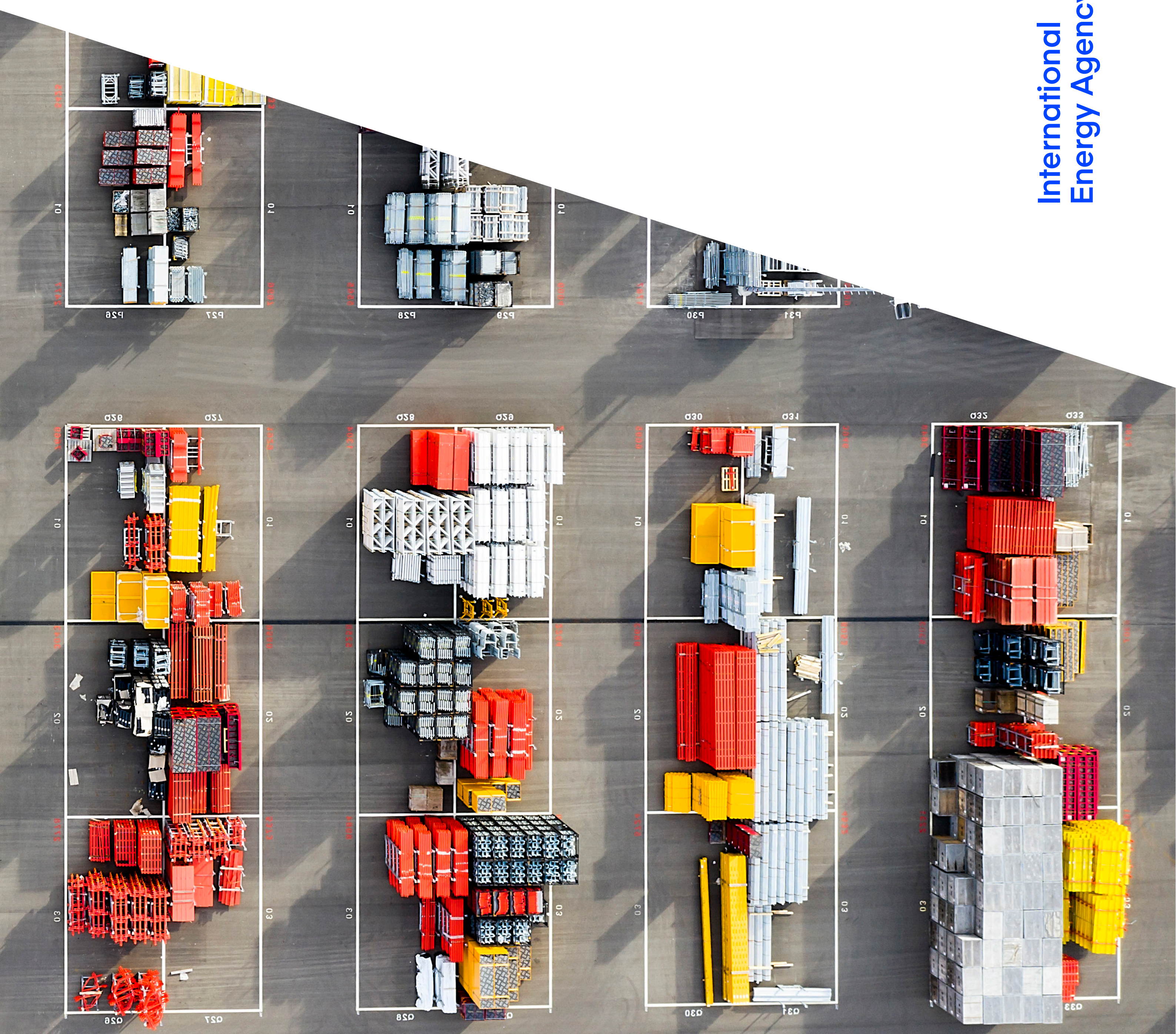
Manufacturing and Trade Model Documentation 2026

International Energy Agency



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Modelling methodology

The IEA's Manufacturing and Trade (MaT) Model was first developed for the 2024 edition of *Energy Technology Perspectives* (ETP) (IEA, 2024a) to produce scenario projections of manufacturing and trade across six key clean energy technology supply chains – for solar photovoltaics (PV), wind turbines, electric cars, batteries, electrolysers and heat pumps. It is part of the IEA's broader modelling framework and is closely linked to the Global Energy and Climate Model (GEC) (IEA, 2025a) as it draws on the same modelling scenarios, each of which is built on a different set of underlying assumptions about how the energy system might evolve over time. This document contains the modelling framework, inputs, assumptions, technical details and data sources for the MaT Model.

Scope

For the purposes of *ETP-2026*, the following boundaries are considered in the modelling and analysis for clean energy technologies and components within each manufacturing supply chain in scope:

Solar PV includes solar modules, solar cells, wafers and polysilicon, for which all values are expressed in direct current (DC) terms. It does not include elements such as backsheets, encapsulants or any balance of system components, such as inverters and racking. Metallurgical-grade silicon is out of scope.

Wind includes wind nacelles, blades and towers for both onshore and offshore wind facilities. Production costs for onshore and offshore wind are modelled separately (differentiating, for example, by capital and investment costs) but a demand-weighted aggregate cost is used for output. Manufacturing of nacelles includes only assembly and not the manufacturing of the upstream components such as the drive train and generator. Other wind components, such as the foundation, yaw bearing, hub and power cables, are assumed to be inputs to the production process. References to wind energy installation costs or turbine pricing by manufacturers include these products.

Electric cars include battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) that belong to the passenger light-duty vehicles category, such as cars and pick-up trucks.

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Batteries include the lithium-ion battery cells[1] and any individual parts that are used to compose a battery cell for use in electric vehicles[2] or battery energy storage systems. Among battery components, only cathodes and anodes (referring to their active material unless stated otherwise) are modelled explicitly, and other inputs such as the electrolyte, separator and current collectors are considered only in terms of their cost as inputs into the production process. Cathode and anode chemistry is not considered explicitly, but chemistry choice is considered exogenously during model calibration. A negative (anode) to positive (cathode) electrode ratio of 1.05 is assumed for the final cells, which implies the need for 5% more anode capacity than cathode capacity per cell.

Electrolysers include all major electrolyser technologies (including alkaline, proton exchange membrane, solid oxide electrolysis and others) when displayed in manufacturing capacity and output figures. Only the final assembly step is considered for capacity. Any upstream components, such as electrodes, are outside the scope. For production cost, only stack manufacturing is considered.

Heat pumps include only heat pumps that deliver heat directly to residential and commercial buildings for space heating and/or hot water provision (industrial heat pumps are excluded). This includes natural source heat pumps, including reversible air conditioners used as primary heating equipment. It excludes reversible air conditioners used only for cooling, or used as a complement to other heating equipment, such as a boiler. Any upstream components, such as compressors, are outside the scope.

For all technologies, unless otherwise specified, stockpiling of components or final products is not included in the modelling scope (solar PV is the exception; see Historical trade flows).

The modelling framework is set up such that a model run for each technology product can be undertaken independently. As a result, the framework can be adapted to include any number of technologies. For example, *ETP-2024* includes the modelling of aluminium, steel and ammonia.

[1] Battery manufacturing capacity refers to manufacturers qualified to supply EV producers internationally, manufacturers not yet qualified to serve EV producers outside of China, and producers that are not yet qualified to supply EV markets but might be certified to serve the EV market in the future.

[2] Including electric cars and other electric vehicles, such as trucks, buses, and two- and three-wheelers.

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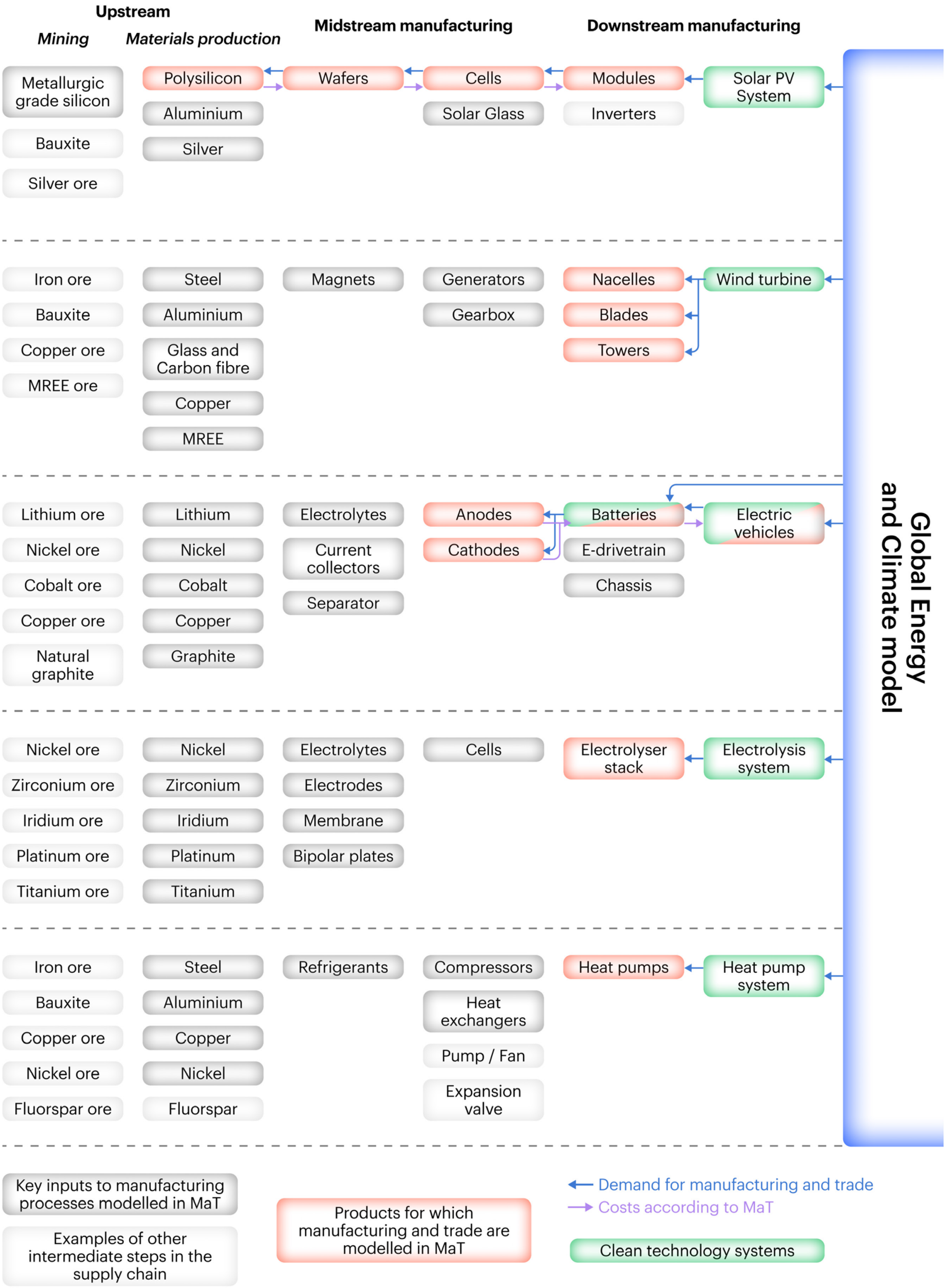
Scope for clean energy technologies in IEA's Manufacturing and Trade Model



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Notes: MaT = Manufacturing and Trade; MREE = magnet rare earth elements; PV = photovoltaic.

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International trade statistics and market sizes

In some instances, international trade statistics and market sizes are reported. International trade statistics do not perfectly match MaT modelling boundaries but are useful in assessing more granular trade data. In some instances, no Harmonized System (HS) code, administered by the World Customs Organization, fits the technology or component in the model – usually because the available codes are too broad and include products other than the material or component being classified. Additionally, calculations relating to market sizes use prices faced by the final user or consumer. For additional information, see the section Prices used for the value of trade and market sizes.

Manufacturing and Trade Model technology and component mapping to Harmonized System codes

MaT Model technology /component	6-digit Harmonized System (HS) 2022 code mapping and description
Solar PV: polysilicon	**280461**: Silicon; containing by weight not less than 99.99% of silicon. **Not included in presentation of international trade statistics as category is too broad.**
Solar PV: wafers	**381800**: Chemical elements doped for use in electronics, in the form of discs, wafers or similar forms; chemical compounds doped for use in electronics. **Not included in presentation of international trade statistics as category is too broad.**
Solar PV: cells	**854142**: Photovoltaic cells not assembled in modules or made up into panels. **854140***: Photosensitive semiconductor devices, including photovoltaic cells, whether or not assembled in modules or made up into panels, light-emitting diodes (LED). *From HS 2017
Solar PV: modules	**854143**: Photosensitive semiconductor devices, photovoltaic cells assembled in modules or made up into panels. **854140***: Photosensitive semiconductor devices, including photovoltaic cells whether or not assembled in modules or made up into panels, light-emitting diodes (LED). *From HS 2017
Batteries: anodes	**850790**: Electric accumulators, including separators therefor, whether or not rectangular (including square); parts. **854519**: Carbon electrodes, carbon brushes, lamp carbons, battery carbons and other articles of graphite or other carbon, with or without metal, of a kind used for electrical purposes; other. **Not included in presentation of international trade statistics as category is too broad.**

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MaT Model technology /component	6-digit Harmonized System (HS) 2022 code mapping and description
Batteries: cathodes (continued)	**284169**: Manganites, manganates and permanganates; other. **284190**: Salts of oxometallic or peroxometallic acids; other. **284290**: Other salts of inorganic acids or peroxoacids (including aluminosilicates whether or not chemically defined), other than azides; other. **285390**: Phosphides, whether or not chemically defined, excluding ferrophosphorus; other inorganic compounds (including distilled or conductivity water and water of similar purity); liquid air (whether or not rare gases have been removed); compressed air; amalgams, other than amalgams of precious metals; other. **382499**: Prepared binders for foundry moulds or cores; chemical products and preparations of the chemical or allied industries (including those consisting of mixtures of natural products), not elsewhere specified or included; other. **850790**: Electric accumulators, including separators therefor, whether or not rectangular (including square); parts. **Not included in presentation of international trade statistics as category is too broad.**
Batteries: cells	**850760**: Electric accumulators; lithium-ion, including separators, whether or not rectangular (including square); Lithium-ion.
Battery electric cars	**870380**: Other vehicles, with only electric motor for propulsion.
Plug-in hybrid electric cars	**870370**: Other vehicles, with both compression-ignition internal combustion piston engine (diesel or semi-diesel) and electric motor for propulsion, capable of being charged by plugging to external source of electric power. **870360**: Other vehicles, with both spark-ignition internal combustion piston engine and electric motor for propulsion, capable of being charged by plugging to external source of electric power.
Wind: blades	**841290**: Other engines and motors; parts.
Wind: nacelles	**850231**: Other generating sets; wind-powered.
Wind: towers	**730820**: Towers and lattice masts.
Heat pumps	**841581**: Incorporating a refrigerating unit and a valve for reversal of the cooling/heat cycle (reversible heat pumps). **841861**: Other refrigerating or freezing equipment; heat pumps; other than air conditioning machines of heading 84.15.
Electrolysers	**854330**: Machines and apparatus for electroplating, electrolysis or electrophoresis. **Not included in presentation of international trade statistics as category is too broad.**

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Box 1 Manufacturing and Trade model developments for ETP-2026

There have been numerous developments to the MaT Model since the publication of *ETP-2024*:

- Final prices for each component and end-product are used to calculate market sizes. Previously, for each component and end-product, a single global average price was used to calculate the market size. Additional detail is now included such that prices are also differentiated by region (see Prices used for the value of trade and market sizes section below).
- To better reflect actual traded values reported in international statistics, *ETP-2026* moves away from using physical units and global average prices to calculate the value of trade, as these prices do not capture variations in transaction costs across regions and products. Instead, values are derived from international trade statistics and combined with bottom-up estimates of physical trade volumes. This approach ensures consistency with physical flows while aligning value estimates with observed trade data. Inferred prices, together with projected price trends, are then used to calculate the future value of trade.
- Trade statistics are a fundamental element of the MaT Model. Previously, the BACI (CEPII, 2025) dataset was the source of international trade statistics. This dataset relies on data from Comtrade, and is useful as it harmonises imports and exports between trading partners. One drawback is that data is available on a 2-year lag. In *ETP-2026*, monthly trade data from Sinoimex (Sinoimex, 2025), which is published with a 2 to 3-month lag, is used to provide more timely estimates of trade flows. Unlike BACI, this dataset consists of raw trade statistics from various countries and is not harmonised.
- Modelling regions have changed. In *ETP-2026*, the modelling regions covering Africa have been consolidated into Northern Africa, South Africa and Other Africa, and Central and South America A has been split into Chile, Colombia and Costa Rica.

The Manufacturing and Trade modelling framework

The model follows a bottom-up, least-cost optimisation approach with a multiregional and myopic structure, solved sequentially on an annual basis. In *ETP-2026*, 2023 and 2024 are historical years and 2025 is the base year (that is, the first modelled year). While the modelling horizon extends to 2050, calibration focuses on the first 10 years.

The modelling framework has two main sub-components: the module for computing bilateral trade flows and the module for calculating the levelised cost of production (LCOP). The **trade module**, given regional demand for a clean energy technology, delivers the manufacturing and trade required to meet this demand at the lowest system cost. This module accounts for CAPEX and OPEX costs, manufacturing

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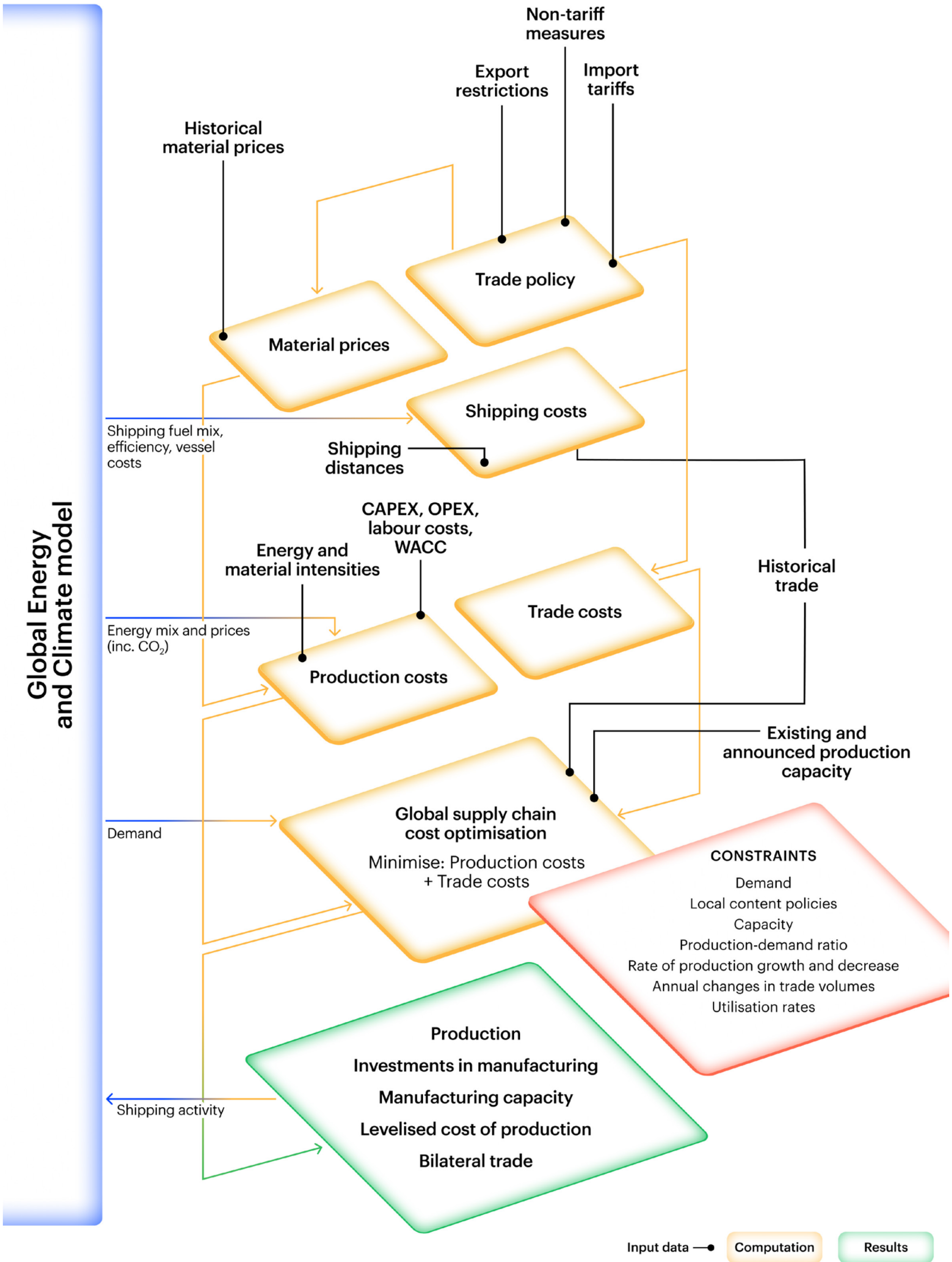
capacity, shipping costs and detailed information on industrial and trade policies. The **Levelised Cost of Production module** calculates the cost of production of a technology in each region, given inputs into production such as labour, materials, investment and energy. Many inputs into the modelling, such as regional demand (deployment) for technologies, are an output from the GEC Model.

IEA's Manufacturing and Trade Model schematic



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Notes: CAPEX = capital expenditure; OPEX = operating expenditure, WACC = weighted average cost of capital. Inputs and results shown are non-exhaustive.

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Along with the inputs, the model delivers a comprehensive set of results across production, manufacturing capacity, manufacturing investment, energy use, emissions and trade for each of the components, regions, years and scenarios. Some of the key results are:

- **Production** in physical units and monetary values.
- **Manufacturing capacity** in annual physical units.
- **Investments in manufacturing** in monetary values.
- **Energy consumption** and **CO_2 emissions** related to the manufacturing process.
- **Bilateral trade flows** between modelling regions in physical units and monetary values.[3]
- **Market sizes** in monetary values.
- **Levelised cost of production** with and without financial support.
- **Trade-weighted prices** reflecting the cost of imports and domestic production.

Trade module

Objective function

For a given component in a given year y, the objective function minimises the total system cost of production, shipping and trade by choosing production, trade, and manufacturing capacity. Lowercase variables are expressed per unit of output (GW, GWh or number of cars), while uppercase variables are totals, unless otherwise specified.

$$\forall\, y \in Y \quad \min_{P_{r,y}, T_{r,r',y}, K_{r,y}} \sum_{r} C^{prod}_{r,y} + \sum_{r}\sum_{r'} C^{trans}_{r,r',y} + \sum_{r}\sum_{r'} C^{trade}_{r,r',y}$$

$y \in Y$	Years and set of years
$r \in R$	Region and set of regions
$r' \in R\backslash r$	Region exclusive of r
$P_{r,y}$	Production in region r in year y
$T_{r,r',y}$	Volume of trade from region r to region r' in year y
$K_{r,y}$	Capacity in region r in year y
$C^{prod}_{r,y}$	Cost of production in region r
$C^{trans}_{r,r',y}$	Transport cost from region r to region r' in year y
$C^{trade}_{r,r',y}$	Trade cost from region r to region r' in year y

[3] The bilateral trade flows are effectively an approximation of net trade flows between the regions, as backflows are not estimated.

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For components that are modelled together in a supply chain, the different components are 'soft-linked' by passing solved values up- and down-stream. Taking batteries as an example, the following process is undertaken:

1. **Solve the battery cell module**, producing demand, supply, trade and production costs by region.
2. **Use battery cell production as demand** in the anode and cathode modules.
3. **Solve the anode and cathode modules**, producing demand, supply, trade and production costs by region.
4. **Feed cost results back into the battery cell module** and repeat until results converge between runs.

To maintain clarity, only the primary equations necessary to understand the model's logic are displayed. Auxiliary equations and intermediate transformations are omitted for brevity, and reflect standard modelling conventions.

Production and demand constraints

The total cost of production is a function of capital costs and fixed and variable operating costs. Demand for each clean technology comes from the GEC Model, based on capacity or stock additions by technology, region and year. Demand for upstream components is based on the production of downstream manufacturing steps. Supply and demand constraints hold such that within a region, production plus imports minus exports must be equal to or greater than demand. To capture policies relating to local content requirements, a certain portion of demand must be met by domestic production (though this can be zero). Production is also limited by the size of the domestic market, which inhibits rapid production growth. Production is limited by capacity, captured by minimum and maximum utilisation rates. Production has upper and lower bounds relative to the previous year to ensure there are no large variations between time periods.

$$C_{r,y}^{prod} = \left(c_{r,y}^{CAPEX,ann} + c_{r,y}^{OPEX,fixed}\right) K_{r,y} + c_{r,y}^{OPEX,var} P_{r,y}$$

$$P_{r,y} + \sum_{r'} T_{r',r,y} - \sum_{r'} T_{r,r',y} \geq D_{r,y}$$

$$P_{r,y} - \sum_{r'} T_{r,r',y} \geq D_{r,y} \theta_{r,y}^{LP}$$

$$P_{r,y} \leq D_{r,y} \theta_{r,y}^{DP}$$

$$P_{r,y} \leq K_{r,y} \theta_{r,y}^{MaxUR}$$

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$$P_{r,y} \geq K_{r,y}\theta_{r,y}^{MinUR}$$

$$P_{r,y} \leq P_{r,y-1}(1 + \theta_{r,y}^{PGR})$$

$$P_{r,y} \geq P_{r,y-1}(1 - \theta_{r,y}^{PDR})$$

$c_{r,y}^{CAPEX,ann}$	Annualised CAPEX per unit in region r in year y
$c_{r,y}^{OPEX,fixed}$	Fixed OPEX per unit in region r in year y
$c_{r,y}^{OPEX,var}$	Variable OPEX per unit in region r in year y
$D_{r,y}$	Demand in region r in year y
$X_{r,r',y}$	Value of exports by region r to region r' in year y
$\theta_{r,y}^{LP}$	Share of demand to be met by local production in region r in year y
$\theta_{r,y}^{DP}$	Upper limit of production to demand ratio in region r in year y
$\theta_{r,y}^{MaxUR}$	Maximum utilisation rate in region r in year y
$\theta_{r,y}^{MinUR}$	Minimum utilisation rate in region r in year y
$K_{r,y}$	Capacity in region r in year y
$\theta_{r,y}^{PGR}$	Maximum percentage production growth in region r in year y
$\theta_{r,y}^{PDR}$	Minimum percentage production drop in region r in year y

Capacity constraints

Capacity is subject to a flow constraint, where capacity in year y is equal to the capacity in the previous year, plus additions and net of plant retirements. Capacity additions have upper and lower limits relative to announced capacity for the years available, and are relaxed following 2030. This category is particularly relevant for capturing the enabling conditions in emerging markets – for example, by applying upper and lower bounds for future capacity additions.

$$K_{r,y} = K_{r,y-1} + K_{r,y}^{add} - K_{r,y}^{ret}$$

$$K_{r,y}^{add} \leq K_{r,y}^{ann}\theta_{r,y}^{KGU}$$

$$K_{r,y}^{add} \geq K_{r,y}^{ann}\theta_{r,y}^{KGL}$$

$K_{r,y}^{ret}$	Capacity retirements in region r in year y
$K_{r,y}^{add}$	Capacity additions in region r in year y
$K_{r,y}^{ann}$	Announced capacity in region r in year y
$\theta_{r,y}^{KGU}$	Upper bound capacity growth ratio in region r in year y
$\theta_{r,y}^{KGL}$	Lower bound capacity growth ratio in region r in year y

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Trade constraints

Trade between regions has upper and lower bounds relative to trade with the same partner in the previous year.

$$T_{r,r',y} \leq T_{r,r',y-1}(1+\theta^{MG}_{r,r',y})$$

$$T_{r,r',y} \geq T_{r,r',y-1}(1-\theta^{MD}_{r,r',y})$$

$\theta^{MG}_{r,r',y}$	Maximum percentage growth of trade from region r to region r'
$\theta^{MD}_{r,r',y}$	Maximum percentage drop of trade from region r to region r'

Transport costs

Transport costs refer to the cost of transporting a given commodity between modelled regions and include freight and insurance costs. Shipping costs are based on GEC modelling, where for each vessel type (dry bulk, break bulk, roll-on/roll-off and container) and scenario, the shipping model produces the cost of transportation between each modelled region. Costs are measured in US dollar (USD) per unit of mass or other physical unit. For example, container costs are expressed as dollars per forty-foot equivalent unit. The weight and size of each unit of technology is estimated and used to estimate the cost of shipping a unit (GW, GWh, or unit). Insurance costs are expressed as a percentage of the value of the exported product, varying by component.

$$C^{trans}_{r,r',y} = T_{r,r',y}\left(\theta^{insurance}_{y}\pi^{exports}_{r,r',y} + c^{ship}_{r,r',y}\right)$$

$$\pi^{exports}_{r,r',y} = c^{LCOP}_{r,y}\left(1+\theta^{profit}_{r,y}\right)$$

$c^{trans}_{r,r',y}$	Cost of transportation from region r to region r' in year y.
$c^{ship}_{r,r',y}$	Cost of shipping per unit from region r to region r' in year y.
$\pi^{exports}_{r,r',y}$	Price of exports from region r to region r' in year y.
$\theta^{profit}_{r,y}$	Profit margin applied by producers in region r
$\theta^{insurance}_{y}$	Insurance cost factor (percentage).

Trade costs

Trade costs represent the costs incurred when importing from one region to another, other than those related to shipping. These costs include tariffs and non-tariff measures (NTMs), expressed as ad valorem equivalents (see Industrial strategies and policies section).

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$$C_{r,r',y}^{trade} = T_{r,r',y} c_{r,r',y}^{domimp}$$

$$c_{r,r',y}^{domimp} = c_{r,r',y}^{import} \left(\tau_{r,r',y}^{AV} + \tau_{r,r',y}^{NTM}\right) + \tau_{r,r',y}^{S}$$

$$c_{r,r',y}^{import} = \left(\pi_{r,r',y}^{exports}\left(1 + \theta_{y}^{insurance}\right) + c_{r,r',y}^{ship}\right)$$

$c_{r,r',y}^{trade}$	Cost of trade from region r to region r' in year y.
$c_{r,r',y}^{domimp}$	Cost of trade policies from region r to region r' in year y.
$c_{r,r',y}^{import}$	Cost of shipping and insurance from region r to region r' in year y.
$\tau_{r,r',y}^{AV}$	Ad valorem tariffs on trade from region r to region r' in year y.
$\tau_{r,r',y}^{NTM}$	Non-tariff measures (expressed as ad valorem equivalent) on trade from region r to region r' in year y.
$\tau_{r,r',y}^{S}$	Specific tariffs on trade from region r to region r' in year y.

Levelised cost of production module

The levelised cost of production (LCOP) module is the fundamental building block of the trade module. It annualises all of the costs associated with producing a product – capital expenditure, operating expenditure, labour, materials and energy – within each region. Early retirements of manufacturing capacity and related savings in fixed OPEX are not considered in the model. LCOP is reported per unit of production.

At the highest level, CAPEX and fixed OPEX are a function of capacity, while variable operating expenditure is a function of production.

$$c_{r,y}^{LCOP} = \frac{c_{r,y}^{CAPEX,ann} + c_{r,y}^{OPEX,fixed}}{\Upsilon_{r,y}} + c_{r,y}^{OPEX,var}$$

$\Upsilon_{r,y}$	Utilisation rate in region r in year y

Annualised CAPEX refers to the costs an organisation bears in acquiring, upgrading, or maintaining physical assets of a manufacturing facility, which is typically a one-time, upfront investment. It is calculated by considering the overnight value of the CAPEX (simply, capacity multiplied by capital cost) available to manufacturing investors per region and year and annualised using the capital recovery factor (CRF).

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The CRF is calculated based on the weighted average cost of capital for each modelling region and by assuming a useful economic lifetime for each clean technology or material.

Fixed OPEX captures the ongoing, regular costs required to operate a manufacturing facility that do not vary with the level of output. Annual fixed operational expenditure is assumed to be proportional to the overnight capital expenditure at a ratio.

Variable OPEX captures the operational costs that vary proportionally to the level of output of a facility, including materials, energy, emissions costs (CO_2), components, labour and overhead costs. It also includes output-linked financial support available.

Material, energy and emissions intensities, as well as energy carbon prices, are from the GEC Model. These are used to calculate the associated costs of these inputs. Material costs are modelled separately (see Material and labour costs section).

$$c_{r,y}^{CAPEX,ann} = \left(c_{r,y}^{CAPEX,overnight} - s_{r,y}^{CAPEX}\right)\theta_{r,y}^{CRF}$$

$$c_{r,y}^{OPEX,fixed} = c_{r,y}^{CAPEX,overnight}\theta_{r,y}^{FOR}$$

$$\theta_{r,y}^{CRF} = \frac{W_{r,y}}{1-\left(1+W_{r,y}\right)^{-L}}$$

$$c_{r,y}^{OPEX,var} = c_{r,y}^{OPEX,mat} + c_{r,y}^{OPEX,energy} + c_{r,y}^{OPEX,CO2} + c_{r,y}^{OPEX,comp} + c_{r,y}^{OPEX,lab} + c_{r,y}^{OPEX,overhead} + c_{r,y}^{OPEX,other} - s_{r,y}^{OPEX}$$

$c_{r,y}^{CAPEX,overnight}$	Overnight value of CAPEX
$s_{r,y}^{CAPEX}$	Financial support available directly related to CAPEX in region r in year y
$\theta_{r,y}^{CRF}$	Cost recovery factor in region r in year y
$\theta_{r,y}^{FOR}$	Fixed OPEX ratio in region r in year y
L	Lifetime of capital
$W_{r,y}$	Weighted adjusted cost of capital in region r in year y
$c_{r,y}^{OPEX,mat}$	Cost of materials in region r in year y
$c_{r,y}^{OPEX,energy}$	Cost of energy in region r in year y
$c_{r,y}^{OPEX,CO2}$	Cost of emissions in region r in year y
$c_{r,y}^{OPEX,comp}$	Cost of components in region r in year y
$c_{r,y}^{OPEX,lab}$	Cost of labour in region r in year y
$c_{r,y}^{OPEX,overhead}$	Cost of overheads in region r in year y
$c_{r,y}^{OPEX,other}$	Other costs in region r in year y[4]
$s_{r,y}^{OPEX}$	Financial support available that is directly related to OPEX in region r in year y

[4] For example, when modelling battery cells, this variable is used to capture manufacturing efficiencies relating to the proportion of batteries produced that meet quality standards once commercial-scale production is reached.

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$$c_{r,y}^{OPEX,mat} = \sum_m i_{r,y,m}^{mat} \pi_{r,y,m}^{mat}$$

$$c_{r,y}^{OPEX,energy} = \sum_f i_{r,y,f}^{energy} \pi_{r,y,f}^{energy}$$

$$c_{r,y}^{OPEX,CO2} = \left(\sum_f i_{r,y,f}^{energy} i_{r,y,f}^{CO2} + e_{r,y}^{process} \right) \pi_{r,y}^{CO2}$$

$i_{r,y,m}^{mat}$	Material intensity in region r in year y for material m
$i_{r,y,f}^{energy}$	Energy intensity in region r in year y for fuel (including electricity) f
$i_{r,y,f}^{CO2}$	CO_2 intensity in region r in year y for fuel f
$\pi_{r,y,m}^{mat}$	Material price in region r in year y per unit of material m
$\pi_{r,y,f}^{energy}$	Energy price per unit in region r in year y per unit of material f
$e_{r,y}^{process}$	Process emissions in region r in year y
$\pi_{r,y}^{CO2}$	CO_2 price in region r in year y

Prices used for the value of trade and market sizes

The MaT Model estimates physical trade flows based on the LCOP. It is assumed that the LCOP is a good proxy for the final output price, which is used in decision-making by firms (noting that the LCOP excludes other costs such as quality control, inventory, warehousing, and processing). However, to best estimate the value of trade, global trade statistics are employed. Where available, the value of trade between regions is divided by the volume of trade between regions to produce bilateral trade prices. Trade statistics are available for solar PV cells, solar modules, battery cells, electric vehicles, wind nacelles, blades (for wind), towers (for wind) and heat pumps. The evolution of prices is estimated using data on historical price trends for each technology. This method allows for the real value of trade to be captured appropriately, as detailed by trade statistics. Where trade statistics are not available, top-down regional price estimates are used instead. It must be noted that trade statistics will include some trade that is not directly related to deployment in a given year, but rather is due to demand for stockpiling. This is most relevant to solar PV (see the Historical trade flows section).

Figures for total market size are estimated by multiplying demand in a region by the trade-weighted average price within the region of each component. The prices used in this calculation are based on top-down regional price estimates which reflect the delivered cost of a component or technology (see the Data sources section).

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Deployment and demand

Demand for clean energy technologies

Demand for each of the finished technology products (the final step of a given manufacturing supply chain) is defined based on the results of the GEC Model per modelling scenario. Demand for upstream components is determined by the MaT Model, based on the production of the downstream steps in the manufacturing supply chain. For example, the model determines the location of manufacturing of electric cars, which influences the demand for battery cells in each region. Unless explicitly mentioned, no stock changes have been considered as part of the demand.

Solar PV: Demand corresponds to the average annual PV capacity additions between that same year and the following one, in order to simulate time spent in stocks between production and use. The demand per modelling region for the immediate upstream component, solar PV cells, corresponds to the production of solar modules in the region within the same year. Similarly, the demand for wafers corresponds to the production of solar cells, and the demand for polysilicon to the production of wafers in the modelling region.

Wind: Demand per modelling region for any given year for all the wind components – nacelles, blades and towers – corresponds to the average annual wind capacity additions (i.e. installations) between the same year and the following one. This compensates for the fact that construction of a wind farm can take place over several years.

Electric cars: Demand per modelling region aligns with new electric car sales in each year.

Batteries: Demand per modelling region corresponds to demand for battery energy storage systems and production of electric vehicles sold in a given year. Battery energy storage demand corresponds to capacity additions per region per year. For electric vehicles other than cars (light commercial vehicles, trucks, buses), the first historical year's import share and trade patterns are assumed to remain constant. For electric two- and three-wheelers, all demand is assumed to be supplied by local vehicle production without any trade.[5]

Electrolysers: Demand per modelling region corresponds to electrolysis plant installations in the same year.

[5] This assumption holds for the major markets such as China, India and Southeast Asia, together accounting for over 75% of global demand for all years and scenarios considered. For other markets, electric two- and three-wheelers are a minor source of battery demand.

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Heat pumps: Demand per modelling region corresponds to heat pump sales in the same year measured in GW thermal (GW_{th}), and not individual units.

Existing and announced manufacturing capacity

Existing manufacturing capacity

Information on existing manufacturing capacity for clean energy technologies in the latest historical year is based on various data sources (see the Data sources section) and is aggregated by model region. If no information on the remaining lifetime of existing manufacturing plants is available, it is assumed that the existing capacity linearly declines to zero over a period equal to the lifetime assumption. Capacity refers to the maximum amount a facility could produce in a year (to which utilisation rates are applied in the modelling) and is measured in physical units.

Announced manufacturing capacity

Announced manufacturing capacity includes both new facilities and capacity expansions of already existing plants. Announced manufacturing capacity is based on various data sources, including external data providers (see Data sources section) and desk research. Announcements on increased manufacturing capacity are categorised by committed (i.e. those under construction or that have reached final investment decision) and preliminary (i.e. those that have not reached final investment decision). Unless otherwise stated, the announced projects dataset assembled for *ETP-2026* comprises announcements dated up to the end of November 2025.

Announced capacity data is used as a model input to inform capacity developments up to the year 2030. In the Stated Policies Scenario (STEPS), committed announced capacity is assumed to be built for clean energy technologies. Preliminary announced capacity is considered in the Net Zero Emissions by 2050 Scenario (NZE Scenario), on top of committed announced capacity.

Forward-looking benchmark output is derived from existing and announced projects. To allow comparison with deployment levels in IEA scenarios, an 85% utilisation rate is assumed.

Material and labour costs

Material costs

Historical spot prices for materials and commodities are retrieved from Bloomberg (BNEF, 2025a). Where there are multiple prices available (for example, from a Chinese and European spot price), each modelling region is assigned a “base” price. Where there is only one spot price available, it is used for all regions.

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Based on production and net trade for each material (from the GEC Model and additional research where required), regions are classified as either self-producing or importers. Regions that are self-producing have prices based on the relevant spot price series, while importers are assigned prices based on the exporting region's prices plus transportation costs. Export partners are considered based on historical trade. If there are any tariffs or export restrictions applicable, they are applied to the price on an ad valorem equivalent basis (see the Industrial strategies and policies section).

Future prices are projected in two steps. First, the "launch" price is calculated by finding the average price in the last 3 years. Special considerations are made when a material price has experienced extreme price fluctuations (such as lithium prices in 2022). Second, a price growth series is applied to the launch prices to project price signals to 2050. The same growth series is applied to all regions within a scenario. The growth series differs between scenarios, resulting from differing levels of demand in each scenario. For critical minerals, a linear regression is employed to estimate the relationship, at the global level, between historical prices and demand for each mineral. For bulk materials such as aluminium and steel, historical production costs from the GEC Model are available and used in place of prices. Altogether, each price series to 2050 is estimated, differing by region and scenario.

Labour costs

Labour costs are region and time specific, drawing on data from the Japan External Trade Organization Investment Cost Comparison (Japan External Trade Organization, 2025). This dataset provides investment cost data for major cities in the world, including wages and the associated costs paid by firms. Different worker classifications are considered (such as engineers and general workers) and the weighted average wage is estimated for each technology, depending on the share of each type of worker in the production process. Labour costs are projected by estimating the relationship between wages and GDP. Labour intensities are estimated for each component and the resulting labour costs are reported in USD per unit of output (GW, GWh, or unit).

Industrial strategies and policies

A wide range of policies can affect industrial manufacturing, often guided by overarching industrial strategies. The figure below illustrates the main policy instruments that could potentially affect the manufacturing of clean energy technologies and materials. Some of these direct measures are explicitly modelled, such as import tariffs, non-tariff measures and production-linked financial support (if part of an announced policy programme). However, other measures, such as ad-hoc incentives granted on a project-by-project basis, innovation policies with long-term effects, and horizontal policies with indirect effects on the wider economy, are not modelled with exogenous parameters, but

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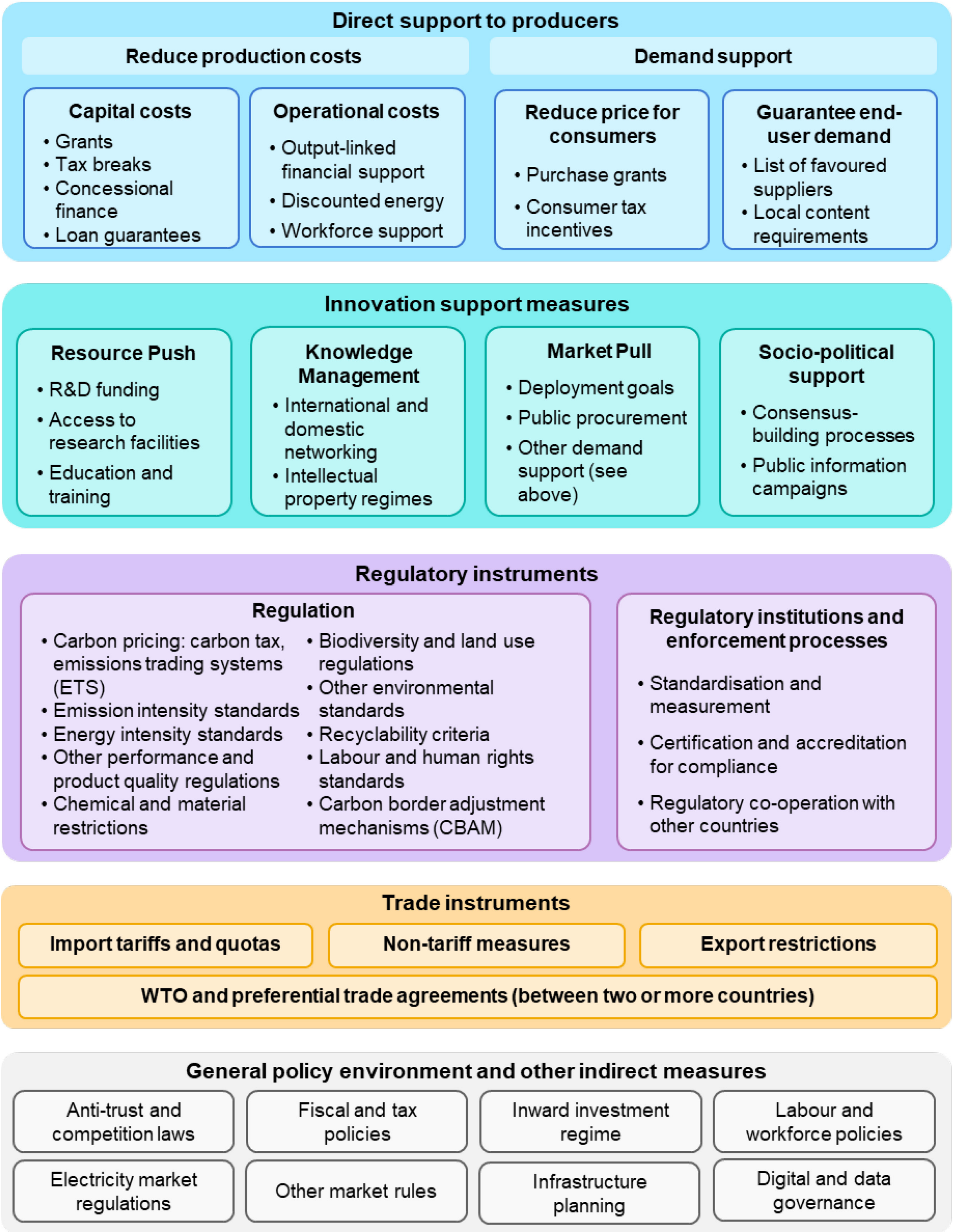
are considered part of the enabling conditions (i.e. the possibility to increase the manufacturing capacity). This is because their direct impact on industrial manufacturing is difficult to quantify.

Industrial strategy policy instruments



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Note: WTO = World Trade Organization.

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Tariff database

Ad valorem and specific tariffs per region are taken from the World Trade Organization (WTO), using applied tariff rates at the 6-digit HS code and country level for 2023, 2024 and 2025. Special and temporary tariffs are added to the database as they are announced and are applied according to their scheduled start and end dates. The interaction of tariffs is also considered. In certain instances, tariffs are cumulative, while in others, tariff programmes establish explicit mutual-exclusion rules or define a maximum applicable tariff, preventing multiple tariffs from being applied simultaneously to the same good. In all cases, and following these rules, tariffs are aggregated using historical trade at the 6-digit HS code level, based on trade flows in 2023 from CEPII (CEPII, 2025). Where a tariff does not have an explicitly scheduled end-date, it is assumed to remain in place for the entire modelling period.

Non-tariff measures

Non-tariff measures (NTMs) are all policy interventions other than tariffs that can potentially affect the quantities and prices of internationally traded goods. NTMs can be measured by estimating their impact on trade patterns or prices. The MaT Model employs the latter by using ad valorem equivalents (AVEs) to quantify NTMs. The AVE of an NTM represents the equivalent uniform tariff that would produce the same price impact as the NTM, capturing the additional costs that NTMs impose on trade. The estimation of AVEs is based on work from Kravchenko et al. (Kravchenko, Strutt, Utoktham, & Duval, 2022).

Export restrictions at the 6-digit HS code level are taken from the OECD Inventory on Export Restrictions on Industrial Raw Materials (OECD, 2025). They are used to inform the material cost inputs and are implemented on an ad-hoc basis depending on the nature of the export restriction. The restrictions are implemented on an ad valorem basis and stack with other tariffs.

Industrial strategies and policy packages

Extensive policy analysis is undertaken to ensure the scenario analysis accurately reflects policy settings. Policy instruments, such as subsidies, regulations, tariffs and NTMs, that are already in place are accounted for in the STEPS. In contrast, aspirational policies or targets for manufacturing that have not yet been translated into concrete and predictable policy instruments are considered only in the NZE Scenario.

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Selected industrial strategies and policy packages targeting clean energy technology manufacturing considered in the MaT Model

Country/region	Key Policies
Australia	• Australia's Battery Strategy (2025) (ARENA, 2025a) • Solar Sunshot Program (2025) (ARENA, 2025b) • Future Made in Australia (Parliament of Australia, 2024)
Brazil	• Support from the National Bank for Economic and Social Development (BNDES, 2025) • New Industry Brazil (Nova Indústria Brasil) (Brazil, Governo Federal, 2025) • MOVER (Green Mobility and Innovation Program) (Leis, 2024)
Canada	• Budget 2023 – A Made-in-Canada Plan Budget, 2024 – Fairness for Every Generation (Government of Canada, 2024) • Canadian tariffs on selected US products (2025) (Government of Canada, 2025)
Chile	• Electromobility Strategy (Chile, Ministry of Energy, 2021) • Hydrogen Strategy (Chile, Ministry of Energy, 2020)
People's Republic of China (China)	• Belt and Road Initiative (BRI) (2013) (NDRC, 2023) • Made in China 2025 (2015) (CSET, 2022) • Dual Circulation Strategy (2020) (China, National Development and Reform Commission, 2022) • Regional Comprehensive Economic Partnership (RCEP) (2020) (ASEAN, 2020) • Export restrictions and bans on rare earths and critical minerals (2025) (China, Ministry of Commerce, 2025) • Retaliatory tariff on all US products (2025) (Huld, 2025)
Colombia	• High-level document on Re-industrialisation Policy (Política de Reindustrialización), including a priority line on the energy transition (Colombia, National Planning Department, 2023)
Egypt	• National Automotive Industry Development Program (AIDP, 2025)

European Union	• European Green Deal (2019) (European Commission, 2019)
	• REPowerEU Plan (2022) (European Commission, 2025e)
	• Green Deal Industrial Plan (2023) (European Commission, 2023)
	• Temporary Crisis and Transition Framework (2023) (European Commission, 2025f)
	• Free trade agreements
	    ○ Türkiye (1995) (European Commission, 2025d)
	    ○ EU-Morocco Association Agreement (2000) (European Commission, 2025b)
	    ○ EU-Korea Free Trade Agreement (2011) (European Commission, 2025c)
	    ○ EU-Japan Economic Partnership Agreement (2019) (European Commission, 2025a)
	• Countervailing duties (CVDs) on Chinese electric vehicles (2024) (European Commission, 2024a)
	• Net-Zero Industry Act (NZIA) (2024) (European Commission, 2024b)

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<table>
<tr><th>Country/region</th><th>Key Policies</th></tr>
<tr><td>India</td><td>National Steel Policy (2017) (India, Ministry Of Steel, 2017)
Production Linked Incentive scheme (2020) (India, Press Information Bureau, 2025)
National Green Hydrogen Mission (2023) (India, Ministry of New and Renewable Energy, 2023)
E-vehicle policy (2024) (India, Ministry of Heavy Industries, 2024)
Tariffs and non-tariff measures on solar PV modules and cells (2022) (India, Press Information Bureau, 2022a)
Preferential trade agreements
South Asian Free Trade Area (SAFTA, 2006) (SAARC, 2025)
ASEAN-India FTA (AIFTA, 2010) (ASEAN, 2012)
India-Korea Comprehensive Economic Partnership Agreement (2010) (Embassy of India, 2025)
India Japan Comprehensive Economic Partnership Agreement (2011) (India, Ministry of Commerce and Industry, 2020)
Local content requirements for wind manufacturing (Reuters, 2025)
Reduction of goods and services tax on renewable energy equipment (2025) (Power Technology, 2025)
Removal of safeguard duty on solar components from all countries (Energetica India, 2025)
Make in India (2014) (India, Press Information Bureau, 2022b)</td></tr>
<tr><td>Indonesia</td><td>Export restrictions on raw materials that can be used for batteries in the electric vehicle (EV) supply chain (IEA, 2024b)</td></tr>
<tr><td>Japan</td><td>65% domestic procurement ratio by 2040 for offshore wind (2025) (Japan Wind Power Association, 2025)
Green Transformation (GX) Promotion Strategy (Japan, Ministry of Economy, Trade and Industry, 2023)</td></tr>
<tr><td>Kazakhstan</td><td>Third Modernization of Kazakhstan: Global Competitiveness (Nazarbayev N., 2017)</td></tr>
<tr><td>Kenya</td><td>4th medium term plan programme and projects (2023-2027) (Government of Kenya, 2024)</td></tr>
<tr><td>Korea</td><td>Industrial Supply Chain 3050 Strategy (2023) (Herh, 2023)</td></tr>
<tr><td>Malaysia</td><td>New Industrial Master Plan 2030 (Malaysia, Ministry of Investment, Trade and Industry, 2023)</td></tr>
<tr><td>Morocco</td><td>Integrated Wind Energy Plan for Morocco (PMIEE) (Morocco, Ministry of Energy Transition and Sustainable Development, 2024)
Financial incentives for battery manufacturers (GreenTimes, 2024)</td></tr>
<tr><td>Nigeria</td><td>Nigeria Energy Transition Plan (Federal Government of Nigeria, 2025)</td></tr>
</table>

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Country/region	Key Policies
Saudi Arabia	• Vision 2030 (Public Investment Fund, 2023)
South Africa	• Just Energy Transition Plan; South African Renewable Energy Masterplan (SAREM) (South Africa, Department of Mineral Resources and Energy, 2025)
United Kingdom	• The Clean Industry Bonus for offshore wind (United Kingdom, Department for Energy Security and Net Zero, 2024)

United States	• Bipartisan Infrastructure Law (2021) (US Congress, 2021)
	• Inflation Reduction Act (2022) (IRS, 2022)
	    o Production tax credits
	    o Investment tax credits
	• Free trade agreements (US Trade Representative, 2025b)
	    o Chile, USCFTA (2004)
	    o Australia, AUSFTA (2005)
	    o Morocco, USMFTA (2006)
	    o Korea, KORUS (2012)
	    o USMCA free trade agreement (2020)
	    o Japan critical minerals agreement (2023)
	• One Big Beautiful Bill Act (2025) (US Congress, 2025a)
	• US International Emergency Economic Powers Act (IEEPA) tariffs on all products from Canada, Mexico, and China (2025) (US Congress, 2025b)
	• US reciprocal tariffs on all products from all trading partners except Mexico and Canada (2025) (US Congress, 2025b)
	• Section 301 tariffs on imports from China (2025) (US Trade Representative, 2025a)
	• Section 232 tariffs on steel and aluminium from all countries (2025) (The White House, 2025)
	• Anti-dumping duties (ADDs) and CVDs on solar components from Viet Nam, Malaysia, Thailand and Cambodia (International Trade Administration, 2025)
	• Proposed financial support schemes in the Inflation Reduction Act where tax credit rules are not yet finalised (45V clean hydrogen production tax credit) (US Department of the Treasury, 2025)

Viet Nam	• ADD on wind components from China (2025) (Vietnam News, 2025)

Additional technical details

Historical trade flows

Solar PV

Due to significant stockpiling of modules in 2023, 2024 and 2025, the volume of PV modules in inventories is considered when modelling historical trade for PV modules. This is reflected in production volumes and global trade volumes for that

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year. In the long run, it is assumed that global production and demand for installations will be balanced, and therefore any results from 2030 onwards do not consider any inventory changes. No inventory changes are considered for PV cells, wafers and polysilicon.

For PV modules, base year trade comes from IEA analysis. This accounts for production that has ended up in inventories of the importing countries, as well as inventory increases in the producing country (generally China). Analysis of trade along the supply chain is based on InfoLink and BNEF, while modules and cells also draw on SPV Market Research and Sinoimex (see Data sources section).

Wind

Trade flows for wind components are modelled without differentiating between onshore and offshore because facilities dedicated to manufacturing wind components can generally serve both sectors. Global trade for wind components can be difficult to track, as the components often fall under different HS codes. Furthermore, given that there are many modes of transportation, and that downstream components are frequently shipped between facilities, it is difficult to acquire official data. To estimate trade for 2023, 2024 and 2025, two key databases are combined: the manufacturing database from S&P Global Commodity Insights, and the installation of turbines per original equipment manufacturer (OEM) database from BNEF (see the Data sources section). For each OEM, trade is assumed to take place between the regions where final installation took place and the regions where its manufacturing hubs are located. As an initial assumption, these trade links are based on weighted averages of where production and installation take place. However, when more sources are available, as in the case of the United States, which tracks imports of nacelles, blades and towers (Harmonized Tariff Schedule codes: 850231, 841290 and 730820, respectively), or when there are published articles on shipments of components to wind farms, these initial assumptions are updated. In the case of blades, manufacturing capacities are also adjusted, as some OEMs use other companies' blades.

Electric cars and plug-in hybrid electric vehicles

BEV and PHEV trade is estimated using historical trade patterns in physical units. PHEV trade is also informed by BEV MaT modelling results. It is assumed that projected PHEV trade mirrors BEV trade, as the factors that influence the cost-effectiveness of BEV and PHEV manufacturing are generally similar. As with other vehicle types, PHEV demand is taken from GEC demand projections and is used in conjunction with each region's import shares to determine final PHEV trade flows. From 2025 to 2040, the share of PHEV imports gradually shifts from today's trade patterns to match the BEV trade model for 2040. After 2040, PHEV import shares are assumed to be the same as BEVs.

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Batteries

Battery and battery component trade flows in the base year are estimated by combining manufacturing capacity, trade statistics, and data on production of the final product (for example, EV production) and their battery cell supplier.

Electrolysers

The trade flows in the base year are estimated by combining the capacity and location of installed and planned electrolyser projects from the IEA Hydrogen Production Projects database (IEA, 2025d), with the location of electrolyser manufacturing facilities based on internal research, taking into account information on electrolyser shipments of manufacturers to specific projects where available.

Heat pumps

Trade flows in the base year are estimated by aggregating the trade values of HS codes 841581 and 841861. Trade for these codes is estimated using a regression analysis of historical 6-digit trade flows from BACI (CEPII, 2025) combined with macroeconomic indicators. The trade flows are weighted based on the relative sales of the different types of equipment, specifically to exclude air-to-air heat pumps not used as primary heating equipment. Future trade flows in the MaT Model are also aggregated and include these two HS categories.

Upstream component considerations

For any upstream components incorporated in the calculation of the LCOP of EVs, battery cells, modules, cells and wafers, the origin-dependent prices have been considered based on the shares of domestic production and imports by trade partners.

For batteries, if not stated otherwise, the historical and projected world capacity-weighted battery chemistry is used to calculate the battery cell and cathode LCOP. Chemistry-dependant conversion factors[6] are used to convert the manufacturing capacity of battery components from tonnes to GWh-equivalent.

For solar PV, the LCOP calculations for PV modules and PV cells assume the use of tunnel oxide passivated contact (TOPCon) c-Si cells. The polysilicon prices include the processing of metallurgical-grade silicon, assuming this is domestically produced. When comparing the LCOP of PV modules between regions, this does not refer to end-to-end domestic production of all the components, as it may be more cost-competitive to import certain components.

[6] For active material precursors, the same conversion factors as the associated active materials are assumed.

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Maritime shipping routes

Trade shipping route modelling informs shipping activity, chokepoint analysis and shipping costs of clean energy technologies and materials. Historical trade between countries is estimated using a range of data sources (see Data sources section). The share of total trade being allocated to maritime shipping is determined using a dataset based on work by Vershuur et al. (Verschuur, Koks, & Hall, 2022) which includes estimates of maritime trade shares between individual countries for specific product groups.

Bilateral seaborne traded quantities are allocated to individual ports using import and export shares for each port provided by Ports Watch (IMF, 2025). Trade between individual ports is assumed to be proportional to their respective shares of a country's imports and exports.

To model the distance and specific route between two ports and assess any extra navigation time, based on co-ordinates, the python package "searoute" is used (Halili, 2024). This package generates the shortest sea route between two points. It offers the possibility of blocking certain maritime chokepoints and is used to close the Northwest Passage and Sunda Strait on the assumption that they represent only a minor share of trade.

Shipping activity

Shipping activity is calculated by multiplying the seaborne traded quantities for each port-to-port combination by the distances involved. Base year estimates are reconciled with the UN Trade and Development (UNCTAD)'s shipping work estimate (UNCTAD, 2025). Trade by commodity is allocated to ship types based on the classification from the International Maritime Organization's Fourth GHG study (IMO, 2020).

For projections, it is first necessary to establish the evolution of traded quantities in different scenarios. These quantities are derived using two methods:

1. Products which are explicitly modelled within the IEA's GEC and MaT Models use their trade results by scenario. Trade is modelled at a regional level and then re-allocated to individual countries based on a combination of historical indicators and macroeconomic indicators from the GEC Model.

2. For products outside of the IEA's modelling scope, regression analysis of historical trade flows and macroeconomic indicators is used to derive growth rates.

The share of maritime trade between individual countries, as well as the use share of each port in a country's imports and exports, is assumed to remain unchanged

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over time and scenarios. Projected bilateral traded quantities by scenario are then used for projections in the chokepoint analysis, and to determine projected shipping activity.

Data sources

The table below summarises the main external data sources used for model calibration, which are supplemented by desk research and personal communications with manufacturers, project developers and other technology experts. IEA scenario and modelling data are used in conjunction with the data below.

Summary of the main data sources used for model calibration

Technology	Data	Source
Solar PV	**Existing and announced capacity** and **historical output** are primarily from InfoLink, supplemented by BNEF, SPV Market Research and RTS for cross-checking and details of certain regions.	InfoLink (InfoLink, 2025) BNEF (BNEF, 2025a) SPV Market Research (SPV Market Research, 2025) RTS Corporation (RTS Corporation, 2025)
	Energy and material intensities for LCOP calculations are from NREL and IEA Photovoltaic Power Systems Programme (PVPS).	NREL (NREL, 2023) IEA PVPS (IEA PVPS, 2025)
	Historical trade data comes from Sinoimex, UN Comtrade and the list of sources above used for output.	UN Comtrade (UN Comtrade, 2025) Sinoimex GTI Data Center (Sinoimex, 2025)
	Historical prices of modules and components are from BNEF.	BNEF (BNEF, 2025a)
Wind	**Manufacturing capacity and output** is primarily from S&P Global Commodity Insights, supplemented with data from WindEurope, BNEF, GWEC and Wood Mackenzie.	S&P Global Commodity Insights (S&P Global Inc., 2025) WindEurope (WindEurope, 2023) BNEF (BNEF, 2025a) GWEC (GWEC, 2023) Wood Mackenzie (Wood Mackenzie, 2025)

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Technology	Data	Source
Wind (continued)	**Levelised costs** are informed by the Wind Supply Chain series from Wood Mackenzie and NREL.	Wood Mackenzie (Wood Mackenzie, 2025) NREL (NREL, 2019)
	Historical trade estimates are primarily from S&P, based on manufacturing capacities and deployment from BNEF, and supplemented by Sinoimex.	S&P Global Commodity Insights (S&P Global Inc., 2025) BNEF (BNEF, 2025a) Sinoimex GTI Data Center (Sinoimex, 2025)
	CAPEX data for nacelles, blades and tower facilities are based on analysis drawing from S&P Global Commodity Insights data. CAPEX estimates of sub-components of nacelles from the Center for Wind Power Drives are converted into regional production estimates.	S&P Global Commodity Insights (S&P Global Inc., 2025) Center for Wind Power Drives (Reichartz et al., 2024)
	Historical prices for turbines are taken from the price survey by BNEF.	BNEF (BNEF, 2025b)
	Energy and material intensities are primarily from NREL.	NREL (NREL, 2019)
Batteries	**Existing and announced capacity for battery cells**, including the preliminary and committed status, is primarily from Benchmark Mineral Intelligence (BMI) and BNEF is used as a supplementary source for manufacturing status. **Existing and announced capacity for cathode and anode** active material, including preliminary and committed status, is primarily from BNEF.	Benchmark Mineral Intelligence (BMI, 2025) BNEF (BNEF, 2024b)
	Historical output draws on battery manufacturing capacity data (BMI), electric vehicles production and cell supplier data from EV Volumes, as well as IEA data and analysis.	Benchmark Mineral Intelligence (BMI, 2025) EV Volumes (EV Volumes, 2025),
	Electric vehicle **battery sizes** used for historical average EV battery sizes (kWh) are from EV Volumes.	EV Volumes (EV Volumes, 2025)

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Technology	Data	Source
Batteries (continued)	**Battery and component material and energy intensities** are primarily from GREET and Degen et al., together with IEA data and analysis.	GREET (Argonne, 2024) Energy consumption of batteries (Degen et al., 2023),
	Conversion factors between battery cells and battery pack and other technical specifications like the anode to cathode ratio are from Frith et al. together with IEA data and analysis. Conversion factors [kWh/t] for battery components are from IEA data and analysis.	A non-academic perspective on the future of lithium-based batteries (Frith, Lacey, & Ulissi, 2023)
	Historical battery prices are primarily from BNEF.	BNEF (BNEF, 2024b)
	Historical trade in value terms is from Sinoimex.	Sinoimex GTI Data Center (Sinoimex, 2025)
Electric cars	**Historical sales and trade** of electric cars (including electric commercial vehicles and buses) is primarily from EV Volumes. Trade values are supplemented by Sinoimex.	EV Volumes (EV Volumes, 2025) Sinoimex GTI Data Center (Sinoimex, 2025)
	Manufacturing capacity is from the Marklines OEM plant dataset. Atlas EV Hub is used to inform the historical EV manufacturing investment analysis.	Marklines (Marklines, 2025) Atlas EV Hub (Atlas EV hub, 2024)
	Energy and material intensities for electric cars are primarily from GREET.	GREET (Argonne, 2024)
	Historical prices of electric cars are from S&P Global Mobility.	S&P Global Mobility (S&P Global Mobility, 2025)
	Levelised costs of electric cars in China, Europe and the United States are informed by studies from BNEF, ICCT, T&E and UBS.	BNEF (BNEF, 2024a) ICCT (ICCT, 2023), (ICCT, 2022) Transport & Environment (BNEF, T&E, 2021) UBS (UBS, 2017), (UBS, 2023)
Electrolysers	**Manufacturing capacity** data are based on announcements by manufacturers and personal communications gathered by the IEA.	Primary research

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Technology	Data	Source
Electrolysers (continued)	**Historical trade** data are derived from the IEA Hydrogen Projects database.	IEA Hydrogen Projects database (IEA, 2025d)
	CAPEX data are from desk research and communication with manufacturers.	Primary research
	Historical price data are from desk research and communication with project developers.	Primary research
Heat pumps	**Manufacturing capacity** is derived using data from CEPII.	CEPII (CEPII, 2025)
	Manufacturing capacity additions and expansion plans are based on public announcements by manufacturers.	Manufacturer announcements
	CAPEX data are based on data from JETRO.	JETRO (Japan External Trade Organization, 2025)
	Historical trade data draws on manufacturing capacity estimates and Sinoimex.	Sinoimex GTI Data Center (Sinoimex, 2025)
Other	**Material prices** are primarily based on data from Bloomberg, IEA Global Critical Minerals Outlook and IEA GEC modelling.	Bloomberg (Bloomberg, 2024) Global Critical Minerals Outlook 2025 (IEA, 2025b) Global Energy and Climate Model (IEA, 2025a)
	Energy prices are from the IEA Energy Prices dataset.	Energy Prices (IEA, 2025c)
	Labour costs are primarily from JETRO, supplemented by ILOSTAT.	JETRO (Japan External Trade Organization, 2025) ILOSTAT (ILO, 2025)
	Weighted average cost of capital data is from Damodaran.	Damodaran Online (Damodaran, 2025)
	Historical trade data in monetary units based on international trade statistics are sourced from Sinoimex, supplemented by CEPII data.	Sinoimex GTI Data Center (Sinoimex, 2025), CEPII (CEPII, 2025)

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Technology	Data	Source
International trade	**Tariff** data is from the WTO.	WTO Tariff and Trade Data (WTO, 2025)
	Non-tariff measures are based on research by Kravchenko et al.	New Price-based Bilateral Ad valorem Equivalent Estimates of Non-tariff Measures (Kravchenko, Strutt, Utoktham, & Duval, 2022)
	Export restrictions are from the OECD.	OECD Inventory of Export Restrictions on Industrial Raw Materials (OECD, 2025)
Trade routes	**Port and container sizes** are from Lloyd’s List.	One Hundred Ports (Lloyd's List, 2023)
	Tankers and dry bulk port capacities, **and maritime share of trade** are from Verschuur et al.	Ports’ criticality in international trade and global supply-chains (Verschuur, Koks, & Hall, 2022)
	Trade by port is from Ports Watch.	Ports Watch (IMF, 2025)
	Hydrogen, ammonia and methanol projects and assumptions are from the Global Hydrogen Review 2024.	Global Hydrogen Review 2024 (IEA, 2024c)
	Shipping activity data is from UNCTAD.	Review of maritime transport (UNCTAD, 2022)

Note: Many of the data sources are only accessible via subscription – in these instances a link to the data provider’s website is provided in the Reference list.

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Annex A: Abbreviations and acronyms

ADD	anti-dumping duty
AIDP	Automotive Industry Development Program
ASEAN	Association of Southeast Asian Nations
AVE	ad valorem equivalents
BEV	battery electric vehicles
CAPEX	capital expenditure
CfD	contract for difference
CRF	capital recovery factor
CVD	countervailing duties
ETP	Energy Technology Perspectives
EV	electric vehicle
GEC	Global Energy and Climate
GHG	greenhouse gas
HS	Harmonized System
IEEPA	International Emergency Economic Powers Act
LCOP	levelised cost of production
LED	light-emitting diodes
MaT	Manufacturing and Trade
NTM	non-tariff measures
NZE	Net Zero Emissions by 2050 Scenario
OEM	original equipment manufacturer
OPEX	operating expenditure
PHEV	plug-in hybrid electric vehicles
PV	photovoltaic
RCEP	Regional Comprehensive Economic Partnership
SAFTA	South Asian Free Trade Area
SAREM	South African Renewable Energy Masterplan
STEPS	Stated Policies Scenario
USD	United States dollar
WTO	World Trade Organization

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