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Executive Summary

Three strategic areas of public policy – energy, industry and trade – are increasingly interwoven. Tensions and trade-offs arise in each of these areas as governments seek to reconcile their commitment to well-functioning markets and cost-effective clean energy transitions, on the one hand, with the need to establish secure, resilient clean technology supply chains, on the other. This involves tough decisions around choosing which industries to support, collaboration with trading partners, and how to prioritise innovation efforts. This 2024 edition of *Energy Technology Perspectives (ETP)* – the "world's clean energy technology guidebook" – is designed to support decision-making in these areas. *ETP-2024* is the first analysis of its kind to explore the future of manufacturing and trade of clean energy technologies, with granular sectoral detail across supply chains, built on a unique bottom-up dataset and a quantitative assessment of countries' industrial strategies.

Manufacturing and trade are foundational for the new clean energy economy

The sizeable economic opportunities associated with manufacturing clean energy technologies are a top priority for government and industry. The global market size for six of the main clean energy technologies – solar PV, wind, electric vehicles (EVs), batteries, electrolysers and heat pumps – has grown nearly fourfold since 2015 to exceed USD 700 billion in 2023, which is around half the value of all the natural gas produced globally that year. Growth has been driven by surging clean technology deployment, particularly for EVs, solar PV and wind. Under today's policy settings, the market for key clean technologies is set to nearly triple by 2035, to more than USD 2 trillion. This is close to the average value of the global crude oil market in recent years.

International trade is essential to the proper functioning of the global economy – including the energy system. Global goods trade – comprising vital supplies of everything from food and clothing to smart phones and semiconductors – amounted to around USD 24 trillion in 2023 in value terms. Fossil fuels accounted for around 10% of this, while bulk materials and chemicals – including steel, aluminium and ammonia – accounted for around 20%. Clean energy technology trade today accounts for a comparatively small share relative to these established industries, at around 1%, but it is growing fast.

At around USD 200 billion, the value of trade in clean technologies is nearly 30% of their global market value. The biggest element is trade in electric cars, which has doubled since 2020, reaching around one-fifth of trade in all cars in 2023 in value terms. Solar PV is the second-most traded technology in value terms. Under today's policy settings, overall clean technology trade is on track to reach USD 575 billion by 2035, or around 50% more than the value of global trade in natural gas today.

Investments in manufacturing are surging in response to rapidly growing demand for clean technologies

A major wave of manufacturing investment in clean technologies is underway, with many new factories being built across the world. Global investment in clean technology manufacturing rose by 50% in 2023, reaching USD 235 billion. This is equal to nearly 10% of the growth in investment across the entire world economy, and around 3% of global GDP growth. Four-fifths of the clean technology manufacturing investment in 2023 went to solar PV and battery manufacturing, with EV plants accounting for a further 15%. The amount of manufacturing capacity being added has been comfortably outpacing current deployment levels. Despite some recent cancellations and postponements of solar PV and battery manufacturing projects, investment in clean technology manufacturing facilities is set to remain close to its recent record levels, at around USD 200 billion in 2024.

Cost competitiveness is an important driver of manufacturing investment – but not the only one. China is currently the cheapest location for manufacturing all the major clean energy technologies considered in this report, without taking into account explicit financial support from governments. Compared with China, it costs up to 40% more on average to produce solar PV modules, wind turbines and battery technologies in the United States, up to 45% more in the European Union, and up to 25% more in India. Cost competitiveness is a key factor explaining China's outsized role in clean technology manufacturing today: it accounts for between 40% and 98% of global manufacturing capacity for the key clean technologies and components we examine, depending on the case. Relative to other countries, China has greater economies of scale, a larger domestic market and highly integrated firms and facilities along the supply chain for these technologies. An IEA survey of more than 50 major manufacturers across clean technology and material supply chains reveals other factors, besides costs, that influence investment decisions. These include various forms of policy support, access to markets, skills and knowledge in the industrial base, and infrastructure.

Trade can help countries play to their economic strengths

Moving energy-related trade towards clean technologies is part of a broader shift in the energy sector that has long-term implications for trade volumes. Fossil fuels provide recurring flows of energy trade, whereas clean technology trade results in a long-lived stocks of energy generation and transformation equipment. For example, based on today's policy settings, the European Union's net imports of fossil fuels and clean energy technologies reach around USD 400 billion in 2035. But the bloc's total import bill tilts towards a higher share of clean energy technologies, from less than 10% in 2023 to 35% in 2035, at the expense of fossil fuels. This has positive impacts on energy resilience: a single journey by a large container ship filled with solar PV modules can provide the means to generate electricity equivalent to the amount generated from the natural gas onboard more than 50 large LNG tankers, or the coal onboard 100 large ships.

Industrial strategies in Europe and the United States are set to alter the outlook for manufacturing and trade

In the European Union, the future of clean technology manufacturing will be shaped by how successfully the targets of the Net Zero Industry Act (NZIA) can be achieved. While the NZIA targets are readily achievable for some technologies like the final steps of wind component and heat pump manufacturing, the task facing the automotive industry is much larger. More than 40% of the internal combustion engine (ICE) vehicles produced in the European Union today are destined for export and facing competition from EV manufacturers in China, as are domestically produced EVs for the EU market. For the EU car industry to compete in the growing EV market, manufacturing cost reductions for electric cars and full integration of supply chains, including batteries, will be essential. In 2023, imports from China accounted for around 20% of EV sales in the European Union. Under today's policy settings, this share roughly doubles to 40% by 2035 despite recently announced import duties that will be in effect for 5 years. If the goals of the NZIA are achieved, a fully integrated EV and battery supply chain would help bring the share down to 20%.

In the United States, the Inflation Reduction Act and Bipartisan Infrastructure Law are bearing fruit. They have already mobilised USD 230 billion of investment in clean technology manufacturing through to 2030. Based on current policy settings – and driven by the incentives provided under these pieces of legislation – US demand for solar PV modules and polysilicon could be met almost entirely by domestic production by 2035, while some demand for cells and wafers would still be met by imports. Existing trading relationships also provide a strong

foundation: Mexico is well placed to become a hub for EV manufacturing for the North American market (as it is today for ICE cars), with Southeast Asia, Korea and Japan being other potential key suppliers.

China remains the world's manufacturing powerhouse and India makes major strides, becoming a net exporter

China's share of global manufacturing for all six key clean technologies in value terms is around 70% today. China's largest solar PV manufacturing facility currently under construction, located in Shanxi province, could alone produce enough modules to cover virtually all EU demand today. Despite the ongoing implementation of industrial strategies in other countries, the value of China's clean technology exports is on track to exceed USD 340 billion in 2035, based on today's policy settings. This is roughly equivalent to the projected oil export revenue of both Saudia Arabia and the United Arab Emirates combined in 2024. China's fossil fuel import bill is currently the highest of any country in the world. Under today's policy settings, the net import bill – accounting for fossil fuel imports and clean technology exports – is cut by around 70% between now and 2035. If markets for clean technologies grow more quickly than projected under today's policy settings, then China's exports of clean technologies would, in value terms, entirely offset its imports of fossil fuels, before 2035.

India pivots from being a net importer of clean technologies today to a net exporter in 2035, if the clean energy transition accelerates. Under today's policy settings, India remains a net importer of clean technologies in value terms in 2035, but with modestly growing production and exports of solar PV modules, EVs and batteries incentivised under the Production Linked Incentive Scheme. In contrast, if the clean energy transition proceeds more quickly in India and around the world, the country's net exports of clean energy technologies could grow rapidly to reach USD 30 billion in 2035, after supplying a large portion of its own rapidly increasing demand. This offsets around 20% of its remaining fossil fuel import bill of around USD 170 billion, reducing India's energy-related trade deficit to around USD 140 billion.

The door of the new clean energy economy is still open to emerging markets

Emerging and developing economies in Latin America, Africa and Southeast Asia account for less than 5% of the value generated from producing clean technologies today. A fair and just transition requires enabling more regions to reap the economic benefits from growing supply chains for clean and modern energy technologies. A faster clean energy transition and larger overall market for clean energy technologies will be foundational for this. Other factors that presently deter investment in emerging markets also need to be overcome, including political and currency risks, a lack of skilled workers and poor infrastructure. But the

opportunities exist: beyond the mining and processing of critical minerals, countries in Africa, Latin America and Southeast Asia all have prospects to boost their competitive advantages and move up the value chain. We collected country-by-country data across over 60 indicators, assessing the business environment, infrastructure for energy and transport (such as electricity grids, gas pipelines and ports), resource availability and domestic market size, to identify opportunities for each country.

Southeast Asia is already an important player in clean technology supply chains, and several countries can take a step up the value chain. The region could be among the cheapest places to produce polysilicon and wafers for solar PV modules by 2035. Several countries there can build on existing manufacturing strengths for electronic and electrical equipment, competitive labour and energy prices, and government policies that are supportive for export-oriented industries. If the region can fully exploit these competitive advantages, and policy action worldwide is compatible with reaching net zero emissions globally by 2050, Southeast Asia could produce over 8 million EVs by 2035 (up from about 40 000 today), of which almost half would be exported.

Latin America, and Brazil in particular, has favourable starting conditions for wind turbine manufacturing, but significant investments in infrastructure and logistics are required to capitalise on this. Today, Brazil produces over 5% of wind turbine blades globally. If the country is able to take advantage of its favourable enabling conditions, in a scenario compatible with net zero emissions by 2050, exports of these components increase sixfold by 2035 compared with current levels, assuming long-lead-time investments in port infrastructure bear fruit. Brazil – among other Latin American countries – is also endowed with abundant renewable energy resources, which form a good basis for exports of near-zero emissions ammonia, iron and steel to markets where these commodities are more costly to produce, such as Europe and Japan.

North Africa could become an EV manufacturing hub. Investment is already underway, and if the region is able to achieve its potential in line with achieving net zero emissions by 2050 globally, North Africa in 2035 exports almost half of the 3.7 million EVs it produces by then, mostly to the European Union. This would build on the existing project pipeline in countries such as Morocco. Elsewhere in Africa, countries have the potential to leverage iron ore and renewable energy resources, for example, to move up the value chain and produce iron with electrolytic hydrogen. Such exports to Europe and Japan could be worth more than four times the value of the same tonnage of iron ore exports at today's prices, if the world pursues climate targets compatible with reaching net zero emissions by 2050, and the barriers to investment in African countries are overcome.

Supply chain concentration puts pressure on the busiest maritime shipping routes

Traffic through some of the busiest maritime chokepoints increases, despite growth in overall shipping activity slowing down. Based on today's policy settings, global maritime goods trade increases by 1% per year by weight over the coming decade – significantly more slowly than over the past two decades, due to slower growth in fossil fuel and steel demand. However, traffic through certain chokepoints intensifies. Around 50% of all maritime trade in clean technologies trade passes through the Strait of Malacca today. Based on today's policy settings, clean technology shipments through Malacca are set to rise substantially, though their share in total maritime trade remains very small. This dependency on maritime chokepoints poses risks to supply chain resilience, especially as the average clean technology cargo is more than ten times the value of the average fossil fuel cargo per tonne.

Well-designed industrial strategies will be crucial for clean energy transitions to continue gathering pace

The tensions and trade-offs between the goals of energy and industrial policies mean that getting trade policy measures right is essential for clean energy transitions. In some cases, the clean energy dividends of trade would be higher if barriers to trade were lower. Today, tariffs on renewable energy systems and components, for example, are more than twice those applied to fossil fuels, on average. Trade measures – including both tariffs and non-tariff measures – already increase the cost of clean technologies. For example, a 100% tariff on solar PV modules today would cancel out the decline in technology costs seen over the past 5 years. The knock-on impact on electricity generation costs would be more limited, as the solar PV modules themselves make up 20-30% of the total installation cost. But for consumer goods, such as electric cars, the impact is likely to be more direct and risks slowing down adoption.

Well-designed industrial strategies can help companies address competitiveness gaps or reach the innovation frontier sooner, but their interplay with trade policy measures needs careful consideration. Industrial policy deployed with a specific, measurable and time-bound goal can support the achievement of energy policy and climate goals. For example, battery production in the European Union is around 50% more expensive than in China today. Innovative battery technologies currently under development could help reduce the cost gap by up to 40% – at which point, the advantages of manufacturing being located in the European Union may outweigh the remaining cost difference. To cultivate and maintain competitiveness and innovation, industrial policies must be closely monitored and amenable to course correction. Trade policy must be

designed carefully if it is to support such goals – broad-based protectionism or blanket financial support are very unlikely to make for a winning industrial strategy.

Industrial strategies must take into account the new parameters and objectives of international trade in clean technology supply chains. To balance efforts to reach climate goals with energy and industrial policy objectives, trade policies will need to be designed with a view to their role in the new clean energy economy, and what it means for industrial competitiveness today. There is no single recipe to follow for these policies, but the analysis presented in *ETP-2024* is designed to help move the debate in this area forward.

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