Energy Technology Perspectives 2024

Annex

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Annex A – IEA's Manufacturing and Trade model

Methodology

IEA's Manufacturing and Trade (MaT) Model was developed for the current edition of Energy Technology Perspectives (ETP) as a framework for projecting different metrics related to manufacturing and trade for six key clean energy technologies – electric cars, batteries, solar photovoltaics (PV), wind turbines, heat pumps and electrolysers. The modelling scope also includes the manufacturing and trade of the main components of these technologies, alongside three relevant materials – steel, aluminium and ammonia (both for industrial and fuel-related applications) – with a focus on near-zero emissions manufacturing processes. For each of the aforementioned technologies or materials, these metrics include capacity and production (both in physical units, such as GW, GWh or million tonnes, and monetary value), investments, energy consumption and CO_2 emissions associated with manufacturing, as well as bilateral trade flows (both in physical units and monetary value) per year.

Scope

For the purposes of *ETP-2024*, the following boundaries are considered in the modelling and analysis for clean energy technologies and components within each manufacturing supply chain in scope:

Batteries include the battery cells and any individual parts that are used to compose a battery cell. The cathodes and anodes are modelled explicitly, but not the electrolyte, separator, or any battery metals from upstream processes (even though they are considered when assessing material costs within production cost calculations, using global averages). If not stated otherwise, cathode and anode refer to their respective active materials.

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.

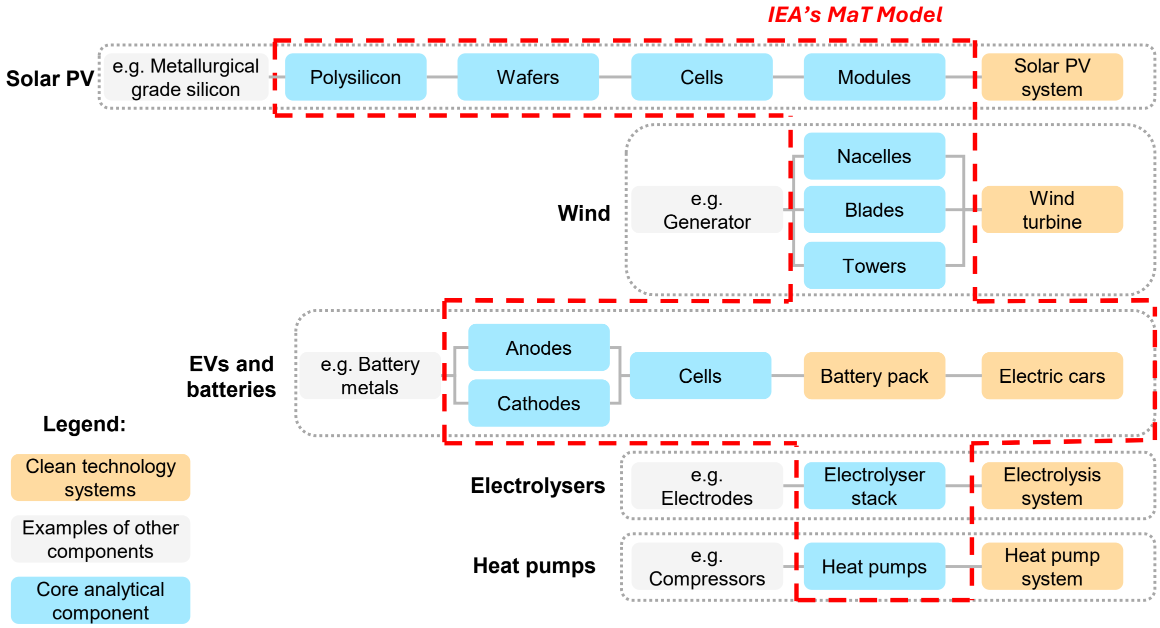
Solar PV includes the solar modules, solar cells, wafers and polysilicon, where all values are expressed in direct current (DC) terms. It does not include elements such as backsheets, encapsulants or any balance of system components, like inverters and racking. Metallurgical-grade silicon is out of scope,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

Wind includes wind nacelles, blades and towers. Manufacturing for nacelles includes only assembly and not the manufacturing of the downstream components such as the drive train and generator. Other wind components such as the foundation, yaw bearing, hub and power cables are not accounted for in the prementioned analysis but are assumed to be inputs to the production process. References to wind energy installation costs or turbine pricing by manufacturers include these products.

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 of capacity, output and trade considered here. For production cost, only the stack manufacturing is considered.

Heat pumps include in this analysis only heat pumps that deliver heat directly to residential and commercial buildings for space heating and/or hot water provision, whereas industrial heat pumps are excluded. It 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 considerations for capacity, output and trade.

Figure A.1 Scope for clean energy technologies in IEA's MaT Model



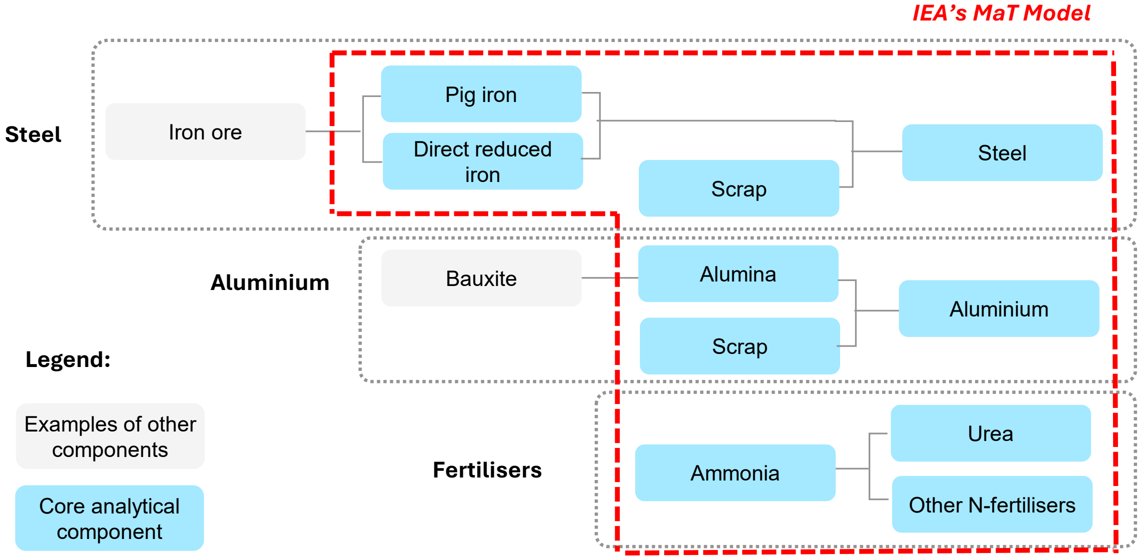
For the purposes of *ETP-2024*, the following boundaries are considered in the modelling and analysis for materials within each manufacturing supply chain in scope:

Iron and steel: Iron (pig iron and direct reduced iron), steel and steel scrap are considered. Steel production refers to crude steel. Steel trade refers to trade in ingots as well as in flat, long and tubular products (Harmonized System [HS] codes 7206 to 7307). Iron ore is outside the modelling boundary, although it is considered as a cost component in ironmaking.

Aluminium: Alumina, aluminium and aluminium scrap are considered. Aluminium trade refers to ingots and semifinished products (HS codes 7601 and 7603 to 7609). Only metallurgical alumina is modelled in the MaT Model. Bauxite is outside the modelling boundary, although it is considered as a cost component in alumina refining.

Ammonia and fertilisers: Ammonia, urea and other nitrogenous fertilisers are included. Other nitrogenous fertilisers include ammonium nitrate, calcium ammonium nitrate, urea ammonium nitrate and ammonium sulphate. Non-fertiliser applications of the products listed above are also considered within the scope (fuel and industrial applications for ammonia and industrial applications for fertilisers).

Figure A.2 Scope for materials in IEA's MaT Model

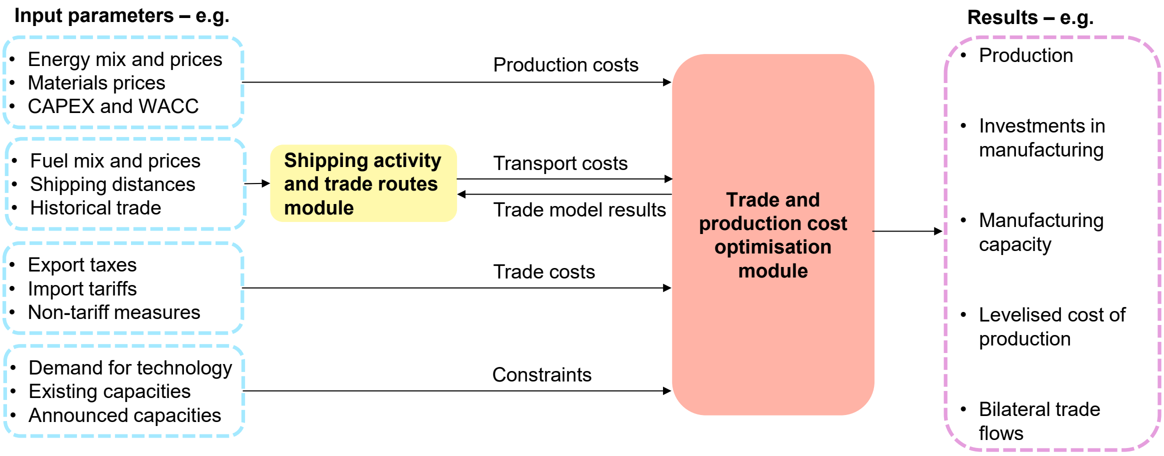


Note: Other N fertilisers = other nitrogenous fertilisers.

Framework description

The modelling framework is based on a least-cost bottom-up multiregional myopic optimisation approach, and consists of a set of models adapted to each clean technology, component and material production step, that are solved sequentially for 1-year periods. The modelling horizon spans from 2023 (base year) to 2050 with annual time steps. The model determines for given regional demands for clean energy technologies and materials the cost-optimal strategies for covering these regional demands with domestic manufacturing or imports from other model regions. Domestic manufacturing is influenced by domestic manufacturing capacity, which is also determined by existing and announced manufacturing capacities (see Table A.1). The modelling framework is informed by production costs, coming from the levelised cost of production (LCOP)[1] module, and trade costs, coming from the shipping activity and trade routes module, as well as by detailed regional information on industrial and trade policies (see section Industrial strategies and policy packages) and an assessment of current enabling conditions for manufacturing investments in emerging markets. Demand for clean energy technologies and materials produced and traded in the different scenarios is introduced exogenously to the MaT Model and taken from the outputs of the Global Energy and Climate (GEC) Model (IEA, 2024b).

Figure A.3 IEA's MaT Model schematic



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

The objective function seeks to minimise the total global costs related to regional production and bilateral trade of clean energy technologies and materials, subject to constraints (see section Constraints) for the production taking place in each region *r* and trade between and trade between exporter *exp* and importer *imp* regions for each year *y*. The objective function includes the production costs for

[1] As a convention, the acronym LCOP is used across the board even when referring to the levelised cost of manufacturing for clean energy technologies and materials. Similarly, 'production costs' also refer to the manufacturing costs of the technologies.

manufacturing clean energy technologies and materials, the transport costs for shipping them between model regions, and trade costs, reflecting costs incurred by trade policy measures and regulations:

$$Obj: min\ f(var\_production_{r,y}, var\_capacity_{r,y},\ \ var\_trade_{exp,imp,y}) = Production\_costs_y + Transport\_costs_y + Trade\_costs_y$$

Sets and indices

r:	region ∈ modelling regions
exp:	export region ∈ modelling regions
imp:	import region ∈ modelling regions
y:	year ∈ years within time horizon
m:	material ∈ materials as input to the manufacturing process
f:	fuel ∈ fuels used in the manufacturing process

Decision variables

$var\_production_{r,y}$:	production in region *r* and year *y*
$var\_capacity_{r,y}$:	manufacturing capacity in region *r* and year *y*
$var\_newcapacity_{r,y}$:	manufacturing capacity addition in region *r* and year *y*
$var\_trade_{exp,imp,y}$:	bilateral trade flow from region *exp* to region *imp* in year *y*

Inputs

Demand by clean energy technology and material

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 IEA's GEC Model per modelling scenario, while demand for intermediate technology components is determined by the MaT Model based on the production centres for the downstream steps in the manufacturing supply chain. For example, the model determines the location of manufacturing centres for electric cars, which influences the demand for battery cells in each region. Demand for materials is determined based on a set of macroeconomic drivers, including population and the value added of relevant economic subsectors, and integrates the impact of material efficiency measures derived from the GEC Model (IEA, 2024b). Unless explicitly mentioned, no stock changes have been considered as part of the demand.

Batteries: The demand for batteries is the sum of battery demands in each segment considered. The main source of battery demand is electric cars (over 70% of global demand for all years and scenarios considered), for which BEV production is modelled explicitly in the MaT Model and PHEV production considers 2023 trade patterns and BEV results (see "Electric cars: plug-in hybrid electric vehicles" in the Additional technical details section). For other non-passenger light-duty vehicle EVs (light commercial vehicles, trucks, buses), the 2023 import share and trade patterns are assumed to remain constant (regional sales from GEC 2024 model results). For electric two- and three-wheelers (2/3Ws), all demand is assumed to be supplied by local production without any trade. 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, the electric 2/3Ws are a minor source of battery demand. The stationary storage battery demand is also taken into account and corresponds to the capacity additions (installations) per region per year.

Electric cars: The demand for electric cars aligns with regional new electric car sales for the same year.

Solar PV: The demand per modelling region for solar PV modules in each year corresponds to the average annual PV capacity additions between that same year and the following one, as a way 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: The 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 as a way to compensate for the fact that construction of a wind farm can take place over several years.

Electrolysers: Demand for electrolysers corresponds to electrolysis plant installations in the same year.

Heat pumps: Demand for heat pumps corresponds to heat pump sales and installations in the same year measured in GW, and not individual units.

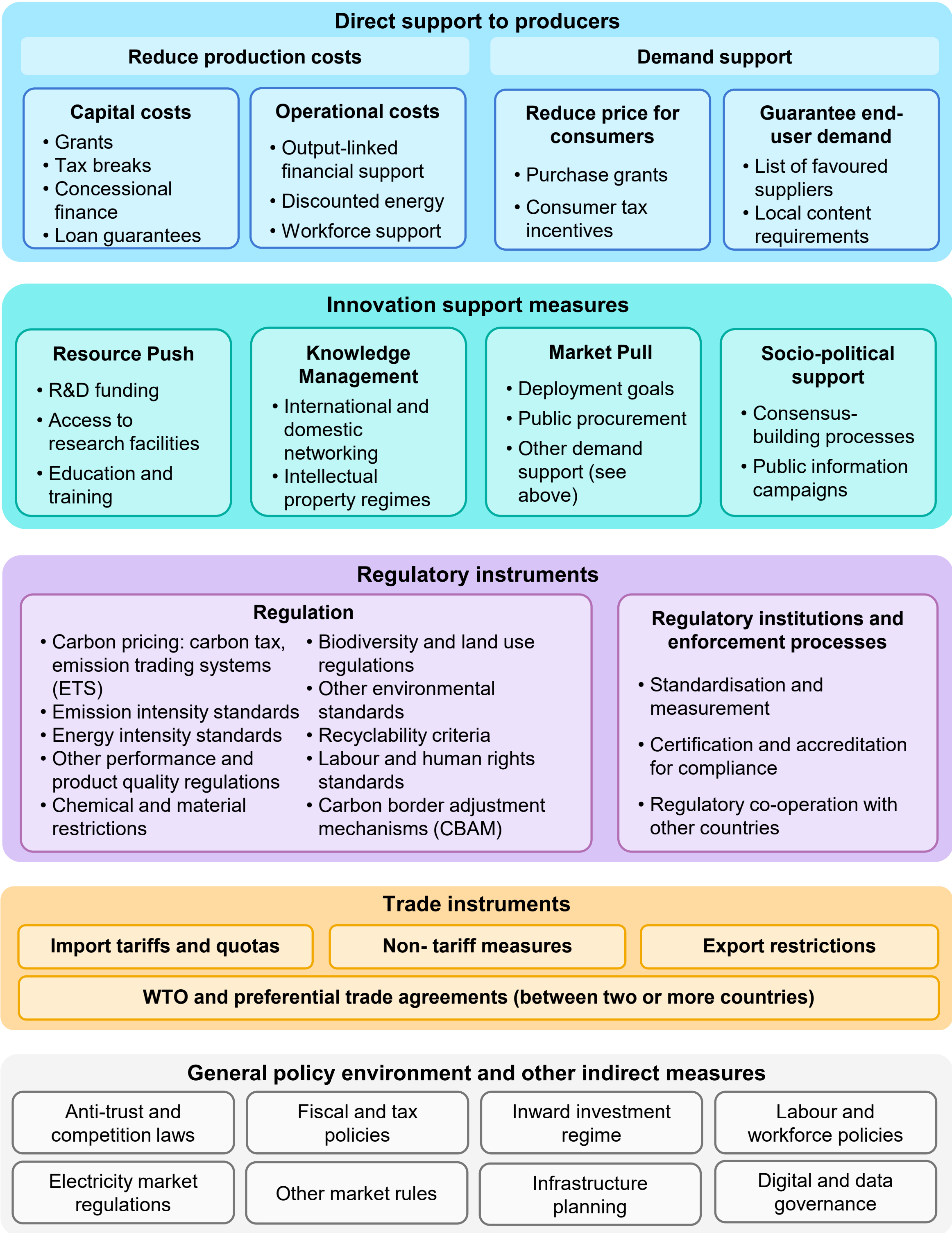
Materials: The demand for steel and aluminium corresponds to the demand for semi-finished steel and aluminium, measured in Mt. The demand for fertilisers is a composite of demand for different fertiliser types (see Scope section above) to allow for production and trade to be modelled. Ammonia demand for existing applications is partially endogenously determined by where fertilisers are produced, and partially exogenously determined when used for other industrial applications. Ammonia demand for fuel applications corresponds to ammonia use for shipping, power and as a hydrogen carrier in the GEC Model.

The projected demand share of near-zero emissions materials (compared to conventionally produced materials) at a global level comes from the projections of production technology shares modelled in the GEC Model. Ammonia for fuel applications is assumed to be only near-zero emissions (as it is in the GEC Model).

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

Figure A.4 Industrial strategy policy instruments



Note: WTO = World Trade Organization.

Trade databases

Ad valorem and specific tariffs per region and HS codes are taken from (WTO, 2024a), using applied tariff rates at six-digit HS code level for 2023. These tariffs are aggregated by modelling region and clean energy technology or material using the following methodology:

- Aggregation of countries into regions: Where a modelling region includes more than one country, the tariffs of each country are aggregated to a single tariff for the entire modelling region.
- Aggregation of HS codes into products: Multiple line tariffs at the six-digit HS code level are aggregated into a single clean energy technology or material.
- Weighted average calculation: Aggregation is performed using a weighted average approach, with weights based on actual trade flows (in economic terms) between countries and at the six-digit HS code level. The trade flow data used for weighting are taken from (CEPII, 2024) for the year 2022, as 2023 data were not yet available.
- Special, temporary and newly announced tariffs: Special tariffs, such as the Section 301 tariffs applied by the United States to imports of certain products from China, and temporary tariffs or exemptions are added to the tariff database on a rolling basis. These tariffs are applied according to their scheduled start and end dates when this information is published. As the WTO data reflect applied tariffs in 2023, updated tariffs during 2024 are also included in our tariff database and become applied tariffs from their implementation dates.

Export restrictions impacting any of the products modelled are taken from the OECD Inventory on Export Restrictions on Industrial Raw Materials (2024a).

IEA's MaT Model uses ad valorem equivalents (AVEs) to quantify non-tariff measures (NTMs). The AVE of an NTM represents the equivalent uniform tariff that would produce the same trade effect as the NTM, capturing the additional costs that NTMs impose on imports. The estimation of AVEs in the ETP-2024 is based on Kravchenko, Strutt, Utoktham, & Duval (2022).

The study by Kravchenko et al. estimates the AVEs of NTMs using a price-based approach at the six-digit HS code level. AVEs are derived as the percentage increase in import prices attributable to NTMs, calculated by comparing price differences between markets with and without these measures. The study uses data on bilateral import flows, which serve as a proxy for import prices and are obtained by dividing trade values by volumes, from the World Bank's World Integrated Trade Solution (WITS) platform for 2015. NTM data are taken from the United Nations Conference on Trade and Development (UNCTAD) TRAINS database, using records closest to 2015. In their modelling process, the six-digit

HS-level AVEs are transformed into Global Trade Analysis Project (GTAP) sectors.

These NTM AVEs are then aggregated by modelling region and clean energy technology or product through the following process:

- Aggregation into modelling regions: Country-specific AVEs are aggregated into five modelling regions: Advanced Economies, China, India, Other Emerging Economies and Least Developed Countries. Least Developed Countries are those listed by the United Nations (UN, 2024).
- Assignment to GTAP sectors: Each clean energy technology or product is assigned to one or more GTAP sectors.
- Weighted averaging: Aggregation is done using a weighted average approach, with weights based on actual trade flows (CEPII, 2024).

It should be noted that the study by Kravchenko et al. considers bilateral flows and classifies NTMs into technical and non-technical types, but excludes zero-trade flows, potentially missing prohibitive NTMs. It also relies on aggregate NTM counts without isolating individual effects. The 2015 data used to estimate the AVEs of NTMs should be considered as a proxy, given the significant increase in clean technology trade volumes and the evolving nature of regulatory frameworks since then.

Industrial strategies and policy packages

A list of main policies included in the report are available in Tables 2.1, 3.1 (United States), 3.3 (European Union), 3.5 (China) and 3.6 (India). Additional industrial strategies and policy packages in other emerging markets and developing economies (EMDEs) are also shown in the Table A.1 below. These strategies and policy packages have an impact on the greater diversification of supply in the NZE Scenario.

Table A.1 Industrial strategies and policy packages targeting clean energy technologies or materials manufacturing in EMDEs other than China and India

Country	Key Policies
Brazil	Support from the National Bank for Economic and Social Development (BNDES); New Industry Brazil (*Nova Indústria Brasil*); and MOVER (Green Mobility and Innovation Program)
Chile	Electromobility Strategy Hydrogen Strategy, CORFO's call to establish electrolyser manufacturing in the country
Colombia	High-level document on Re-industrialisation Policy (*Política de Reindustrialización*), including a priority line on the energy transition

Country	Key Policies
Egypt	National Automotive Industry Development Program
Indonesia	Export restrictions on raw materials that can be used for batteries in the EV supply chain
Kazakhstan	Third Modernization of Kazakhstan: Global Competitiveness
Kenya	4th medium term plan programme and projects (2023-2027)
Malaysia	New Industrial Master Plan 2030
Morocco	Integrated Wind Energy Plan for Morocco (PMIEE); Financial incentives for battery manufacturers
Nigeria	Nigeria Energy Transition Plan
Saudi Arabia	Vision 2030
South Africa	Just Energy Transition Plan; South African Renewable Energy Masterplan (SAREM)

Note: Financial support policies for energy inputs are not included in this table.

Cost data

The cost data used as inputs for the MaT Model can be separated into production costs, transport costs and trade costs associated with the domestic production or import of a clean energy technology or a material.

Production costs

These come from the levelised cost of production (LCOP) module, which is used to estimate the annualised CAPEX ($annualised\_CAPEX_{r,y}$), the fixed OPEX ($fixed\_OPEX_{r,y}$) and variable OPEX ($variable\_OPEX_{r,y}$) costs per unit of output over the lifetime of a production asset for the clean energy technologies and materials featured in *ETP-2024*. It accounts for all the costs associated with producing a product and is used to assess the competitiveness of outputs produced within a specific region. In the case of materials, different cost components have been considered for conventional and near-zero emissions production.

Annualised CAPEX: This refers to the costs an organisation bears in acquiring, upgrading, or maintaining physical assets of a manufacturing facility, and is typically a one-time, upfront investment. It is calculated by taking into account the overnight value of the CAPEX ($overnight\_CAPEX_{r,y}$) minus the financial support ($CAPEX\_FinSupport_{r,y}$) available to manufacturing investors per region and year, and annualised using the capital recovery factor ($CRF_{r,y}$). The CRF is calculated based on the weighted average cost of capital ($WACC_{r,y}$) for each modelling region and by assuming a useful economic lifetime for each clean technology or material.

$$annualised\_CAPEX_{r,y} = \left(overnight\_CAPEX_{r,y} - CAPEX\_FinSupport_{r,y}\right) * CRF_{r,y}$$

$$CRF_{r,y} = \frac{WACC_{r,y}}{1-(1+WACC_{r,y})^{-Lifetime}}$$

Fixed OPEX: This refers to the ongoing, regular costs required to operate a manufacturing facility that do not vary with the level of output and therefore remain constant regardless of the operational activity level. Annual fixed operational expenditure is assumed to be proportional to the overnight capital expenditure at a ratio ($fixed\_OPEX\_ratio_{r,y}$) for each region *r* and year *y*.

$$fixed\_OPEX_{r,y} = overnight\_CAPEX_{r,y} * fixed\_OPEX\_ratio_{r,y}$$

Variable OPEX: This refers to the operational costs that vary proportionally to the level of output of a facility, such as material inputs ($material\_costs_{r,y}$), energy consumption costs ($energy\_costs_{r,y}$), and emissions costs ($emissions\_costs_{r,y}$). For manufacturing of clean energy technologies, variable OPEX also include labour costs ($labour\_costs_{r,y}$), while for material manufacturing labour costs are accounted as fixed OPEX. For this calculation, any grouped other OPEX costs ($other\_OPEX_{r,y}$) have been included in the variable OPEX for clean energy technologies, as well as any costs stemming from the use of upstream components ($components\_costs_{r,y}$), where applicable, that are inputs of another product within the MaT Model, such as the solar PV cells which are inputs for the production of solar PV modules, or the cathode active material for the production of battery cells. The total variable OPEX is reduced by the amount of output-linked financial support available for a product in each region *r* and year *y* ($OPEX\_FinSupport_{r,y}$).

[2]
$$variable\_OPEX_{r,y} = material\_costs_{r,y} + energy\_costs_{r,y} + emissions\_costs_{r,y} + components\_costs_{r,y} + labour\_costs_{r,y} + other\_OPEX_{r,y} - OPEX\_FinSupport_{r,y}$$

The material, energy and emissions costs are calculated based on the energy[3] and emissions prices ($energy\_prices_{r,y,f}, CO2\_prices_{r,y}$), the material ($material\_intensity_{r,y,m}$), energy ($energy\_intensity_{r,y,f}$), and emissions intensities, ($emission\_intensity_{r,y,f}$) and the process emissions ($process\_emissions_{r,y}$). These come from IEA's GEC Model (IEA, 2024b),

[2] The expression presents the comprehensive list of elements taken into account; however, depending on the clean technology component or material, certain terms might be accounted for elsewhere, such as components costs for clean technologies without upstream components in scope or labour costs for materials.

[3] The energy prices correspond to the average national prices for industrial consumers and do not capture any sub-national prices (e.g. province level for China), individual contracts between large consumers and producers or effective costs for auto-producers.

complemented by additional research. The exact formulas are as follows for each region *r*, year *y* and material *m* or energy input *f*.

$$material\_costs_{r,y} = \sum_m material\_intensity_{r,y,m} * materials\_prices_{r,y,m}$$

$$energy\_costs_{r,y} = \sum_f energy\_intensity_{r,y,f} * energy\_prices_{r,y,\mathrm{f}}$$

$$CO2\_costs_{r,y} = (process_{emissions_{r,y}} + \sum_f energy\_intensity_{r,y,f} * emission_{intensity_{r,y,f}}) * CO2\_prices_{r,y}$$

For material prices, Bloomberg data are used for historical values (BNEF, 2024a), whereas price signals are projected forward using different methods for bulk materials and critical minerals:

For bulk materials, demand and LCOP projections from the GEC Model ($bulk\_materials\_demand_y, bulk\_materials\_LCOP_y$) are used to generate price signal projections ($bulk\_materials\_prices_y$) specific to each scenario, based on the multi-linear regression between historical prices, demand and LCOP.

$$bulk\_materials\_prices_y = \beta 0 + bulk\_materials\_demand_y * \beta 1 + bulk\_materials\_LCOP_y * \beta 2$$

For critical minerals, historical prices and changes in annual demand are compared to get the elasticity ($elasticity$). This ratio is then applied to critical mineral demand projection ($critical\_minerals\_demand_y$) from the GEC Model to generate price signal projections ($critical\_mineral\_price_y$).

$$critical\_mineral\_price_{y+1} = \left(\left(\frac{1}{elasticity} * \frac{critical\_minerals\_demand_{y+1} - critical\_minerals\_demand_y}{critical\_minerals\_demand_y}\right) + 1\right) * critical\_mineral\_price_y$$

The costs of upstream components that are used as inputs in multi-step supply chains are estimated by considering their respective LCOP increased by a profit margin and based on the composition of their origins, where for imported ones the eventual trade and transport costs are also added.

Overall production costs are expressed as in the equation below:

$$Production\_costs_y = \sum_r ((annualised\_CAPEX_{r,y} + fixed\_OPEX_{r,y}) * var\_capacity_{r,y} + variable\_OPEX_{r,y} * var\_production_{r,y})$$

Transport costs

These refer to the cost of transporting a given commodity between modelled countries and regions and include freight and insurance costs. The shipping costs ($shipping\_costs_{exp,imp,y}$) are linked to the shipping model embedded in the IEA's GEC Model (IEA, 2024b), which projects energy demand by fuel for international and domestic shipping operations by vessel type and scenario. Costs coming from other means of transport are considered to be growing or decreasing proportionally to shipping. Insurance costs are expressed as a percentage ($insurance_y$) of the value of the exported product ($export\_price_{exp,imp,y}$), that varies across clean technologies and materials. Overall transport costs are expressed as in the equation below:

$$Transport\_costs_y = \sum_{exp} \sum_{imp} ((shipping\_costs_{exp,imp,y} + export\_price_{exp,imp,y} * insurance_y) * var\_trade_{exp,imp,y})$$

Trade costs

The trade costs are all the costs incurred when bringing a product from a country to another country. These costs include, among others, direct duties, such as export taxes, import tariffs or the impact of carbon border adjustment mechanisms (CBAM), and some indirect costs, such as NTMs, whose quantification is based on AVEs (see previous section).

To calculate the domestic price of a product in the country where it is manufactured ($domestic\_production\_price_{r,y}$) an assumed profit margin ($profit\_margin_y$) is added to its production cost ($LCOP_{r,y}$):

$$domestic\_production\_price_{r,y} = LCOP_{r,y} * (1 + profit\_margin_y)$$

The export cost of a product ($export\_cost_{exp,imp,y}$) considers the costs incurred by potential ad valorem ($exptax\_advalorem_{exp,imp,y}$) and specific taxes ($exptax\_specific_{exp,imp,y}$):

$$export\_cost_{exp,imp,y} = domestic\_production\_price_{exp,y} * exptax\_advalorem_{exp,imp,y} + exptax\_specific_{exp,imp,y}$$

$$export\_price_{exp,imp,y} = domestic\_production\_price_{exp,y} + export\_cost_{exp,imp,y}$$

The import cost of a product ($import\_cost_{exp,imp,y}$) considers the costs incurred by ad valorem ($tariffs\_advalorem_{exp,imp,y}$) and specific tariffs ($tariffs\_specific_{exp,imp,y}$), as well as the estimated impact on costs of NTMs using AVEs ($ntm\_ave_{exp,imp,y}$).

$$import\_cost_{exp,imp,y} = [export\_price_{exp,imp,y} * (1 + insurance_y) + shipping\_cost_{exp,imp,y}] * (tariffs\_advalorem_{exp,imp,y} + ntm\_ave_{exp,imp,y}) + tariffs\_specific_{exp,imp,y}$$

Overall trade costs are expressed as in the equation below:

$$Trade\_costs_y = \sum_{exp}\sum_{imp}[(import\_cost_{exp,imp,y} + export\_cost_{exp,imp,y} + CBAM\_cost_{exp,imp,y}) * var\_trade_{exp,imp,y}]$$

Other inputs

Existing manufacturing capacity

Information on existing manufacturing capacity for clean energy technologies and materials related to 2023 is based on various data sources (see Data sources) and is aggregated by model region. If no information on the remaining lifetime of existing manufacturing plants was available, it was assumed that the existing capacity linearly declines to zero over a period that is equal to their lifetime. Capacity represents the amount a facility is nominally able to produce, i.e. not taking into account utilisation rates, and is measured in the physical units.

Announced manufacturing capacity

Announced manufacturing capacity by companies for the production of clean energy technologies or materials 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 on desk research. Like existing manufacturing capacity, announced capacity represents the amount a facility would nominally be able to produce in 1 year and is measured in physical units. Announcements on increased manufacturing capacity are categorised by committed (i.e. those under construction or that have reached final investment decision) and preliminary announcements (i.e. those that have not reached final investment decision). Unless otherwise stated, the announced projects dataset assembled for *ETP-2024* comprises announcements dated up to end of June 2024.

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 and any near-zero emissions capable facilities for materials. Preliminary announced capacity is considered in the Announced Pledges Scenario (APS), on top of committed announced capacity (see Constraints section).

To derive forward-looking benchmark quantities of output from existing and announced projects such that a comparison can be made with deployment levels in IEA scenarios (see Chapter 2), utilisation rates of 85% are applied as an assumption.

Results

The IEA's MaT Model determines based on global least-cost optimisation the manufacturing locations and trade patterns within a set of constraints for each year in the modelling horizon 2023-2050, for different scenarios, and produces the following results:

Manufacturing results

- **Production** of each technology component or material per region and production technology for each annual period. This is calculated in the physical units for each product, as well as monetary values based on relevant price projections.
- **Manufacturing capacity** per region and production technology for each year of the model horizon.
- **Investments in manufacturing** which are derived from the capacity expansions per period and the CAPEX for each facility.
- **Energy consumption** and **CO_2 emissions** related to the manufacturing of clean energy technologies and components.[4]

[4] The respective results for materials come from the GEC Model.

Inter-regional trade results

- **Bilateral trade flows** between pairs of modelling regions.[5] These are calculated in physical units for each product, as well as monetary values based on relevant price projections.

Levelised cost of production

The LCOP values resulting from the respective modules concern the total costs coming from CAPEX, fixed OPEX and variable OPEX. The LCOP annualises and sums up all costs incurred throughout the economic lifetime of the manufacturing facility, using an assumed high but feasible utilisation rate (UR) of 85% for clean energy technology manufacturing. Early retirements of manufacturing capacity and related savings in fixed OPEX are not considered in the model. The LCOP costs ($LCOP_{r,y}$) include the annualised CAPEX ($annualised\_CAPEX_{r,y}$), the fixed OPEX ($fixed\_OPEX_{r,y}$) and the variable OPEX ($variable\_OPEX_{r,y}$) according to the following formula applied per individual product for each region *r* and year *y*:

$$LCOP_{r,y} = \frac{annualised\_CAPEX_{r,y} + fixed\_OPEX_{r,y}}{UR} + variable\_OPEX_{r,y}$$

Other results

- Other outputs which are calculated in the context of the manufacturing and trade modelling include market sizes, which are derived from the demand for a product and its global price.
- LCOP without financial support, which excludes any kind of financial support from the calculations.
- Imported product prices for each importing region depending on the exporting region, which reflect the per-unit costs of production of the exporting region with an additional profit margin, together with the transport costs and trade costs associated with each pair of exporters-importers.

Constraints

A set of constraints are incorporated into IEA's MaT Model to reflect technical and practical considerations. They can be divided into three categories:

Balance constraints: these ensure that fundamental balancing rules are respected, such as supply-demand balances that ensure that domestic production

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

plus imports and minus exports meets domestic demand. A capacity balance constraint requires that installed capacity in year *y* equals the installed capacity in the previous year *y-1* plus new capacity additions and minus capacity retirements from plants reaching the end of their technical lifetime. Production-capacity balance constraints are also included, ensuring that production cannot exceed the available installed manufacturing capacity, taking into account typical maximum utilisation rates for manufacturing facilities. An example of a demand-supply balance constraint is shown below, valid for each region *r,* and each year *y*, where *imp* and *exp* belong to the full set of regions:

$$var\_production_{r,y} \geq demand_{r,y} + \sum_{imp} var\_trade_{r,imp,y} - \sum_{exp} var\_trade_{exp,r,y}$$

Policy constraints: these allow representation of government policies and regulations such as local content requirements and import quotas, among others. An example of local content requirements is shown below, for each region *r*, and each year *y*, where *imp* belongs to the full set of regions and local requirements ($local\_requirement_{r,y}$) is an exogenous input parameter, describing the share of domestic demand that needs to be covered by domestic production:

$$var\_production_{r,y} - \sum_{imp} var\_trade_{r,imp,y} \geq demand_{r,y} * local\_requirement_{r,y}$$

Calibration constraints: these constraints limit the rate at which production can be ramped up or down and the rate at which bilateral trade flows can change from year to year. This category also includes constraints that take account of a detailed assessment of current enabling conditions for manufacturing investments in emerging markets and that ensure that project announcements for future clean energy technology manufacturing and for near-zero emissions production of materials are reflected in installed manufacturing capacity, as relevant. For example, up to 2030 inclusive, the announced manufacturing capacity ($announced\_projects_{r,y}$) for future clean energy technology manufacturing in each region *r*, and year *y*, which are exogenous inputs as observations based on research, can serve as lower and upper bounds within a relaxed corridor by applying lower ($lower\_bound_{r,y}$) and upper ($upper\_bound_{r,y}$) factors of a few percentage points (e.g. 1-2%) for manufacturing capacity additions ($var\_newcapacity_{r,y}$) which are the change in capacity ($var\_capacity_{r,y}$) between year y and y-1 by considering also the retired capacity on that year ($retirements_{r,y}$):

$$var\_newcapacity_{r,y} \leq announced\_projects_{r,y} * (1 + upper\_bound_{r,y})$$

$$announced\_projects_{r,y} * (1 - lower\_bound_{r,y}) \leq var\_newcapacity_{r,y}$$

$$var\_newcapacity_{r,y} = var\_capacity_{r,y} - var\_capacity_{r,y-1} + retirements_{r,y}$$

For any regions r and years y where the upper (or lower) bound contradicts with the application of policies and/or strategic ambitions depending on the scenario (e.g. 40% of domestic EU production in the Net-Zero Industry Act) or the total global demand coverage, the bound limits have been relaxed, giving priority to policies and the scenario narrative.

Additional technical details

Batteries

Battery manufacturing capacity refers to 2023 and announced lithium-ion battery (cell) manufacturing capacity to 2030. The analysis includes all Tiers (I, II, III), where Tier I is defined as a manufacturer qualified to supply multinational EV producers in China and outside of China, Tier II are not yet qualified to serve EV producers outside of China, and Tier III are producers that are not yet qualified to supply EV markets, but that might be able to serve smaller markets like electric two- and three-wheelers and stationary storage, or be certified to serve the more valuable EV market in the future.

Differences in battery chemistry are not considered explicitly in the modelling and analysis, but different chemistry choices (as the predominant use of lithium iron phosphate [LFP] rather than lithium nickel manganese cobalt oxides [NMC] batteries or vice versa) are considered exogenously during the model calibration based on IEA analysis. The 2023 and projected world capacity-weighted battery chemistry is used to calculate the battery cell and cathode LCOP (e.g. about 40% LFP and 60% nickel-based (NMC and lithium nickel cobalt aluminium oxide [NCA]) chemistries in 2023) (IEA, 2024d).

For the conversion from tonnes to GWh of cathode and anode active materials, a material energy density of around 670 Wh/kg (NMC and NCA cathode active material), 465 Wh/kg (LFP cathode active material) and 1 500 Wh/kg (graphite-silicon blended anode active material) is assumed. A negative (anode) to positive (cathode) electrode ratio of 1.05 is assumed for the final cells, which implies 5% more anode capacity than cathode capacity per cell.

Battery and battery components trade flows in the base year are estimated by combining manufacturing capacity (see Data sources section), data on production of the final product (e.g. of EVs using data from EV Volumes), and the battery cell supplier.

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

Electric cars: plug-in hybrid electric vehicles

PHEV car trade is estimated using 2023 trade patterns and BEV MaT Model results. It is assumed that PHEV trade is likely to mirror BEV trade, as the factors that influence the cost-effectiveness of BEV and PHEV manufacturing are generally similar. After 2040, PHEV import shares are assumed to match those of BEVs. As with other vehicle types, PHEV demand is taken from GEC Model demand projections, and this is used in conjunction with the share of imports in regional demand to determine final PHEV trade flows.

Solar PV

Due to the significant amount of stockpiling of modules in 2023 (base year), the amount of PV modules ending up in inventories has been taken into account when modelling historical trade for PV modules. This is reflected in the production volumes and global trade volumes for that year. In the long run, it has been assumed that the 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 have been considered for PV cells, wafers and polysilicon.

For PV modules, the base year trade comes from IEA analysis. This takes into account production that has ended up in inventories of the importing countries, as well as inventory increases in the producing country (generally China). The sources for this analysis are InfoLink (2024), BNEF (2024a), SPV Market Research (2024) and UN Comtrade (2024). The same sources have been considered for the trade of PV cells, whereas the analysis of trade of wafers and polysilicon was based primarily on InfoLink (2024) and BNEF (2024a).

The LCOP calculations for PV modules and PV cells assume mono passivated emitter rear cells (PERC) c-Si cells. For any upstream components incorporated in the calculation of modules, cells and wafers, the origin-dependent prices have been considered based on the shares of domestic production and imports by trade partners. 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 start-to-end domestic production of all the components, as it may be more cost competitive to import certain components.

Wind

Trade flows for wind components were modelled without differentiating between onshore and offshore. This is because facilities dedicated to manufacturing wind components can generally serve both sectors. However, regional transport costs, production costs and capital costs for factories (used in investment calculations) were calculated separately for offshore and onshore. To determine the final costs, the global split between offshore and onshore derived from GEC Model results was used (which show a growing share of offshore over time).

Global trade for wind components can be difficult to track, as the components often fall under different sets of HS codes. Furthermore, the many means of transporting them, and the fact that downstream components are frequently shipped in between facilities makes it difficult to acquire official data on this. To estimate the trade situation for 2023 a combination of resources was used. At the basic level, two databases were combined: the manufacturing database (see the Data sources section), and the installation of turbines per original equipment manufacturer (OEM) database. For each OEM, trade was modelled 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 were based on weighted averages of where production and installation take place. However, when more sources were available, as in the case of the United States, which tracks imports of nacelles, blades and towers (Harmonised Tariff Schedule [HTS] codes: 85023100, 8412909081 and 7308200020, respectively), or published articles on shipments of components to wind farms, these initial assumptions were slightly altered. In case of blades, manufacturing capacities were also adjusted, as some OEMs use other companies' blades.

Electrolysers

The trade flows in the base year are estimated by combining capacity and location of installed and planned electrolyser projects from the IEA Hydrogen Production Projects database (IEA, 2024f), 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 trade values of HS codes 841581 (Air conditioning machines; containing a motor driven fan, other than window or wall types, incorporating a refrigerating unit and a valve for reversal of the cooling/heat cycle (reversible heat pumps)) and 841861 (Heat pumps; other than air conditioning machines of heading no. 8415). Trade for these two 6-digit HS codes are estimated using data from Oxford Economics (2024b) available for the parent 4-digit codes and then disaggregating them to 6-digit level codes based on the CEPII/BACI (CEPII, 2024) trade flows for 2022 values within each 4-digit code. 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.

Trade shipping routes modelling

Trade shipping routes modelling was developed to inform shipping activity assessment, shipping energy demand modelling in the GEC Model, the chokepoint analysis (see section 5.2) and to calculate the cost of shipping clean energy technologies, materials and fuels. Shipping costs were also used in the alternative fuel refuelling infrastructure analysis (see section 5.3). Historical trade between countries was estimated using a range of data sources (see “International trade” in the Data sources section). The share of total trade being allocated to maritime shipping was determined using a dataset underlying work by Vershuur et al. (2022) which includes estimates of maritime trade shares between individual countries for specific product groups.

Bilateral seaborne traded quantities were then allocated to individual ports using import and export shares for each port provided by Ports Watch (IMF, 2024). Trade between individual ports was assumed to be proportional to their respective share of a country’s imports and exports.

To model the **distance and specific route between two ports**, given the co-ordinates, the python package “searoute” was used (Halili, 2024), which generates the shortest sea route between two points. It offers the possibility of blocking certain maritime chokepoints; this feature was used to close the Northwest Passage and Sunda Strait on the assumption that they represent only a minor share of trade.

For the **shipping routes** displayed on the world map (see section 5.1) Automatic Identification System (AIS) data have been used (UN Global Platform, 2024), as they reflect a more realistic picture: the load factor was estimated for each ship and each point in time from the reported draught, and then multiplied by the ship deadweight tonnage to estimate the mass of cargo transported. This dataset could not be used for the chokepoint analysis because it does not give precise information on the type of goods transported.

For the **maritime chokepoints analysis**, the coordinates of the route generated between two ports were intersected with a buffer around each chokepoint, and the sum of the trade routes intercepting the defined buffer zone determined the amount of maritime traffic passing through said chokepoint. The results were calibrated against external sources tracking traffic through chokepoints (EIA, 2024).

For the **alternative fuel refuelling infrastructure analysis**, the distance between the supplier ports and the receivers was obtained with the "searoute" package and then multiplied by the transport cost per unit of energy and distance as per Table 5.6.

Shipping activity

Shipping activity was calculated by multiplying the seaborne traded quantities for each port-to-port combination by the distances involved. Base year (2023) estimates were then reconciled with UNCTAD's shipping work estimate (2023). Trade by commodity was allocated to ship types based on the classification from the International Maritime Organization's Fourth GHG study (2020).

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

1. Products explicitly modelled within the IEA's GEC and MaT Model: For these products, trade results are differentiated by scenario. Trade was modelled at a regional level and then re-allocated to individual countries based on a combination of historic indicators and macroeconomic indicators from the GEC-Model.

2. Other products: For products that do not fall within our modelling scope, we relied on trade projections from Oxford Economics' Trade Prism (2024b).

The modal share of maritime trade between individual countries, as well as the share of each port in their country's imports and exports, was assumed to remain unchanged over time and scenarios. Projected bilateral traded quantities by scenario were 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 in this report, which are supplemented by desk research and personal communications with manufacturers, project developers and other technology experts. IEA scenario and modelling data from IEA's Global Energy and Climate Model (IEA, 2024a) are used in conjunction with the data below for the MaT Model.

Table A.2 Description of the main data sources used in this report

Technology	Data on manufacturing and trade	Data sources	Description
Solar PV	• Existing capacity • Announced capacity • Energy and material intensity • Capital costs • Historic output • Historic component prices • Historical trade	InfoLink (InfoLink, 2024), BNEF (BNEF, 2024a), IEA PVPS (IEA PVPS, 2024), SPV Market Research (SPV Market Research, 2024), RTS Corporation (RTS Corporation, 2024), NREL (NREL, 2023), (UN Comtrade, 2024)	InfoLink data is the primary source for capacity and output data, supplemented by BNEF and SPV Market Research for cross-checking and details for certain regions. Trade data come from a compilation of sources including the list of sources above used for output and UN Comtrade. PV components' prices timeseries come from BNEF, whereas NREL and IEA PVPS studies have been used for the intensities of LCOP. CAPEX data come from IEA desk research on investments, in conjunction with the capacity data above.
Wind	• Existing capacity • Announced capacity • Energy and material intensity • Capital costs • Wind components prices • Historical output • Historical trade	S&P Global Commodity Insights (S&P Global, 2024a), BNEF (BNEF, 2024a), GWEC (GWEC, 2023), WindEurope (WindEurope, 2023), Wood Mackenzie (WoodMackenzie, 2024) and NREL (NREL, 2019)	S&P Global Commodity Insights is the primary data source for capacity and output data, which are supplemented with data from WindEurope, BNEF, GWEC and Wood Mackenzie. The Wind Supply Chain series from Wood Mackenzie and NREL studies were used to inform the assessment of levelised costs. Blades and nacelles trade estimates for 2023 are done based on manufacturing capacities per country and OEM from S&P and deployment per country and OEM, assuming that each OEM will deploy first locally and then ship components to other sites; in this context demand for components is calculated as the average between the current and next year. CAPEX data are based on analysis drawing from S&P Global Commodity Insights data.
Batteries	• Existing capacity • Announced capacity • Battery sizes • Active material conversion factors • Energy and material intensity • Capital costs • Battery components prices • Historical output • Historical trade	Benchmark Mineral Intelligence (BMI, 2024), EV Volumes (EV Volumes, 2024), BNEF (BNEF, 2024b), (Dai et al., 2019), (Argonne, 2024), (Frith, Lacey, & Ulissi, 2023)	Benchmark Mineral Intelligence (BMI) is the primary data source for current and projected battery cell manufacturing capacity and for classifying announcements as committed or preliminary. EV Volumes is used for historical average EV battery sizes (kWh). BNEF is used as a supplementary source for battery cell manufacturing status (committed or preliminary) and as the primary source for cathodes and anodes active material manufacturing capacity and plants' status

Technology	Data on manufacturing and trade	Data sources	Description
			(committed or preliminary). CAPEX data come from IEA desk research on investments in conjunction with the capacity data above. GREET and Dai et al. are used, together with IEA analysis, for battery and components material and energy intensities. Frith et al. is used for the conversion factors between battery cells and battery pack and other technical specifications like the anode to cathode ratio.
Electric cars	• Electric car sales • Car manufacturing capacity • Energy and material intensity • Capital costs • Electric car prices • Historical output • Historical trade	EV Volumes (EV Volumes, 2024), Marklines (Marklines, 2024), Atlas EV Hub (Atlas EV hub, 2024), ICCT, S&P Global Mobility (S&P Global Mobility, 2024), BNEF (BNEF, 2024d), Transport & Environment (BNEF, T&E, 2021), UBS (UBS, 2017)	EV Volumes is the primary source used for historical sales and trade of electric cars (including electric commercial vehicles and buses). Marklines' OEM plant dataset is used to inform the car regional manufacturing capacity estimates. Atlas EV hubs is used to inform the historical EV manufacturing investment analysis. Historical purchase price values of electric car are taken from S&P Global Mobility. BNEF, ICCT, T&E and UBS all published studies that helped inform the LCOP estimates for electric cars in China, Europe and the United States.
Electrolysers	• Existing capacities • Announced capacity • Energy and material intensity • Capital costs • Electrolyser prices • Historical output • Historical trade	Primary research, IEA Hydrogen Projects database (IEA, 2024f)	Manufacturing capacity data are based on announcements by manufacturers and personal communications gathered by the IEA. Historic trade data are derived from the IEA Hydrogen Projects database. CAPEX data are coming from desk research and communication with manufacturers.
Heat pumps	• Existing capacity • Announced capacity • Energy and material intensity • Capital costs • Heat pump prices • Historical output • Historical trade	CEPII (CEPII, 2024), Oxford Economics Trade Prism (Oxford Economics, 2024b), JETRO (JETRO, 2024)	Manufacturing capacities are derived by combining heat pump sales in different regions and trade flows based on Oxford Economics and CEPII. Manufacturing capacity additions and expansion plans are based on public announcements by manufacturers, whereas CAPEX data are based on analysis of JETRO data.
Other	• Material prices • Energy prices • Labour prices • Energy and material intensity • WACC	Bloomberg (Bloomberg, 2024), IEA World Energy Prices (IEA, 2024c), ILOSTAT (ILO, 2024), JETRO (JETRO,	Bloomberg is the primary source for information on material prices; IEA data are used for end-user prices for energy and ILOSTAT data are used to calculate labour costs. Academic literature is consulted to derive

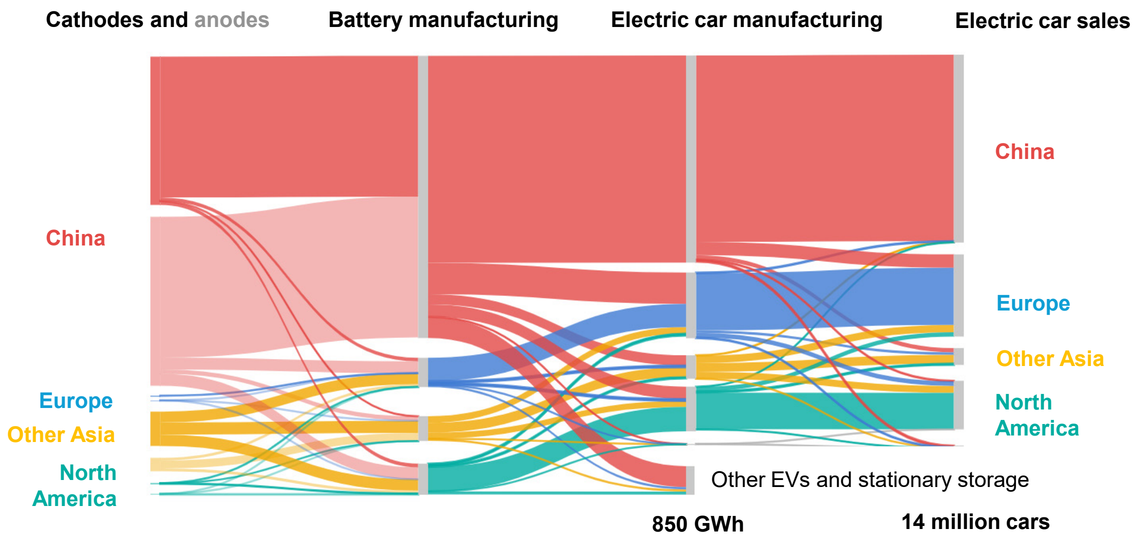
Technology	Data on manufacturing and trade	Data sources	Description
		2024), (Damodaran, 2024)	material, labour and energy intensities and to benchmark results for levelised cost. The weighted average cost of capital is based on data from Damodaran.
Materials (capacity data)	• Existing capacity • Announced capacity	(IFA, 2024a), (CRU, 2024), (GEM, 2024), (OECD, 2024b), (IEA, 2024f)	For conventional production capacity, steel numbers are sourced from OECD; iron from CRU; alumina and ammonia from CRU; ammonia from the IFA. For near-zero emissions capacity, the IEA Hydrogen Production and Infrastructure Projects Database is used for ammonia while data for other materials rely on announcements by manufacturers, gathered by the IEA.
International trade	• Historical trade in physical and monetary values	(Oxford Economics, 2024b), (CEPII, 2024), (EV Volumes, 2024), (InfoLink, 2024), (IEA, 2024j), (IEA, 2024h)	Oxford Economics and CEPII data are used to estimate the trade for most commodities. Exceptions being: EVs relying on EV Volumes; Solar PV on InfoLink; Fossil fuels on IEA data.
Trade routes	• Port capacity • Maritime trade • Historical shipping routes • Shipping activity	(Lloyd's List, 2023b) (Verschuur et al., 2022) Ports Watch (IMF, 2024), (UNCTAD, 2022)	Lloyd's List is used for the size of the ports for containers; Verschuur is used for the tankers and dry bulk port capacities, maritime share of trade; Ports Watch to select relevant ports for the chokepoint analysis; and for their share in their country's imports/exports; Global Hydrogen Review 2024 for hydrogen, ammonia and methanol projects and assumptions; UNCTAD shipping activity data for calibration in the base year.

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.

Current and future trade flows by clean energy technology

Electric cars and batteries

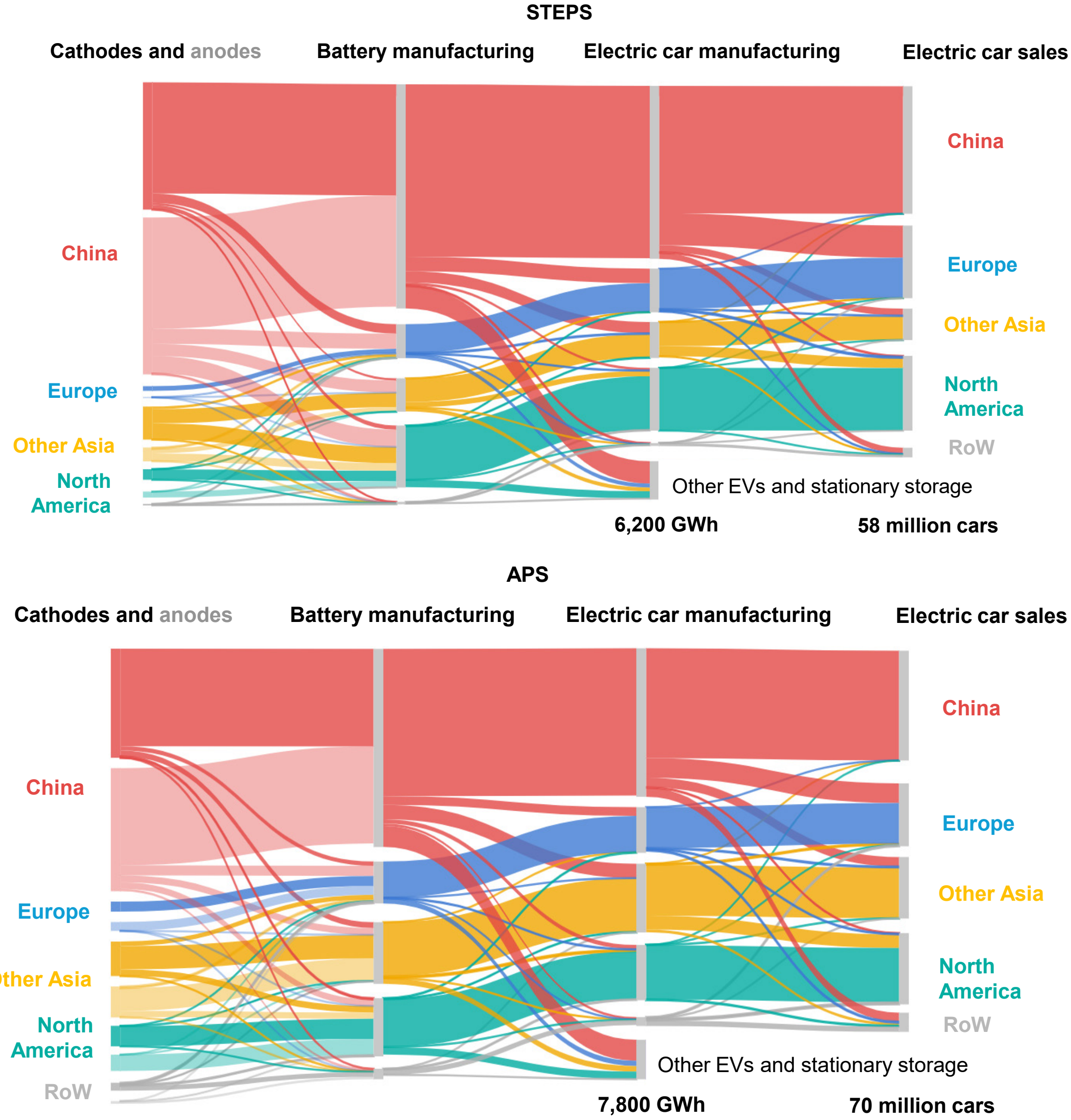
Figure A.5 Global manufacturing and trade flows of electric cars and lithium-ion batteries, 2023



Notes: Flows are normalised to the battery (cell) manufacturing step, with cathodes and anodes normalised such their sum is scaled to the battery cell volume. Numbers below the charts refer to the total demand, not only the traded volume. The lighter-colour version of the flows going to battery manufacturing represents the anodes.

Sources: IEA analysis based on EV Volumes and Benchmark Mineral Intelligence for the 2023 trade flows.

Figure A.6 Global manufacturing and trade flows of electric cars and lithium-ion batteries in the Stated Policies Scenario and Announced Pledges Scenario, 2035



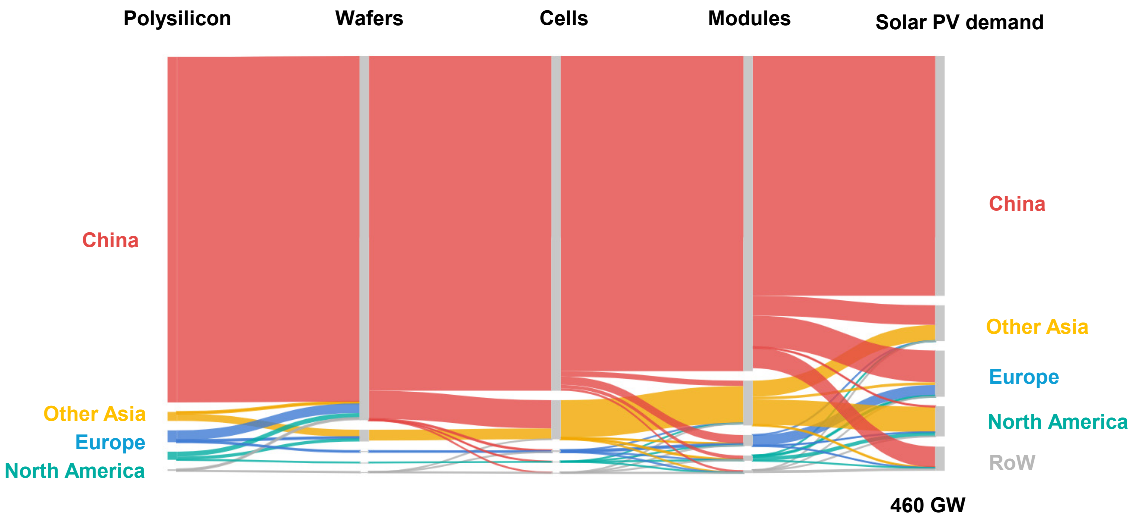
Notes: RoW = Rest of World, STEPS = Stated Policies Scenario, APS = Announced Pledges Scenario. Flows are normalised to the battery (cell) manufacturing step, with cathodes and anodes normalised such their sum is scaled to the battery cell volume. Numbers below the charts refer to the total demand, not only the traded volume.

The lighter-colour version of the flows going to battery manufacturing represents the anodes.

Sources: IEA analysis based on EV Volumes and Benchmark Mineral Intelligence for the 2023 trade flows.

Solar PV

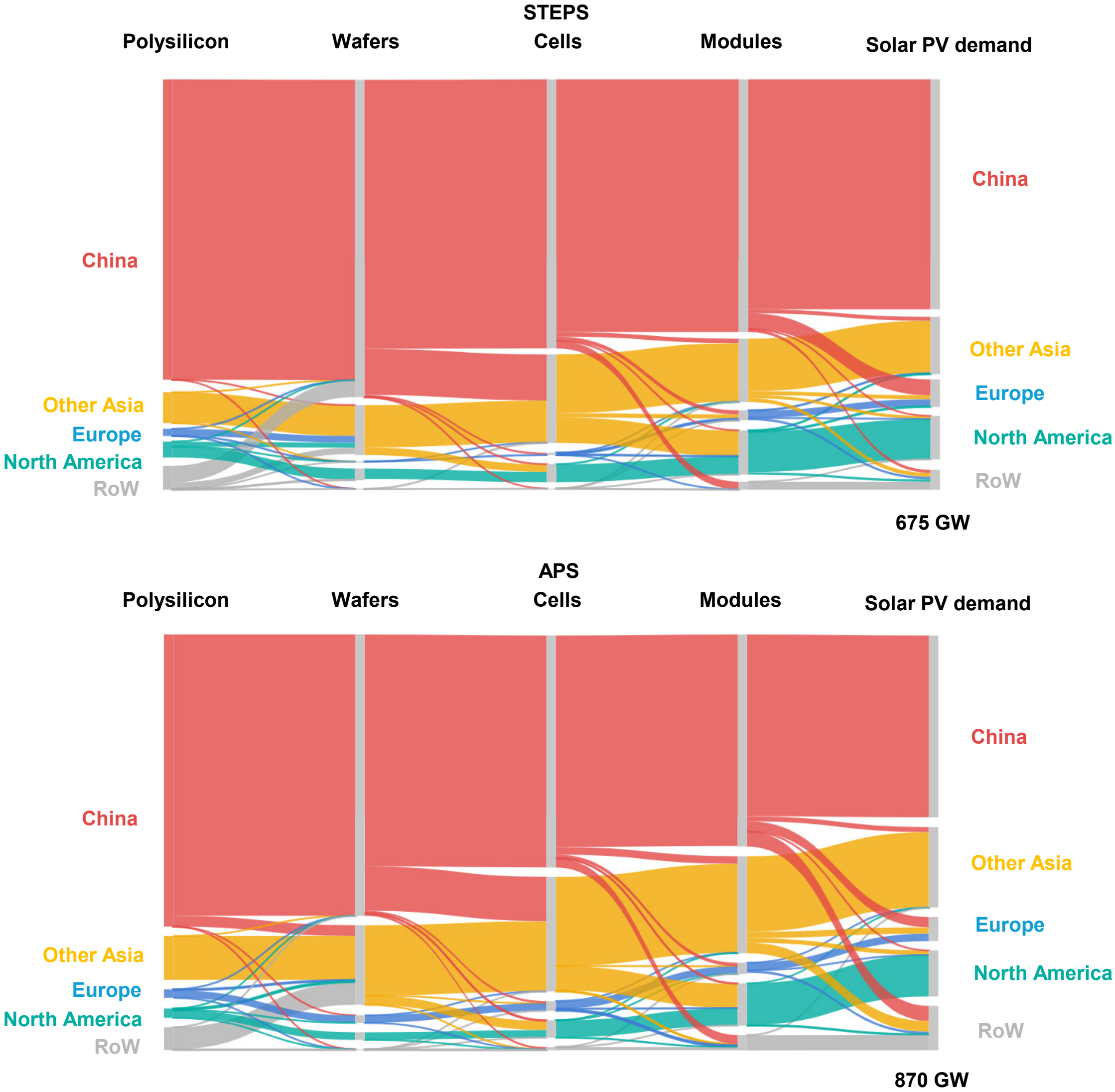
Figure A.7 Global manufacturing and trade flows of solar PV modules and components, 2023



Notes: RoW = Rest of World. Flows are normalised for each sequential component and include quantities going to inventories for the demand step in 2023. Numbers below the charts refer to the total demand, not only the traded volume. The demand number excludes the quantities going to inventories.

Sources: IEA analysis based on InfoLink (2024); BNEF (2024a); SPV Market Research (2024); and UN Comtrade (2024) for the 2023 trade flows.

Figure A.8 Global manufacturing and trade flows of solar PV modules and components, Stated Policies Scenario and Announced Pledges Scenario, 2035

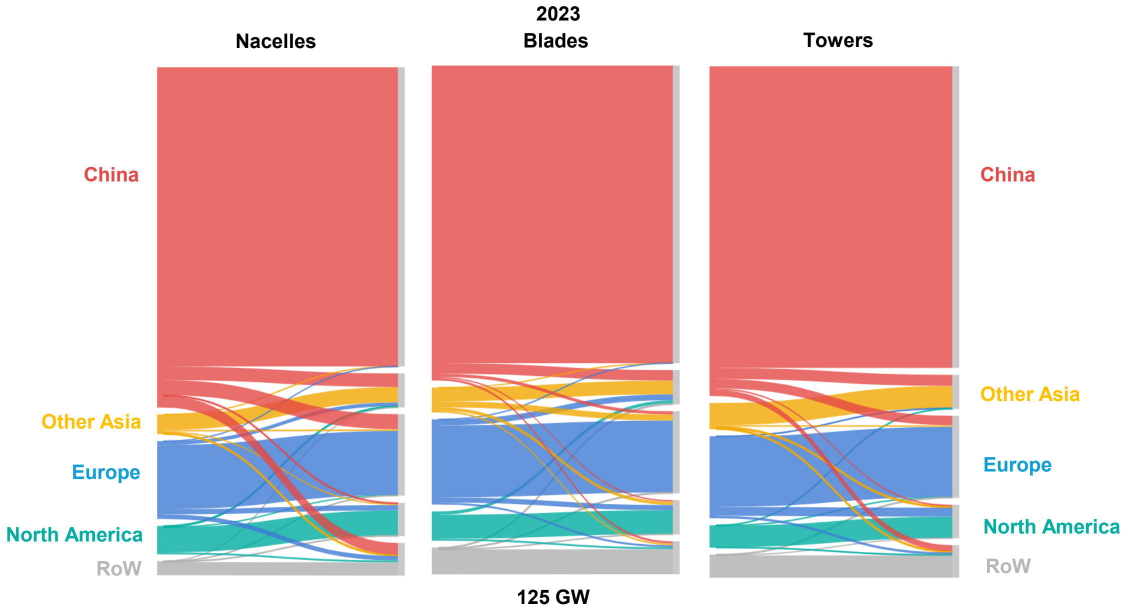


Notes: RoW = Rest of World, STEPS = Stated Policies Scenario, APS = Announced Pledges Scenario. Flows are normalised for each sequential component. Numbers below the charts refer to the total demand, not only the traded volume.

Sources: IEA analysis based on InfoLink (2024); BNEF (2024a); SPV Market Research (2024); and UN Comtrade (2024) for the 2023 trade flows.

Wind

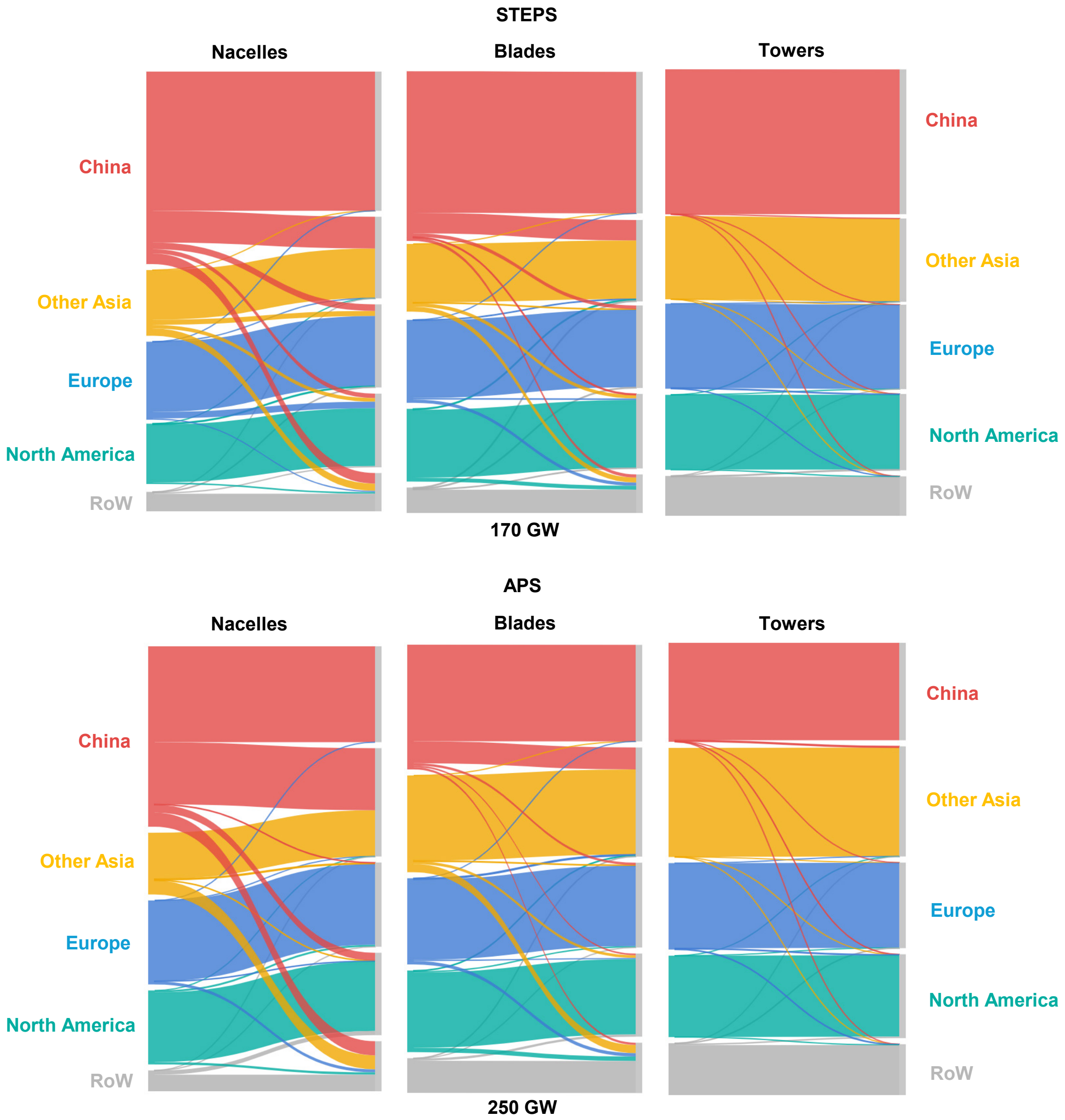
Figure A.9 Global manufacturing and trade flows of nacelles, blades and towers, 2023



Notes: RoW = Rest of World. Flows are normalised for each component. Numbers below the charts refer to the total demand, not only the traded volume.

Sources: IEA analysis based on GWEC (2023); BNEF (2024c); S&P Global (2024a); Rystad Energy (2023); and USITC (2024) for the 2023 trade flows.

Figure A.10 Global manufacturing and trade flows of nacelles, blades and towers in the Stated Policies Scenario and Announced Pledges Scenario, 2035

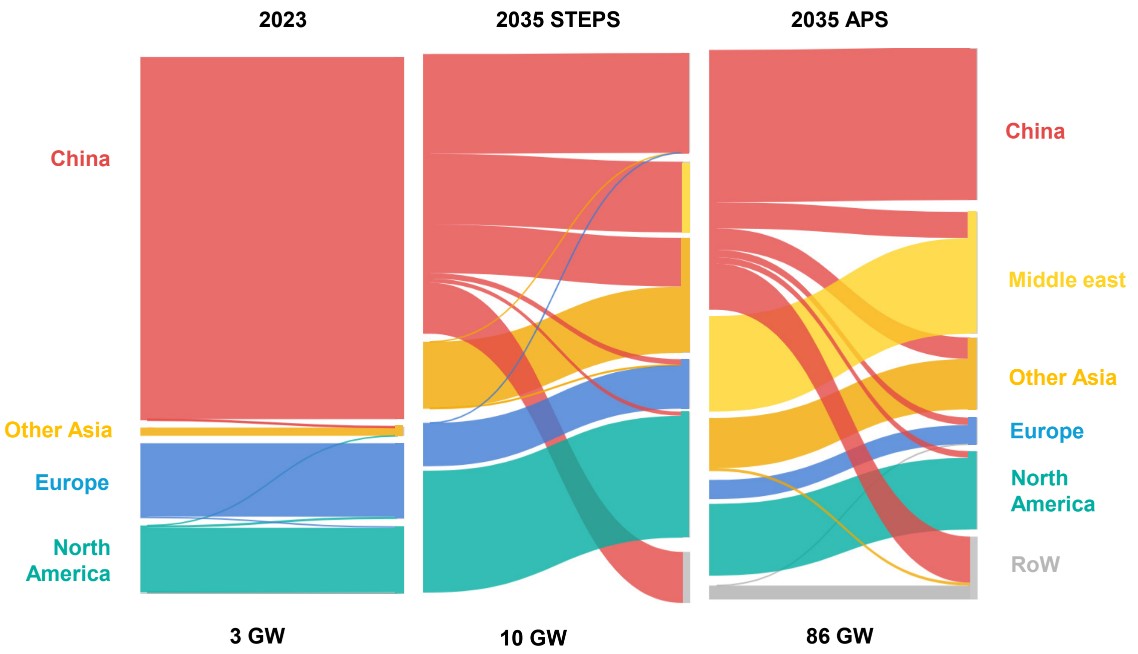


Notes: RoW = Rest of World; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. Flows are normalised for each component. Numbers below the charts refer to the total demand, not only the traded volume.

Sources: IEA analysis based on GWEC (2023); BNEF (2024c); S&P Global (2024a); Rystad Energy (2023); and USITC (2024) for the 2023 trade flows.

Electrolysers

Figure A.11 Global manufacturing and trade flows of electrolysers, 2023, and in the Stated Policies Scenario and Announced Pledges Scenario, 2035

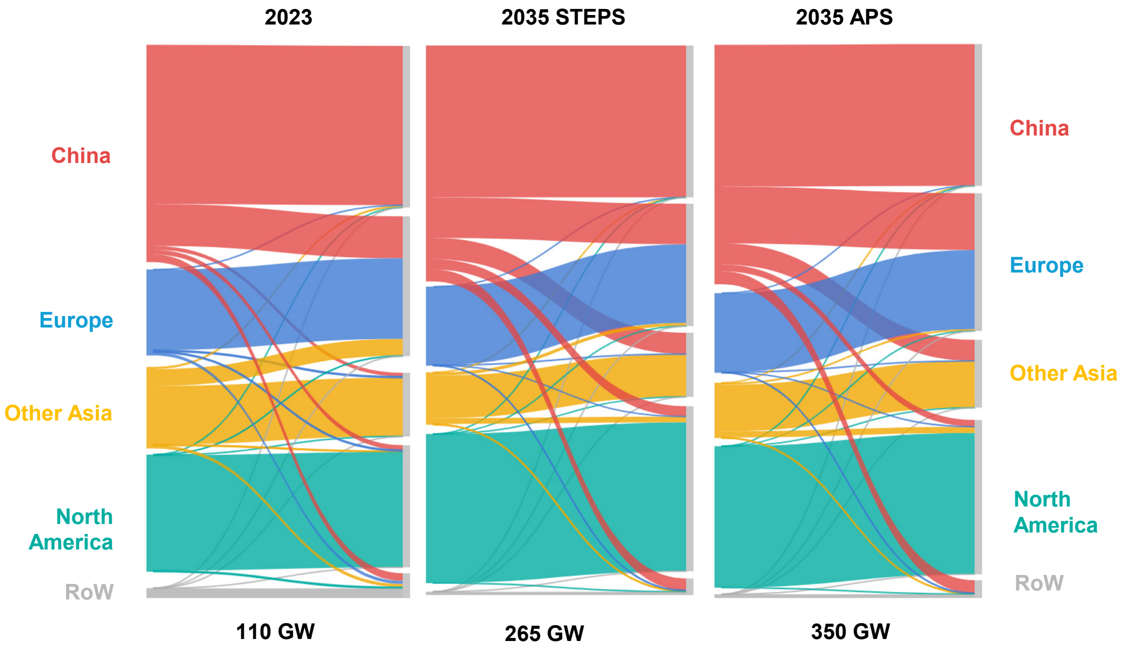


Notes: RoW = Rest of World; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. Numbers below the charts refer to the total demand, not only the traded volume.

Sources: IEA analysis based on (IEA, 2024f), announcements by manufacturers and personal communications.

Heat pumps

Figure A.12 Global manufacturing and trade flows of heat pumps, 2023, and in the Stated Policies Scenario and Announced Pledges Scenario, 2035



Notes: RoW = Rest of World; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. Numbers below the charts refer to the total demand, not only the traded volume.

Sources: IEA analysis based on Oxford Economics for the 2023 trade flows.

Annex B – Manufacturing analysis

Industrial survey methodology

To support the analysis in *ETP-2024*, a survey was conducted with manufacturers and project developers to better understand the drivers for investments in clean energy manufacturing projects. The survey involved stakeholders from clean energy technology and near-zero emissions materials supply chains. 51 respondents who are actively involved in investment decisions for manufacturing facilities around the world (engineers, managers, and business or strategy professionals) participated. Responses were obtained anonymously from each of the following manufacturing supply chains: electric cars and batteries, solar PV, wind turbines, heat pumps and electrolysers, iron and steel, aluminium and ammonia.

Table A.3 Industrial survey questions

Please select from the following list the supply chain segment(s) in which your **main business activities** are situated:	
Where is your business **headquartered**?	
Where does your business conduct its **main activities** identified in Question 1?	
How important are the following **upfront cost** considerations when evaluating an investment decision? Would these same considerations be of **greater or lesser importance** if the investment was **in a developing country**?	• Government policy incentives and charges (e.g. investment tax credits) • Costs associated with trade and trade policy (e.g. capital controls) • Initial hiring and relocation costs • Cost of debt capital • Cost of equity capital • Infrastructure costs • Construction costs • Equipment costs • Hedging currency risk • Insurance costs
How important are the following **operational cost** considerations when evaluating an investment decision? Would these same considerations be of **greater or lesser importance** if the investment was **in a developing country**?	• Government policy incentives and charges (e.g. production tax credits) • Costs associated with trade and trade policy (e.g. tariffs on inputs or outputs) • Wage costs • Energy costs • Other input costs • Other fixed costs • Transport costs • Hedging currency risk • Insurance costs • Security costs
How important are the following **employment** considerations when evaluating an investment decision?	• Attractiveness of location for relocation of existing workers • Income taxes and employer contributions

Would these same considerations be of **greater or lesser importance** if the investment was **in a developing country?**	• Availability of high-skilled workers, such as engineers and managers (e.g. ISCO-08 Skill levels 3 and 4) • Availability of medium-skilled workers, such as clerical workers and plant operators (e.g. ISCO-08 Skill level 2) • Availability of low-skilled workers, such as labourers and delivery drivers (e.g. ISCO-08 Skill level 1) • Stringency of professional certification schemes and training regulations • Occupational health and safety standards and limits on working hours • High labour standards around non-discrimination and equal opportunity • High labour standards around termination, severance and dismissal, freedom of association and collective bargaining rights • Stringent enforcement of standards to prevent child labour, forced labour and human trafficking
How important are the following **infrastructure and supply chain** considerations when evaluating an investment decision? Would these same considerations be of **greater or lesser importance** if the investment was **in a developing country**?	• Local port infrastructure available and in good condition • Local road and rail infrastructure available and in good condition • Easy access to airports with frequent commercial flights • Efficient permitting procedures for new construction and infrastructure projects • High reliability of the energy supply • Access to low-cost renewable electricity and/or low-emissions fuels (i.e. biofuels, hydrogen and hydrogen-based fuels) • Good access to specific suppliers of key inputs locally • Good access to specific customers for key outputs locally • Few/no other competitors in the same industry • Large, or potentially large, domestic market
How would you rank the attractiveness of the following **government policies** when considering an investment decision?	• Investment incentives (e.g. investment tax credits) • Production incentives (e.g. production tax credits) • Project grants (e.g. non-reimbursable government funding matched by private investment) • Debt financing (e.g. government loans with preferential interest rates) • Green procurement policy (e.g. premium in government contracts for sourcing items produced with lower CO_2 emissions) • Off-take contract guaranteed by the government for a fixed period • High regulatory charges (e.g. CO_2 pricing) • Debt guarantees (e.g. government guarantees on project borrowing) • Project equity financing (e.g. government financing in return for project equity stake)
How would you rank the importance of the following considerations relating to **trade and trade policy** when considering an investment decision in an export-oriented location?	• Low/no border tariffs and quotas • Formalised bilateral partnership arrangements for a specific commodity or sector (e.g. a free trade agreement) • Low/no local content requirements • Short physical distance between partners, facility to facility • Short physical distance between partners, port to port • Depth and breadth of economic integration between jurisdictions

	• Low/no technical border charges (e.g. carbon border adjustments) • Low non-energy transport costs between jurisdictions (e.g. port and canal fees, insurance) • Availability of low-emissions shipping between jurisdictions • Presence of 'chokepoints' (e.g. Suez Canal) to traverse between jurisdictions
Please feel free to share any other perspectives, in particular with regards to any recent changes in the considerations covered in this survey that you think will delay or accelerate investments.	

Enabling indicators for manufacturing investments

A range of enabling factors – categorised here as the business environment, access to energy and transport infrastructure, and access to resources and domestic markets – will contribute to determining which location the investor chooses for manufacturing projects (see Chapter 4). Some factors that affect cost – the primary driver of the economic and financial viability of a clean energy investment – are determined by geographical location, notably mineral and renewable energy resources, and proximity to overseas markets and suppliers. The others are strongly influenced by policy.

The table below lists all the indicators which have been gathered for assessing the suitability of emerging markets and developing economies for developing manufacturing capacities. There are some sector-specific enabling conditions which cover key clean energy technologies – electric cars, batteries, solar PV and wind turbines – and their components, as well as key materials and chemicals – steel and ammonia (both for industrial and fuel-related applications) – and their precursors (iron).

The data collected for each indicator were normalised across countries to a value range of [0-1]. Advanced economies, including the United States, Japan and Germany, were used to provide the benchmark indicator values. The normalised values of all indicators for an overarching enabling factor were averaged to obtain one value [0-1] per enabling factor and country. Specific weights were applied for each supply chain, omitting indicators not relevant to a particular supply chain. Each enabling factor was then given an importance grade that is also unique for each supply chain, with values ranging from 1 (least important) to 5 (most important). The gradings were based on information gathered in industry surveys and on expert judgement. For all enabling factors within a supply chain, the averaged normalised enabling factor value was multiplied by the corresponding importance grade. Finally, the total opportunity value for each country was calculated for each technology or material by summing the weighted values of all enabling factors together.

Table A.4 List of the enabling indicators used in Chapter 4 for assessing the manufacturing potential of Emerging Markets and Developing Economies

Category	Enabling factor	Indicator	Description	Source
Business environment	Ease of doing business	Ease of doing business	The simple average of the scores for each of the Doing Business topics: starting a business, dealing with construction permits, getting electricity, registering property, getting credit, protecting minority investors, paying taxes, trading across borders, enforcing contracts and resolving insolvency	(World Bank, 2021)
		Political stability	Measures perception of the likelihood of political instability and/or politically motivated violence, including terrorism	(World Bank, 2023b)
		Corruption perception indicator	Measures perception of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests	(World Bank, 2024b)
	Industrial competitiveness	Competitive Industrial Performance index (CIP)	Benchmark of the ability of countries to produce and export manufactured goods competitively	(UNIDO, 2024)
		Economic Complexity Index (ECI)	Ranking of countries based on the diversity and complexity of their export basket	(Center for International Development at Harvard University, 2023)
		Total trade volume	Total trade flow considering imports and exports [kt]	(CEPII, 2024)
		Labour cost	Average hourly wage across all sectors	(ILO, 2024)
	Financing cost	Weighted average cost of capital (WACC)	Weighted Average Cost of Capital for more mature technologies [%]	(IEA, 2024a)
Energy and Infrastructure	Energy infrastructure	Electricity access	Share of population with access to electricity	IEA analysis
		Electricity demand per capita	-	(IEA, 2024h)
		Natural gas demand per capita	-	(IEA, 2024h)
	Reliability of electricity supply	System Average Interruption	Average total duration of outages (in hours) experienced by a customer in a year	(World Bank, 2024a)

Category	Enabling factor	Indicator	Description	Source
		Duration Index (SAIDI)		
		System Average Interruption Frequency Index (SAIFI)	Average number (count) of service interruptions experienced by a customer in a year	(World Bank, 2024a)
	Access to low-emissions energy	Renewable energy potential	Sum of solar and wind energy potential	(IEA, 2024a)
		Low-emissions energy supply	Share of low-emissions energy (excluding primary solid bioenergy)[6] in total primary energy supply	IEA analysis
		Regulatory Indicator for Sustainable Energy (RISE)	Regulatory Indicator for Sustainable Energy: assesses countries' policy and regulatory support for renewable energy	(World Bank, 2024a)
	Energy prices	Electricity prices	Price [USD/kWh] for consumers with demand > 1000 kWh/month	(IEA, 2024c) (Global Petrol Prices, 2023)
		Natural gas prices	Index considering end-use natural gas prices in 2021 for the industry (residential where data is missing) sector by country (or region where data is missing)	(IEA, 2024g)
	Transport infrastructure	Spare port container capacity	Port container spare capacity [TEU]	(MDS Transmodal Ltd., 2024)
		Port capacity - dry bulk	Capacity of a country's dry bulk ports [kt]	(Verschuur at al., 2022)
		Port capacity - ammonia	Capacity of a country's operational ammonia infrastructure [kt]	(IEA, 2024f)
		Logistics performance index	Reflects perceptions of a country's logistics based on the efficiency of customs clearance process, quality of trade- and transport-related infrastructure, ease of arranging competitively priced shipments, and quality of logistics services.	(World Bank, 2023a)
Resources and domestic markets	Raw and other material inputs	Iron ore production	-	(World Bureau of Metal Statistics, 2022)
		Lithium production	-	(IEA, 2024e)

[6] Includes biofuels, biogases, renewable municipal waste, nuclear, hydro, wind, solar PV, solar thermal, geothermal, tide, wave and ocean.

Category	Enabling factor	Indicator	Description	Source
		Nickel production	-	(World Bureau of Metal Statistics, 2022)
		Phosphate production	-	(USGS, 2024b)
		Aluminium production	-	(IEA, 2024a)
		Copper production	-	(World Bureau of Metal Statistics, 2022)
		Crude steel production	-	(World Steel Association, 2024)
		Scrap steel availability	-	(IEA, 2024a)
		Iron ore reserves	-	(USGS, 2023a) (USGS, 2023b) (USGS, 2023c) (S&P Global, 2024b)
		Lithium reserves	-	(USGS, 2024a) (S&P Global, 2024b)
		Nickel reserves	-	(S&P Global, 2024b)
		Phosphate reserves	-	(USGS, 2024b)
		Solar resource potential	Energy potential from solar resources. Calculated electricity output for a 100 m^2 area with 1 MW installed considering country-specific resource availability [MWh/year]	(Global Solar Atlas, 2024)
		Wind resource potential	Energy potential from wind resources	(Shell, 2017)
		Water stress	Base level water stress	(WRI, 2024)
	Domestic demand	Solar PV deployment	Installed capacity	(IEA, 2024i)
		Wind deployment	Installed capacity	(IEA, 2024a)
		Crude steel consumption	Apparent consumption (production + imports - exports)	(World Steel Association, 2024)

Category	Enabling factor	Indicator	Description	Source
		N-fertilisers consumption	-	(IFA, 2024b)
		Electric car sales	Annual sales of new BEV and PHEV	(EV Volumes, 2024)
		EV production	Cumulated production of BEV and PHEV over 2010-2024	(EV Volumes, 2024)
	Market size of related industries	EV battery manufacturing capacity	Annual battery manufacturing capacity [GWh]	(BMI, 2024)
		Cathode and anode manufacturing capacity	Cathode and anode manufacturing capacity (GWh)	(BNEF, 2023)
		Ammonia production	-	(IFA, 2024a)
		Iron and steel market	Share of iron & steel value added in relation to a country's gross value added [%]	(Oxford Economics, 2024a)
		ICE manufacturing capacity	Share of ICE manufacturing value added in relation to a country's gross value added [%]	(Oxford Economics, 2024a)
		Basic chemicals market	Share of basic chemical value added in relation to a country's gross value added [%]	(Oxford Economics, 2024a)
		Manufacturing industry	Share of manufacturing value added in relation to a country's gross value added [%]	(Oxford Economics, 2024a)
		Electric fittings and batteries market	Share of electric fittings & batteries value added in relation to a country's gross value added [%]	(Oxford Economics, 2024a)
		Aviation industry	Share of turbines, engines, fluidics, pumps & gears and aerospace sectors value added in relation to a country's gross value added [%]	(Oxford Economics, 2024a)
		Mineral extraction market	Share of mineral extraction value added in relation to a country's gross value added [%]	(Oxford Economics, 2024a)
Resources and domestic markets	Workforce skills	Innovation	Intellectual property - resident applications of patents, trademarks, and industrial designs per million inhabitants	(WIPO, 2024)
		Employment in chemicals industry	Share of total working population employed in manufacture of chemicals and chemical products [%]	(ILO, 2024)
		Employment in electrical equipment industry	Share of total working population employed in manufacture of electrical equipment [%]	(ILO, 2024)
		Employment in manufacturing	Share of total working population employed in manufacture of	(ILO, 2024)

Category	Enabling factor	Indicator	Description	Source
		fabricated metal products	fabricated metal products, except machinery and equipment [%]	
		Employment in vehicle manufacturing	Share of total working population employed in manufacture of motor vehicles, trailers, and semi-trailers [%]	(ILO, 2024)
		Employment in mining metal ores	Share of total working population employed in mining of metal ores [%]	(ILO, 2024)
		STEM education	Number of STEM students per 1000 inhabitants (2018-2023 average)	IEA analysis based on (UNESCO, 2024)
		Vocational education	Proportion of 15-24 year-olds enrolled in vocational education	(UNESCO, 2024)
		Public spending on education	Public spending on education per capita [USD/cap]	(UNESCO, 2024)
		Public spending on R&D	Share of GDP spent on R&D [%]	(UNESCO, 2024)

Notes: EV = electric vehicle; BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle; ICE = internal combustion engine; STEM = science, technology, engineering and mathematics.

Annex C – Shipping decarbonisation

Technologies for shipping decarbonisation

Table A.5 Deployment status of selected technologies to decarbonise shipping

Technology	Description	TRL 2020	TRL 2024	Importance for net zero	Deployment status
Operational energy efficiency					
Slow steaming	Slow steaming consists of voluntarily reducing the sailing speed of ships to save fuel. In order to keep the carrying capacity constant, the number of ships in the fleet would need to be increased in proportion, but because the energy consumption is a function of speed with an exponent higher than one, the net effect is to reduce fleet consumption.	9	9-10	High	Slow steaming started around 2008, the period when the market started to experience an oversupply of shipping capacity, declining freight rates, and increasing bunker prices. Nowadays, ships routinely sail at a much lower speed than their maximum (e.g. 16 vs 24 knots for containerships (IMO, 2020)), but there is potential for further reduction.
Dynamic route optimisation	Waves, wind, and currents have an influence on the ship's energy consumption, which can be reduced through algorithms that use artificial intelligence, relying on weather forecasts and data from satellites or buoy networks.	9	9	Moderate	The first systems were commercialised in 2014, and with the latest developments, overall energy savings of up to 3-5% can be expected. Major bulk carrier operators announced in 2023 that this solution will be rolled-out to their fleets (Dry bulk, 2023).
Trim and draught optimisation	Draught measures how deep the ship is submerged into the water and trim the difference between bow and stern draught. Depending on the trim, the wetted surface area of the hull will be different, which affects energy consumption.	9	9	Moderate	Actively planning cargo loading, and thereby optimising the trim and draught, can save fuel: typically 0.5-3% and up to 5% for container and Ro-Ro ships that tend to navigate in partial load conditions. Such systems have been on the market for 10 years and equip

Technology	Description	TRL 2020	TRL 2024	Importance for net zero	Deployment status
					1 000 ships today (DNV, n.d.).
Technological energy efficiency					
Kite sails	Large towing kites are attached to the ship with long cables to access strong winds 100 metres above the ship. Kite sails have the advantage of being fully retractable and take up limited deck space.	8	8-9	Moderate	A first full-scale prototype was installed in 2021. In 2024 a major shipping company announced plans to start commercial operation, ultimately with potential for deployment on 50 bulk carriers (The Maritime Executive, 2024). Energy savings are expected to be in the order of 3%.
Rotor sails	Rotor sails are vertically oriented spinning cylinders that attach to the vessel's deck to make a virtual sail.	8-9	8-9	High	Rotor sails can typically generate energy savings of around 10% and are suited to large ocean-going vessels, especially bulk carriers They are available commercially for new builds, as well as for retrofitting: currently over 15 ships are operating, with potential to equip 50 ships by 2025 (Norsepower, n.d.) (Anemoi, n.d.) (Lloyd's Register, 2023a)
Waste heat recovery	Waste heat recovery systems recover the thermal energy from the exhaust gas and convert it into electrical energy, while the residual heat can further be used for ship services (such as hot water and steam).	9	9-10	Moderate	Power/Steam Turbine Generator is a commercially available and mature technology that can generate energy savings of typically 5%. Organic Rankine Cycle has a higher saving potential but is less mature
Anti-fouling hull coating	Hull coatings are spread on the immersed body of the ship to reduce the hydrodynamic drag caused by corrosion, algae and shells.	10	10	Moderate	Anti-fouling coatings are available from several paint companies and common across vessel types and trades, but there is still room for significantly increased penetration (penetration rate estimated at 12.5% of ships in 2018 (IMO, 2020)). Typical energy savings can be in the order of 4-5%.
Hull form optimisation	Hull form optimisation is a highly effective tool for	8-9	9	Moderate	Hull form optimisation (through computational

Technology	Description	TRL 2020	TRL 2024	Importance for net zero	Deployment status
	reducing hull total resistance for a given speed on new vessels, if implemented early in the design process.				fluid dynamics) is available as a service from multiple international companies. Expected energy efficiency improvements is 3-8%, with ships operating at above 10 knots being the preferred target.
Air lubrication	Air lubrication uses compressed air released over the bottom of a vessel hull to reduce the friction incurred by the passing water.	8-9	9	Moderate	Up to 2018, 23 vessels were identified to have air lubrication system installed on board (ABS, 2019). Currently, this technology is readily available commercially and applicable to ships with large flat-bottom hulls, typically LNG carriers and some containerships. As of August 2024, it is deployed to more than 200 ships in service. The typical energy savings are 3 – 9%
Fuel switching					
Ammonia combustion engine powered ships	Ammonia is one of the most promising synthetic fuels, as it is carbon-free and easier to store than hydrogen. However, it is very toxic and thus necessitates specific design and operation measures, as well as refrigerated storage tanks more than 3 times larger than for diesel for the same energy capacity. Exhaust after-treatment is necessary to eliminate emissions of N_2O, which is a potent GHG, NOx and NH_3. Ammonia is hard to ignite, and the current engine designs make use of fossil or biodiesel as pilot fuel.	8-9	9	Very High	Wärtsilä's 4-stroke ammonia engine, suitable for smaller merchant vessels, has been commercially available since Dec. 2023 (Ammonia Energy Association, 2023). The main engine makers are announcing the commercialisation in the next 2 years of large 2-stroke ammonia engines suitable for ocean-going vessels (Reuters, 2024) (NYK, 2024) (WinGD, 2023). As of Aug. 2024, more than 20 ammonia ships are on order books, including 10 very large bulk carriers, 9 liquefied gas tankers, 2 Aframax oil tankers and 1 containership, with deliveries starting in 2026.
Methanol combustion engine powered ship	Methanol is easier to handle than ammonia, but still highly flammable and toxic. It necessitates double walled piping and storage	4-5	4-5	High	Methanol has been used as fuel by chemical tankers since the mid-2010s. In 2024, methanol ships represented close to 10%

4-5

Technology	Description	TRL 2020	TRL 2024	Importance for net zero	Deployment status
	tanks 2.5 larger than for diesel with the same energy capacity. Methanol is easier to ignite than ammonia, but current designs still typically use fossil or biodiesel as pilot fuel.				of ships on order in terms of gross tonnage (DNV, Maritime forecast to 2050, 2024a). As of Aug 2024, around 300 methanol ships are operating or on order, including around 170 containerships, 50 chemical tankers, more than 10 bulk carriers, and almost 10 oil tankers.
Hydrogen combustion engine powered ship	One of the difficulties in using hydrogen as a fuel on a ship is the need for cryogenic storage tanks 7.2 times larger than for diesel with the same energy capacity. Liquid hydrogen needs to be expanded to gas before combustion.	7	8	Moderate	Small scale demonstration vessels (tug and crew transfer vessel) have been operation since 2022 (Baird Maritime, 2022). As far as larger ocean-going vessels are concerned, in 2023 a Japanese engine maker, shipyard and ship operator announced their intention to start testing a 17 500 DWT ship powered by a hydrogen 2 stroke engine from 2027 (J-Eng, 2023).
Hydrogen fuel cell powered ship	Hydrogen fuel cells can have a higher energy efficiency than for a hydrogen combustion engine but a higher cost (in particular OPEX, as the fuel cell internals have a much lower lifetime than a combustion engine) and a lower energy storage density.	8-9	9	Moderate	The technological maturity depends on the type of membrane for the fuel cells: TRL8 for proton exchange membrane, TRL7 for solid oxide or molten carbonate. Almost 20 hydrogen fuel cell ships are currently operating or on order books, mostly smaller passenger and service vessels, as well as two 730 TEU containerships planned for delivery in 2025 and 2026.
Battery electric ship	In battery electric ships, the power for propulsion and auxiliaries comes from batteries, which are charged while at berth from the onshore electricity grid.	3-4	3-4	Moderate	Currently there are almost a thousand electric ships in operation and almost 500 on order. About two thirds of those are hybrids, the remaining one third being split between plug-in hybrids and pure electric (DNV, 2024c). Given the limitations of the energy density of batteries, most applications are on short-

Technology	Description	TRL 2020	TRL 2024	Importance for net zero	Deployment status
					distance routes (typically less than 50 nm) where they can charge frequently: ferries, offshore service ships, short range merchant ships. The recent development of a 700 TEU electric containership for fluvial navigation in China gives a perspective for a much longer range (Elective, 2024).
Nuclear propulsion	Pressurised water reactors (PWRs) have been used on military ships and civilian icebreakers for decades. The long refuelling cycle (several years) and high power density are appealing, but the high initial investment cost, high operation costs, safety and non-proliferation concerns have hindered the development of nuclear ships.	9	9	Low	Russia has currently 7 nuclear icebreakers in operation. In the future, marine applications could take advantage of modern SMRs. An initiative funded by the US DOE that started in 2021 considers that onshore demonstration could happen in 2025 and aiming at a demonstration in the maritime environment in 2028-2030 (DOE, 2021). In 2023, China announced that its design for a thorium reactor 24 000 TEU containership obtained AiP (The Maritime Executive, 2023).
Cold ironing	So-called “cold ironing” or Alternate Maritime Power (AMP) consists of plugging in the vessel to the grid instead of running the auxiliary engine(s) of the ship when at berth to operate ventilation, heating and cooling systems.	9	9	High	Relevant regulations are being introduced, especially in the European Union through AFIR (EU, 2023), to require that ships use shore electric power when at berth. Currently more than 30 ports in the world have at least 1 berth with onshore power for cruise ships, mainly in Northern Europe, China and North America (CLIA, 2024).
Carbon capture and storage					
Onboard Carbon Capture (OCC)	CO_2 captured after combustion is liquefied and stored onboard before being later off-loaded on shore and then ultimately stored permanently. OCC has a			Low	The different components of the onboard system (CO_2 capture, liquefaction, on board storage, discharging) are currently at TRL 7 to 8. Partial

3

Technology	Description	TRL 2020	TRL 2024	Importance for net zero	Deployment status
	significant impact on the ship's energy consumption (up to +40%), which has the side effect of increasing the consumption of fossil energy. This technology is often presented as a solution to alleviate the pressure on alternative fuel production ramp-up.				testing at scale has taken place in the past 2 years (MOL, 2024) (Offshore Energy, 2024a). A full system test at an unknown scale on a 14 000 TEU containership was also reported in 2024 (Offshore Energy, 2024b). A remaining challenge is to develop in parallel a network of CO_2 collection points at port, as well as for transportation to final storage locations.

Notes: TRL = technology readiness level. The TRL provides a snapshot in time of the level of maturity of a given technology. It provides a common framework that can be applied consistently to any technology to assess and compare the maturity of technologies across sectors. The technology journey begins from the point at which its basic principles are defined (TRL 1). As the concept and area of application develop, the technology moves into TRL 2, reaching TRL 3 when an experiment has been carried out that proves the concept. The technology then enters the phase where the concept itself needs to be validated, starting from a prototype developed in a laboratory environment (TRL 4), through to testing in the conditions it which it will be deployed (TRL 5-6). The technology next moves to the demonstration phase, where it is tested in real-world environments (TRL 7), eventually reaching a first-of-a-kind commercial demonstration (TRL 8) on its way towards full commercial operation in the relevant environment (TRL 9). Beyond this stage, technologies need to be further developed to be integrated within existing systems or otherwise evolve to be able to reach scale: TRL10 denotes that the solution is commercial and competitive, but needs further integration efforts, and TRL11 denotes that it has reached predicable growth. SMR = Small Modular Reactor, AiP = Approval in Principle by a classification agency. This table does not aim to be exhaustive. For a more comprehensive list and description please refer to the IEA's Clean Technology Guide.

Sources: IEA Clean Energy Technology Guide (2024); US Department of Transportation (2022); GloMEEP (2019).ship order books from UN Global Platform (2024).

Ports for alternative fuels exports

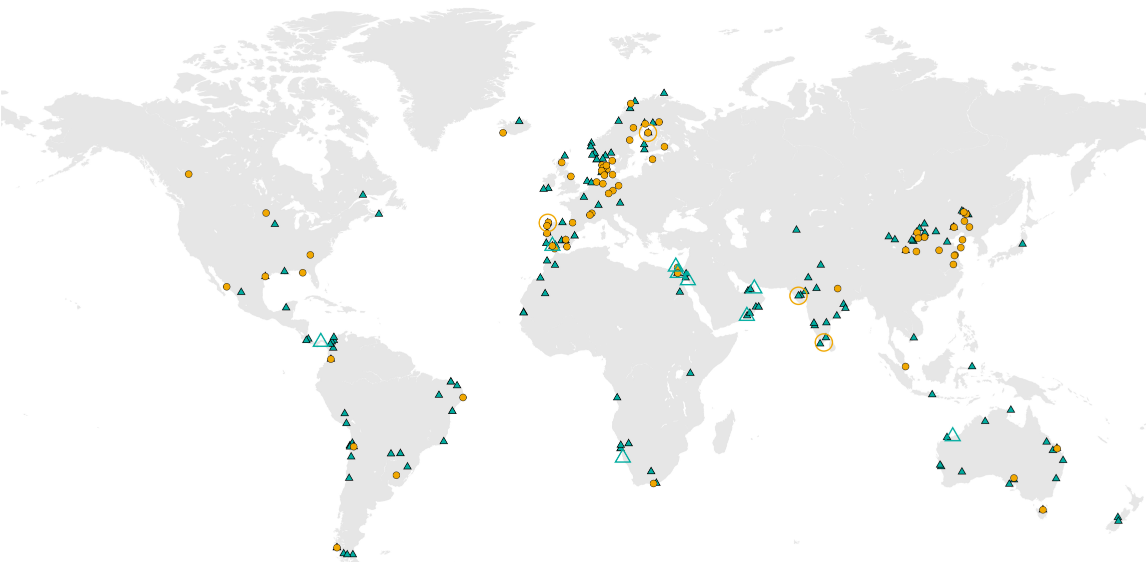
When considering options for ports that might have a role in bunkering low-emissions ammonia and methanol, a set of ports was selected (Table A.5) to limit the scope of the analyses. The selected ports have made explicit their intention to produce these fuels or are in the proximity of announced projects to produce these fuels (Figure A.13) (IEA, 2024f), but not all of them have made specific plans to develop the necessary refuelling infrastructure. The ports listed are those mentioned in Figures 5.37 and 5.38 of the report.

Table A.6 Selected ports for the analysis of alternative refuelling infrastructure

Fuel	Country	Port
Ammonia	Oman	Port of Salalah
Ammonia	Saudi Arabia	Port of NEOM
Ammonia	Australia	Port Hedland
Ammonia	Spain	Port of Huelva
Ammonia	Egypt	Port of Ain Sokhna

Fuel	Country	Port
Ammonia	Namibia	Port of Lüderitz
Ammonia	United Arab Emirates	Port of Fujairah
Ammonia	Panama	Port of Balboa
Ammonia	Egypt	Port of Damietta
Methanol	India	V.O. Chidambaranar Port at Thoothukudi (formerly Tuticorin)
Methanol	India	Port of Kandla
Methanol	Spain	Port of A Coruña
Methanol	Finland	Port of Kokkola

Figure A.13 Selected ports for the analysis of alternative refuelling infrastructure and methanol or ammonia announced projects



Source: IEA (2024f).

Annex D – Definitions

Glossary

Ad valorem tariff: A tariff rate levied as a fixed percentage of the value of the imported product at customs. This value includes the product's price, in this report modelled as the levelised cost of production plus a profit margin, along with freight and insurance costs.

Announced capacities: Refers to the aggregate stated capacity – or estimated nominal maximum output – of potential manufacturing facilities (projects) that have been announced. This includes projects for building new facilities or expanding existing ones that are at different stages of development. "Committed" projects include those that have already reached a final investment decision (FID), or are under construction, whereas "preliminary" projects include those that have not yet reached an FID, meaning feasibility studies or earlier steps are underway. Wherever data is available, we distinguish committed projects from preliminary announcements across the key technologies in focus, which allows for more robust projections of future manufacturing capacity.

Announced Pledges Scenario (APS): This scenario assumes that governments will meet, in full and on time, all of the climate-related commitments that they have announced, including longer-term net zero emission targets and pledges in Nationally Determined Contributions, as well as commitments in related areas such as energy access. It does so irrespective of whether or not those commitments are underpinned by specific policies to secure their implementation. Pledges made in international fora and initiatives on the part of businesses and other non-governmental organisations are also taken into account wherever they add to the ambition of governments. In addition, the scenario takes on board all the manufacturing projects that have been announced, including preliminary plans.

Battery: Batteries considered in the *ETP-2024* report include advanced electrochemical energy storage technologies based on lithium-ion (Li-ion) or post Li-ion batteries used in road transport or stationary storage applications. If not stated otherwise, battery always refers to battery cells.

Breakbulk shipping: refers to the transportation of goods that are too large or cumbersome to be placed in containers, or that are transported individually rather than in bulk. Breakbulk cargo typically includes items like machinery, vehicles, steel and construction materials. These items are loaded, stacked and transported piece by piece using cranes and other handling equipment, often requiring specialised handling and stowage.

Bunkering: The process of supplying fuels to a ship.

CAPEX: Capital expenses (or expenditures).

Chartering: The process of hiring or leasing a ship to transport goods from one port to another. This is a common practice in the maritime industry, in which shipowners lease out their vessels to companies (known as charterers) that need to transport cargo.

Clean energy technology: Those energy technologies that result in minimal or zero emissions of CO_2 and pollutants. For the purposes of this report, clean energy technologies refer to the following: Batteries, Electric cars, Solar PV, Wind, Electrolysers and Heat pumps.

Container shipping: Container shipping is the transport of goods using large, standardised containers that can be easily transferred between different modes of transportation (ships, trains, trucks) without unloading the cargo itself. These containers come in standard sizes (e.g. 20-foot and 40-foot containers) and are used to ship a wide variety of goods, from consumer products to machinery. Container ships are used to transport containers.

Critical materials: A wide range of minerals and metals that are essential in clean energy technologies and other modern technologies and have supply chains that are vulnerable to disruption. Although the exact definition and criteria differ among countries, critical minerals for clean energy technologies typically include chromium, cobalt, copper, graphite, lithium, manganese, molybdenum, nickel, platinum group metals, zinc, rare earth elements and other commodities, as listed in the Annex of the IEA special report on the Role of Critical Minerals in Clean Energy Transitions (2021).

Deadweight tonnage (DWT): A measure used in shipping to indicate the maximum weight a ship can safely carry, including cargo, fuel, fresh water, ballast water, provisions, crew and passengers. It represents the carrying capacity of the vessel, excluding the ship's own weight (the hull, engines, etc.).

Delayed Deployment Case: This case is a variation of the NZE Scenario that assumes a 5-year delay in the deployment of key clean energy technologies (solar PV, wind, EV batteries, electrolysers, heat pumps) across the global energy system starting in 2024. It illustrates the additional emissions that would result if it were not possible to scale up manufacturing of these technologies in line with NZE Scenario demand.

Dry bulk shipping: refers to the transportation of unpackaged, loose commodities in large quantities that are solid and dry. These goods are typically stored directly in the hold of a ship without the use of containers or packaging. Common examples of dry bulk cargo include coal, grain, iron ore, cement and salt. The ships used for this purpose are called bulk carriers or dry bulk carriers.

Electric cars: Refer to EVs that belong to the passenger light-duty vehicles category such as cars and pick-up trucks.

Electric vehicles (EVs): Vehicles that use electricity as a source of propulsion. Electric vehicles comprise battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs).

Electrolysers: A device that uses direct electrical current to drive an otherwise non-spontaneous chemical reaction. Commonly used in the production of chemicals such as chlorine. Water electrolysers split water into hydrogen and oxygen, for the production of hydrogen, and are increasingly being applied to energy challenges such as the conversion of CO_2 to useful products and the reduction of iron ore. In the context of the *ETP-2024* report, if not otherwise specified, electrolysers refer to water electrolysers for the production of hydrogen, including all major technologies such as alkaline, proton exchange membrane, solid oxide electrolysis and others. Manufacturing capacity refers to the assembly capacity, and upstream components capacity is not considered.

Export tax: A tax imposed on commodities being exported out of the country.

Freight rate: The price charged by a carrier (shipowner or charterer) or freight forwarder to transport goods from one place to another. This price is determined by the cost of transporting goods, as well as market conditions.

Heat pumps: A device that consumes energy, usually electricity, to transfer heat from a source to a sink using a refrigeration cycle (compression, condensation, expansion and evaporation of a refrigerant working fluid). The devices can extract heat from the outside air (air-source heat pump), shallow subsurface (ground-source heat pump) or other nearby sources as water. These may be designed to operate reversibly to provide air conditioning as well as heating, or only to provide heating. The performance of a heat pump, expressed as the coefficient of performance (COP) or seasonal coefficient of performance (SCOP), is usually such that the heat delivered is several multiples of the energy contained in the input electricity. Heat pumps in this report refer to those that deliver heat directly to households and residential or commercial buildings for space heating and/or domestic hot water provision. They include natural source heat pumps, including reversible air conditioners used as primary heating equipment. They exclude reversible air conditioners used only for cooling, or used as a complement to other heating equipment, such as a boiler.

High Potential Case: This case identifies opportunities for emerging markets to build out their clean energy manufacturing sectors where global demand for clean energy technologies and near-zero emissions materials is compatible with the energy sector reaching net zero emissions by 2050. This case assumes that emerging markets succeed in overcoming barriers to exploiting all their competitive advantages in manufacturing a targeted scope of clean technologies and near-zero emissions materials, tailored to their respective high potential areas and enabled by international support mechanisms.

HS codes: Harmonised System (HS) Codes are a standardised numerical system to classify internationally traded goods, developed by the World Customs Organization (WCO). HS codes are used by authorities to identify products, to determine tariffs applicable to a product and collect trade statistics. Internationally standardised HS codes consist of a two-digit number (“Chapter”), four-digit number (“Heading”) and six-digit number ("Sub-Heading”).

Import quotas: A limit on the quantity of a product that can be imported into a country in a given period. There are two types: absolute and tariff rate. Absolute quotas strictly limit the physical quantify of a product that can enter in a country, while tariff-rate quotas allow a certain quantity to enter at a reduced tariff rate, and once this is reached, the product can still enter but at a higher tariff.

Import tariff: An import tariff is a customs duty levied on an imported product. There are different types of tariffs: ad valorem tariffs (see Annex: ad valorem tariff), specific tariffs (see Annex: specific tariff), tariff-rate quotas (see Annex: import quotas) and compound tariffs, which combine an “ad valorem” duty and a “specific” duty, added together or subtracted from each other.

International marine bunkers: Includes marine fuels delivered to ships of all flags that are engaged in international navigation. The international navigation may take place at sea, on inland lakes and waterways, and in coastal waters. Consumption by ships engaged in domestic navigation is excluded. The domestic/international split is determined on the basis of port of departure and port of arrival, and not by the flag or nationality of the ship.

Inter-regional trade: This covers all trade flows that move between distinct modelling regions, but does not capture any flows of international trade that might be taking place between countries belonging to the same modelling region.

Investment overnight: These are the capital costs (USD) that are considered to be incurred in a single time period (“overnight”), i.e. at the time of installation of a facility or deployment of a technology. They are calculated by multiplying the unit capital expenditure, without accounting for discount rates with the capacity additions (GW or GWh of annual capacity).

Investment spending: Investment spending (USD) is derived from overnight investments using the assumption of an even distribution of expenditure over the period between FID and the start of operations. This period is assumed to be 2 years for all materials, technologies and components considered in the analysis, apart from solar PV modules and cell facilities, for which we assume a period of 1 year. An even spending profile during this period is assumed, meaning that an investment with a 2-year FID-to-operation period will see 50% of the spending take place in the year the facility becomes operational and 50% the year before.

Investments: Investments always refer to manufacturing capacity investment if not stated otherwise. Investments for manufacturing of clean technologies and materials refer to greenfield capacity additions only. They do not include upgrades to existing facilities for clean technologies, while for materials the conversion of existing capacity to near-zero ones is accounted for (assuming the same cost as greenfield investment).

Levelised cost of production (LCOP): A measure of the average cost of producing a unit of output from a manufacturing facility over its lifetime.

Local content requirements: Policies that specify a minimum share of domestically manufactured goods, domestically supplied services or domestic labour that must contribute to a product or service, often expressed as a percentage of the final value. Certain incentives may be available only for products that meet these local content thresholds.

Low-emissions fuels: Includes bioenergy, low-emissions hydrogen and low-emissions hydrogen-based fuels.

Low-emissions hydrogen: Includes hydrogen which is produced through water electrolysis with electricity generated from a low-emissions source (such as renewables, e.g. solar and wind turbines, and nuclear). Hydrogen produced from biomass or from fossil fuels with carbon capture, utilisation and storage (CCUS) technology is also counted as low-emissions hydrogen. Production from fossil fuels with CCUS is included only if upstream emissions are sufficiently low, if capture – at high rates – is applied to all CO_2 streams associated with the production route, and if all CO_2 is permanently stored to prevent its release into the atmosphere. The same principle applies to low-emissions feedstocks and hydrogen-based fuels made using low-emissions hydrogen and a sustainable carbon source (of biogenic origin or directly captured from the atmosphere).

Low-emissions hydrogen-based fuels: Fuels produced from low-emissions hydrogen. Includes ammonia, methanol and other synthetic hydrocarbons (gases and liquids) made from low-emissions hydrogen when any carbon inputs, e.g. from CO_2, are not from fossil fuels or fossil-derived process emissions.

Manufacturing capacity: The maximum amount of a material, component or technology a facility is nominally able to produce.

Maritime chokepoints: A strategic, narrow passage connecting two larger areas of the world's oceans and seas. They are often straits or canals through which a significant share of global vessels transit.

Market size: The market size (USD) for clean technologies and materials is calculated based on the demand for this technology or material multiplied by its global unit price. In the calculation of total market size for clean technologies as a whole, only the final components are taken into account if these are in a serial supply chain, e.g. the market size for PV is equal to the market size for modules. For the case of the EV and batteries supply chain, the market size includes the total value of all electric cars (with their battery therein), as well as the value of batteries used in electric two- and three-wheelers, light commercial vehicles, buses, trucks, and stationary storage (altogether referred to as “other batteries”).

Modern bioenergy: Bioenergy including liquid biofuels (biogasoline, biodiesel, biojet kerosene, other liquid biofuels), biogases (biogas, biomethane) and all solid bioenergy products, except the traditional use of biomass.

NACE codes: NACE (Nomenclature statistique des Activités économiques dans la Communauté Européenne [Statistical Classification of Economic Activities in the European Community]) Codes are a standardised numerical system to classify industrial sectors within the European Union. NACE codes are used by authorities for statistical purposes and can correspond with the United Nations ISIC classification system.

Near-zero emissions materials: in this report, technologies that can produce steel from iron ore, aluminium from bauxite, and ammonia with emissions intensities that are compatible with the IEA Net Zero Emissions by 2050 Scenario are referred to as “near-zero emissions technologies”, and their outputs as “near-zero emissions materials’’. See Box 1.1 for more details.

Net Zero Emissions by 2050 Scenario (NZE Scenario): This scenario is a normative scenario that sets out a pathway to stabilise global average temperature at 1.5°C above pre-industrial levels. The NZE Scenario achieves global net zero energy sector CO_2 emissions by 2050 without relying on emissions reductions from outside the energy sector. In doing so, the advanced economies reach net zero emissions before EMDEs. The NZE Scenario also meets the key energy-related UN Sustainable Development Goals, achieving universal access to energy by 2030 and securing major improvements in air quality.

Non-tariff measures (NTM): Policy measures, other than ordinary customs tariffs, that can potentially have an impact on the value, quantity or quality of traded goods. These typically include regulations and technical specifications, such as requirements for efficiency, durability, environmental impact or safety, which can have a significant impact on trade costs, especially if they differ significantly between countries.

OPEX: Operating expenses (or operational expenditure), including both fixed and variable operating expenses.

Ro-Ro (roll-on/roll-off) shipping: Ro-Ro shipping involves the transportation of vehicles and wheeled cargo, such as cars, trucks, trailers and heavy machinery, that can be driven directly on and off the ship.

Shipping activity: In this report, shipping activity is defined as the mass of cargo multiplied by the distance over which the cargo is moved.

Specific tariff: A fixed charge levied at the point of import based on a defined physical quantity, such as per tonne or per unit, regardless of the value of the imported product.

Stated Policies Scenario (STEPS): This scenario is designed to provide a sense of the direction the energy system is heading in, based on a detailed review of the current policy landscape. The STEPS looks in detail at what governments are actually doing to reach their current targets and objectives across the energy economy. Outcomes in the STEPS reflect a detailed sector-by-sector review of the policies and measures that are actually in place or that have been announced; the aims of these policies are not automatically assumed to be met; they are incorporated in the scenario only to the extent they are underpinned by adequate provisions for their implementation. Aspirational energy or climate targets are not taken into consideration. This scenario also takes account of projects that have been announced to build manufacturing capacity for clean energy technologies and associated materials for which funds have been committed, i.e. they have reached the stage of a final investment decision (FID). In the case of local content requirements, a corresponding level of domestic production is assumed for certain components, depending on the technology and type of requirement.

Traditional use of biomass: Refers to the use of solid biomass with basic technologies, such as a three-stone fire or basic improved cook stoves (ISO tier < 3), often with no or poorly operating chimneys. Forms of biomass used include wood, wood waste, charcoal, agricultural residues and other bio-sourced fuels such as animal dung.

Total cost of ownership (TCO): The total costs associated with acquiring, operating, and maintaining an asset over its lifecycle.

Twenty-foot equivalent unit (TEU): A standard unit of measurement used in the shipping industry to describe the capacity of container ships, and the volume of cargo handled at ports. It represents the size of a standard shipping container of size 20x8x8.5 ft.

Utilisation rate: The proportion of the maximum capacity of a facility which is used on average over a set period of time. For the purposes of *ETP-2024* and its respective modelling, this period is a calendar year.

Value added: A measure which reflects the value generated by producing goods and services. Value added is measured as the value of output minus the value of intermediate consumption.

Wet bulk shipping: Wet bulk shipping involves the transportation of liquid commodities in large volumes, such as crude oil, petroleum products, liquefied natural gas (LNG), chemicals, and other liquid cargo. These materials are typically carried in tankers, which are specially designed to transport fluids safely. The ships used are referred to as tankers, with specialised variants like oil tankers and chemical tankers.

Abbreviations and acronyms

ACC	Advanced Chemistry Cell
AFIR	Alternative Fuels Infrastructure Regulation
AiP	Approval in principle
AIS	Automatic Identification System
ALMM	Approved List of Models and Manufacturers
AMP	Alternate Maritime Power
APEC	Asia-Pacific Economic Co-operation
APS	Announced Pledges Scenario
ASEAN	Association of Southeast Asian Nations
AVE	Ad valorem equivalent
BC	Back contact (cells)
BEV	Battery electric vehicles
BF-BOF	Blast furnace basic oxygen furnace
BIL	Bipartisan Infrastructure Law
BNDES	The National Bank for Economic and Social Development (Brazil)
BOF	Basic oxygen furnace
BP	Bayer process
BRI	Belt and Road Initiative
BTL	Biomass to liquid
CAPEX	Capital expenditure
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon capture and storage
CCUS	Carbon capture, utilisation and storage
CII	Carbon Intensity Index

CO_2	Carbon dioxide
COP	Coefficient of performance
DAC	Direct air capture
DC	Direct Current
DRI	Direct reduced iron
EAF	Electric arc furnace
EC	European Commission
EEDI	Energy efficiency design index
EGA	Environmental Goods Agreement
EHPA	European Heat Pump Association
EIB	European Investment Bank
EITI	Extractive Industries Transparency Initiative
EMDE	Emerging markets and developing economies
ESG	Environmental, social and governance
ETP	Energy Technology Perspectives
ETS	Emissions Trading Scheme
EV	Electric vehicles
FAME	Faster Adoption and Manufacturing of Electric Vehicles
FAME	Fatty acid methyl ester
FAO	Food and Agriculture Organization
FID	Final investment decision
FTA	Free trade agreement
GDP	Gross domestic product
GEC	Global Energy and Climate
GHG	Greenhouse gas
GTFS	Green Technology Financing Scheme
GWP	Global warming potential
GX	Green Transformation
G7	Group of Seven
HFC	Hydrofluorocarbons
HFO	Heavy Fuel Oil
HH	Hall-Heroult
HHI	Herfindahl-Hirschman Index
HJT	Heterojunction (cells)
HPC	High Potential Case
HS	Harmonized Commodity Description and Coding System
HVO	Hydrotreated vegetable oil
ICE	Internal combustion engine
ICEV	Internal combustion engine vehicle
IDDI	Industrial Deep Decarbonisation Initiative
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IGC	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IGF	Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development

ILO	International Labour Organization
IMF	International Monetary Fund
IMO	International Maritime Organization
IOE	Iron ore electrolysis
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
ISIC	International Standard Industrial Classification of All Economic Activities
ITC	International Trade Commission
ITU	International Telecommunications Union
JPN	Japanese yen
LCOP	Levelised cost of production
LFP	Lithium iron phosphate
LNG	Liquefied natural gas
LOI	Letter of intent
LPG	Liquefied petroleum gas
MARPOL	International Convention for the Prevention of Pollution from Ships
MaT	Manufacturing and trade
MDB	Multilateral development banks
MEPS	Minimum Energy Performance Standards
MFN	Most-Favoured Nation
MIIT	Chinese Ministry of Industry and Information Technology
MOU	Memorandum of Understanding
MOVER	Green Mobility and Innovation Program (Brazil)
MSW	Municipal solid waste
NMC	Lithium nickel manganese cobalt oxide
NTM	Non-tariff measure
NZE	Net Zero Emissions by 2050 Scenario
NZIA	Net-Zero Industry Act
N_2O	Nitrous oxide
NO_X	Nitrogen oxides
NH_3	Ammonia
OCC	Onboard Carbon Capture
OCED	Office of Clean Energy Demonstrations (United States)
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OPEX	Operating expenditure
PEM	Proton exchange membrane
PERC	Passivated emitter rear cells
PHEV	Plug-in hybrid vehicles
PLDV	Passenger light-duty vehicles
PLI	Production Linked Incentive
PTA	Preferential trade agreements
PTC	Production tax credits
PV	Photovoltaic
PWR	Pressurized water reactors

R&D	Research and development
RCA	Revealed comparative advantage
RCEP	Regional Comprehensive Economic Partnership
RD&D	Research, Development and Demonstration
RISE	Regulatory Indicators for Sustainable Energy
Ro-Ro	Roll-on/Roll-off
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCOP	Seasonal coefficient of performance
SIGHT	Strategic Interventions for Green Hydrogen Transition
SMR	Small Modular Reactors
SMR	Steam methane reforming
SOE	Solid oxide electrolyser
STEPS	Stated Policies Scenario
SUV	Sport utility vehicle
TBT	Technical Barriers to Trade
TESSD	Trade and Environmental Sustainability Structured Discussions
TOPCon	Tunnel Oxide Passivated Contact
TRL	Technology readiness level
UNCTAD	United Nations Trade and Development
UNIDO	United Nations Industrial Development Organization
USD	United States dollars
USMCA	United States-Mexico-Canada Agreement
VLBC	Very large bulk carriers
VLOC	Very Large Ore Carriers
WACC	Weighted average cost of capital
WCO	World Customs Organization
WIPO	World Intellectual Property Organization
WPID	Working Party on Industrial Decarbonisation
WTO	World Trade Organization
ZEV	Zero-emission vehicle

Units of measure

DWT	Deadweight tonnage
EJ	exajoule
FEU	Forty-foot Equivalent Unit
g CO_2	grammes of carbon dioxide
g CO_2/kWh	grammes of carbon dioxide per kilowatt hour
GJ	gigajoule
Gt	gigatonnes
Gtce	gigatonnes of coal equivalent
Gt CO_2	gigatonne of carbon dioxide
Gt/yr	gigatonnes per year

GW	gigawatt
GWh	gigawatt hour
kg	kilogramme
km	kilometre
kt	kilotonne
kW	kilowatt
kWh	kilowatt hour
mb/d	million barrels per day
MJ	megajoule
Mt	million tonne
MTEU	million twenty-foot equivalent units
Mtpa	million tonnes per annum
MW	megawatt
MWh	megawatt hour
PJ	petajoule
t	tonne
tcm	trillion cubic meters
TEU	Twenty-foot equivalent units
tkm	tonne-kilometre
toe	tonne of oil equivalent
TW	terawatt
TWh	terawatt hour
W	watt

Currency conversions

Exchange rates (2023 annual average)	1 US dollar (USD) equals:
British Pound	0.80
Chinese Yuan Renminbi	7.08
Euro	0.92
Indian Rupee	82.60
Japanese Yen	140.49
Korean Won	1 305.66

Note: all values are expressed in the 2023 USD.

Regional groupings

Advanced economies: Australia, Austria, Belgium, Bulgaria, Canada, Chile, Colombia, Costa Rica, Croatia, Cyprus,[7,8] Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel,[9] Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Malta, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, United Kingdom and United States.

Africa: Algeria, Angola, Benin, Botswana, Cameroon, Côte d'Ivoire, Democratic Republic of the Congo, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Kingdom of Eswatini, Libya, Madagascar, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Republic of the Congo (Congo), Rwanda, Senegal, South Africa, South Sudan, Sudan, United Republic of Tanzania (Tanzania), Togo, Tunisia, Uganda, Zambia, Zimbabwe and other African countries and territories.[10]

Asia Pacific excluding China: Southeast Asia regional grouping and Australia, Bangladesh, Democratic People's Republic of Korea (North Korea), India, Japan, Korea, Mongolia, Nepal, New Zealand, Pakistan, Sri Lanka, Chinese Taipei, and other Asia Pacific countries and territories.[11]

Central Africa: Burundi, Chad, Cameroon, Central African Republic, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Republic of the Congo (Congo), Sao Tome and Principe.

Central and South America: Argentina, Plurinational State of Bolivia (Bolivia), Bolivarian Republic of Venezuela (Venezuela), Brazil, Chile, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru,

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[7] Note by Republic of Türkiye: The information in this document with reference to "Cyprus" relates to the southern part of the island. There is no single authority representing both Turkish and Greek Cypriot people on the island. Türkiye recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Türkiye shall preserve its position concerning the "Cyprus issue".

[8] Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Türkiye. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

[9] The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD and/or the IEA is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

[10] Individual data are not available and are estimated in aggregate for: Burkina Faso, Burundi, Cabo Verde, Central African Republic, Chad, Comoros, Djibouti, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Malawi, Mali, Mauritania, Sao Tome and Principe, Seychelles, Sierra Leone and Somalia.

[11] Individual data are not available and are estimated in aggregate for: Afghanistan, Bhutan, Cook Islands, Fiji, French Polynesia, Kiribati, Macau (China), Maldives, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga and Vanuatu.

Suriname, Trinidad and Tobago, Uruguay and other Central and South American countries and territories.[12]

China: Includes (The People's Republic of) China and Hong Kong, China.

East Africa: Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Seychelles, Somalia, South Sudan, Sudan, United Republic of Tanzania (Tanzania) and Uganda.

Emerging market and developing economies: All other countries not included in the advanced economies regional grouping. For the purposes of Chapter 4, the term “emerging markets” refers to all the countries in Latin America, Africa and Southeast Asia.

Eurasia: Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, the Russian Federation (Russia), Tajikistan, Turkmenistan and Uzbekistan.

Europe: European Union regional grouping and Albania, Belarus, Bosnia and Herzegovina, Gibraltar, Iceland, Israel,[9] Kosovo, Montenegro, North Macedonia, Norway, Republic of Moldova, Serbia, Switzerland, Türkiye, Ukraine and United Kingdom.

European Union: Austria, Belgium, Bulgaria, Croatia, Cyprus,[7,8] Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain and Sweden.

Latin America: Central and South America regional grouping and Mexico.

Middle East: Bahrain, Islamic Republic of Iran (Iran), Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic (Syria), United Arab Emirates and Yemen.

North Africa: Algeria, Egypt, Libya, Morocco and Tunisia.

North America: Canada, Mexico and United States.

Southeast Asia: Brunei Darussalam, Cambodia, Indonesia, Lao People’s Democratic Republic (Lao PDR), Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam. These countries are all members of the Association of Southeast Asian Nations (ASEAN).

[12] Individual data are not available and are estimated in aggregate for: Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, Bonaire, Sint Eustatius and Saba, British Virgin Islands, Cayman Islands, Dominica, Falkland Islands (Malvinas), Grenada, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Pierre and Miquelon, Saint Vincent and Grenadines, Saint Maarten (Dutch part), Turks and Caicos Islands.

Southern Africa: Angola, Botswana, Kingdom of Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Zambia and Zimbabwe.

West Africa: Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo.

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Typeset in France by IEA - October 2024
Cover design: IEA
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