Part of the World Bank Report
Green Horizon: East Asia's Sustainable Future

EXECUTIVE SUMMARY

INDUSTRIAL DECARBONIZATION IN EAST ASIA

TRANSFORMING ENERGY, FINANCE, TECHNOLOGY, AND JOBS

WORLD BANK GROUP

Cover design: Kevin Kunyu Sun

Cover image: The images featured on the four designed banners are adapted from artwork generated using ChatGPT-5 in August 2025. Each banner image was developed based on a specific prompt: the green banner ("solar panels, wind turbines, smart grids, and battery storage in a single composition"); the blue banner ("dynamic sustainable finance and financial markets in action"); the silver banner ("representative image for green hydrogen, green ammonia, carbon capture utilization and storage, and green steel"); and the gold banner ("jobs and workforce for green industries requiring digital and interdisciplinary skills"). All other cover elements were originally created by the cover designer.

Contents

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This report is the first to systematically address the complex challenge of industrial decarbonization in East Asia, one of the world's most dynamic economic areas. Drawing on original data and in-depth assessments of three key economies—China, Indonesia, and Viet Nam—the report identifies viable technical pathways, unveils implementation challenges, and offers a comprehensive policy package to accelerate the transition to net-zero industry.

Importance | Transforming 40 percent of global industrial output for sustainable growth and the energy transition

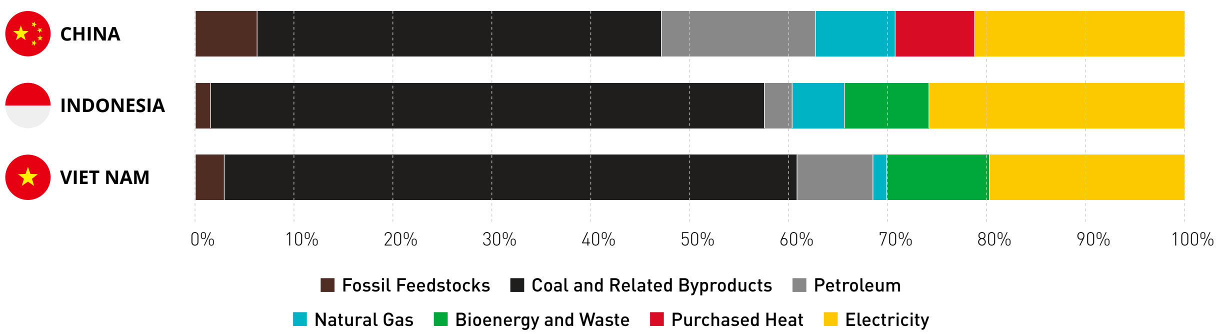
The powerhouse of global economic growth, East Asia is anchored by a dynamic industrial sector that contributes 38 percent of regional GDP and employs nearly a third of its workforce (World Bank 2025b).

The region's industries are diverse and strategically significant: China leads in heavy industries, accounting for more than 50 percent of global steel, cement, aluminum, copper, and nickel production; Indonesia anchors resource-based sectors and petrochemicals; and Viet Nam is rapidly expanding its light manufacturing and electronics exports. Beyond the nearly 300 million direct jobs it provides, industry generates widespread indirect employment by fueling demand along the value chain—from energy production and construction to finance, engineering, and digital services.

The region consumes 40 percent of global primary energy, emits 40 percent of global greenhouse gases, and remains heavily dependent on fossil fuels for industrial energy use (Ritchie et al. 2024).

In 2022, the industrial sector accounted for the largest share of final energy use in China (47 percent), Indonesia (44 percent), and Viet Nam (51 percent). Coal, related byproducts and fossil feedstocks dominate industrial energy use—47 percent in China, 57 percent in Indonesia, and 61 percent in Viet Nam. Fossil fuel shares rise to 71, 66, and 70 percent, respectively, when petroleum and natural gas are included (FIGURE ES.1) (NBS 2024, MEMR 2024, VNEEP 2024, and VSA 2024). As a result, these countries' industrial emissions, as a share of their total energy-related emissions, far exceed the global average: industry contributes 26 percent of energy-related carbon dioxide (CO_2) emissions in China, 24 percent in Indonesia, and 31 percent in Viet Nam, versus 18 percent globally. Adding emissions from electricity consumed by industries, the share rises to 65, 48, and 57 percent in China, Indonesia, and Viet Nam respectively, versus a world average of 30 percent (IEA 2023c).

FIGURE ES.1 Industrial sector energy use by fuel for China, Indonesia, and Viet Nam shows fossil fuel dependence



Industrial decarbonization presents a strategic opportunity to accelerate the energy transition, boost economic competitiveness, and create quality jobs across the East Asian region.

For developing economies, industrial decarbonization delivers a triple dividend: greater productivity through energy and material efficiency, increased investment and green job creation, and improved public health and social welfare from reduced air pollution and an enhanced work environment. By shifting to clean energy and modern industrial processes, countries in the region can meet their net-zero targets (i.e., 2060 for China and Indonesia, 2050 for Viet Nam), avoid locking in carbon-intensive infrastructure, and gain competitiveness in an increasingly carbon-conscious global market.

Decarbonizing industry remains a critical yet overlooked component in the energy transition.

The carbon- and energy-intensive industrial sector has made limited progress and receives just 1.4 percent of global climate finance (Naran et al. 2024). While power and transport dominate decarbonization policy priorities, the industrial sector, especially in developing countries, remains largely neglected. One key reason for this policy gap is the sector's inherent complexity, its deep interlinkages with other areas of the economy, and its contribution to economic competitiveness. Practical challenges compound this gap, including the high cost of clean energy, grid constraints on renewable deployment, low readiness of emerging technologies, and shortages of skilled labor. Without targeted attention, this sector could become the weak link in achieving national and global decarbonization goals.

Methodology | Unpacking industrial decarbonization strategies and global best practices

This report employs a mixed-methods approach combining technical modeling, case studies, and stakeholder consultation.

It integrates bottom-up quantitative modeling with five international case studies to identify technical pathways and policy recommendations for industrial decarbonization in China, Indonesia, and Viet Nam. In addition, stakeholder consultations in studied countries were conducted for contextualization. Together, the three countries account for 85 percent of energy-related CO_2 emissions from the Asia-Pacific industrial sector. Their distinct industrial profiles and energy system characteristics offer a compelling case for advancing industrial decarbonization—both within the region and globally.

Given the complexity of industrial decarbonization, six tiers of technical strategies were defined to clarify how limited resources can deliver the greatest impact.

These technical strategies are ranked based on cost-effectiveness and technological readiness. As shown in TABLE ES.1, lower-numbered tiers include the most mature and affordable interventions, while higher-numbered tiers feature more-expensive and less-developed solutions. Each tier represents a distinct, nonoverlapping set of measures that can cumulatively cut 95–97 percent of each country's industrial emissions. These include direct CO_2 emissions from fossil fuel combustion at industrial facilities, process CO_2 emissions from cement production, and fugitive methane (CH_4) emissions associated with the extraction of fossil fuels purchased by industry. The modeling scope is limited to the industrial sector, with the assumption that the power sector will achieve full decarbonization in line with the countries' net-zero targets.

TABLE ES.1 The Six-Tier Approach: Strategies for industrial decarbonization based on cost-effectiveness and technological readiness

Tiers	Strategies	Interventions	Targeted industrial subsectors
Tier 1	**Energy efficiency, material efficiency, and product longevity**	• Improving thermal and electrical energy efficiency (e.g., waste heat recovery, energy management systems, energy-efficient equipment) • Material-saving product design and manufacturing technologies (e.g., net shape manufacturing, fewer process steps) • Designing products and buildings for longevity and maintenance	Key processes and cross-cutting systems (process heating, steam, motors, pumps, fans, etc.) across all industrial subsectors
Tier 2a	**Easy electrification:** electrification of nonthermal processes, low-temperature heating, and scrap-based steelmaking	• Replacing diesel engines with electric motors • Replacing fossil-fueled boilers with industrial heat pumps for low-temperature (<150°C) industrial heating • Switching a portion of primary steelmaking based on blast furnace-basic oxygen furnace (BF-BOF) to secondary scrap-based steelmaking in electric arc furnaces (scrap-EAF)	Food and beverage, textiles, pulp and paper, and iron and steel Also targets motor and steam systems used across most industrial subsectors
Tier 2b	**Other electrification:** electrification of medium-to-high-temperature process heating	• Replacing fossil-fueled boilers with electric boilers and thermal batteries • Replacing fossil-fueled furnaces, kilns, and other heating equipment with electrified replacements (such as electric resistance heating, induction heating, electric arcs/plasma torches, dielectric heating, and infrared heating)	Chemicals, refining, nonferrous metals, nonmetallic minerals, and manufacturing of machinery and equipment
Tier 3	**Carbon capture, utilization and storage (CCUS)**	• Amine-based CO_2 capture • Oxy-fuel combustion CO_2 capture • Direct capture of process CO_2 emissions from cement-making • Retrofitting a portion of blast furnaces (BF-BOF) with CCUS • CO_2 transport and use or sequestration	Nonmetallic minerals (cement, lime, etc.), iron and steel
Tier 4a	**Green hydrogen (H_2)**	• Transitioning a portion of primary steel production from the BF-BOF route to the green hydrogen–based direct reduced iron-electric arc furnace (H_2-DRI-EAF) method • Replacing fossil fuel combustion with green hydrogen in high-temperature processes where electrified options are technologically immature • Replacing fossil fuel combustion with green hydrogen in subsectors that already use hydrogen for other purposes	Iron and steel, chemicals, refining, and nonmetallic minerals (glass, cement)
Tier 4b	**Clean feedstocks**	• Replacing fossil fuels used as chemical feedstocks (e.g., coal, natural gas, and petroleum) with clean feedstocks (green H_2, blue H_2, bioenergy)	Ammonia, methanol, olefins, aromatics (used in fertilizers, plastics)

The modeling incorporates anticipated technological and financial developments that can be applied under the policy recommendations provided in this report.

The modeling assumptions include a substantial reduction in the cost of clean hydrogen,[1] with green hydrogen reaching $1.80/kilogram (kg) in China, $3.50/kg in Indonesia, and $2.17/kg in Viet Nam by 2050, respectively.[2] It also incorporates a carbon price that increases from present-day values to $50/tonne CO_2 by 2050,[3] which represents the combined effects of direct carbon pricing such as carbon markets and carbon taxes, as well as indirect carbon pricing, such as withdrawing existing fossil fuel subsidies and accounting for the social cost of carbon.[4] These modeling assumptions affect the cost-effectiveness of the technological interventions. The full list of technical model assumptions is presented in Appendix D.

Five global case studies were analyzed to assess the enabling policies and support frameworks behind successful industrial decarbonization initiatives across major energy-intensive sectors.

The cases cover steel, cement, chemicals, and industrial parks—in both developed and developing countries. The cases illustrate key technical pathways in these sectors: steelmaking powered by renewable energy (RE) in India, green hydrogen in Sweden and Saudi Arabia, carbon capture and storage (CCS) in Norway, and renewable integration in China's industrial parks. A common framework was used to examine policy, financing, institutional coordination, and infrastructure readiness in various contexts.

[1] "Clean hydrogen" includes hydrogen produced from fossil fuels coupled with carbon dioxide capture and storage (combustion based) or carbon storage (pyrolysis based). These are also known as "low-carbon hydrogen" or "blue hydrogen." Hydrogen produced from water electrolysis using renewable electricity or from biomass is known as "renewable hydrogen" or "green hydrogen." "Conventional hydrogen" or "gray hydrogen" refers to fossil fuel-based production without carbon dioxide capture and storage.

[2] The estimated 2050 green hydrogen cost for China is from Erofeev (2025) citing the latest estimate from BloombergNEF. The estimated 2050 green hydrogen cost of 2050 for Vietnam is from UNDP (2023), Tuyen (2024), and ERIA (2024); and the 2050 green hydrogen cost of Indonesia are from ERIA (2024) and Bloomberg NEF (2023).

[3] In this report, "$" signifies U.S. dollars unless otherwise specified and that "tonne" signifies "metric ton".

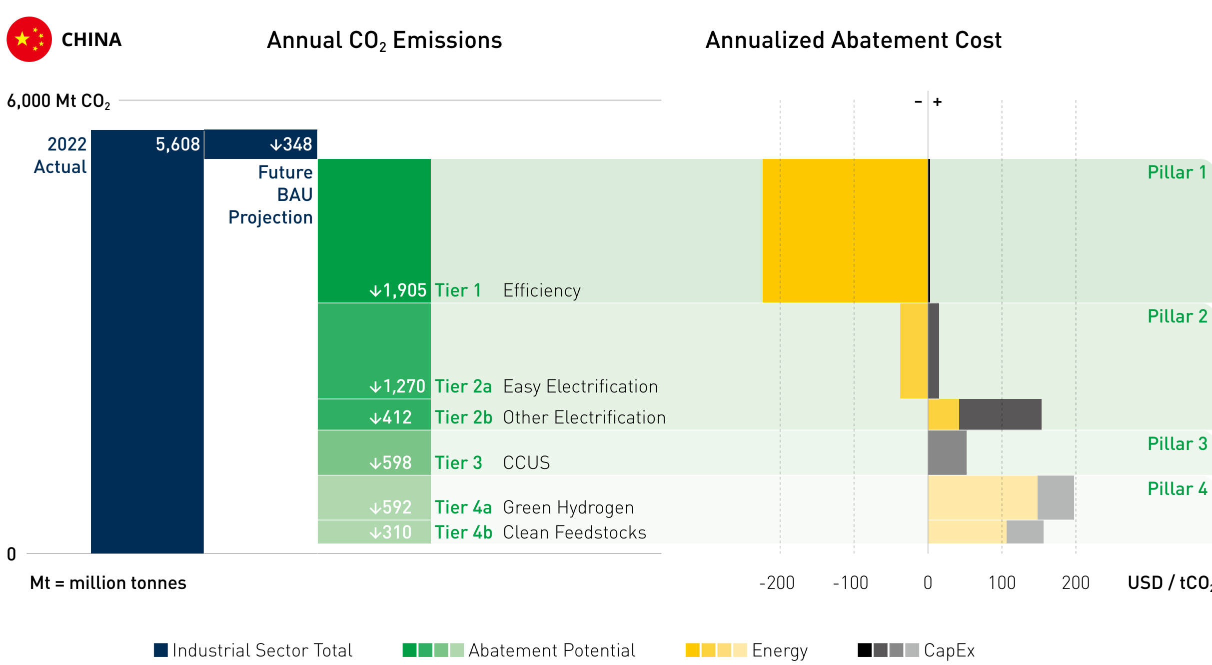
[4] We define "present day" carbon prices based on prevailing carbon market levels in 2023–2024, particularly in East Asia, which remain well below global policy-guided shadow price levels: in 2024-2025, carbon pricing in China is around $13/tonne CO_2, and about $2/tonne CO_2 in Indonesia, and around $5/tonne CO_2 in Vietnam (voluntary markets). The $50/tonne cap was selected to reflect this market reality and provide a conservative benchmark for assessing near-term investment competitiveness. We note that the World Bank's Shadow Price of Carbon (SPC), recommended for project economic appraisal, is distinct from prevailing or market carbon prices and also from the Social Cost of Carbon (SCC), which estimates the external damages from emissions. As noted in the World Bank's 2024 SPC Guidance note, the SPC in the range of $40–80 per tonne of CO_{2e} in 2020, rising to $50–100 per tonne of CO_{2e} by 2030, is based on a review carried out by the High-Level Commission on Carbon Prices and assumes a supportive global policy environment. Since many East Asian countries do not yet have strong carbon pricing frameworks or enabling conditions, our use of a $50/tonne cap reflects a realistic upper bound for short- to medium-term decision-making in the regional context.

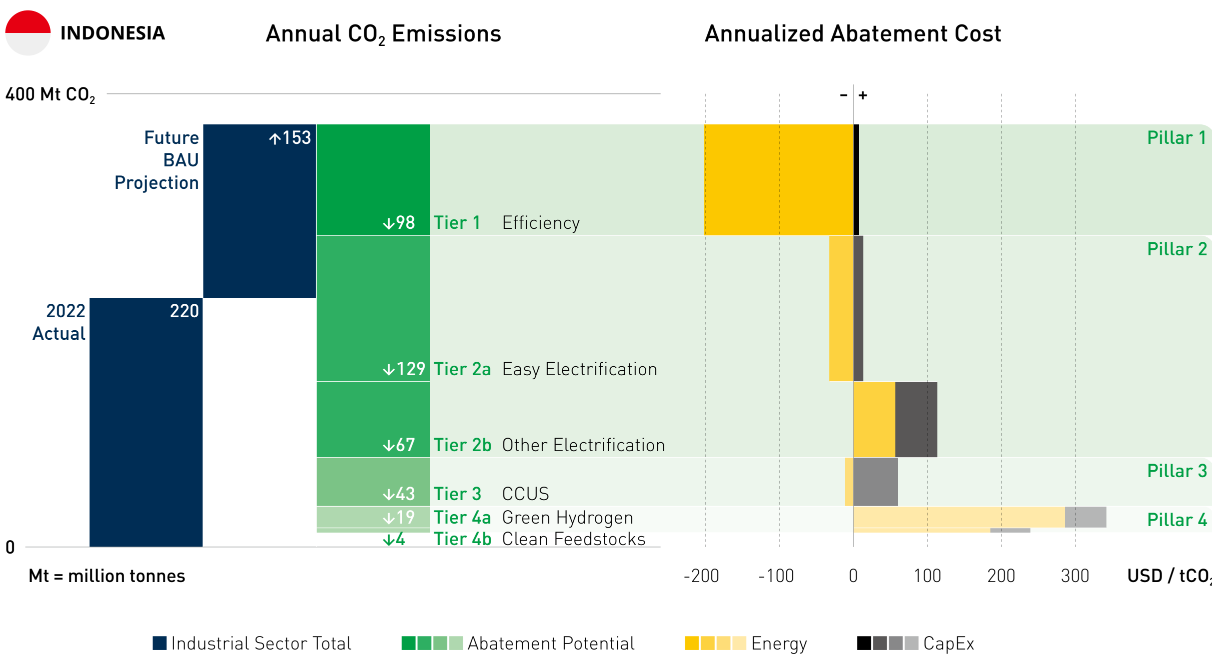
Technical Pathways | Decarbonization potential, cost-effectiveness and trade-offs

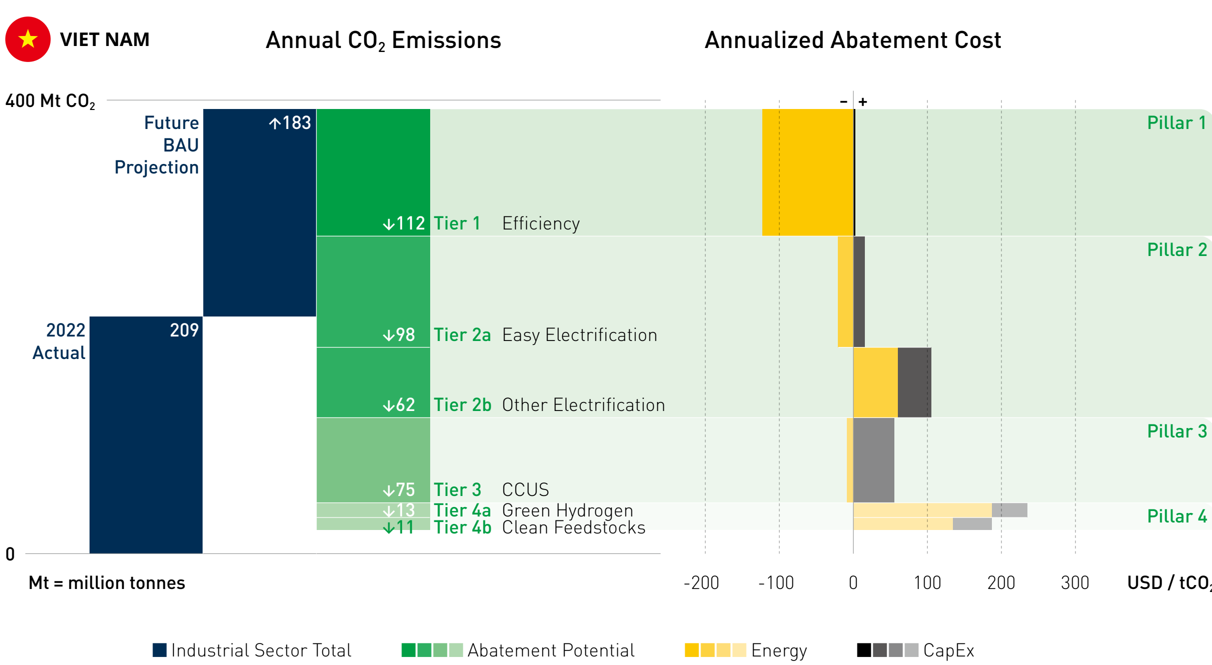
The modeling revealed common technical pathways to reach net-zero industrial emissions in all three countries, even after considering country-specific industrial structures, economic scales, and development stages.

Within this pathway, the six tiers are grouped into four pillars of industrial abatement for China, Indonesia, and Viet Nam **(FIGURE ES.2)**: (1) energy and material efficiency; (2) electrification with renewable energy; (3) carbon capture, use, and storage (CCUS); and (4) green hydrogen and clean feedstocks. This section explains the abatement potential, abatement cost, and focus subsectors of each technical pillar based on modeling results.

FIGURE ES.2 Industry decarbonization technical pathways: Abatement potential and abatement cost per tonne of CO_2




INDONESIA
Annual CO_2 Emissions
Annualized Abatement Cost
400 Mt CO_2
Future BAU Projection
↑153
2022 Actual
220
↓98 Tier 1 Efficiency
↓129 Tier 2a Easy Electrification
↓67 Tier 2b Other Electrification
↓43 Tier 3 CCUS
↓19 Tier 4a Green Hydrogen
↓4 Tier 4b Clean Feedstocks
Pillar 1
Pillar 2
Pillar 3
Pillar 4
0
Mt = million tonnes
-200 -100 0 100 200 300 USD / tCO_2
Industrial Sector Total
Abatement Potential
Energy
CapEx


VIET NAM
Annual CO_2 Emissions
Annualized Abatement Cost
400 Mt CO_2
Future BAU Projection
↑183
2022 Actual
209
↓112 Tier 1 Efficiency
↓98 Tier 2a Easy Electrification
↓62 Tier 2b Other Electrification
↓75 Tier 3 CCUS
↓13 Tier 4a Green Hydrogen
↓11 Tier 4b Clean Feedstocks
Pillar 1
Pillar 2
Pillar 3
Pillar 4
0
Mt = million tonnes
-200 -100 0 100 200 300 USD / tCO_2
Industrial Sector Total
Abatement Potential
Energy
CapEx

Pillar 1 Supercharging energy and material efficiency (Tier 1)

The largest emissions reduction potential comes from improving energy efficiency, material efficiency, and product longevity—strategies applicable across all subindustries. They represent the most practical, cost-effective, and scalable approach and are therefore a no-regrets solution for all countries. Even if the power sector fails to decarbonize, the CO_2 reduction potential from these efficiency measures remains largely unchanged because such measures can reduce energy demand, material demand, or both.

Abatement potential: Pillar 1 abates 36 percent of industrial CO_2 emissions in China, 26 percent in Indonesia, and 29 percent in Viet Nam through efficiency measures alone **(FIGURE ES.2)**. Energy efficiency is the most important strategy, with the potential to reduce energy consumption by 13–19 percent for most industrial subsectors. Material efficiency can reduce material intensity of products by 5–24 percent depending on product type, with the highest achievable reductions for plastics and the lowest for pulp and paper. Product lifetime extension can cut demand by as much as 25 percent, depending on the subindustry.

Cost-effectiveness: Efficiency measures have the lowest capital costs because efficient technologies are relatively mature and often not capital-intensive relative to less efficient equipment. More importantly, efficiency measures cut energy use substantially, thus lowering energy costs. Overall, this pillar saves $223 per tonne of CO_2 in China, $196 per tonne in Indonesia, and $119 per tonne in Viet Nam. Savings are greatest in China and Indonesia because their 2050 projected energy prices for industrial firms are higher than those in Viet Nam.

Pillar 2 Scaling up electrification with renewable energy (Tiers 2a and 2b)

Direct electrification, powered by RE, is the best solution for most industrial process heat, given its favorable emissions impact compared to CCUS and its impressive efficiency compared to green hydrogen combustion. Implementing Tier 2a (using industrial heat pumps for low-temperature heat, electrifying nonthermal processes, and scaling up electric arc furnaces for scrap-based steelmaking) significantly reduces CO_2 emissions—especially when paired with grid decarbonization and distributed renewable energy solutions. Specific choices between grid-purchased electricity and captive installations depend on a range of factors, such as cost of acquired electricity and energy storage, electricity load demand profiles, type of industries, locations, and emission reduction needs. However, without a clean grid, Tier 2a has little effect on emissions, as 85–90 percent of the avoided emissions from the industrial sector are replaced by increased emissions from the electricity sector. Tier 2b (electrifying medium- and high-temperature heat) could even lead to an increase in CO_2 emissions in Indonesia and China, whose electric grids have higher carbon intensities than Viet Nam's. Therefore, renewable energy adoption must be scaled up alongside electrification measures to fully realize the decarbonization potential of electrification.

Abatement potential: Overall, Pillar 2 abates 32 percent of industrial CO_2 emissions in China, 53 percent in Indonesia, and 41 percent in Viet Nam **(FIGURE ES.2)**. These differences arise from differences in subindustry structure. Electrification plays a bigger role in Indonesia, which has a large food and beverage industry that is relatively easy to electrify. Electrification makes a smaller dent in Viet Nam's industrial emissions, much of which are cement process emissions, or China's, which primarily arise from heavy industries that require high temperatures. The highly efficient Tier 2a technologies deliver 24 to 35 percent of total abatement, while Tier 2b technologies achieve 8 to 18 percent of total abatement—provided that all electrification is backed by RE.

Cost-effectiveness: In this modeling, Tier 2a is modestly cost-saving, reducing expenses by $23 per tonne of CO_2 abated in China, $19 per tonne in Indonesia, and $5 per tonne in Viet Nam in 2050, meaning the annual energy cost savings more than offset the annualized capital investment required. In Tier 2b, the annualized capital and energy costs are $88 per tonne of CO_2 abated in China, $115 per tonne in Indonesia, and $104 per tonne in Viet Nam. In these cases, energy costs account for 49 to 58 percent of the total, while capital expenditures make up the remainder.

Pillar 3 Unlocking CCUS for hard-to-abate emissions in specific subsectors (Tier 3)

CCUS is a crucial technology for decarbonizing cement-making and for decarbonizing primary steelmaking through blast furnace retrofits, until alternative solutions (e.g., hydrogen direct reduced iron or electrolysis of iron ore) are commercially available. The cement industry is the largest energy-consuming sector in Viet Nam and currently depends on coal for over 80 percent of its energy. Cement is also among the top four energy-consuming sectors in Indonesia and China. CCUS plays a dual role in the cement industry, capturing both process emissions and those energy-related emissions that are not directly electrified. Meanwhile, CCUS also has significant downsides, including upstream emissions from fossil fuel extraction and processing, residual on-site emissions (since CCUS captures less than 100 percent of the formed CO_2), the risk of locking in fossil fuel–using equipment and infrastructure, the need for the industrial facility to be located near a suitable CO_2 storage site, and long-term risks of CO_2 leakage from underground storage (or the use of captured CO_2 in products that ultimately release that CO_2 when they are burned or decay).

Abatement potential: CCUS is responsible for 11–12 percent of total industrial abatement in China and Indonesia, and 19 percent in Viet Nam, where cement constitutes a larger fraction of the industrial sector **(FIGURE ES.2)**.

Cost-effectiveness: The annualized capital and energy costs for CCUS are $53 per tonne of CO_2 abated in China, $48 per tonne in Indonesia, and $46 per tonne in Viet Nam. Capital expenditures account for essentially all of the added costs, as spending on the additional fuels needed to power the CCUS process is offset by savings from avoided CO_2 emissions under the $50/tonne carbon price. CCUS's capital costs per tonne of CO_2 abated are the highest of all modeled technology tiers (inclusive of equipment to capture carbon, transport it by pipeline, and inject it underground), but its energy costs are low because carbon capture relies on fossil fuels, mostly coal, which is several times cheaper than electricity in China, Indonesia, and Viet Nam. While overall CCUS abatement costs are relatively low (lower than medium-to-high temperature electrification in Tier 2b or green hydrogen combustion in Tier 4a), they are unlikely to decline much further, whereas the abatement costs of electrification and hydrogen could decline significantly with renewable energy deployment and technological advancement.

Pillar 4 Closing the gap with green hydrogen and clean feedstocks (Tiers 4a and 4b)

Green hydrogen plays a crucial role in decarbonizing industrial processes requiring high-temperature heat that cannot be electrified. It also offers a vital pathway to shift from fossil-based to clean chemical feedstocks. In refining chemicals, nonmetallic minerals (cement and glass), and iron and steel, green hydrogen combustion provides emission-free heat (Tier 4a). In the chemicals industry, green hydrogen (alongside blue hydrogen and bioenergy) replaces hard-to-abate fossil-based feedstocks (Tier 4b). Green hydrogen is essential for decarbonizing ammonia and methanol where conventional hydrogen is already used. However, since green hydrogen is produced using renewables, the availability and affordability of clean power is essential to its decarbonization results. Green hydrogen is energy-intensive, costly, and technically complex, so it should be deployed strategically—where other decarbonization options are not feasible—to close the emissions gap.

Abatement potential: The contribution of green hydrogen combustion (Tier 4a) to total industrial decarbonization in the model is 11 percent in China, 5 percent in Indonesia, and 3 percent in Viet Nam (FIGURE ES.2). China's percentage is the largest owing to the country's major refining and chemicals subsectors. Meanwhile, transitioning to clean chemical feedstocks (Tier 4b) is responsible for around 6 percent of total abatement in China, 1 percent in Indonesia, and 3 percent in Viet Nam.

Cost-effectiveness: The annualized capital and energy costs for green hydrogen combustion (Tier 4a) are $198 per tonne of CO_2 abated in China, $341 per tonne in Indonesia, and $234 per tonne in Viet Nam, making it the most expensive abatement strategy. The differences in cost are largely due to differences in projected 2050 prices for clean hydrogen. In each country, over 80 percent of the cost is attributed to requirements for renewable energy and electrolyzers. Clean feedstocks

(Tier 4b) have costs of $157 per tonne abated in China, $239 per tonne in Indonesia, and $187 per tonne in Viet Nam. Clean feedstock economics are favorable compared to hydrogen combustion economics. First, clean feedstocks displace refined petroleum and natural gas feedstocks, defraying some of the cost. In contrast, much clean hydrogen combustion occurs at refineries, where it displaces low-value refinery fuel gas and petcoke. Second, in some cases, hydrogen feedstock use replaces costly grey hydrogen production (for instance, to make ammonia for fertilizers). That said, some clean feedstock technologies are not yet fully commercialized, so their economics are still uncertain.

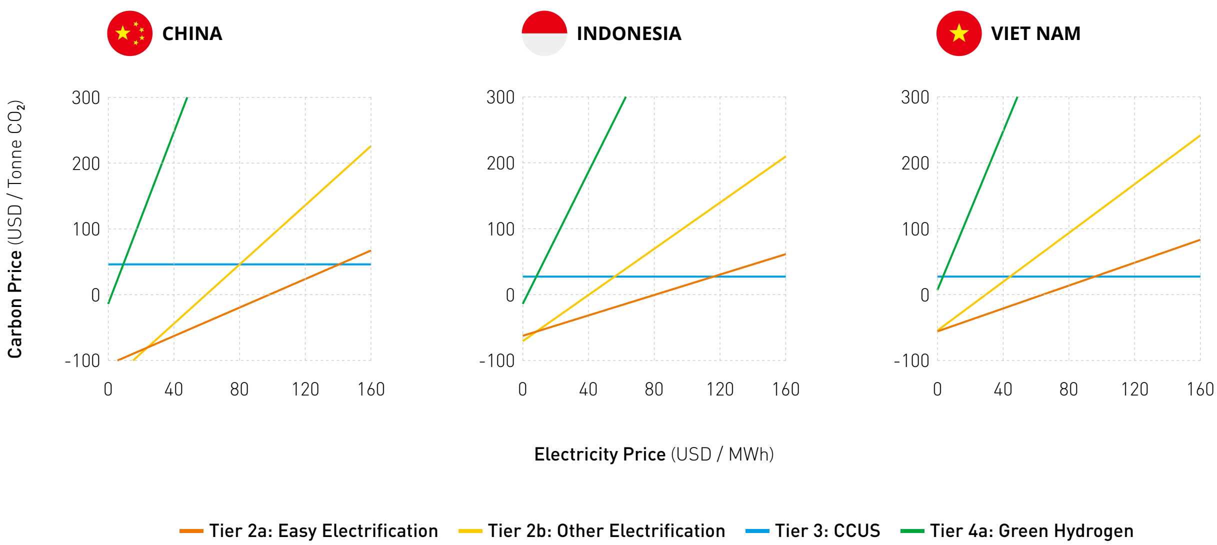
Electricity price and carbon pricing trade-offs

Achieving financial viability for clean industrial technologies is essential for scaling their deployment. Clean industrial investments must demonstrate a credible pathway to returns that meet or exceed those of conventional, high-emission production methods. Beyond addressing the higher upfront capital costs of clean technologies, it is equally important to narrow the operating cost gap between clean energy and fossil fuels. This report models targeted interventions—such as optimized electricity pricing and the introduction of carbon pricing mechanisms—to illustrate the trade-offs involved and the policy levers available to improve the competitiveness of low-carbon industrial solutions.

FIGURE ES.3 presents a theoretical modeling of the electricity and carbon price combinations required to achieve breakeven annual energy costs for selected clean industrial technologies in each modeled country. Taking Viet Nam as a representative case, the analysis shows that easy electrification (Tier 2a) measures are already cost-competitive at current electricity prices of $72/megawatt-hour (MWh) for industrial buyers, even with minimal carbon pricing. Other electrification measures (Tier 2b) would need carbon prices of approximately $100 per tonne of CO_2 to be cost-competitive at these electricity price levels or require significantly lower electricity prices. Electricity prices do not affect CCUS (Tier 3), as the process does not depend on additional electricity. Consequently, it can achieve breakeven annual energy costs at a carbon price of around $25 per tonne of CO_2. By contrast, green hydrogen combustion (Tier 4a) remains cost-prohibitive under current market conditions, requiring electricity prices of around $40/MWh and carbon prices of $250 per tonne of CO_2 to break even—levels not anticipated in the near term.[5]

[5] Electricity used to produce green hydrogen can be obtained at lower cost than typical purchased electricity because: 1. Dedicated renewable resources can be built for hydrogen production, and 2. hydrogen electrolyzers can be operated flexibly, producing more hydrogen in the hours of the day when electricity is cheapest and most abundant, and the hydrogen can be stored until needed. Therefore, $40/MWh electricity may be achieved for green hydrogen production even when the price of purchased electricity is higher.

FIGURE ES.3 Breakeven carbon pricing and electricity cost combinations in China, Indonesia, and Viet Nam



Note: *Technologies that deliver efficiency gains (Tier 1) are excluded, as they generate operating cost savings under virtually all pricing conditions. Tier 4b is also excluded, as feedstock-related emissions are typically realized downstream and are not subject to carbon pricing under current frameworks.*

While electricity market reforms and carbon pricing are critical to closing cost gaps, they may not be sufficient on their own, calling for targeted policy and market intervention. In cases where operating cost parity remains unattainable, governments may consider complementary instruments such as technology-neutral performance standards or product-based carbon-intensity benchmarks. Such measures would allow industrial producers to pass through incremental costs, enabling capital recovery while positioning domestic industry to remain competitive in international markets that are increasingly subject to carbon border adjustments.

Implementation Challenges | Energy, finance, technology, and jobs

Successful implementation of industrial decarbonization strategies relies on four distinct but interconnected foundations:

- Sufficient and cost-competitive clean power;
- Adequate and fit-for-purpose financing;
- Commercially viable and locally available technologies;
- A skilled workforce.

However, the readiness level of each of these foundations faces significant challenges in Asia-Pacific countries.

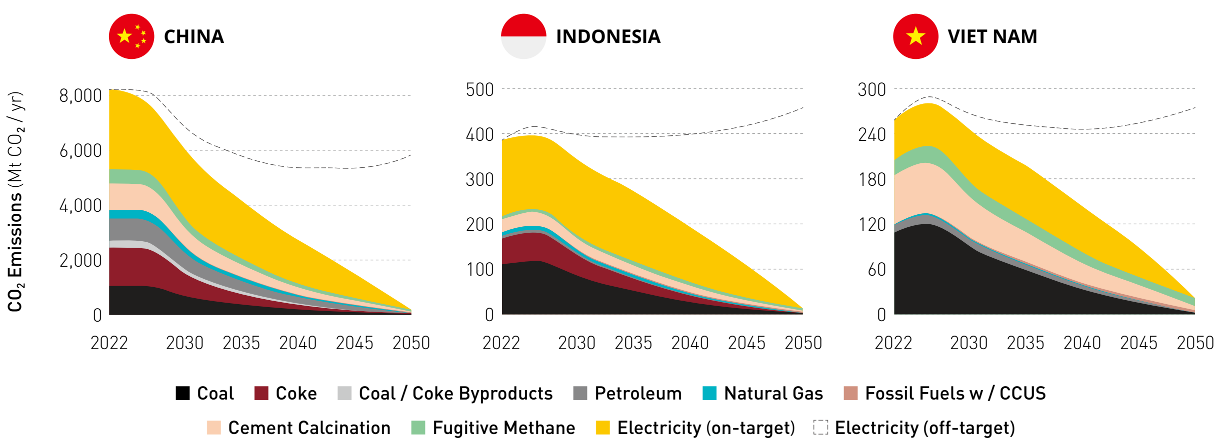
Energy: Sufficient and cost-competitive clean power

Countries in East Asia must scale up clean power to meet rapidly rising industrial demand for electricity over the next three decades, driven by economic growth and decarbonization. Modeling results indicate that for industrial emissions to approach net zero, even with strong improvements in energy and material efficiency (Pillar 1), Chinese industry will require 1.9 times as much electricity as it would in a future business-as-usual (BAU) scenario.[6] The corresponding figures are 1.5 times for Indonesia and 1.6 times for Viet Nam. However, many countries in the region lack the transmission infrastructure needed to reliably deliver low-carbon power to industrial users. In Viet Nam, renewable energy's growth has outpaced grid upgrades, leading to power shortages and clean energy curtailment. In Indonesia, industrial facilities like nickel processors are often far from major grids and rely on captive coal-fired plants. Cumbersome interconnection requirements further discourage industrial electrification at scale.

[6] The BAU scenario reflects a continuation of existing policies, such as today's carbon pricing or energy efficiency standards. Targets (such as each country's economywide net-zero targets) are not considered policies in this context. The net-zero targets are not achieved in the BAU scenario, as additional policies are required to reach these targets. The BAU scenario includes projected changes in industrial output and growth of electricity demand. In 2050, in the BAU scenario, the industrial sector demands 1.04, 1.8, and 3.1 times as much electricity as in 2022 in China, Indonesia, and Vietnam respectively.

All electricity must come from zero-emission sources if industrial decarbonization goals are to be realized. **(FIGURE ES.4)** shows that if power sector decarbonization targets are missed (e.g., not on track to decarbonize by 2050), direct emissions from industrial facilities would be offset by rising emissions from industrial electricity use (dotted line in figure). In fact, the East Asian region has some of the most coal-dependent power systems in the world: In 2022, coal accounted for around 61 percent of electricity generation in China, 62 percent in Indonesia, and 40 percent in Viet Nam. China is the world's largest coal consumer, responsible for more than half of global coal-fired power generation and continued to install 94.5 gigawatt (GW) of thermal power in 2024. Indonesia is the world's largest exporter of coal for power generation. Despite the growing share of renewable energy in the power mix, a substantial gap remains if industrial clean power needs are to be met in the region. To reach net-zero in China, Indonesia, and Viet Nam, rising industrial electricity demand must be powered by clean energy.

FIGURE ES.4 CO_2 emissions from industry and from electricity purchased by industry



The price of clean energy, and of electricity in general, combined with insufficient and unreliable power supply, is among the top barriers for the industrial clean energy transition. The cost of energy represents most of the abatement cost in identified strategies (apart from CCUS), and in most countries of the East Asian region, fossil fuels are far cheaper than electricity for industries. In China, at 2022 retail rates for industrial buyers, electricity cost eight times more than coal per unit of energy and more than twice as much as natural gas (although rates varied province by province). Part of the energy price differential in China comes from cross-subsidy policies, where industrial users pay around 40 percent more to subsidize the residential and agricultural sectors. In the United States and Europe, by contrast, industries benefit from lower tariffs owing to their stable and predictable load profiles and grid operators' need to maintain less electricity distribution infrastructure versus that required to serve widely distributed residences.

Fossil fuel subsidies distort market prices, making clean energy more expensive and less competitive. In 2022, explicit fossil fuel subsidies were $104 billion in China (1 percent of GDP), $34 billion in Indonesia (3 percent of GDP), and $33 billion in Viet Nam (5 percent of GDP) (IEA 2023a). When implicit subsidies, such as overlooking environmental and health costs, forgoing tax revenues, or direct funding support for fossil fuel projects are included, subsidies in China amounted to $2.2 trillion (12.5 percent of GDP), while Indonesia and Viet Nam each allocated over 14 percent of their GDP for the same purpose (Black et al. 2023). These price distortions risk delaying industry's shift to cleaner power, posing a major obstacle to decarbonization.

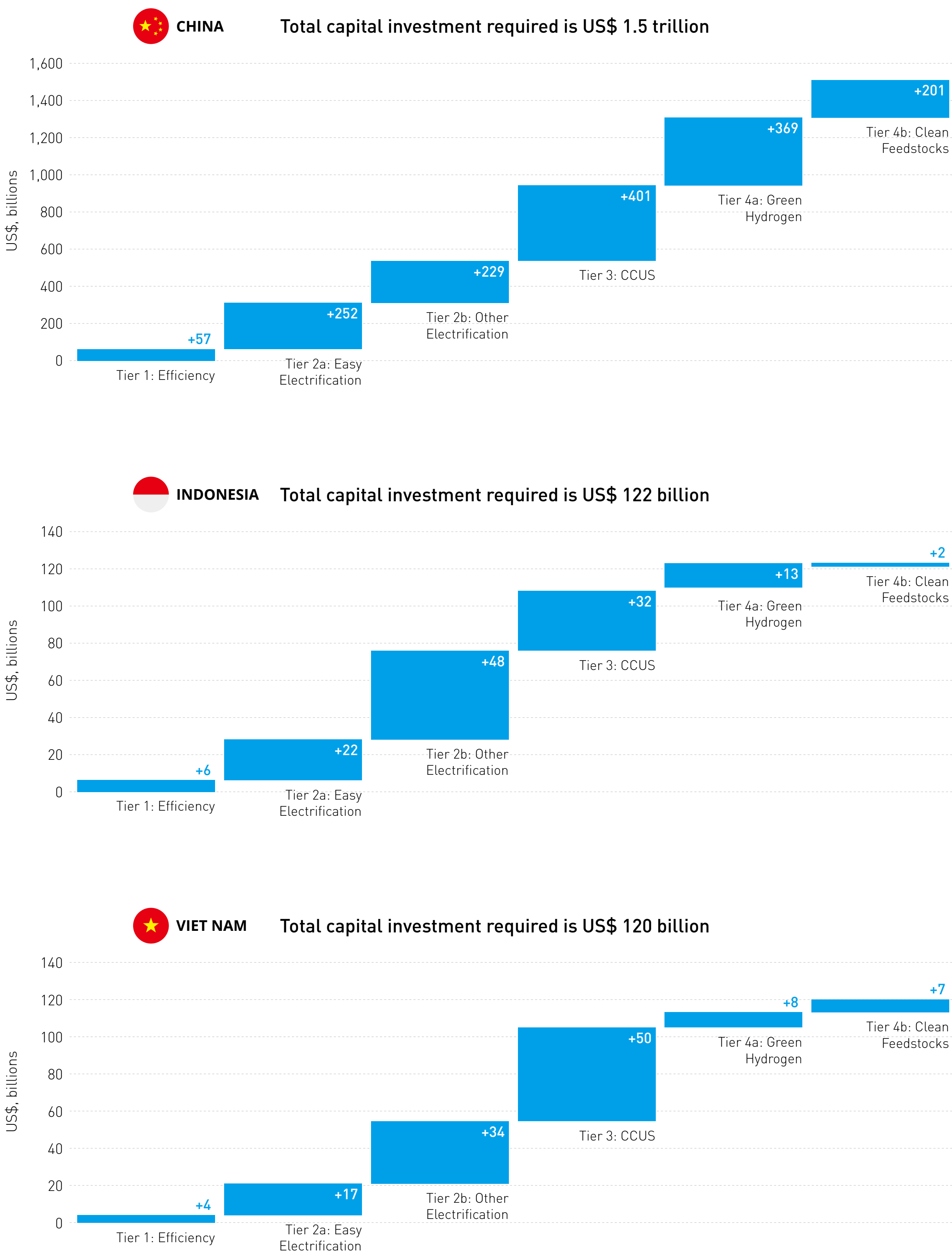
Finance: Adequate and fit-for-purpose

While the capital investments needed to decarbonize industry are significant, they yield substantial emissions reductions and long-term benefits. This study finds that China requires $1.5 trillion in capital investment, with Indonesia and Viet Nam needing $122 billion and $120 billion, respectively, to reach net-zero emissions in the industrial sector **(FIGURE ES.5)**. Over 25 years, this translates into an annual, inflation-adjusted need of $60 billion per year in China and $5 billion per year in Indonesia and Viet Nam. These figures refer to capital investments in equipment in the industrial sector and hydrogen electrolyzers, excluding additional capital investment in the electricity sector—such as renewable and clean power generation capacity, grid expansion and enhancement, utility scale energy storage and other renewable integration investments. These investments could deliver substantial emissions reductions—5.1 billion tonnes of CO_2 per year in China, 360 million tonnes CO_2 per year in Indonesia, and 371 million tonnes CO_2 per year in Viet Nam in 2050—at relatively low average capital costs per tonne of CO_2 abated.

Current financial flows in the East Asian region—both public and private—are insufficient to meet the scale of investment needed for industrial decarbonization. In 2022, only $52 billion (1.4 percent) of the finance was directed toward industrial decarbonization (Naran et al. 2024). Across the region, public investment is constrained by a sluggish post-COVID recovery and global economic uncertainty, especially concerning international trade, while private sector participation remains limited due to high perceived risks and delayed returns. The absence of a scalable public-private partnership framework and an enabling environment further hinders long-term private investment for both industrial decarbonization and supporting infrastructure. These factors collectively pose major barriers to mobilizing capital for a low-carbon industrial transition.

The complexity and diversity of industrial decarbonization strategies require highly tailored investment instruments that many financiers are ill-equipped to provide. Investments must align with the unique financing needs of the sector, including longer payback periods and higher risks associated with newly commercialized technologies. Industrial equipment, processes, and supply chains are complex, heterogenous, and unstandardized, requiring novel investment strategies and deep sector expertise (U.S. DOE 2023b). Successful investments within a facility often depend on their coordination with other investments in enabling infrastructure, including

FIGURE ES.5 Capital investment needed per tier in China, Indonesia, and Viet Nam to reach net-zero



renewable energy generation and grid expansion, hydrogen electrolyzers and pipelines, and CO_2 storage sites. These substantial investments require a comprehensive enabling environment.

Technology: Commercially viable and locally available

While many industrial decarbonization strategies are technically feasible, their adoption in the region remains limited owing to high upfront costs, constrained availability, and low market awareness. The limited uptake of clean technologies has resulted in a shortage of dependable, context-specific performance data for industrial firms. This information gap further reduces confidence in low-carbon industrial technologies and impedes their broader uptake. In addition, the weakness or absence of industrial standards for energy efficiency, emissions reduction, and robust monitoring, reporting, and verification (MRV) systems discourage investment in advanced technologies. More innovative technologies like thermal batteries, CCUS, green hydrogen, and clean feedstocks are still in the early stages for some applications, making research and development (R&D), demonstration projects, and early deployments critical for their commercialization.

Jobs: A skilled and robust workforce

A growing mismatch exists between the skills demanded by emerging industrial decarbonization jobs and those provided by current education systems. China's rapid energy and industrial transition, for example, is driving increased demand for professionals who can integrate technical expertise with decarbonization literacy, digital capabilities, and a strong understanding of regulatory frameworks at the local, national, and international levels. However, graduates of technical and vocational education and training (TVET) institutions—and even universities—are often not adequately prepared for real-world roles involving industrial energy management, carbon accounting, stakeholder engagement, or environmental compliance. This gap is further widened by the rise of hybrid roles such as carbon trading specialists and clean energy market analysts, which are becoming essential to the industrial transition. Bridging this skills gap is critical to developing a workforce capable of supporting large-scale industrial transformation. In addition, job creation opportunities from the industrial transition also depend on addressing supply chain challenges, including the current global concentration of key equipment manufacturing. Countries are increasingly adopting local content policies to build domestic capabilities and retain value-added jobs, though such policies may raise costs or delay deployment if domestic supply chains are underdeveloped.

The Policy Package

To align with East Asian countries' focus on industrial competitiveness, the policy package emphasizes on making key technical strategies viable and scalable. Recommendations are structured around the four enabling foundations—energy, finance, technology, and jobs—and include twelve actionable policies for the near, medium, and long term.

TABLE ES.2 summarizes the comprehensive policy package, with color bars to indicate the importance of the policy for enabling each technical pillar. Longer bars represent higher priority policies, while shorter bars represent lower-priority policies for each technical pillar.

TABLE ES.2 The industrial decarbonization policy package for East Asia

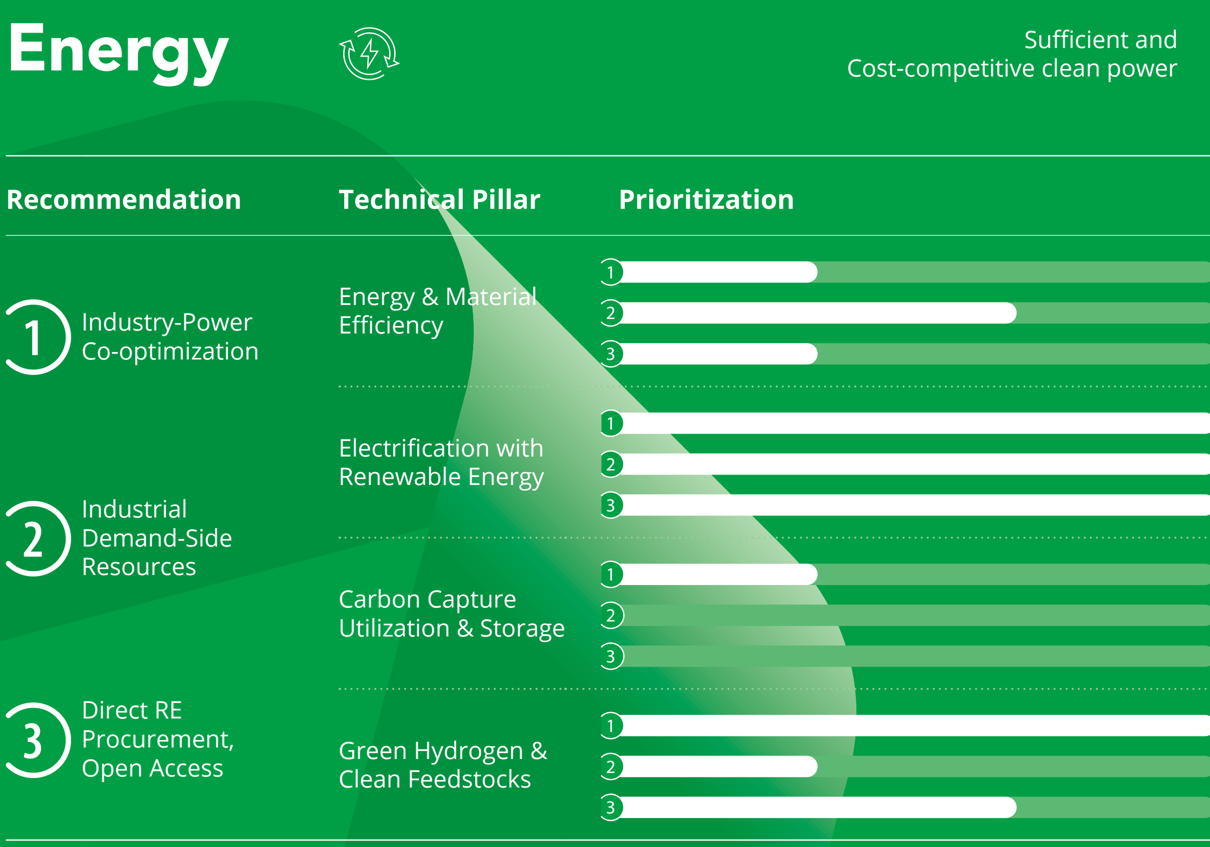
	Recommendation	Technical Pillar
Energy Sufficient and Cost-competitive Clean Power	1 Industry-Power Co-optimization 2 Industrial Demand-Side Resources 3 Direct RE Procurement, Open Access	Energy & Material Efficiency Electrification with Renewable Energy Carbon Capture Utilization & Storage Green Hydrogen & Clean Feedstocks
Finance Adequate and Fit-for-purpose	4 Cluster-Based Approach via Concessional Finance & PPP 5 Carbon Pricing & Carbon Finance 6 Derisking Instruments	Energy & Material Efficiency Electrification with Renewable Energy Carbon Capture Utilization & Storage Green Hydrogen & Clean Feedstocks
Technology Commercially Viable and Locally Available	7 Industrial Standards & MRV 8 Pilot Emerging Technologies & Business Models 9 Technical Assistance	Energy & Material Efficiency Electrification with Renewable Energy Carbon Capture Utilization & Storage Green Hydrogen & Clean Feedstocks
Jobs Skilled and Robust Workforce	10 Vocational Training 11 Digital & Interdisciplinary Competence 12 Workforce Transition Program	Energy & Material Efficiency Electrification with Renewable Energy Carbon Capture Utilization & Storage Green Hydrogen & Clean Feedstocks

Prioritization

Enabling the energy foundation

Electrification, green hydrogen, and clean feedstock strategies depend on substantial clean electricity tailored to different industrial needs, necessitating co-optimization between the industry and power sectors.

Sector coupling allows industrial firms to access reliable and affordable clean energy. At the same time, industries can contribute to grid expansion by investing in their own renewable generation and flexibility resources. Industries can also support grid stability by offering services such as load optimization and demand response. In return, they can benefit from compensation or preferential electricity rates. Realizing this synergy, however, requires integrated system planning, power market reforms, and coordinated development of industrial ecosystems.



Recommendation 1 Industry-Power Co-optimization

Balancing power system expansion with rising clean power demand from industrial electrification and green hydrogen is critical. Major low-carbon electrification projects—such as switching from coal-based blast furnaces to electric arc furnaces (EAFs)—can increase electricity demand dramatically. For example, producing one tonne of steel with an EAF using scrap requires around 530 kilowatt hours (kWh) of electricity, whereas a blast furnace that makes steel from iron ore gets almost all its energy from coal and coke, not electricity. If the EAF uses green hydrogen–based direct reduced iron (DRI) instead of scrap, total electricity demand can be up to 3.5 MWh per tonne of steel, with roughly two thirds powering the hydrogen electrolyzer and the remainder consumed by the EAF and ancillary equipment (Rissman 2024). These sharp, location-specific load increases require coordinated system planning and targeted expansion of renewable energy.

Early integration of clean hydrogen development into power grid planning is essential to prevent infrastructure bottlenecks in later stages. The cases of northern Sweden's green industrial hub and Saudi Arabia's green ammonia projects highlight the critical role of infrastructure planning in enabling industrial transformation projects. Large-scale electrolyzers introduce significant and often localized electricity demand. One million tonnes per year of green hydrogen production requires about 10 GW of electrolyzers and 20 GW of RE (World Bank 2025a). The localized surge in demand from hydrogen production requires aligning the siting of production with proactive grid upgrades, efficient connection processes, and integration of renewable energy. Such coordination is essential to avoid congestion in transmission lines, ensure timely access to power, and maintain system reliability.

Optimizing existing grid infrastructure through grid-enhancing technologies should be prioritized to support early industrial decarbonization. Enhancing current infrastructure before pursuing major grid expansion investments—which often take longer to materialize—offers a more cost-effective and strategic approach. Amid the increased integration of renewable energy, technologies such as dynamic line ratings, advanced power flow control, and topology optimization become vital. These tools improve real-time power flow management, boost grid flexibility, and unlock additional capacity, helping to meet short-term demand and maintain system stability. In the long term, combining targeted deployment of grid-enhancing technologies with strategic grid expansion is optimal for supporting renewable growth and ensuring a resilient energy transition.

Recommendation 2 Industrial Demand-side Resources

Industries offer significant demand-side resources that can mitigate rising electricity needs from decarbonization while providing valuable grid services. These include demand response, distributed energy resources, energy storage, and load optimization. When well-supported, these resources can reduce peak demand, defer infrastructure investments, and improve system efficiency. Their impact is further enhanced when aggregated through virtual power plants (VPP), which enable coordinated participation in energy markets that benefit large-, medium-, and small-sized industries.

Unlocking industry-grid synergy via demand-side resources requires a shift in mindset and strengthened digital infrastructure. Flexibility must be seen not as a disruption but as a strategic asset. Effective coordination between the industrial and power sectors depends on advanced digital management tools that enable real-time integration and optimization—using sensors, control systems, and automation to enable real-time energy management, as well as energy storage systems such as thermal batteries to allow industrial facilities to continue steady operations while being flexible in their electricity consumption. While these technologies increase responsiveness, their high cost remains a barrier. Accelerating adoption will require targeted investments, supportive policies, and access to affordable financing.

Power market design plays a critical role in making industrial demand-side participation viable. Dynamic pricing mechanisms—like time-of-use rates or real-time pricing—are essential to incentivize flexible energy use. Experience in the United States and Europe shows strong industry engagement when reductions are monetized through wholesale or flexibility markets. Meanwhile, China is rapidly shifting toward market-based pricing mechanism to liberalize renewable electricity generation and enhance the flexibility market. This report's analysis of Viet Nam's power market for industrial demand side resources shows that its current policy framework for demand response has key gaps in both incentive design and regulatory adaptability (Appendix B). Strengthening financial incentives for industrial consumers via market-based mechanisms would significantly enhance program effectiveness and align consumption behavior with evolving grid needs.

Recommendation 3 Direct Renewable Energy Procurement and Open Access

Corporate procurement of renewable energy is a powerful lever for industries to secure its supply at market prices. This report's in-depth look at industrial electrification in China (Chapter 6) shows that green electricity certificates (GECs) have become a key mechanism to certify renewable energy use and support environmental, social, and governance reporting. Recent policies have strengthened the GEC framework by expanding eligibility to all renewable sources and introducing mandatory green power quotas for high-emitting industries. In Viet Nam, a direct power purchase agreement pilot program launched in 2024 enables large electricity consumers to directly procure renewable energy from independent power producers, marking a significant step toward liberalizing the power market and accelerating corporate clean energy adoption.

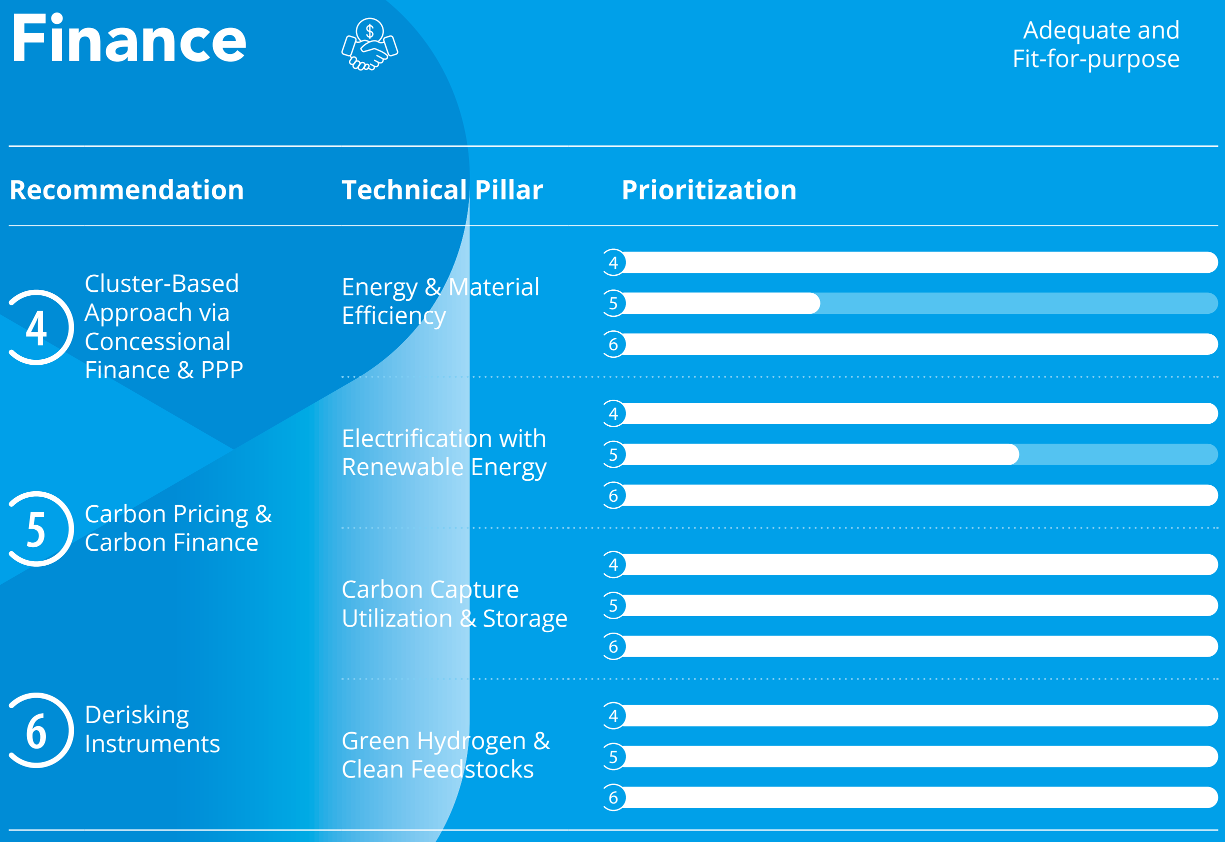
Open-access policies are critical enablers of industrial decarbonization, allowing companies not only to procure renewable energy via power purchase agreements, but also to develop their own renewable generation capacity and contribute to grid expansion. The report's case study on India demonstrates how such policies empower both large- and medium-sized industries to invest in substantial renewable energy generation projects to reduce emissions and enhance energy security. By enabling long-term power purchase agreements, open access helps de-risk renewable investments, improve cost predictability, and accelerate clean energy deployment. These policies not only advance industrial sustainability but also foster greater competition and innovation within the power sector. The Swedish case further highlights the critical role of open access policy in enabling zero-carbon industrial transformation by securing vast renewable energy supply at competitive prices.

To strengthen corporate renewable energy procurement and open access as a tool for industrial decarbonization, certain improvements in market design and policy are essential. In China, the green electricity certificate market faces several challenges, including oversupply, low prices, limited international recognition, and the risk of double counting of green electricity certificates and carbon credits. Key policy enhancements could include implementing differentiated pricing mechanisms by region and technology to reflect the true value of green power, addressing rebound effects through parallel energy efficiency initiatives, and improving the transparency and credibility of green electricity certificates to meet international standards. Establishing a clear separation between carbon and green electricity certificate markets, along with streamlined rules to prevent double counting, will help build trust and support global recognition. With the right policy framework, both GECs and direct power purchase agreements can drive stronger corporate investment in renewable energy and accelerate industrial decarbonization.

Enabling the finance foundation

By rethinking how clean technologies are deployed and financed, innovative business and financial models can improve the commercial viability of low-carbon solutions and accelerate adoption across the value chain.

Meanwhile, financial strategies must be tailored to the diverse and complex needs of each technical pathway, rather than relying on undifferentiated increases in funding volumes. Models such as cluster-based decarbonization support scalable and viable industrial decarbonization projects. Long-term concessional finance, combined with deep sector expertise, enables systemwide investments across industrial clusters and shared infrastructure like clean power, hydrogen, and CCUS (IEA 2021b). For small and medium enterprises (SMEs), derisking mechanisms incentivize private capital. Additionally, hybrid carbon price and carbon finance tools help to create strong market signals and ensure fair competition while also delivering upfront capital and revenue certainty for industrial decarbonization investments.



Recommendation 4 Clustered-Based Approach via Concessional Finance and Public Private Partnership

The cluster-based approach offers a powerful pathway to accelerate industrial decarbonization by leveraging geographic proximity to enable shared infrastructure, coordinated planning, and aggregated demand across co-located industries. The approach not only reduces costs and mitigates risk but also fosters innovation and systemwide efficiency (IEA 2021b). Compelling examples are offered in this report, including Norway's zero-carbon cement production (enabled by a CCUS hub), and China's emerging zero-carbon industrial parks, which supply 80–100 percent green electricity through dedicated renewable energy, energy storage, and demand optimization across firms.[7] In addition, these clusters can offer traceable green electricity and carbon abatement certificates through shared energy and carbon management digital platforms, enhancing firms' global competitiveness (World Economic Forum 2025). These cases demonstrate how clustering can enable collective transitions that would be difficult for individual firms to achieve independently. However, realizing the full potential of cluster-based decarbonization requires moving beyond isolated pilots to scalable and replicable models.

Public-private partnerships are essential for the acceleration of cluster-based decarbonization that can be activated through supportive regulation, anchor projects, and collective financing. First, enabling regulatory frameworks that facilitate joint investment in shared low-carbon infrastructure, such as carbon transport and storage networks, hydrogen hubs, and centralized renewable energy systems, should be established. Second, anchor projects with long-term offtake agreements that reduce market uncertainty for first movers and create a strong demand signal for follow-on investments across the cluster should be identified and supported by public and private consortia. Third, blended finance mechanisms must be deployed in a coordinated manner—including contracts for difference, innovation grants, and concessional loans—to de-risk early-stage technologies and bridge the commercial viability gap. International financial institutions (IFIs) can also play an important role in financing and investing in common-use infrastructure in these industrial clusters. By aligning regulation, finance, and industrial planning, policy makers can unlock the full benefits of cluster-based decarbonization and position industrial parks as engines of low-carbon growth.

Recommendation 5 Carbon Pricing and Carbon Finance

A hybrid carbon-pricing approach—combining explicit and implicit instruments—offers a pragmatic and effective pathway to narrow the decarbonization cost gap. Explicit tools such as carbon taxes and emissions trading systems directly assign a cost to greenhouse gas emissions, creating strong financial incentives to reduce them. While effective, these instruments can face

[7] For details, see Chapter 4: Case Studies of International Industrial Decarbonization in the full report.

political resistance and implementation challenges. Implicit measures—including fuel excise taxes, as well as removing fossil fuel subsidies and tax differentials—though not always labeled as climate policies, still influence carbon-intensive behaviors by shifting relative energy costs. Integrating both explicit and implicit mechanisms enables governments to uncover hidden incentives, close policy gaps, and develop more balanced and context-sensitive carbon pricing frameworks.

Aligning with international carbon pricing mechanisms—such as the Europe's Carbon Border Adjustment Mechanism—can accelerate export-oriented industrial decarbonization in developing countries by reshaping market incentives and safeguarding the competitiveness of low-carbon industries. Predictable and gradually rising carbon prices help firms plan compliance strategies and invest in cleaner technologies. To effectively align with Europe's Carbon Border Adjustment Mechanism and similar international measures, developing countries must establish credible MRV systems. Robust MRV frameworks are essential for accurately tracking emissions, demonstrating compliance and ensuring transparency. In addition, complementary financial instruments such as green bonds and carbon contracts for difference can mobilize upfront capital and provide long-term revenue certainty to support industrial decarbonization efforts.

Recommendation 6 Derisking Instruments

Small and medium-sized enterprises (SMEs) account for nearly half of the regional economy yet often struggle to access finance for decarbonization and competitiveness upgrades. Risk-sharing facilities are effective instruments to unlock finance for SMEs pursuing low-carbon technologies, particularly in the East Asian region, where access to credit remains constrained. By reducing lender risk through publicly funded guarantees, risk-sharing facilities enhance the bankability of clean technology investments. India's Partial Risk Sharing Facility, supported by the World Bank, has successfully mobilized sizable commercial financing for SME energy efficiency projects. However, the impact of such mechanisms depends not only on sound design but also on effective execution. Strong capacity building for financial institutions and SMEs—alongside technical assistance—is essential to ensure proper risk assessment, infrastructure development, and long-term sustainability.

Enabling the technology foundation

Effective energy efficiency and emissions standards—underpinned by reliable data and robust enforcement—create the regulatory certainty needed to accelerate the deployment of both mature and emerging technologies.

Targeted pilot projects and technical assistance further support the localization and commercialization of innovative solutions, helping bridge the gap between technical viability and market adoption.

Technology

Commercially viable
and Locally available

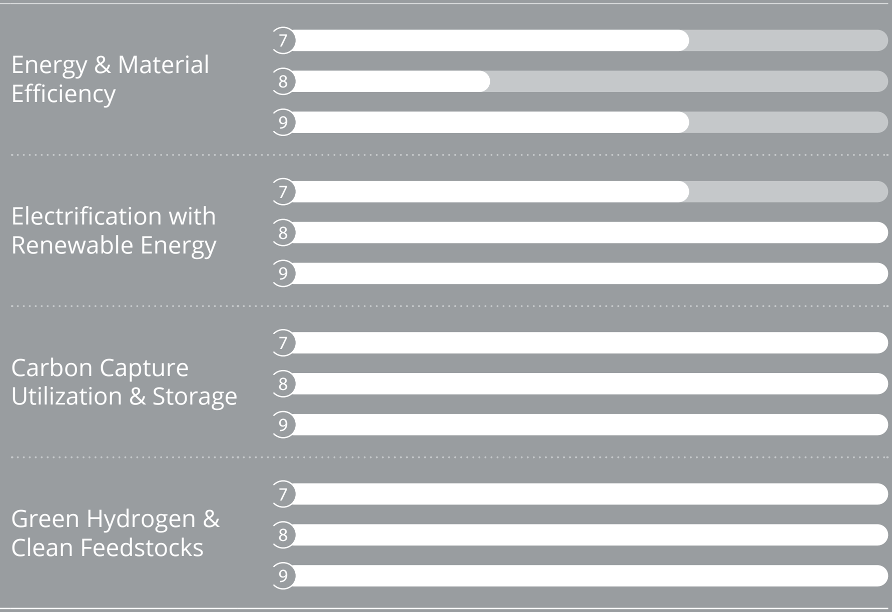
Recommendation

7 Industrial Standards & MRV

8 Pilot Emerging Technologies & Business Models

9 Technical Assistance

Technical Pillar / **Prioritization**



Recommendation 7 Industrial Standards and MRV system

Industrial standards play a critical role in supporting decarbonization by providing clear technical benchmarks and regulatory certainty. Energy efficiency and emissions standards drive the adoption of cleaner technologies and operational improvements, while emerging areas like CCUS require standardized protocols to ensure safety, reliability, and environmental integrity. Similarly, green hydrogen development depends on robust safety and handling standards to build investor and public confidence. Establishing and enforcing such standards reduces technical and financial risks, fosters market trust, and accelerates the scale-up of low-carbon solutions across industrial sectors.

Without reliable data, the enforcement of standards becomes weak, affecting the impact of decarbonization policy. A robust MRV system is therefore critical for the effective implementation of energy efficiency and emission standards. It ensures compliance, enables performance tracking, and builds confidence among investors and regulators. China's experience demonstrates this clearly—its Top-1,000 and Top-10,000 energy efficiency programs were anchored by a standardized MRV framework that required enterprises to submit verified annual energy data. This enabled data-driven policy adjustments, facilitated benchmarking across industries, and directed financial support to high-performing firms, leading to notable improvements in industrial energy intensity.

Recommendation 8 Pilot Emerging Technologies and Business Models

Targeted piloting of innovative technologies and business models accelerates the commercialization of emerging technologies in hard-to-abate sectors. Strategic pilots—such as thermal battery storage, CCUS in cement, and clean feedstocks in the chemicals industry—can validate technical performance, reduce costs, and de-risk future investments. Pilot projects also support building local capacity and facilitating international collaborations. A few high-impact pilot projects can guide action, as described below.

- **Thermal battery technology:** Commercializing thermal batteries offers a potentially cost-effective, scalable way to decarbonize heat-intensive industries. These systems store heat from low-cost electricity—up to 1,700°C—for later use (Rissman and Gimon 2023). In China, for example, heat makes up 90 percent of industrial fossil fuel use, indicating a large potential market. Thermal batteries not only reduce electricity costs for industrial firms but also support grid stability and clean energy deployment by absorbing excess renewable energy and giving utilities a financial return on this electricity that otherwise might have been curtailed.

- **CCUS hub:** By clustering emissions-intensive industries—such as refineries, cement plants, and power stations—CCUS hubs unlock economies of scale, significantly reducing the unit cost of CO_2 transport and storage. Co-location creates synergies by optimizing shared infrastructure and supply chains, while existing industrial hubs can seamlessly transition to incorporate CCUS.
- **Clean feedstocks:** Piloting green hydrogen for ammonia and fertilizer production may replace fossil-based hydrogen. Fertilizer markets offer stable demand, making them ideal early adopters of green hydrogen. Pilots also facilitate testing RE integration of the fertilizer industry, build operational expertise, and inform supportive policies like subsidies and offtake agreements. In the longer term, pilots using green hydrogen and captured carbon or bioenergy to produce petrochemicals such as methanol, olefins, and aromatics will be key to decarbonizing the rest of the chemicals value chain.

Piloting innovative models like clean-energy-as-a-service is key to accelerating industrial decarbonization and complements traditional approaches for deploying technologies such as industrial heat pumps. In the heat-as-a-service (HaaS) model,[8] the technology provider or an energy service company (ESCO) owns, installs, operates, and maintains the system, while the industrial customer pays a fixed or performance-based rate for the heat delivered. This structure reduces the upfront capital burden for end users, lowers financial risk, and incentivizes efficient system performance. When combined with renewable energy procurement and infrastructure services, such as dedicated substations or independent power feeds, HaaS models can further stabilize energy costs, enable flexible siting, and unlock new innovative business models for ESCOs.

Recommendation 9 Technical Assistance

Targeted technical assistance is key to building local capacity, fostering research, development and demonstration (RD&D) ecosystems, and enabling international knowledge exchange. As low-carbon technologies and business models remain nascent in most East Asian countries, technical assistance is essential to accelerate their commercialization. Support should focus on strengthening local capacity through research training and certification programs for industrial standards development, MRV system implementation, and the deployment of innovative technologies and business models. In parallel, technical assistance should help shape an enabling policy environment that incentivizes investment in cost-effective, low-carbon solutions. Finally, fostering international collaboration—through knowledge exchange, joint RD&D, and technology transfer—can facilitate the adoption of global best practices, promote adaptation to local conditions, and scale up the deployment of advanced technologies across the region.

[8] For an in-depth discussion, please see Appendix B: "Policy Recommendations for Electrification of Industrial Heating: Focus on Heat Pumps and Financing Mechanisms."

Enabling the jobs foundation

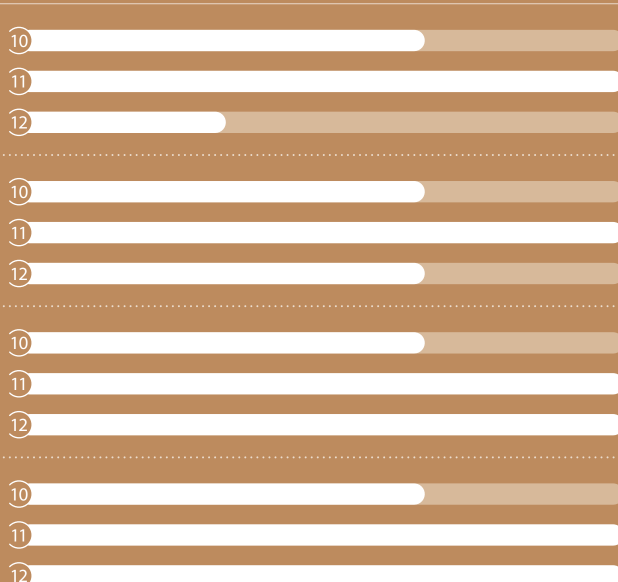
Enhanced vocational training, upskilling for digital and interdisciplinary competence, and targeted workforce transition programs are key enablers of industrial decarbonization.

Workforce development is not only essential for ensuring a socially equitable transition—particularly in regions with concentrated fossil-dependent employment—but also a strategic investment in industrial productivity and competitiveness, especially in emissions-intensive sectors undergoing digital and technological transformation. To ensure real-world uptake, these efforts must be embedded in concrete institutional delivery mechanisms, integrated financing strategies, and demand-side labor absorption tools.

Jobs

Skilled and Robust workforce

Recommendation	Technical Pillar	Prioritization
10 Vocational Training	Energy & Material Efficiency	
11 Digital & Interdisciplinary Competence	Electrification with Renewable Energy	
12 Workforce Transition Program	Carbon Capture Utilization & Storage	
	Green Hydrogen & Clean Feedstocks	



Recommendation 10 Vocational Training

Vocational training must evolve beyond mechanical or electrical basics to incorporate green competencies such as energy management, carbon accounting, energy and carbon market literacy, and safety protocols for clean technologies. To align vocational training with decarbonization goals, policy makers should define high-potential job families—such as retrofit technicians, energy auditors, carbon accounting analysts, and hydrogen safety specialists—and establish national green skills certification authorities and sectoral skills councils with formal mandates to revise curricula accordingly. Institutionalizing partnerships between policy makers, industry, and training providers is essential to ensure that training remains relevant to evolving market demands, with regular updates to curricula and structured apprenticeships embedded in green infrastructure and industrial transformation projects. In Indonesia, efforts are already underway to better align training with industry needs in green manufacturing and energy. These efforts are exemplified by Stranas Vokasi—the National Strategy for Technical and Vocational Education and Training (TVET) Reform—and the establishment of the National Team for TVET Coordination. In addition, linking vocational reform efforts to climate finance through industrial transition funds, or results-based grant instruments, will support training at scale, especially in emerging industrial clusters.

Recommendation 11 Digital and Interdisciplinary Competence

The workforce must be both digitally fluent and interdisciplinary to meet the demands of a decarbonizing industrial sector. Industrial decarbonization requires professionals capable of navigating complex, data-driven systems that span engineering, environmental science, and policy. This calls for embedding digital fluency, systems thinking, and sustainability across vocational, tertiary, and continuing education systems. Applied research universities and TVET institutes, especially in second-tier cities with industrial clusters, have a central role in delivering continuing education and lifelong learning, cultivating mid-level professionals, who can integrate production, compliance, and innovation functions. Policy makers should incentivize the co-development of curricula between industry and academic institutions and support flexible delivery mechanisms, including modular, stackable credentials that bridge sustainability, data systems, and regulatory compliance.

Recommendation 12 Workforce Transition Programs

A targeted workforce transition strategy is essential to prioritize the reskilling of the labor force and to prevent the deepening of social and regional inequalities during the industrial transition. In China, for instance, the decline of fossil-intensive sectors has disproportionately affected provinces like Shanxi and Inner Mongolia, where automation further reduces the availability of low-skilled jobs. Similar dynamics are emerging in Indonesia, where coal-dependent provinces such as East Kalimantan are facing employment vulnerabilities due to shifting energy priorities. In Viet Nam, workforce skilling gaps are particularly acute among SMEs and in rural industrial zones, where access to reskilling opportunities remains limited. Targeted reskilling programs—including through mobile learning platforms to reach workers in underserved regions—are needed to support displaced workers in transitioning to cleaner roles. Performance-based reskilling grants, co-financed through blended finance instruments and tied to verifiable employment outcomes, and demand-side hiring incentives, such as wage subsidies or tax credits for firms that absorb retrained workers, can help scale these efforts. Embedding labor strategies into industrial and infrastructure investment planning is therefore critical across the region to ensure that workforce transition advances in parallel with decarbonization goals.

The World Bank Playbook | Operationalizing country and regional actions

The comprehensive policy package in this report provides a playbook for tackling the core challenge of industrial decarbonization in the East Asian region.

Informed by technical modeling, grounded in global best practices, and validated through in-depth stakeholder consultations, the report offers practical solutions for governments, industry leaders, power sector actors, and other stakeholders. Each country can tailor its implementation strategy by selecting a combination of approaches that align with its national industrial priorities and socioeconomic conditions.

Distinct opportunities exist across the region, shaped by each country's economic and industrial structure.

For instance, China can accelerate the development of zero-carbon industrial parks by reforming power markets to incentivize investments in industrial demand response, battery and thermal storage, distributed RE, electrification, and virtual power plants. China is also well placed to lead global efforts in clean feedstock production and utilization. Indonesia can accelerate investment to tap into its significant energy efficiency and industrial electrification potential, while expanding renewable energy for both grid-connected and dedicated industrial use. Viet Nam, in addition to continuing efforts on industrial energy efficiency, can adopt high proportion clean power for new electric arc furnaces in steelmaking and for electrifying other industrial processes. Viet Nam can also pilot strategic clean ammonia projects to reduce reliance on imports.

With a well-coordinated combination of public policy and targeted financing, East Asia is well positioned to lead the global shift toward clean and competitive industrial systems.

The World Bank, with development partners, is committed to accelerating industrial decarbonization in the region through strategic policy and financing support. This includes investing in critical infrastructure—such as low-carbon power systems, green hydrogen, and CCUS—while de-risking clean technology deployment through blended finance and private capital mobilization. World Bank technical assistance also helps governments strengthen institutions, create enabling policies, and foster market demand for low-carbon industrial products. Through global expertise and concessional financing, the World Bank aims to catalyze transformative projects that drive competitiveness, job creation, and a sustainable, inclusive future.

Lastly, the report's open-source model supports countries' use of data and policy analytics to accelerate industrial transition.

It underscores the commitment of the World Bank and its partners to advancing the global knowledge agenda on industrial decarbonization and mutual learning.

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