023

Not exhaustive

Final status as of June 7, 2023. Published in September 2023

Out of 25 identified 'relevant' raw materials (RMs), China is dominant world extractor for 7 (28%) and dominant processor for 14 (56%) RMs

World extraction and processing capacities across relevant raw materials (%-share)



- Across all **25 relevant raw materials**, China is dominant for both raw material extraction (+ 50% of world capacities for 7 RM) and raw material processing (plus 50% for 14 RM)
- **Few other countries with significant market shares** including Brazil (91% Niobium), Australia (53% Lithium) and USA (41% Silicon) for extraction capacities

Strategic material | Critical material | Relevant material | **xx** Insufficient EU extraction | Australia | Brazil | Chile | China | Russia | South Africa | Turkey | United States | RoW | Other countries with capacities <10%

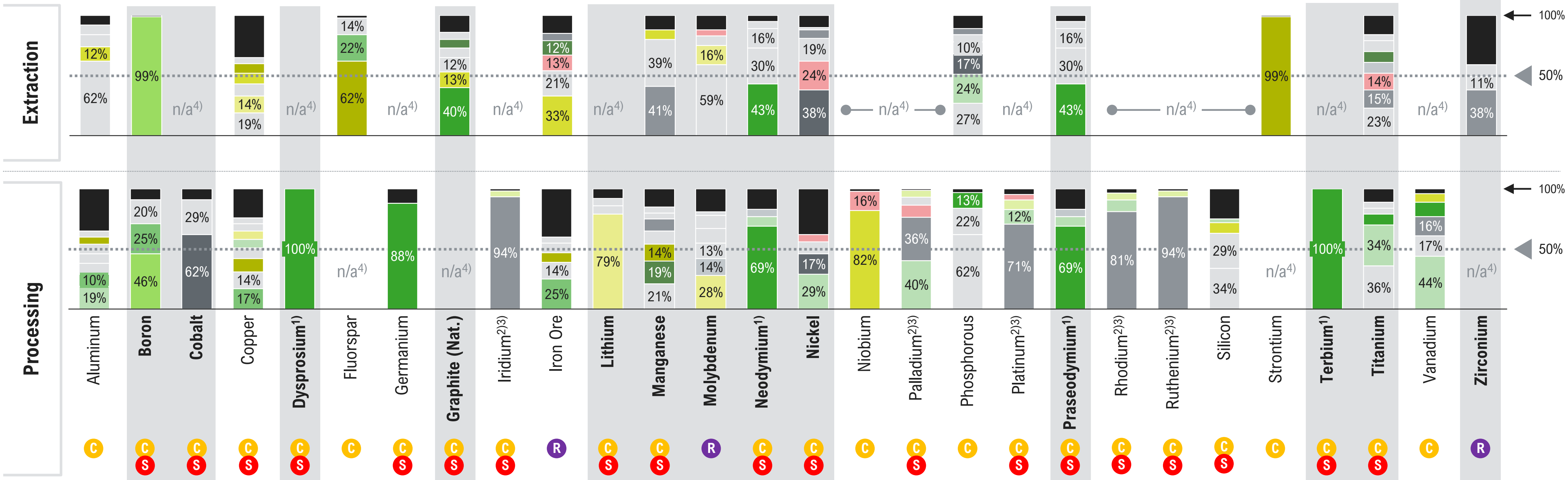
1) Raw materials of the group Rare Earth Elements (REEs)

Source: European Union (2023)

Not exhaustive

In contrast, Europe seems more diversified for suppliers in extraction & processing – However, due to the strong Chinese positioning a 'sub-dependency' seems likely

EU sourcing share across relevant raw materials (%-share)



- At extraction stage, the **EU key suppliers appear more diversified** than expected given the Chinese dominance at world
- Across all relevant 28 raw materials including the REEs and PGMs five are being dominated by China and four by South Africa in the processing stage

Strategic material | Critical material | Relevant material | xx Insufficient EU extraction

Brazil | Chile | Finland | Russia | Spain | Ukraine | Zimbabwe | Canada | China | Germany | South Africa | Turkey | United Kingdom | ROW | Other countries with capacities >=5%

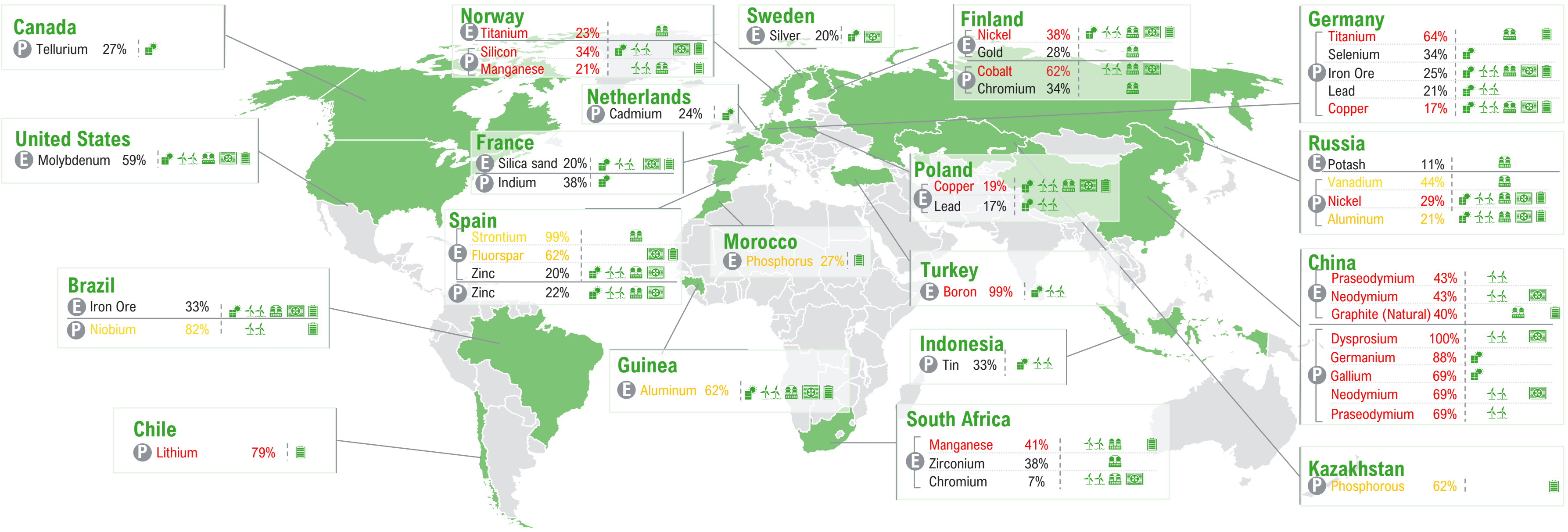
1) Raw materials of the group Rare Earth Elements (REEs) 2) Raw materials of the Platinum-group metals (PGMs) 3) Values for PGM are global market numbers; 4) No data available – Extraction/processing unknown

Source: European Union (2023)

Not exhaustive

From raw material perspective, EU already extracts and processes from deposits within the territory – However, dependencies given esp. for rare metals

Key EU sourcing countries[1] (%-share)



- **Sweden, Finland, France, Spain, Poland, Germany** and **the Netherlands** are among key EU producers of required raw materials
- **EU-based raw material extraction** could cover 10 (43%) of identified relevant raw materials completely considering current EU extraction volumes and as-is demand
- **Key non-EU extraction and/or processing countries** are China, Russia[1] and South Afrika
- **China** remains key trading partner due to dominance in raw material extraction and specifically processing from a world-view
- **Other key trading partners** include South Africa, US and Brazil – Russia with importance, however, current trade relations are unclear

Strategic material | Critical material | E Extraction | P Processing | PV | Wind | Electrolyzer | Heat Pump | Battery

1) Figures pre-Russian invasion on the Ukraine, which would impact the sourcing strategy and reduce the imports from Russia significantly

Source: European Union (2023)

Not exhaustive

Key implications derived from as-is and VC assessment tackle the footprint, UMCs, level of disruption as well as component/raw material sourcing across technologies

Implications on scenarios and policies

Key implications & hypotheses

As-is geographic production footprint. Current footprint concentrated in Northern/Western Europe in known technology strongholds such as Germany, France and Italy for **PV**, Spain for **Wind**, Germany for **Electrolyzer**, Sweden, France and Germany for **Heat Pumps** and Poland, Hungary and Sweden for Batteries. While the building of technology hubs can lead to positive spillover effects, the Eastern European countries appear underdeveloped in their production capacities

Arbitraging Unit Manufacturing Costs (UMCs). The Western-Europe focused footprint drives up the Unit Manufacturing Costs particularly with regards to Labor and Energy. While significant cost decreases can be achieved when shifting to low labor- and energy cost countries, countermeasures such as financial, legislative and infrastructure levers are required to keep the existing, and potentially newly built, manufacturing industries competitive in European high-cost countries

Disruption & innovation. Technologies show varying degree of disruptive threats caused by ongoing technology advancements and/or substitutes. PV with strongest threat due to high TRL of new technologies. Wind, Electrolyzer, Heat Pump and Battery with low-to-medium threat-level. EU-led R&D efforts can mitigate potentially adverse effects to existing manufacturing footprint and support shifts and/or transfers to new technologies

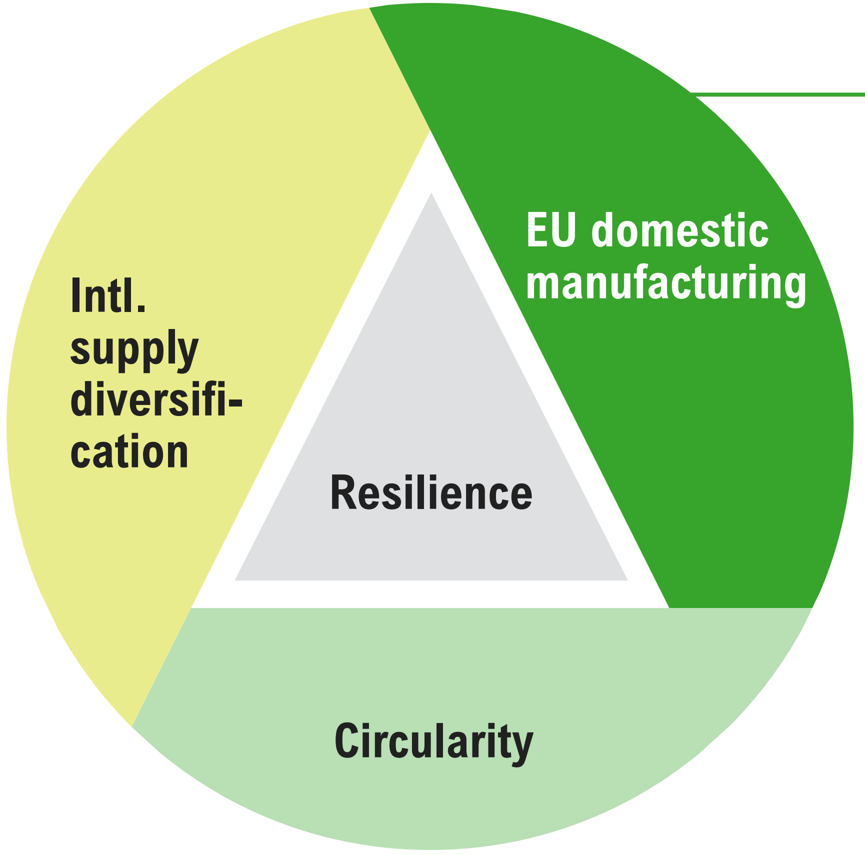
Component sourcing. Asia – specifically China – is key origin and main trading partner for all technology imports: PV's import rate is 10-fold its technological peers. Exports are an important lever to ensure utilization of manufacturing capacities at or above yearly demand level with the EU leveraging strong existing relationships with, for example, the US and the United Kingdom (i.e., Wind, Electrolyzer)

Raw material sourcing. China is key trading partner for both extracted and processed raw materials. While the EU produce some required raw materials by tapping into own sources, imports remain indispensable for raw materials with insufficienty supply (e.g., Graphite, Lithium, Cobalt) or for those not available in the EU such as heavy and light rare earth materials and the platinum group. Most EU material insufficiencies for Battery, Wind and Electrolyzer

B.2 Supply scenarios

Resilience is driven by EU domestic production, the international supply diversification and circularity – Project focus is set on EU domestic manufacturing

Introduction resilience



Focus

1 What is appropriate level of EU domestic manufacturing to balance resilience and cost optimization?

2 Which sectors and segments of the value chain should be prioritized for public support?

3 What is the resilience premium for increased levels of EU manufacturing?

From a scenario perspective, manufacturing resilience is ultimately understood as from risk derived share of EU-based manufacturing vs. total European demand

Definition of manufacturing resilience [Scenario view]

Manufacturing resilience

- Understood as **ability to mitigate risks to the overall European market** derived from the dependencies on imports into the EU
- **Influenced by the (resulting) level of EU-based manufacturing supply** vs. the total demanded annual deployments
- **Measured as**

%-RL [Resilience Level] = **%- RAS [Risk Assess-ment Score]**

Risk assessment score

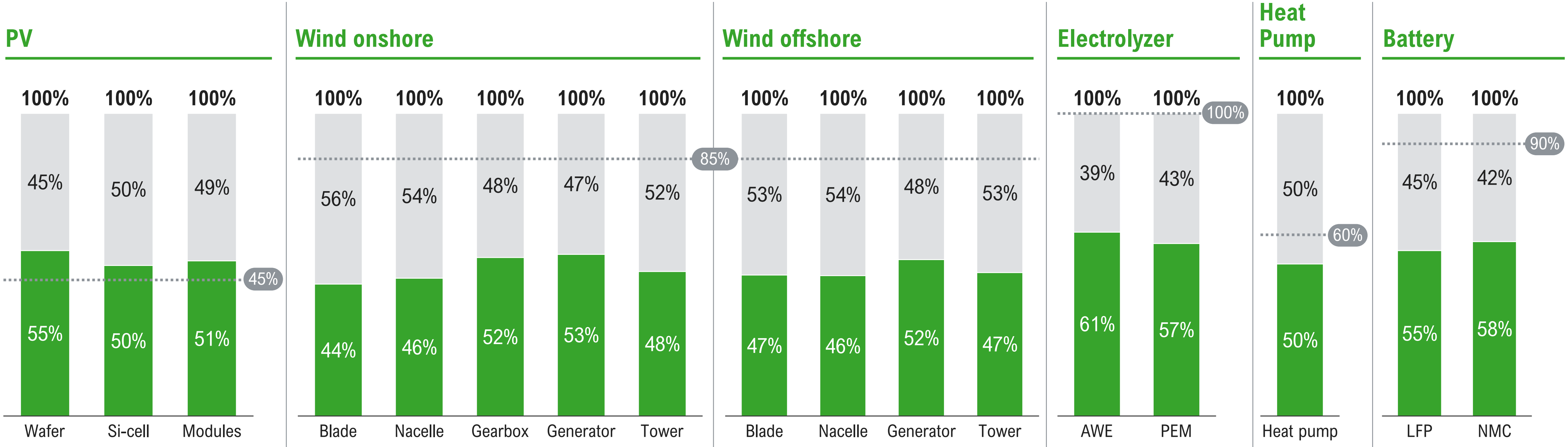
Category		Risk	Weight	Score	Score total
Economical	1	Demand & supply gap	10%	0-1	0-1
	2	Supplier/partner dependence	10%	0-1	
	3	Material & labor shortage	10%	0-1	
Geopolitical	4	Regulation (e.g., ESG)	10%	0-1	
	5	Political risks (e.g., sanctions)	10%	0-1	
Technological	6	Incremental tech. innovations	10%	0-1	
	7	Disruptive technologies	10%	0-1	
Geographic	8	Blockade of transport/trade routes	10%	0-1	
	9	Force majeure (environmental)	10%	0-1	
Digital	10	Digital malfunctions	10%	0-1	

- The higher the assessed level of risk, the higher the resulting desired level of EU-based manufacturing should be
- Risk assessment & quantification is performed based performed based on a set of key identified risks for each technology
- For the technology-specific scores, all risks are weighted equally

Final status as of June 7, 2023. Published in September 2023

PV, Electrolyzer, Heat Pump and battery are evaluated with higher target market shares due to greater supplier concentration & import reliance – NZIA targets differ

Risk assessment score: Resulting market shares by technology and component [%]



- Assessment based on selected risk parameters results in **differentiated targets for the value chain coverage** by technology and by component due to different risk exposures and value chain characteristics – compared to individual (unofficial) NZIA targets per technology
- Especially for PV, Electrolyzer and battery, **higher investments are required** to increase the resilience of the respective value chains

EU supply   Demand gap   XX Targeted market shares from NZIA

Source: European Commission (2023)

Three scenarios are differentiated: Base case, two-leveled resilience-led case and NZIA target case – Resilience premium derived by comparing base vs. scenarios

Introduction scenario logic & KPIs

	Scenario 1	Scenario 2		Scenario 3
	1 Base case Developing EU's manufacturing base according to known capacity additions and overall market intelligence	**2a EU-optimized** Developing EU's manufacturing base to mitigate identified risk profiles considering the best allocation within the EU based on cost comparative advantages	**2b Country-optimized** Developing EU's manufacturing base to mitigate identified risk profiles while considering each countries' national ambitions	**3 NZIA target(s)** Developing the manufacturing supply according to the NZIA targets across Europe 'as a whole'[1]
KPIs per technology	Total costs; Geographic allocation; GW/technology & market share[2]	Total costs; Geographic allocation; GW/technology & market share[2]	Total costs; Geographic allocation; GW/technology & market share[2]	Total costs; Geographic allocation; GW/technology & market share[2]
Manufacturing resilience premium	EUR[3]	EUR[3]	EUR[3]	EUR[3]
		Premium 1	Premium 2	Premium 3

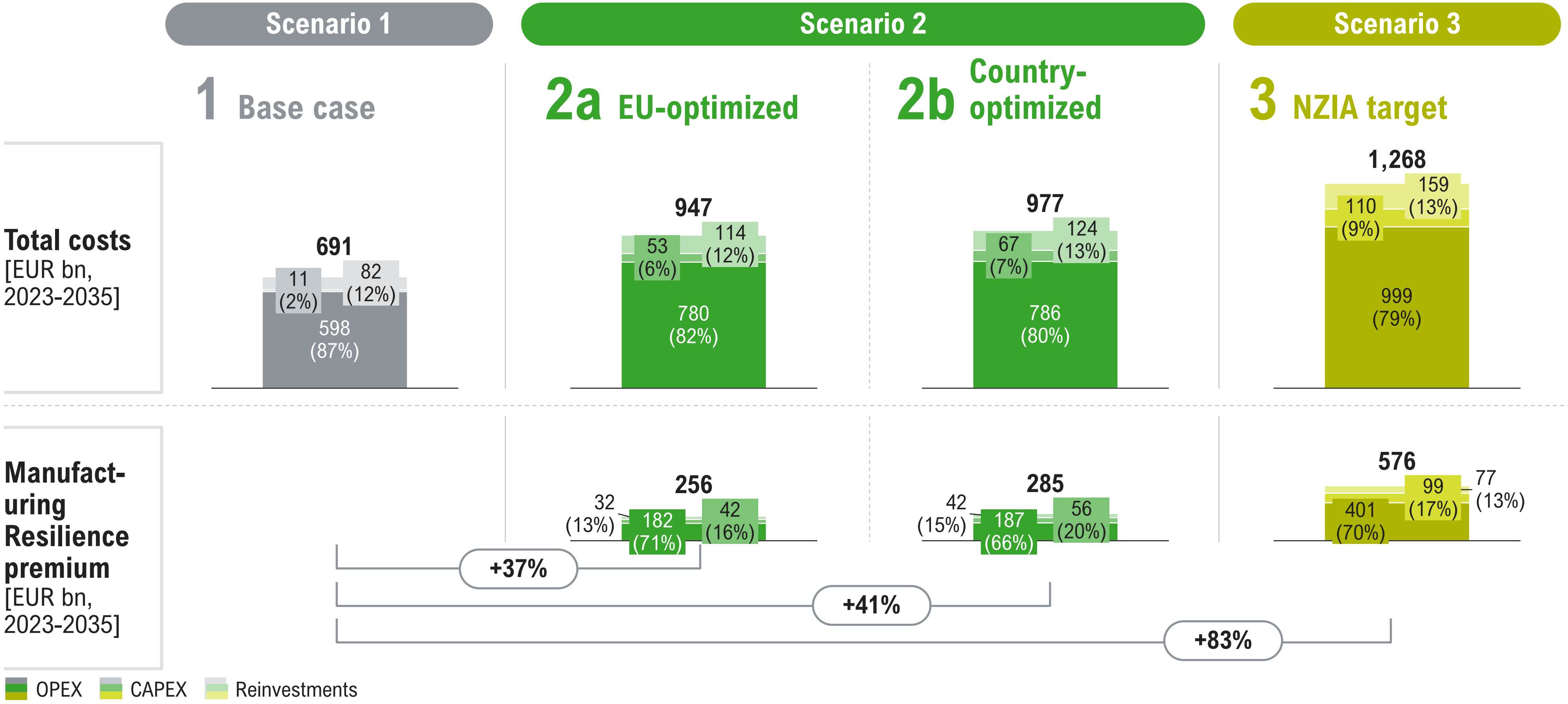
- **Scenarios are quantified by three key KPIs:**
  - Total **costs** (UMC plus capital costs)
  - **Geographic allocation**
  - Total **GW and market share** of supply by technology
- **Resilience premium**…
  - Depicts the **level of risk mitigation for European-based manufacturing** vs. base case
  - Compares the resulting EUR per technology and scenario vs. the EUR per technology of the base case
  - Can **only be summed up and compared at scenario-level in total EUR** due to differences in volume denominations
- **World-based EU supply** is derived as residual value

1) No official individual targets available – Shares of PV: 45%, Wind: 85%, Electrolyzer: 100%, Heat Pump: 60% and Battery: 90% of 2030 demand according to Commission Staff Working Document (European Commission, 2023); 2) Market share understood as share of EU manufactured supply of total EU demand for a technology; 3) EUR/kW available at component/technology sub-type level

Indicative

Resilience premium ranges between EUR c.256bn – c.576bn across all technologies – CAPEX & reinvestments with highest direct and targeted policy lever relevance

Overview scenario results: Total costs & resilience premium [cum. EUR bn, 2023-2035]



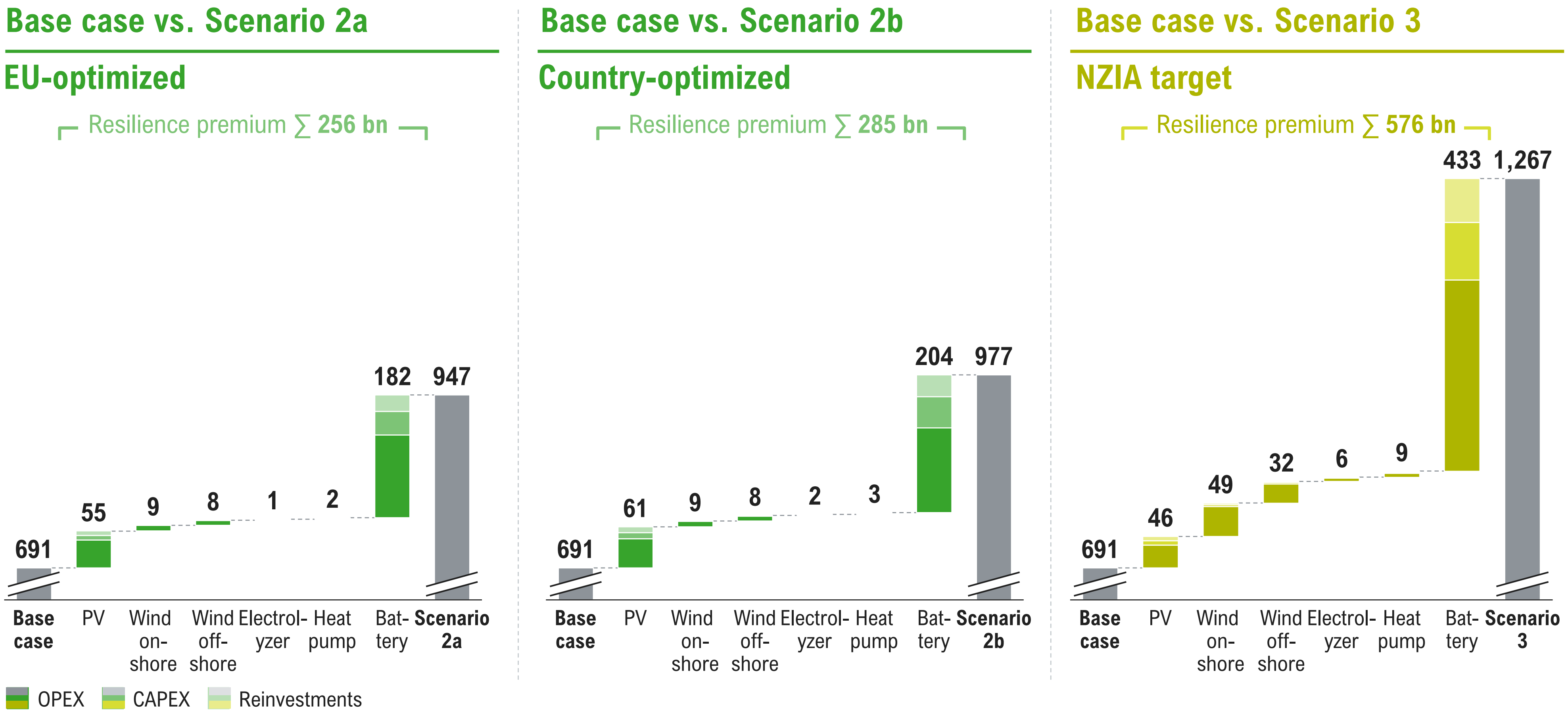
- **Total costs** include annual OPEX as well as CAPEX calculated as DCF[1] applying an avg. EU interest rate
- **Manufacturing resilience premium of EUR c.256-576bn** calculated as delta between base case and scenarios
- **OPEX** are biggest expense, however, only indirect subsidies likely (energy, labor)
- **CAPEX and reinvestments** with highest potential for targeted financial instruments from policy perspective

Note: Rounding differences may appear
1) DCF = Discounted Cash Flow

Indicative

PV and Battery drive the resilience premium across all three scenarios – CAPEX in both scenarios with higher growth than OPEX due to required increase in capacity

Overview scenario results: Break-down resilience premium [vs. Base case, EUR bn, 2023-2035 cum.]



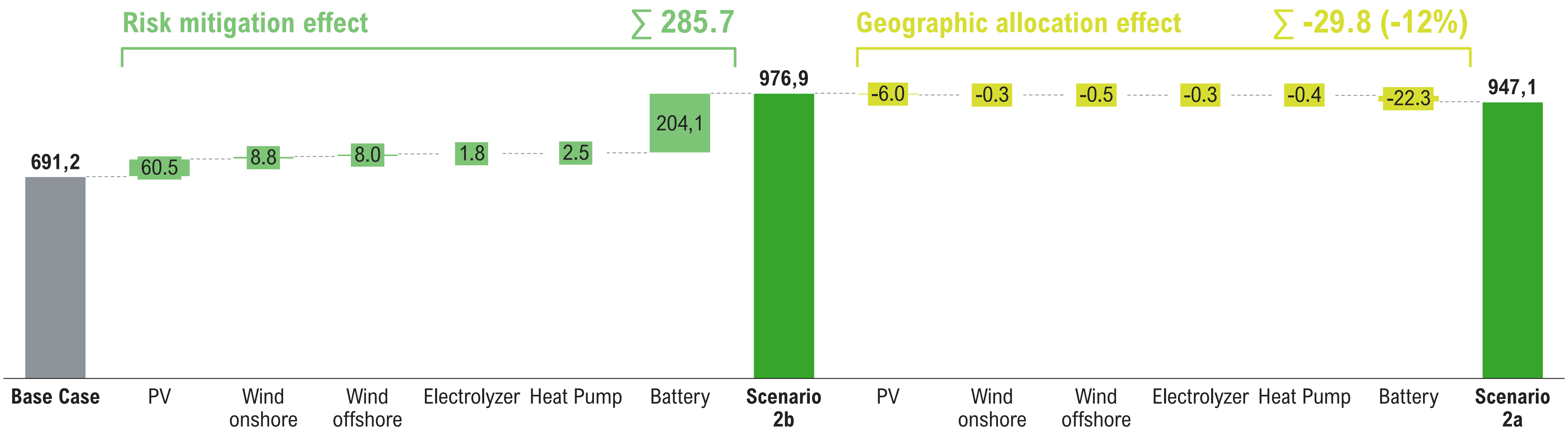
- **Comparison of ramp-ups** displays **differences in technology impact across scenarios** and by this, main **drivers of resilience premium differences**
- **Key drivers for differences in technology resilience** premiums include
  – Aspired market share and as-is manufacturing capacity for PV and Battery
  – Reinvestments and OPEX for technologies with already close to or resilient supply levels (e.g.: Wind, Electrolyzer, Heat Pump)

Note: Rounding differences may appear

Indicative

Risk mitigation effect of EUR c.286bn for scenario 2b compared to base case – Scenario 2a at EUR c.30bn (c.12%) lower level due to geographic allocation effect

Overview scenario results: Total cost comparison of scenarios [EUR bn, 2023-2035 cum.]



- **Risk mitigation effect** of **EUR c.286bn** for scenario 2b (vs. base case) mainly driven by supply increases for PV and Battery
- **Geographic allocation effect** of **EUR c.30bn** of scenario 2a vs. scenario 2b is result of differences in country allocation between scenario 2b and 2a – Europe-optimized scenario with cost advantages realized vs. following purely country ambitions

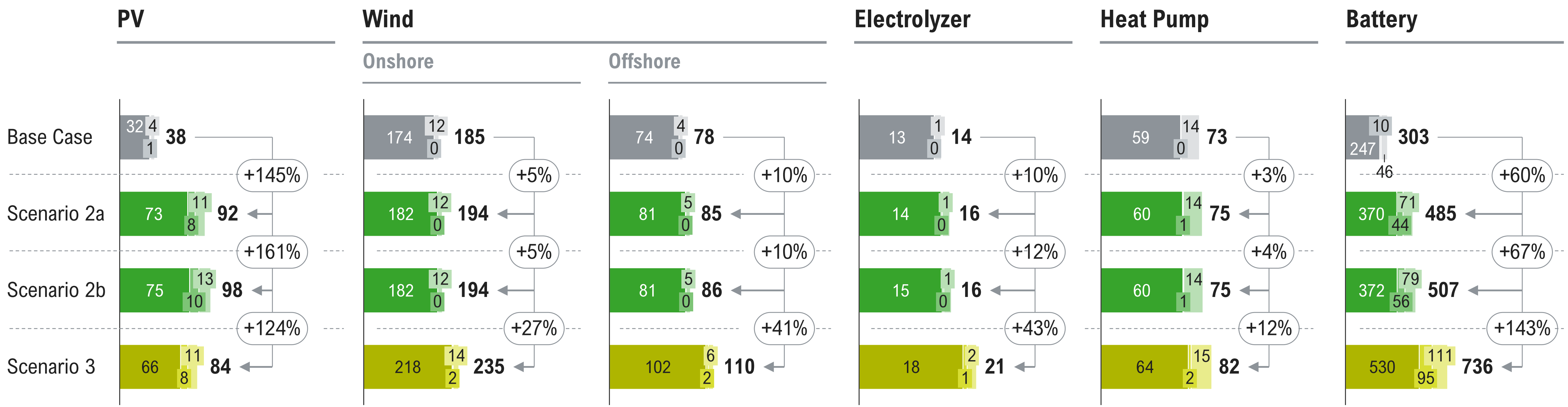
Total | Risk mitigation effect | Geographic allocation effect

Note: Rounding differences may appear

Indicative

Technologies total cost increase range between 3% - 161% for scenarios compared to base case – CAPEX focus for PV and Battery due to gap in resilience level

Overview scenario results: Total costs by technology [cum. EUR bn, 2023-2035][1)]



- **PV:** CAPEX focus due to gap between as-is supply and resilience targets
- **Wind onshore & Wind offshore:** OPEX focus with as-is supply already at resilient level – However, decrease in as-is manufacturing base currently not addressed in resilience premium (no adjustment for trend-based decrease)
- **Electrolyzer:** Limited investment needs due to strong base case growth in line with market growth and desired level resilience levels
- **Heat Pumps:** Limited investment due to existing high resilience level
- **Battery**: CAPEX focus due to gap between as-is supply and resilience targets especially for NMC technology

OPEX CAPEX Reinvestments

1) Differing scales per technology applied to ease legibility

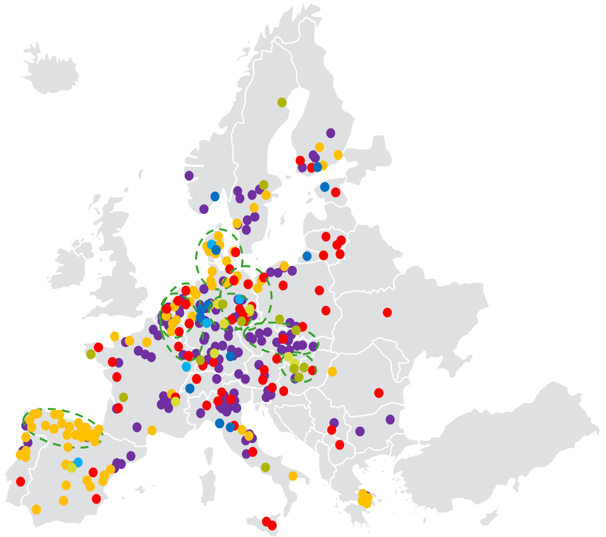
Note: Rounding differences may appear

Indicative

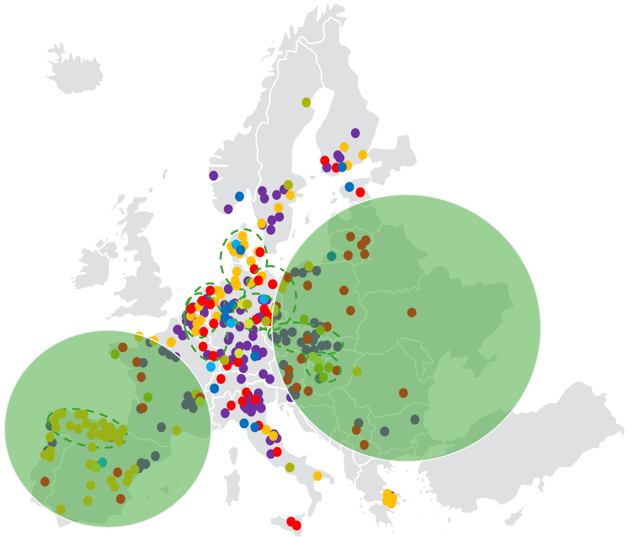
Scenario 2a focuses on building manufacturing capacity in Central/Eastern and Southern Europe – In contrast, scenario 2b favors Northern & Western Europe

Scenario additions at European-level [schematic]

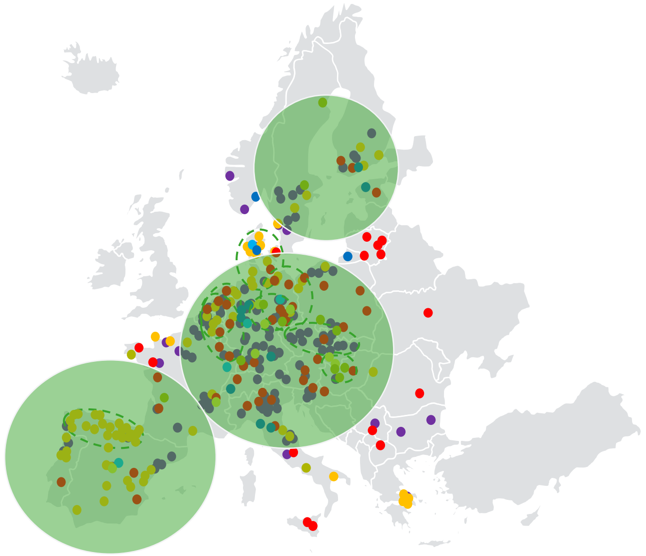
Base case



Scenario 2a: 'EU-optimized'



Scenario 2b: 'Country-optimized'



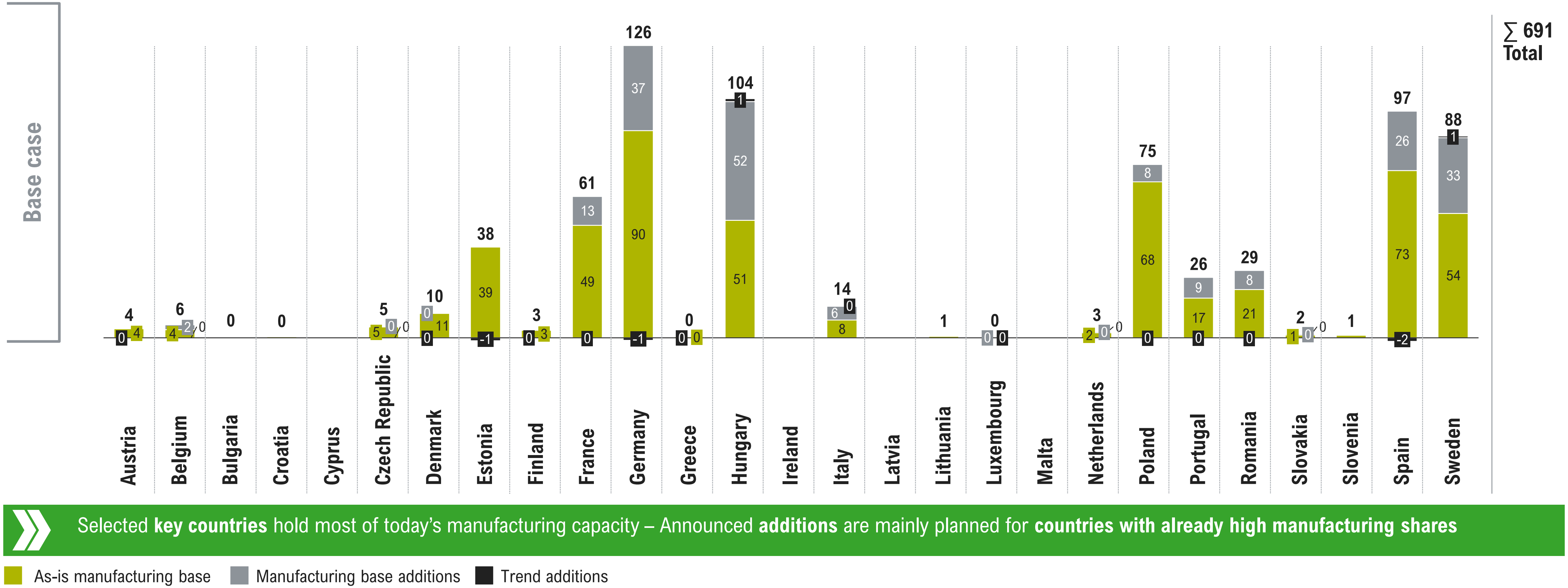
- **Scenario 2a – 'EU-optimized':** Focus on **Central & Eastern** (e.g.: Latvia, Bulgaria, Lithuania, Estonia, Hungary) and **Southern** (e.g.: Portugal, Spain) Europe due to higher cost competitiveness compared to Western European countries
- **Scenario 2b – 'Country-optimized':** Focus on **Northern** (e.g.: Spain, Finland), **Western** (e.g.: Germany, France, Luxembourg) and **Southern** (e.g.: Spain) Europe to high country-specific drive as well as their financial and economic power

PV · Wind · Electrolyzer · Electrolyzer (advanced planning/under construction) · Heat Pump · Battery (In operation) · Battery (Under construction) · Focus of scenario-based additions

Indicative

The total costs of the base case are largely distributed across c.10 main countries – Highest share generated in Germany, followed by Hungary, Spain and Sweden

Overview scenario results: Total costs of base case by geography [EUR bn, 2023-2035 cum.]



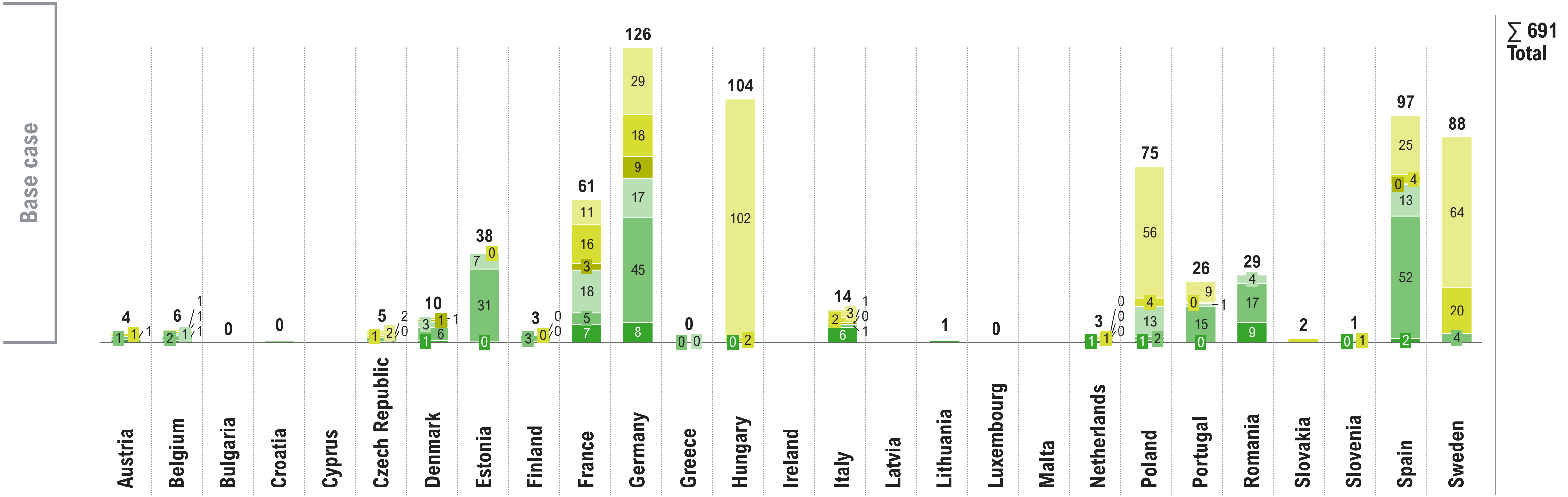
» Selected **key countries** hold most of today's manufacturing capacity – Announced **additions** are mainly planned for **countries with already high manufacturing shares**

Note: Rounding differences may appear

Indicative

Costs are mostly well-distributed – Accumulations of costs can be seen for battery in Hungary, Sweden and Poland, and for Wind onshore in Spain and Germany

Overview scenario results: Total costs of base case by technology [EUR bn, 2023-2035 cum.]



While **most countries** host a **diversified** production of technologies, **some focus clearly** on selected technologies, i.e., Hungary for Battery

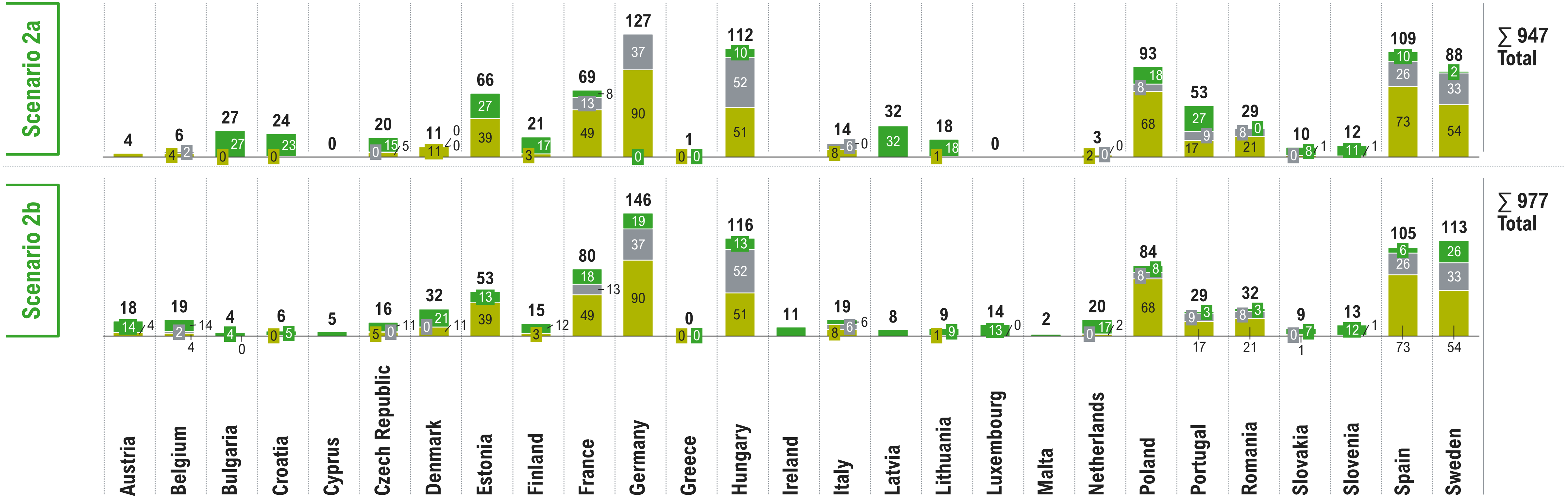
Solar PV | Wind onshore | Wind offshore | Electrolyzer | Heat pump | Battery

Note: Rounding differences may appear

Indicative

In the EU-optimized scenario 2a Portugal, Latvia and Bulgaria receive higher capacities while Scenario 2b allocation goes to Sweden, Denmark and Germany

Overview scenario results: Total costs of Scenario 2a/b by geography [EUR bn, 2023-2035 cum.]



In scenario **2a capacity** is distributed across **15 countries** with highest shares in **Portugal, Latvia and Bulgaria** – Almost all countries receive capacity in **scenario 2b** with **Sweden, Denmark and Germany** in the lead

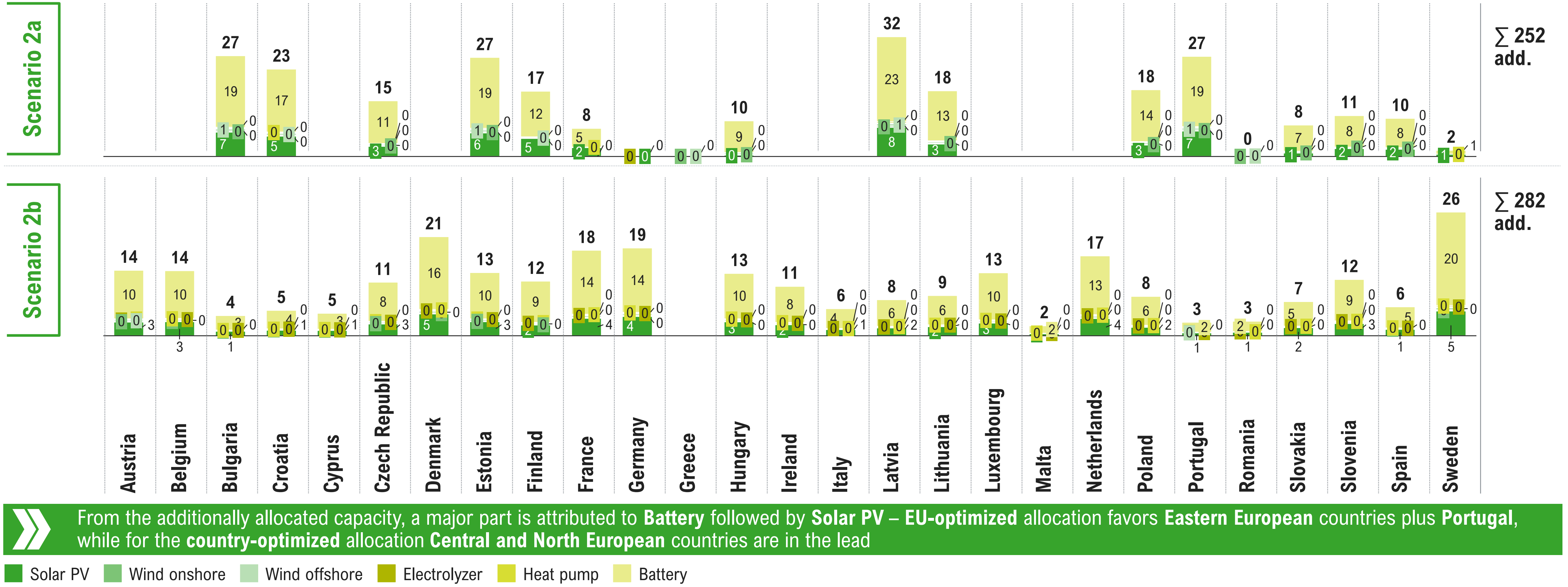
As-is manufacturing base | Manufacturing base additions | Scenario 2a/b additions

Note: Rounding differences may appear

Indicative

The country allocated capacity of the scenarios 2a/2b is distributed across multiple countries – In 2a, the capacity is allocated to less countries therefore higher shares

Overview scenario results: Additional costs of Scenario 2a/b by technology [EUR bn, 2023-2035 cum.]



From the additionally allocated capacity, a major part is attributed to **Battery** followed by **Solar PV** – **EU-optimized** allocation favors **Eastern European** countries plus **Portugal**, while for the **country-optimized** allocation **Central and North European** countries are in the lead

Note: Rounding differences may appear

Based on the country allocation OPEX reductions of up to c. 15% are possible driven by highly country-specific labor and energy costs – Highest savings for scenario 2a

Overview scenario results: OPEX – Unit manufacturing costs per component

PV

Significant OPEX savings achievable in scenario 2a, followed by NZIA and then 2b

- Highest absolute OPEX reduction for **wafer** while most significant relative reduction rates are achieved for **Si-cells**
- On average[1] c. 39% **labor cost** reduction for 2a, c. 2% for 2b and c. 12% for NZIA
- On average c. 22% **energy cost** reduction for 2a, c. 11% for 2b and c. 8% for NZIA

Wind

Major reduction possible in scenario 2a, medium savings for 2b and partially OPEX increase for NZIA scenario

- **Onshore nacelle** and **tower**[2] generate main savings in labor (up to c. 50% in 2a) and lower for energy (c. 14%) – Labor cost increase for tower in 2b by c. 9%
- Comparably even higher savings for **offshore blade**[2] could be traced back to expensive country allocation of the base case

Electrolyzer

High labor cost savings for PEM in 2a followed by NZIA and 2b, low energy savings achievable

- C. **-62% labor cost** reduction for **PEM**[2] in 2a and only a third thereof for 2b
- Energy costs reduce in 2b by c. 8% while 2a and NZIA show -5% – Relatively low savings imply already **low energy countries** in the **base case**
- Solid NZIA savings show base case costs ranging clearly above EU-average costs, esp. labor

Heat Pump

Medium savings detectable for 2a driven by labor followed by NZIA, while 2b hardly differentiates from the base case

- **Labor** savings possible with highest **impact on 2a** with c. 48%, followed by NZIA with c. 24%
- **Energy cost** decrease only for 2a with c. 4%, while an **increase** of c. 10-13% appears for **2b and NZIA** – Hence, the base case already includes a footprint of low energy cost countries

Battery

Relatively low reduction potential due to low labor and energy cost share of total OPEX as well as cost-efficient base case

- Similar trend for both LFP and NMC
- While **labor cost** savings of c. 29% are achievable for 2a, costs for **2b and 3 increase** implying country ambitions in high labor cost countries
- **Energy costs** hardly decrease for 2a (c. 4%) and **increase** for 2b and NZIA (c. 3-7%)

» Major OPEX savings achievable in the scenarios for labor and energy due to country allocation – By far **highest savings** possible **for scenario 2a**
- Up to **c. 60% labor cost** reduction possible, while **energy costs** decrease by up to **c. 25%** - Impact on **total OPEX** of up to **c. 15 %**

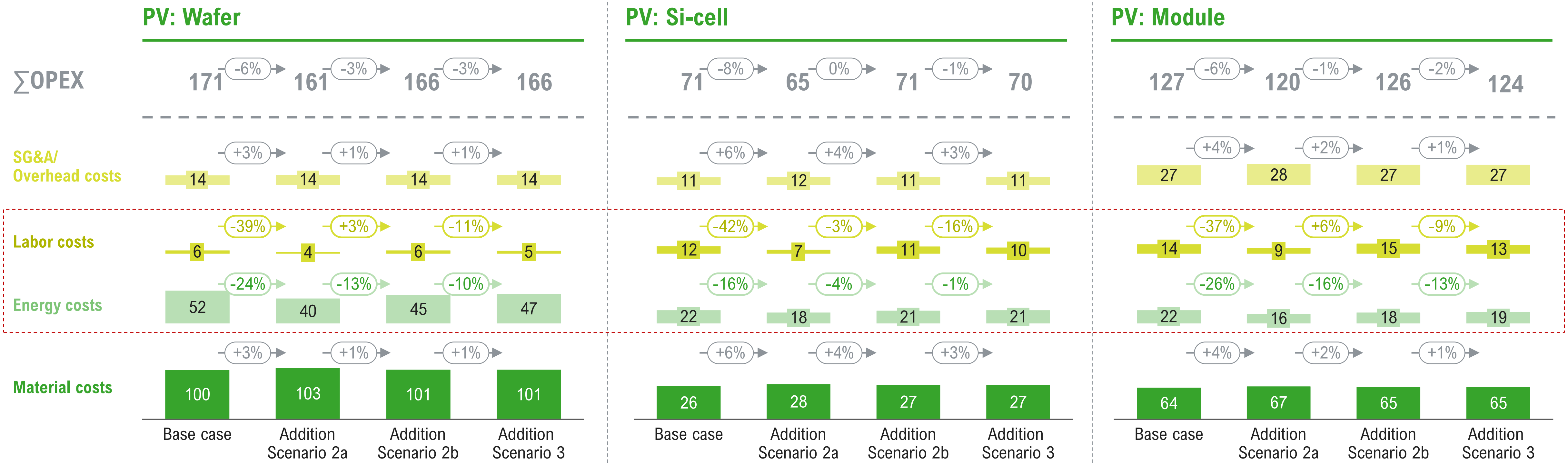
1) Average reduction rates across components, no weighting of absolute values; 2) Only component(s) with capacity expansions in scenarios 2a and 2b

Source: IEA (2022), European Commission (2023), IRENA (2022), NREL (2023), Fraunhofer ISE (2021), Durham University (2021), IEA (2023), Department of Energy & Climate Change (2016), Universität Münster (2021)

Exemplary deep dive | Indicative analysis

OPEX decrease for 2a by 6-8% and by < 3% for 2b and 3 – Decrease driven by labor savings in relative terms (c. -40% for 2a), energy (c. -22% for 2a) in absolute terms

Unit manufacturing costs per component: Example PV [EUR/kW]



- Highest absolute OPEX reductions due to highest share of total Solar PV OPEX costs
- Most relative savings for labor costs in scenario 2a across all components
- Most relative savings for energy costs in scenario 2a across all components

Material costs | Energy costs | Labor costs | SG&A/Overhead costs | -x% / -x% Change compared to base case based on country-specific costs | +x% Change compared to base case based on inflation

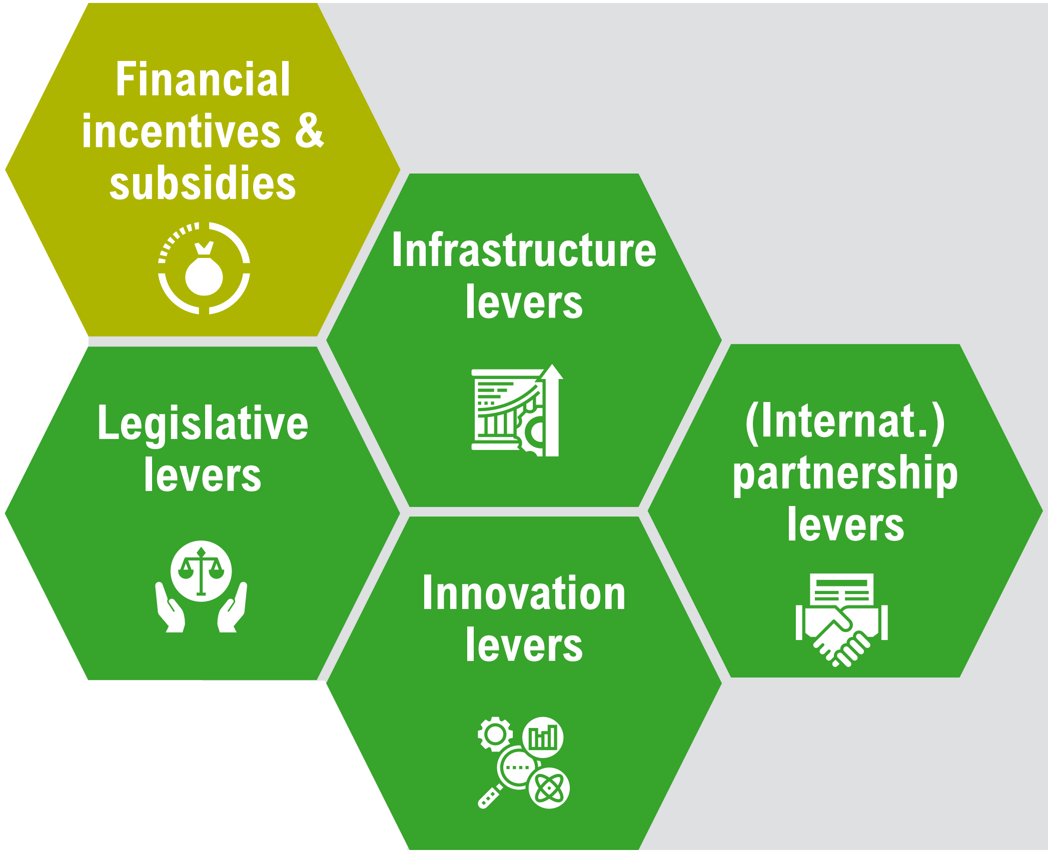
Source: IEA (2022), European Commission (2023), IRENA (2022), NREL (2023), Fraunhofer ISE (2021), Durham University (2021), IEA (2023), Department of Energy & Climate Change (2016), Universität Münster (2021)

B.3 Policies

B.3.1 Summary policy levers

The policy booklets cover five key levers across all technologies: Financial incentives & subsidies, infrastructure, legislation, R&D and international partnerships

Key components financial incentives, subsidies and policy levers

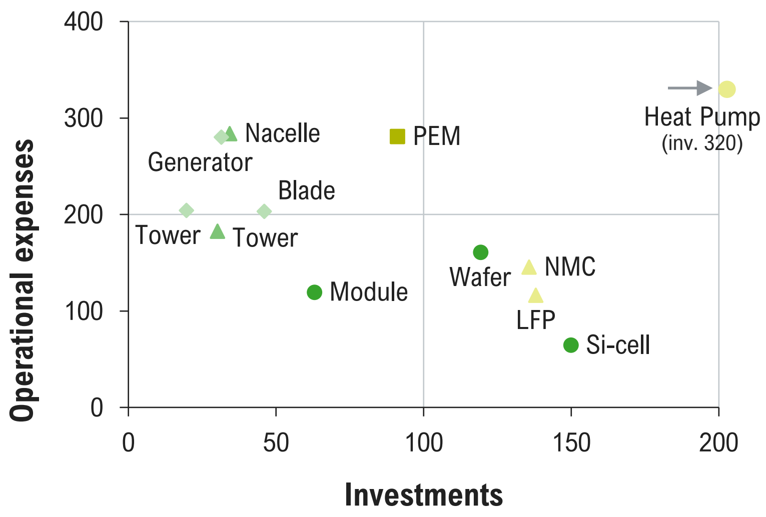


- **Assessment and evaluation of all five key policy levers** across the focus technologies (PV, Wind, Electrolyzer, Heat Pump and Battery) from an EU-wide point of view
- **Identified policy levers …**
  - Focus **on public-led initiatives** supporting the required scale-up to realize the growth in EU-based manufacturing
  - Identify and tackle international partnerships needed to successfully navigate the growth pattern
  - Support and enable required private investments
- Evaluation tackles key issues and risks identified throughout the project without specific focus on an individual scenario

Wind components appear to benefit most from OPEX-support, whereas Wafer, Cell and Battery show more CAPEX needs – Heat Pump & PEM show overall high

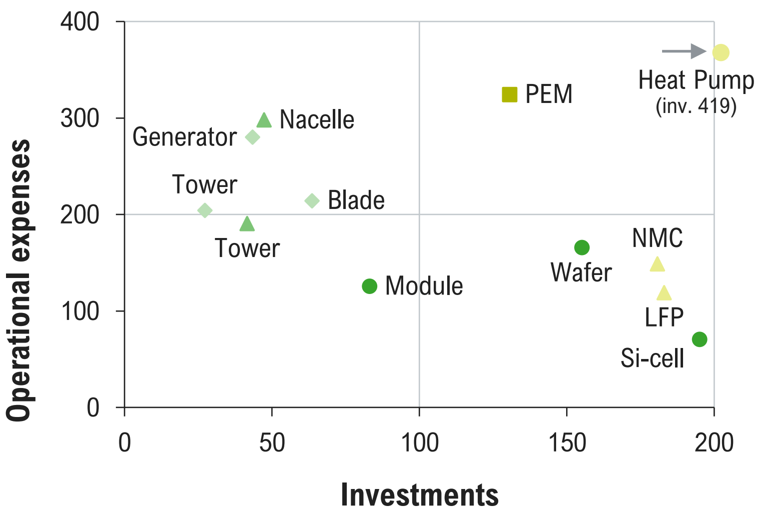
Overview financial incentives and subsidies by investments and OPEX [2035]

Scenario 2a [EUR/kW[1)]]



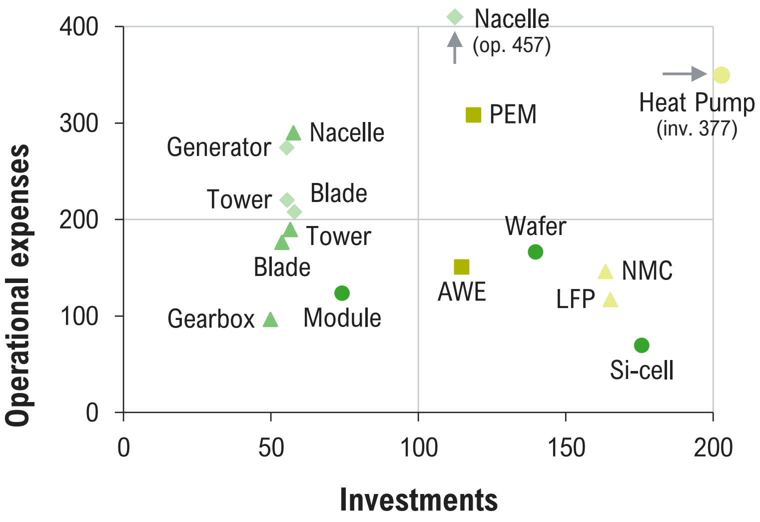
- For **PV (Wafer, Si-cell)** and **Battery** (LFP, NMC), **CAPEX** incentives could balance required investments (considering capacity ramp-ups)
- **Offshore Generator, Onshore Nacelle** and **Electrolyzer (PEM)** could benefit from **OPEX** subsidies while investments are below average
- **Heat Pump** are categorized by both, high OPEX as well as investment costs – Financial support warranted in both dimensions

Scenario 2b [EUR/kW[1)]]



- For **PV Wafer** and **Si-cell** plus **Battery, CAPEX** requirement are even higher than in S2a – CAPEX-driven incentives could be advised
- **Wind** components show **above average OPEX**, particularly Onshore Nacelle and Offshore Generator
- **Heat Pump** are both, OPEX as well as investment-intensive, followed by **PEM** – General financial support necessary

Scenario 3 [EUR/kW[1)]]



- Besides **Battery** and **PV Wafer** and **Si-cell**, **AWE** Electrolyzer show higher investment requirements in scenario 3
- **Wind components** have lower investment costs while OPEX partially rise above average in need for financial incentives
- **Heat Pump** show high OPEX and investments, followed by **Offshore Nacelle** with extreme OPEX and **PEM** in the fourth quadrant

● PV ▲ Wind onshore ◆ Wind offshore ■ Electrolyzer ▲ Battery ● Heat Pump

1) For Battery, the unit is EUR/kWh

Key levers include high importing standards, supporting the expansion of raw material extraction & processing, supporting innovation and fostering relationships

Key policy levers across all technologies

1 Legislative levers

- **Creating a strong, but fair border for non-EU manufactured technologies from low-cost countries** (e.g.: China)
  - **Minimum level of proof of origin for energy mix used** (RES) during production, raising the bar for Chinese-fossil fuel produced PV panels
  - **Minimum level of proof of origin for used raw materials** upholding highest ESG-Standards (e.g.: child labor, Employee treatment, etc.) – Particularly for rare heavy and light metals
- **Ensuring an agile and swift local market** with eased permitting procedures and a harmonized legislative framework at EU- and country-level

2 Infrastructure levers

- **Raw material extraction & processing**
  - Leverage and foster **EU extraction capacities** to fulfill demand for high intensity materials from 'within' Europe: Iron Ore, Silica sand/Silicon, Aluminum, Copper
  - Support and set-up of **raw material processing and refining sites** including Polysilicon for PV
  - Explore **expanding & tapping into existing, but not yet explored deposits** of raw materials (e.g.: Lithium, Copper, REEs) within the EU (e.g.: Finland, Sweden)
  - Increase **recycling of key raw materials** and components by setting up appropriate infrastructure and end-to-end processes
- **Components**
  - Invest in increasing **capacities for manufacturing of pre- or subcomponents** such as permanent magnets for Wind, chips/semiconductors for Heat Pumps and anode/cathode production for batteries
  - Increase in **energy supply** and **strengthening of the energy grid**
  - **Invest in and increase job attractiveness** to train more installers to execute on given demand given the skilled labor shortage across Europe

3 Innovation levers

- **Supporting innovations:**
  - Lean and efficient production processes for existing, market preferred technologies
  - Establish innovation support for pre- and/or sub-components (e.g., Balsa wood alternatives for Blades)
- Support establishing **market entry level of new, high TRL technologies**
- Launch and strengthen **further R&D of medium TRL** solutions with high potential

4 International partnerships

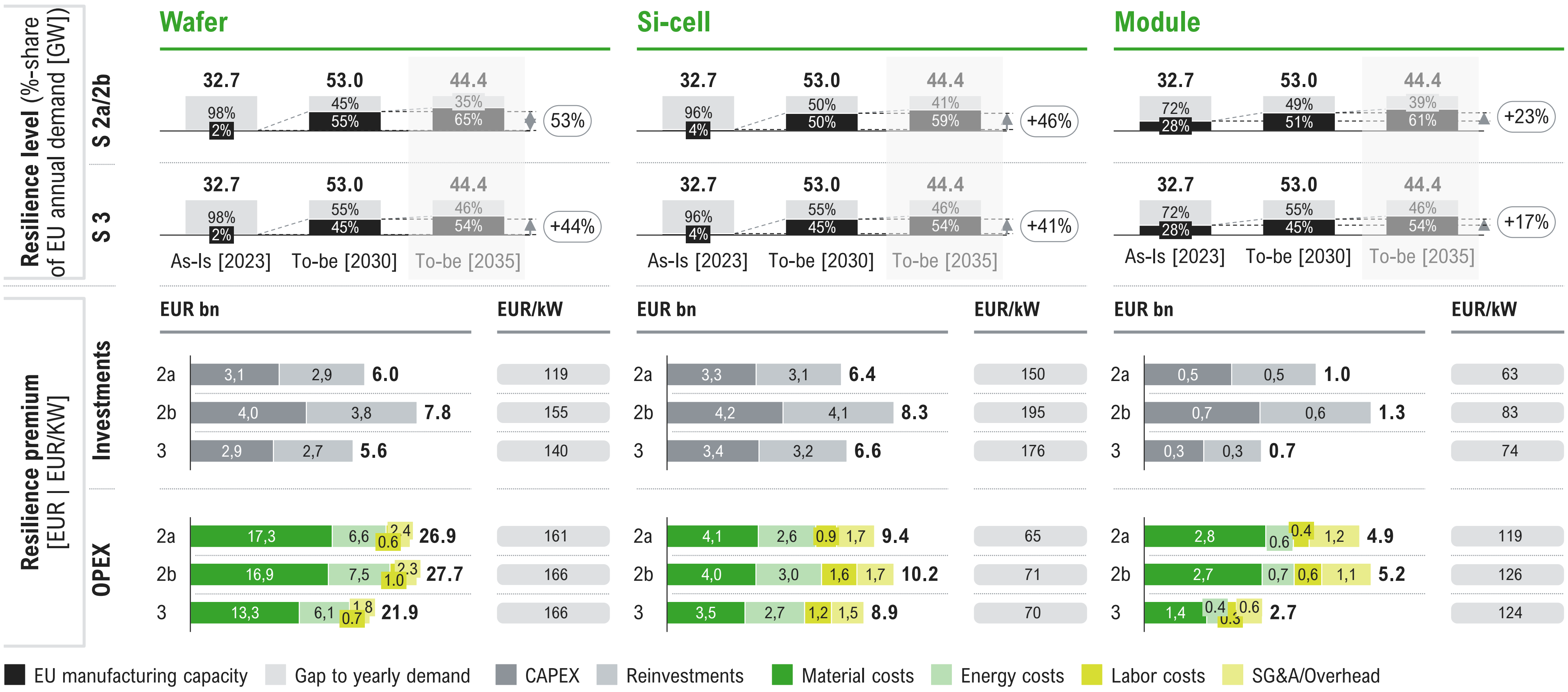
- **Raw material extraction & processing:** Establish/foster trade relationships with potential alternatives to sourcing raw materials from extraction/processing-rich countries
  - **Diversify and enhance number of suppliers for high volume materials** incl. Iron Ore, Silica Sand, Copper, Aluminum, Zinc, Nickel and Graphite
  - **Set-up preferred supplier schemes** and **incentives for medium-and-low material density materials** with high relevance, including Manganese, Chromium, Lithium, Cobalt, Molybdenum, Silicon and Phosphorus
  - Strengthen and foster **trade relationships for materials with small material density, but high impact on production**, including, REEs, PGMs, Titanium, Zirconium and Boron
- **Components**
  - Diversify supply of key components for technology manufacturing, including permanent magnets, semiconductors and membranes
- **Exports:** Strengthen partnerships and trade relations with existing key export destinations such as North America (US), Europe (UK, CH) and Asia

Source: JRC (2022), European Commission (2023)

B.3.2 Technology deep dives

For PV, wafer production with highest OPEX/GW due to material and Si-cells with highest CAPEX/GW requirements – Module mid-range in between

Financial incentives & subsidies: PV



- **Manufacturing resilience level** set to increase by 23 to 53 ppts. (S2a/b) vs. 217 to 44 ppts. for S3
- **Wafer production** with highest OPEX/GW due to material costs (polysilicon) and energy intensity of production process
- **Si-cell production** with highest capital intensity per GW due to esp. high equipment costs
- **Module production** with lowest capital intensity per GW due below-average equipment costs
- For **OPEX-oriented incentives & subsidies**, focus should be primarily on energy
- For **investment-oriented measures**, consideration of both new (CAPEX) and existing (reinvestments) production facilities

Note: Rounding differences may appear

PV will require substantial CAPEX-support due to the desired increase in resilience – Key levers raise the bar for non-EU products and foster partnerships

Policy levers: PV

1 Legislative levers

- **Creating a strong, but fair border for non-EU PV**
  - **Minimum level of proof of origin for energy mix used** (RES) during production, raising the bar for Chinese-fossil fuel produced PV panels
  - **Minimum level of proof of origin for used raw materials** upholding highest ESG-Standards (e.g.: child labor, Employee treatment, etc.) – Particularly for rare heavy and light metals
- **Ensuring an agile and swift local market** with eased permitting procedures and a harmonized legislative framework at EU- and country-level

2 Infrastructure levers

- **Raw material extraction & processing**
  - Leverage and foster **EU extraction capacities** to fulfill demand for high intensity materials from 'within' Europe, including Iron Ore, Silica sand/Silicon, Aluminum, Copper and Silver
  - Support and set-up of **raw material processing sites**, particularly for the polysilicon production (besides Wacker Chemie in Germany) to ease processing dependency on China
  - Increase **recycling of key raw materials** and components including Copper (from 55%), Aluminum (from 32%) Iron Ore (from 31%), Silicon (from 1%), Silica sand (from 0)
- **Components**
  - **Wafer:** (Potential) Increase in energy supply and strengthening of the grid due to high energy needs for production
  - **Cells and modules:** Promote reliable energy supply and foster a skilled workforce

3 Innovation levers

- **Supporting innovations:**
  - **Wafer production**
    - Invest into lean and efficient production processes to enable a competitive wafer production considering China's current monopoly
- **Support establishing market entry level of new, high TRL technologies**
  - Focus on **HJT** (Heterojunction) and **TopCon** for improvements for monocrystalline cells as technologies with currently highest technology readiness
- **Launch and strengthen further R&D of medium TRL solutions with high potential**
  - Mid-term potential of **Perovskite** and **bifacial modules** with medium, premature TRL levels – R&D necessity to advance development

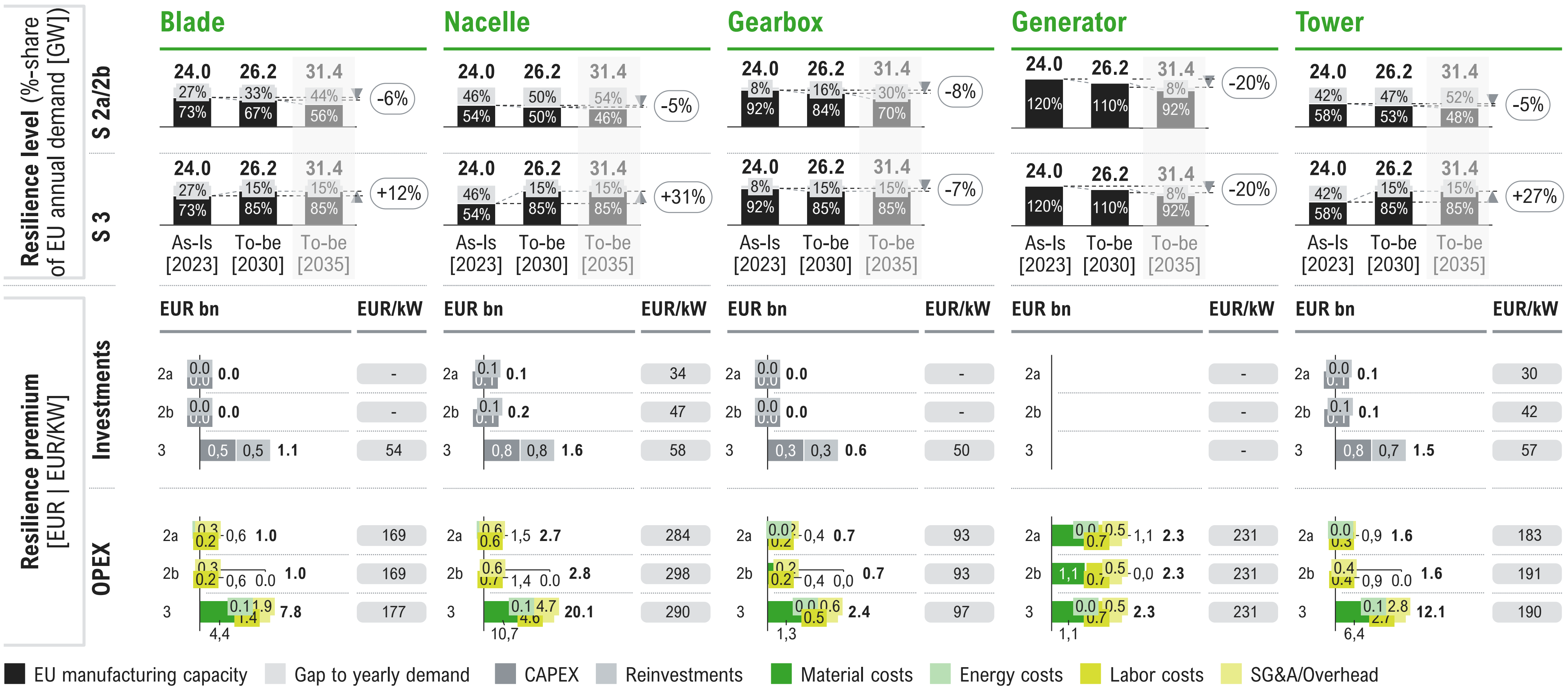
4 International partnerships

- **Imports:** Establish/foster trade relationships with potential alternatives to sourcing raw materials and components from China
  - **Raw material extraction & processing**
    - **Aluminum:** Australia, Guinea, Brazil and India
    - **Copper:** Chile, Peru, US & Australia
    - **Silver:** Mexico, Peru, Chile & Australia
  - **Components**
    - Strengthen partnerships with current key sourcing partners Japan, US, Malaysia, Taiwan
    - Consider further diversification of trade partners for cell sourcing, e.g.: Canada, South Korea, Taiwan, Malaysia, Singapore, Vietnam, India and the US
- **Exports:** Strengthen partnerships and trade relations with existing key export destinations, including the United States, Singapore, UK, Switzerland and Turkey

Source: JRC (2022), European Commission (2023)

Limited investments for Wind onshore needed with comparable CAPEX/GW shares – Nacelle, Generator and Tower with highest OPEX/GW shares

Financial incentives & subsidies: **Wind onshore**

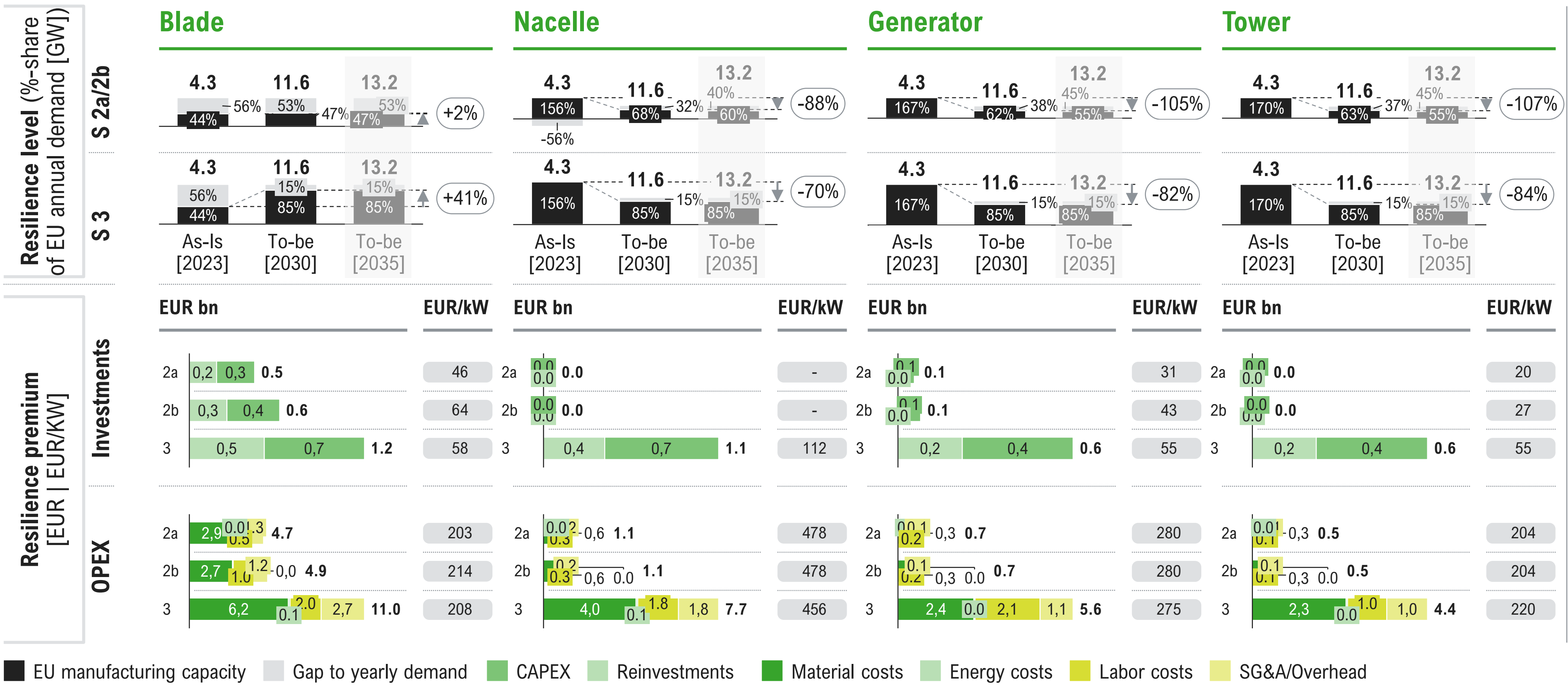


- **Manufacturing resilience level** set to decrease by -20 to -5 ppts. (S2a/b) vs. -20 to +31 ppts. for S3
- No expansion of Generator production in any scenario targeted
- **Blade and Gearbox production only expanded in S3** – Comparable CAPEX/GW, however higher OPEX/GW for Blade production
- Nacelle and Tower with expansions in all scenarios at comparable CAPEX/GW – Nacelle with highest OPEX/GW needs
- For **OPEX-oriented incentives & subsidies**, focus should be primarily on labor
- For **investment-oriented measures**, consideration of both new (CAPEX) and existing (reinvestments) production facilities

Note: Rounding differences may appear

OPEX dominate Wind offshore costs and would likely require financial incentives – Similar OPEX/GW for Blade, Generator and Tower with expansions in the scenarios 2

Financial incentives & subsidies: Wind offshore



- **Manufacturing resilience level** set to change by -107 to +2 ppts. (S2a/b) vs. -84 to +41ppts. for S3
- **Nacelle production only expanded in S3** – Highest CAPEX/GW as well as OPEX/GW across all components
- Minimal expansions for Tower– Lowest CAPEX/GW and lower end OPEX/GW needs
- Relevant expansions across all scenarios for Blade and Generator – Mid- to lower-ranged CAPEX and OPEX per GW requirements
- For **OPEX-oriented incentives & subsidies**, focus should be primarily on labor
- For **investment-oriented measures**, consideration of both new (CAPEX) and existing (reinvestments) production facilities

Note: Rounding differences may appear

Rare Earth Elements supply and availability drives Wind onshore and offshore technologies – Strengthening and building new trade relationships key lever

Policy levers: Wind onshore & offshore

1 Legislative levers

- **Creating a strong, but fair border for non-EU Wind components**
  - **Minimum level of proof of origin for energy mix used** (RES) during production
  - **Minimum level of proof of origin for used raw materials** upholding highest ESG-Standards (e.g.: child labor, Employee treatment, etc.) – Particularly for rare heavy and light metals
- **Ensuring an agile and swift local market** with eased permitting procedures and a harmonized legislative framework at EU- and country-level

2 Infrastructure levers

Raw materials – On- & offshore

- **Extraction & Processing**
  - Leverage and foster EU extraction capacities to fulfill demand for high intensity materials from 'within' Europe, e.g.: Iron Ore, Copper, Silica Sand & Aluminum
  - **Support exploration & set-up of REE mining opportunities** (e.g.: SE, FI)
  - Explore options to tap **into explorable known deposits** for Iron Ore & Copper
- **(Further) increase recycling rates** for **high-material intensity materials** incl. Copper (from 55%), Zinc (from 34%), Aluminum (from 32%) Iron Ore (from 31%) and Manganese (from 9%)
- **Boost recycling rates, especially for REEs & magnets** from currently <1%

Components – Offshore

- Support EU-based manufacturing of permanent magnets for PMSGs[1] to decrease overall dependency of China

3 Innovation levers

Support establishing market entry level of new, high TRL technologies

- **Generator – Onshore // Gearbox-driven**
  - **Hybrid-drives** with smaller permanent magnets due decrease dependency on REEs and already high TRL
  - **SCIG**[2] as mature technology - Focus on decreasing efficiency disadvantage

Launch and strengthen further R&D of medium TRL solutions with high potential

- **Generator – Offshore // Direct drive**
  - **HTS**[3] as potential alternative due to REEs savings and chances for production output increases – early TRL requires R&D investments
- **Blades (incl. rotor)**
  - Alternatives to Balsa Wood including Recycled polyethylene terephthalate (rPET) or other hybrid designs as well as bio-composite materials such as hemp curd cellulose

4 International partnerships

Imports: Avoid Chinese market dominance

- **Raw materials**
  - **Diversification of the REE**[4] and Boron supply for permanent magnets away from China (see following deep dive)
  - **Balsa Wood (Blade):** Ecuador (close to 90%) and China
  - **Molybdenum:** Chile, US, Peru, Mexico
  - **Manganese:** South Africa, Australia, Gabon, Ghana, Brazil for extraction and Norway, Ukraine & Spain for processing
  - **Nickel:** Finland, Canada, Greece, South Africa for extraction and Finland, Nor-way, Canada & Australia for processing
- **Components**
  - Magnet manufacturing in China

Exports:

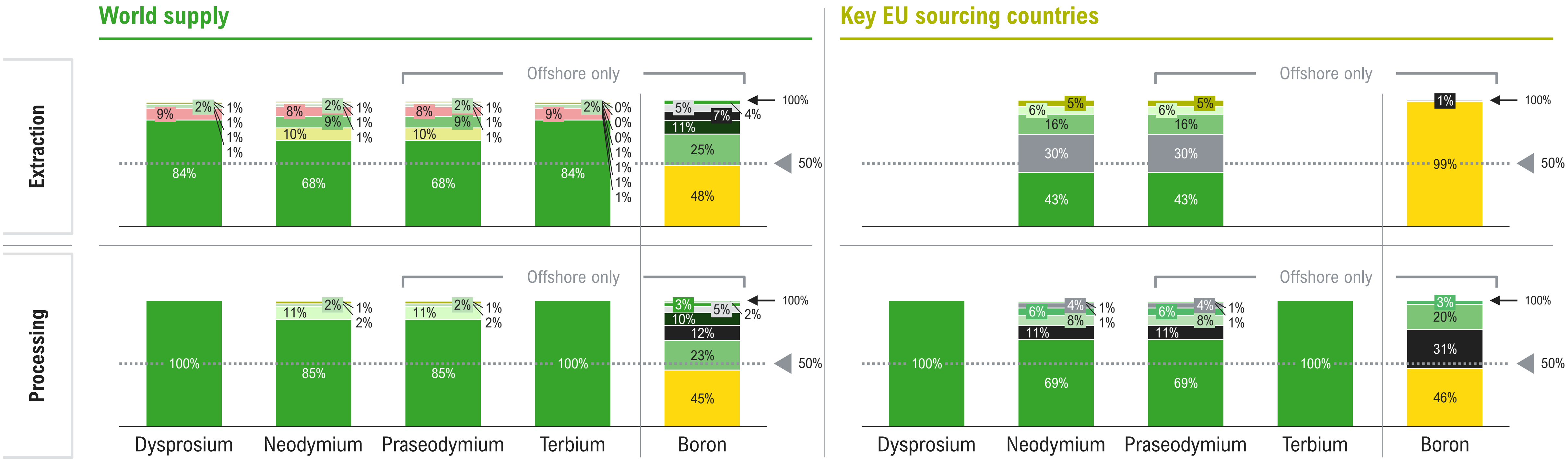
- Strengthen partnerships and trade relations with existing key export destinations, including the UK, the US, Taiwan and Turkey

1) Today, only 8 permanent magnet manufacturers are based in Europe with total capacity of 1000 tons, resulting in not only a raw material, but also sub-component dependency to China; 2) SCIG: Squirrel Cage Induction Generator – With full converter; 3) HTS: High-temperature superconductors; 4) REE = Rare Earth Elements; Neodymium & Dysprosium for Wind onshore; Neodymium, Dysprosium, Praseodymium and Terbium for Wind offshore

Source: JRC (2022), European Commission (2023)

China dominates REE extraction & processing – However, alternative supply routes with Myanmar, the US, Australia and Malaysia could alleviate some dependencies

Overview world supply & key EU sourcing countries for REEs[1] & Boron



China is dominant in the Rare Earth Elements' (REE) world supply both for extraction and processing – However, Europe is already working on a diversified supply for extraction (Japan, US, Malaysia, India) and processing (Russia, UK and Japan) for Neodymium and Praseodymium

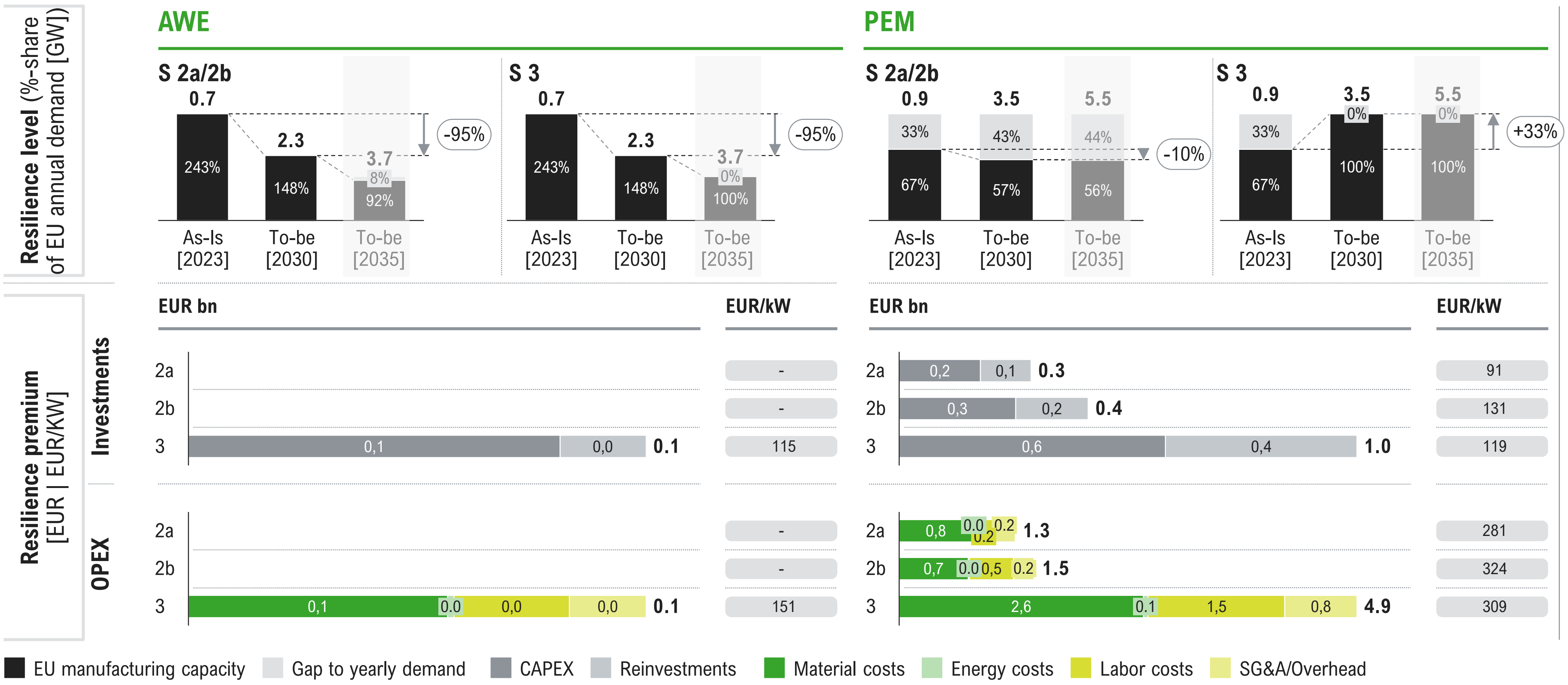
Australia | Brazil | China | India | Japan | Malaysia | Myanmar | Russia | Thailand | United Kingdom | United States | Vietnam | Turkey | Chile | Bolivia | RoW

1) REEs = Rare Earth Elements

Source: European Commission (2023)

PEM Electrolyzer as only technology with expansions across all scenarios – C. triple absolute OPEX compared to CAPEX requirements with higher OPEX/GW than AWE

Financial incentives & subsidies: Electrolyzer



- **Manufacturing resilience level** set to decrease by -10 to 95 ppts. (S2a/b) vs. -95 to +33 ppts. for S3
- **AWE production only expanded in S3** – Slightly lower CAPEX/GW for S3, while OPEX/GW are significantly lower
- **PEM expansions in all scenarios** with lowest CAPEX/GW in S2a, while CAPEX/GW for S2b are c. 44% higher – Similar but weaker trend for OPEX/GW
- For **OPEX-oriented incentives & subsidies**, focus should be primarily on labor
- For **investment-oriented measures**, consideration of both new (CAPEX) and existing (reinvestments) production facilities

Note: Rounding differences may appear

Albeit being technology leader, Europe is heavily dependent on raw material imports for its (comparably) well developed Electrolyzer manufacturing sites

Policy levers: Electrolyzer

1 Legislative levers

- **Creating a strong, but fair border for non-EU produced Electrolyzer**
  - **Minimum level of proof of origin for energy mix used** (RES) during production
  - **Minimum level of proof of origin for used raw materials** upholding highest ESG-Standards (e.g.: child labor, Employee treatment, etc.) – Particularly for rare heavy and light metals
- **Ensuring an agile and swift local market** with eased permitting procedures and a harmonized legislative framework at EU- and country-level

2 Infrastructure levers

Raw materials

- Leverage and foster **EU extraction capacities** to fulfill demand for high intensity materials from 'within' Europe, e.g.: Iron Ore & Aluminum (PEM, AWE) and Copper (PEM)
- Exploring options to tap into **minable deposits to produce key materials** needed for Electrolyzer production (i.e.: Natural Graphite in Germany)
- Setting up the appropriate **recycling infrastructure** for the collection, dismantling and processing of the relevant products, components and materials at EU-wide level to alleviate pressure on raw material & component sourcing
- Increase especially the PGM recycling rate (from 12%)

3 Innovation levers

Overall

- Developing circular Electrolyzer design options including new procedures for recycling and collecting used materials
- Foster and support research focused on substitution of materials for existing, mature technologies, e.g.: Avoidance of PGM (Platinum Group Metals) for PEM

Support establishing market entry level of new, high TRL technologies

- SOE[1] already in demonstration phase of development – Requires further investment to support market maturity – Technology with low-cost materials

Launch and strengthen further R&D of medium TRL solutions with high potential

- AEM[2] as technology with medium TRL, combining 'best of both worlds' from AWE and PEM with high efficiency & lower cost

4 International partnerships

Imports:

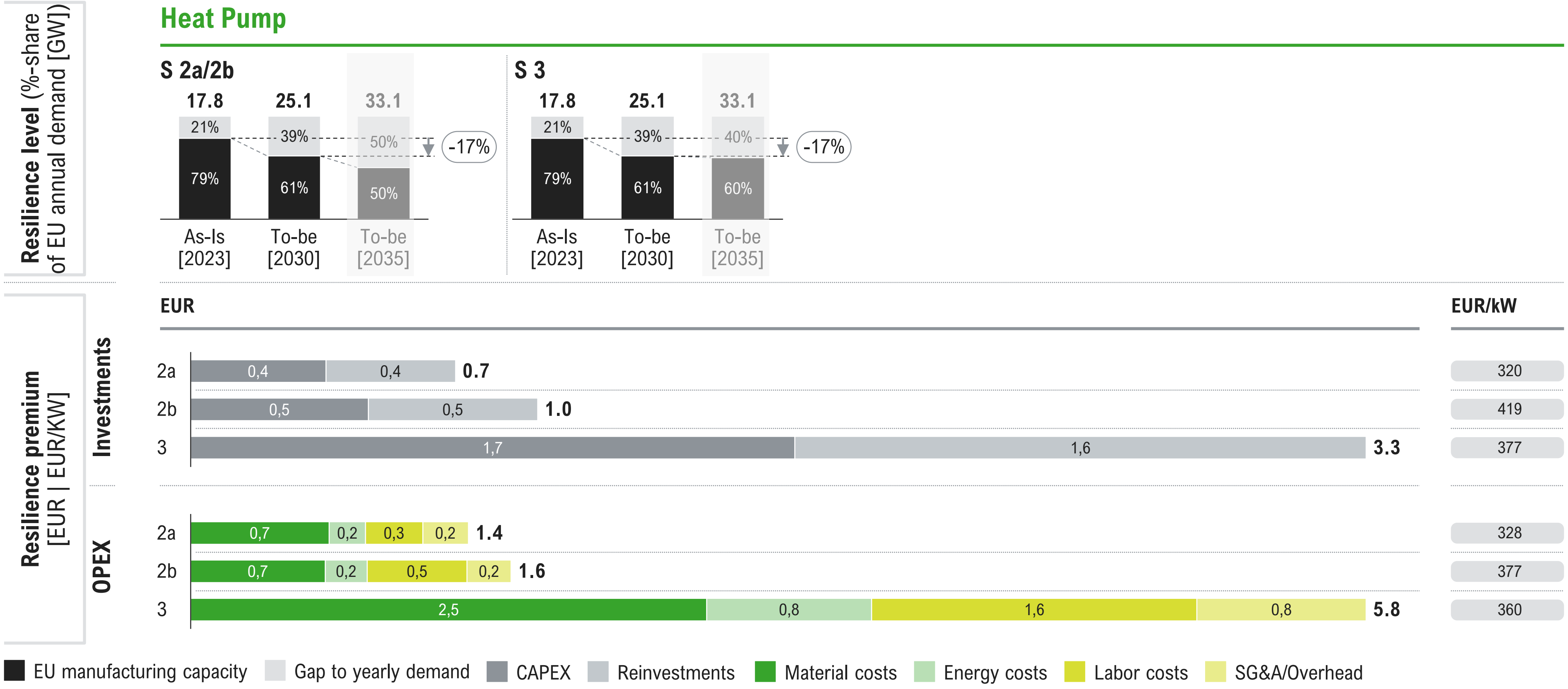
- **Raw materials**
  - **PEM**
    - **Focus on establishing reliable trade route(s) for Platinum Group Metals (PGM)** due to dependence on South Africa and its alternative Russia
    - **Titanium:** Australia for extraction and Japan, Kazakhstan and Ukraine as alternatives to CN & RU for processing
  - **AWE**
    - **Nickel:** Indonesia, Philippines, Canada
    - **Zirconium:** Australia, South Africa, Mozambique and Senegal for extraction
    - **Natural Graphite:** Brazil, Mozambique, India and Madagascar for extraction

1) SOE = Solid oxide Electrolyzer; 2) AEM = Anion Exchange Membrane

Source: JRC (2022), European Commission (2023)

In case of OPEX subsidies, the focus should lie on the labor-intensive production of Heat Pumps – Financing for both households and manufacturers is reasonable

Financial incentives & subsidies: **Heat Pump**



- **Manufacturing resilience level** set to decrease by 17ppts. for S2a/b as well as for S3
- **Similar CAPEX as well as OPEX** absolute and per GW ranges – Highest costs for S2b followed by S3
- For **OPEX-oriented incentives & subsidies**, focus should be primarily on labor
- For **investment-oriented measures**, consideration of both new (CAPEX) and existing (reinvestments) production facilities
- **Increase availability of finance** both for **households** (for the up-front cost of purchasing the Heat Pump) and **manufacturers** (for the expansion and conversion of production lines)

Note: Rounding differences may appear

Key levers for Heat Pumps focus on supporting industries such as semiconductor production and provision of skilled labor – Some raw material dependency on China

Policy levers: Heat Pump

1 Legislative levers

- **Creating a strong, but fair border for non-EU produced Heat Pumps**
  - **Minimum level of proof of origin for energy mix used** (RES) during production
  - **Minimum level of proof of origin for used raw materials** upholding highest ESG-Standards (e.g.: child labor, Employee treatment, etc.) – Particularly for rare heavy and light metals
- **Ensuring an agile and swift local market** with eased permitting procedures and a harmonized legislative framework at EU- and country-level

2 Infrastructure levers

Raw materials

- **Extraction & Processing**
  - Leverage and foster EU extraction capacities to fulfill demand for high intensity materials from 'within' Europe, e.g.: Iron Ore, Copper, Aluminum & Nickel (very limited capacities in EU)

Subcomponents

- **Address overall chips/semiconductor shortage** (required in the circuit board of the Heat Pump controller) by investing in local EU production
- **Support the recycling of parts** (i.e. valves, fans, etc.) by setting-up and/or leveraging key infrastructure (i.e. collection of parts)

Other

- Invest in and increase job attractiveness to train more installers to execute on given demand given the skilled labor shortage across Europe in this area

3 Innovation levers

Support establishing market entry level of new, high TRL technologies

- Advance usage of **Heat Pumps in industrial processes** beyond the low-temperature marks (+200°C) (TRL 4-7)

Launch and strengthen further R&D of medium TRL solutions with high potential

- Support innovation efforts for new technologies including magnetocaloric, thermo-acoustic, membrane and transcritical thermal compression Heat Pumps (all in early R&D stages)

Other

- Investment in advancing existing technologies' by decreasing upfront costs, increasing efficiency yields and establishing plug-and-play business models

4 International partnerships

Imports: Establish/foster trade relationships with potential alternatives to sourcing raw materials and components from China

- **Raw materials**
  - **Aluminum:** Australia, Guinea, Brazil and India
  - **Copper:** Chile, Peru, US & Australia
  - **Nickel:** Finland, Canada, Greece, South Africa for extraction and Finland, Nor-way, Canada & Australia for processing (alternatives to Russian supply)
- **Components**
  - Foster relationships with current trade partners other than China, including Japan, the UK, Malaysia and Thailand

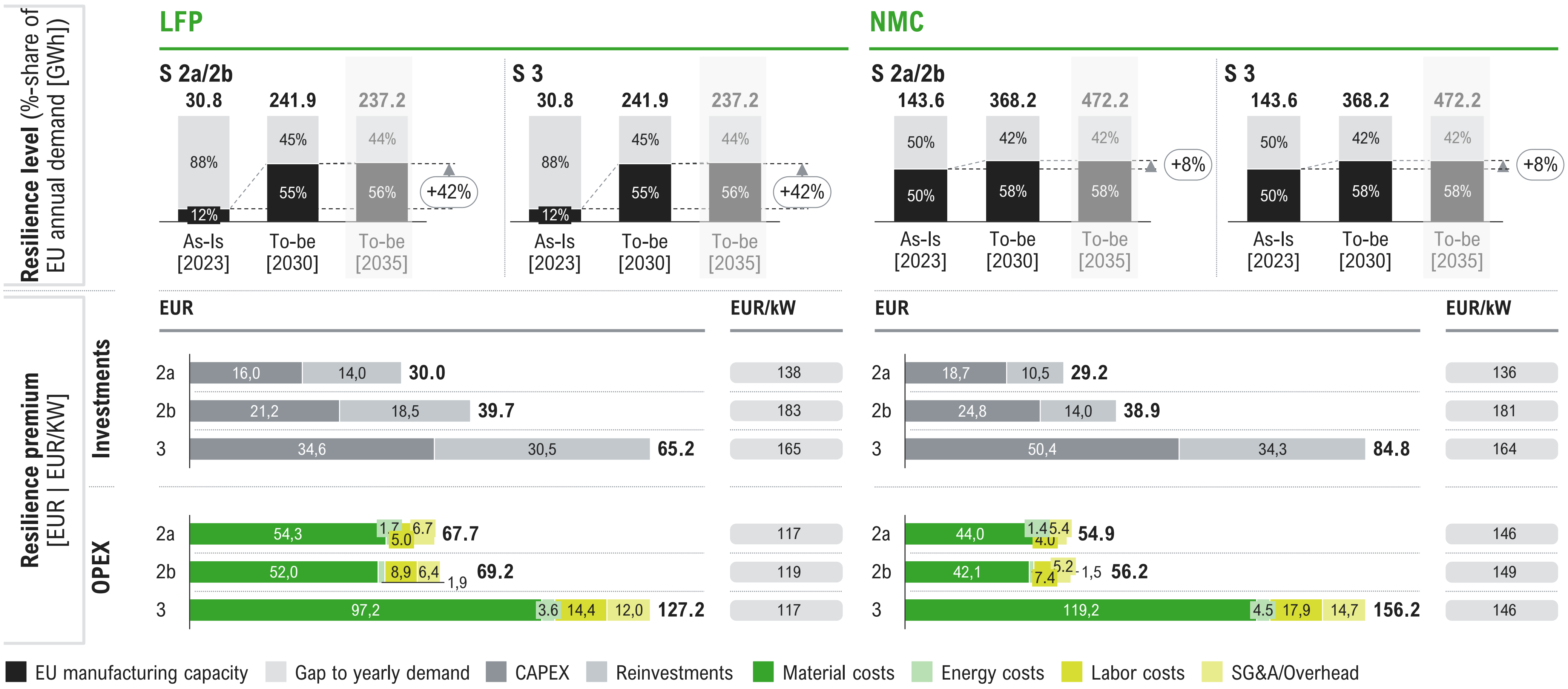
Exports:

- Strengthen partnerships and trade relations with existing key export destinations, including Switzerland, the UK, the US, Norway and Australia

Source: JRC (2022), European Commission (2023)

Battery LFP and NMC show similar figures for CAPEX and OPEX to increase vs. uphold resilience level – OPEX costs driven by labor costs after material share

Financial incentives & subsidies: Battery



- **Manufacturing resilience level** set to increase by 42 ppts. across all scenarios for LFP and by +8% for NMC
- Similar CAPEX/GW for both technologies, while OPEX/GW for NMC are higher than for LFP
- In absolute terms, CAPEX range equally while OPEX for LFP are higher for S2a/b
- For **OPEX-oriented incentives & subsidies**, focus should be primarily on labor
- For **investment-oriented measures**, consideration of both new (CAPEX) and existing (reinvestments) production facilities

Note: Rounding differences may appear

Constraints in availability of key materials require well-thought out and managed international partnerships to manage risk and ensure smooth production runs

Policy levers: **Battery**

1 Legislative levers

- **Creating a strong, but fair border for non-EU produced Electrolyzer**
  - **Minimum level of proof of origin for energy mix used** (RES) during production
  - **Minimum level of proof of origin for used raw materials** upholding highest ESG-Standards (e.g.: child labor, Employee treatment, etc.) – Particularly for rare heavy and light metals
- **Ensuring an agile and swift local market** with eased permitting procedures and a harmonized legislative framework at EU- and country-level

2 Infrastructure levers

Raw materials

- **Applicable to both technologies**
  - Support refining of key raw materials applicable to both technologies such as lithium, copper and manganese
  - Setting up the appropriate **recycling infrastructure** for the collection, dismantling and processing of the relevant products, components and materials at EU-wide level
- **LFP**
  - Support the establishing of refining of battery-grade Lithium and Graphite – Lithium also with untapped deposits
- **NMC**
  - Expand existing capacities for battery-grade refining of Nickel and Cobalt
- **Components**
  - Support implementing the operating capacity in the EU for producing anodes and cathodes as key sub-components

3 Innovation levers

Support establishing market entry level of new, high TRL technologies

- NMC
  - Support development and existing **trend towards** replacing high cobalt tech. such as NMC622 by **nickel-rich chemistries** like NMC811
- **Launch and strengthen further R&D of medium TRL solutions with high potential**
- **Flow battery**
  - **Organic redox flow** (recyclable organic materials, TRL 4-5) **entering market**, other flow batteries still at **early stage of development**
- **Solid state battery**
  - Potential for **thinner, more flexible** design, increased **energy density** as well as **safety** due to no liquid and flammable electrolyte
  - **Entering EV market**, however still in development

4 International partnerships

Imports:

- **Raw materials**
  - **Cobalt:** Congo, DR, Canada, Australia for extraction and Finland, Belgium, Canada, Norway & Japan for processing
  - **Phosphorus:** US for extraction & processing, Kazakhstan, Vietnam and UK as existing EU trade partners
  - **Lithium:** Key import countries include Chile, Australia and Argentina
  - **Manganese:** South Africa, Australia, Gabon, Ghana, Brazil for extraction and Norway, Ukraine & Spain for processing
  - **Natural Graphite:** Brazil, Mozambique, India and Madagascar for extraction
- **Components/parts**
  - China, US and UK for battery imports (NMC, LFP)

Source: JRC (2022), European Commission (2023)

B.3.3 Competitive outlook

Overall competitive outlook is positive given the weight of political will to establish and nurture an economically beneficial technology environment

Competitive outlook – Key elements

1 European cost competitiveness

Reaching and/or maintaining cost competitiveness vs. Asian manufacturers (i.e.: China) at the global market is likely only achievable if:

- OPEX-focused subsidies are kept in place permanently
- And/or innovations leading to significant cost reductions for only European manufacturers are made

2 European technology leadership

Strong focus on innovation and European IP creation required to safeguard and expand Europe's technology leadership position beyond proven technology tracks into new, disruptive technologies to ensure staying ahead of the curve, especially with regards to changes required in production set-ups

3 Learning curve and scaling effects

In the medium-to-long-term, a significant learning curve and scaling effect must be reached to support achieving a reasonable production size and to maintain 'right to play' at global scale (i.e.: Production size capacities in PV and for Battery vs. China) – This also applies to raw material and sub-component processing and production sites

4 International partnerships for sourcing

Focus on building new and foster existing relationships with key suppliers of

- High-material intensity materials required in large quantities (e.g.: Iron Ore, Aluminum, Copper)
- Medium-to-low, but rare and/or sought after materials (e.g.: PGMs, REEs, Manganese, Titanium, etc.)

5 Powerhouse for skilled labor

Raise in attractiveness of skilled labor profiles across all technologies in Europe to curb the exodus of needed specialists and keep up with high-level demand of both production-oriented and installation-oriented human capacities

6 Net zero targets and political motivation

Raise in overall attractiveness of technologies via given political pathways (i.e.: clear demand for RES for net zero targets) will further nourish the already foreseeable influx in private investments (i.e.: battery gigafactory announcements)

Given sufficient political support, Europe can maintain its technology leadership position across the focus technologies

C. Supporting documents

C.1 Technologies

Trends indicate that PV faces the highest disruption risk with HJT and TOPCon potentially ousting PERC cells – Elsewhere, technologies differ in application areas

Overview technology focus areas

Assessment in technology deep dives

PV

Overview & focus technology

- Ground-mounted or rooftop PV modules
  - **Crystalline silicon (c-Si)**
    - **Monocrystalline**
    - Multicrystalline
  - Thin-film solar (e.g., cadmium telluride, copper indium gallium selenide, amorphous silicon)

Upcoming innovations

Technology	TRL	Disruption level
mono-Si, HJT	8	↗
mono-Si, TOPCon	8	↗
Perovskite	4-6	→ / ↗

Overall rationale

Focus **on monocrystalline silicon** as unique proxy for PV due to high market share and efficiency advantages compared to multicrystalline silicon

Wind

Overview & focus technology

- **Gearbox double-fed induction generator (GB-DFIG)**
- Gearbox permanent-magnet synchronous generator (GB-PMSG)
- **Direct-drive permanent-magnet synchronous generator (DD-PMSG)**
- Direct-drive electrically excited synchronous gener. (DD-EESG)

Upcoming innovations

Technology	TRL	Disruption level
DD, HTS	4-5	↗
GB, hybrid drives	7-8	→ / ↗
GB, SCIG	9	→

Overall rationale

Focus on **DFIG for onshore** and **PMSG for offshore turbines** due to their high and increasing market share

Electrolyzer

Overview & focus technology

- **Alkaline Water Electrolyzers (AWE)**
- **Proton Exchange Membrane (PEM)**
- Solid oxide Electrolyzer (SOE)
- Anion Exchange Membrane (AEM)

Upcoming innovations

Technology	TRL	Disruption level
SOE	7	↘ / →
AEM	4-5	↘

Overall rationale

Focus on **AWE and PEM Electrolyzers** due to high market share and lower technology readiness of alternatives SOE and AEM

Heat Pump

Overview & focus technology

- **Air source (ASHP)**
  - Air-water[1] (ATW)
  - Air-air (ATA)
- Ground source (GSHP)
  - Ground-water[1] (GTW)
  - Ground-air (GTA)
- Water source (WSHP)
  - Water-water[1] (WTW)
  - Water-air (WTA)

Upcoming innovations

Technology	TRL	Disruption level
Industrial	4-9	↘ / →
Thermally driven	8-9	↘
Hybrid systems	9	↘

Overall rationale

ASHP will be used as proxy technology due to large market share of ATW and ATA and comparable processes and costs of ATW and ATA

Battery

Overview & focus technology

- Lithium-Ion battery:
  - **Lithium Iron Phosphate (LFP)**
  - **Lithium Nickel Manganese Cobalt Oxide (NMC), incl. subtypes, e.g., NMC111, NMC622, NMC811**
  - Others (e.g., NCA, LTO, LCO, LMO)

Upcoming innovations

Technology	TRL	Disruption level
NCA, LCO, LMO, LTO	9	→
Sodium (Na)	9	→
Solid state	5-6	↘ Medium-term

Overall rationale

Focus on **LFP and NMC** cell due to high market share for battery electric vehicles and battery energy storage

Disruption level: ↗ High → Medium ↘ Low

1) Alternative clustering: Hydronic Heat Pumps with water as heat distribution system, to be distinguished from air output Heat Pumps with air as distribution system

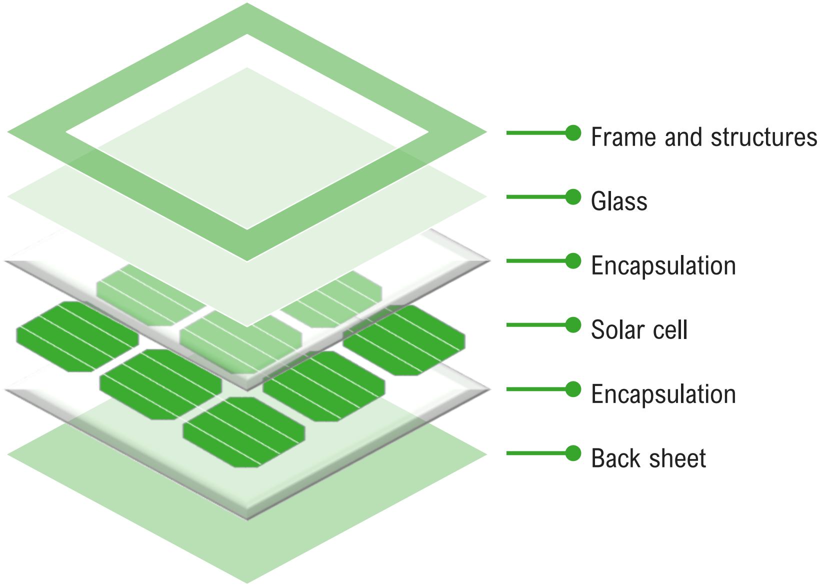
C.1.1 PV

Illustrative

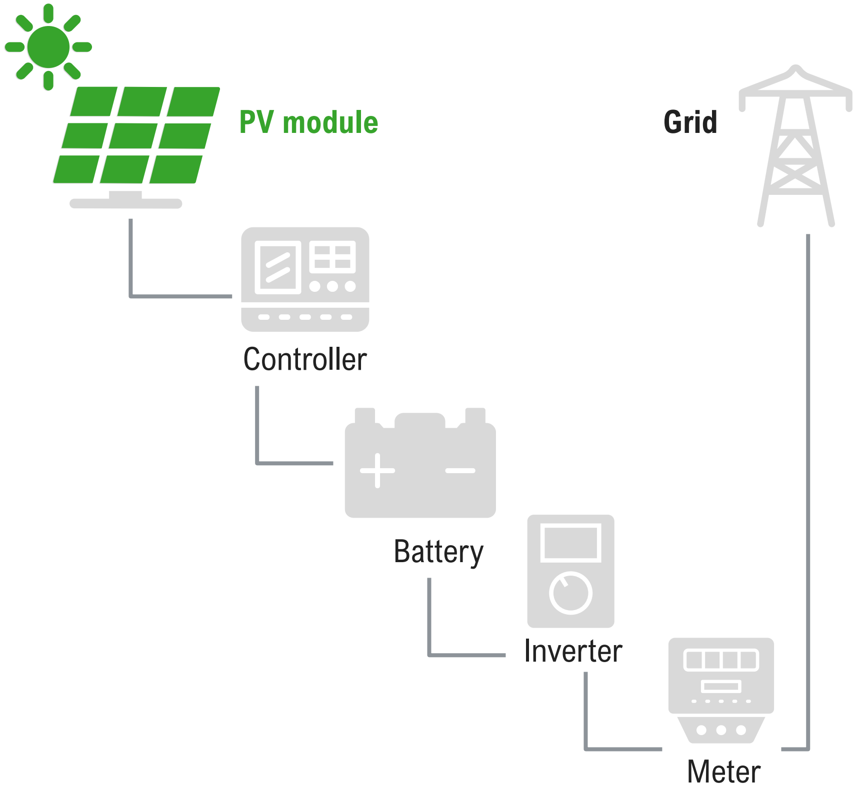
As part of the PV solar system, the PV module consists of solar cells with encapsulation and framing components – No focus on additional system appliances

Introduction: PV module

PV module



Integration of PV module with further appliances



Focus on **PV module and its components including standard structures**, without specialized racks (e.g., AgriPV) or foundations and without additional (electrical) appliances due to higher availability and individual designs

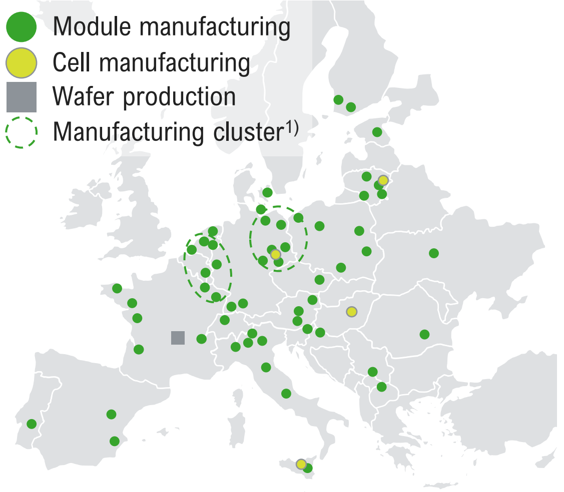
Within scope of the analysis | Out of scope

Source: European Union (2023), European Union (2020)

PV shows a minor European footprint with 28% domestic module and 4% domestic Si-cell manufacturing leading to a high international dependence

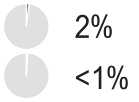
Technology overview – Solar PV

European value chain landscape

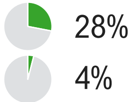


EU manufacturing capacities [2022]

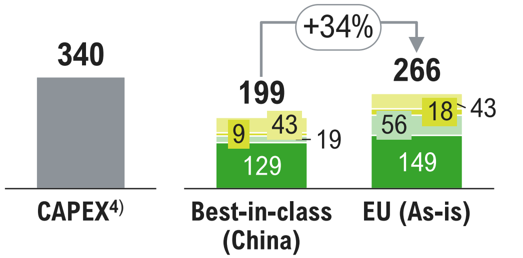
Global market share

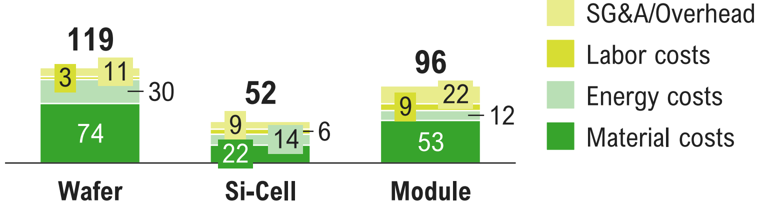


EU demand share[2)]

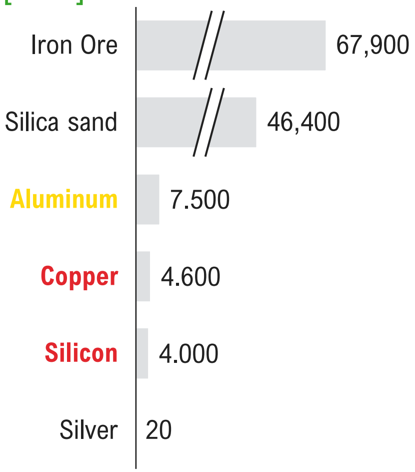


As-is unit manufacturing costs

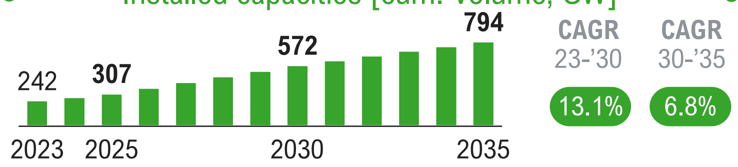


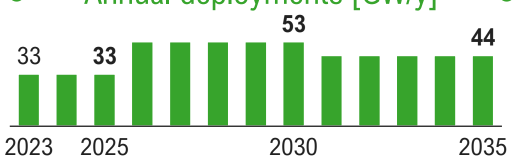


Raw material intensities[3)]



Demand [forecast 2023-2035]





Main supply risks

- **Key risks** include high **concentration of suppliers** and high **dependence on imports** with special exposure to Asian markets, resulting also in high **blockade of transport/trade routes** risks as well as medium political and force majeure risks
- **Disruptive technologies** such as HJT, TOPCon and Perovskite have the **potential to oust the predominant mono-Si technology** PERC

Strategic material Critical material

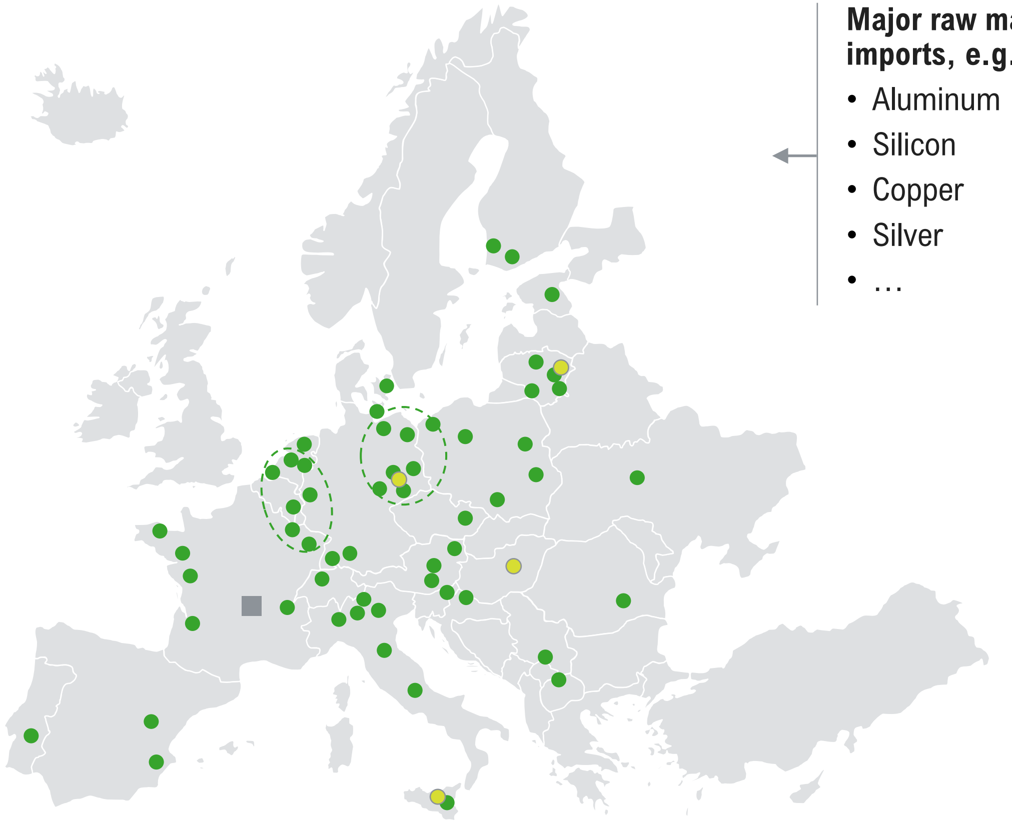
1) Geographical component manufacturing cluster; 2) Demand share understood as share of EU manufacturing capacity of total EU demand for a technology – Based on demand forecast for 2023 according to Agora EU Gas Exit Pathway and EU manufacturing capacity from literature analysis; 3) Selection of main raw material intensities – Assessment of strategic and critical raw materials according to European Unition (2023); 4) EUR/kW per yearly capacity; 5) Polysilicon is not depicted as separate component, therefore silicon processing is included as wafer material costs

Source: European Commission (2018, 2020, 2022), European Union (2023), Fraunhofer ISE (2022), IEA (2022, 2023), IRENA (2022), NREL (2022, 2023), Solar Power Europe (2022)

Map – non-exhaustive

For PV, geographical concentrations of module manufacturing plants can be found in Eastern Germany as well as in the Benelux region

PV: European value chain landscape



Major raw material imports, e.g.:
- Aluminum
- Silicon
- Copper
- Silver
- …

Component manufacturing: Module | Component manufacturing: Cell | Wafer production
Manufacturing cluster[1)]

EU manufacturing capacities[2)] [2022 | 2023 for EU demand share]

PV module [GW/y]	9	Global market share:	2 %	EU demand share:	28 %
Solar cell [GW/y]	1	Global market share:	<1 %	EU demand share:	4 %

Selected module manufacturing plants in Europe

Company	Country	Manufacturing capacity [GW/y]	Status
Enel (3Sun)	Italy (flag)	0.2 (expansion to 3 by 2024)	In operation
Meyer Burger	Germany (flag)	0.4 (expansion to 1)	In operation
Sonnenstromfabrik	Germany (flag)	0.2 (expansion to 0.5)	In operation
Solarwatt	Germany (flag)	0.3	In operation

Key European players with international manufacturing activities

enel (Italy)

REC (Norway)

1) Geographical component manufacturing cluster; 2) Demand share as share of EU manufacturing capacity of total EU demand (according to Agora EU Gas Exit Pathway, 2023)

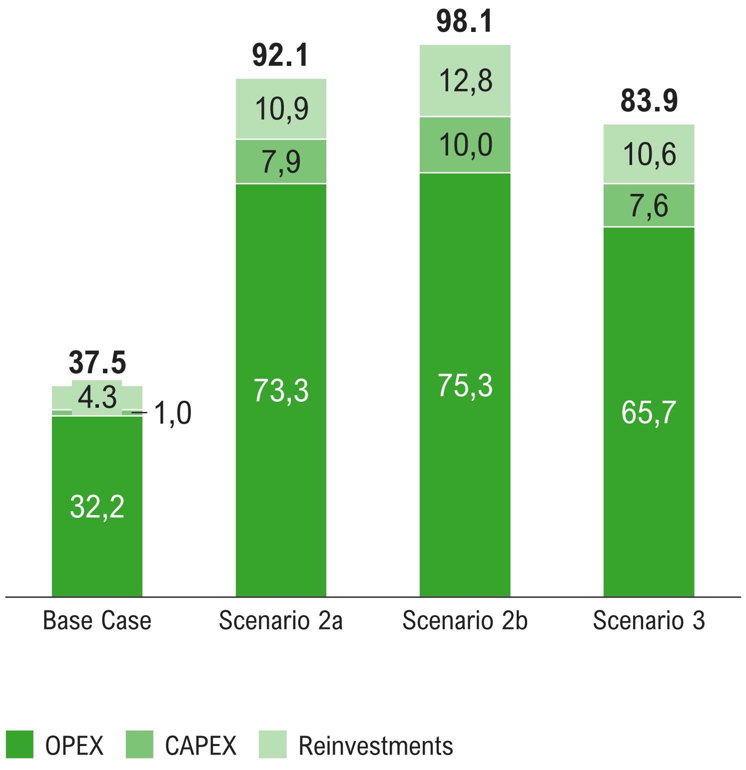
Source: Fraunhofer ISE (2022), IEA (2023), Solar Power Europe (2022)

While 2a/b OPEX costs double compared to the base case, CAPEX costs rise by the factor 9 – Major investments in wafer and Si-cell for resilience necessary

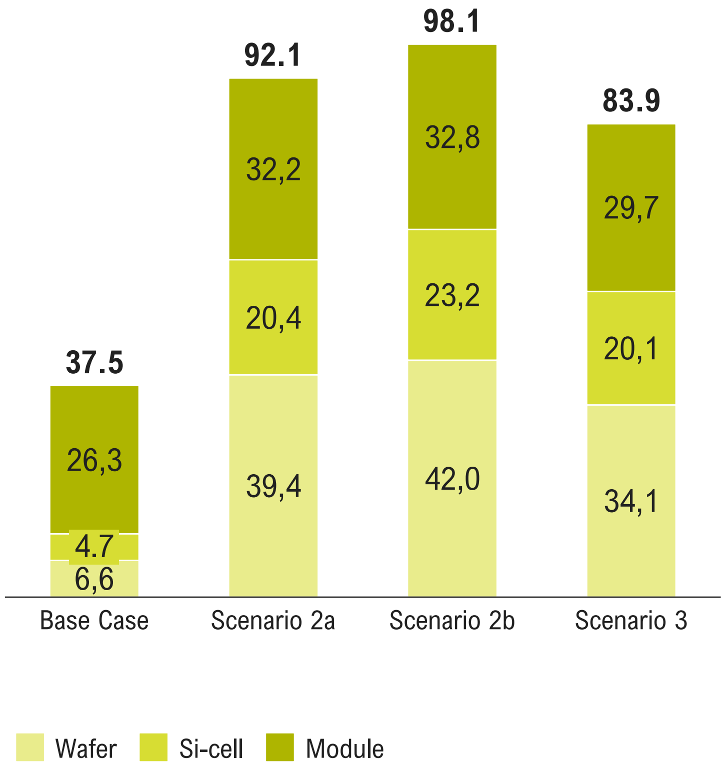
PV – Overview scenarios: Costs & resilience premium [EUR bn, 2023-2035 cum.]

Total costs [EUR bn, 2023-2035]

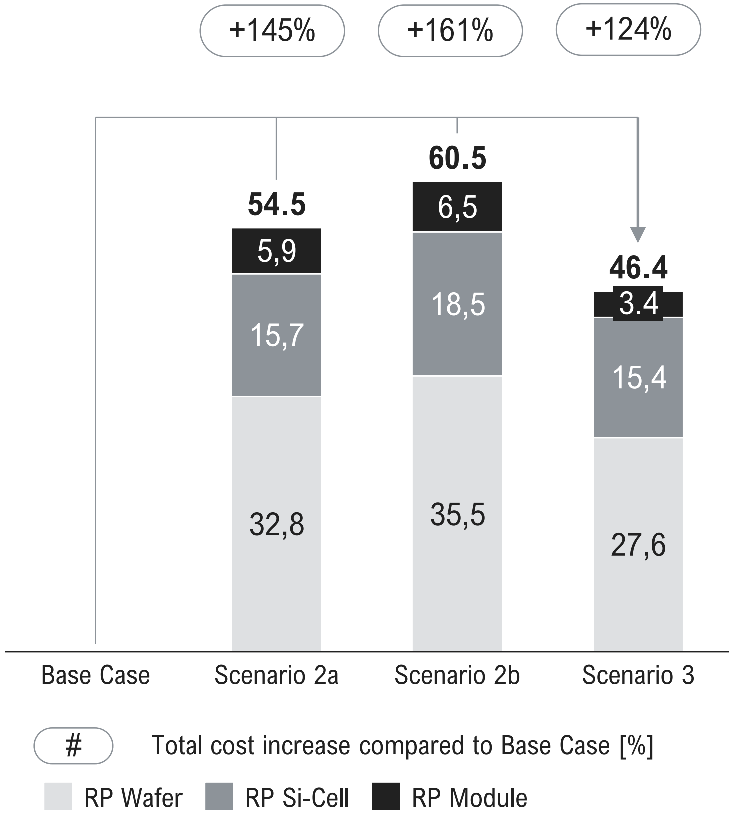
Cost types



Components



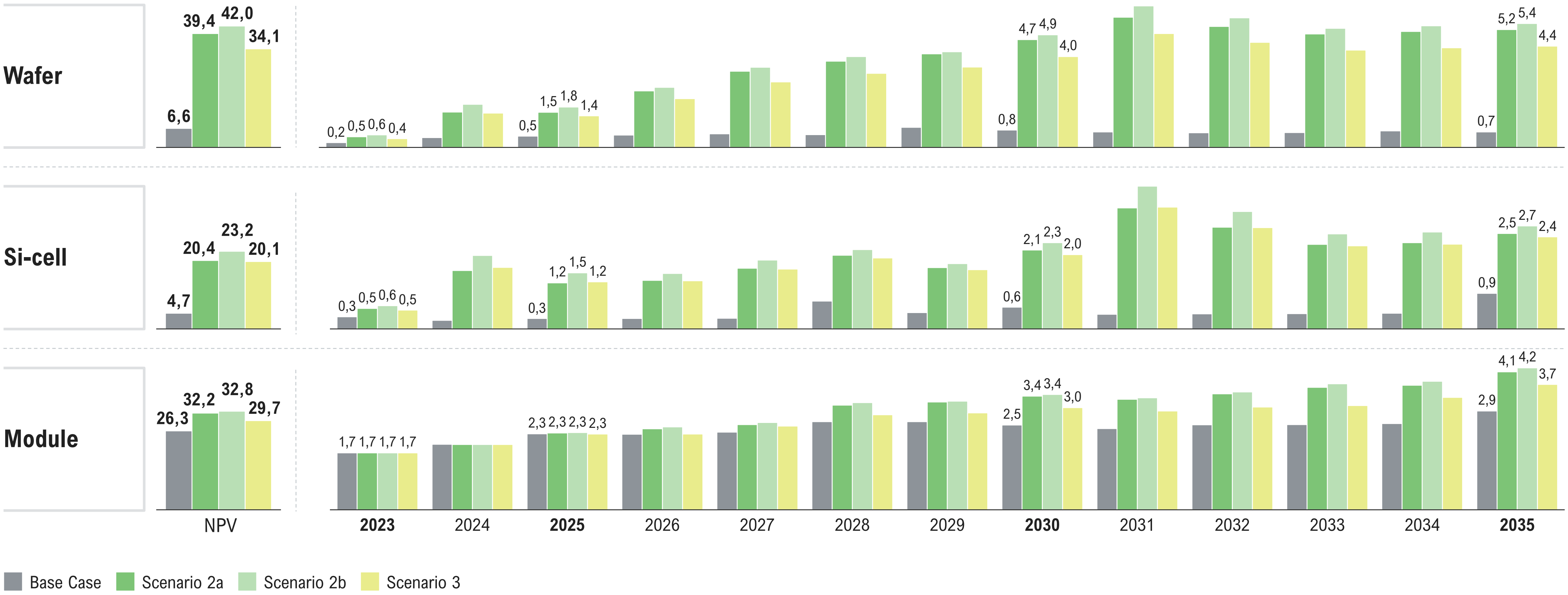
Resilience premium [EUR bn]



Final status as of June 7, 2023. Published in September 2023

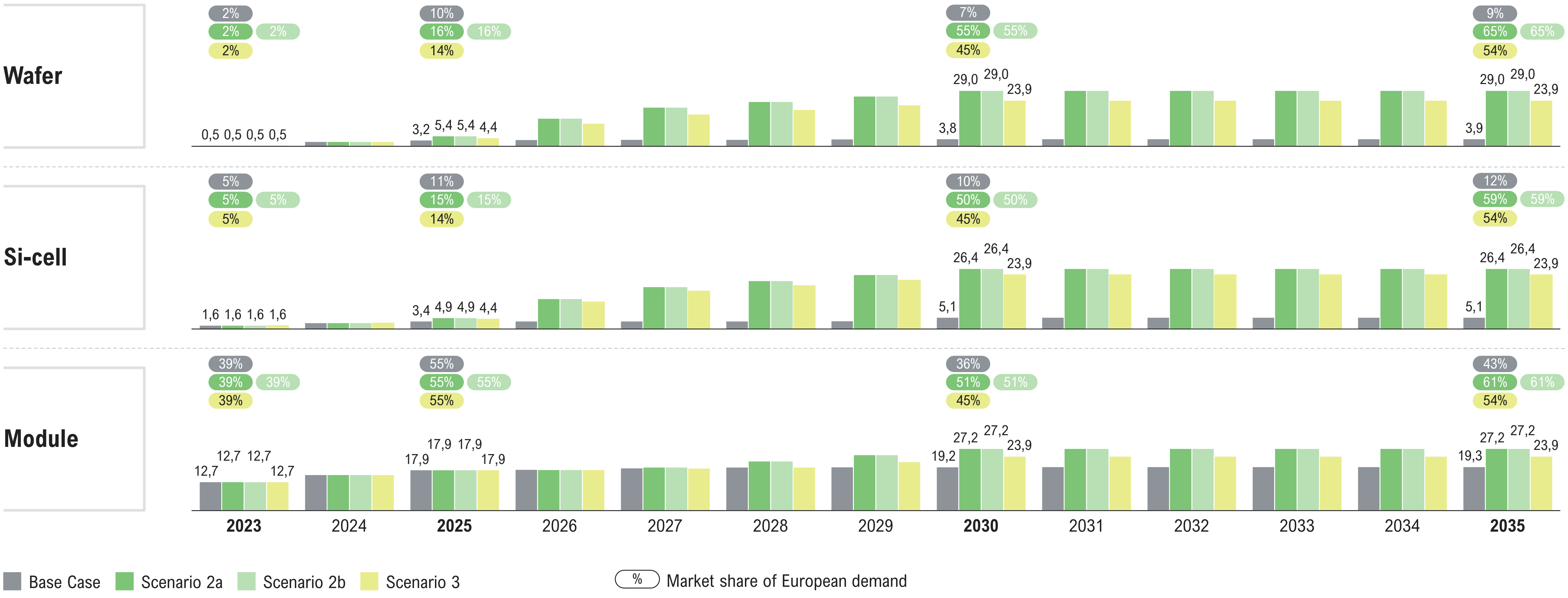
Wafer and Si-cell costs rise until c.2030 driven by CAPEX investments and stabilize thereafter – Modules show a steady increase trend driven by OPEX growth

PV – Overview scenarios: Total costs & NPV [EUR bn, NPV 2023-2035 cum.]



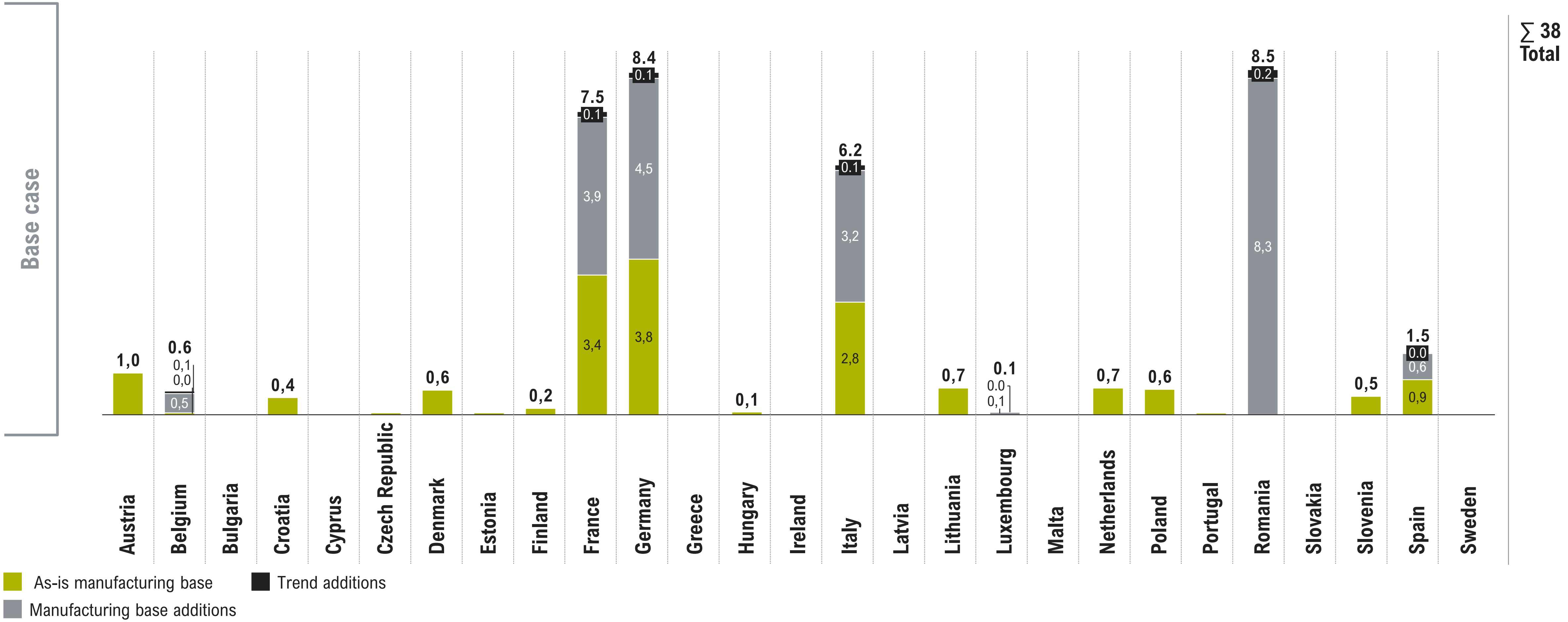
Extensive capacity ramp-up for wafer and Si-cell due to minimal existing capacities, while modules start with a market share of 39% and approx. double capacity

PV – Overview scenarios: Capacity and market shares [GW | %-share]



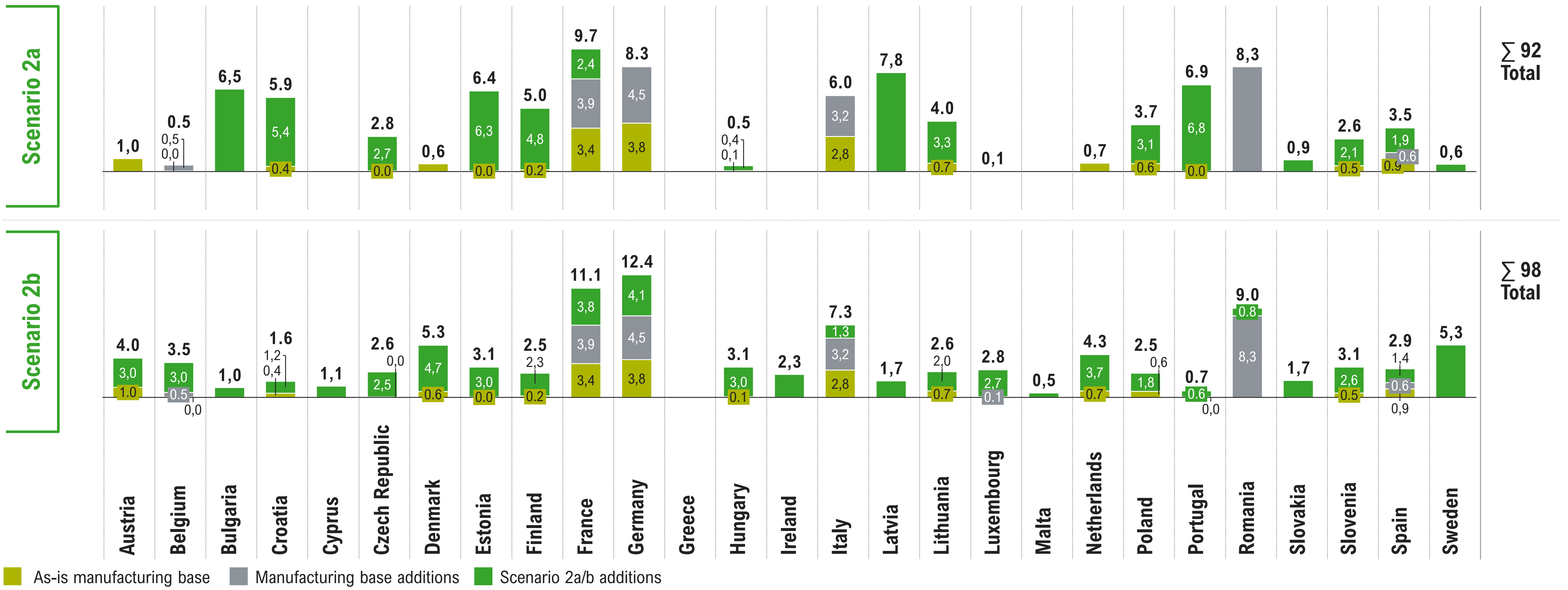
Additional capacity is announced in already strong manufacturing countries Germany, France and Italy except for a new expansion in Romania

PV – Overview scenarios: Total costs by geography [EUR bn, 2023-2035 cum.]



While country-optimized allocation is assigned to Denmark, Belgium and Hungary, EU-optimized capacities are more distributed with high rise in Portugal and Bulgaria

PV – Overview scenarios: Total costs by geography [EUR bn, 2023-2035 cum.]



Final status as of June 7, 2023. Published in September 2023

OPEX decrease for 2a by 6-8% and by < 3% for 2b and 3 – Decrease driven by labor savings in relative terms (c. -40% for 2a), energy (c. -22% for 2a) in absolute terms

PV – Overview scenarios: Unit manufacturing costs per component[1] [EUR/kW]

PV: Wafer

	Base case	Change	Addition Scenario 2a	Change	Addition Scenario 2b	Change	Addition Scenario 3
∑OPEX	171	-6%	161	-3%	166	-3%	166
SG&A/ Overhead costs	14	+3%	14	+1%	14	+1%	14
Labor costs	6	-39%	4	+3%	6	-11%	5
Energy costs	52	-24%	40	-13%	45	-10%	47
Material costs	100	+3%	103	+1%	101	+1%	101

- Highest absolute OPEX reductions due to highest share of total Solar PV OPEX costs

PV: Si-cell

	Base case	Change	Addition Scenario 2a	Change	Addition Scenario 2b	Change	Addition Scenario 3
∑OPEX	71	-8%	65	0%	71	-1%	70
SG&A/ Overhead costs	11	+6%	12	+4%	11	+3%	11
Labor costs	12	-42%	7	-3%	11	-16%	10
Energy costs	22	-16%	18	-4%	21	-1%	21
Material costs	26	+6%	28	+4%	27	+3%	27

- Most relative savings for labor costs in scenario 2a across all components

PV: Module

	Base case	Change	Addition Scenario 2a	Change	Addition Scenario 2b	Change	Addition Scenario 3
∑OPEX	127	-6%	120	-1%	126	-2%	124
SG&A/ Overhead costs	27	+4%	28	+2%	27	+1%	27
Labor costs	14	-37%	9	+6%	15	-9%	13
Energy costs	22	-26%	16	-16%	18	-13%	19
Material costs	64	+4%	67	+2%	65	+1%	65

- Most relative savings for energy costs in scenario 2a across all components

Material costs · Energy costs · Labor costs · SG&A/Overhead costs · -x% / -x% Change compared to base case based on country-specific costs · +x% Change compared to base case based on inflation

1) Only scenarios with additional capacity expansions illustrated – No scenario additions for generator, therefore not displayed

Source: IEA (2022), European Commission (2023), IRENA (2022), NREL (2023), Fraunhofer ISE (2021), Durham University (2021), IEA (2023), Department of Energy & Climate Change (2016), Universität Münster (2021)

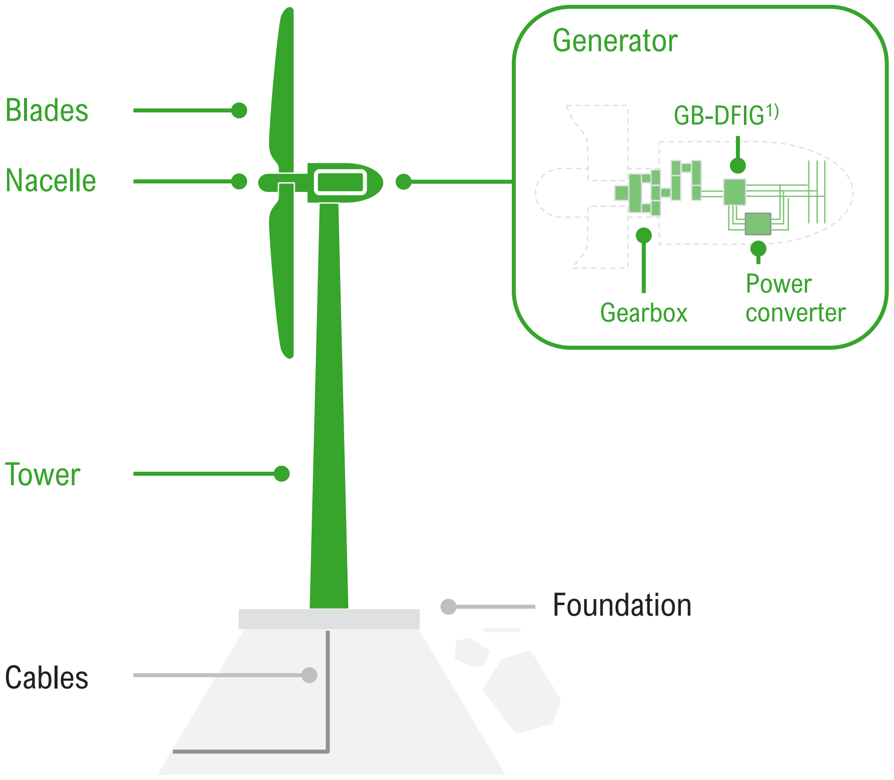
C.1.2 Wind onshore

Illustrative

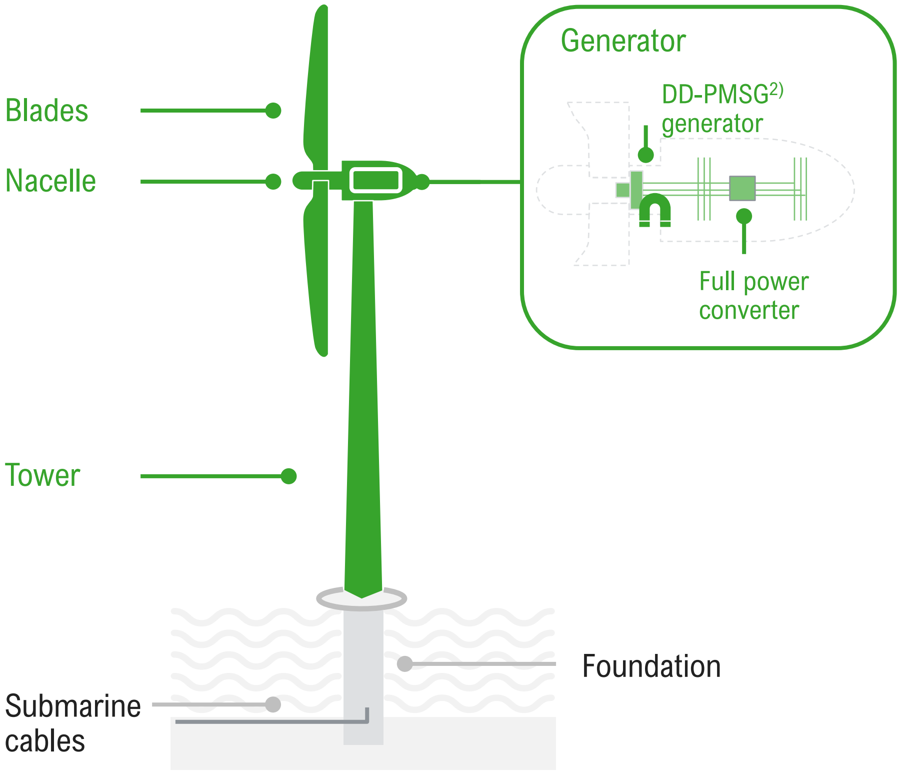
The report differentiates between major components of onshore and offshore Wind turbine without considering foundation and system integration components

Introduction: Wind turbine

Onshore



Offshore



Focus of the analysis on **Wind turbines and their components** and particular generator types for each onshore and offshore, without considering foundation and cables due to higher availability and individual designs

Within scope of the analysis   Out of scope

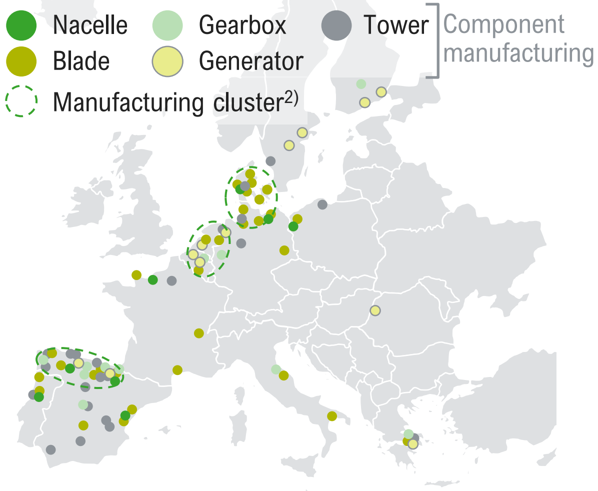
1) Gearbox double-fed induction generator (GB-DFIG); 2) Direct-drive permanent-magnet synchronous generator (DD-PMSG)

Source: European Union (2020), GoldWind (2023)

Onshore Wind shows a strong EU manufacturing position with a significant coverage of Europe's demand with domestic manufacturing capacity

Technology overview – Wind onshore

European value chain landscape[1)]

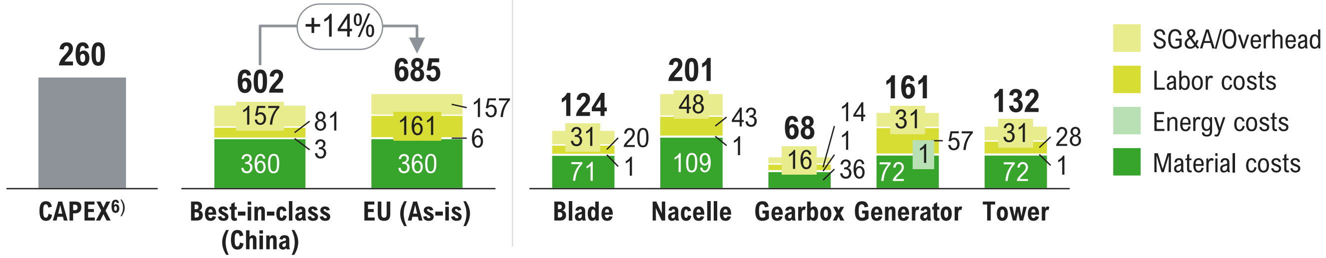


EU manufacturing capacities[3)] [2022]

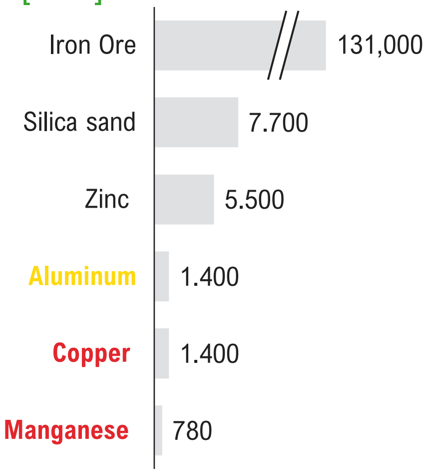
Global market share

EU demand share[4)]

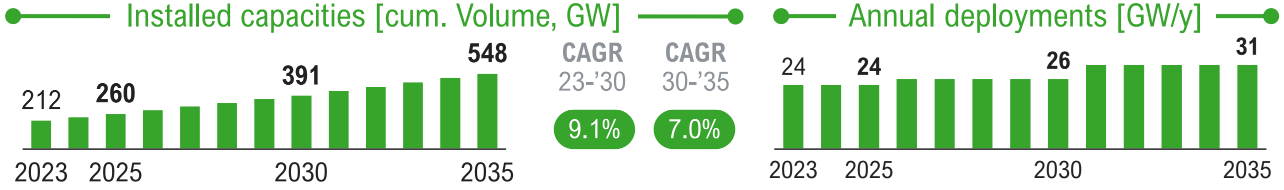
As-is unit manufacturing costs



Raw material intensities[5)]



Demand [forecast 2023-2035]



Main supply risks

- **Medium to large risk exposure** to **supplier concentration** and **import dependency** given a more diversified supply side and established manufacturing companies in the EU
- **Medium technological risk** due to new developments, especially in **generator** technology

Strategic material Critical material

1) Map for on- and offshore together; 2) Geographical manufacturing cluster; 3) Capacity equals to minimum capacity of towers, nacelles and blades. Market share calculated as weighted average of the three based on their respective capacities; 4) Demand share understood as share of EU manufacturing capacity of total EU demand for a technology – Based on demand forecast for 2023 according to Agora EU Gas Exit Pathway & EU manufacturing capacity from literature analysis. For Wind, minimum component capacity depicted (See EU demand share overview); 5) Selection of main raw material intensities – Assessment of strategic and critical raw materials according to European Unition (2023); 6) EUR/kW per yearly capacity

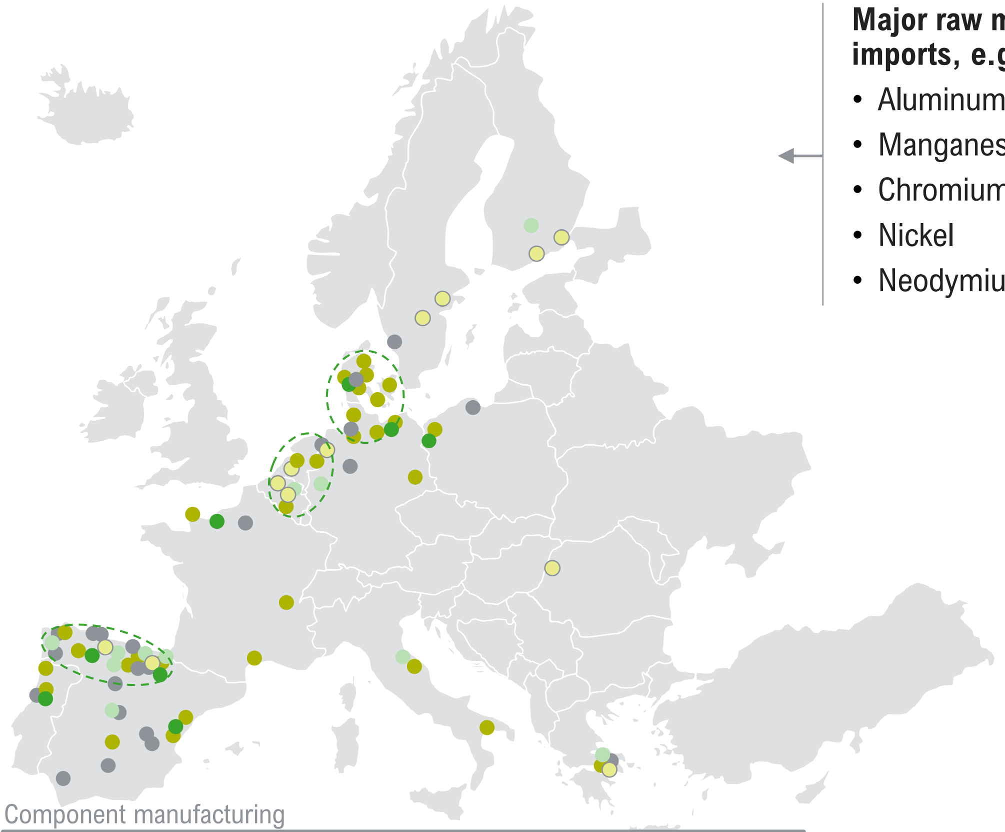
Source: Bareiß et al. (2019), US Department of Energy & Climate Change (2016), Durham University (2021), European Commission (2022, 2023), European Union (2023), Energy Transitions Commission (2023), Fraunhofer ISE (2021), IEA (2022, 2023), IRENA (2022), Koj et al. (2017), NREL (2023), Universität Münster (2021), WindEurope (2023)

Final status as of June 7, 2023. Published in September 2023

Map – non-exhaustive

The production of Wind components is centered around three geographic clusters: Northern Germany and Denmark, Benelux and Northern Spain

Wind: European value chain landscape



Component manufacturing

Blade · Nacelle · Gearbox · Generator · Tower · Material refining & processing[2)]

Manufacturing cluster

Major raw material imports, e.g.:

- Aluminum
- Manganese
- Chromium
- Nickel
- Neodymium

EU manufacturing capacities[1)] [2022 | 2023 for EU demand share]

Onshore [GW/y]	13	Global market share:	16 %	EU demand share:	54 %
Offshore [GW/y]	2	Global market share:	23 %	EU demand share:	44 %

Selected manufacturing plants in Europe

Company	Country	Manufacturing type	Status
Siemens Gamesa		Offshore	In operation
Nordex		Onshore (nacelle)	In operation
Vestas		Offshore	Construction

Key European players with international manufacturing activities

SIEMENS Gamesa RENEWABLE ENERGY (Germany/Spain)

Vestas (Denmark)

NORDEX (Germany)

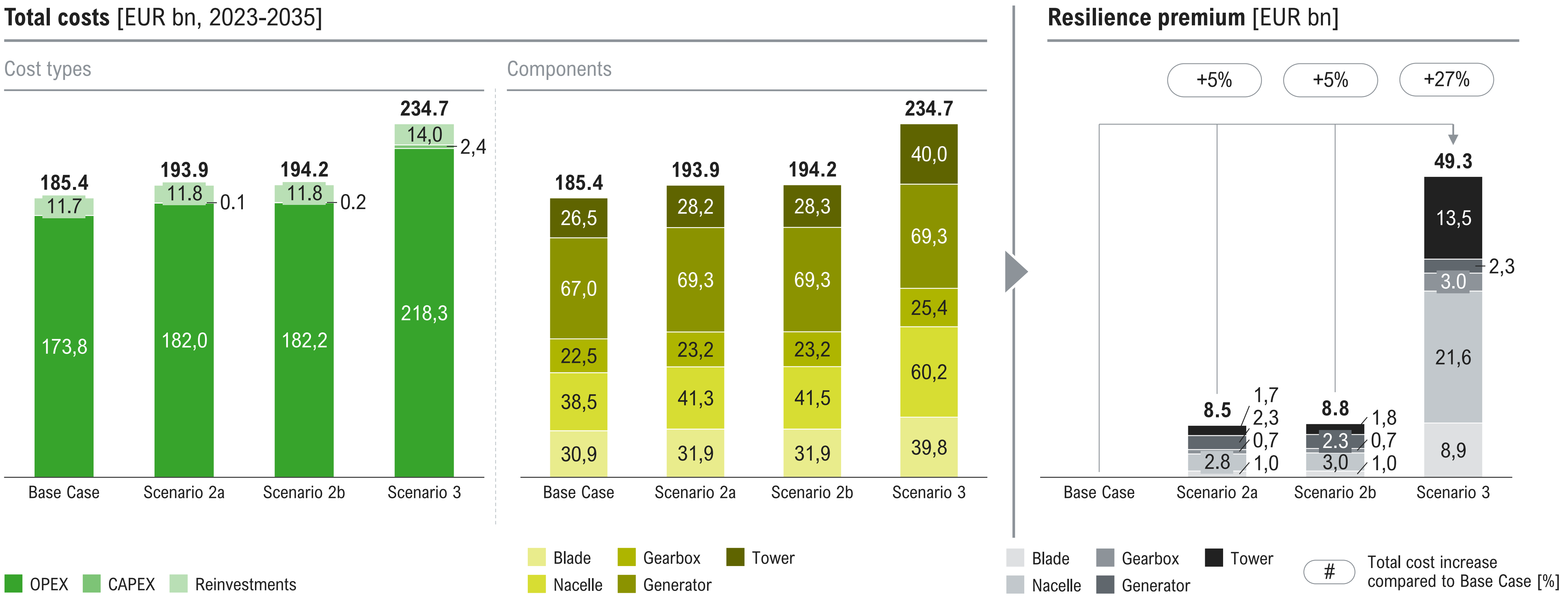
ENERCON ENERGIE FÜR DIE WELT (Germany)

1) Capacity [GW/y] equals to the minimum of manufacturing capacity of towers, nacelles and blades. Global market share is calculated as weighted average share of the three based on their respective capacity. Demand share as share of EU manufacturing capacity of total EU demand (Agora EU Gas Exit Pathway, 2023). For Wind, minimum component capacity depicted (See EU demand share overview); 2) Integrated value chain, thus players summarized as component manufacturing

Source: IEA (2023), European Commission (2022), WindEurope (2023)

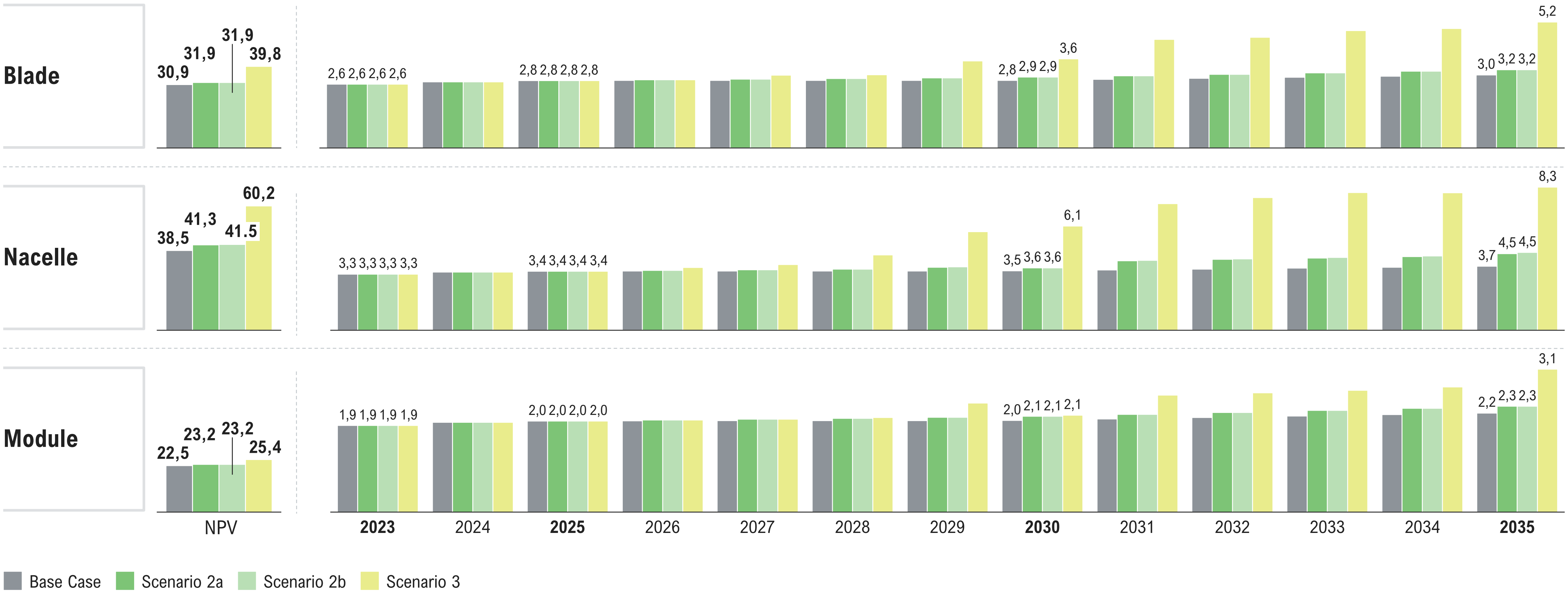
Due to high current market shares minimal CAPEX investments are required, thus Wind is mainly driven by OPEX, especially for generator

Wind onshore – Overview scenarios: Costs & resilience premium [EUR bn, 2023-2035 cum.]



Total costs for Wind onshore rise are rather stable due to minimal capacity expansions – High scenario 3 costs to maintain ambitious NZIA market shares

Wind onshore – Overview scenarios: Total costs & NPV [EUR bn, NPV 2023-2035 cum.]

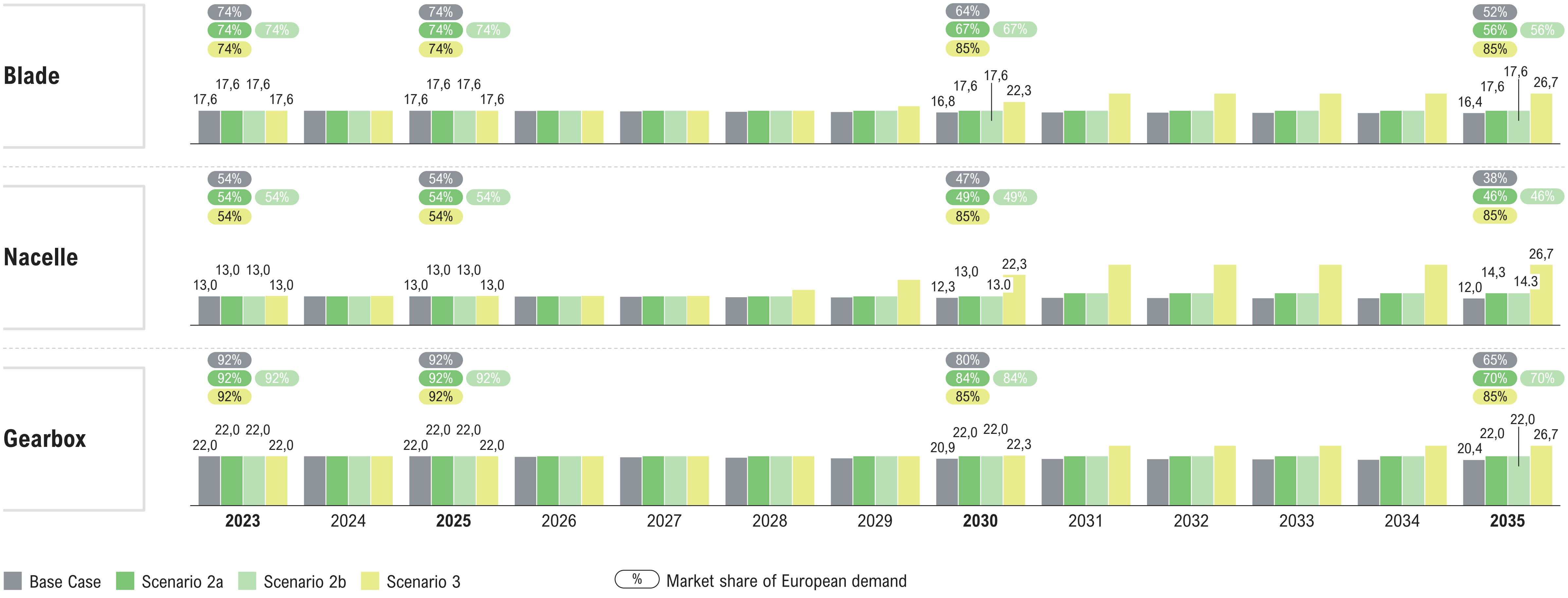


Generator show extremely high current market shares (>100%), hence stable cost development even for ambitious NZIA scenario

Wind onshore – Overview scenarios: Total costs & NPV [EUR bn, NPV 2023-2035 cum.]

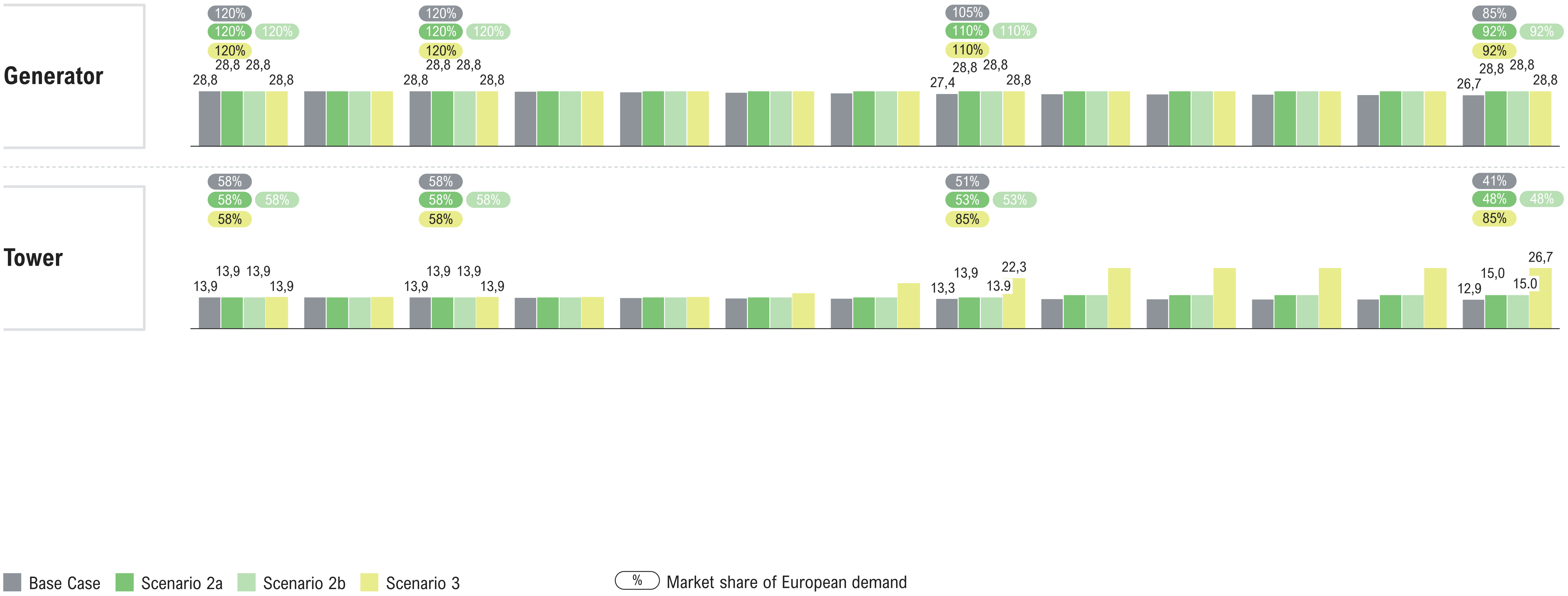
Significant capacity expansions are only necessary to achieve scenario 3 NZIA levels – Overall, extensive market coverage, especially for gearbox and blade

Wind onshore – Overview scenarios: Capacity and market shares [GW | %-share]



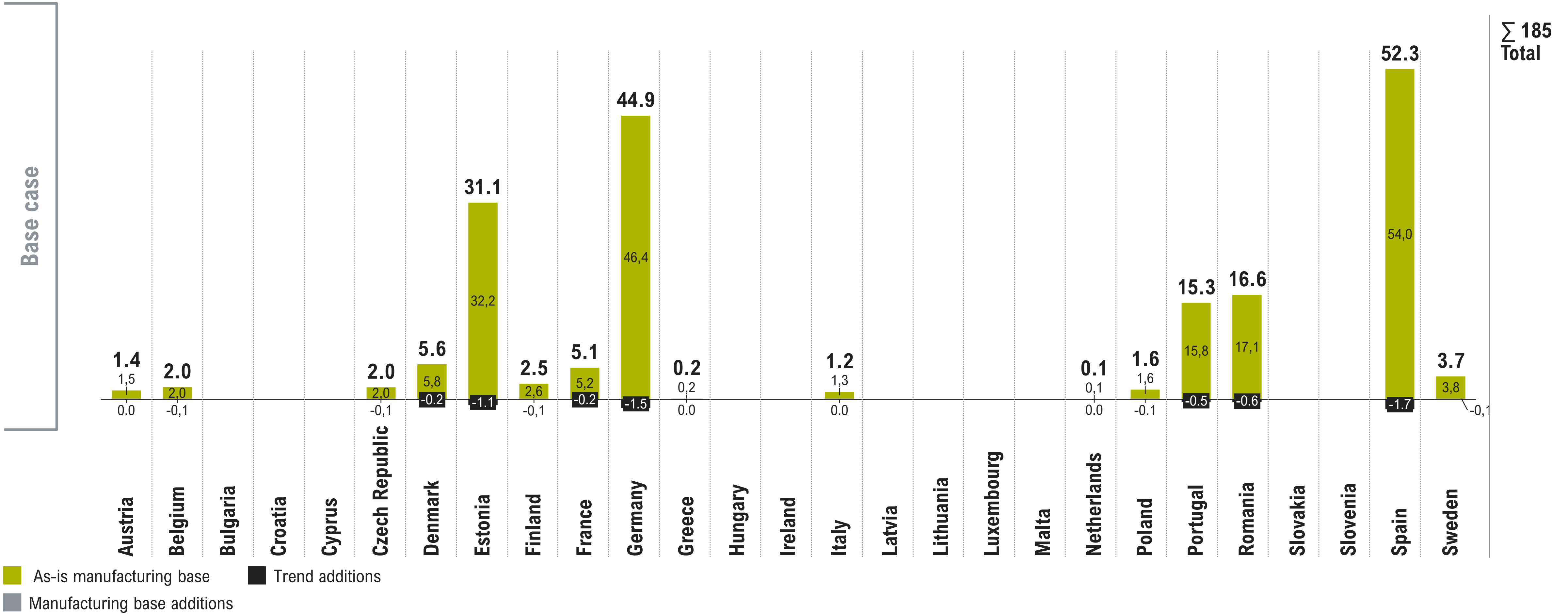
Overcapacity for European demand seen for generator, hence almost no capacity expansions necessary – Tower capacity development similar to other components

Wind onshore – Overview scenarios: Capacity and market shares [GW | %-share]



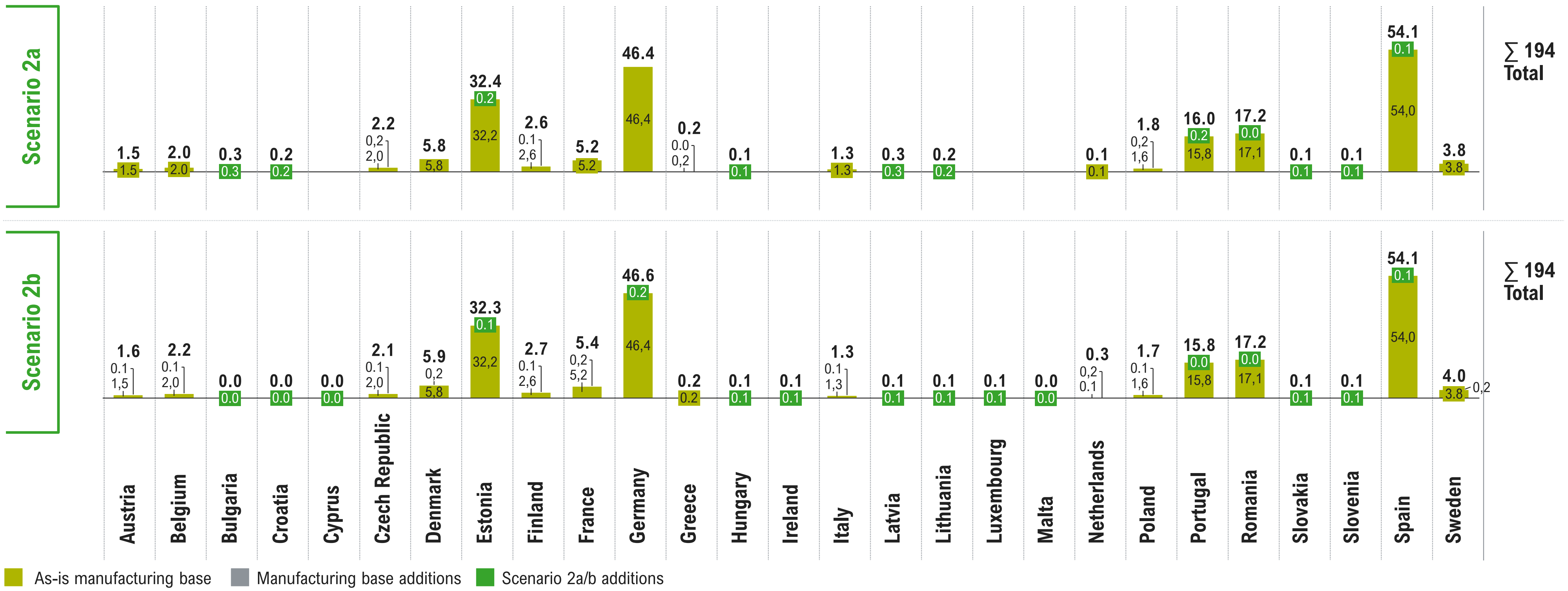
Today's manufacturing capacity is mainly located in Spain, Germany and Estonia – Negative trend forecasted due to current low profitability market environment

Wind onshore – Overview scenarios: Total costs by geography [EUR bn, 2023-2035 cum.]



The minimal additional capacity to achieve resilience is allocated to similar countries for 2a and 2b – 2b shows a more distributed allocation of bigger shares

Wind onshore – Overview scenarios: Total costs by geography [EUR bn, 2023-2035 cum.]



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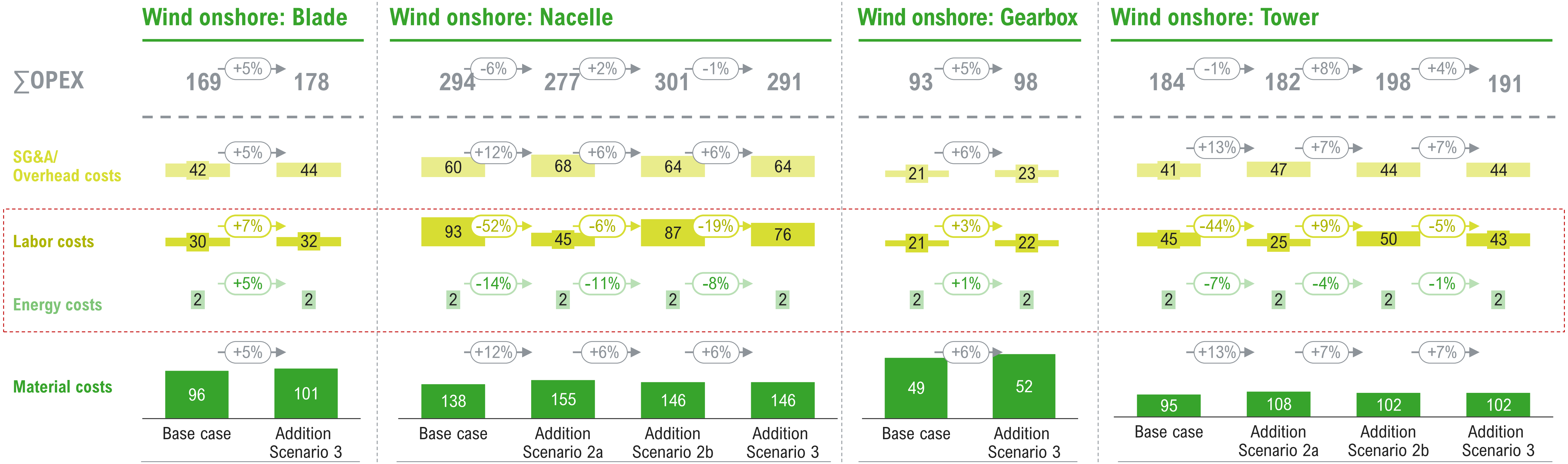
OPEX decrease for 2a by 1-6% driven by labor savings in absolute as well as relative terms – For 2b and 3 OPEX mostly increase due to lower cost base case

Wind onshore – Overview scenarios: Unit manufacturing costs per component[1] [EUR/kW]



- OPEX cost increase implies lower than EU-27 base case allocation

- Highest absolute savings across components for labor and energy costs in 2a
- Medium 2b and NZIA savings

- OPEX cost increase implies lower than EU-27 base case allocation

- Relevant savings for 2a, lower reduction for NZIA
- Labor cost increase for 2b due to ambitions of high labor cost countries

Material costs | Energy costs | Labor costs | SG&A/Overhead costs | -x% -x% Change compared to base case based on country-specific costs | +x% Change compared to base case based on inflation

1) Only scenarios with additional capacity expansions illustrated – No scenario additions for generator, therefore not displayed

Source: IEA (2022), European Commission (2023), IRENA (2022), NREL (2023), Fraunhofer ISE (2021), Durham University (2021), IEA (2023), Department of Energy & Climate Change (2016), Universität Münster (2021)

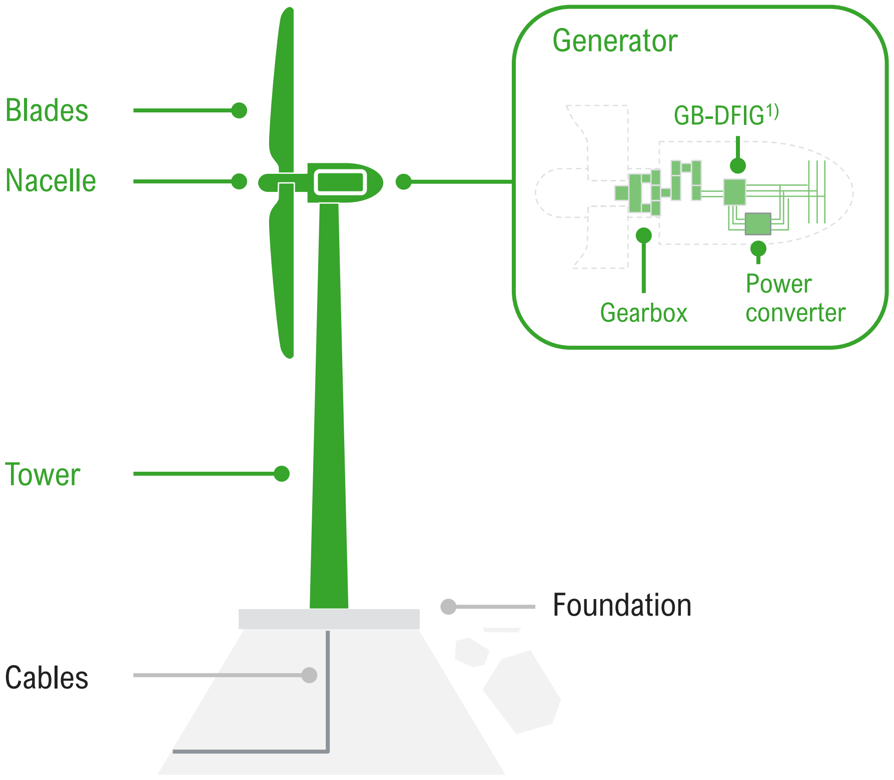
C.1.3 Wind offshore

Illustrative

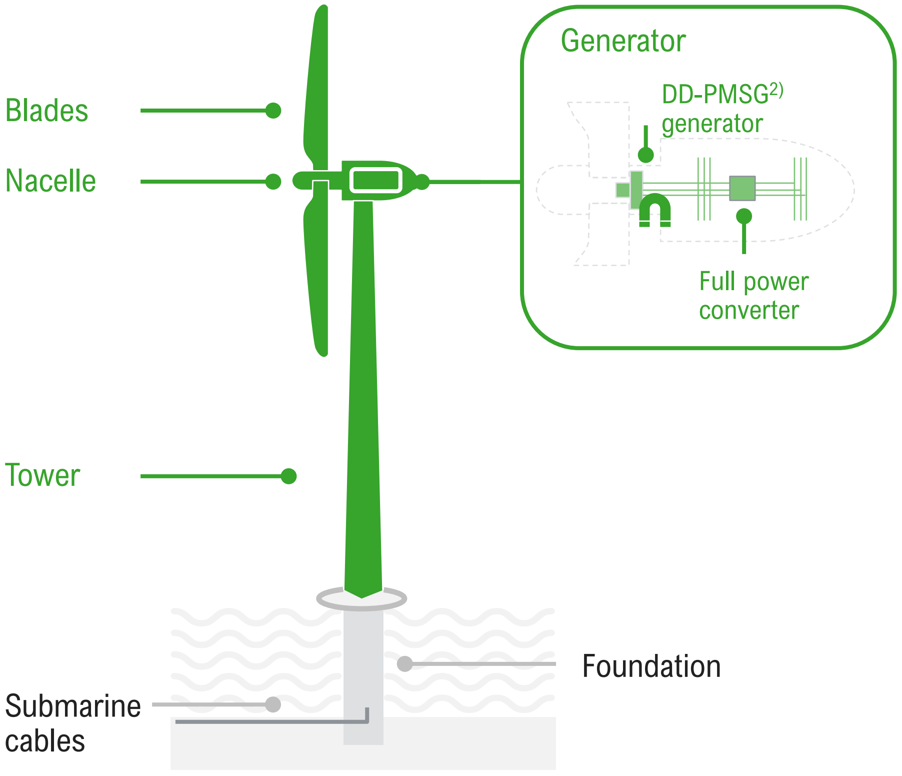
The report differentiates between major components of onshore and offshore Wind turbine without considering foundation and system integration components

Introduction: Wind turbine

Onshore



Offshore



Focus of the analysis on **Wind turbines and their components** and particular generator types for each onshore and offshore, without considering foundation and cables due to higher availability and individual designs

Within scope of the analysis | Out of scope

1) Gearbox double-fed induction generator (GB-DFIG); 2) Direct-drive permanent-magnet synchronous generator (DD-PMSG)

Source: European Union (2020), GoldWind (2023)

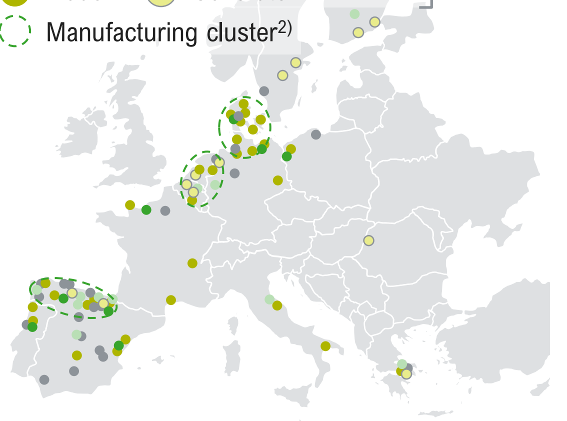
Domestic Wind offshore manufacturing capacity currently covers EU demand for most components but blade, however little additions in recent years

Technology overview – Wind offshore

European value chain landscape[1]

Nacelle · Gearbox · Tower · Blade · Generator — Component manufacturing

Manufacturing cluster[2]



EU manufacturing capacities[3] [2022]

Wind offshore [GW/y]: 2

Global market share

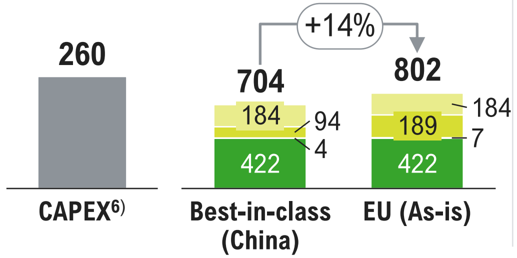
23%

EU demand share[4]

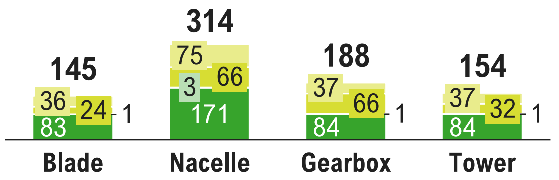
44%

As-is unit manufacturing costs

Total costs: CAPEX & OPEX [EUR/kW]

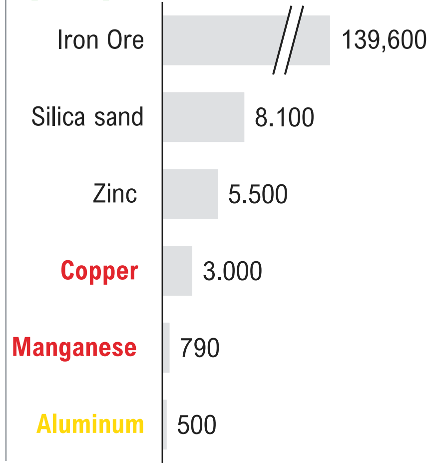


EU OPEX by component [EUR/kW]



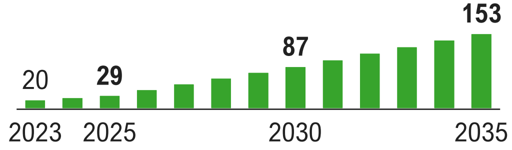
Raw material intensities[5]

[t/GW]



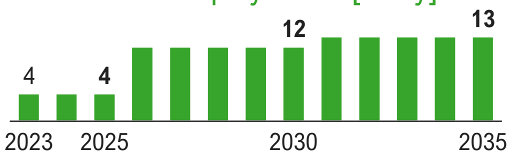
Demand [forecast 2023-2035]

Installed capacities [cum. Volume, GW]



CAGR 23-'30	CAGR 30-'35
23.1%	12.0%

Annual deployments [GW/y]



Main supply risks

- **Medium to large risk exposure** to supplier concentration and import dependency given a more diversified supply side and established manufacturing companies in the EU
- **Demand & supply gap** to be identified rather for Wind offshore compared to Wind onshore due to little offshore additions in recent years

Strategic material · Critical material

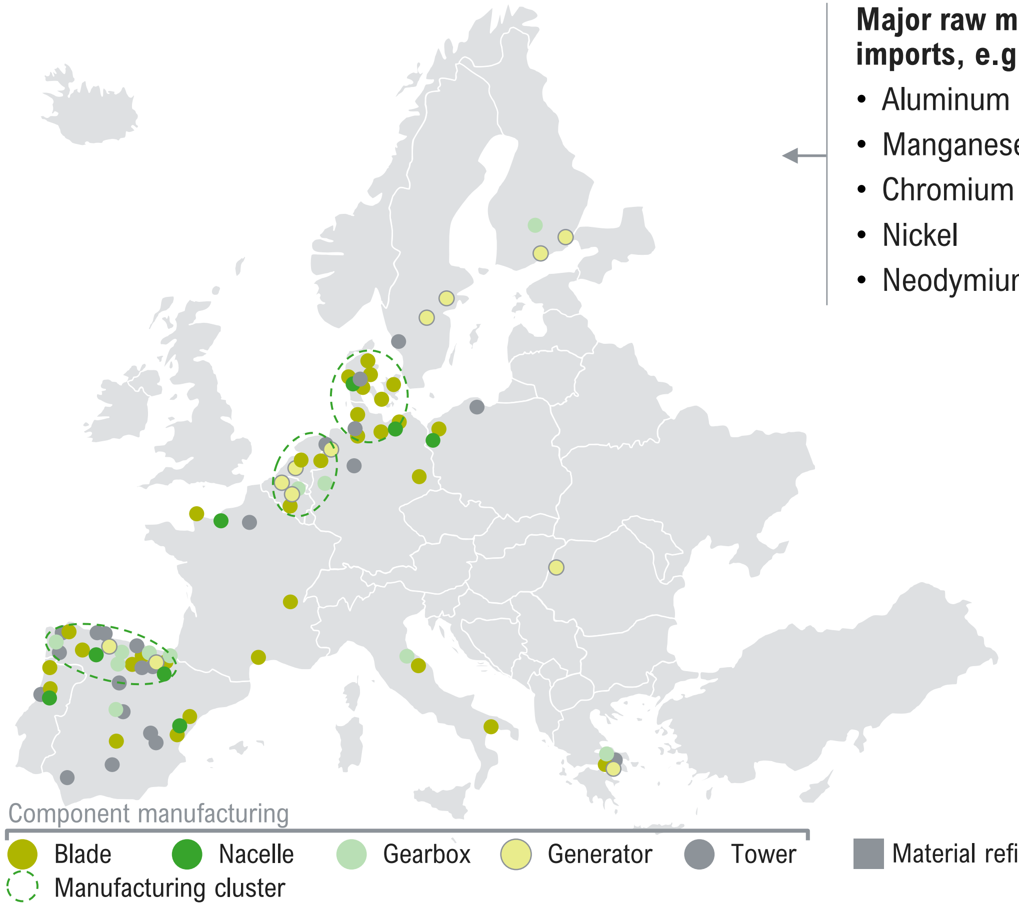
1) Map for on- and offshore together; 2) Geographical manufacturing cluster; 3) Capacity equals to minimum capacity of towers, nacelles and blades. Market share calculated as weighted average of the three based on their respective capacities; 4) Demand share understood as share of EU manufacturing capacity of total EU demand for a technology – Based on demand forecast for 2023 according to Agora EU Gas Exit Pathway and EU manufacturing capacity from literature analysis. For Wind, minimum component capacity depicted (See EU demand share overview for details); 5) Selection of main raw material intensities – Assessment of strategic & critical raw materials according to EU(2023); 6) EUR/kW per yearly capacity

Source: Bareiß et al. (2019), US Department of Energy & Climate Change (2016), Durham University (2021), European Commission (2022, 2023), European Union (2023), Energy Transitions Commission (2023), Fraunhofer ISE (2021), IEA (2022, 2023), IRENA (2022), Koj et al. (2017), NREL (2023), Universität Münster (2021), WindEurope (2023)

Map – non-exhaustive

The production of Wind components is centered around three geographic clusters: Northern Germany and Denmark, Benelux and Northern Spain

Wind: European value chain landscape



Major raw material imports, e.g.:
- Aluminum
- Manganese
- Chromium
- Nickel
- Neodymium

EU manufacturing capacities[1] [2022 | 2023 for EU demand share]

Onshore [GW/y]	13	Global market share:	16 %	EU demand share:	54 %
Offshore [GW/y]	2	Global market share:	23 %	EU demand share:	44 %

Selected manufacturing plants in Europe

Company	Country	Manufacturing type	Status
Siemens Gamesa	Germany, France	Offshore	In operation
Nordex	Germany	Onshore (nacelle)	In operation
Vestas	Poland	Offshore	Construction

Key European players with international manufacturing activities

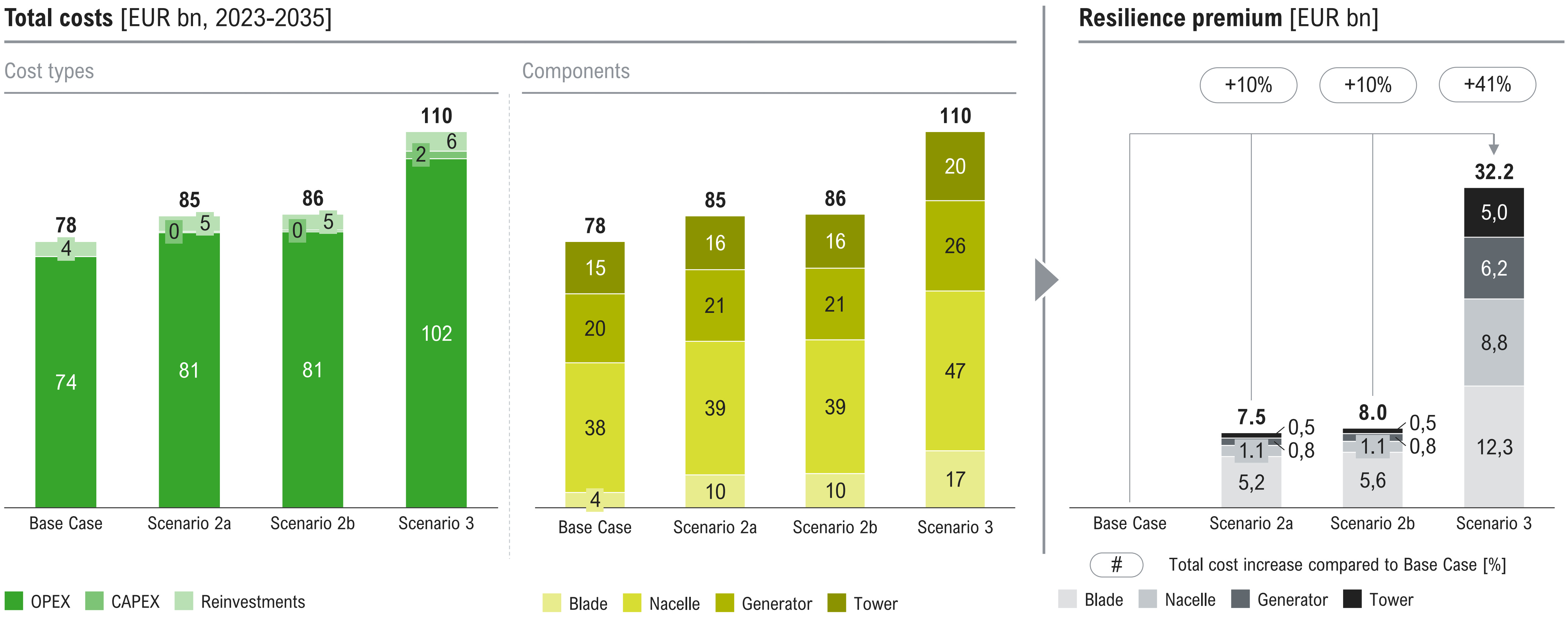
SIEMENS Gamesa RENEWABLE ENERGY (Germany/Spain) | Vestas (Denmark) | NORDEX (Germany) | ENERCON ENERGIE FÜR DIE WELT (Germany)

1) Capacity [GW/y] equals to the minimum of manufacturing capacity of towers, nacelles and blades. Global market share is calculated as weighted average share of the three based on their respective capacity. Demand share as share of EU manufacturing capacity of total EU demand (Agora EU Gas Exit Pathway, 2023). For Wind, minimum component capacity depicted (See EU demand share overview); 2) Integrated value chain, thus players summarized as component manufacturing

Source: IEA (2023), European Commission (2022), WindEurope (2023)

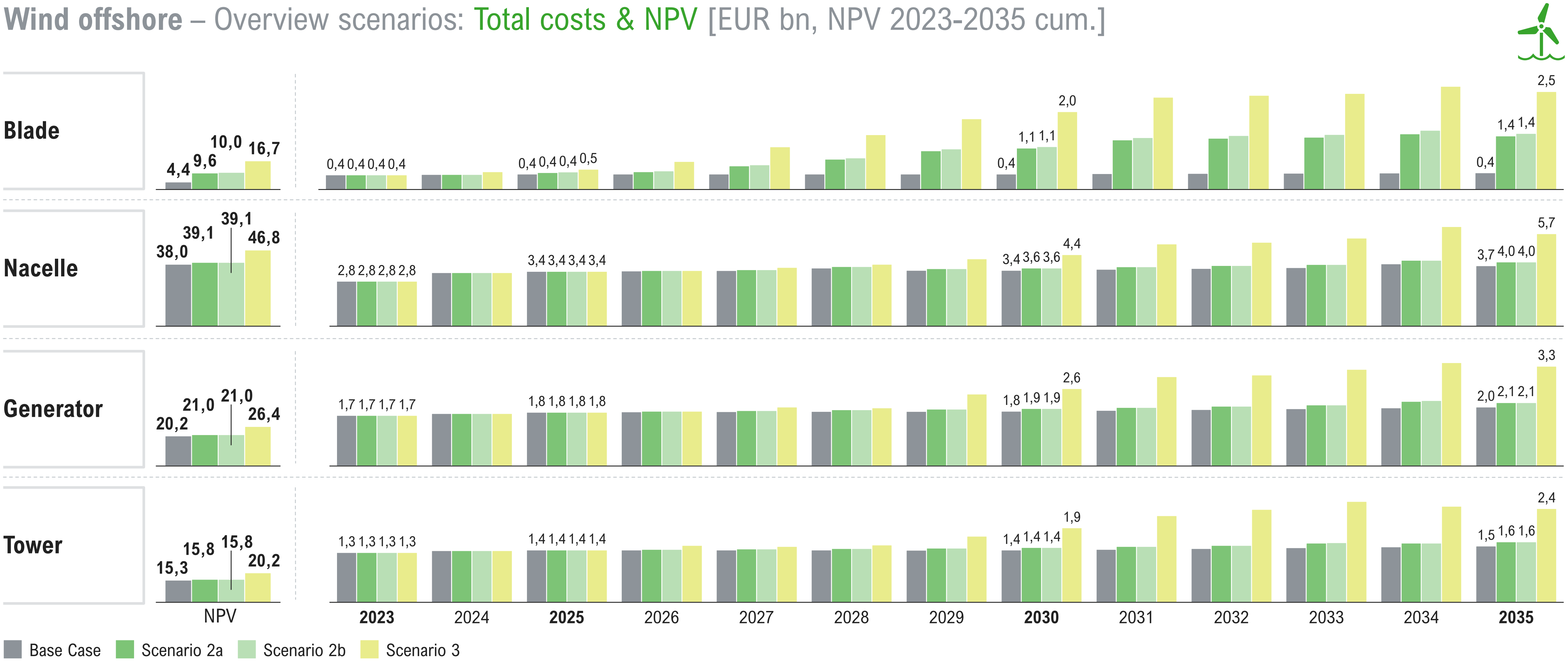
Similar to Wind onshore, offshore costs are driven by OPEX due to minimal CAPEX needs – Nacelle as main component of base, blade for resilience premium

Wind offshore – Overview scenarios: Costs & resilience premium [EUR bn, 2023-2035 cum.]



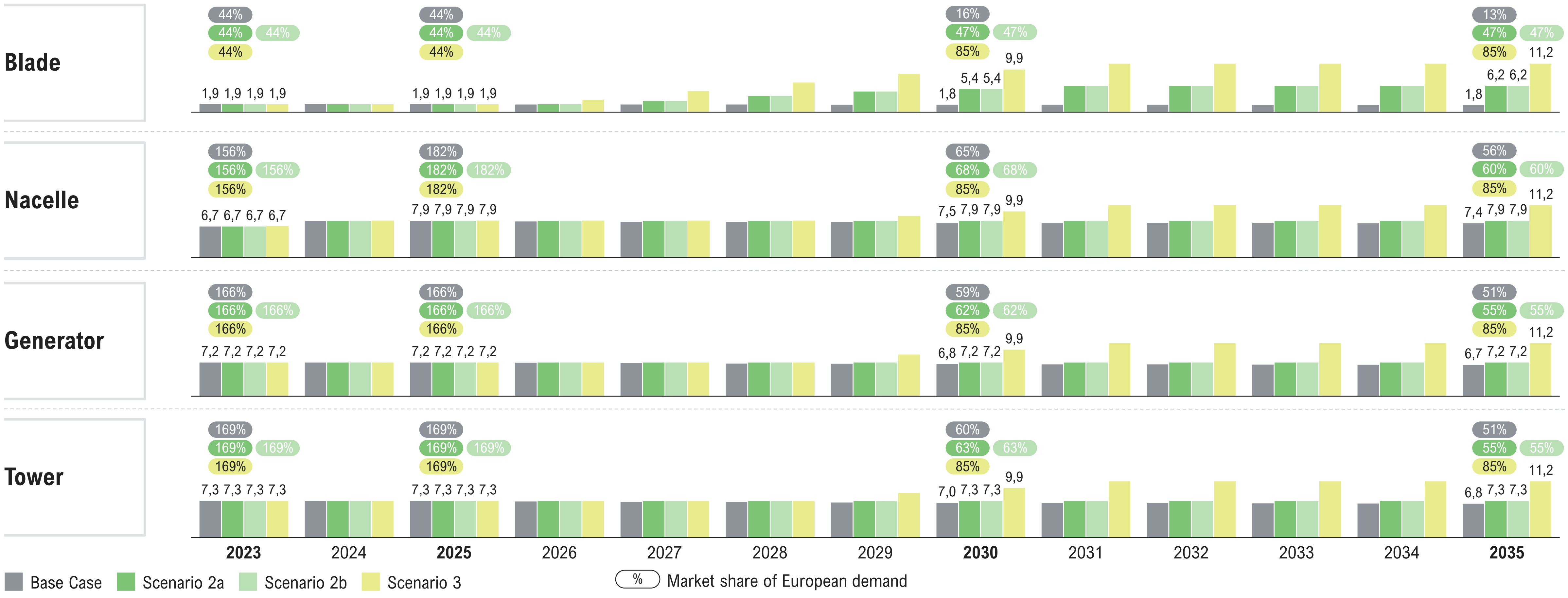
Stable cost development for all components except for blade, which shows a significant increase – Highest expenses are attributed to nacelle

Wind offshore – Overview scenarios: Total costs & NPV [EUR bn, NPV 2023-2035 cum.]



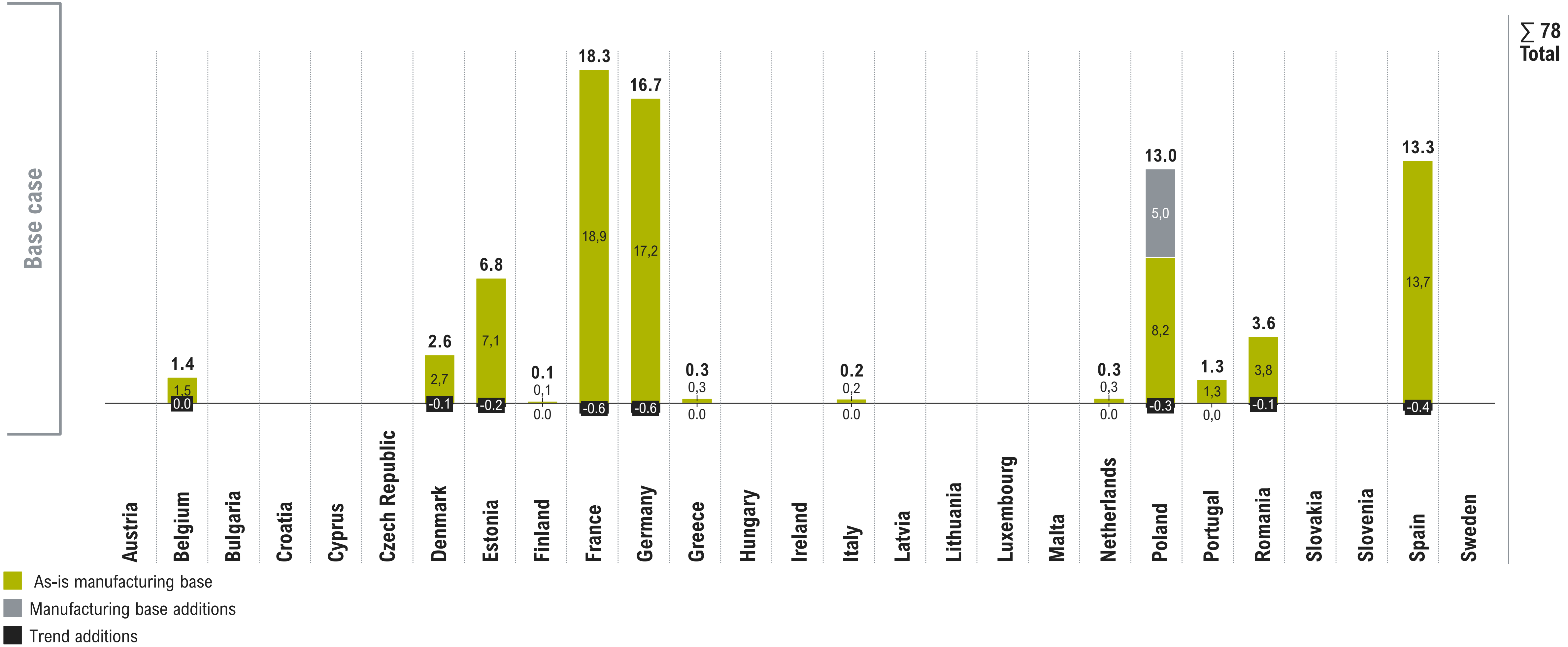
Except for blade, all offshore components show overcapacity of European demand with market shares of >150%, which decrease to resilience level in 2a/b by 2035

Wind onshore – Overview scenarios: Capacity and market shares [GW | %-share]



Equivalent to onshore, Wind offshore is manufactured in few focus countries led by France, Germany and Spain – Announcements for additions in Poland

Wind offshore – Overview scenarios: Total costs by geography [EUR bn, 2023-2035 cum.]



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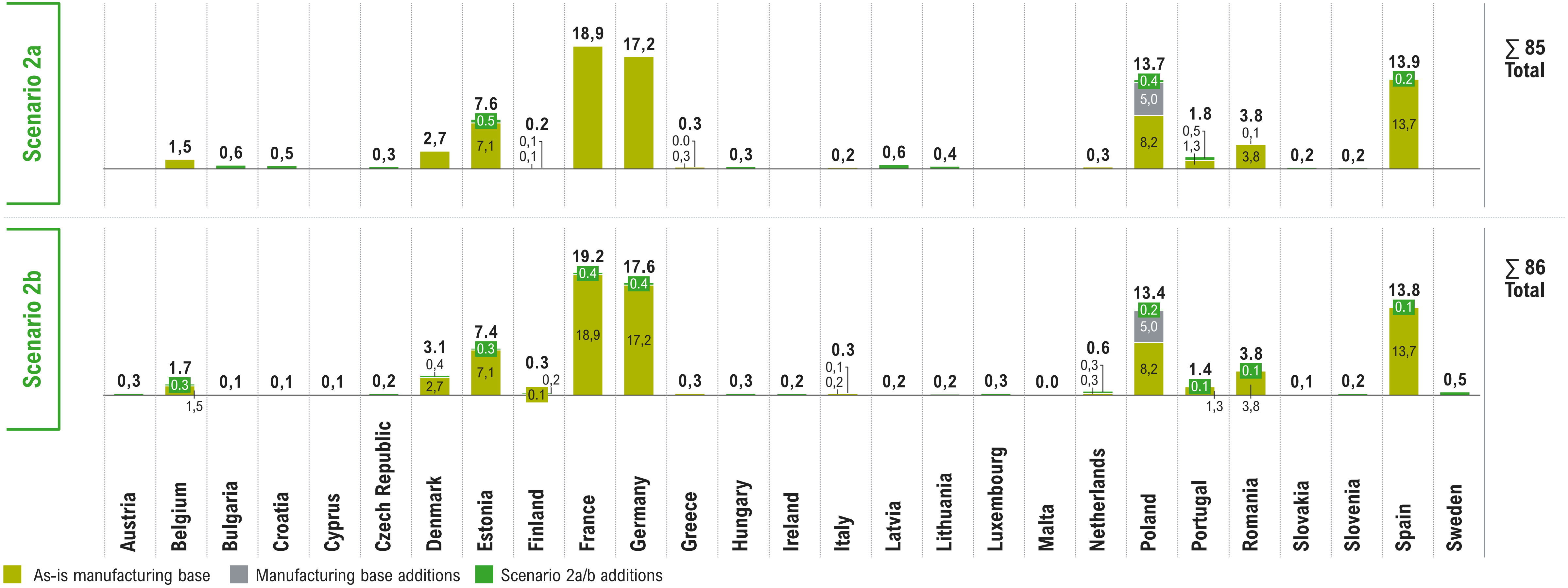
Resilience capacities can be found in similar countries for scenarios 2a and 2b, whereas higher distribution of relevant capacities across countries is seen in 2b

Wind offshore – Overview scenarios: Total costs by geography [EUR bn, 2023-2035 cum.]



Final status as of June 7, 2023. Published in September 2023

OPEX change for 2a blade by -8% and by -5 to +9% for all components in 2a and 3 – Tower NZIA cost increase state lower than EU-27 average labor costs in base case

Wind offshore – Overview scenarios: Unit manufacturing costs per component[1] [EUR/kW]

Wind offshore: Blade

	Base case		Addition Scenario 2a		Addition Scenario 2b		Addition Scenario 3
∑OPEX	220	-8%	203	-2%	214	-5%	208
SG&A/ Overhead costs	49	+12%	54	+6%	52	+6%	51
Labor costs	57	-62%	22	-25%	43	-35%	37
Energy costs	2	-21%	2	-18%	2	-16%	2
Material costs	112	+12%	125	+6%	118	+6%	118

- Significant labor cost reduction for 2a and also 2b
- Highest relative savings potential for NZIA across all components

Wind offshore: Nacelle

	Base case		Addition Scenario 3
∑OPEX	475	-4%	455
SG&A/ Overhead costs	107	-1%	106
Labor costs	119	-14%	103
Energy costs	4	+4%	4
Material costs	245	-1%	242

- Trend implies lower than EU average labor and higher energy costs in base case

Wind offshore: Generator

	Base case		Addition Scenario 3
∑OPEX	280	-2%	276
SG&A/ Overhead costs	54	-3%	52
Labor costs	101	2%	103
Energy costs	2	0%	2
Material costs	123	-3%	119

- Base case country footprint shows lower cost country allocation than EU average

Wind offshore: Tower

	Base case		Addition Scenario 3
∑OPEX	204	+9%	223
SG&A/ Overhead costs	48	+7%	52
Labor costs	43	+17%	50
Energy costs	2	+2%	2
Material costs	111	+7%	119

- Base case shows significantly lower cost country allocation than EU average

Material costs · Energy costs · Labor costs · SG&A/Overhead costs · -x% / -x% Change compared to base case based on country-specific costs · +x% Change compared to base case based on inflation

1) Only scenarios with additional capacity expansions illustrated

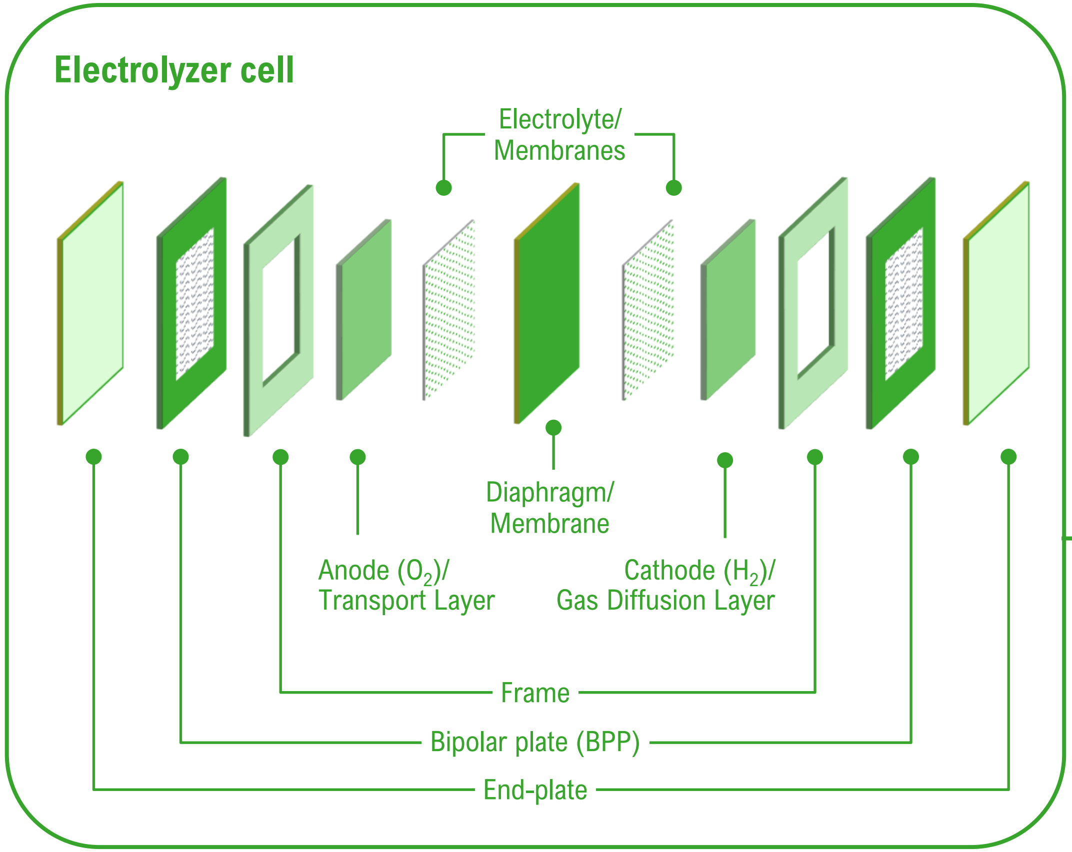
Source: IEA (2022), European Commission (2023), IRENA (2022), NREL (2023), Fraunhofer ISE (2021), Durham University (2021), IEA (2023), Department of Energy & Climate Change (2016), Universität Münster (2021)

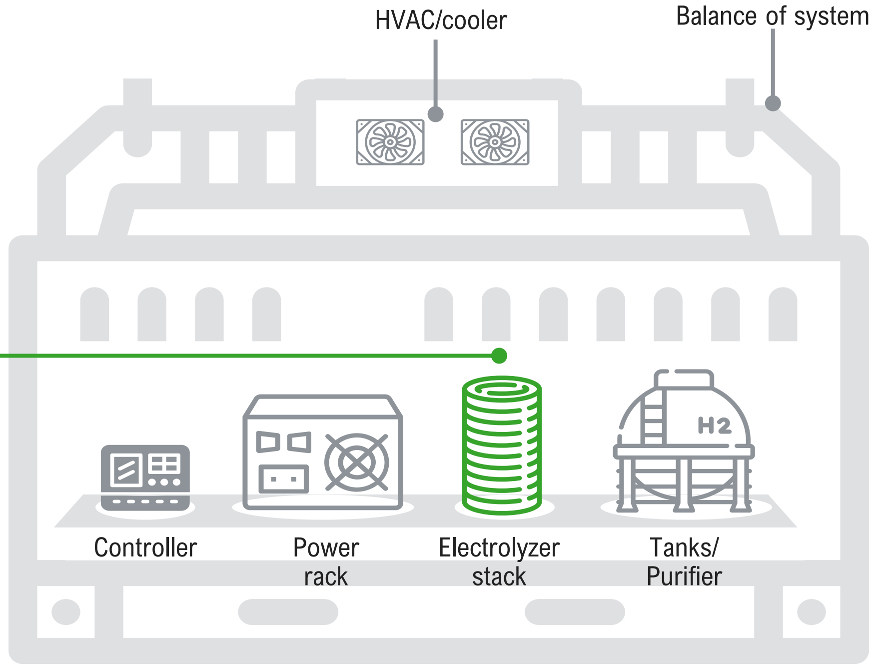
C.1.4 Electrolyzer

Illustrative

The analysis focuses on the Electrolyzer cell within the Electrolyzer stack and its main components – Additional systems within the Electrolyzer are out of scope

Introduction: Electrolyzer cell[1]





Focus on the **Electrolyzer cell which is stacked within the Electrolyzer**, without considering further components and systems due to higher availability and individual designs

Within scope of the analysis | Out of scope

1) Simplified illustration based on alkaline and proton exchange membrane Electrolyzers

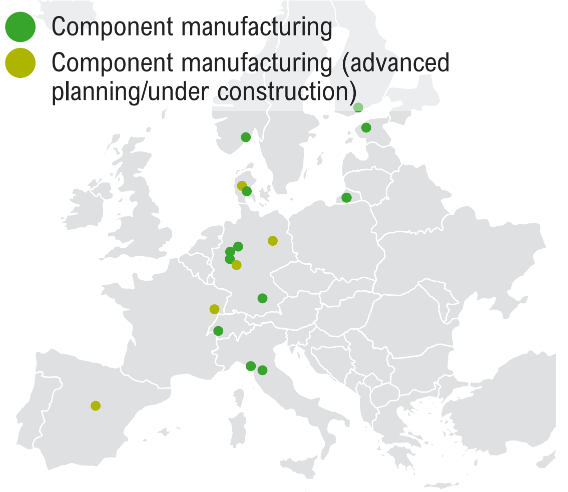
Source: Fraunhofer ISE (2022)

EU Electrolyzer capacity covers current domestic demand for AWE – Major increase in demand expected, implying a high demand & supply gap risk

Technology overview – Electrolyzer

European value chain landscape

- Component manufacturing
- Component manufacturing (advanced planning/under construction)



EU manufacturing capacities [2022]

Electrolyzer [GW/y]: 2

Global market share

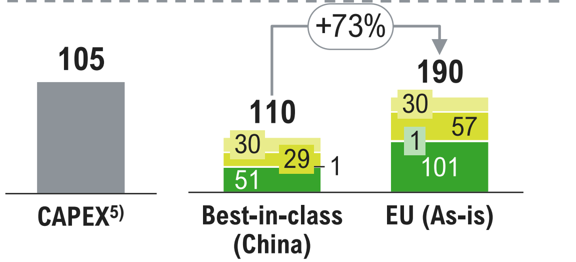
21%

EU demand share[1)]

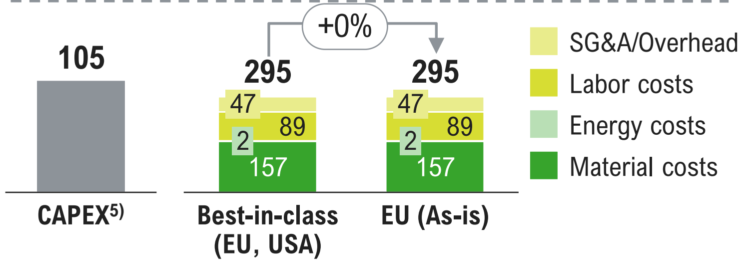
>100%

As-is unit manufacturing costs

AWE[3)] total costs: CAPEX & OPEX [EUR/kW]



PEM[4)] total costs: CAPEX & OPEX [EUR/kW]



Raw material intensities[2)]

AWE [t/GW]

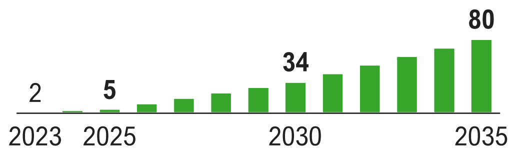
Iron Ore	33,333
Nickel	3.167
Copper	333
Zirconium	183
Aluminum	75
Graphite	72

PEM [t/GW]

Iron Ore	6,472
Titanium	528
Copper	100
Aluminum	27
PGM[6)]	1

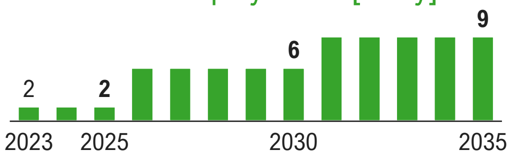
Demand [forecast 2023-2035]

Installed capacities [cum. Volume, GW]



CAGR 23-'30	CAGR 30-'35
52.2%	18.7%

Annual deployments [GW/y]



Main supply risks

- **High demand & supply gap** due to strong ramp-up of capacities planned until 2030 and beyond, challenging the existing European supply base
- **Strong focus on R&D** of the relatively young technology leading to higher **risk of incremental innovations** of the predominant technology
- **Geographic and digital risks** depending on China for AWE and the US for PEM

Strategic material | Critical material

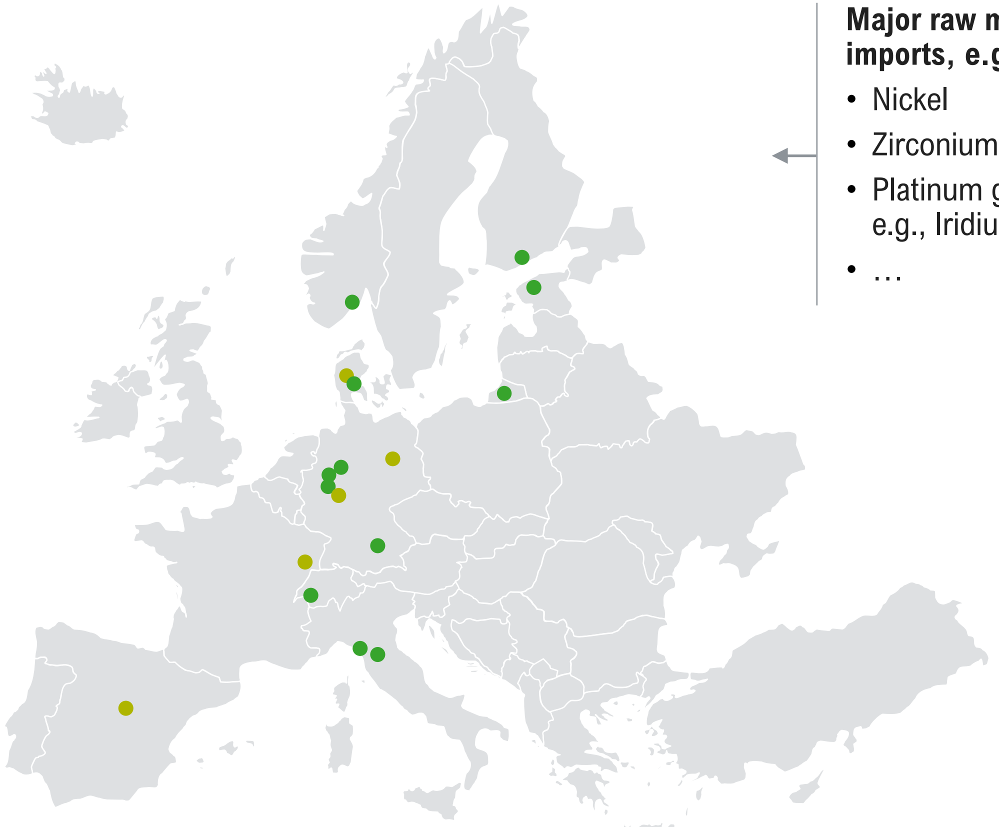
1) Demand share understood as share of EU manufacturing capacity of total EU demand for a technology – Based on demand forecast for 2023 according to Agora EU Gas Exit Pathway and EU manufacturing capacity from literature analysis. Percentage value represents both sub-technologies in total (See EU demand share overview for details); 2) Selection of main raw material intensities – Assessment of strategic and critical raw materials according to European Unition (2023); 3) Alkaline water Electrolyzers (AWE); 4) Proton Exchange Membrane (PEM); 5) EUR/kW per yearly capacity; 6) Other platinum group metals (except palladium, shown separately)

Source: : IEA (2023), European Union (2023), European Commission (2018, 2020, 2022), Energy Transitions Commission (2023), Bareiß et al. (2019), Koj et al. (2017), IEA (2022), IRENA (2022), NREL (2023), Fraunhofer ISE (2021), Durham University (2021), US Department of Energy & Climate Change (2016), Universität Münster (2021)

Map – non-exhaustive

The manufacturing of Electrolyzer is a relatively new business with most plants in Central and Northern Europe – Numerous new plants are announced and upcoming

Electrolyzer[1)]: European value chain landscape



Major raw material imports, e.g.:
- Nickel
- Zirconium
- Platinum group metals, e.g., Iridium, Platinum
- …

Component manufacturing
Manufacturing cluster[4)]
Material refining & processing[3)]
Component manufacturing (advanced planning/under construction)

EU manufacturing capacities[2)] [2022]

Electrolyzer [GW/y]: 2 | Global market share: 26 % | EU demand share: 80%

Selected manufacturing plants in Europe

Company	Country	Manufacturing capacity [GW/y]	Status
Nel Hydrogen	Norway	0.5	In operation
McPhy	Italy	0.3	In operation
Sunfire	Switzerland, Germany	0.24 CH (+ 0.5 planned in DE)	In operation
Siemens Energy	Germany	1.0	COD in 2023
Topsoe	Denmark	0.5	COD in 2024

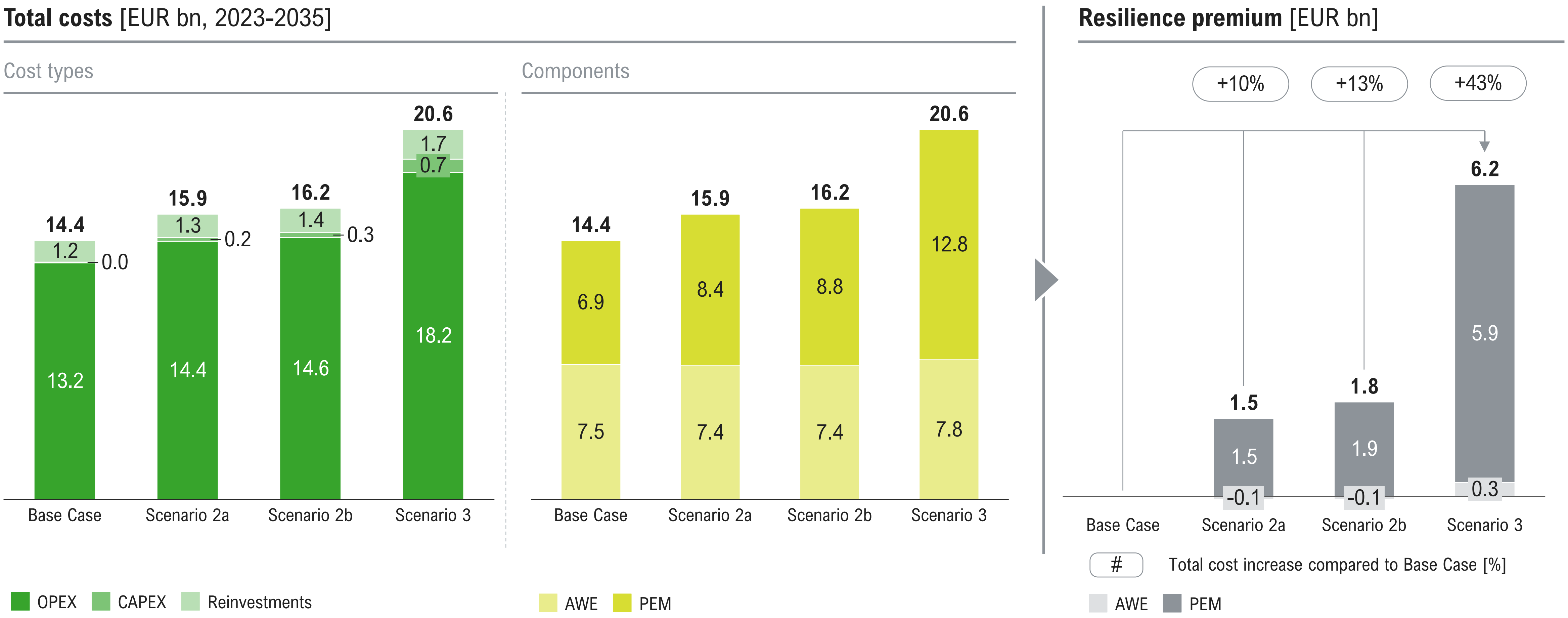
Key European players with international manufacturing activities

nel (Norway) | TOPSOE (Denmark) | McPhy (France) | SIEMENS energy (Germany)

1) Due to the less mature state of technology compared to e.g., PV or Wind, and the currently planned major capacity expansions, the landscape map is extended to plants under construction to include upcoming short-term developments; 2) Electrolyzer with all use cases. Demand share as share of EU manufacturing capacity of total EU demand (Agora EU Gas Exit Pathway, 2023), percentage value represents both sub-technologies in total (See EU demand share overview for details); 3) Integrated value chain, thus players summarized as component manufacturing; 4) No cluster established so far
Source: IEA (2023)

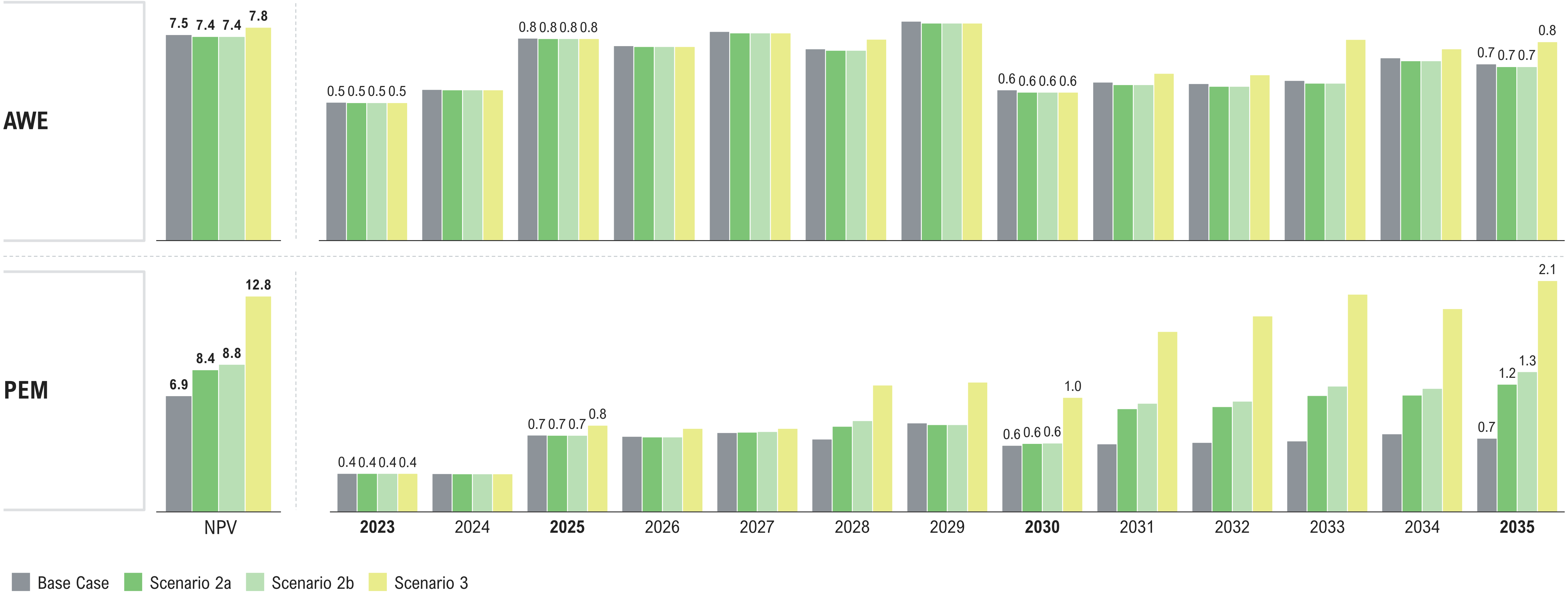
The relatively high market share of domestic Electrolyzer manufacturing capacity results in costs driven mainly by OPEX and a comparably low resilience premium

Electrolyzer – Overview scenarios: Costs & resilience premium [EUR bn, 2023-2035 cum.]



Total costs are stable for AWE in all scenarios due to significant existing capacity – PEM shows a moderate increase overtime in scenarios 2a and 2b

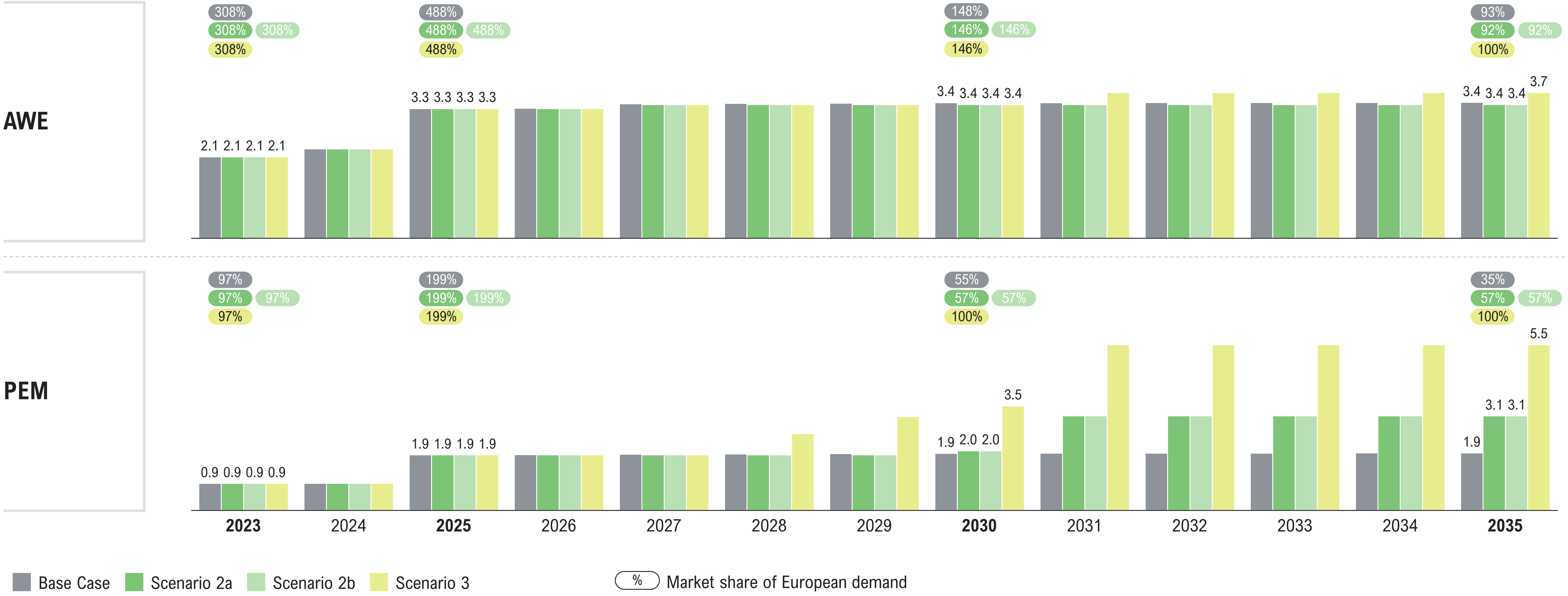
Electrolyzer – Overview scenarios: Total costs & NPV [EUR bn, NPV 2023-2035 cum.]



Final status as of June 7, 2023. Published in September 2023

AWE and PEM show significant overcapacity declining overtime – Lasting high level for AWE, while PEM capacity expansions are necessary to maintain resilience level

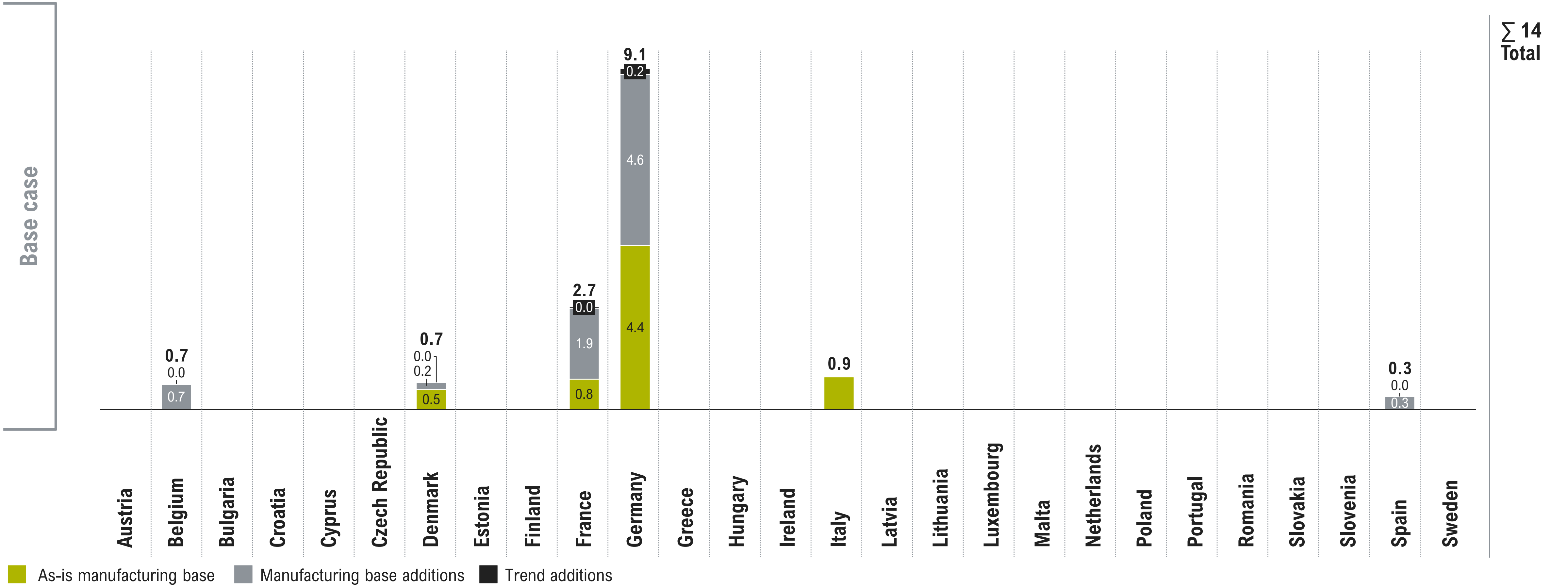
Electrolyzer – Overview scenarios: Capacity and market shares [GWh | %-share]



Final status as of June 7, 2023. Published in September 2023

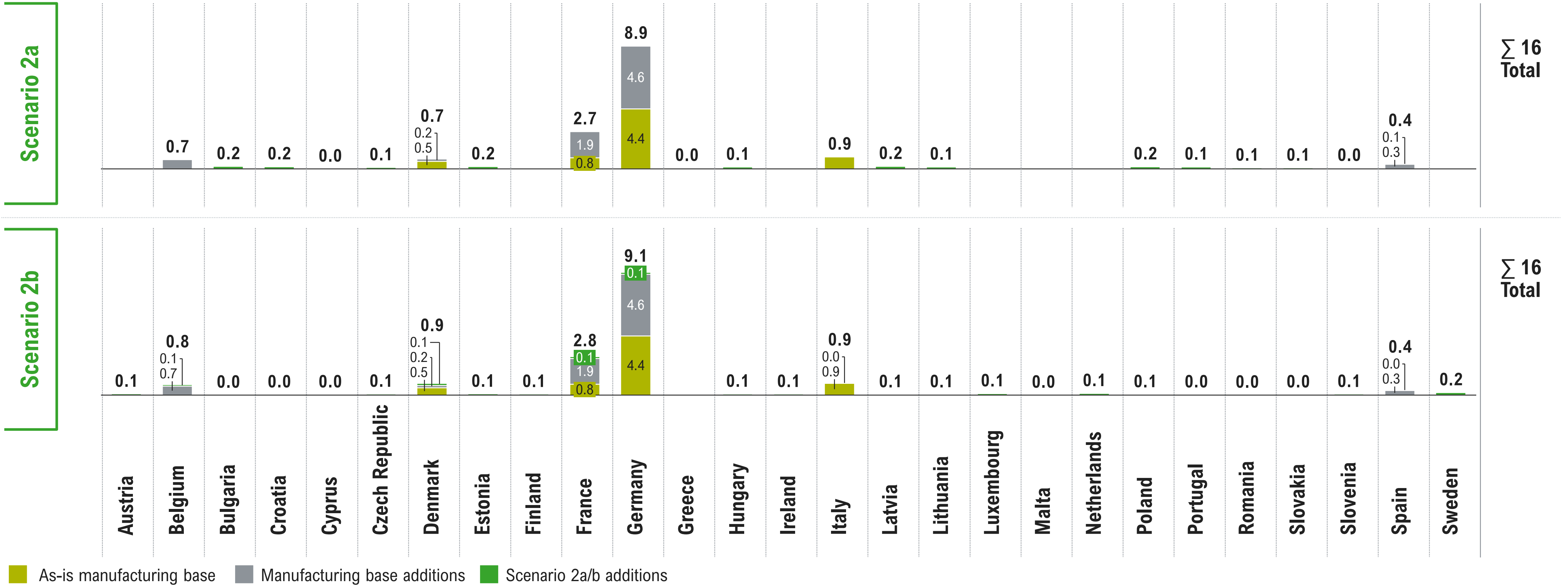
Current manufacturing capacity located in Germany, France, Italy and Denmark – Major announcements in Germany and France, while other countries remain small

Electrolyzer – Overview scenarios: Total costs by geography [EUR bn, 2023-2035 cum.]



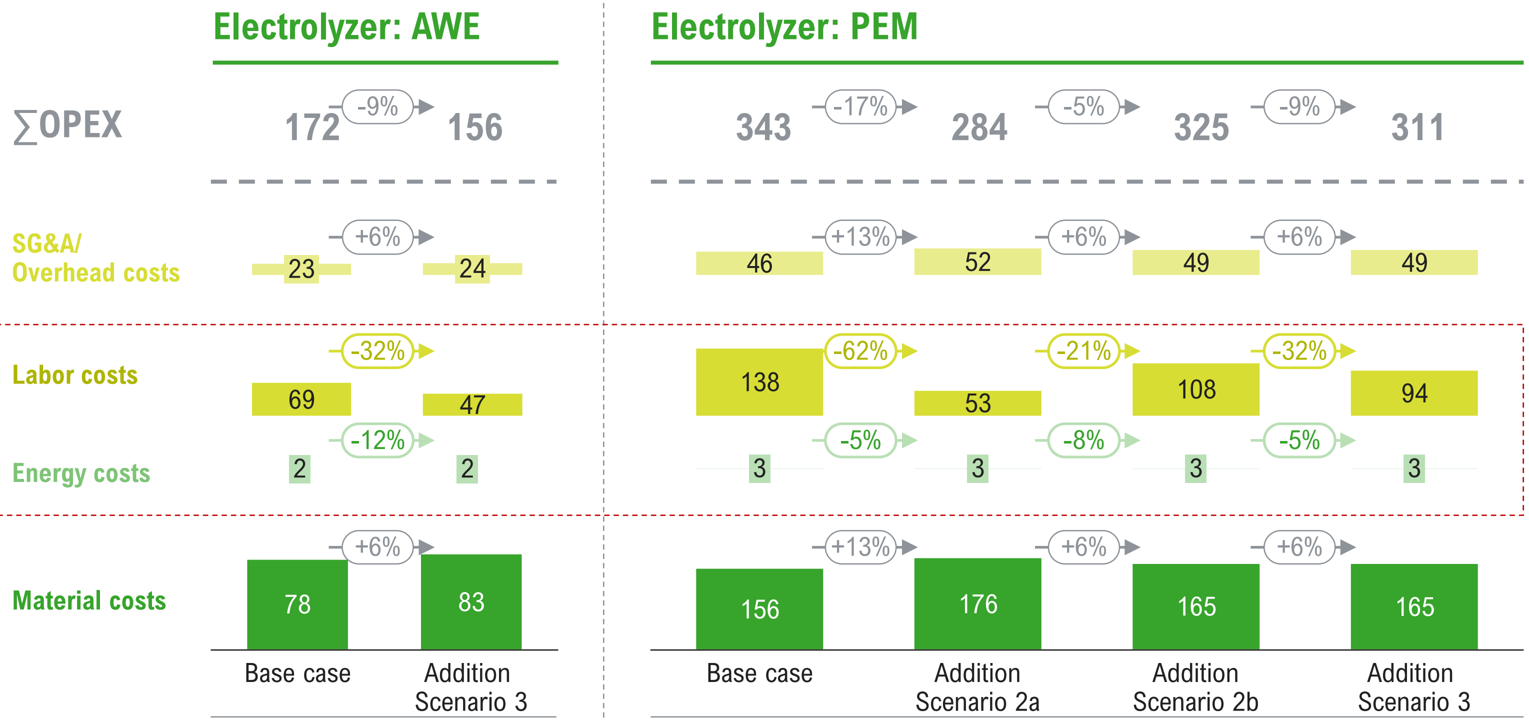
The countries manufacturing in the base case cover most of the demand – Marginal capacity increase for scenarios 2a/b, mostly in already active countries

Electrolyzer – Overview scenarios: Total costs by geography [EUR bn, 2023-2035 cum.]



For Electrolyzer OPEX decrease by 17% in 2a and 5-9% for 2b and 3 – Driven by labor cost decrease

Electrolyzer – Overview scenarios: Unit manufacturing costs per component[1] [EUR/kW]



Electrolyzer: AWE
- Relevant savings by country allocation possible compared to base

Electrolyzer: PEM
- Significant labor cost reduction possible, esp. for 2a
- Lower relative as well as absolute cost reduction potential for energy costs

Material costs | Energy costs | Labor costs | SG&A/Overhead costs | -x% -x% Change compared to base case based on country-specific costs | +x% Change compared to base case based on inflation

1) Only scenarios with additional capacity expansions illustrated

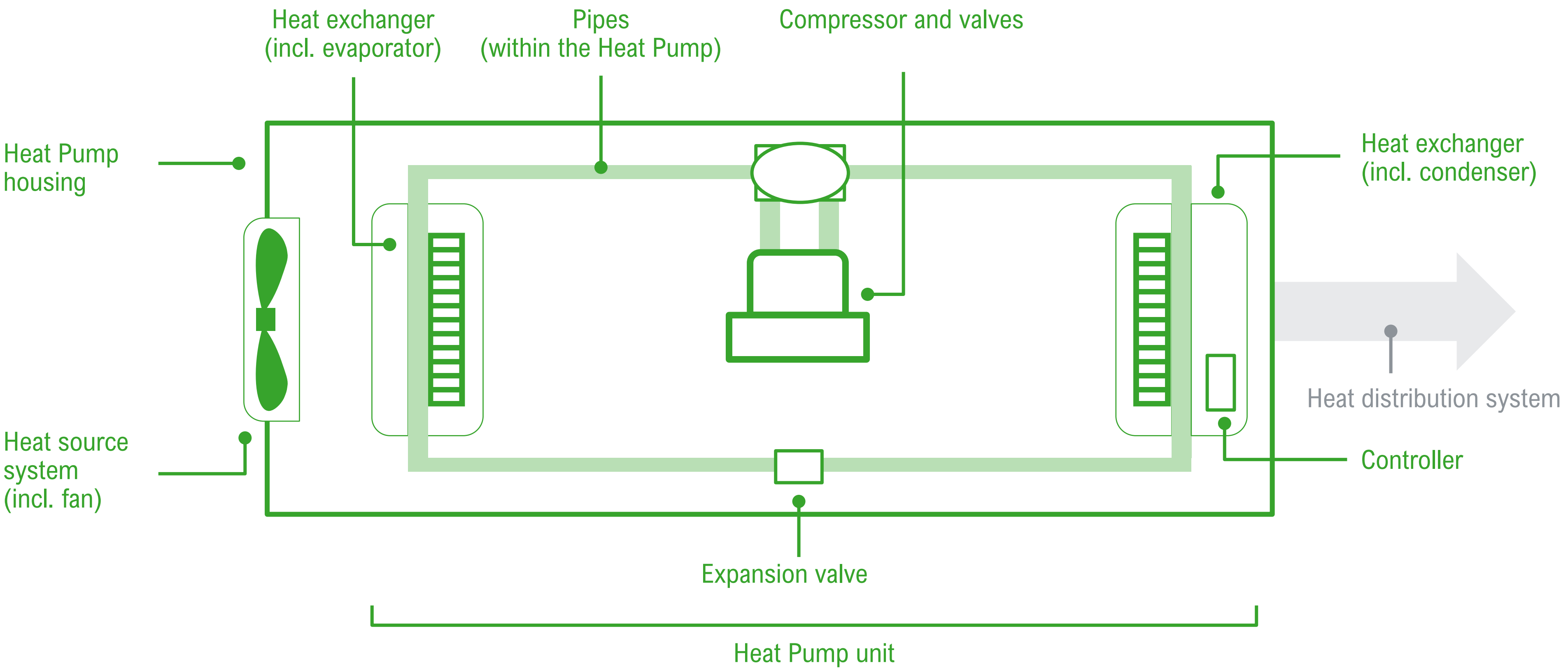
Source: IEA (2022), European Commission (2023), IRENA (2022), NREL (2023), Fraunhofer ISE (2021), Durham University (2021), IEA (2023), Department of Energy & Climate Change (2016), Universität Münster (2021)

C.1.5 Heat Pump

Illustrative

Heat Pump is analyzed based on the main components required for completing the heating cycle – Additional installations for heat distribution are out of scope

Introduction: Heat Pump[1)]



Focus on **Heat Pump**, without considering further components and equipment related to the installation, e.g., insulation, equipment for the heat distribution system, due to high availability and individual designs

Within scope of the analysis

Out of scope

1) Based on air source Heat Pump

Source: US DoE (2023), IEA (2022)

Today's high EU demand share for Heat Pumps is potentially threatened by growing demand and an increasing import dependency from Asia

Technology overview – Heat Pump

European value chain landscape

EU manufacturing capacities [2022]

Heat Pump [GW/y] 14

Global market share

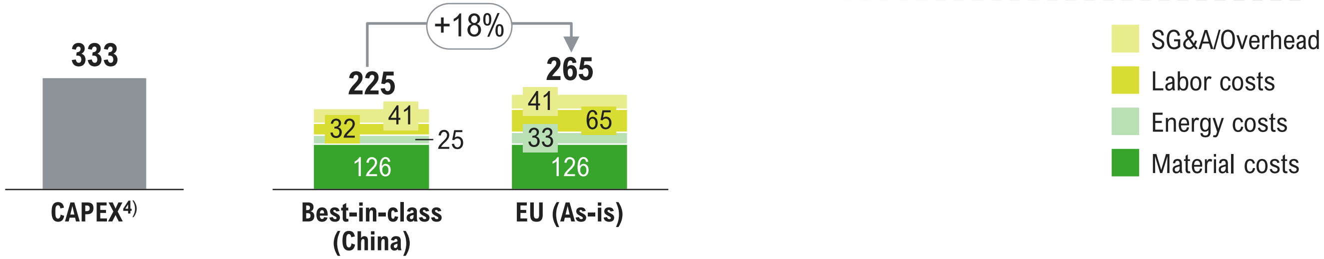

16%

EU demand share[2)]


79%

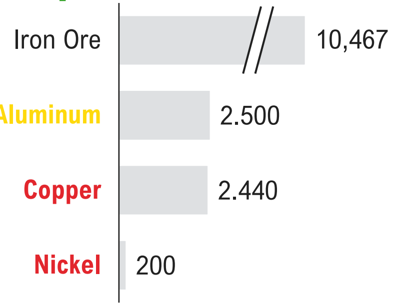
As-is unit manufacturing costs

Total costs: CAPEX & OPEX [EUR/kW]



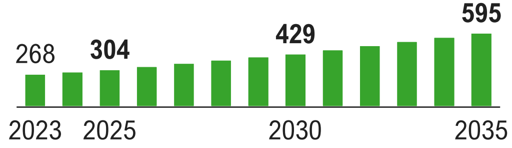
Raw material intensities[3)]

[t/GW]



Demand [forecast 2023-2035]

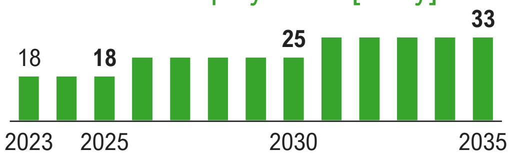
Installed capacities [cum. Volume, GW]



CAGR 23-'30 7.0%

CAGR 30-'35 6.7%

Annual deployments [GW/y]



Strategic material Critical material

Main supply risks

- **Economic risks:** Low to medium due to increased Heat Pump adoption and diverse supplier base in Europe
- **Growing import dependency from Asia** with political and geographical risks
- **Technology risks** to be identified especially from **incremental improvements** of Heat Pumps for additional use cases (e.g., large scale, hybrid systems)

1) Geographical component manufacturing cluster; 2) Demand share understood as share of EU manufacturing capacity of total EU demand for a technology – Based on demand forecast for 2023 according to Agora EU Gas Exit Pathway and EU manufacturing capacity from literature analysis; 3) Selection of main raw material intensities – Assessment of strategic and critical raw materials according to EU (2023); 4) EUR/kW per yearly capacity

Source: US DoE (2023), IEA (2022), EHPA (2023), European Commission (2022), European Union (2022), European Commission (2023), IRENA (2022), NREL (2023), Fraunhofer ISE (2021), Durham University (2021), IEA (2023), US Department of Energy & Climate Change (2016), Universität Münster (2021)

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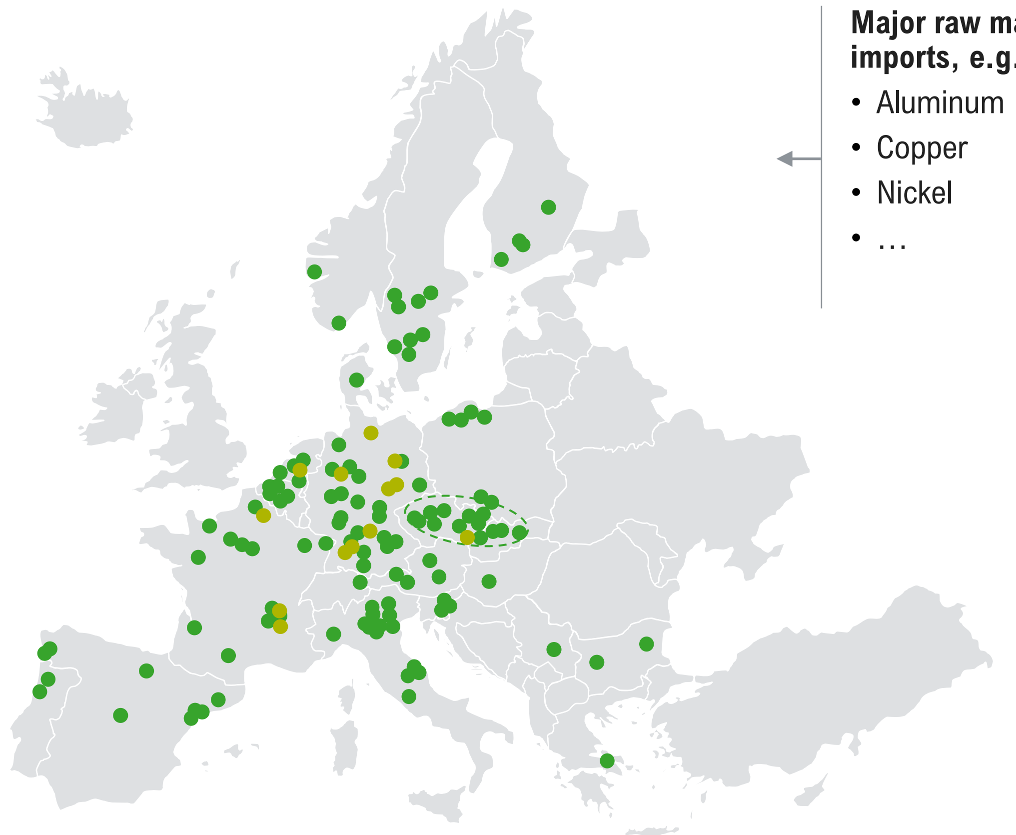
Map – non-exhaustive

The manufacturing landscape for Heat Pump is more dense – Eastern Europe includes both major plant capacities operated and expansions planned

Heat Pump: European value chain landscape



Major raw material imports, e.g.:
- Aluminum
- Copper
- Nickel
- …

Component manufacturing: Heat Pump | Compressor manufacturing | Material refining & processing[1]
Manufacturing cluster

EU manufacturing capacities[2] [2022]

Heat Pump [GW/y] 14 | **Global market share:** 16 % | **EU demand share:** 79 %

Selected manufacturing plants in Europe

Company	Country	Manufacturing capacity	Status
Vaillant		300,000 units/y	In operation
Hoval		n/a	In operation
Panasonic		Expansion to 500,000 units/y	In operation
Viessmann		n/a	COD 2023

Key European players with international manufacturing activities

VIESSMANN	Vaillant	NIBE	STIEBEL ELTRON
(Germany)	(Germany)	(Sweden)	(Germany)

1) Integrated value chain, thus players summarized as component manufacturing; 2) Demand share as share of EU manufacturing capacity of total EU demand (according to Agora EU Gas Exit Pathway, 2023)

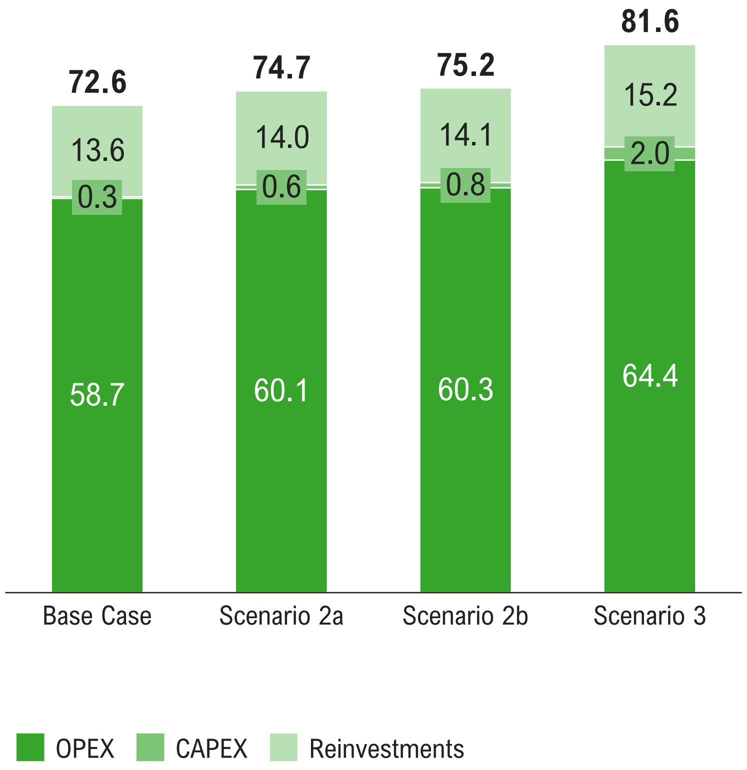
Source: EHPA (2023), European Commission (2022), European Union (2022)

For Heat Pumps, the comparably high market share of domestically manufactured units (as-is) leads to costs incurred mainly for OPEX and reinvestments

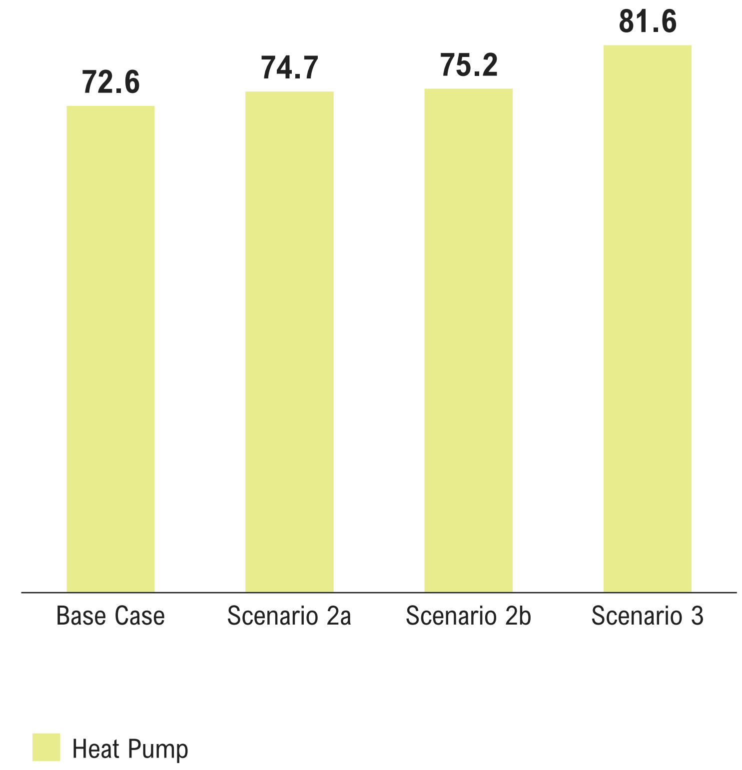
Heat Pump – Overview scenarios: Costs & resilience premium [EUR bn, 2023-2035 cum.]

Total costs [EUR bn, 2023-2035]

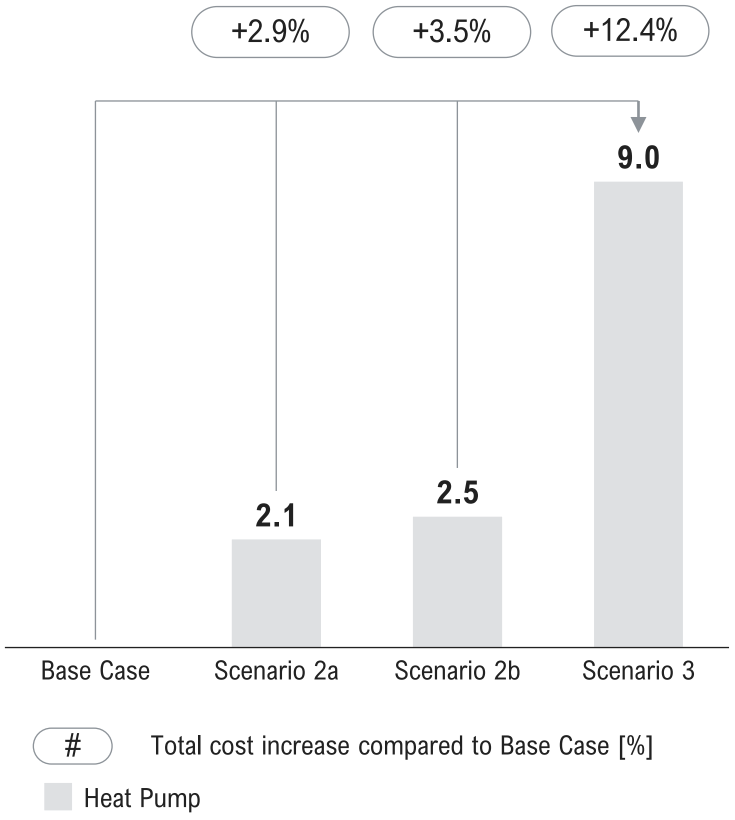
Cost types



Components

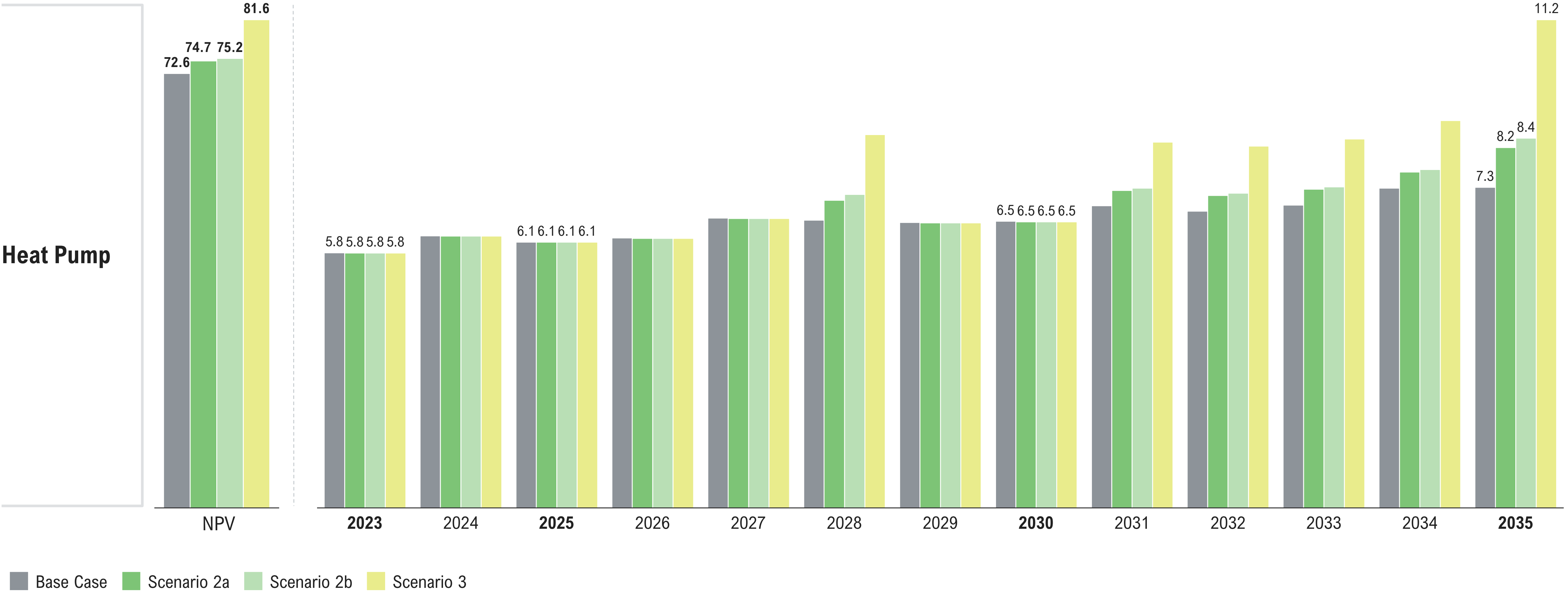


Resilience premium [EUR bn]



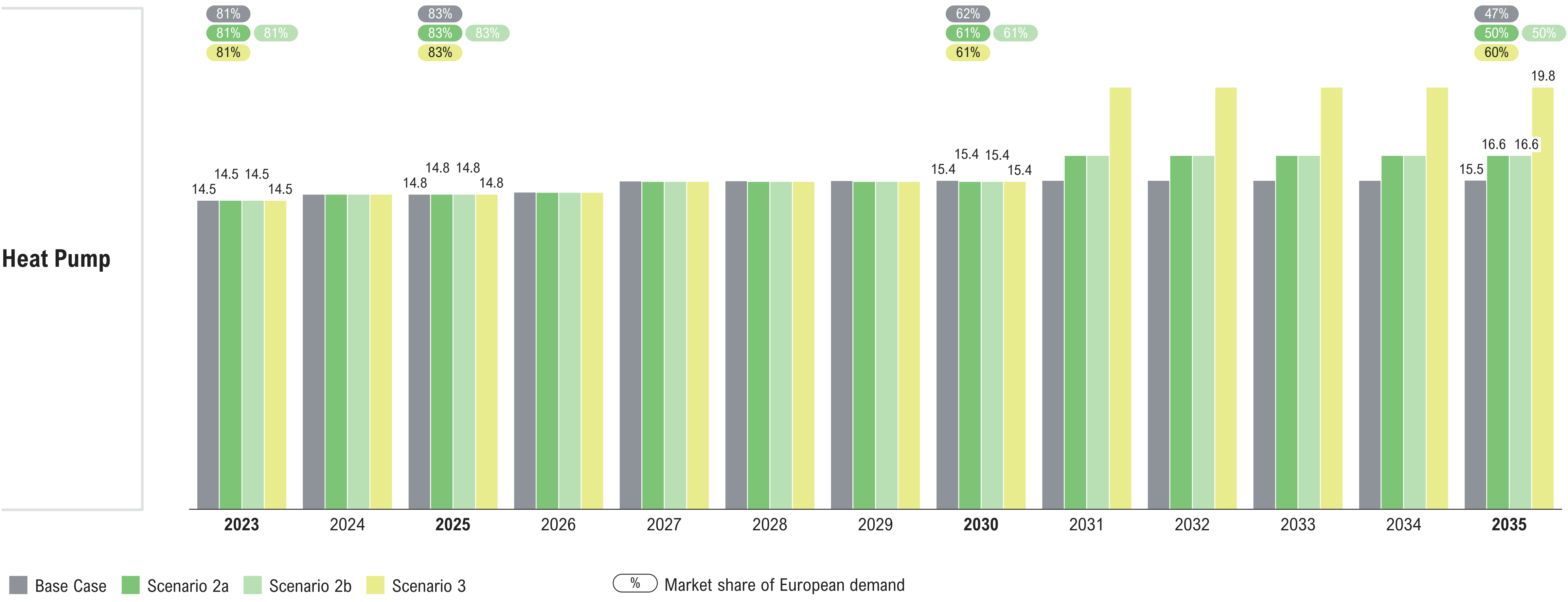
Total costs for Heat Pump manufacturing capacity increase moderately but steadily over the time horizon – Only scenario 3 shows a more extensive increase

Heat Pump – Overview scenarios: Total costs & NPV [EUR bn, NPV 2023-2035 cum.]



Until 2030 capacity is steadily rising due to announced additions while market shares decline – Thereafter, expansions are needed, especially in scenario 3

Heat Pump – Overview scenarios: Capacity and market shares [GW | %-share]



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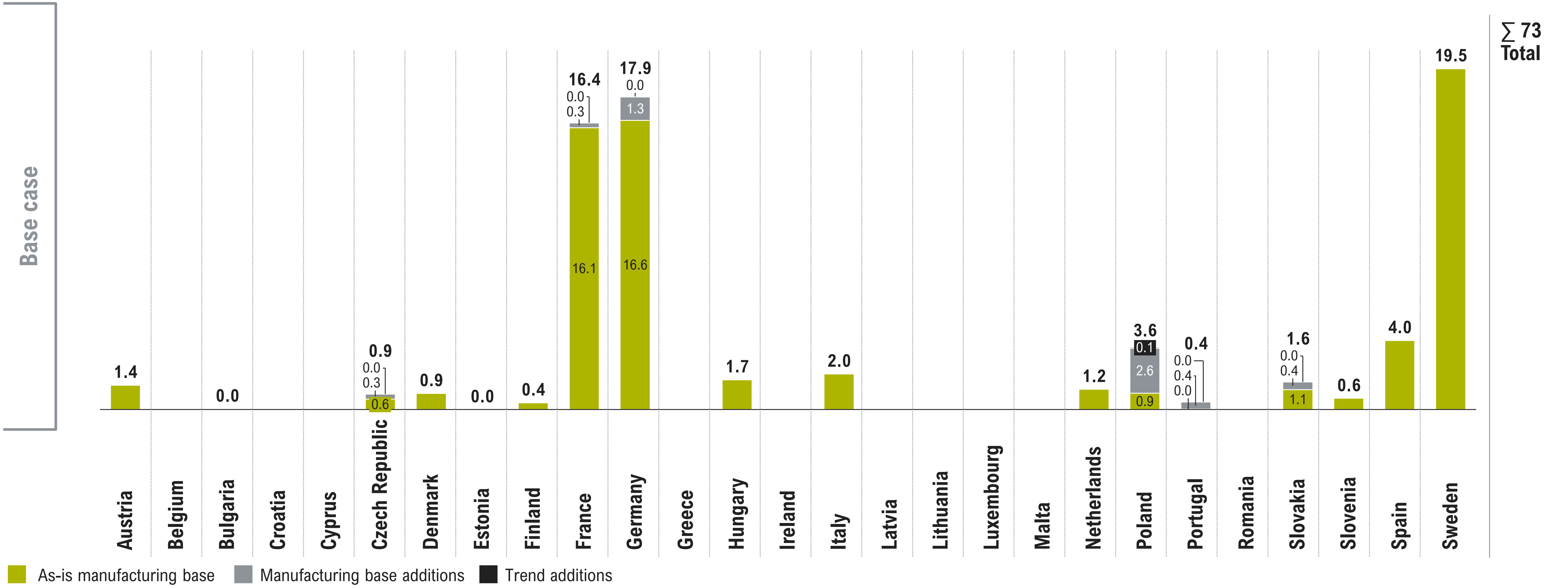
Total manufacturing capacity costs in the base case are mainly allocated to Sweden, Germany and France – Significant announced additions in Poland

Heat Pump – Overview scenarios: Total costs by geography [EUR bn, 2023-2035 cum.]



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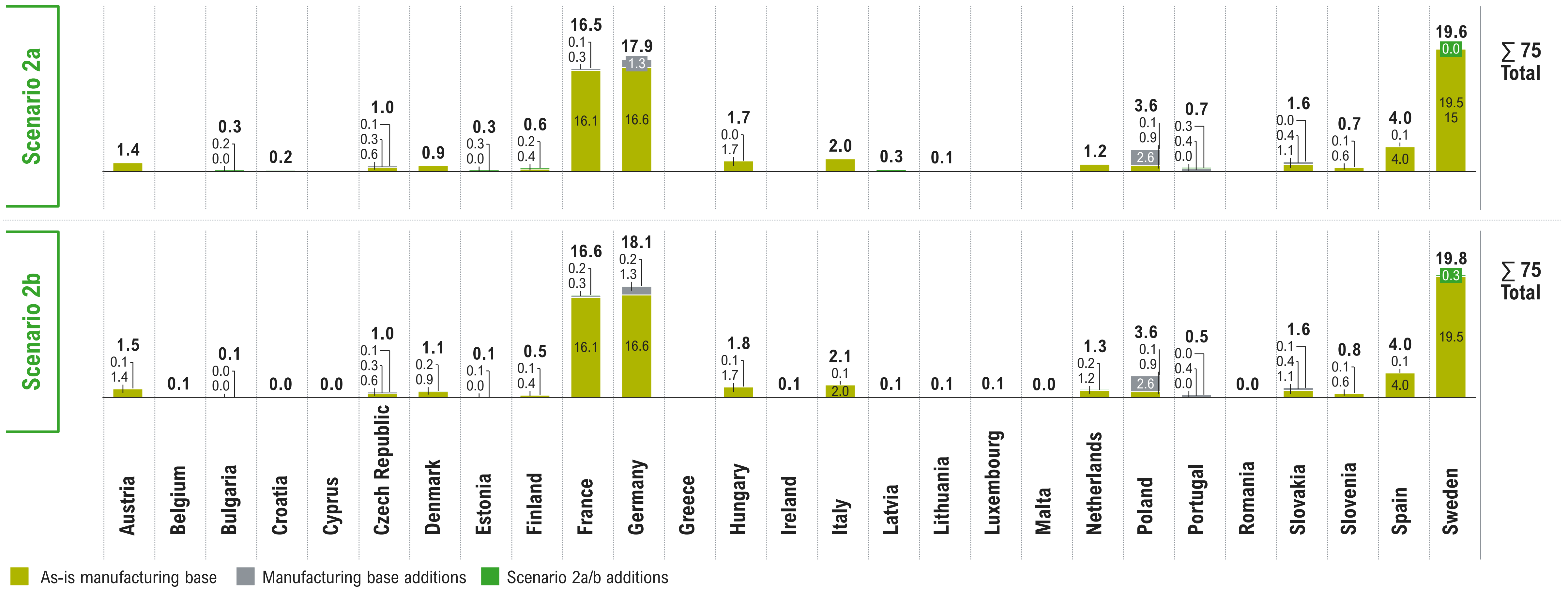
Due to the high level of demand coverage from the as-is production base, the resilience premium for the scenarios 2a/b is minimal and production barely changes

Heat Pump – Overview scenarios: Total costs by geography [EUR bn, 2023-2035 cum.]



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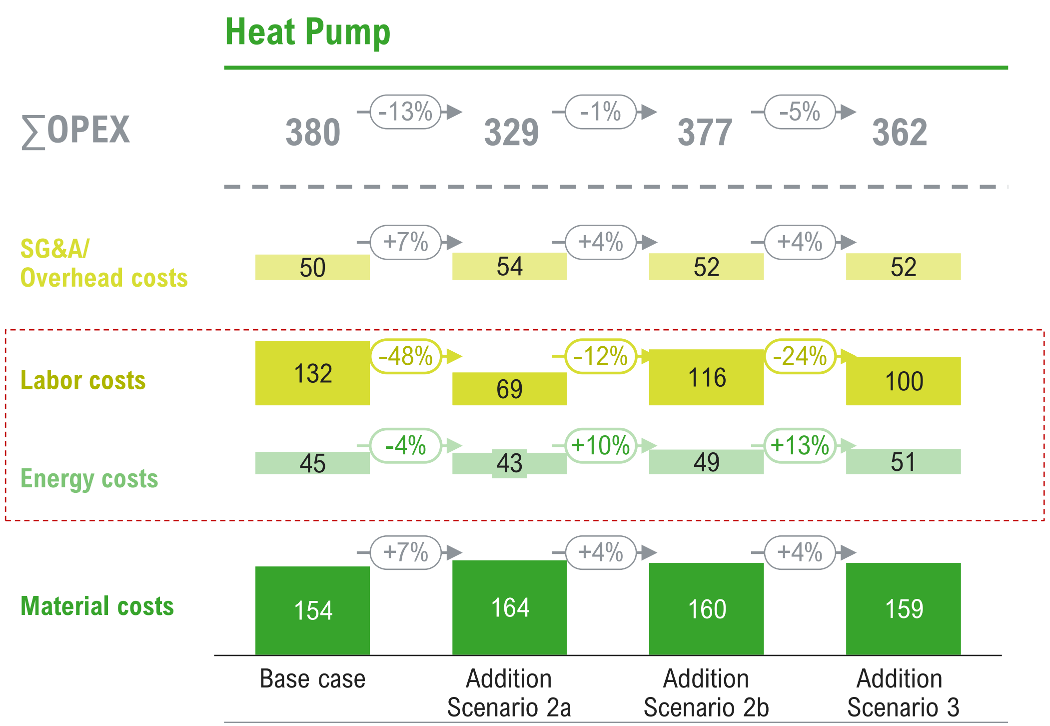
For Heat Pump OPEX decrease by 13% in 2a and 1-5% for 2b and 3 – Driven by labor cost decrease

Heat Pump – Overview scenarios: Unit manufacturing costs per component[1] [EUR/kW]



- Major reduction potential in absolute as well as relative terms for labor costs, particularly for 2a
- Reduction for energy in 2a, increase for 2b and 3

Material costs   Energy costs   Labor costs   SG&A/Overhead costs   -x% -x% Change compared to base case based on country-specific costs   +x% Change compared to base case based on inflation

1) Only scenarios with additional capacity expansions illustrated

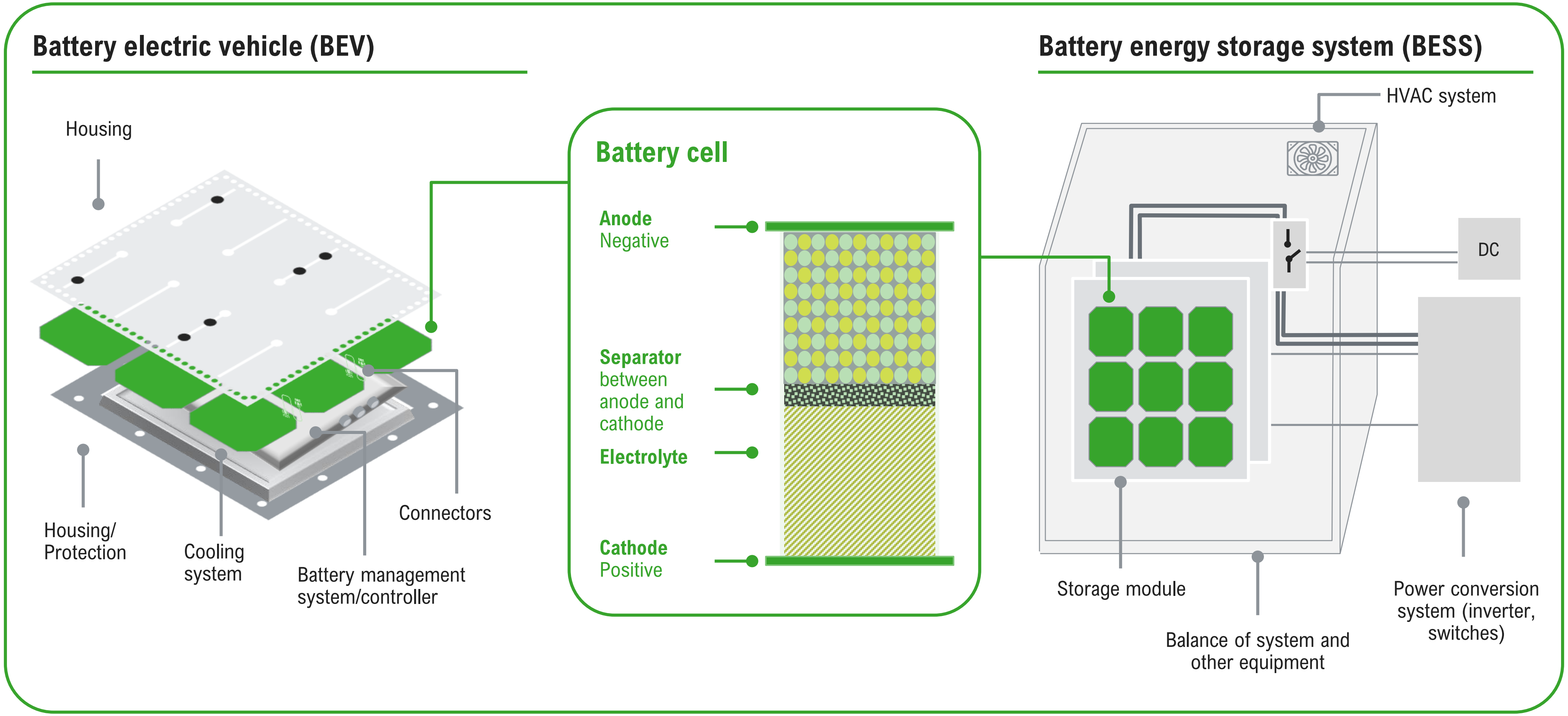
Source: IEA (2022), European Commission (2023), IRENA (2022), NREL (2023), Fraunhofer ISE (2021), Durham University (2021), IEA (2023), Department of Energy & Climate Change (2016), Universität Münster (2021)

C.1.6 Battery

Illustrative

Battery cell and its main components are in the focus of the report – Additional components of battery module in vehicles or as stationary storage out of scope

Introduction: Battery

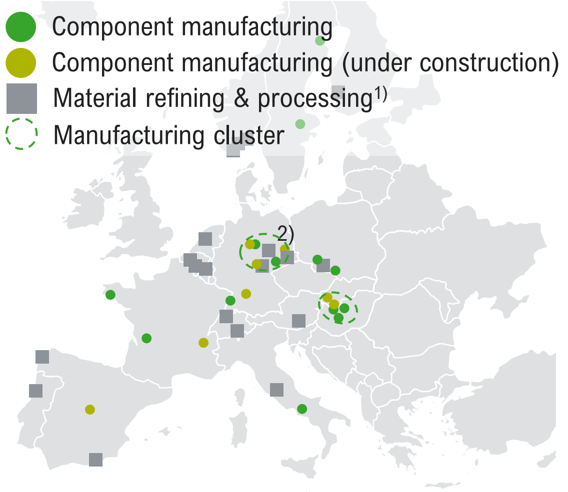


Focus on **battery cell which is stacked within packs for electric vehicle or storage system**, without considering further components and systems due to higher availability and individual designs

The significant battery demand increase bears major economical risks in connection with the high import and strategic materials dependency

Technology overview – Battery

European value chain landscape



EU manufacturing capacities [2022]

Battery [GWh/y] 75

Global market share

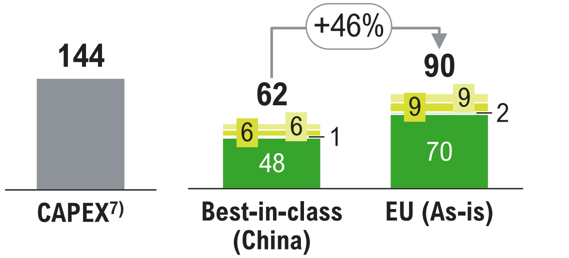
8%

EU demand share[3]

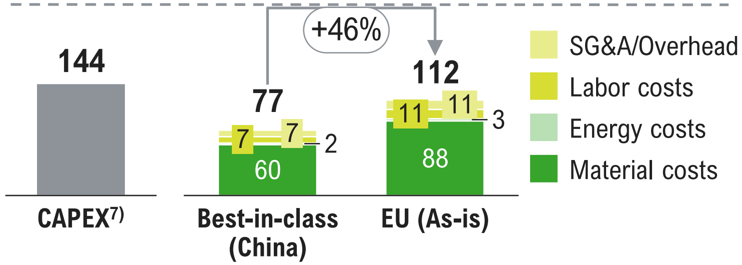

43%

As-is unit manufacturing costs

LFP[5] total costs: CAPEX & OPEX [EUR/kWh]

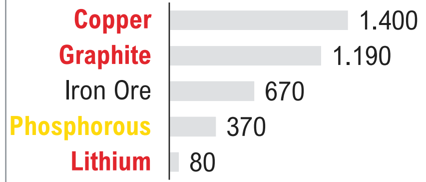


NMC[6] total costs: CAPEX & OPEX [EUR/kWh]

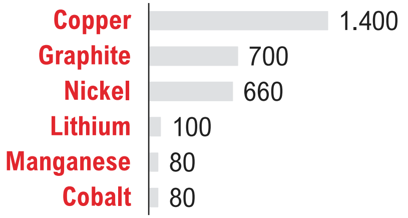


Raw material intensities[4]

LFP [t/GWh]

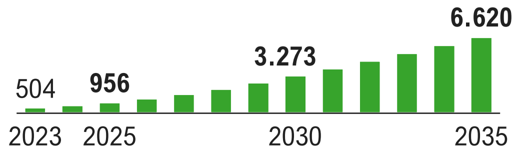


NMC [t/GWh]



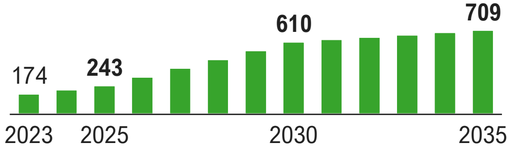
Demand [forecast 2023-2035]

Installed capacities [cum. Volume, GWh]



CAGR 23-'30: 30.6%
CAGR 30-'35: 15.1%

Annual deployments [GWh/y]



Main supply risks

- **Major economical risks** due to capacity ramp-up especially for EVs and high dependency on few large global suppliers (Asia), driving also key geographic risks
- **Increased regulatory risk exposure** due to the use of critical raw materials
- Lithium-Ion batteries face **technology risks** from improvements in cell chemistries (incremental), while disruptive technologies are still under development

Strategic material Critical material

1) Active material suppliers (Graphite, cobalt, lithium, nickel), all sites up to COD in 2023; 2) Major projects announced, manufacturing cluster expected; 3) Demand share understood as share of EU manufacturing capacity of total EU demand for a technology – Based on demand forecast for 2023 according to Agora EU Gas Exit Pathway and EU manufacturing capacity from literature analysis. Percentage value represents both sub-technologies in total (See EU demand share overview for details); 4) Selection of main raw material intensities – Assessment of strategic and critical raw materials according to EU (2023); 5) Lithium Iron Phosphate (LFP); 6) Lithium Nickel Manganese Cobalt Oxide (NMC); 7) EUR/kWh per yearly capacity

Source: : IEA (2023), RWTH Aachen/VDMA (2022), European Commission (2018, 2020, 2022, 2023), Energy Transitions Commission (2023), IEA (2023), Bareiß et al. (2019), IEA (2022), IRENA (2022), NREL (2023), Fraunhofer ISE (2021), Durham University (2021), US Department of Energy & Climate Change (2016), Universität Münster (2021) Koj et al. (2017)

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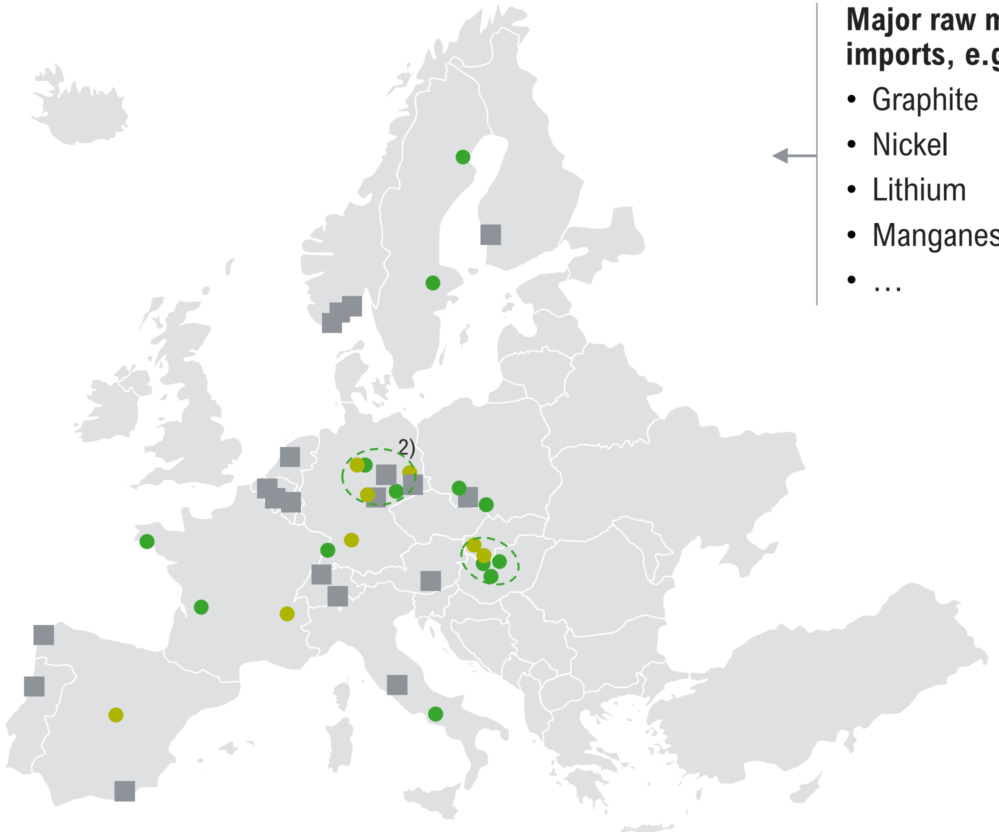
Map – non-exhaustive

Significant manufacturing capacities are announced for battery – Potential clusters might appear in Eastern Germany as well as Hungary (Eastern Europe)

Battery[1]: European value chain landscape



Major raw material imports, e.g.:
- Graphite
- Nickel
- Lithium
- Manganese
- …

Component manufacturing
Manufacturing cluster
Material refining & processing[3]
Component manufacturing (under construction)

EU manufacturing capacities[4] [2022]

Battery cell [GWh/y] 75 | **Global market share:** 8 % | **EU demand share:** 43 %

Selected manufacturing plants in Europe

Company	Country	Manufacturing capacity [GWh/y]	Status
Samsung SDI	Hungary	30 (expansion up to 40)	In operation
SK Innovation	Hungary	7.5	In operation
LG Chem	Poland	35 (expansion up to 70-115)	In operation
Northvolt	Sweden	16	In operation
CATL	Germany	14	In operation

Key European players with international manufacturing activities

northvolt (Sweden) | saft (France) | VARTA (Germany)

1) Due to the less mature state of technology compared to e.g., PV or Wind, and the currently planned major capacity expansions, the landscape map is extended to plants under construction to include upcoming short-term developments; 2) Major projects announced, manufacturing cluster expected; 3) Active material suppliers (Graphite, cobalt, lithium, nickel), all sites up to COD in 2023; 4) Demand share as share of EU manufacturing capacity of total EU demand (Agora EU Gas Exit Pathway, 2023), percentage value represents both sub-technologies in total (See EU demand share overview for details)

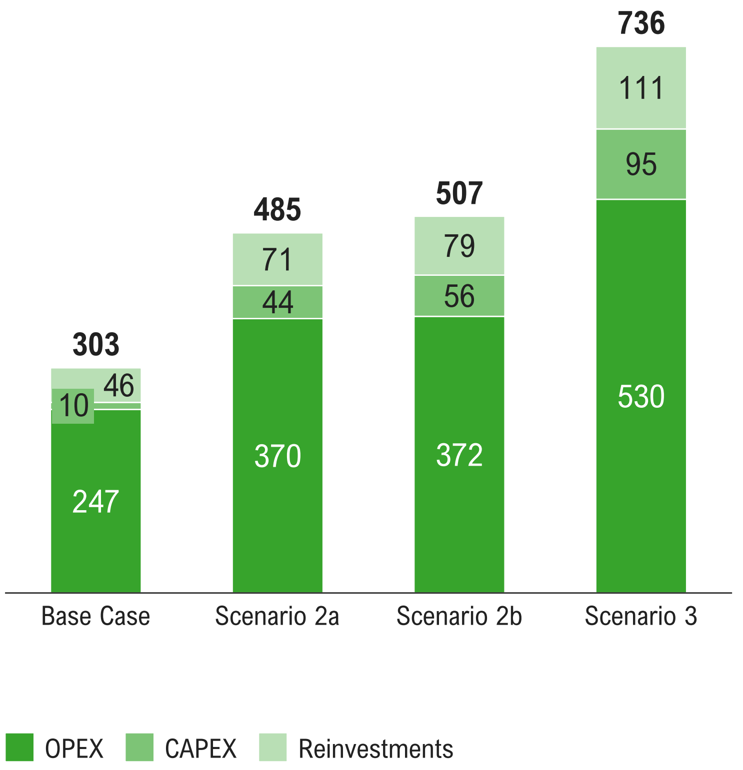
Source: IEA (2023), RWTH Aachen/VDMA (2022), European Commission (2023), European Commission (2022)

To achieve resilience battery CAPEX investments must increase by a factor of 4-5, while OPEX rises by c.50% – High costs caused by NMC capacity expansions

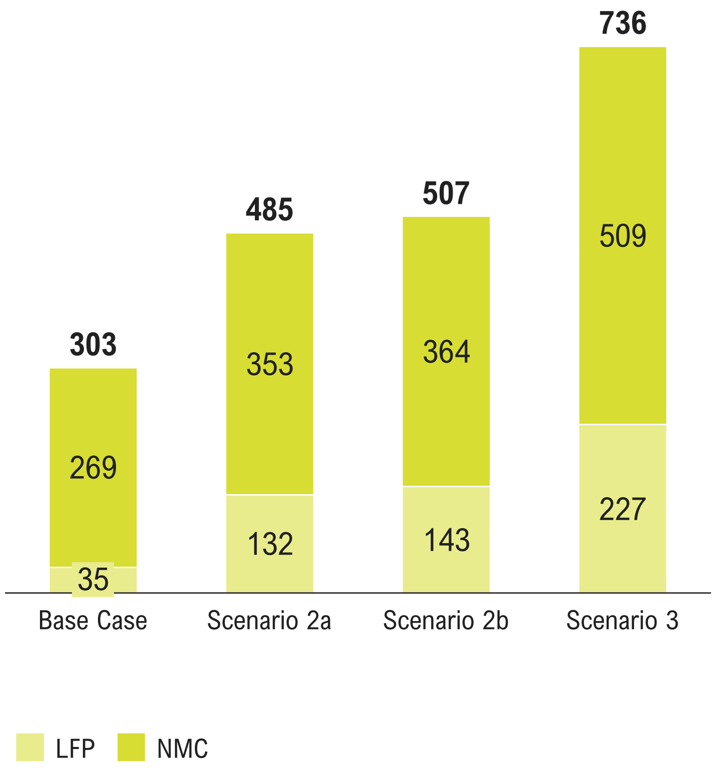
Battery – Overview scenarios: Costs & resilience premium [EUR bn, 2023-2035 cum.]

Total costs [EUR bn, 2023-2035]

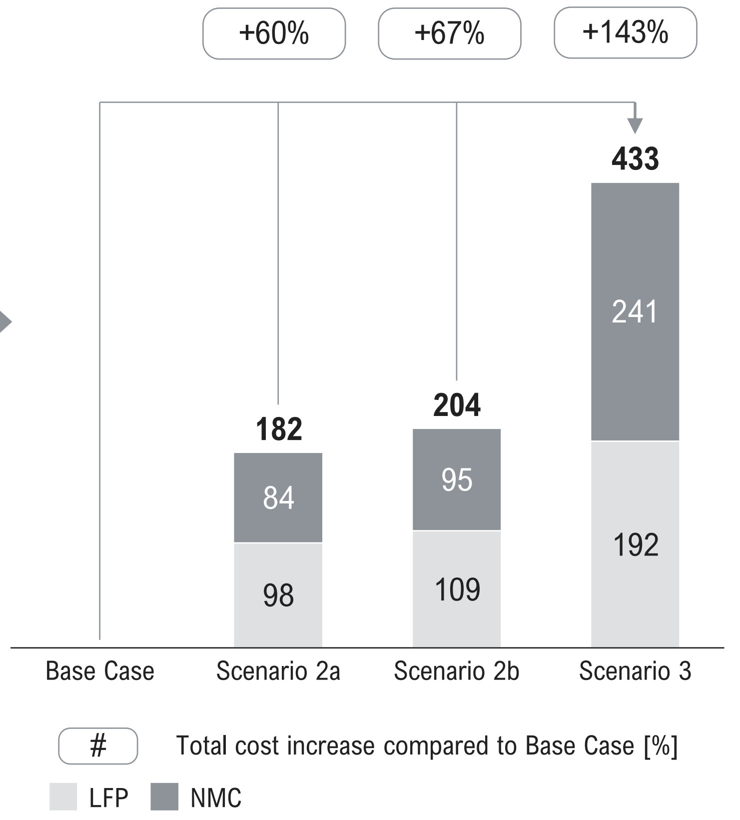
Cost types



Components

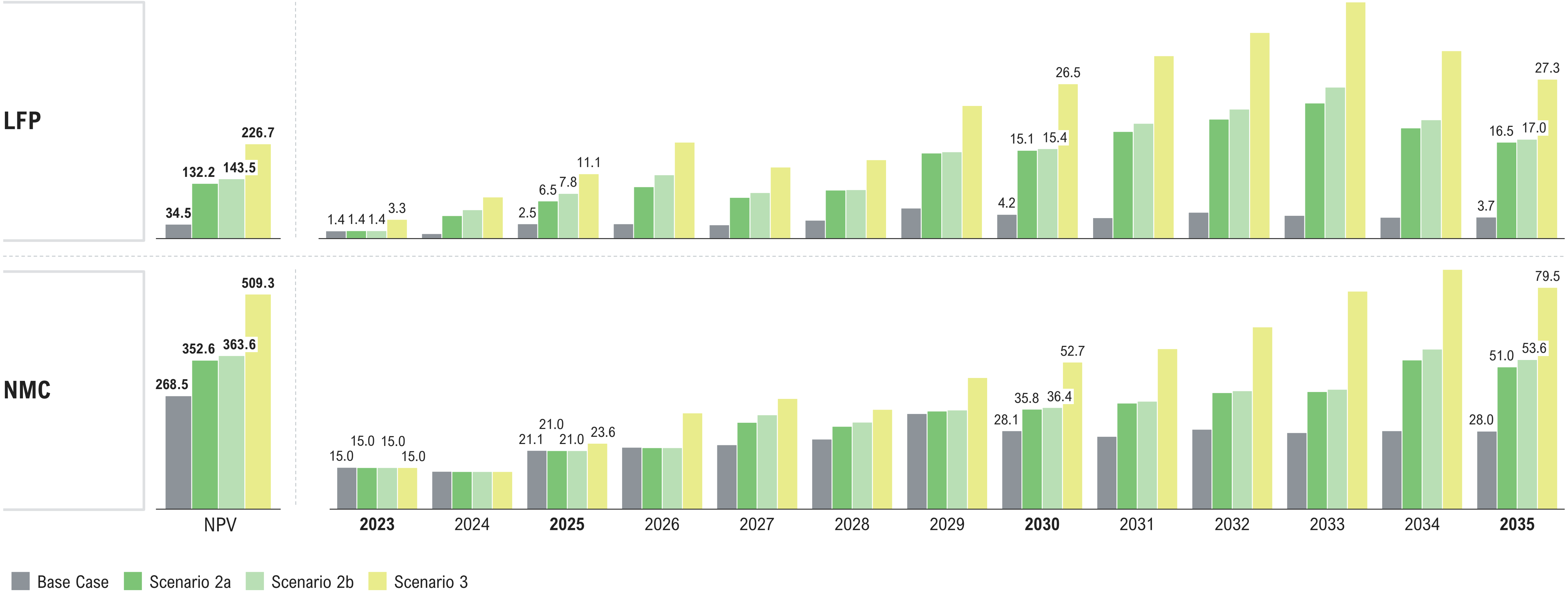


Resilience premium [EUR bn]



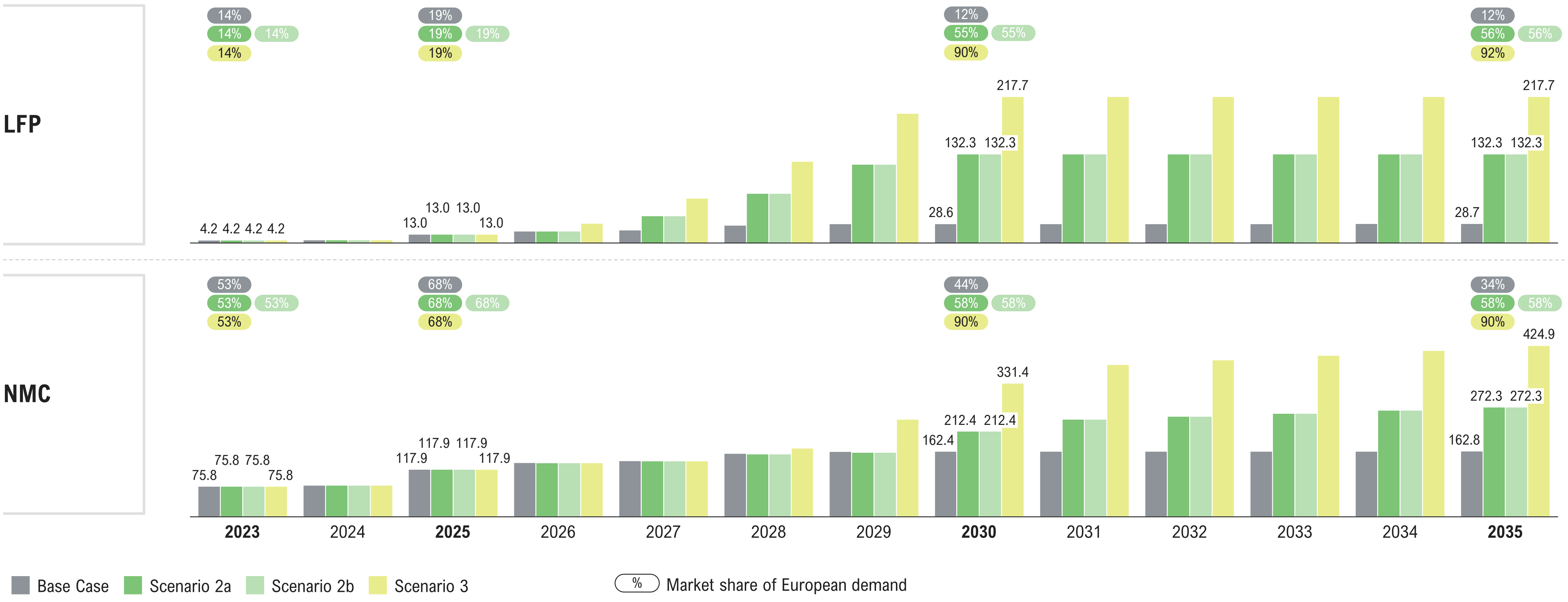
LFP and NMC costs are characterized by a strong and constant increase over time across all scenarios to meet targets – Highest cost rise for scenario 3

Battery – Overview scenarios: Total costs & NPV [EUR bn, NPV 2023-2035 cum.]



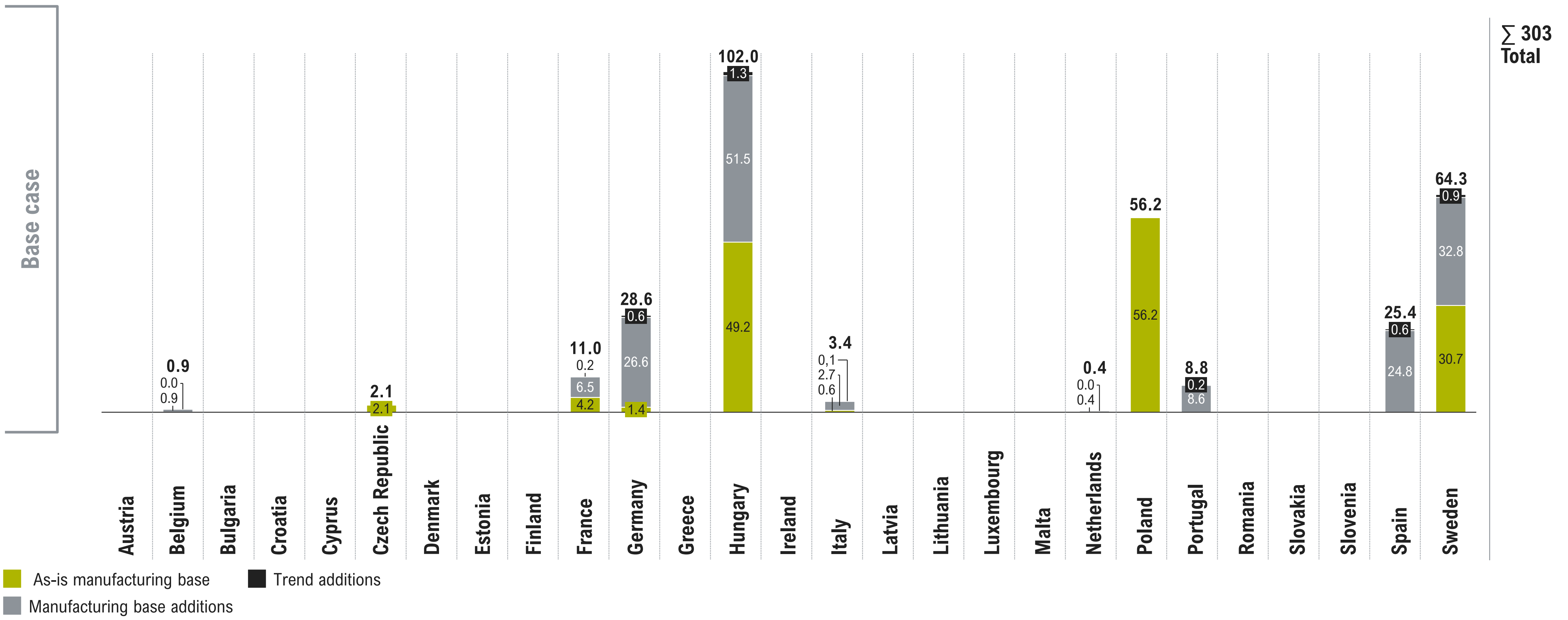
For NMC a strong capacity increase in absolute terms is necessary to maintain resilience, while LFP shows higher relative growth rates to achieve resilience

Battery – Overview scenarios: Capacity and market shares [GWh | %-share]



The battery manufacturing base is concentrated in Poland, Hungary and Sweden with significant additions planned in Hungary, Sweden, Germany and Spain

Battery – Overview scenarios: Total costs by geography [EUR bn, 2023-2035 cum.]



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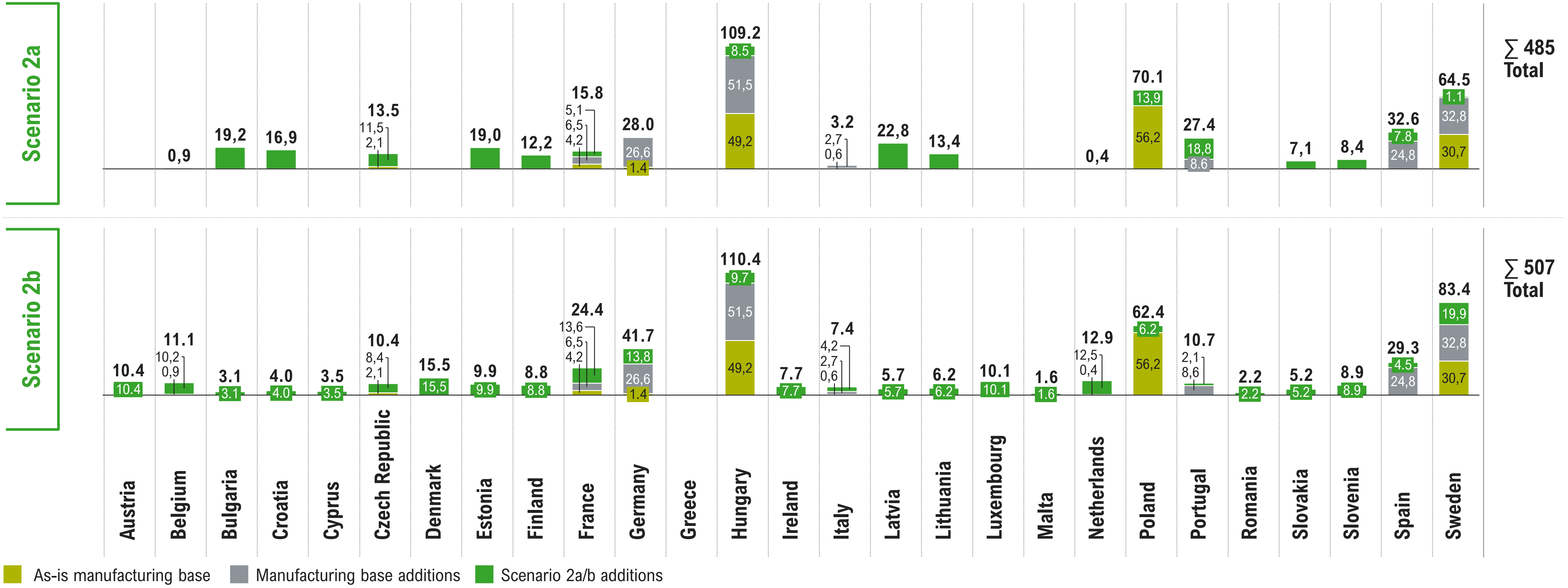
The country allocation of the scenarios 2a/b favor similar countries – Differences in country weight and few exceptions like high shares in Denmark in scenario2b

Battery – Overview scenarios: Total costs by geography [EUR bn, 2023-2035 cum.]



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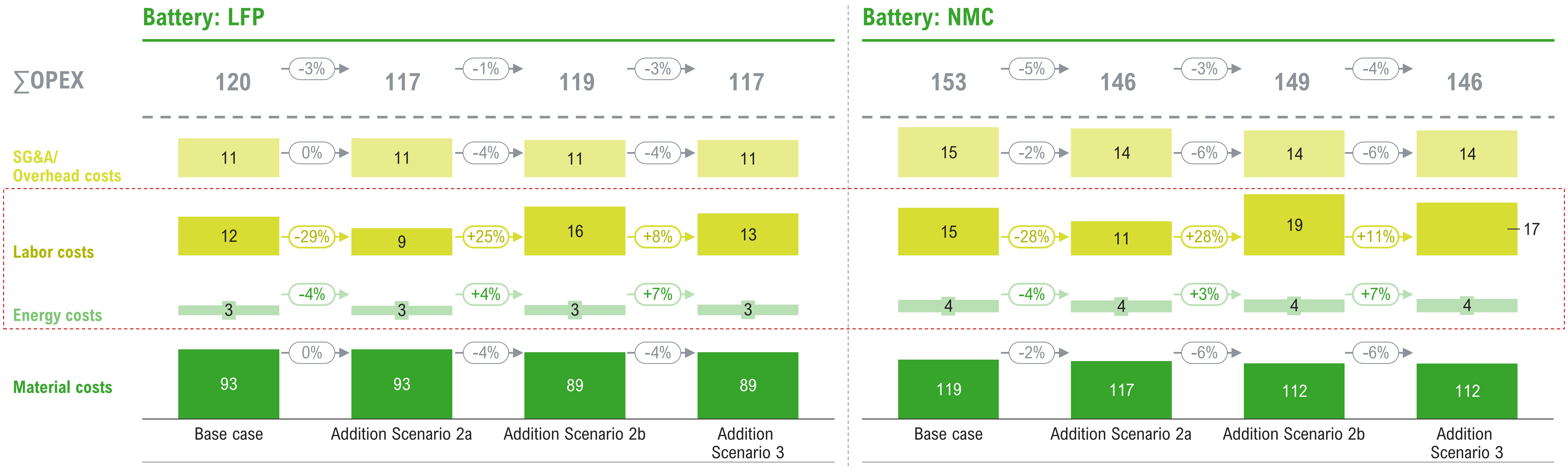
Relatively low savings of <5% across scenarios imply already low-cost base case for Battery, especially regarding labor and energy costs increasing for 2b and 3

Battery – Overview scenarios: Unit manufacturing costs per component[1)] [EUR/kWh]



Battery: LFP
- Labor and energy savings for scenario 2a possible, especially for labor
- Costs for 2b and 3 increase implying low-cost base case country footprint

Battery: NMC
- Labor and energy savings for scenario 2a possible, especially for labor
- Costs for 2b and 3 increase implying low-cost base case country footprint

Material costs | Energy costs | Labor costs | SG&A/Overhead costs | -x% -x% Change compared to base case based on country-specific costs | +x% Change compared to base case based on inflation

Source: IEA (2022), European Commission (2023), IRENA (2022), NREL (2023), Fraunhofer ISE (2021), Durham University (2021), IEA (2023), Department of Energy & Climate Change (2016), Universität Münster (2021)

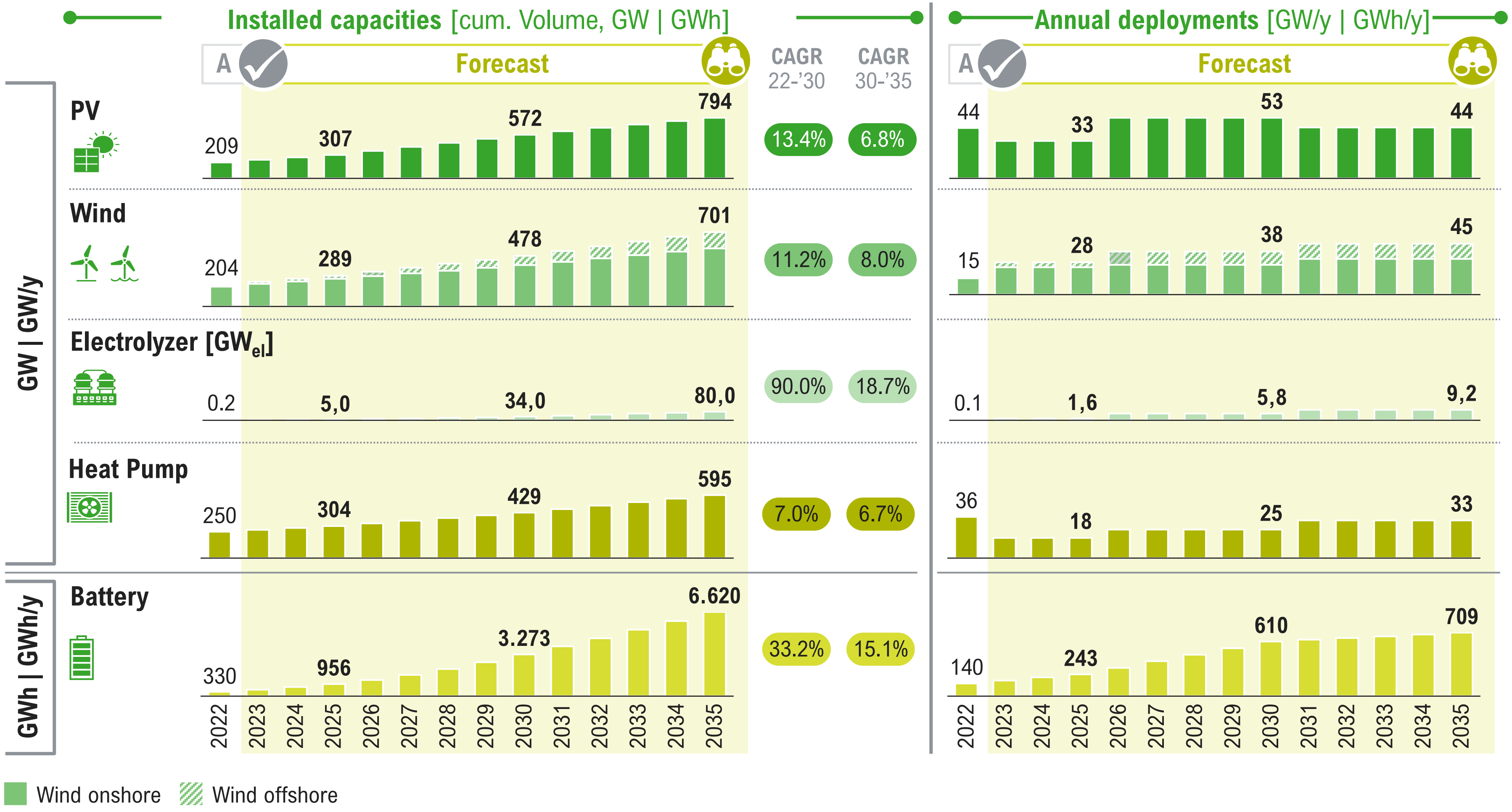
C.2 Other key supporting documents

C.2.1 As-is and value chain assessment

Based on data supplied by Agora (exception: Battery)

AGORA EU Gas Exit scenario is input for demand ramp-up, more than doubling capacities for PV, Wind & Heat Pump – Steep increase for Electrolyzer & battery

EU demand: Installed capacities and annual deployments – **Volume** [GW | GWh / GW/y | GWh/y]



- Actuals (A) 2022 based on installed manufacturing base as per end of 2022 (according to EU and market reports)
- For **PV, Wind, Electrolyzer and Heat Pump**, **analysis will be based on Agora EU Gas Exit Pathway scenario** with
  - Installed capacity data for 'focus years' 2025, 2030 and 2035
  - Ramp-up between 'focus years' calculated as linear steps
  - Ramp-up between as-is 2022 and 2025 distributed linearly as well
- For **Batteries**
  - GEXIT accounting for stationary battery storage, no data available for EV battery
  - Target value 2030 of 610 GWh based on recent EU study (European Commission, 2023), conservative proxy in line with market studies indicating demand ranges from 400-1000 GWh/y in 2030
  - Target value for 2035 with moderate growth rate based on market expectations

Source: Agora 'GEXIT' Scenario; European Union (2023), Solar Power Europe (2023), WindEurope (2023), IEA (2022), EHPA (2023), Eurobat (2023), Stiftung Wissenschaft und Politik (2022)

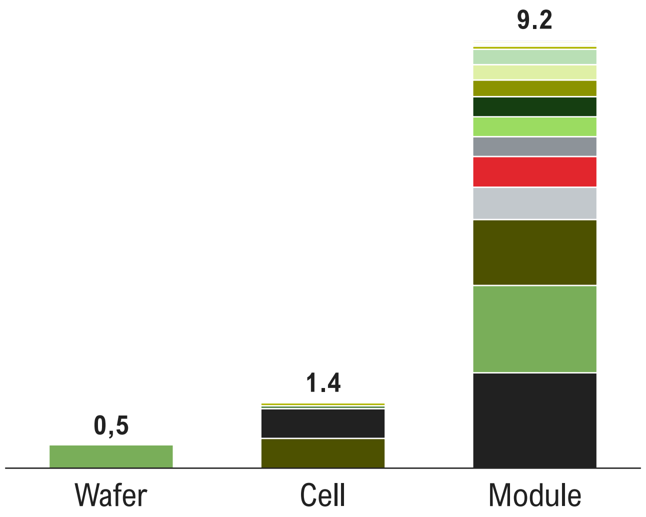
Final status as of June 7, 2023. Published in September 2023

Indicative analysis

EU manufacturing of PV focuses on modules with diversified distribution of capacities while Wind components are dominated by Spain, Germany and Portugal

EU manufacturing capacities by component and by country [as-is 2022, GW/y]

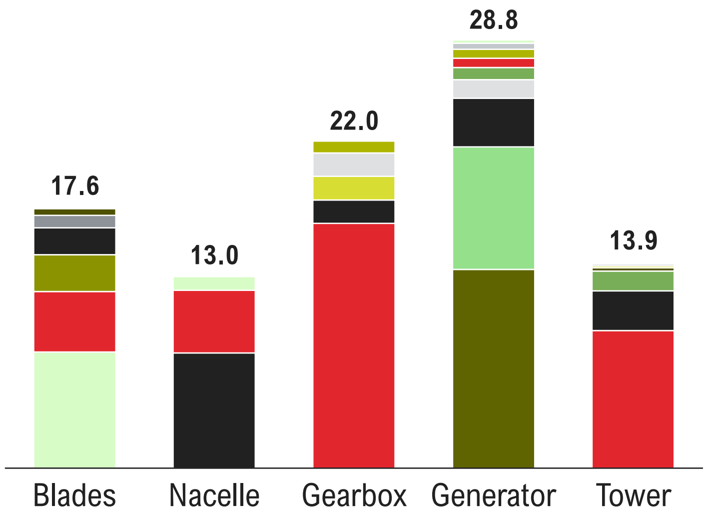
PV [GW/y]



- Estimation of geographic split by number and size of companies for wafer, cell and module manufacturing in the EU
- Numbers without Norway (Silicon processing and wafer)

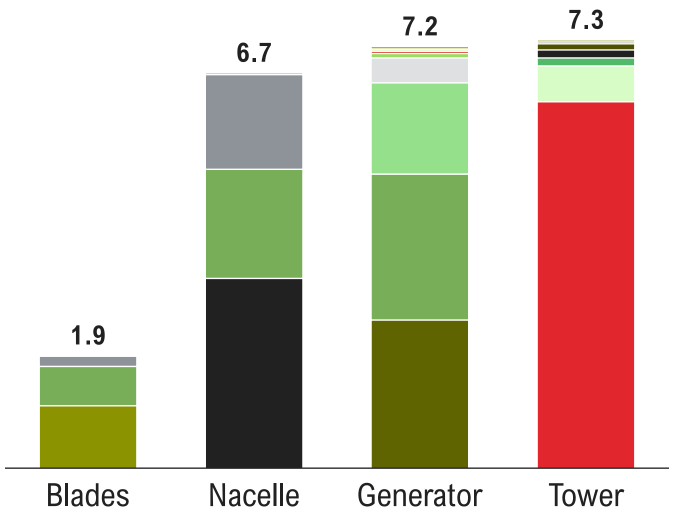
Wind [GW/y]

Onshore



- Estimation of geographic split by number and size of companies for onshore components and partly sites with both on- and offshore
- Split derived by number of employees of major sites

Offshore



- Estimation of geographic split by number and size of companies for onshore components and partly sites with both on- and offshore
- Split derived by number of employees of major sites

Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden

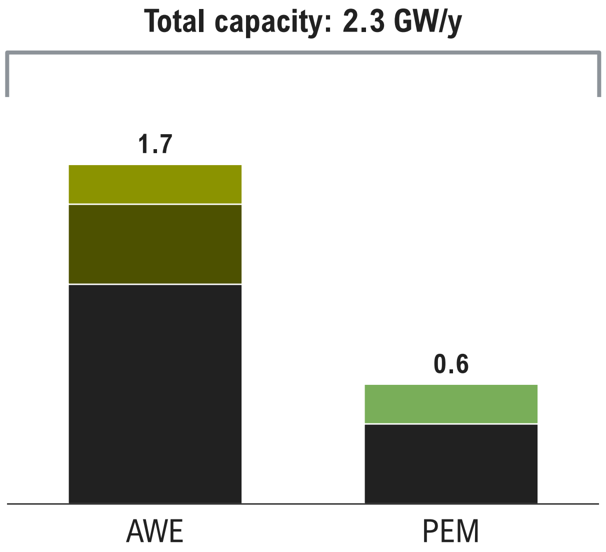
Source: European Union (2023), Fraunhofer ISE (2023), Solar Power Europe (2023), WindEurope (2023), Company information

Indicative analysis

Electrolyzer is characterized by German sites, while Heat Pumps show a more diversified pattern with Sweden leading – Major battery plants in Poland and Hungary

EU manufacturing capacities by component and by country [as-is 2022, GW/y and GWh/y]

Electrolyzer [GW/y]



- Numbers according to manufacturing sites already in operation
- Split by AWE and PEM derived from current split of installed Electrolyzer capacities in Europe (60% PEM)

Heat Pump [GW/y]

- Manufacturing capacities by country derived from EU production data (production value)

Battery [GWh/y]

- Numbers according to sites already in operation, split by technology type not available
- Major sites are located in Poland (LGES) and Hungary (Samsung SDI)

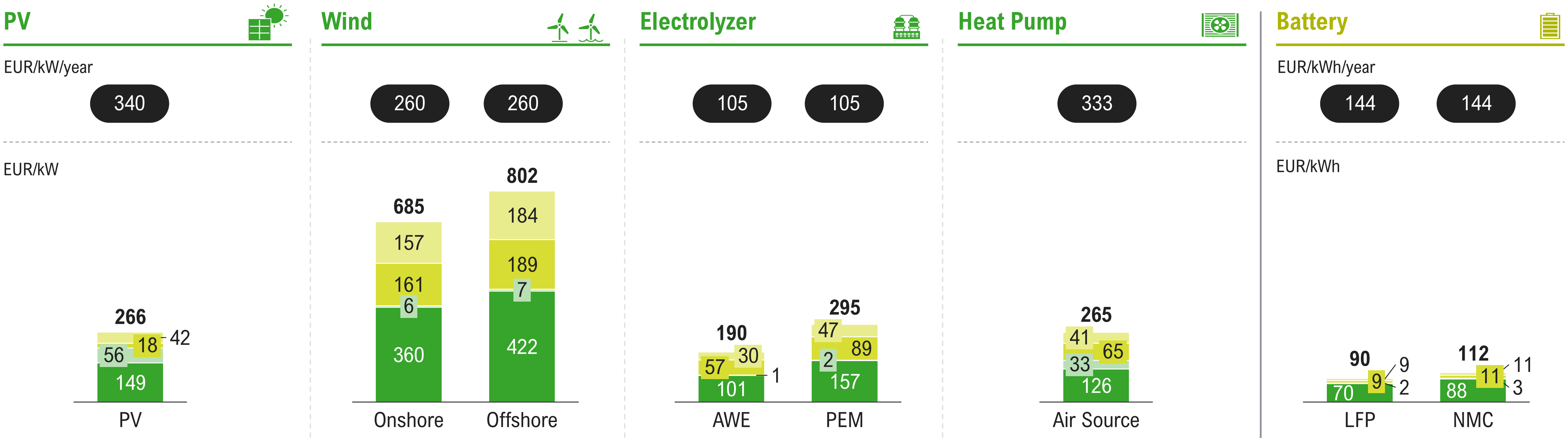
Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Other

Source: European Commission (2023), S&P Global Market Intelligence (2022), Eurostat (2023)

Indicative

Besides CAPEX, material costs significantly drive manufacturing costs with c. 55% of costs for PV and up to c. 80% for battery (excl. CAPEX)

As-is unit manufacturing costs **EU**: Technology-type splits [2022]



PV
- Manufacturing costs for monocrystalline PV modules
- Polysilicon is not depicted as separate component, hence silicon processing is included as wafer material costs

Wind
- Scaled manufacturing costs for offshore based on average turbine cost differences
- Same CAPEX for onshore and offshore assumed

Electrolyzer
- Costs of Electrolyzer stacks only for AWE and PEM
- Split of manufacturing costs based on inputs for PEM, scaled to AWE
- Same CAPEX for PEM/AWE assumed

Heat Pump
- Based on average Heat Pump prices without installation, with splits for equipment and non-equipment costs for a 12-40 kW ASHP

Battery
- Manufacturing costs of battery cells
- Cost split based on inputs for a 35 GWh factory for NMC cells, scaled to LFP based on general cost differences
- Same CAPEX for LFP/NMC assumed

Material costs | Energy costs | Labor costs | SG&A/Overhead | CAPEX in EUR/kW per yearly capacity

1) Measured as investment needed per unit per year, based on European Commission (2023) to ensure comparability

Source: IEA (2022), European Commission (2023), IRENA (2022), NREL (2023), Fraunhofer ISE (2021), Durham University (2021), IEA (2023), Department of Energy & Climate Change (2016), Universität Münster (2021)

Major risks for the supply chain can be categorized in economical, geopolitical, technological, geographic and digital risks

Overview of risks

Economical risks

1 **Demand & supply gap**
- Ambitious growth levels for installed capacities of technologies leading to bottlenecks along the manufacturing value chain (e.g., supply of materials, manufacturing capacities)

2 **Supplier/partner dependence**
- Concentration of single partner and/or homogenic group of suppliers/partners with high dependence on financial performance and reliability

3 **Material & labor shortage**
- Scarcity of material or labor implies price volatility as well as delays along the supply chain

Geopolitical risks

4 **Regulation (e.g., ESG)**
- National law and policies concerning sourcing quotas, child labor, environmental standards, etc., enforcing shift in production processes or of production locations

5 **Political risks (e.g., sanctions)**
- Trade restrictions due to international conflicts as constraint for import and export flows

Technological risks

6 **Incremental technological innovations**
- Danger to existing technologies due to incremental innovations

7 **Disruptive technologies**
- Danger to existing technology advantages due to new, disruptive alternative solutions
- Threat of built-up manufacturing capacities to become obsolete

Geographic risks

8 **Blockade of transport/trade routes**
- Delays in shipping due to blockades, strikes, etc. resulting in process delays

9 **Force majeure (environmental)**
- Drought, floods, storms, etc. damaging sites, transport and overall process

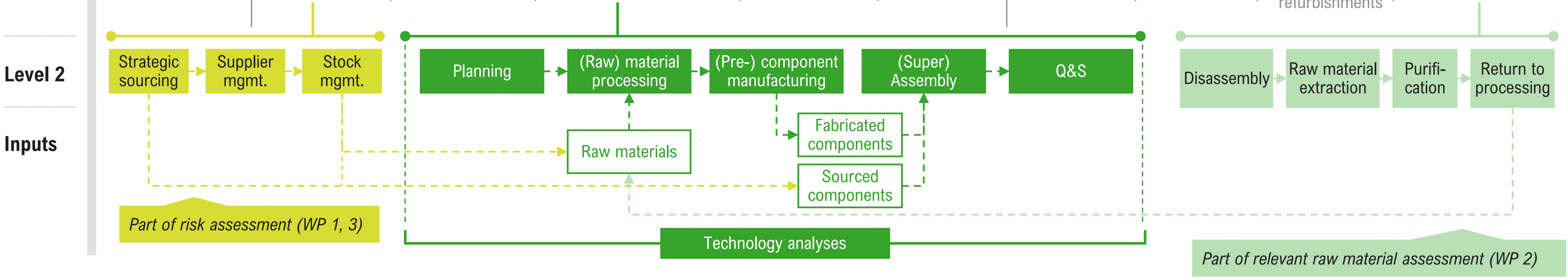
Digital risks

10 **Digital malfunctions**
- Data leakages, failure of control software or cyber attacks jeopardizing processes along the value chain

A manufacturer's value chain typically includes development, manufacturing, sales & marketing as well services & support activities – Our focus is on manufacturing

Manufacturer's high-level value chain (VC)

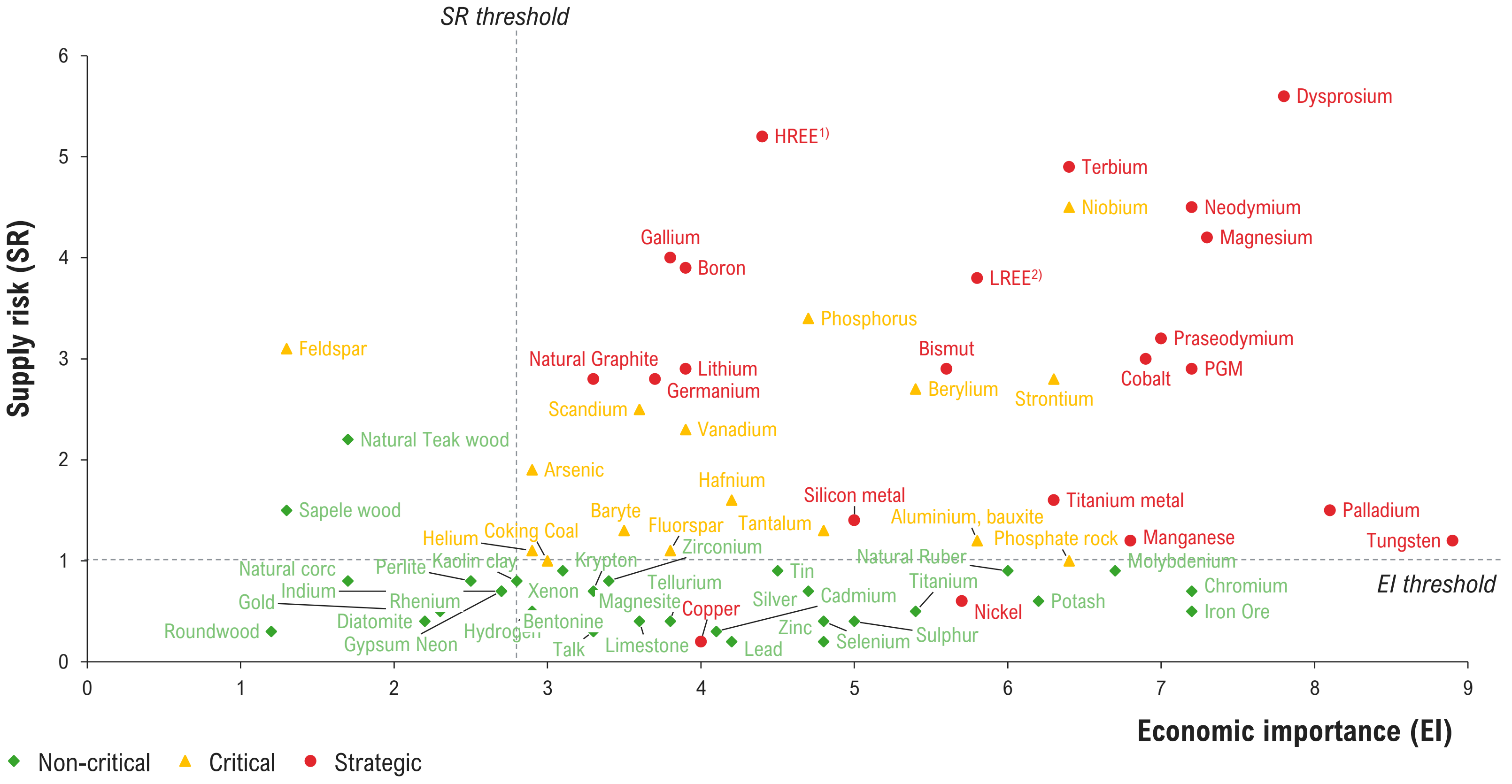
Step	Development	Manufacturing			Sales & marketing		Services & support			
Level 1	R&D and product design	Sourcing	Logistics	Production & QS	Sales	Marketing	Installation	Customer service	Maintenance	Decommissioning
	• Product development • Product modifications	• Sourcing of raw materials • Sourcing of ready-built components	• Overall inbound logistics • Organization and delivery of raw materials & (sub-) components	• Preparation and processing of materials • Manufacturing of components • Final assembly of end product	• Contract negotiation • New customer acquisition	• Brand manage-ment • Sales strategy	• Overall outbound logistics • On-site construction and system integration	• Offering of dedicated aftersales services to the customer	• Provision of maintenance services for sold stations • Ad-hoc repair services • Repowering/ refurbishments	• De-construction • Material recycling • Land redevelopment



European Commission first established a list of criticial raw materials in 2011 – Revised approach including strategic raw material differentiation prepared in 2023

Overview Critical Raw Materials' List [2023]

Criticality assessment results [2023]



- **European Commission** first introduced the list of **Critical Raw Materials in 2011**
  – 2023 included an **assessment for strategic raw materials** for the first time
- **Key assessment criteria** include
  – **Economic Importance (EI)** indicating the importance of a material in the EU for end-use applications
  – **Supply Risk (SR)** stating the risk of a disruption in supply of a specific material

Critical: High risk of supply disruptions and high overall importance to EU economy

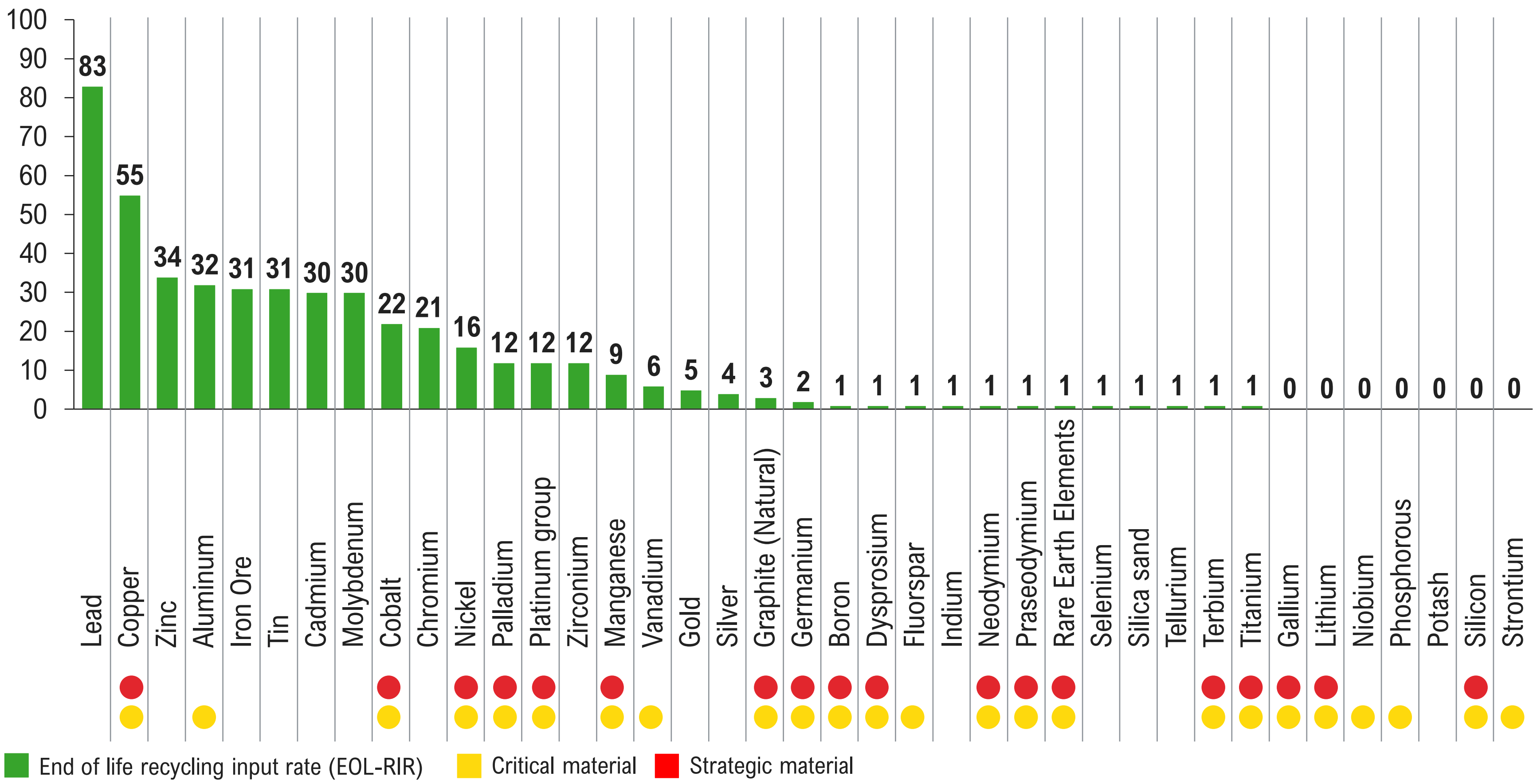
Strategic: Importance for strategic areas (i.e., Renewable energy), projected growth vs. current supply and difficulties in scaling up production

1) Heavy rare earth elements (HREE); 2) Light rare earth elements (LREE)

Source: European Union (2023)

EU's ambition is to increase the recycling rate to c. 15% – Today, only few raw materials already reach this threshold

EU end of life input recycling rate [%]



1) Definition: An aggregate of the maximum annual production volume of recycling operations for strategic raw materials, including the sorting and pre-treatment of waste and its processing into secondary raw materials, located in the Union

Source: European Union (2023)

- **End-of-life recycling input rate** (EOL-RIR) refers to the ratio of recycling of old scrap in the EU to the EU supply of raw material
- For focus technologies, **RIRs are mostly limited and focus on metals** such as Copper, Iron Ore and Tin – Majority of elements show a recycling rate of 10% or less
- **Critical Raw Materials Act** is a proposal for a legislative regulation on establishing a framework for ensuring a secure and sustainable supply of critical raw materials
- Ambition is set at **15% Recycling capacity**[1)] of strategic raw materials until 2030

All technologies include numerous relevant materials in their components – Aluminum, Copper and Nickel are used across all technologies

Relevant raw materials by technology and component

PV

Wafer
- Boron
- Silicon

Si-Cell

-

Module[1]
- Aluminum
- Copper
- Iron Ore
- Nickel

Wind

Blade
- Aluminum

Nacelle (incl. rotor)
- Aluminum
- Copper
- Iron Ore
- Manganese
- Nickel
- Silicon

Gearbox
- Aluminum
- Iron Ore
- Manganese
- Nickel
- Silicon

Generator
- Aluminum
- Boron
- Copper
- Dysprosium
- Iron Ore
- Manganese
- Neodymium
- Nickel
- Praseodymium
- Silicon
- Terbium

Tower
- Aluminum
- Iron Ore
- Manganese
- Nickel
- Niobium
- Silicon

Electrolyzer

AWE & PEM
- Aluminum
- Copper
- Graphite (Natural)
- Iron Ore
- Manganese
- Nickel
- Zirconium

AWE
- Cobalt
- Rare Earth Elements
- Strontium
- Vanadium

PEM
- Palladium
- Platinum group
- Titanium

Heat Pump

- Aluminum
- Copper
- Fluorspar
- Iron Ore
- Nickel
- Palladium
- Silicon

Battery

LFP & NMC
- Aluminum
- Copper
- Fluorspar
- Graphite (Natural)
- Iron Ore
- Lithium
- Niobium
- Phosphorous
- Silicon
- Titanium

NMC only
- Cobalt
- Manganese
- Nickel

»

- **Relevant** raw materials are allocated to technologies and components[2)]
- For PV and Wind, raw **materials differ by component** leading to different risks, e.g., wafer compared to PV module
- For Electrolyzer and battery, raw material needs **differ by technology type**, e.g., with cobalt for NMC
- Technology trends in-clude efforts to **substi-tute single critical raw materials**, e.g., neody-mium for Wind generator

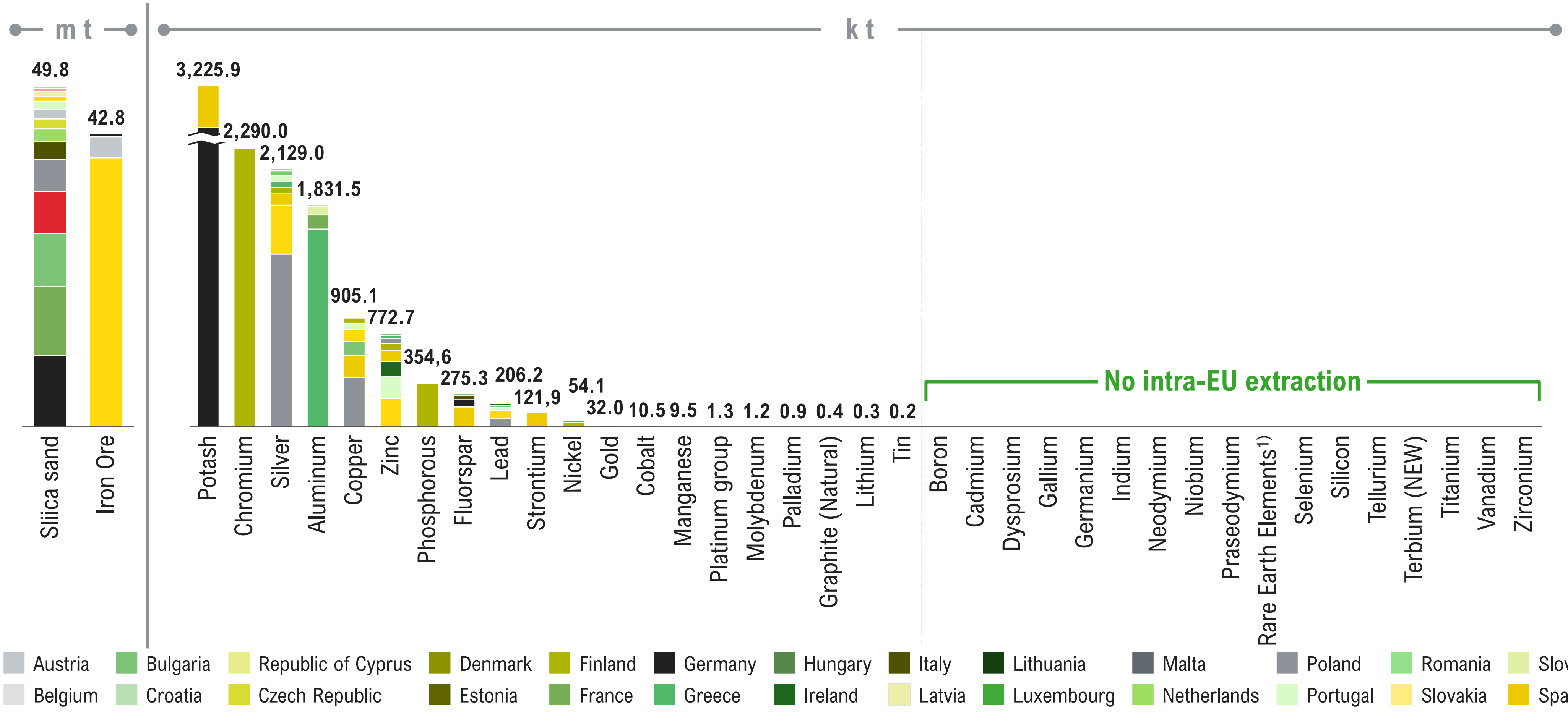
xx Onshore only xx Offshore only

1) Including frames/structures, wiring & electronics, glass/encapsulation, other module components; 2) Further raw materials, e.g. silica sand for Si-cell in PV or blade in Wind not depicted here

Source: European Union (2023), USGS (2022), British Geological Survey (2022)

Silica sand and Iron Ore are the materials with by far the largest intra-EU extraction (>40 m t) – Potash, Silver and Aluminum follow with 2-3 k t

Raw material **extraction**: Extraction capacities by country and raw material [as-is yearly average c. 2020; m t | k t]



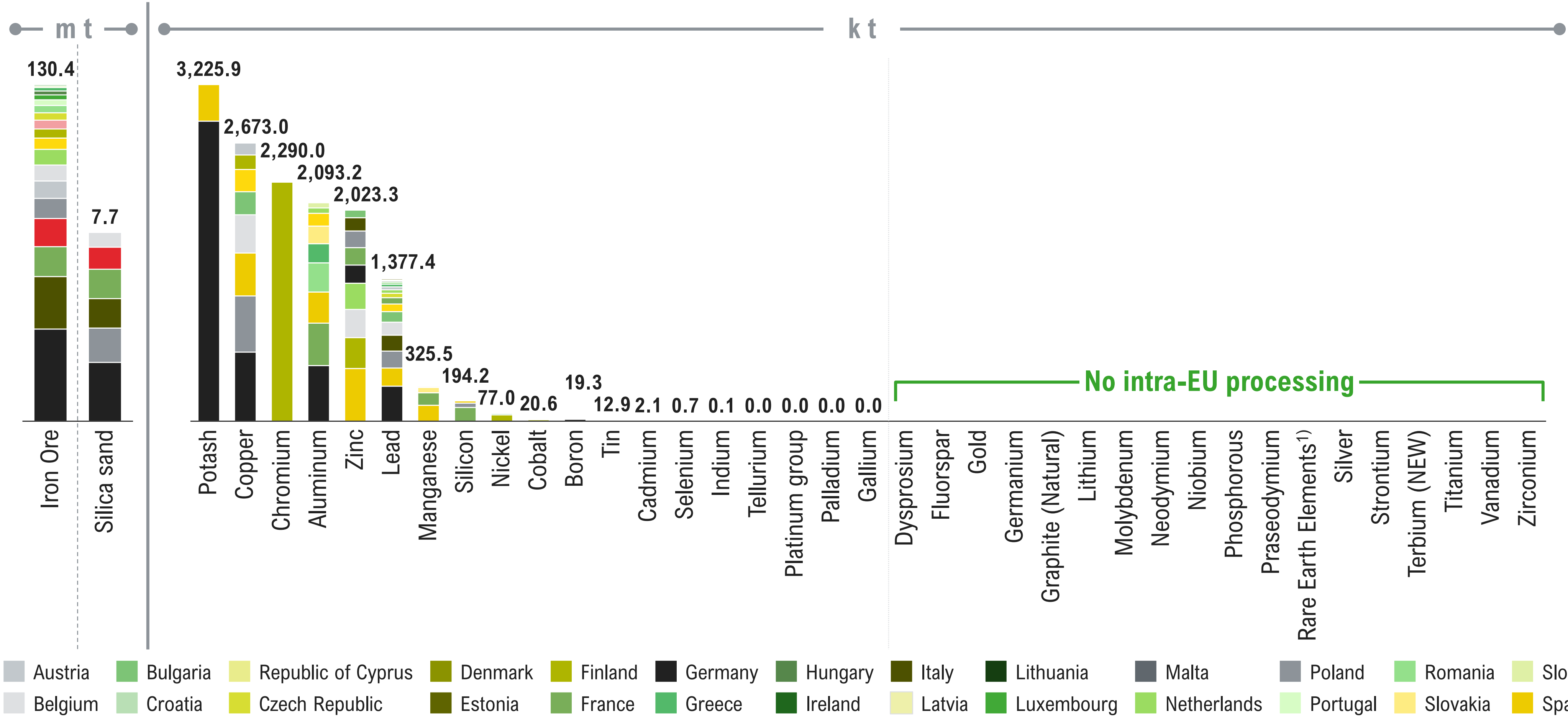
- The extraction of **Silica sand** is spread across multiple countries, incl. **Germany, France and Bulgaria**
- **Iron Ore** is mostly extracted in **Sweden** (c. 92%)
- C. 89% of active **Potash** deposits are located in **Germany**
- For **Silver**, the most relevant country is **Poland**, for **Aluminum Greece** and for **Chromium Finland**

1) Deposits encountered in Sweden and Finland – Extraction/processing tbd

Source: European Union (2023), USGS (2022), British Geological Survey (2022)

Iron Ore is the single most processed raw material in Europe with 130 m t – For Silica sand, Potash, Copper, Aluminum and Zinc 2-8 k t are processed

Raw material **processing**: Processing capacities by country and raw material [as-is yearly average c. 2020; m t | k t]



- Across the most relevant materials **Germany** is a **common country for processing**
- In contrast to the extraction, a **fraction** (c. 15%) **of EU-extracted Silica sand** is **processed intra-EU**
- For **Iron Ore** the opposite is the case: **3 times** the extracted amount is **processed**
- For **Copper and Zinc higher amounts than extracted**[2)] are processed intra-EU

1) Deposits encountered in Sweden and Finland – Extraction/processing tbd; 2) Reference to recycling rates

Source: European Union (2023), USGS (2022), British Geological Survey (2022)

For fluorspar, iron ore, lithium and copper, major untapped reserves can be identified in the EU while additional resources have higher uncertainty

Raw material **reserves**[1]: Major untapped reserves of relevant raw materials by country [as-is 2022; t, % of global]

Germany

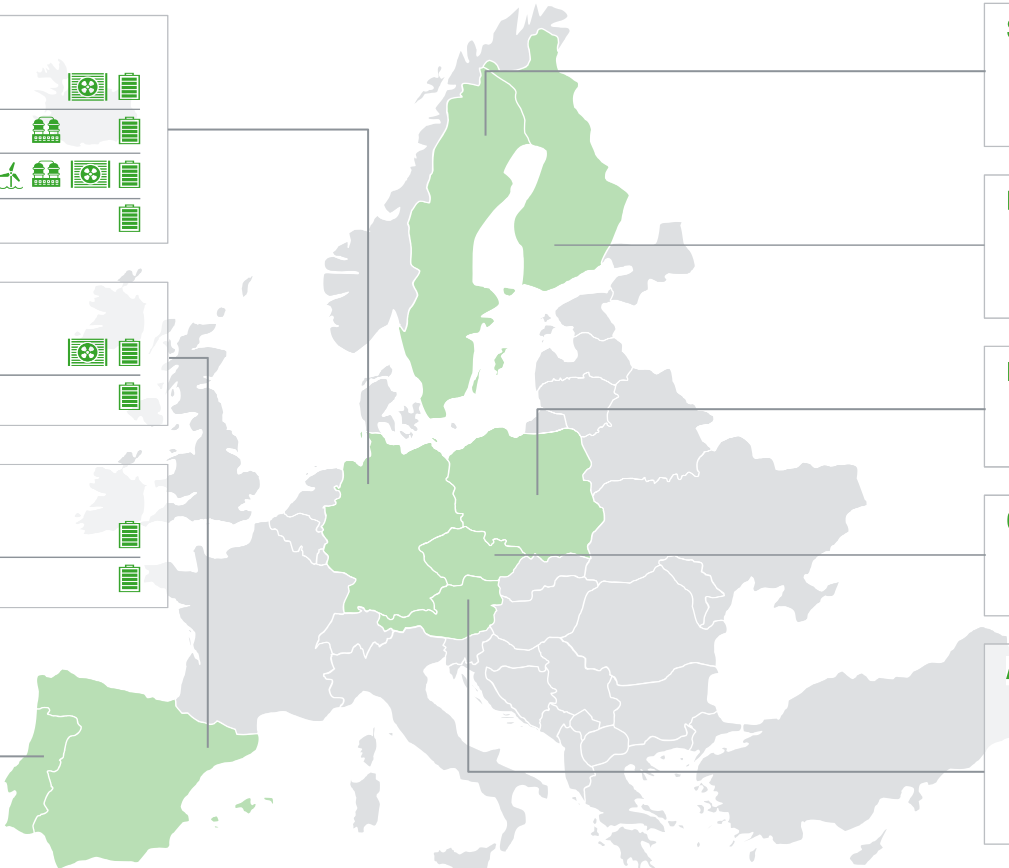
Fluorspar	*not quantified*
Graphite (natural)	*not quantified*
Iron ore	*not quantified*
Lithium	*Resources[2]: 2.7m (3%)*

Spain

Fluorspar	10 m (3%)
Lithium	*Resources[2]: 300,000 (0%)*

Portugal

Lithium	60.000 (0%)
Lithium	*Resources[2]: 270,000 (0%)*



Sweden

Iron Ore	1.3 m (1%)
Rare Earth Elements	*not quantified*

Finland

Phosphorous	1 bn (1%)
Lithium	*Resources[2]: 50,000 (0%)*

Poland

Copper	31.000 (0%)

Czech Republic

Lithium	*Resources[2]: 1.3 m (1%)*

Austria

Graphite (natural)	*not quantified*
Iron ore	*not quantified*
Lithium	*Resources[2]: 60,000 (0%)*

EU27 country with reserves or resources

1) Reserves defined as: Quantities with specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth; economical extraction is possible; 2) Resources defined as: Economic extraction of a commodity from the concentration is currently or potentially feasible

Source: USGS (2023), OECD (2022), Desk research

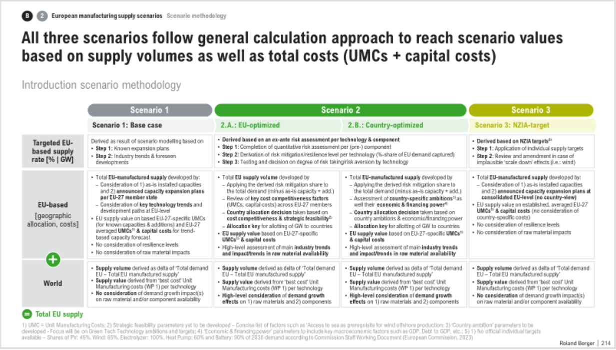
C.2.2 Supply scenarios

The base case incl. the as-is manufacturing supply, additions and trends is compared to scenarios' targeted supply levels

Overview scenario methodology and calculation logic

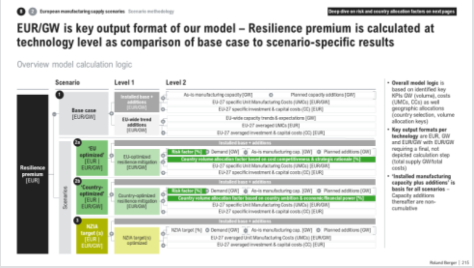
Methodology

- Supply scenarios split in base case and scenarios 2a (EU-optimized) and 2b (country-optimized) and scenario 3 (NZIA targets)
- **Base case** consists of As-is manufacturing base and market-communicated planned additions **as installed base** as well as trend-based additions
- **Scenarios aim to reach a target supply level**: Risk-based for scenarios 2a/2b or top-down given for scenario 3 (NZIA targets). Supply levels are thereafter assessed to the installed base and additions added if required to meet set targets
- **Resilience premium** is the resulting difference between the base case development (incl. trends) and the set scenario development
- **Output formats** are GW at component/technology level and EUR

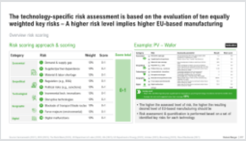


Calculation logic

- Calculation of EU-based GW supply and corresponding costs (OPEX, CAPEX) per scenario
- GW allocation based on risk scoring and country allocation keys for scenarios 2a/2b
- OPEX discounted based on
  - Debt capital interest rate (country-specific)
  - Tax shield (30% average EU rate)
  - Risk rate based on Technologies' inherent risk
- OPEX calculated based on country-specific Unit Manufacturing Costs (UMCs)

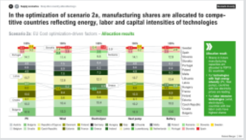


Key inputs

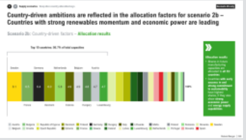


Risk scoring for targeted supply level

EU-optimized



Country-optimized



Country allocation keys for scenario 2a and 2b

In scenario 2a/b, manufacturing capacities will be allocated to EU countries using optimization and country-driven factors – Allocation key based on country scores

Scenario 2 – Country allocation factors: Methodology for country allocation keys for scenario 2a/b

Scenario 2a: EU Cost optimization-driven factors

Cost competitiveness (80%)
Optimization of manufacturing costs by selecting countries with low input costs **depending on technology characteristics**

Strategic rationale (10%)
Optimization of manufacturing processes by selecting countries with optimal conditions (apart from direct costs)

Energy supply capability (10%)
Assessment if countries are capable to provide sufficient electricity for hosting additional manufacturing capacities

Ranking of countries based on their **capability and characteristics to optimize** manufacturing processes

Scenario 2b: Country-driven factors

Country ambition (50%)
Investment decision for manufacturing capacities in countries with strong intention to engage into clean technologies in general

Economic power (40%)
Investment decisions for manufacturing capacities in countries with large economic 'firepower' and fast ramp-up possibilities

Energy supply capability (10%)
Assessment if countries are capable to provide sufficient electricity for hosting additional manufacturing capacities

Ranking of countries based on their **ambition and the feasibility to invest** into clean energy manufacturing

Volume allocation

- **Standardized scoring** for both factors taking into account country-specific strengths with results in a range of 0-1
- **Allocation of manufacturing capacities** based on the standardized score and a distribution function
- For **EU cost optimization**, capacities are allocated for the **TOP 15 countries only** to ensure significant optimization effect

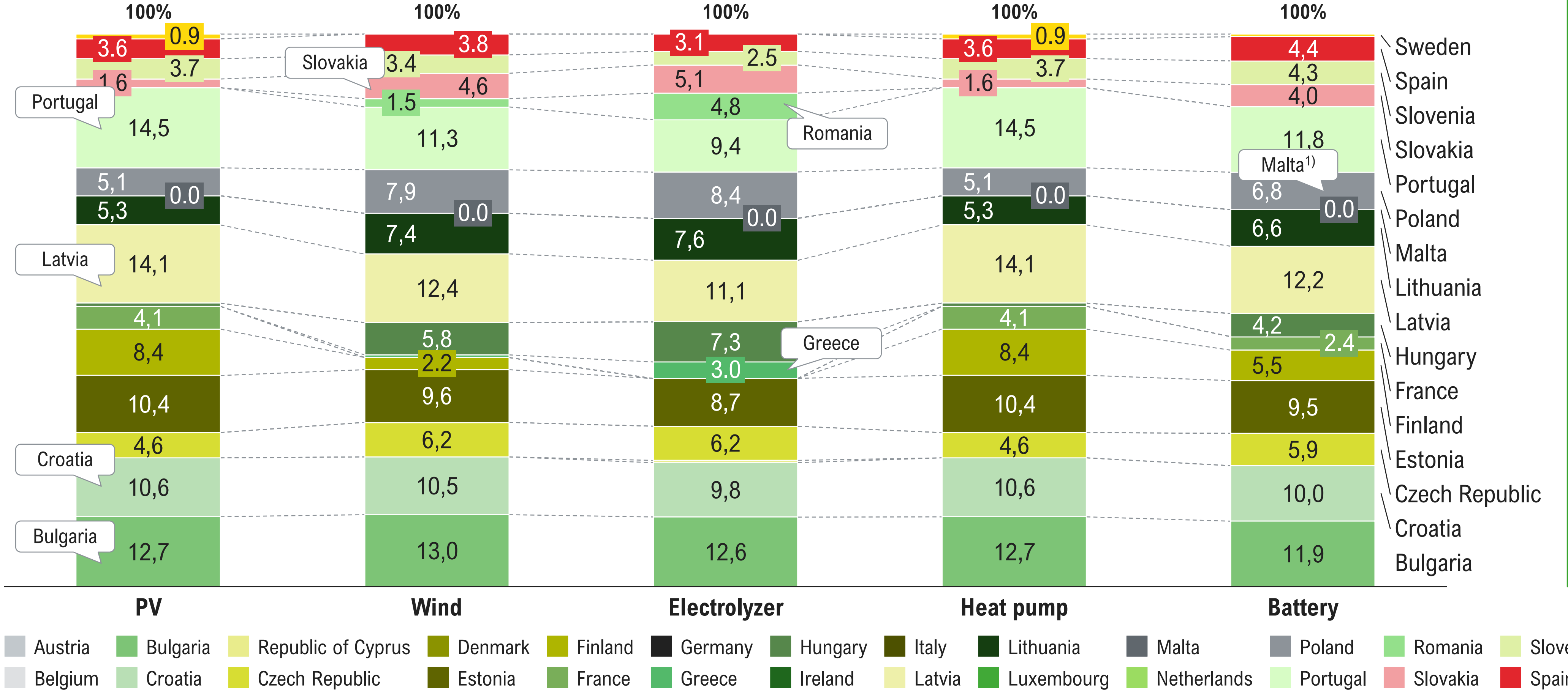
Key to **distribute annual manufacturing capacity** to country according to optimization- and country-driven factors

Weight for calculating ranking factor with technology-specific sub-weights (80% – Cost competitiveness)

Weight for calculating ranking factor with technology-agnostic sub-weights (all other weights)

In the optimization of scenario 2a, manufacturing shares are allocated to competitive countries reflecting energy, labor and capital intensities of technologies

Scenario 2a: EU Cost optimization-driven factors – Allocation results



Allocation result:

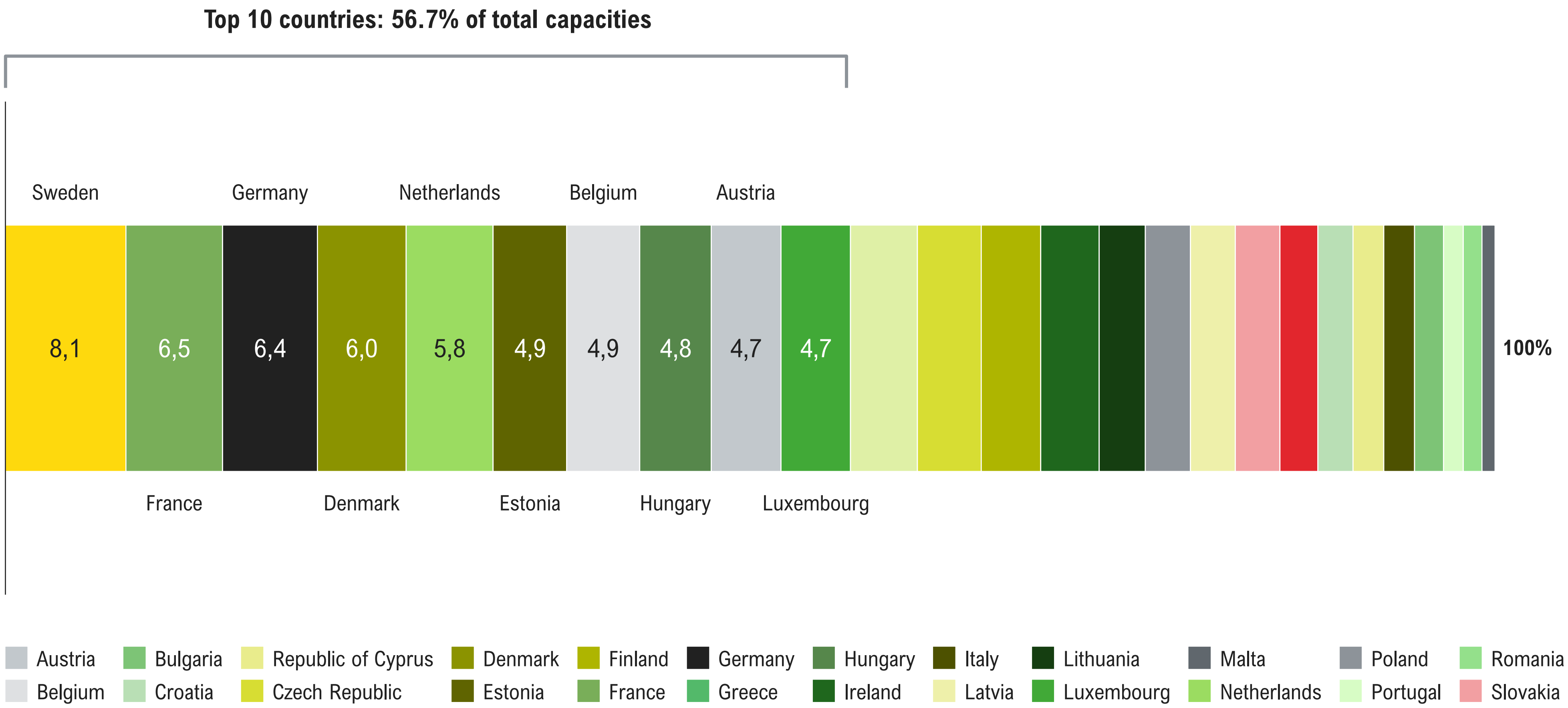
- Shares in future manufacturing capacities are allocated to TOP15 EU countries
- For **technologies with high energy intensity** (PV, Heat Pump), countries with low electricity prices are leading
- For **labor intensive technologies** (Wind, Electrolyzer), countries with low labor costs have highest shares

1) Due to the country size as well as its disadvantageous infrastructure connection to the European grid as an island Malta is excluded from the optimization and set to 0%

Scenario 2b only

Country-driven ambitions are reflected in the allocation factors for scenario 2b – Countries with strong renewables momentum and economic power are leading

Scenario 2b: Country-driven factors – Allocation results



Allocation results

- Shares in future manufacturing capacities are allocated to **all EU countries**
- Countries **with early success in and strong commitment to sustainability** have highest shares, if they also show **strong economic power** and **energy supply capabilities**

Not exhaustive

The underlying financial and technological key assumptions influence the model results significantly

Key assumptions (1/2)

Financial

- **Inflation:** Differentiation across countries according to International Monetary Fund forecast, converging towards 2% by 2029, stable rate onwards. Included in all financial components to account for country differences (OPEX, CAPEX and reinvestments)
- **Discount factor:** Discounting with EU-27 average of 10-year government bond forecast to account for future value of money which is held in reserve in the EU budget – Equal across technologies, stable values after 2032. No consideration of tax shield
- **Interest rate:** Interest payments on CAPEX and reinvestments neglected due to financing by the EU budget
- **CAPEX investments:** 100% investments in concerning year (year with capacity requirement minus lead time), no depreciation period
- **Reinvestments:** Stable reinvestments for base in terms of 1/lifetime per year; year-specific reinvestments for all newly built capacity after lifetime (reduced by lead time)
- **Exchange rate:** USD/EUR of 1.05 for UMC cost conversion

Technological

- **Lifetime:** 7 years machinery lifetime for reinvestment cycles, except for Wind with 6.5 years (excl. building lifetime); half years are rounded down to avoid malfunctioning
- **Lead time:** Investments 2-3 years before capacity installation (2 for PV and Wind except for Wind tower with 2.5, rest 3 years); half years are rounded up to avoid delays
- **Ramp up of target levels:** Gradual increase with full target level achieved by 2030, start of ramp up in 2025/2026 according to lead time with 30% of target (20pp steps with flattening steps in last years of 10pp)
- **UMC:** Country-specific for energy and labor according to electricity and labor cost levels of each country, EU-27 level for material and SG&A/Overhead; stable over years for energy and labor, declining trend for material and SG&A/Overhead based on specific technology learning rate
- **CAPEX costs:** Country-specific according to construction cost index for each country, stable development over years

Not exhaustive

The scenario target levels represent minimum market shares – For scenario 3, the supply targets are derived from the NZIA 2025/2030 capacity goals

Key assumptions (2/2)

Model functionality

- **Target levels:** Minimum level of market share, i.e., market share can be higher due to extensive existing capacity or announced additions
- **Overcapacity:** No consideration of divestments of installed capacity due to diminishing demand; neither for base and announced additions nor for installations to achieve target levels

NZIA supply targets

- Derivation of 2030 target levels based on the Commission Staff Working Document (European Commission, 2023):
  - PV: 45%
  - Wind: 85%
  - Electrolyzer: 100%
  - Heat Pump: 60%
  - Battery: 90%

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