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SHANGHAI CLIMATE WEEK
上海气候周

CLIMATETECH IN FOCUS
INNOVATIONS FOR A GREENER SUPPLY CHAIN

Contents

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Shanghai Climate Week aims to advance climate action and sustainable development through innovation and collaboration. Rooted in the “China Action, Asia Voice, Global Standard” principles, we are committed to elevating practical solutions to address global climate challenges and shaping international standards for green development. Our annual flagship report, ClimateTech In Focus, jointly developed with UNITAR and PECC, amplifies our advocacy for comprehensive climate solutions integrating technological innovation with sustainable practices. This year, the report offers insights and forward-thinking strategies for cultivating environmentally responsible and efficient supply chains.

Executive Committee & Institute of Research
Shanghai Climate Week

As the Youth Council of Shanghai Climate Week, we are proud to have shaped this year’s ClimateTech In Focus report with cutting-edge technical insights, leadership connections, and innovative foresight. Our contributions highlight the indispensable role young people play in advancing sustainable supply chains and climate solutions. We urge youth worldwide to harness their innovation and creativity to drive collective action for a sustainable future.

Youth Council
Shanghai Climate Week

SHANGHAI CLIMATE WEEK
上海气候周

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Preface I

Nine years ago, the world embraced an ambitious journey by adopting the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs). These goals provided a globally recognized roadmap that called upon nations to harmonize the needs of people and the planet. Countries and regions are united around a shared commitment to foster sustainable development and to work toward a more equitable and prosperous future for all.

However, as we cross the midpoint of the 2030 Agenda, the reality is clear: we are falling far short of our ambitious targets. The Intergovernmental Panel on Climate Change (IPCC) has sounded an urgent alarm. With global temperatures already 1.1°C above pre-industrial levels, we are rapidly approaching the critical threshold of 1.5°C—expected to be surpassed by 2035—potentially plunging us into a state of “global boiling.” Despite notable advancements in green technology, global action remains hindered by hesitation, blame-shifting, and insufficient collaboration. Now, more than ever, we need governments, financial institutions, innovators, and academics to unite in response to humanity’s greatest challenge.

This year’s report spotlights the greening of the supply chain—a vital theme that translates the ambitious goals of climate action into tangible outcomes that directly impact our work and daily lives. The supply chain is a critical nexus where climate change, market forces, technology, and economic interests converge. In line with the mission of the United Nations, we are committed to exploring how climate technology can unlock new leadership opportunities and generate meaningful employment. As the research and training arm of the United Nations, the United Nations Institute for Training and Research (UNITAR) focuses on assessing the integration of new technologies in manufacturing and energy systems and determining whether our social frameworks and learning ecosystems are equipped to ensure educational equity and help talent adapt to this rapidly changing landscape.

This report provides valuable insights into the transformative role of ClimateTech in reshaping global supply chains. Through in-depth case studies and dialogues with global leaders across industries, we hope to bring the climate crisis to the forefront for our readers and explore practical solutions that inspire decisive, collective action. It is only through such concerted efforts that we can foster a broader consensus on the urgency of addressing these challenges together.

While the future may be uncertain, it holds immense potential. The United Nations will continue strengthening its collaboration with diverse stakeholders to collectively achieve the 2030 Agenda for Sustainable Development. We have always called for united global action to ensure a livable, thriving planet for future generations. Together, we can turn this potential into reality.

Nikhil Seth
Assistant Secretary-General, United Nations
Executive Director, United Nations Institute For Training and Research

Preface II

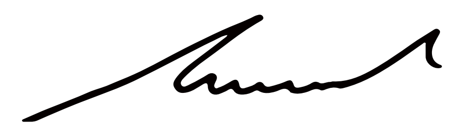
While crafting this report and engaging with world leaders from various sectors to explore the transformation of supply chains and the future of climate change, I was repeatedly struck by the urgency of achieving a sustainable future: we must act now and act together. The Pacific Economic Cooperation Council (PECC) has long championed sustainable development in the Asia-Pacific region, and our relentless efforts reflect our unwavering commitment.

PECC’s core mission is rooted in the understanding that sustainability is the foundation of global survival and prosperity. We recognize Asia-Pacific’s unique and tremendous potential to advance sustainable practices and are dedicated to further boosting this potential for the benefit of all. Our work promotes policies, fosters dialogue, and encourages actions to ensure a future where economic growth and environmental conservation go hand in hand.

Global technology and innovation serve as beacons of hope in the face of climate change. ClimateTech is not a fleeting trend confined to laboratories; it stands as one of the most promising avenues for humanity to tackle climate change and drive sustainable progress. We are heartened to see many technological innovations moving from labs to factories, industrial zones, markets, communities, and homes, making a lasting, tangible impact on our fight against climate change. PECC will continue actively supporting and nurturing these advancements, endorsing projects that push technological innovations and sustainable solutions. Our region can become a global leader in green technology and sustainable practices through collaboration and knowledge sharing.

In the previous PECC report, “*State of the Region 2023-2024*,” we surveyed the current status of the Asia-Pacific and identified “*Strengthen Supply Chain Resilience*” and “*Update the region’s ambitions on climate and clean energy*” as two prominent strategic priorities. This report, “*ClimateTech In Focus: Innovations for a Greener Supply Chain*,” provides an in-depth perspective of these priorities by diving into the origins of green supply chains, the market landscape of ClimateTech, and the potential for significant impact in key areas. Additionally, it analyzes the critical roles that finance, education, and infrastructure play in driving progress and offers actionable recommendations. Through this in-depth study, we call on all stakeholders to collaborate in promoting sustainable practices and implementing actionable initiatives.

We find ourselves at a decisive moment in history, where our actions today will shape the legacy we leave for future generations. I sincerely hope that as the region moves towards our vision of sustainability, participants can be inspired by the collective efforts of our region, working together to create a future that is not only sustainable but also prosperous.



Antonio Basilio
Chairman, Pacific Economic Cooperation Council
Philippine National Committee
Director, APEC Business Advisory Council

Preface III

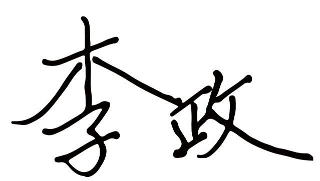
Climate change presents a significant, long-term, and multifaceted challenge for humanity. A global green revolution is quietly emerging, leveraging the transition to a green economy to drive sustainable, high-tech, and high-quality development. Rising temperatures and the increasing frequency of extreme weather events lead to biodiversity loss, ultimately threatening human survival and development. Additionally, geopolitical tensions and unilateral actions exacerbate the challenges posed by climate change.

Countries have implemented various measures to address the climate crisis. For China, achieving carbon peak and neutrality goals is both a significant challenge and a major opportunity. Balancing emission reductions with development requires substantial effort, promoting innovative practices while ensuring energy security aligns with the carbon peaking and neutrality objectives. The end goal of sustainability strategies should not only focus on low-carbon issues but also aim to build a fair, prosperous society and a competitive, green, low-carbon economy. The ultimate goal is to enhance human sustainable development, which holds profound economic and social significance.

As the premier climate action platform for Asia and developing countries, Shanghai Climate Week's efforts have advanced climate change progress in technological innovation, social consensus, and youth empowerment. We have brought together over 1,000 government entities, businesses, academic institutions, international organizations, and financial institutions during 2024 Shanghai Climate Week to engage in dialogue and seek effective solutions. Looking ahead, the ClimateTech In Focus series of reports will spearhead our thought leadership in exploring how different parties can advance climate technology development and drive sustainable transformation through innovation with a future-oriented perspective.

As the inaugural report for the series, it has engaged over 50 public and private sector leaders worldwide in examining the green development pathways of supply chains across policy, technology, finance, education, and talent dimensions. In addition, a dozen industry best practices have been included as case studies, which aim to inspire and provide readers with tangible examples of leveraging climate technology innovation in green supply chains.

We look forward to more partners' participation in building a green supply chain and jointly promoting sustainable development. Through cross-national, cross-industry, and cross-functional cooperation, we seek safe, efficient, and scalable green solutions together. I firmly believe that through our collective efforts, climate technology will become a highlight of human wisdom and technological innovation, serving as a new engine for economic growth and playing a crucial role in pursuing sustainable development.



Li Zheng
President of Institute of Climate Change and Sustainable Development, Tsinghua University
Chief Expert, Shanghai Climate Week Institute of Research

Executive Summary

As the report collectively addresses the pervasive challenge of climate change, the synthesis of knowledge presented in "ClimateTech In Focus" underscores the transformative potential of ClimateTech within global supply chains. The report identifies awareness, government goals, and economic incentives as primary driving forces for advancing climate action, though the prominence of each force varies across different regions and contexts. Key insights highlight the critical need for science-based strategies and active stakeholder engagement and synergy to formulate and implement effective government goals. Despite these efforts, human society still requires extra efforts to meet net-zero targets, underscoring the urgent need for affirmative action.

In terms of policymaking, establishing a legal framework is the first step towards achieving sustainability goals; robust enforcement and comprehensive legislative education translate these frameworks into tangible actions. Developing countries, in particular, must focus on the economic implications of climate goals, balancing environmental imperatives with growth and development objectives.

Progressing from lean to green in supply chains requires prioritizing traceability, addressing hard-to-abate sectors, and shifting from compliance to excellence. Achieving these objectives depends on retrofitting existing infrastructure and redistributing cost burdens effectively across supply chains. Several motivators, including risk management, operational efficiency, and brand differentiation, drive the transition from compliance to excellence.

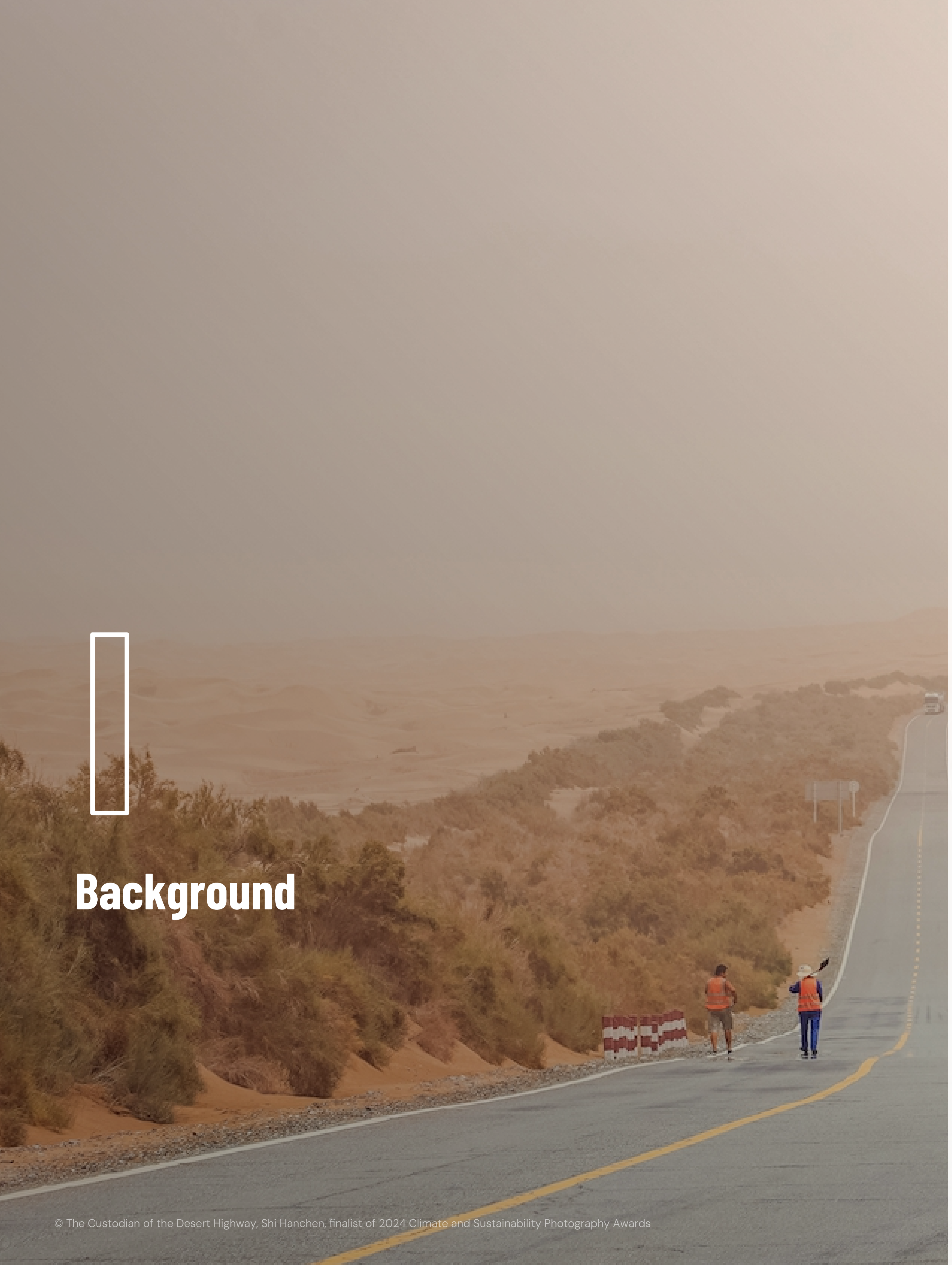
This report refers to technical and adoption readiness metrics to categorize and prioritize the ClimateTech market landscape. This analytic framework ensures a focused approach toward technologies with the greatest potential for impact. Key insights also reveal the importance of big data and AI, the decarbonization of traditional energy systems, the role of green hydrogen and primary chemicals, and the integration of clean energy in logistics as significant areas for development.

Moreover, innovative finance models, such as proof-of-concept funds, are critical to driving innovation from the lab to the factory. These models provide the funding necessary to translate promising ideas into market-ready solutions, overcoming the commercialization challenges often faced by ClimateTech startups.

Effective policy frameworks, strategic financial investments, and comprehensive educational initiatives are indispensable for a sustainable future. Government policy must provide the stability and incentives necessary to encourage green innovation, while finance must extend its reach through innovative tools supporting burgeoning ClimateTech enterprises.

Education's mission extends beyond traditional boundaries. It includes cultivating future leaders and professionals and providing vocational training that equips individuals with the skills necessary for the green economy. This mission is critical in cultivating a workforce capable of implementing and maintaining ClimateTech solutions and supporting sustainable practices across industries.

Achieving ClimateTech's full potential requires a concerted global effort. Collaboration among governments, investors, innovators, educational institutions, and enterprises can actualize a green economy cycle. This collective endeavor will ensure that the transition to greener supply chains is feasible and beneficial, resulting in a resilient and thriving future where sustainability and progress coexist harmoniously.



Background

© The Custodian of the Desert Highway, Shi Hanchen, finalist of 2024 Climate and Sustainability Photography Awards

> *In the face of global economic challenges and emerging climate imperatives, the synergy between developed and developing countries becomes pivotal. The evolution from carbon emission reduction marks a strategic shift required to mitigate climate change effectively. Such an approach highlights the importance of collaborative international frameworks to harmonize climate objectives with economic sustainability across global supply chains.*

Dr. Graciela Chichilnisky
Lead Negotiator, Kyoto Protocol

The supply chain represents the system from raw material extraction to finished product delivery and the recycling or disposal of such products, which significantly affects the lives of consumers. With 450 million individuals[1] engaged in this process and accounting for 60% of global emissions and final energy consumption,[2] transformations in a green supply chain extend far beyond mere academic discourse and technical adjustments; they influence employment, enterprises, investments, and household incomes, ultimately shaping the fabric of everyone's work and daily lives.

FIGURE 1.1 **Overview of Supply Chain Components, Emission Sources, and Green Factors**

Source: WeCarbon

Modern supply chain management is shaped by both "lean" and "green" principles. Lean principles prioritize efficiency and economic goals, including cost reduction,[3] inventory optimization, and improved productivity,[4] which have been the most influential principles in the supply chain domain,[5] as they meet the value demands of various stakeholders, such as shareholders, clients, and regulators. As sustainability becomes an increasing awareness for these stakeholders, supply chain participants are increasingly adopting green principles to lessen environmental impact and align with the evolving trend of customer expectations. While both principles reflect a shared effort to meet stakeholder value propositions and reduce waste, trade-offs and conflicts still exist. For instance, the just-in-time (JIT) delivery approach following lean principles typically requires an extensive transportation network for quick response, whereas green principles might aim to reduce this setting.[6,7]

> "
> *Climate change is a worldwide problem, but it still divides people—many are unaware and still think it is a hoax. The supply chain is even more challenging as it directly impacts jobs and families. Reaching a consensus will be difficult, and we can only achieve it by finding a way to create jobs and address business interests.*
>
> **Dr. Mohamad Bashir Kharrubi**
> Former Senior Advisor to the President, OPEC

The global supply chain is increasingly committed to adopting green principles. As a lens of this trend, worldwide private investments in clean energy exceeded USD 135 billion in 2023.[8] Despite this growing momentum, contributors to this report and academic research still suggest that progress in supply chain climate initiatives remains limited in terms of adequacy and balance:

- **Implementation pathways** – Global climate actions have reached a sound alignment with overarching goals but still need agreement on specific implementation pathways. For example, while there is a broad agreement on moving away from fossil fuels, described as the "Beginning of the End" in COP28, further clarification is still required on the detailed transition plan and financial responsibilities, which are crucial details required for alleged climate actions.
- **Incentives** – Policies should not presume supply chain participants to willingly compromise their economic interests for decarbonization.[9] Market-based incentives should be further developed, while it's also important for policymakers to avoid these incentives from hindering fair competition and becoming barriers to open market access.
- **Policy consistency** – Long-term investment in the green supply chain requires a stable policy environment.[10,11] However, climate policies in the real world can sometimes be regressive or inconsistent due to fluctuating awareness, which may lead to increased transition risks on these investments, potentially undermining their viability and progress.

ClimateTech refers to technologies that address the global climate challenges. ClimateTech adoption boosts efficiency, reduces cost, and minimizes disruption to operation in the decarbonization process of the supply chain. Through introducing innovative products and services with sustainable impacts, ClimateTech cultivates economic opportunities. Such opportunities can be complicated to discover, given the dynamic shifts in customers' motivations for eco-conscious choices in the context of global sustainability trends. The motivations below are frequently seen as crucial for customers to recognize values and decide on purchase.

FIGURE 1.2 **Value-creation Mechanisms Behind Decisions for Green Products**

Individual Consumers	Corporate	Government
Perceived green value (PGV) aligning with the customers' pro-environmental beliefs and concerns[12,13,14]	Compliance with Environmental, Social, and Governance (ESG) standards, climate regulations, sustainability targets, governmental directives, and clients' requirements	Alignment with national and UN goals
Boosted confidence in product quality, lowered perceived risks in health, performance, and reliability[12,15,16,17,18,20]	Enhanced brand image through alignment with customer's sustainability values[21,23,24]	Reduced environmental costs and impact[25,26,28]
Self-expression of altruism and environmental awareness[19]	Mitigated external supply chain risks (policy, quality, operations); mitigated internal operational risks by improving the organization's "bottom line"[22] in ethics, compliance, and corporate responsibility	Support for economic growth and spread of ClimateTech[25,26,27,29]

In addition to adding the above values to products, the other key value proposition of ClimateTech is to significantly improve supply chain transparency. Technologies such as blockchain and the Internet of Things (IoT) enable the real-time monitoring and verification of emissions and environmental footprints, permitting accurate monitoring, reporting, and validation (MRV) of carbon emissions and sustainability schemes.

This transparency strengthens consumer and investor trust and empowers companies to identify inefficiencies and areas for enhancement, thus cultivating more sustainable operations. In addition, ClimateTech makes implementation of climate policy more feasible, thereby facilitating policy execution and streamlining the integration of control measures related to sustainability metrics.

From Awareness to Action: Driving Forces towards the Greening Supply Chain

Driving forces in the green supply chain include awareness, governmental goals, and economic incentives. The weights of these forces vary across regions and economic development stages.

FIGURE 1.3 **Primary Driving Forces of Green Supply Chain Development Across Countries and Regions**

Awareness

Green supply chain inception force for specific countries and regions in the Global North, shaped by increased citizen sustainability awareness, fueled by the growing middle class and social attention shift driven by concerns of increasingly frequent climate-related incidents.

In lower public awareness areas, government awareness and policies (e.g., Green Public Procurement) are the primary motivators.

In certain cases in the Global South, governmental awareness and policy structures can also be fostered by international financial cooperation, particularly from multilateral development banks (MDBs).

International/National Goals

Green supply chain inception force for major developing countries/regions and late-industrializing regions, aligning with UN and government targets.

In other regions, UN and government objectives may also accelerate the transition to green supply chains.

Economic Incentives

Green supply chain inception force for a large number of the Global South developing countries and regions, from climate disaster economic losses or potential to secure global market position and create new economic opportunities.

Economic incentives are expected to motivate countries and regions to adopt sustainable practices.

This perspective provides a useful lens in evaluating green supply chain progress on a national scale, though factors can diverge at more localized levels locally. Dr. Ese Owie, Chief Executive Officer of the Oxford Climate Alumni Network (OxCAN), highlighted that in certain local areas in Africa, social activists can play a key role in spurring early environmental awareness. Conversely, in parts of the affluent Global North, established economic practices, conservative cultural norms, and weak environmentalist culture[30] can lead to resistance to new environmental policies and objectives, with local green supply chains primarily motivated by economic incentives.[31]

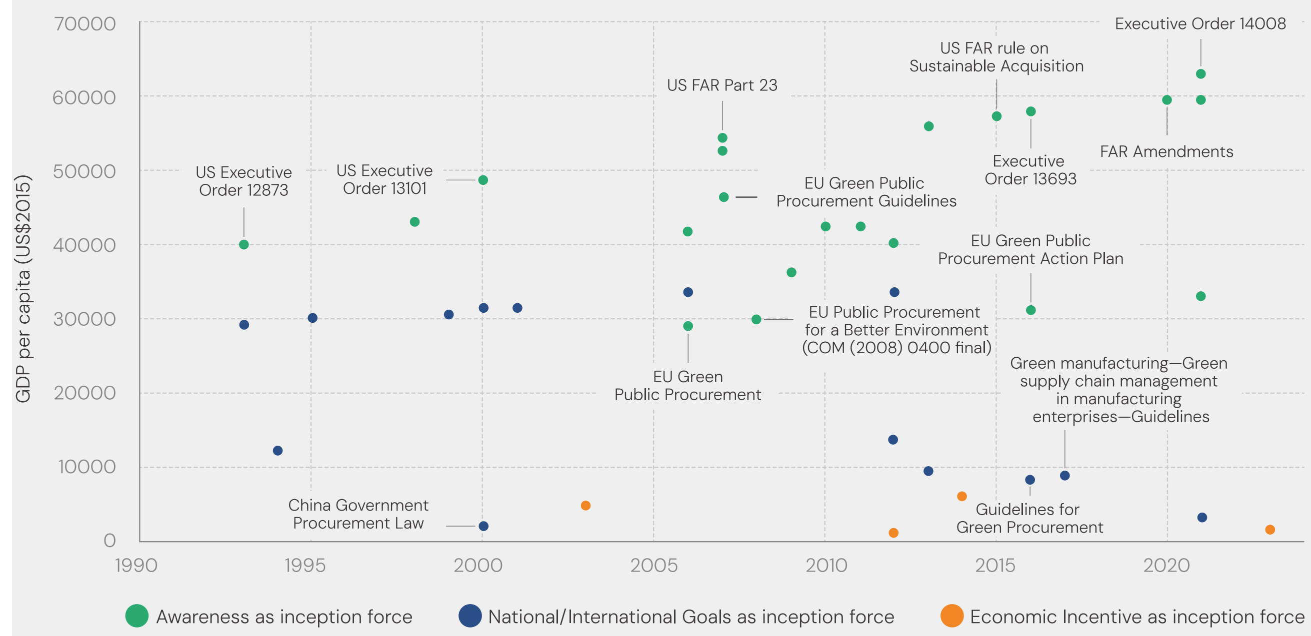
Early Awareness of Citizens and Governments

In certain Global North areas, the emergence of green supply chains is rooted in the burgeoning social affluence of the post-industrial era, beginning in the early 1990s. With increased productivity, affluence, and modernization, an expanding middle class began prioritizing post-material values, including environmental sustainability, thus shaping both policy and consumption.[32,33]

Accordingly, governments and organizations implemented tangible actions to address environmental sustainability challenges, most notably through Green Public Procurement (GPP). Government procurement, contributing to approximately 15% of global greenhouse gas emissions,[34] started to mandate the integration of environmental standards into the acquisition of public goods and services.[35,36] GPP demonstrates effectiveness at various levels, but anyway reflects an early awareness of the government's environmental concerns and their attempt to resolve such concern with policy and regulatory measures.[37,38,39,40] However, a government-led initiative tends to rely on existing standards, some of which may fall behind innovation trends. In certain cases, bureaucratic processes[41] and occasionally limited official expertise and awareness[42,43] may also constrain GPP's capacity to drive innovation.

A correlation analysis between GPP policies and respective GDP per capita in the year of effect indicates that over 80% of GPP policies originate in regions with a GDP per capita exceeding USD 14,000, which indicates a higher level of income. In regions with lower GDP per capita, policy adoption is primarily motivated by economic incentives.

FIGURE 1.4 **GPP Policies and GDP Per Capita During Implementation**



Source: World Bank

When implementing GPP policies, training and education should be strategically prioritized to facilitate vendor alignment with sustainability objectives and also to empower government officials to conduct equitable vendor selections, thereby enhancing the procurement process's credibility and effectiveness.[43,44]

> *Public awareness translates policies and technologies into concrete actions. When individuals understand the stakes and available solutions, they are more likely to support necessary changes, thereby fostering a conducive environment for climate action.*
>
> **Butti Almheiri**
> Next-generation Climate Fellow, UN Foundation

Besides GPP, there are also other types of environmentally oriented policies are also being developed. In such an early stage of global awareness, certain policies demonstrate a relatively long pace. The initiative to prohibit chlorofluorocarbons (CFCs), for instance, intended to preserve the ozone layer, encountered opposition and required a decade to progress from initial acknowledgment to effective resolution through the Montreal Protocol.[45,46] This 1987 international accord successfully phased out the production and consumption of ozone-depleting substances, thereby creating a remarkable achievement by delaying the first ice-free Arctic summer by up to 15 years.[47] While being a valuable model for climate change mitigation, the negotiation of the Montreal Protocol highlights the complicated process often necessary for such policies to reach full implementation. The phase-out of methyl bromide, another ozone-depleting substance similar to CFCs, experienced delays in this process of resistance.[48]

Currently, governments in developing countries and regions demonstrate increasing willingness to adopt green supply chain procurement regulations, with certain cases guided by awareness and methodologies introduced with support from global institutional investors, especially MDBs. Most MDBs have integrated climate change mandates, incorporating green procurement within their policy frameworks. Under ADB's Operational Priority 3—

Addressing Climate Change, Building Climate and Disaster Resilience, and Enhancing Environmental Sustainability—the Sustainable Public Procurement (SusPP) framework facilitates the identification and advancement of green procurement practices. Through investments in developing countries and regions, ADB introduces this framework and its associated procurement systems, offering developing member countries (DMCs) access to advanced clean technologies and promoting their integration into projects. Therefore, these frameworks have become influential procurement guidelines for relevant governments and further impact other domestic projects.

CASE STUDY 1 | Strengthening Sustainable Procurement in Indonesia

The Asian Development Bank (ADB) represents a significant partner in Indonesia's sustainable development, implementing more than 800 projects with sovereign lending totaling USD 46 billion as of April 2024. However, ADB's role extends beyond finances; the bank has been playing a critical role in developing Indonesia's public sector management. A significant collaboration has been ADB's work with the Government of Indonesia to integrate its Sustainable Public Procurement (SusPP) framework into the country's procurement regulations.

In 2022, ADB carried out a significant initiative. It partnered with Indonesia's National Public Procurement Agency (LKPP) with the objective of elevating sustainable procurement systems in the country. This partnership comprised several dynamic trainings that were focused on increasing awareness of sustainable procurement and enhancing understanding among Indonesian public procurement practitioners.

These sessions transcended the traditional instructor-learner method. These were interactive workshops that offered decision-makers the information and the requisite knowledge and tools to integrate and apply SusPP frameworks. The collaborative efforts extended beyond training. ADB, in collaboration with LKPP, developed a suite of regulations and management tools, a comprehensive framework including standards, guidelines, and bidding documents. The objective of these tools was to establish standards for sustainable procurement at the national and global levels.

ADB's support facilitated the implementation of advanced ClimateTech solutions in Indonesia. Using its extensive procurement system and outreach capabilities, ADB introduced technologies such as remote sensing, big data analytics, and other clean technologies to the country. In 2023, ADB, in collaboration with Indonesia's State Electricity Corporation (PLN), initiated a project with an approved investment of USD 3.4 million. This project aimed to enhance capacity for low-carbon power infrastructure development, improving processes, practices, and workforce skills to transition from fossil fuels to low-carbon electricity. Building on this success in 2024, ADB established the "Advance Sustainable Clean Energy Network for Development" initiative, which concentrates on delivering knowledge solutions and capacity building in clean energy technology. In addition to these initiatives, ADB also contributed to the enhancement of Indonesia's procurement framework in support of its commitment to sustainable development.

Source: Asian Development Bank, 2022[49]

49. Box 5: Strengthening Sustainable Procurement in Indonesia. In Annual Procurement Report 2022. Manila: ADB. p.17. © ADB. https://dx.doi.org/10.22617/SPR230092-2. CC-BY 3.0 IGO.

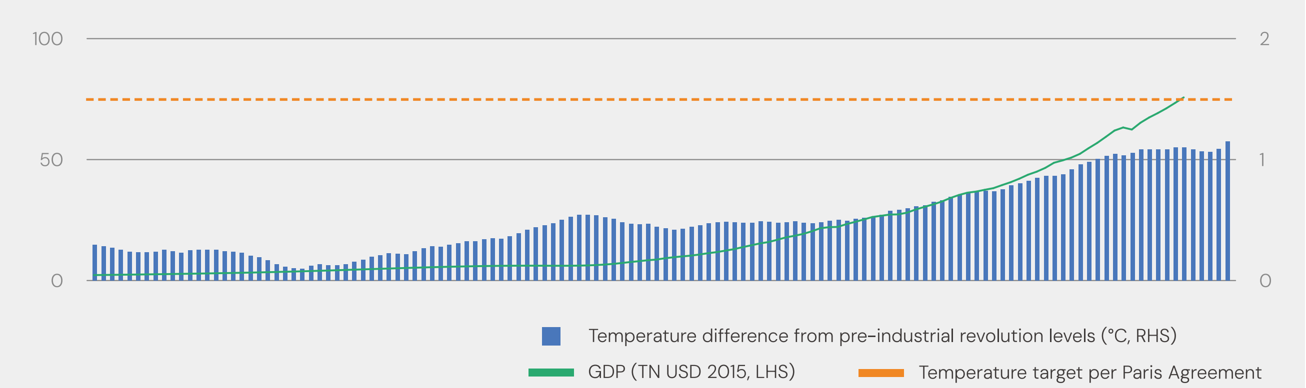
Goals Conceptualized by Global Environment Concerns

"Prevention is smarter than cure. We need to take preventive steps now for the climate instead of waiting for the problem to happen. At that time, running for the cure may be thousands of times more expensive than preventing the disaster.

H.E. Zayed Bin Rashid Bin Aweidha
Chief Executive Officer, Abu Dhabi Investment Group

Due to greenhouse gas emissions from human industrial and agricultural activities, the average surface temperature of the Earth has risen by 1.15°C compared to pre-industrial levels, reaching the highest point in the past 100,000 years.[50] This climatic shift is altering weather patterns and disrupting human habitats, leading to extreme weather events such as heatwaves, glacial melting, heavy rainfall, floods, droughts, and wildfires, all of which result in substantial loss of life and property. If climate change remains unchecked and global temperatures increase beyond 2°C, extreme heat would exceed the critical threshold of tolerance for industries, agriculture, and human health. This would lead to crop failures, trigger widespread forest fires, raise sea levels, and submerge cities, causing irreversible ecological disasters for human society.

FIGURE 1.5 **Trends in Global Average Temperature and Levels of Industrial Development**



Source: IPCC, WeCarbon analysis

Following the adoption of the Paris Agreement in 2015, many countries and regions formalized their initial national climate goals, referred to as nationally determined contributions (NDCs). With extensive international negotiations, diplomatic efforts, and civil society advocacy, a shift occurred to convert climate concerns from academic or scientific discussions towards tangible policies. During this time, concepts such as "green/ sustainable supply chain" also evolved to be concrete in many areas of the world.

Establishing global climate goals is a complex process beyond the outcome visible as policy paperwork. As Mujeeb Khan, project manager of Clean Rivers, observed, the process of achieving the multinational consensus at COP28 UAE exemplifies this complexity. "COP28 was a historic moment in climate negotiations, marked by unprecedented inclusivity involving negotiators, member states, civil society, and various stakeholders." However," the world grapples with a poly-crisis, where climate risk stands out as a significant future threat." An assessment of COP28's achievements indicates three critical factors underpinning effective multilateral climate goals. Science is the foremost in ensuring climate goals are feasible in terms of economics, technology, and engineering. Grounding these objectives in rigorous scientific analyses and data generates a comprehensive view, forecasting the impact of climate goals.

Moreover, stakeholder engagement and synergy are also critical. Composing climate policies with various participants and sectors facilitates substantive contributions and the fair sharing of costs and benefits among the participants. Such inclusiveness is a prerequisite for the achievement of goals. Moreover, only by connecting dialogue, policymaking, technology, and economic growth can the set goals be achieved. The objective of integrating different elements is to transcend conditions where the zero-sum strategy benefits only one party. Rather, it seeks to promote virtuous cycles of development of green economies that are beneficial to all stakeholders. Therefore, these factors ensure that climate objectives are not only ambitious but also realistic and widely supported. As Dr. Mohamed Gouali, Chief Executive Officer of Blue Capital Advisory highlights, promoting climate change awareness and building consensus is crucial for achieving long-term benefits through international cooperation, not just through protocols and meetings. Effective mechanisms, both economic and policy-oriented, are necessary to solidify the UAE consensus and pursue the 1.5°C objective.

"Saudi Arabia is serious about international collaboration on achieving sustainable development goal. If the developing countries don't get help like subsidies, it's hard to do it by themselves. It's a must that powerful countries provide support.

H.E. Nabil Al Saleh
Former Deputy Minister of General Affairs, Kingdom of Saudi Arabia

Scientific methodologies, such as data technology and macroeconomic tools, formulate and assess climate goals. A frequently used benchmark is the Net Zero 2050 target under the Paris Agreement. Such tools project the economic and social repercussions of policies at the equilibrium scenario between supply chain continuity and environmental objectives, thereby capable of evaluating the economic effects of climate policies. A typical tool used to assess the climate scenario is the Integrated Assessment Model (IAM). This model enables the identification of optimal policy intensity for both economic growth and sustainable implementation. Since 2020, the Network for Greening the Financial System (NGFS), comprising 114 central banks and regulators, has offered scenario projections in evaluating the financial and risk implications of climate policies. The scenarios prepared by the International Energy Agency (IEA) are similarly used extensively.

Current Net Zero 2050 projections based on these models urge significantly more efforts required in global transition compared to the anticipated level. Fossil fuels are projected to constitute 81.5% of the global energy mix in 2024,[51] a figure that must decrease to 5% in 2050 for Net Zero achievement.[52] This requires a dramatic expansion of clean energy adoption with the current pace way too slow. Despite certain figures catching up with Net Zero projections, regional disparities remain. The levelized cost of electricity (LCOE), for instance, has fallen from 460 USD/MWh in 2010 to 44 USD/MWh in 2023 and is projected to reach 30 USD/MWh by 2030, making a remarkable achievement.[53] Nevertheless, regions in Africa contend with LCOEs exceeding 105 USD/MWh and limited photovoltaic energy availability, despite abundant solar resources. Moreover, instability and disruptions in energy supply result in higher costs in Europe. For instance, in certain regions within Germany and the Netherlands, LCOEs have surpassed 80 USD/MWh.[54] Global progress in carbon removal technologies also remains insufficient. Scientists advocate for the annual removal of 5-10 billion tons of CO_2 by mid-century; however, current removal totals only 2 billion tons annually.[55] The high cost of Carbon Dioxide Removal (CDR) technologies, such as Direct Air Capture (ranging from USD 250 to 600 per ton),[56] presents a significant impediment to broader implementation. In addition, the lack of a comprehensive MRV framework compromises the credibility of CDR, thus hindering both policy support and technological advancement.

The data shows global progress toward green supply chain objectives remains deficient. The significant delays call for ClimateTech innovation and more climate actions to confront these obstacles and align supply chains with climate objectives.

Countries and regions globally have recently enacted laws and regulations to their supply chains to achieve synergy in stakeholder engagement. These regulatory actions, compared with historical ones, embed operational rules and procedures for assessing and ensuring supply chain sustainability. The European Union, for instance, introduced the Carbon Border Adjustment Mechanism (CBAM) to combat carbon leakage and strengthen its Fit for 55 initiative, a key component of the EU's climate strategy. The United States' proposed Clean Competition Act (CCA), which has not yet been enacted at the time of this report, alongside the Inflation Reduction Act (IRA), aims to enhance the competitiveness of its clean energy sector, consistent with its Long-term Climate Strategy. Such regulations impose practical requirements on the industry, including specific compliance processes, subsidies, and restrictions.

Despite ambitious global climate goals and existing progress, regulations concerning green and sustainable supply chains need to continue to develop in order to achieve their intended effect. Enacting a new regulation only marks an initial step, as Dr. Gu Wei, President of the Sino Research Institute of Green Finance, emphasizes that robust enforcement systems and inclusive legislative education are also prerequisites. Green supply chain regulations also face complexities and significant cost of verifying data across multi-jurisdictional supply chains. To reduce these expenses, cultivating international cooperation and trust in shared data and standards is necessary. Supporting frameworks, including international collaboration, mutual data and certifier recognition, and standardized metrics, must be developed. These advancements will promote regulation that is more practical, equitable, and beneficial to the sustainability of supply chains.

FIGURE 1.6 **Climate Strategies Around the World**

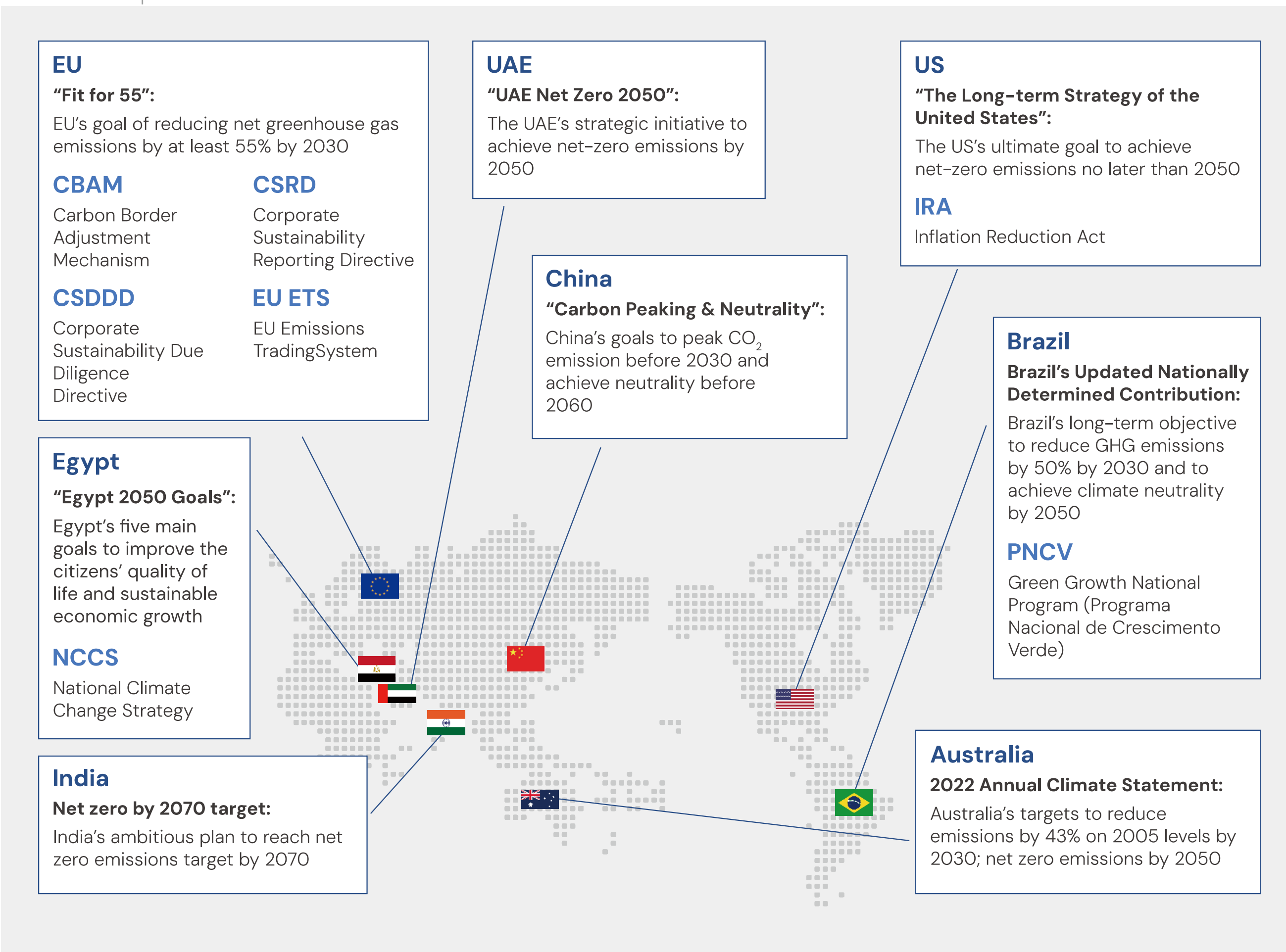


FIGURE 1.7 **Fit for 55 and EU's CBAM Goals**

Fit for 55 Framework & Policies

Aligned with the European Green Deal's 2050 climate neutrality objective, the European Union's Fit for 55 initiative seeks a 55% reduction in greenhouse gas emissions by 2030. This initiative requires substantial revisions to EU energy and climate policies, including an updated EU Emissions Trading System (ETS), more stringent CO_2 standards for vehicles, and CBAM. In April 2023, the EU approved ETS reforms, establishing a 62% emissions reduction target (below 2005 levels) for applicable sectors by 2030. These reforms initiate the phase-out of free allowances and the gradual implementation of CBAM.

CBAM Design: Aiming for Carbon Accountability

CBAM aims to address carbon leakage by aligning carbon costs between EU and non-EU producers. Beginning in 2026, importers of goods such as cement and steel will be required to submit CBAM declarations reflecting their emissions. The associated costs will correspond to the EU's carbon pricing.

Future of Fit for 55: Pathway to Further Policies

By increasing emission costs, Fit for 55 incentivizes investment in green technologies. The initiative holds the potential to expand carbon pricing to maritime shipping, buildings, and road transport. The EU intends to allocate ETS revenues to compensate climate-vulnerable segments of society to reduce the impacts of decarbonization. This strategy, designed to support sustainable growth, establishes a precedent for other countries and regions.

Source: European Parliament, 2022

In specific developing economies, green supply chain objectives face more complex benefit dynamics of stakeholders and prioritize economic advancement through development more than restrictive measures.[57] These approaches effectively synthesize environmental protection and economic expansion. For instance, Ethiopia's Long-Term Low Emission and Climate Resilient Development Strategy (LT-LEDS) boosts economic growth and enhances forest management expertise in the timber supply chain, reducing degradation and generating carbon credits in line with the UN's REDD+ framework. The strategy also emphasizes job creation in the electric vehicle sector, further contributing to sustained economic growth. Typically, multi-objective green initiatives that prioritize environmental sustainability while also addressing poverty alleviation, increased employment, or local economic prosperity are more likely to be successfully implemented in these countries and regions.[58]

Trade restrictions, especially between the Global North and South, have the potential to elevate emissions. Studies suggest that trade restrictions may shift production to regions with lower efficiency, leading to a rise in emissions if these areas do not enhance their emission standards.[59,60] Lord Adair Turner, Chairman of the Committee on Climate Change, asserted, "The intention behind the CBAM and other green supply chain policies is not protectionism, and theoretically, there should be no disadvantage to the exporting country." All countries and regions are urged to adopt measures further aligning with international standards and multilateral principles to ensure the continuity of the supply chain.

Varied standards recognition and interpretation across countries and regions can lead to unequal policy costs. The European Union, for instance, has mandated a series of environmental declarations for specific imports since 2006. While manufacturers frequently obtain Renewable Energy Certificates (RECs) to demonstrate their renewable energy consumption or use them as an offset, the declaration rule acknowledges only a select few, including North America's Green-e, Europe's Guarantees of Origin (GO), and the International REC Standard (I-REC, now I-TRACK). Regional REC schemes face rejection due to discrepancies in standards, insufficient verification, or the risk of double counting. Therefore, producers in these regions are subjected to increased costs associated with redundant REC acquisitions, extra certification requirement, or other processes to meet compliance requirements.

Bridging the divide of environment standards and regulations between the Global North and South requires international cooperation and dialogue. A growing number of bilateral partnerships and multilateral mechanisms have focused on aligning environmental standards with facilitating technology transfer, capacity building, and financial aid. These initiatives empower developing countries and regions to pursue their green objectives while sustaining economic progress. The future expansion of such initiatives through multilateral channels should be a priority.

"

The global multilateral cooperation system coordinates, promotes, supervises, and implements efforts to combat climate change. By fostering collaboration and joint action among nations on climate governance, the multilateral system ensures the establishment and execution of global climate objectives while also facilitating the global flow of funds and technology.

Zhou Yiping
Former Director, United Nations Office for South-South Cooperation

Economic Incentives Driven by the Maturing Green Economy

Business interests and profit are prerequisites for sustainable efforts. A green supply chain, therefore, must be viable not only environmentally but also economically, cultivating jobs and economic growth in addition to ecological benefits. By enhancing productivity or redirecting resources from less sustainable, conventional operations, businesses can benefit from climate actions and green investments.

While many frequently tout the superior investment alpha and long-term performance of green or sustainable assets, academic consensus regarding the magnitude of returns from such investments remains elusive. Observed growth of investment is frequently ascribed to increased investor awareness of climate change and thematic investing.[61] However, the characteristics of green assets — long-term horizons, reduced funding costs, and potentially lower risk due to policy stability — suggest returns inferior to those of conventional assets. Real-market analyses indicate that green bonds can underperform conventional bonds by 0 to 20 basis points.[62,63]

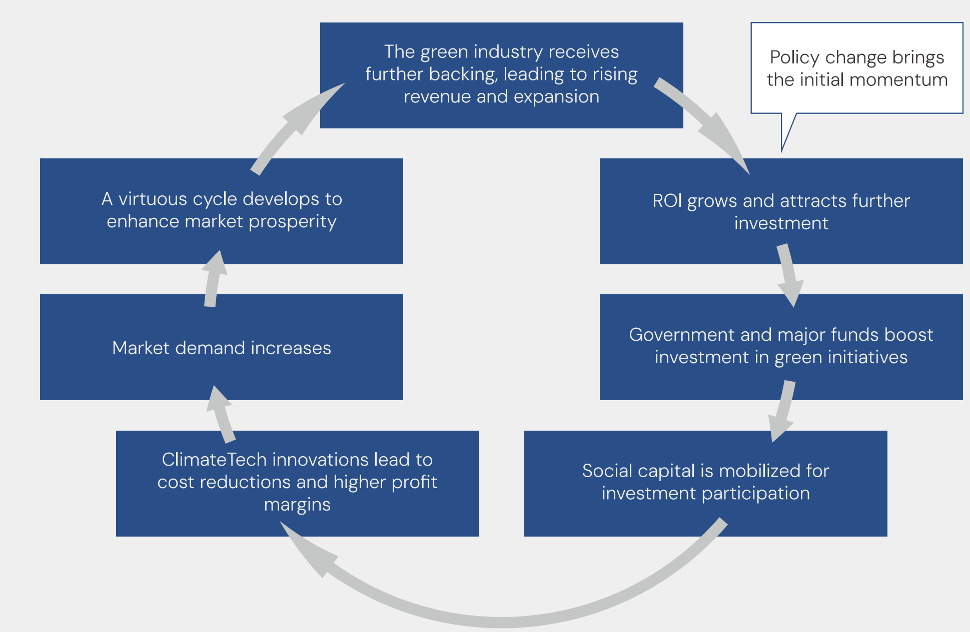
A recent study on the ASEAN green bond standards highlights both the potential and challenges of green finance in the region. The ASEAN Green Bonds Standards (ASEAN GBS) aim to promote sustainable investments within regional capital markets. However, the study found that most respondents perceive green bonds as offering "no distinct financial advantages" over conventional bonds. This perception poses a significant challenge to the expansion of the green bond market, as traditional financial performance metrics continue to influence investment decisions more heavily than sustainability considerations.

Respondents from Malaysia, Singapore, and Thailand noted an insufficient number of green projects and a limited supply of green bonds, which hinder market growth. These findings suggest that, while there is theoretical interest in sustainable investments, practical barriers such as unclear financial benefits and market liquidity issues must be addressed. Enhancing awareness, increasing transparency, and developing more green investment opportunities could help align investor expectations with the long-term benefits of green assets, ultimately fostering greater acceptance and growth of the green finance market in the ASEAN region.[64]

The appeal of a green economy relies on its capacity to reallocate business interests through policy. These policies often create market mechanisms that constrain the brown industry, strengthen green initiatives, and facilitate a priced transition to ensure greener supply chains experience reduced policy risks and enhanced cash flow compared to their brown counterparts. Countries and regions may initiate green economic transitions by imposing limits on manufacturing processes levying immediate financial penalties, and employing subsidies to reduce initial costs. Pricing mechanisms, such as ETS, redistribute resources toward green initiatives and drive down greenhouse gas emissions while promoting economic development. While this approach shifts existing value, necessary infrastructure and markets are also required to achieve Pareto improvements for green economy participants.[65,66,67]

© South-to-North Water Diversion Project, Jiang Chenqi, finalist of 2024 Climate and Sustainability Photography Awards

FIGURE 1.8 **Virtuous Cycle of Green Economy**



Source: WeCarbon

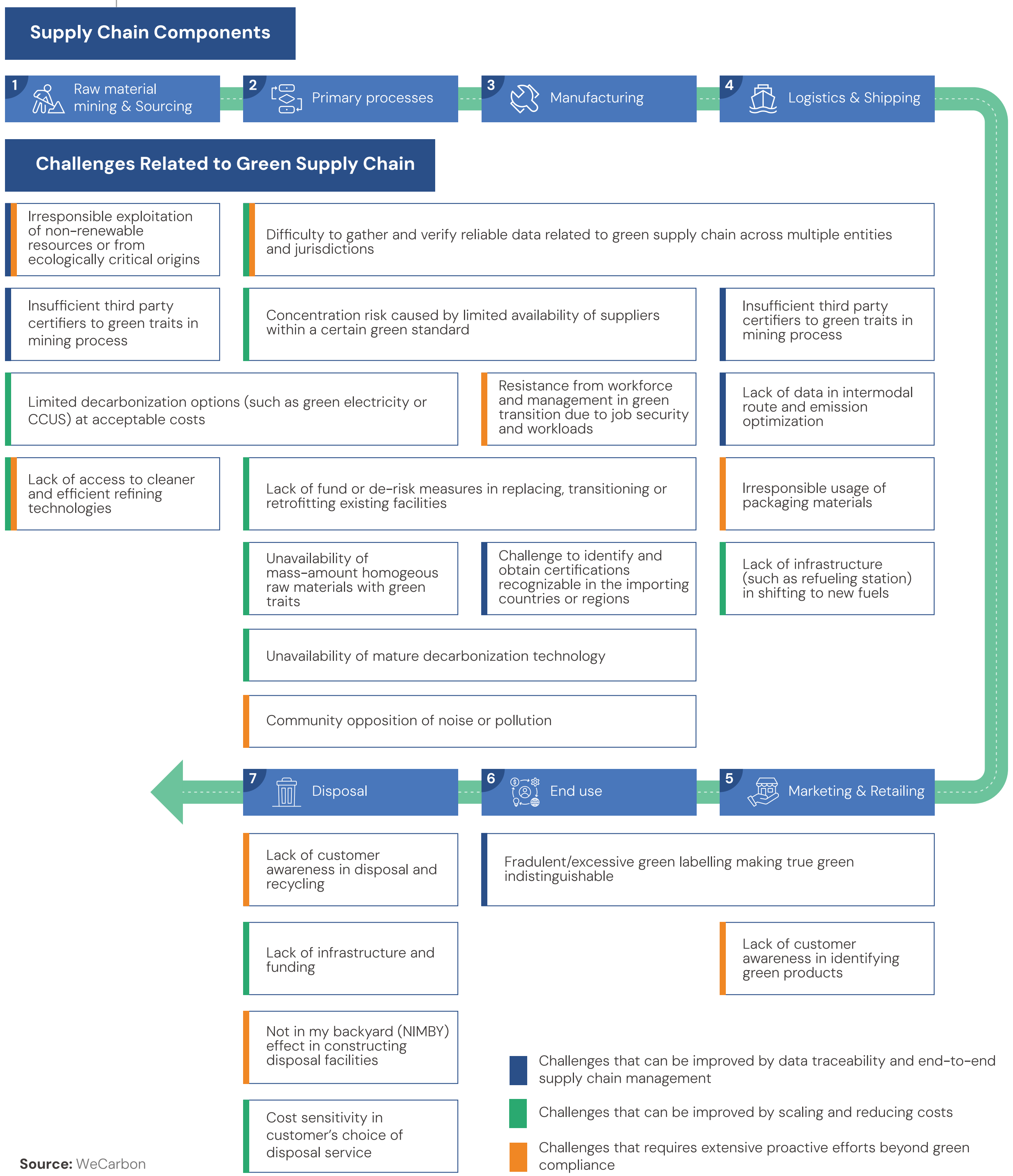
Though penalties appear unfavorable, they prove to be direct and powerful in disincentivizing harmful practices and stimulating ClimateTech innovations, as studies reveal.[68,69,70] However, both penalties and subsidies require extensive social governance and associate costs, which can be constrained by economic or social pressures. When these pressures make it challenging for governments to manage governance costs, there may be a tendency to ease or alter policies, potentially leading to the return of unsustainable practices.

Conversely, pricing mechanisms present a durable, long-term strategy for promoting sustainable practices. These mechanisms work by incorporating the environmental costs of products and services into their market prices, thereby incentivizing continuous investment in green technologies. This market-based approach ensures consistent, long-term incentives, which can stimulate local technological development while minimizing the volatility caused by fiscal, tax, and financial pressures on green technological advancement. Consequently, it provides stable support for green technologies with a lower relevance to economic fluctuations.

Global South countries and regions have established legal acts to support the green economy and promote investments, which has been proven effective in harmonizing governmental efforts and creating an investment-friendly environment for a green economy. One prominent example is the Philippines's "Green Lanes" initiative under Executive Order No. 18, which targets projects for climate mitigation and sustainability in line with national development plans.[71] Complementing this, the Blue Economy Act (Senate Bill No. 2450) aims to adopt the blue economy as a framework and create a council to manage marine resources, coastal plans, and resilient investments, further bolstering the nation's commitment to sustainable finance.[72] Under this act, the Blue Economy Council is proposed to align integrated coastal management plans, including fisheries management plans, coastal resource management plans, climate action plans, and marine spatial plans to determine zones and designate allowed, regulated, and restricted activities. The council also is responsible for identifying climate-resilient and environmentally sound investments, infrastructure, and technologies, which have become a strong impetus for green and blue economy locally.

From Lean to Green: Challenges to be Resolved by ClimateTech

FIGURE 1.9 | **Challenges Related to Supply Chain Components**



Source: WeCarbon

Achieving environmental sustainability in a supply chain requires a holistic transformation of its components, from energy and design to raw materials, manufacturing, logistics, shipping, end-use, and recycling. This chapter explores the overarching issues influencing these supply chain elements. Resolving such challenges constitutes a primary impetus for developing and deploying ClimateTech solutions.

End-to-end Supply Chain: Data and Traceability

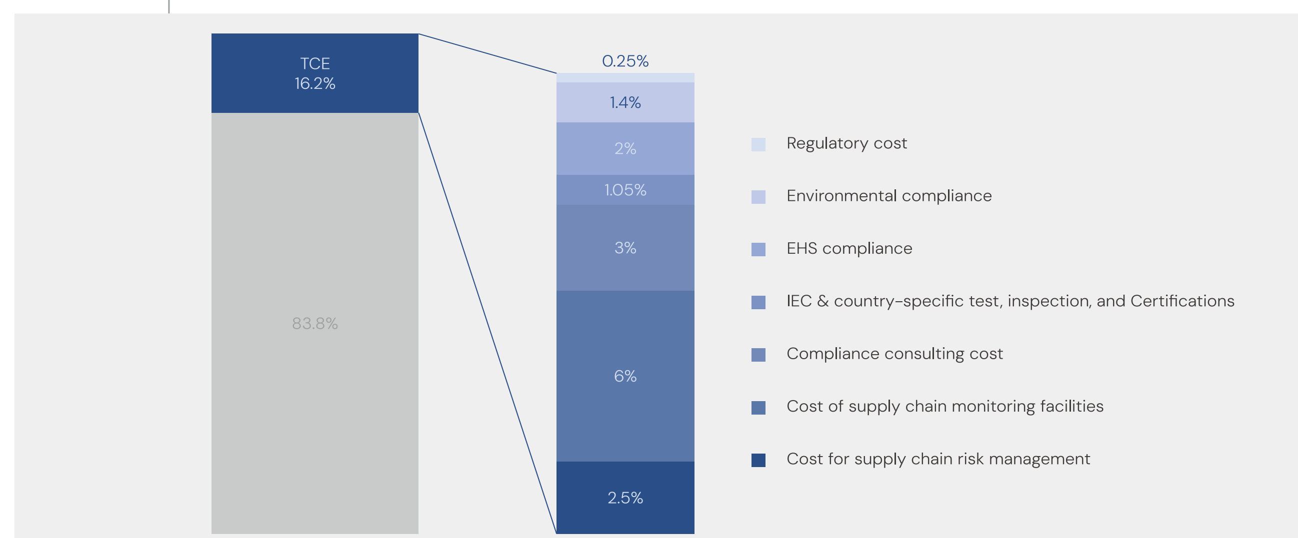
Traceability ensures every corner of the temporally and geographically dispersed supply chain compliance with green principles, rules, and regulations—including accurate carbon footprint reporting and certified responsible sourcing of raw materials—and offers real-time risk and disruption identification, reducing potential ESG issues. Bain's latest Global State of Traceability Survey, comprised of insights from over 150 senior supply chain executives, indicates that 68% consider traceability "very important" or "extremely important."[73]

Recognizing the critical role of traceability in green supply chains, many countries and regions have taken proactive steps. The European Union, for instance, has introduced the Regulation on Deforestation-Free Products (EUDR), which mandates operators handling forest products to trace their supply chain back to the geolocation coordinates of timber harvesting. The new EU battery regulation requires a 'battery passport' for tracing the recycling process of key materials such as nickel, cobalt, lithium, and lead. Similarly, the Australian government is developing a national framework dedicated to the traceability of recycled content, thereby enhancing both traceability and the quality assurance of imports.

Complexity of traceability depends on the magnitude of temporality and organizational boundaries in data acquisition. Coordinating information from different sources presents a risk of misaligned standards, high communication costs, and the compromise of sensitive commercial data. Such risks can result in reluctance among supply chain participants to share traceability information, particularly concerning raw materials, suppliers, clients, and production methodologies. The World Steel Association (WSA) reports that 800 Mt, or 41%, of global crude steel production in 2021 originated from steel plants with capacities below 8 Mt.[74] A significant percentage of these smaller facilities lack adequate traceability infrastructure, hindering the establishment of robust data archives. The potential for extended periods between the manufacture of steel and its incorporation into a final product further complicates traceability efforts. A reliable archive is required to recover information before a tracking request is fulfilled.

Striking a balance between sustainability data accuracy and supply chain cost efficiency, which is a component of the 'lean-and-green balance,' is a significant challenge. Carbon footprints and other sustainability metrics should be accurately calculated with minimized manual data entry so as to reduce the potential for manipulation. Government-certified documents, third-party verification, and IoT devices should be treated as reliable data sources. However, these approaches, while enhancing accuracy, also introduce added complexity and transactional costs to supply chain management. For instance, an estimated 16.2% of battery supply chain revenue is consumed by transaction costs associated with compliance, certification, and risk management.

FIGURE 1.10 | **Transaction Cost Structure of a Typical Battery Producer**



Source: CDP, EcoVadis

In addition to governmental regulation, the dominant firms in supply chains are also a source of power for enhanced traceability. With significant purchasing leverage, these corporations can compel compliance with stringent environmental standards among their suppliers. Moreover, such enterprises actively employ their influence to establish comprehensive connections throughout the supply chain, ensuring end-to-end traceability and sustainability supported by credible evidence.

CASE STUDY 2 | End-to-end Supply Chain Management

Schneider Electric, a global industrial technology leader, operates a comprehensive, green, and diverse supply chain, bringing world-leading expertise in electrification, automation, and digitization to smart industries, resilient infrastructures, future-proof data centers, intelligent buildings, and intuitive homes. 74% of its mid-2024 global revenue came is impact revenues, i.e., revenues coming from offerings in bringing energy, climate, or resource efficiency to customers, aiming for 80% by 2025. With a record revenue of nearly EUR 36 billion in fiscal 2023 and an extensive supply chain, Schneider Electric recognizes driving a green supply chain transition as a long-term strategic priority.

End-to-end supply chain management is Schneider Electric's primary framework for this transition. Its key is to set cohesive green standards across design, procurement, manufacturing, delivery, and maintenance instead of the industry typically focusing on managing isolated aspects such as supplier certificates or qualifications.

1. Product Design

Schneider Electric considers the impact of products on the environment from the perspective of the whole life cycle, and uses Eco-Design principles to develop sustainable products that meet Net-Zero targets. For instance, Schneider Electric utilizes dry air instead of sulfur hexafluoride (SF_6), a gas traditionally used in conventional products with a Global Warming Potential (GWP) 23,500 times that of CO_2 to significantly reduce the environmental impact.

2. Procurement & Manufacturing

Schneider Electric has carried out a supplier carbon emission assessment and only suppliers that meet the criteria can be included on the list. Schneider Electric procurement teams mandate tailored and strict green standards for key materials such as aluminum, copper, and plastic. Schneider Electric is promoting and accelerating the Net-Zero Factory by embracing digitization, the circular economy, and clean energy. Currently, Schneider Electric has 19 "Zero Carbon Factories" and 15 "Green Factories" in China. Compared with the 2019 baseline. China's supply chain energy consumption has been reduced by 15.5%.

3. Delivery & Maintenance

Schneider Electric upholds high standards by eliminating single-use plastics in packaging by 2025, using 100% recyclable paper, and employing AI for logistics optimization, aiming for a 15% reduction in transport-related emissions by 2025. Additionally, it collaborates strategically with supply chain participants to develop green ecological logistics and provides. The company also provides end-to-end lifecycle services such as EcoConsult, EcoCare, and EcoFit™ with the help of software and digital tools.

Schneider Electric has extended its supply chain practices to further enhance its ecosystem. In 2021, Schneider Electric launched The Zero Carbon Project, which partners with 1,000 suppliers and targets a 50% reduction of operations emissions by 2025. It offers strategic advisory, technology, resources, and on-site support, including digital carbon management, CDP declaration assistance, green energy certificate procurement, and on-site engineering support. By mid-2024, the project has helped suppliers reduce operational CO_2 emissions by 33%.

Source: Schneider Electric, 2024

"As the industry supply chain leader, Schneider Electric's commitment is beyond zero carbon emission from our operations in 2030, but also achieving zero carbon emission for the end-to-end value chain by 2050. Going forward, Schneider Electric will work with industry partners and all sectors of society to explore efficient and sustainable development models for the future as a sustainability 'Impact Maker'.

Zhang Kaipeng, Senior Vice President, Global Supply Chain China, Schneider Electric

Certifiers are the third parties who link producers, procurers, and regulators, verifying compliance with established standards. They also started to adopt ClimateTech for traceability. As noted by Xu Qiuming, General Manager of Sustainability Services from TÜV Rheinland, the company pioneered the use of chain-of-custody methods for commodities such as palm oil, recycled plastics, batteries, and marine waste. In addition, TÜV Rheinland assists service providers in maintaining data accuracy for green electricity verification and collaborates on QR code implementation for product traceability. Such initiatives emphasize the role specialized service providers play in enhancing supply chain traceability and sustainability. (Please refer to Chapter 4.1 for more information on certifiers' use of ClimateTech to ensure traceability.)

Traceability may continue after the product leaves the factory. Consumer goods manufacturers increasingly emphasize the importance of an end-to-end approach, especially focusing on the environmental data in the end-use and recycling stages to preserve sustainability throughout a product's lifecycle.

CASE STUDY 3 | Tracking for Less

Roca Group, a global leader in the sanitaryware industry, maintains an extensive multi-nation manufacturing and distribution network. Driven by an ambitious 2045 carbon net zero emissions target, a goal that sets a new standard in the industry, Roca demonstrates a strong commitment to both sustainability and innovation. This commitment is realized through a comprehensive approach that systematically integrates technological advancements, sophisticated manufacturing management, and robust recycling practices.

Central to Roca's sustainability strategy is the implementation of tracking technology. This technology empowers the company to monitor and optimize resource consumption throughout its operations, tracking energy, water, and raw material usage in manufacturing processes and finished products.

1. Regarding manufacturing, Roca leverages tracking technology through plant-wide metering systems directly associated with a centralized monitoring hub at headquarters. This system oversees water and gas consumption, raw material use, and recycling rates across all production processes. Such centralized management ensures alignment with Roca's sustainability objectives and facilitates close monitoring of progress toward these goals.

2. Tracking technology informs Roca's product design decisions. For instance, tracking systems regulate water usage in Roca toilets, automatically optimizing the volume of water per flush for enhanced conservation. Tracking-based technologies such as Quick Reaction®, Cold Start, and the Security 38° system employed in thermostatic faucets and aerators further achieve resource efficiency. These innovations contribute to more efficient resource use and a lower environmental footprint.

Roca's 2023 Integrated Report highlights progress in energy conservation and carbon footprint reduction through these sustainable actions. Since 2018, direct carbon dioxide equivalent emissions have decreased by 50%, energy intensity has fallen by 57%, and waste recycling has reached an impressive 69%. Roca remains committed to its 2045 carbon net zero emission goal, pursuing further innovation to propel the industry toward a more sustainable future.

Source: Roca Group, 2023

"Reaching carbon net zero emission isn't just an ambition, but requires investment and evolution in key components. A mindset change is happening where we manage everything from product design to manufacturing, distribution, recycling, and tracking over the entire process.

Guillem Pages, Managing Director, Roca China

Hard-to-abate Sectors: Scaling and Cost-down Challenges

Hard-to-abate sectors, consisting of industries such as steel, chemicals, cement, refining, aviation, and shipping, contribute over 30% of global emissions.[75] These sectors are considered "hard to abate" mainly due to dependence on high-temperature processes, fossil fuels, and chemical reactions resistant to decarbonization. The decarbonization pathway for these industries binds with challenges across financial, cost, market, and technological domains.

30%+

global emissions contributed by hard-to-abate sectors

Many contributors to this report do not believe that the decarbonization pathways for these sectors rely on unknown ClimateTech breakthroughs but on scaling and cost-down. Certain sectors might decrease the cost premium for green technology through technological advances over time. For instance, by 2050, steel produced from green hydrogen sourced from renewables could become more economical than coking coal. However, reaching this point requires large-scale technology development driven by significant demand". Instead of developing new approaches, the market requires the identification of suitable materials, processes, and supportive policies to lower costs to an acceptable market range. Two key obstacles to expanding green capacity are evident: retrofitting existing infrastructure and redistributing cost structure.

Retrofitting infrastructure in long-established industries such as steel and cement presents a challenge due to their significant historical investments and extensive workforces. These facilities can be the pillar of the local economy and employment in many countries and regions. For instance, an optimal transition in steel production requires transitioning from blast furnaces to electric arc furnaces (EAF). This transition would further lead to zero emission by incorporating scrap metal, integrating hydrogen-based direct reduction iron (H2DRI), and deploying carbon capture, usage, and storage (CCUS) technologies for emissions management. However, the global blast furnace capacity remains at least 1454 Mt per year, with construction continuing to expand. Over 46% of this capacity is under 15 years old, suggesting significant remaining depreciation value according to standard accounting practices. Besides, over 280 million tons of new blast furnace capacity per year is currently under construction globally. While older facilities lack substantial accounting residual value, they represent entrenched economic and employment anchors in their respective regions, thereby complicating the retrofitting process.

FIGURE 1.11 | **World Blast Furnace Production Power**

Source: Global Energy Monitor, WeCarbon analysis

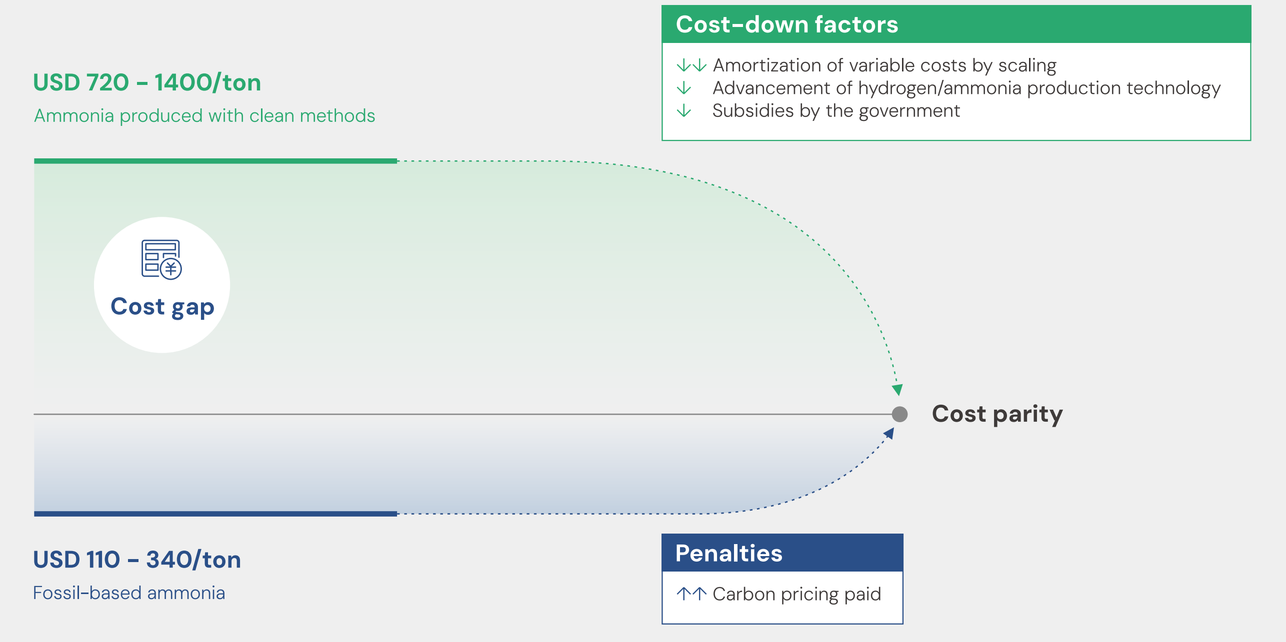
Negative consequences can happen if the complexity of transitioning these production processes is not managed carefully, including investment losses, unemployment, operational halts, and supply chain disruptions. The workforce from operators and welders to technicians, specialists, and sales representatives requires retraining to catch up with the transition. For example, truck drivers will need to adopt new loading, unloading, and scrap metal recycling procedures for EAF. Should H2DRI be implemented, these drivers must also acquire proficiency in safe hydrogen transport protocols.

Redistributing cost structure is another challenge. The cost structure in these long-standing sectors is already at highly optimized cost efficiencies and minimized expenses to the lowest possible levels. For green products to achieve market adoption by procurers, the cost differential compared to traditional products must be addressed. This objective can be accomplished by reducing the manufacturing costs of green products or increasing the costs of conventional alternatives through market factors, policy adjustments, or revisions to supply chain regulations.

For instance, a significant cost differential exists between green ammonia and its fossil-based counterpart. To reduce this difference, advancements in hydrogen and ammonia production technologies seek to enhance efficiency and reduce energy consumption. Electrolysis, powered by renewable sources such as wind and solar energy, further minimizes carbon emissions. Government subsidies can support initial capital investment and cultivate industry growth. Policies such as carbon pricing and emissions penalties, by internalizing the environmental costs of carbon emissions, reduce the attractiveness of fossil-based ammonia. This incentivizes the industrial transition to cleaner options, cultivating the development of novel green ammonia supply chains and partnerships that integrate sustainability into industrial operations.

Inter-organizational collaboration between businesses, governments, and research institutions drives innovation and cost reduction, thereby enabling the technologies and infrastructure necessary to widely adopt green ammonia. Aligning financial incentives with environmental objectives will position green ammonia as a viable alternative and contribute to decreased carbon emissions in ammonia-dependent sectors.

FIGURE 1.12 | **Cost Parity for Green Ammonia**



Source: IRENA,[76] WeCarbon analysis

Disruption to existing manufacturing processes should be minimized to avoid complete shutdowns and implement cost-effective scaling-up. Available market strategies primarily center on amelioration and relocation. Amelioration requires in-situ upgrading or retrofitting specific facility components, thus ensuring continuous production.

CASE STUDY 4 | In-Situ Transition for Steel Production

China Baowu Steel Group (Baowu) is the world's largest steel producer by volume. Historically reliant on traditional blast furnaces, which account for 93.5% of its production, Baowu faces substantial challenges in the current era of decarbonization. To address these challenges, Baowu has focused on an in-situ transition, integrating various technology solutions to optimize its existing blast furnace operations.

Baowu has improved its energy efficiency using a Best Available Control Technology (BACT) library, an internal resource identifying the most effective solutions for decarbonization. This technology is applied throughout production, guiding equipment upgrades within the existing blast furnace infrastructure. For example, Baowu employs vertical cooling furnace technology in its sinter vertical cooling system at its Meishan Base, achieving a 100% improvement in waste heat recovery compared to conventional systems while maintaining the core blast furnace setup.

Baowu has also explored adding hydrogen to its blast furnaces instead of constructing new plants to reduce CO_2 emissions. This in-situ transition involves incorporating hydrogen-enriched carbon cycle technology into the existing blast furnace process. This initiative demonstrated the potential to reduce carbon emissions by 15% by injecting coke oven gas and ultra-high oxygen smelting, showcasing how traditional blast furnaces can be adapted for modern environmental standards.

Beyond enhancing its blast furnaces, Baowu is actively engaged in the research and development of electric arc furnaces and other advanced steelmaking processes. One notable innovation is the hydrogen-based shaft furnace technology, which replaces traditional carbon-based reduction with hydrogen to reduce iron ore, aiming for net-zero carbon emissions in steelmaking. Baowu has invested CNY 1.89 billion in a demonstration project at its Dongshan Base, complemented by constructing a high-efficiency electric furnace to create China's first zero-carbon factory for high-grade thin steel plates.

Baowu's strategic approach to integrating advanced technologies and innovative processes within its existing blast furnace infrastructure addresses the pressing need for decarbonization and sets a benchmark for the global steel industry. This in-situ transition highlights how traditional methods can be facilitated to meet sustainability standards without needing entirely new facilities.

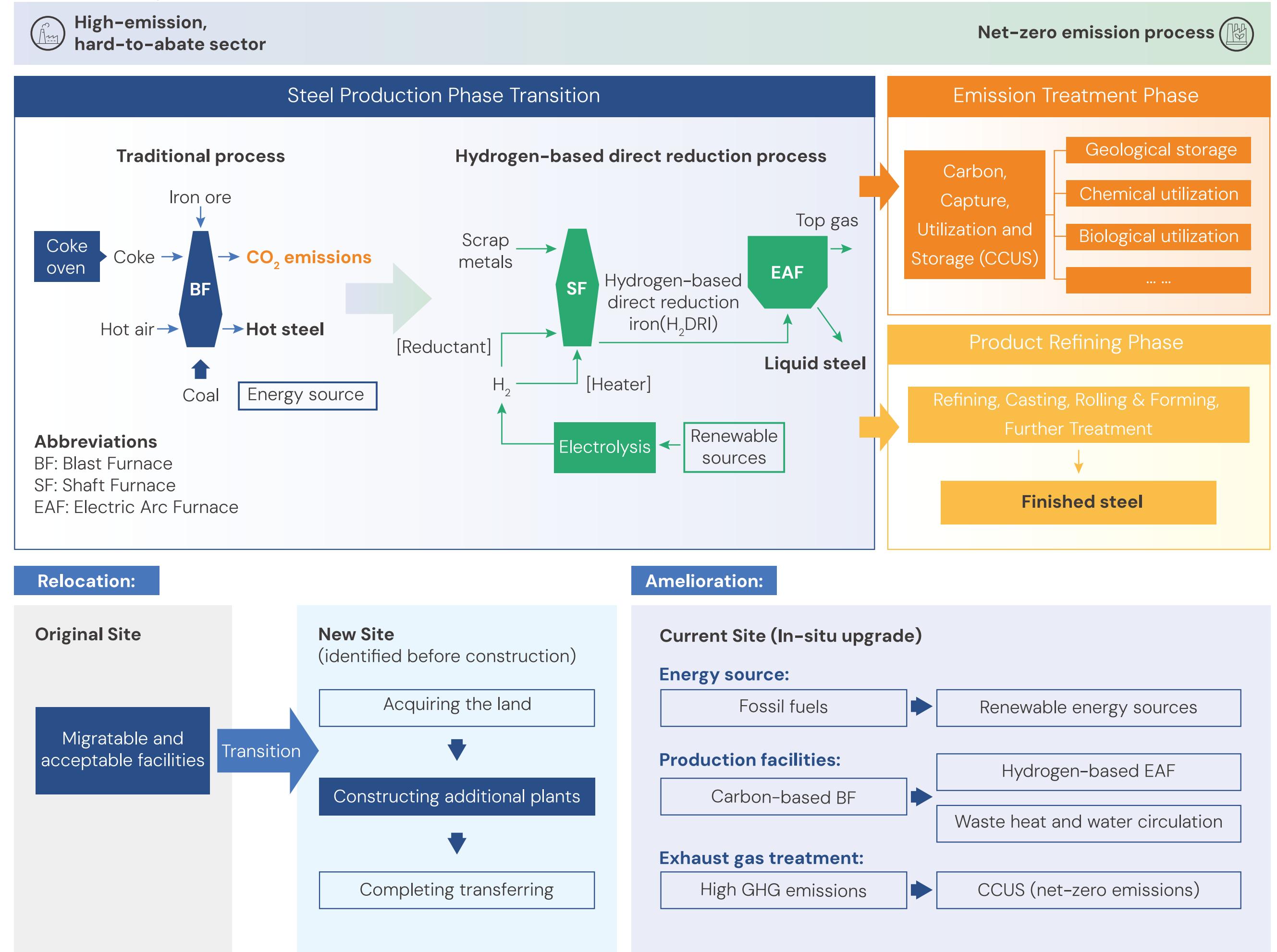
Source: China Baowu Steel Group, 2022[77]

> *Baowu aspires to become both forerunner and leader in achieving carbon neutrality in the steel industry. By advancing green manufacturing, strengthening technological innovation and creating a green industrial ecosystem, we aim to build a new type of low-carbon metallurgical industry chain to facilitate the green and low-carbon transformation of the steel sector.*
>
> **Gao Jianbing,** Deputy General Manager, China Baowu Steel Group

Manufacturing relocation involves the identification of a new production site and the integration of reusable components from existing facilities into this new location. This strategy expedites uninstalled components' relocation, installation, and operation, thereby minimizing operational downtime. Through the incremental transfer of equipment and supporting infrastructure, companies maintain production capacity and reduce the risks of a complete cessation of operations. In addition, this staged approach cultivates the incorporation of advanced technologies and sustainable practices, finally enhancing operational efficiency and lessening environmental impact.

Within this relocation process, ClimateTech innovations contribute by facilitating the efficient disassembly and reassembly of components, and by upgrading existing components for integration with the new site's typically digital and smart infrastructure. For example, technological advancements permit the incorporation and reuse of gas cleaning systems or heat recovery systems from blast furnaces in electric arc furnaces. Refractory materials are also amenable to recycling and reuse with new technologies. To facilitate integration with digital systems, innovative retrofit digitalization solutions, such as clamp-on flow meters or sampling probes, no longer require extensive revising or cutting of existing pipework.

FIGURE 1.13 | Transition Process of a Steel Manufacturing Plant



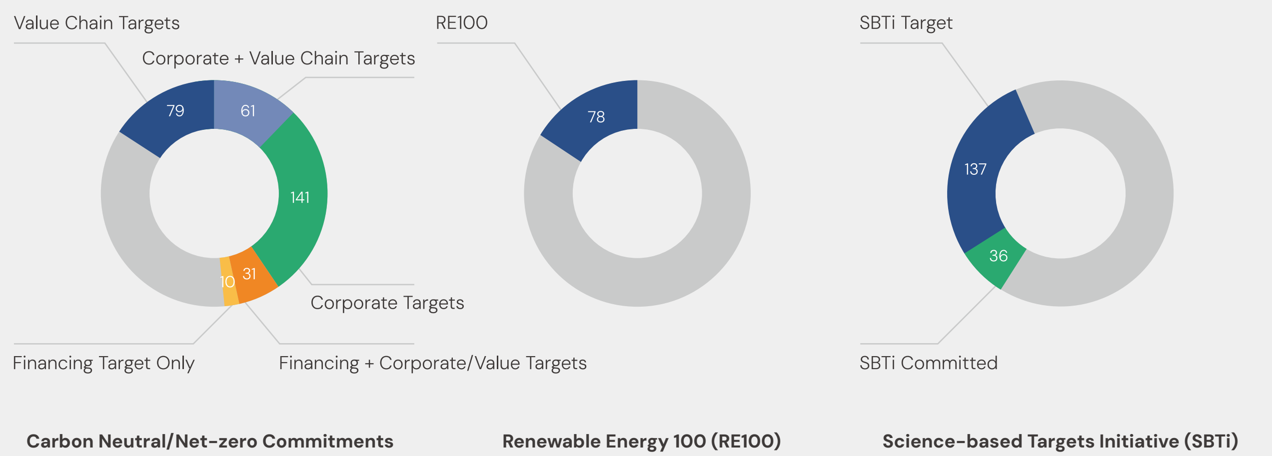
Source: Our World in Data, WeCarbon analysis[78]

Compliance to Excellence: Marching Towards Sustainability

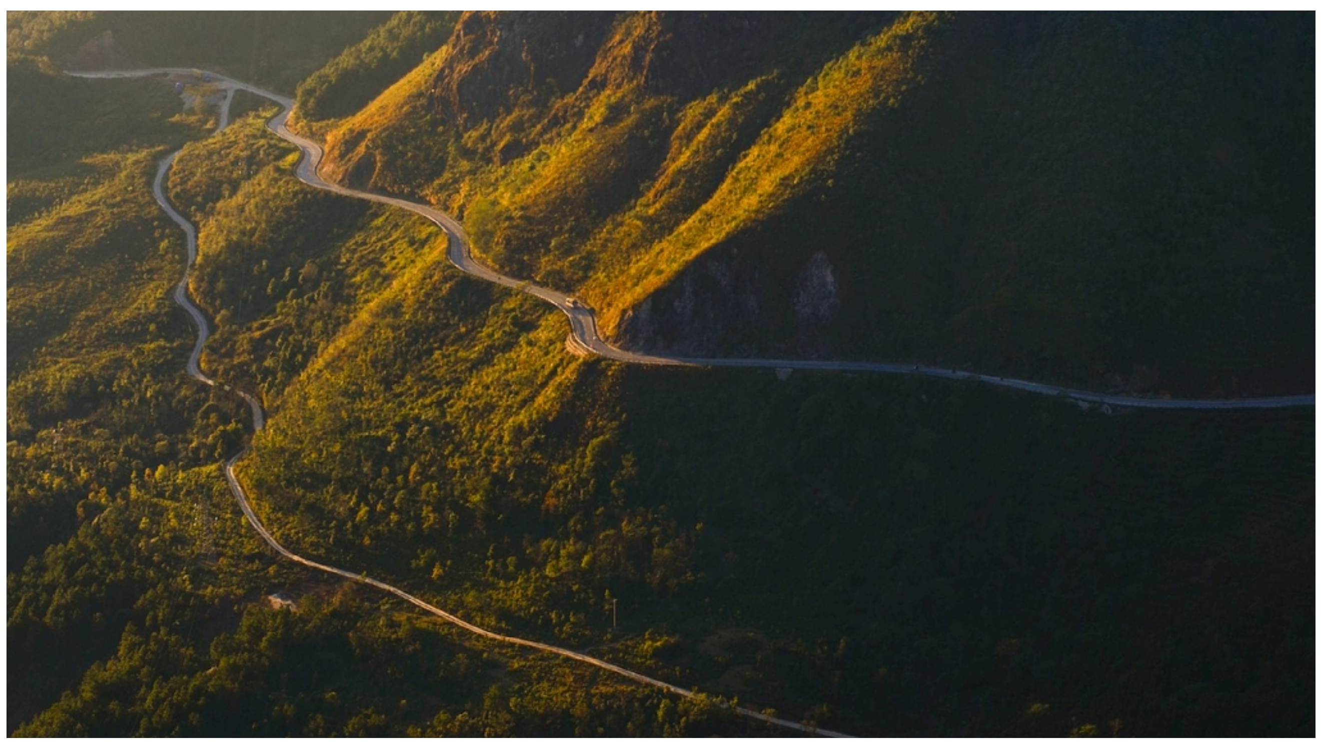
Prior sections explored decarbonization strategies mostly focused on regulatory compliance. While fundamental, such compliance represents a reactive posture that can be insufficient for driving transformative change.

Major conglomerates are transitioning beyond mere compliance with regulations, actively cultivating sustainability excellence, and establishing and pursuing industry-leading standards. This shift is propelled by societal pressures and the cascading effects these conglomerates exert across their supply chains and stakeholder networks. Therefore, small and medium-sized enterprises likewise adopt sustainability principles, perceiving competitive advantages and long-term benefits in environmentally responsible practices.

FIGURE 1.14 **Climate-related Commitments Within Fortune 500**



Source: Climate Impact Partners



To broaden corporate participation in sustainability, it's crucial to understand the motivations that propel companies beyond mere compliance toward excellence. The notion that social responsibility or ESG metrics alone suffice as motivational forces must be dispelled; these function more as performance indicators than drivers. True progress requires balancing economic value with sustainability, ensuring stakeholders perceive the benefits for the company.

Contributors to this report identify several key motivators for pursuing sustainability excellence: unique brand competency, risk management, growth prospects, investor relations, and operational efficiency. All motivators reflect a principle that environmental excellence should align with the business strategy, not simply a matter of either compliance or altruism. Companies that strategically integrate these motivations frequently achieve competitive advantage and sustained financial strength, thus furthering broader sustainability objectives and enhancing resilience in an increasingly environmentally aware marketplace.

FIGURE 1.15 **Motivations from Compliance to Excellence**

Unique brand competency branding and customer perception

Achieving sustainability excellence helps strengthen the company's and brand's positioning and enhance customer awareness, trust, and resonance.

"*We infuse our brand with sustainability concepts and designs through electrification, smart technology, and recyclable materials, setting us apart from other luxury car brands, creating a differentiated competitive position, and attracting customers who share our values and vision.*

Alexious Lee
Chief Financial Officer & Chairman of ESG Committee, Lotus Tech

Building long-term resilience against climate, regulatory, or supply chain risks proactively in response to the global green trend

Achieving sustainability excellence aligns with green transition trends and addresses regulatory challenges in decarbonizing the company's supply chain.

"*Investor pressure and regulatory changes are driving companies to prioritize sustainability, which mitigates reputational and operational risks. By integrating ESG values and pursuing decarbonization, companies not only align with global green trends but also build resilience against climate and supply chain risks.*

The Hon. Warwick Smith AO
Former Federal Government Minister, Australia

Prospects of next areas of growth

Achieving sustainable excellence helps the organization explore the next areas of growth.

"*Sustainability is deeply integrated into the corporate culture and is a key factor for future growth. We offer continuous improvement and innovation through sustainable development, enhancing quality and efficiency to maintain a leading position in corporate advancement.*

Zhang Kaipeng
Senior Vice President, Global Supply Chain China, Schneider Electric

Other factors include:

- Enhancing investor trust and expanding investment opportunities through environmental commitments
- Reducing costs and improving the bottom line via efficient resource utilization
- Attracting and retaining motivated employees by fostering a sustainability-focused workplace

To achieve true sustainability excellence, companies incorporate creative practices and elements of brand culture and design into their strategies. Compliance-driven sustainability strategies may appear ar homogenous, while those striving for excellence demonstrate unique and frequently groundbreaking qualities.

CASE STUDY 5 | Sustainable Supplier Management for Vehicle Manufacturing

Lotus Technology Inc. (Lotus Tech) stands at the forefront of the luxury electric vehicle market, committed to providing high-end battery electric vehicles. The company prioritizes world-class research and development in next-generation automotive technologies, including electrification and digitalization. As consumer preferences shift towards more sustainable and intelligent transportation solutions, Lotus Tech is committed to achieving electrification and intelligent transformation by 2028, with a goal of carbon neutrality across its entire value chain by 2038.

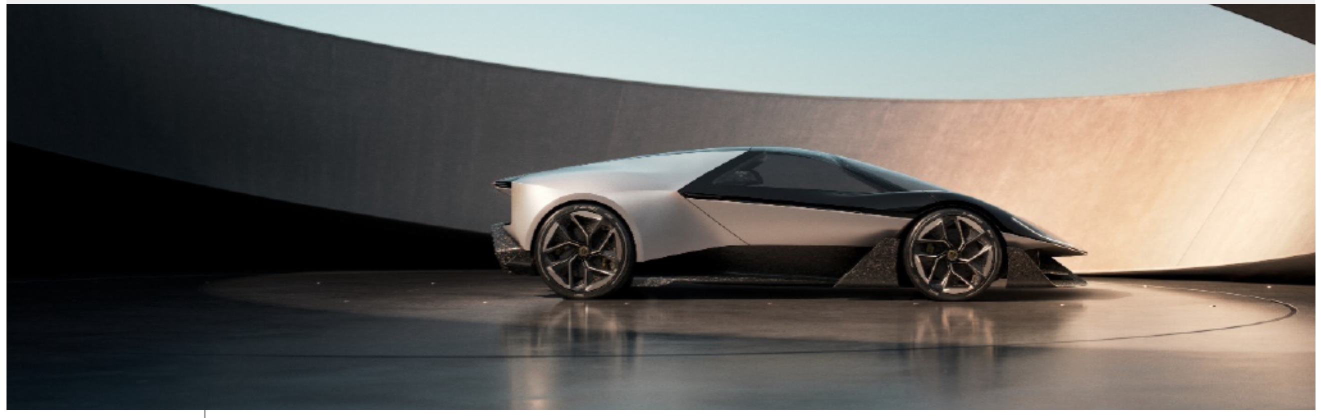
Lotus Tech collaborates closely with partners and suppliers to innovate sustainable practices in design and manufacturing. The company emphasizes using recyclable and reusable materials that it has incorporated advanced sustainable materials including WYRON truecycled® and Alcantara into its products. Emeya, the fully electric hyper-GT, has achieved a material recyclability rate of over 91.4%. Additionally, Lotus repurposed aluminum from historic Lotus F1 race cars to create elegant, eco-friendly pens, weaving the brand's rich heritage into its sustainability narrative.

In 2024, Lotus has unveiled Theory 1, its first concept car that has been designed with only ten main A-surface materials with performance, durability, lightweight, recycled, and recyclable properties. This includes cellulose based Glass fibre, recycled chopped carbon fibre, titanium, recycled glazing, recycled polyester, recycled rubber, elastomeric Polyurethane, transparent polycarbonate, thermoplastic polyurethane, and recycled aluminum. This demonstrates Lotus' commitment to pure minimalism, which is a nod back to Lotus' simplicity of construction and lightweight principles of the company's heritage vehicles.

Product innovation is inseparable from good supply chain management. Lotus Tech has introduced a digital traceability platform utilizing blockchain technology. This platform not only enables more in-depth tracking of material information and assessment of risks but also lays a robust foundation for comprehensive supply chain due diligence. Through this innovative measure, it ensures the reliability of the supply chain and presents exceptional products to highly discerning customers, setting a new standard in the industry.

Lotus Tech has also initiated an industry-first pilot project on natural capital assessment with its suppliers, identifying nature-related risks and opportunities across its procurement, assembly, and manufacturing processes. Based on the findings, Lotus Tech has worked with its suppliers to drive further changes in raw materials sourcing, including increasing the use of recycled materials and green energy.

Source: Lotus Tech, 2024



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Lotus thrives on quantifying the sustainable performance of its suppliers and actively incentivizes the outperformers, to collaboratively push for the green transition of the entire vehicle manufacturing supply chain.

Alexious Lee, Chief Financial Officer & Chairman of ESG Committee, Lotus Tech

Regarding operational excellence in the consumer goods sector, businesses are integrating sustainability throughout the product lifecycle. Companies recognize the need for comprehensive sustainability from design to end-of-life, which reduces environmental impact and enhances brand perception. Through targeted narratives on climate-related themes, businesses can align with consumer values, increasing recognition of their efforts.

CASE STUDY 6 | Empower Circularity for Sports Footwear

Nike, a global leader in sports footwear, is dedicated to advancing sustainable development through a circular economy for its products. This commitment is exemplified by the Nike Grind program, which repurposes end-of-life shoes and manufactures scrap into Nike Grind materials. These materials are then used to construct athletic surfaces such as playgrounds and runways for underprivileged children worldwide and are incorporated into the design of other recycled products.

Nike Grind material, primarily composed of recycled rubber particles, faces challenges in separating, transforming, and synthesizing old shoe materials. In collaboration with the Institute of Circular Economy at Tongji University in China, Nike developed a comprehensive recycling system for waste sports shoes.

This technological pathway addresses the complexities of recycling sports shoes and enhances the environmental application of Nike Grind material in various contexts. By August 2024, the Nike Grind project had produced 140 million pounds of recycled materials, which were integrated into partners' products and used to build sports spaces of over 1 billion square feet across more than 10,000 projects globally. Nike's commitment to sustainability extends beyond athletic surfaces; the program also incorporates recycled materials into the design of physical retail environments and workplace settings for employees.

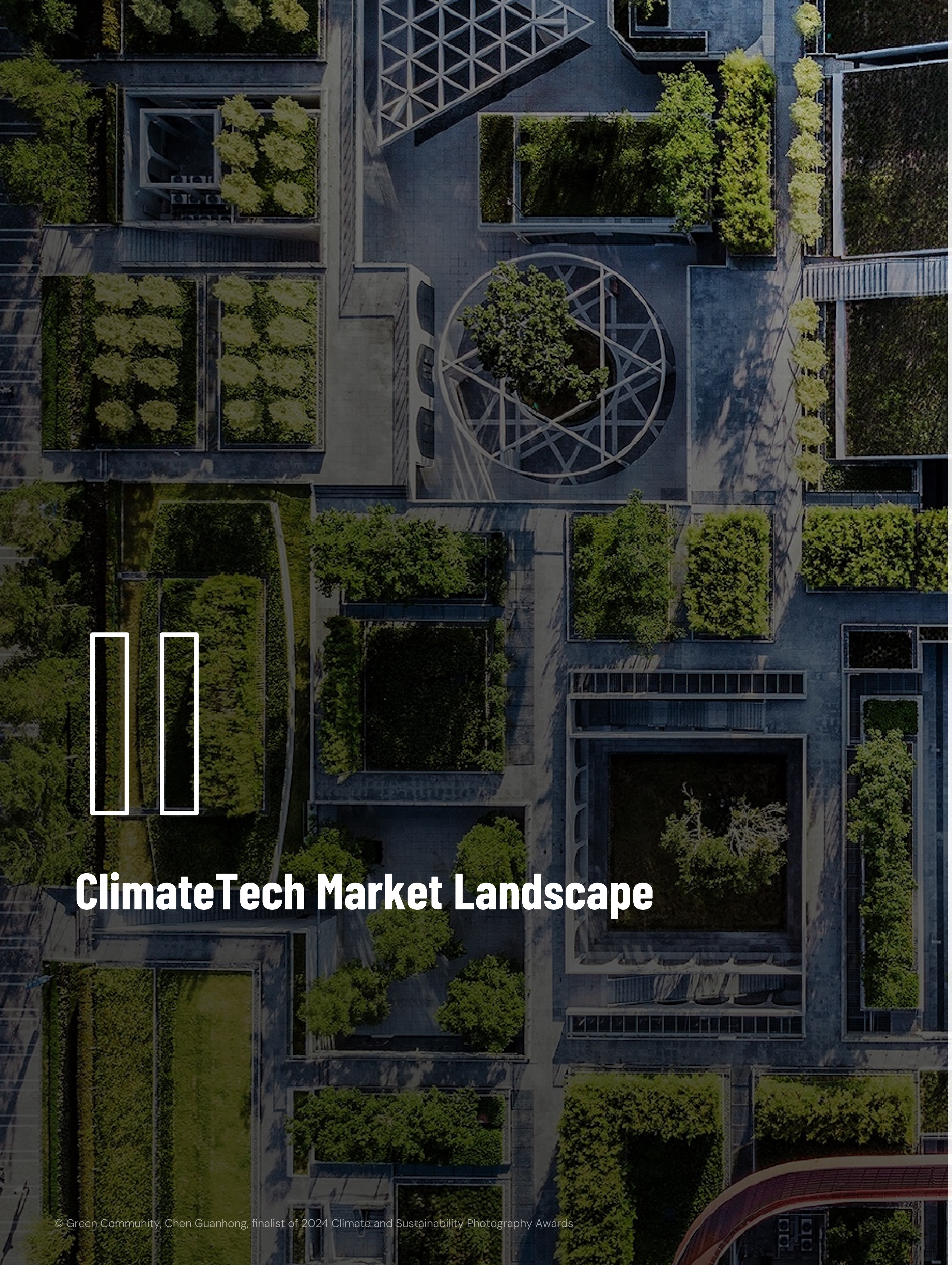
The Nike Grind recycling model, Recycle a Shoe, actively encourages consumers to donate their old shoes, which are then transformed into Nike Grind materials. This initiative enhances consumer participation in Nike's sustainable efforts and represents a significant step towards circular design and a green business model. By engaging consumers in recycling, Nike builds stronger customer loyalty and aligns its brand with the growing consumer demand for sustainability. Ultimately, this enhances Nike's market position and drives long-term business success through a green brand strategy.

Source: Nike, 2024

“

It is great to see that the Recycle A Shoe program is enabling more people to put sustainability into practice in their daily lives. Nike will continue to be committed to innovating and creating a bigger impact in protecting the planet and empowering the next generation.

Stanley Chang, Vice President of Supply Chain Greater China, Nike



ClimateTech Market Landscape

> *"Government providing systems and processes to provide quality assurance to the purchasers and developers of products, that creates a market that gets investment to flow. To compete in a low carbon economy, we will have to invest in supporting industry and businesses. So I think that's changing the decisions of the domestic government here as well. If we wanna sell into low-carbon markets, we need to make sure that we're competitive.*

The Hon. Matt Kean
Chair, Climate Change Authority

Assessing ClimateTech Readiness

ClimateTech spans multiple industries and technologies, rendering diverse patterns of innovation spread. To comprehend these patterns, it is necessary to highlight the distinctive features of ClimateTech that demonstrate how innovations in this sector are spreading. This knowledge provides insight into the current status of ClimateTech and aids in forecasting which technologies are likely to experience substantial growth and adoption by 2030.

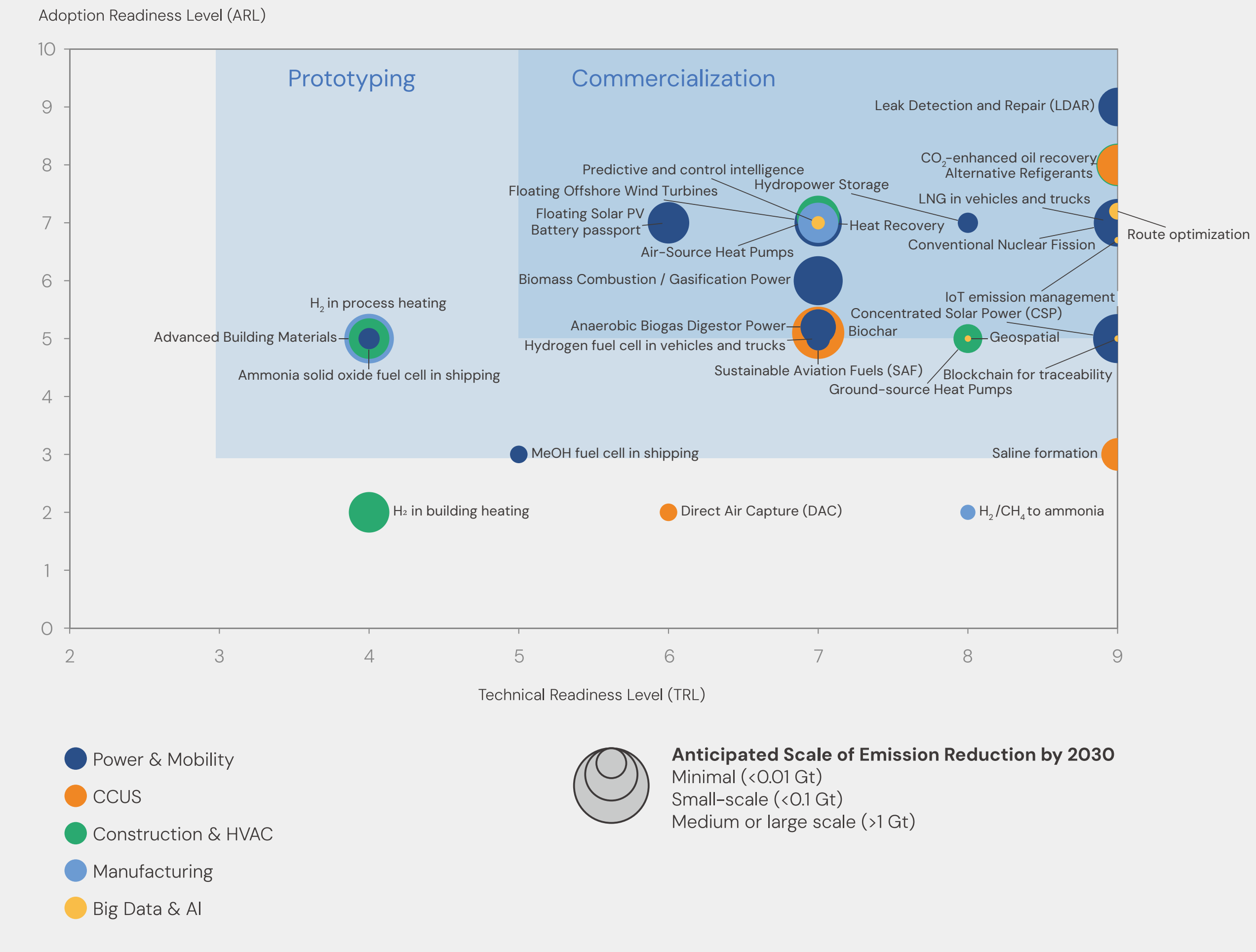
A significant factor in the spread of ClimateTech innovation is the extent of substitution. Substitution can be total, as illustrated by green electricity and alternative fuels, which mimic the physical and chemical properties of standard energy sources. Alternatively, substitution may be partial, as seen with electric vehicles and sustainable agriculture, where the products are comparable but uniquely differ in terms of performance, appearance, consumer perception, and health advantages. Certain climate technologies, such as those facilitating green certification, finance, or carbon capture, do not replace existing products but provide complementary services or standalone solutions.

Technical readiness significantly influences products with higher substitution effects, where consumers weigh costs almost as the only factor against traditional alternatives. Cost can include direct pricing and indirect value factors such as penalties, incentives, public perception, policy consistency, risk management, and opportunity costs. Adoption of these factors generally begins with pilot projects initiated by governments and major corporations that place importance on these indirect value factors. Smaller enterprises tend to adopt these technologies when there are direct policy incentives. Once technical readiness reaches a threshold level, the market leads to substantial cost reduction followed by exponential scaling.

Adoption readiness impacts ClimateTech sectors with lower substitution effects, including consumer goods and also standalone ClimateTech solutions such as direct air carbon capture and technologies for certification, financing, or MRV services, whose focus is more on whether the market has matured sufficiently to enable these ClimateTech solutions to deliver customer perceived value, such as generating revenue or enhancing the income profile of clients.

This report quantifies the ClimateTech sectors by examining two key indicators: technology readiness level (TRL) and adoption readiness level (ARL). TRL serves as an indicator for assessing if climate technology solutions can reach cost-effective thresholds. Meanwhile, ARL evaluates the ability of these solutions to generate customer perceived value and gain market acceptance.

FIGURE 2.1 | **Readiness of Key Technologies in ClimateTech**



Source: IEA, WeCarbon analysis

Decarbonization efforts by 2030 heavily rely on the widespread adoption of mature technologies while embracing innovative solutions that are gradually gaining traction. Solar, wind, nuclear energy and widespread usage of renewable energy in logistics, shipping, and manufacturing are poised to make substantial contributions due to their advanced readiness and proven effectiveness. Their scalability leads to achieving significant emission reductions on a global scale.

In addition to these mature technologies, innovation in renewable energy presents exciting potential. Floating Offshore Wind Turbines and Floating Solar PV are advancing towards commercialization, offering novel options for scalable and efficient renewable energy solutions. This diversification reduces dependency on fossil fuels. Furthermore, the integration of alternative fuels, such as methanol in shipping, marks a transformative shift in logistics, promising cleaner and more sustainable operations.

Hydrogen technologies are also increasingly prominent, with hydrogen fuel cells nearing commercialization across various sectors. Their versatility underscores their importance in decarbonizing traditionally challenging areas. Heat management solutions, like Air-Source Heat Pumps, are enhancing energy efficiency, significantly contributing to emissions reduction. Complementing these efforts, Big Data and AI act as catalysts, optimizing energy systems and facilitating intelligent decision-making. Together, these elements form a comprehensive approach to achieving sustainable energy goals by 2030.

Drivers and Barriers for the Future Adoption

To enhance the readiness of technology in ClimateTech, it is essential to understand the drivers and barriers influencing technical maturity patterns across different regions.

Investment remains the most significant driver for ClimateTech advancements. In 2023, most of the ClimateTech investments occurred in North America, followed by Europe, then China. Mobility and energy are the main drivers behind climate investments, accounting for more than two-third of total ClimateTech investments.[79] However, there is a clear regional divergence in investment patterns. In North America and Europe, investments are more evenly distributed across a broader range of sectors, with the energy sector still commanding the largest share. Europe, in particular, stands out with a higher proportion of investments in industrials compared to other regions. Meanwhile, in Asia-Pacific and China, there has been a noticeable shift from mobility-driven investments toward energy and other emerging sectors.

> *The battle against climate change will be won or lost in Asia.*
>
> **Dr. Xing Zhang**
> Senior Climate Specialist, Asian Infrastructure Investment Bank

Overall, there is a misalignment between technologies with the highest potential and those that receive the most funding. Technologies with relatively higher emissions reduction potential, like green hydrogen, receive small shares of startup investment. Yet, technologies such as light-duty battery EVs receive the most share of investment despite limited emission reduction potential.[79] To mitigate these gaps, public sector financing, such as government loans can overcome the high capital requirements and bridge private investment gaps.

The U.S. Department of Energy's Loan Programs Office (LPO) provides over USD 400 billion in loan capacity to support clean energy initiatives like renewable energy and advanced nuclear projects. This helps mitigate the financial risks that often deter private investors. Similarly, the European Union, through the European Investment Bank (EIB), aims to mobilize EUR 1 trillion by 2030 for climate-related projects. These government-backed loan programs de-risk high-capital projects, enabling the clean energy transition by attracting further private capital.

Government-backed loans are only part of the solution; meeting global climate goals will require significantly more investment from both the public and private sectors. To achieve net-zero emissions by 2050, the world will require an extraordinary level of investment in clean energy and related technologies. According to estimates, global investment must rise to about USD 6.7 to 7 trillion per year from now through 2050.[80] This would total nearly USD 200 trillion in clean energy investments over the next few decades. These funds will support the rapid deployment of renewable energy, carbon capture and storage, hydrogen production, and advanced nuclear technologies.

> *The current state of the investment landscape for climate change technologies is promising as it has been embraced wholeheartedly by a range of participants. In achieving the energy transition and the climate action, the role of government is to be catalytic or spark that's helpful in bringing in external funding.*
>
> **Mark Cutis**
> Senior Advisor, Abu Dhabi Investment Council

Despite promising developments in ClimateTech, adoption faces significant barriers across technological, financial, regulatory, and social dimensions, creating complex challenges for scaling solutions for a low-carbon future. Technologically, while solar and wind are well-developed, others like hydrogen and carbon capture remain less mature, with hydrogen for steel production being prohibitively expensive compared to fossil fuels. Renewable energy deployment also struggles with energy storage due to the intermittent nature of wind and solar, requiring advanced battery solutions.

Financially, a formidable barrier is the hefty upfront investments required for technologies like CCS, hydrogen infrastructure, and large-scale renewables, with actual investments in ClimateTech falling short of the USD 6.7 trillion annually needed to meet net-zero targets by 2050. This shortfall is acute in developing economies with higher risks and fewer incentives, with public funding and private investment often insufficient. Regulatory hurdles include inconsistent policies that hinder progress despite progressive initiatives like the EU's Green Deal and the U.S. Inflation Reduction Act. Market limitations, such as inadequate EV charging infrastructure and nascent hydrogen facilities, further constrain adoption, demanding significant capital and industry-government coordination. Social and behavioral resistance adds another layer of complexity. Overcoming these multifaceted challenges requires coordinated efforts: policymakers should implement coherent regulations, investors must allocate more capital to early-stage technologies, and society needs to shift towards sustainable practices to accelerate ClimateTech adoption and meet net-zero targets.

US$ 6.7 trillion

investment required in CCS to meet net-zero targets by 2050

Driving the Pathway of Market-Readiness from Lab to Factory

The analysis of TRL and ARL underscores the importance of understanding how ClimateTech transitions from laboratory research to industrial production. Many contributors to this report highlight that startup teams emerging from university laboratories frequently encounter commercialization challenges. Some academics and scientists might indulge in technical research, and some might ideally hope that incubators and venture capital funds could resolve issues related to sales and funding, allowing them to concentrate solely on technical advancements. However, most contributors to this report disagree with this perspective. They argue that a blend of skills, particularly in sales, government relations, and investor relations, is equally critical in ClimateTech entrepreneurship .

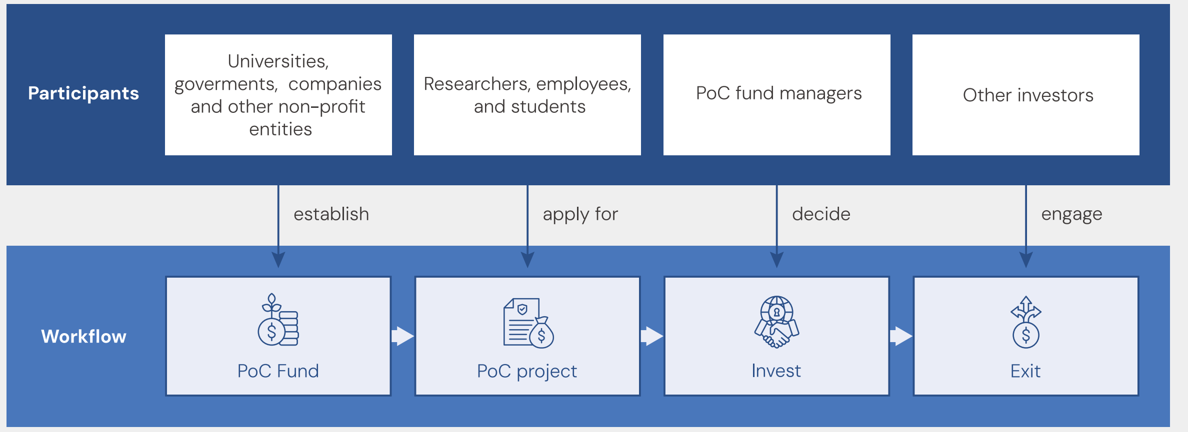
In cases where these skills are missing, professional service providers are needed. Dr. Li Zheng, President of the Institute of Climate Change and Sustainable Development at Tsinghua University, points out that services are in great need to bridge financing, compensation, subsidies, tax allowances, and other resources to the innovators. Moreover, assistance from experienced professionals is also a strong force for product development so as to help scholars turn their work into market-ready products. Universities may establish technology transfer offices (TTOs) to assist researchers with intellectual property and partnerships.

Supporting mechanisms are required in the transition from the lab to the factory, especially those involving venture capital and government support to help technologies achieve application and breakthroughs in specific industries. Moreover, their success depends on establishing proper rules and mechanisms. Technologies that remain confined to the lab pose risks too high for even early-stage venture capitalists to bear. Therefore, innovative mechanisms are necessary to bridge this gap and shorten the pathway to early tests and prototypes.

Regulatory sandboxes facilitate the testing of scenarios under controlled regulatory oversight, allowing innovators to experiment with new technologies and business models in real-world settings while ensuring compliance with existing regulations. In the context of green technology, smart grids, and new fuels serve as notable examples. The impact of smart grids or microgrids is often measurable only within interconnected power grids. Certain grid configurations, such as those involving decentralized energy production or dynamic pricing models, may conflict with current regulations designed for static energy systems. By testing these innovations within a regulatory sandbox, policymakers can observe their real-world effects and adjust regulations to accommodate new technologies that enhance sustainability and efficiency. For fuels like hydrogen, regulatory sandboxes provide an opportunity to test these fuels in real-world scenarios that do not fully adhere to existing regulatory standards, provided such tests are scientifically proven to be safe. In 2019, Republic of Korea approved hydrogen refueling stations with limitations partially lifted, including one at the National Assembly Building, showing support for ClimateTech growth.

Proof of Concept Fund (PoCF) is a type of venture capital that focuses on filling the funding gap from research to the technically viable product. PoCFs provide early-stage funding to validate the technical and commercial potential of new technologies, helping to de-risk projects and make them more attractive to larger investors. By supporting initial development and market testing, PoCFs enable startups to demonstrate the viability of their innovations, thereby increasing their chances of securing further investment. This type of funding matches the characteristics of ClimateTech, where the path from laboratory research to industrial application can be long and capital-intensive.

FIGURE 2.2 **Typical Workflow of a Proof of Concept Fund**



Source: WeCarbon

Initiating a PoC demands a significant tolerance for risk due to the high likelihood of failure. The concept of "fail fast, fail well" underscores the value of learning from these failures, as they often provide insights that success might not reveal. Additionally, PoCs can help discard unfeasible ideas early on, preventing the allocation of substantial funding to projects that are ultimately impractical.

Consequently, many proof of concept initiatives receive support or management from government entities. These funds sustain their business model by providing limited but adequate financial backing for initial projects, with guidance from experienced experts who assist in planning. For promising subsectors, these funds may continue to track companies even if the initial trials are unsuccessful. Additionally, the knowledge gained from these failures offers first-hand insights into the viable and profitable areas of a sector, granting these funds an early investment edge in future ventures. According to Ravenna Chen, Chief Executive Officer of TusStar Asia-Pacific, there are market-driven funds collaborating with governments to establish PoCF, combining industry expertise with the government's mandate to support green industries. Such funding typically provides targeted financial resources under supervision, ensuring that funds are allocated correctly and used appropriately.

Large conglomerates often establish labs within their own factories and open them to third party collaborators for technology testing, especially for technologies related to hard-to-abate or heavy sectors, such as steel, automotive, or aluminum. Testing facilities require operational manufacturing plants, making them expensive and difficult for innovators to access. By providing these test scenarios, innovations can be evaluated efficiently. Additionally, these conglomerates gain an early advantage in identifying new technological trends and accessing venture capital investment opportunities. With comprehensive knowledge of the technology and its feasibility within their own plants, they can invest with a certain degree of certainty.

To conclude, the successful commercialization of ClimateTech relies on a harmonious blend of technical innovation, entrepreneurial acumen, and strategic institutional support. Beyond just funding and research, the integration of cross-disciplinary skills and targeted mechanisms plays a role in bridging the gap between the lab and the market. These approaches are promising for overcoming commercialization hurdles and driving impactful climate solutions on a global scale.

III Focus Area Deep-dive

> "*Africa is facing the challenges of switching to a just transition. South Africa has lots of fossil fuel resources of the best quality. While switching to green technology, we must consider what to do with coal and the power stations that are powered by these fossils at this particular point of time. We need planning, finance, and expertise.*"

H.E. Mohammed Dangor
Member of Parliament, South Africa

Big Data & Artificial Intelligence

Artificial intelligence (AI) can mimic and even transcend human intelligence, responsiveness, and memory in managing supply chains especially when confronted with large data sets and real-time requirements for decision prioritization. While the report contributors largely acknowledge the transformative potential of AI in supply chain management, they also recognize the gap between solutions in labs and factories. Based on the current market landscape, identifying specific use cases to generate tangible value in supply chains can be the next key success factor for AI services and products.

Supply Chain Management through Predictive and Control Intelligence

Contemporary AI technologies are widely deployed to address sustainability and efficiency concerns, with a number of applications achieving maturity. Predictive and control intelligence functionalities in AI leverage pattern analysis to forecast events such as adverse weather and fluctuating market demand, thus empowering supply chains to adapt proactively. These predictive and control elements can function autonomously, as exemplified by market trend prediction in procurement intelligence or synergistically, as demonstrated by Model Predictive Control (MPC) in industrial settings.

Predictive analytics, focusing on forecasting future supply chain metrics such as inventory, demand, maintenance, and energy use, are particularly important in guiding decisions. Early machine learning methodologies, like Long-Short Term Memory (LSTM), focus on learning repeated historical trends and momentums and have been largely employed to forecast cyclic incidents, such as seasonal demand surges or fluctuation of power grid usages within each day. This is useful yet suffers from the logical fallacy that correlation does not imply causation and consumes a large amount of data within the supply chain, which can be expensive or time-consuming to attain. The latest predictive analysis algorithms focus on transfer learning using more sophisticated pre-trained base models, less extra training data, and more transferrable reasoning capabilities. The use of a multimodal Large Language Model (LLM) enables information in heterogeneous raw real-world supply chain data to be captured and processed at the earliest chance and relieves the pressure of manual data cleaning and standardization. Control intelligence further exploits the data value by taking action to the supply chain processes, such as route optimization, thereby reducing fuel consumption and emissions.

Johnson Yeh, Former Head of Circular Economy Initiative at the World Economic Forum, observes the advancement of a particular use case in identifying and sorting inventory, typically by using computer vision (CV) and classification algorithms. With the development of Generative Pre-trained Transformers (GPT), these traditional specialized predictive, control, and identification models can be wrapped as agents and orchestrated by the GPT LLM, forming the "LLM-Agent" architecture. This framework allows AI to provide general reasoning while excelling in specific tasks with high accuracy. To extend the knowledge base of LLMs and agents, the trending Retrieval Augmented Generation (RAG) technique attaches databases and search agents to provide vast information on domain knowledge. These AI-driven systems represent a significant step towards more autonomous and sustainable supply chain management, promising further gains in efficiency and sustainability as technology evolves.

Despite these advancements, scaling and reusing AI across supply chains presents significant challenges due to the inherent volatility of these systems. Many underestimate the costs and complexities involved. Many AI techniques are trained to perfect the use case in a certain location, context, or model set. Due to different supply chain dynamics, regulations, and infrastructure, scaling or reusing AI can require extensive recalibration and, in certain cases, even a complete redesign of algorithms. The market needs more advanced calibration and transfer learning techniques to minimize the cost of scaling and reusing. For example, HVAC optimizers should be built on completely different complexity in individual factory units versus interconnected units. In simple cases, model training may converge quickly and receive a sound out-of-sample performance while cases involving a large set of factors can only

seek partial optimization and should be very cautious about overfitting. Here, metaheuristic approaches, particularly deep reinforcement learning (DRL), genetic algorithms (GA), or particle swarm optimization (PSO), are effective for finding these partial optimization heuristically. Scaling AI also means computational power requires decentralization, leading to the use of edge computing.[81,82,83]

Beyond using more advanced algorithms, early-moving data can significantly improve model performance. The Prior Information Notice (PIN) system functions as an alert system in which the demand information is received before the actual demand arrives. Integrating PIN systems with AI enhances predictive accuracy. This synergy creates a dynamic feedback loop where AI insights inform data collection needs, refining algorithms' ability to foresee issues like shortages or delays. Implementation of this system requires robust data governance and infrastructure capable of ensuring the quality, consistency, and availability of the data throughout the supply chain. While not a standalone solution, the integration of PIN systems and AI is a significant powerful enabler designed to address contemporary supply chain problems and sustain responsiveness in ever-changing conditions.

CASE STUDY 7 | **AI-driven Energy Management Platform**

As a global leader in technology and services, Bosch has integrated sustainability into its core business strategy. Since 2020, more than 400 Bosch locations globally have achieved carbon neutrality, covering Scope 1 and 2 emissions under the "Greenhouse Gas Protocol Corporate Standard." Bosch's strategy to reach this milestone is driven by four levers: increasing energy efficiency, generating renewable energy, purchasing green electricity, and offsetting remaining carbon emissions through carbon credits.

As Bosch's largest market outside of Germany, Bosch China has been actively taking steps to contribute to sustainable development, particularly in the area of increasing energy efficiency. In 2023, Bosch China introduced nearly 220 new projects with savings potential of 27 GWh. By harnessing advanced technologies like artificial intelligence (AI), Bosch China is making significant progress in energy management, process optimization, and related areas.

One example is the AI-powered energy-saving initiative at its Qingdao plant, which produces diesel injection systems. In recent years, traditional energy-saving measures have approached their maximum potential, prompting the adoption of advanced digital solutions. An energy management platform provided the plant with clear insights into consumption patterns, showing that over 15% of its energy was used by the cooling systems. In response, Bosch installed an AI system developed by Bosch employees to optimize chiller performance. This system analyzes historical data and uses real-time weather and cooling demand inputs to dynamically adjust temperature setpoints. As a result, the AI system improved efficiency, cutting energy consumption by at least 10% during continuous 24-hour manufacturing processes. Following its success in Qingdao, this AI-driven system has been extended to Bosch's plants in Wuxi, Xi'an, and Wujin, where large-scale implementation is currently underway.

Source: Bosch, 2024

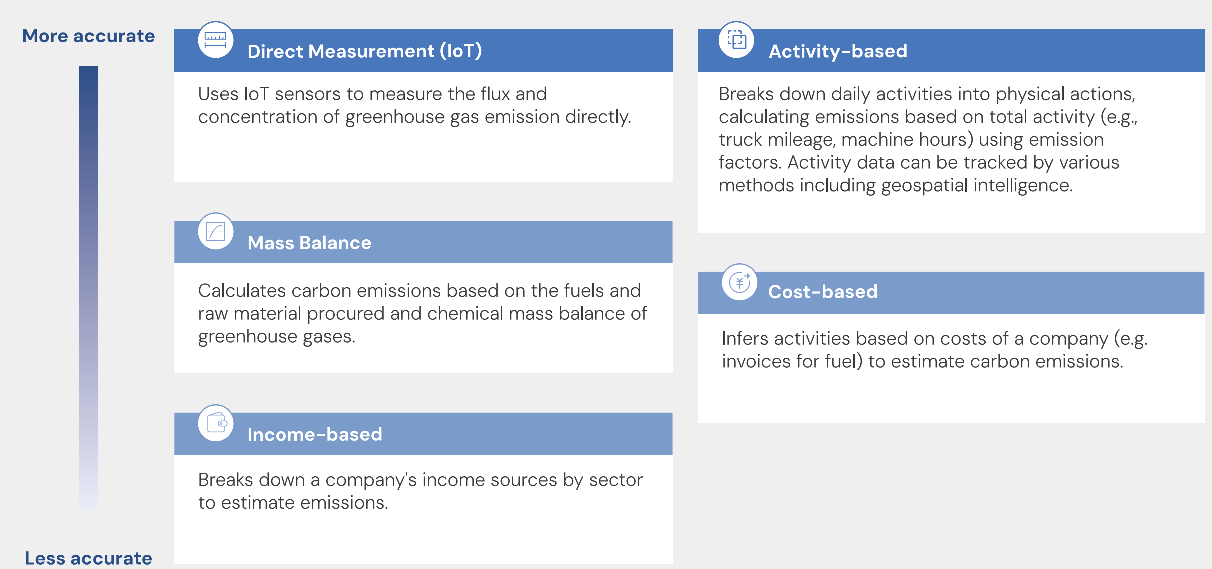
"*Sustainability is one of the core strategies driving Bosch's business development. Bosch is committed to advancing our products, technology, and operations, while uniting the entire supply chain to shape a greener future.*

Dr. David Xu, President, Bosch China

Emission Tracking through IoT and Geospatial Intelligence

Accurate emission monitoring is the cornerstone in incentivizing supply chain participants and facilitating green supply chain activities. However, accuracy also leads to high costs, especially in sectors in vast venues or difficult circumstances, such as agriculture, mining, and certain industrial activities. The trade-off between accuracy and cost largely depends on commercial sensitivity — for example, carbon accounting for financing portfolios involves vast, various entities, access to whose accurate activity data can be limited, thus favoring faster and cheaper options. Conversely, for commercially sensitive activities, such as certification, trade compliance, and green asset trading, usually require higher accuracy.

FIGURE 3.1 **Emission Tracking Methods by Accuracy**

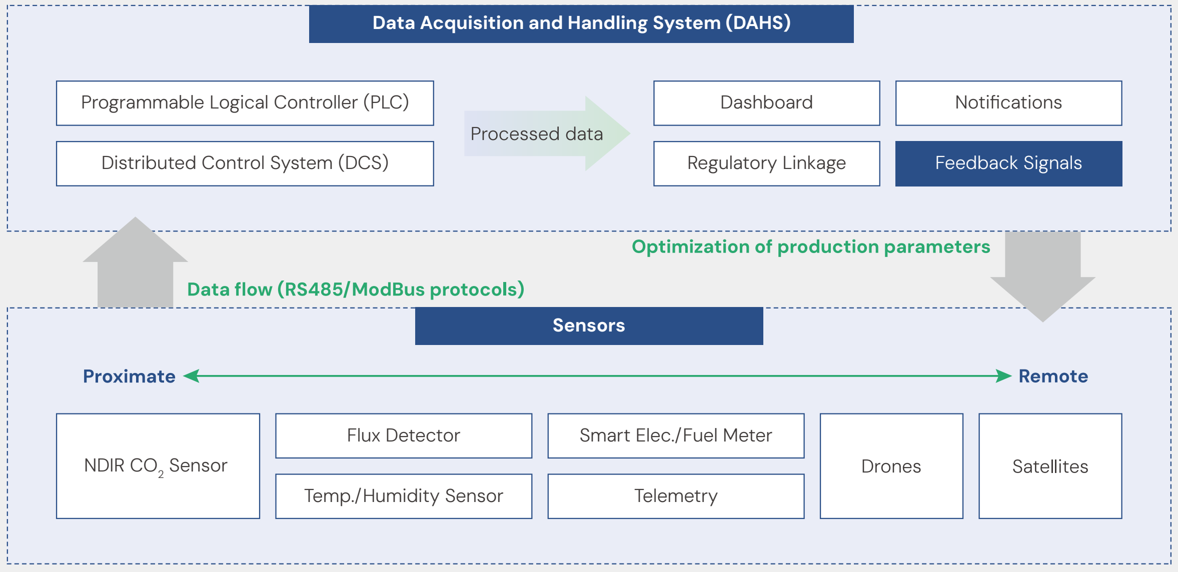


Source: WeCarbon

Automated tracking technology, such as Continuous Emission Monitoring System (CEMS) and IoT, features precise tracking of greenhouse gas (GHG) emissions with automated data collection, emissions calculations, and regulatory reporting. Apart from precision, the technology also elevates data credibility by minimizing manual intervention to prevent indeliberate disturbances, fraud, or greenwashing. Many countries and regions have started to mandate connecting the CEMS data with regulators to monitor real-time CO_2 or methane emission, which is already an established regulatory practice for air pollutants such as sulfur dioxide and nitrogen monoxide. In the analysis of the data, multiple AI techniques can be used to identify anomalies, facilitate preemptive maintenance, and convert data into compliance reports.

Measuring the greenhouse gas, particularly CO_2, relies on their capacity to absorb light at certain wavelengths. For industrial settings, Non-Dispersive Infrared (NDIR) sensors and Ultraviolet Differential Optical Absorption Spectroscopy (UV-DOAS) represent the prevalent methods. Simpler gas compositions typically employ NDIR, while UV-DOAS accommodates more complex mixtures. Further methods, such as Fourier Transform Infrared Spectroscopy (FTIR) and Tunable Diode Laser Absorption Spectroscopy (TDLAS), offer alternative solutions adapted to specific requirements.

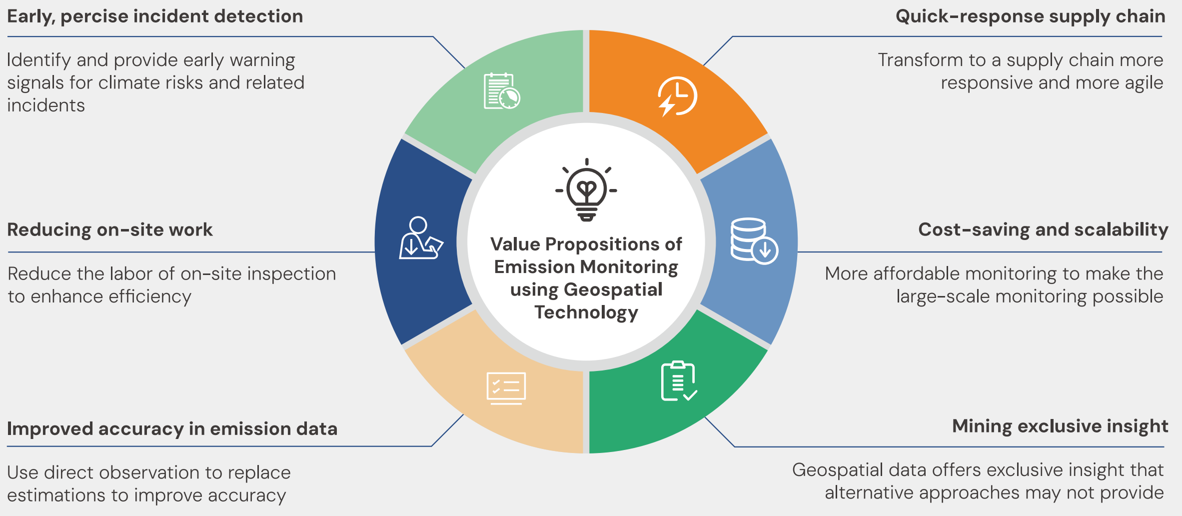
FIGURE 3.2 **Emission Tracking Using Sensors**



Source: WeCarbon

Geospatial technology serves as a cost-effective alternative in scenarios where the intrusive or widespread installation of IoT systems is not feasible, such as in agriculture and certain types of mining. Instead, geospatial technology collects electromagnetic information from satellites, aircraft, helicopters, or drones. For example, Light Detection And Ranging (LiDAR) drones are employed in measuring the volume of carbon sink in afforestation. Synthetic aperture radar (SAR) assesses the depth, slope, and flow direction of water surfaces to model the growth conditions of rice crops. Thermal infrared sensor (TIRS) measure temperature fluctuations to generate insights on manufacturing plant activity. Such geospatial data significantly improves the data availability of emission accounting, thus furthering adherence to reduction targets.

FIGURE 3.3 **Value Propositions of Geospatial Analysis**



Source: WeCarbon

Integrating more diverse and more accurate sensors is the theme of geospatial analysis. The latest civil imagery satellites reach extreme accuracy with a very high resolution (VHR, about 50cm). Through the integration of data channels from diverse spectrums, the user can gain comprehensive insights through modeling the ecological and manufacturing conditions.

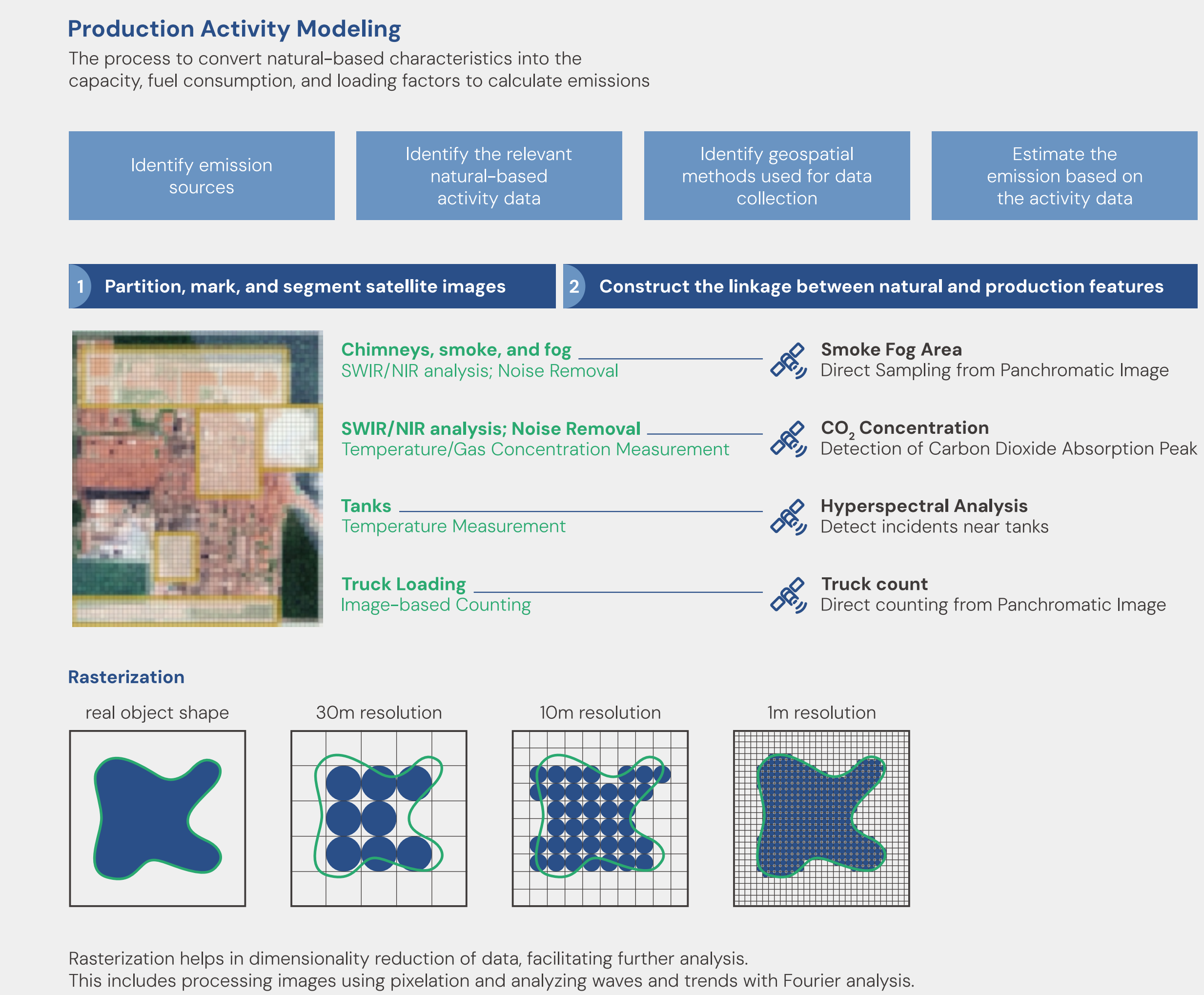
Figure 3.4 **Channels and Sensors Used in Geospatial Analysis**

Visible Light	Panchromatic	Observes ground contours and monitor elements such as truck numbers and warehouse inventories. This helps assess enterprise production and operational status.
	Multispectral	Detects ground color features like smoke color and snow cover to minimize data errors and interference.
Hyperspectral	HRGS	Estimates surface and atmospheric characteristics, including greenhouse gases, temperature, and surface states.
	TIRS	Measures temperature traits and deducing production conditions and fuel combustion.
	IUVS	Assesses ozone layer pollution and levels of particular gases (e.g. SO_2).
	SWIR	Analyzes atmospheric carbon dioxide concentration through absorption spectrum analysis.
Radar	SAR	Enables the creation of 3D terrain models, evaluates topography and moisture, and assesses industrial activity with a focus on carbon emissions in relation to production factors.

Source: WeCarbon

Simultaneously with data collection, geospatial analysis usually builds a production activity model to align the natural features from remote sensing with production processes and metrics. Such a model identifies emission types, sources, and locations to depict a clear view of emissions. Due to rain, snow, or other meteorological conditions, normalization is required to remove their effect on data perspectives.

FIGURE 3.5 **Process of Production Activity Modelling**



Source: Google Earth,[84] WeCarbon analysis

Traditional CV algorithms are still dominant in analyzing geospatial data, such as wavelet and Fourier analyses in spectrum analysis, debris removal, and ground monitoring. The inception of AI adds more insights and allows early warning when observing non-specific anomaly incidents. Beyond emission forecasting, geospatial technology is also useful in warning climate-related disasters, such as severe air pollution, floods, and maritime incidents.

Traditional Energy System Decarbonization

> "
> *CCUS is expected to be a game changer in Thailand's decarbonization efforts. With sufficient technology and capital investment, we anticipate success in CCUS projects.*
>
> **Dr. Twarath Sutabutr**
> President of Office of Knowledge Management and Development, Thailand

The world has agreed on COP28 to lower carbon footprints and gradually transition away from traditional energy sources such as coal, oil, and natural gas. Key technology to reduce their carbon footprints include Carbon Capture, Utilization, and Storage (CCUS), and also modernized grids and energy storage systems.

Carbon Capture, Utilization, and Storage (CCUS) Technologies Advancements

CCUS is a type of technology to capture CO_2 from sources such as industrial activities, power plants, or directly from the air.[85] After capturing, CCUS also demands storage of CO_2 in geological formations or used in processes like chemical production or construction materials. CCUS acts as a straightforward emission reduction method that usually requires less extensive upgrades in existing facilities, especially in hard-to-abate sectors like steel, cement, chemicals, and fossil fuel-powered energy facilities.

FIGURE 3.6 | **Process of CCUS**

Capture	Transportation	Storage or Utilization
CO_2 is isolated from industrial emissions using methods like post-combustion, pre-combustion, or Direct Air Capture.	CO_2 is transported through pipelines to storage or utilization sites, with ships or trucks as smaller-scale options.	CO_2 can be stored underground in geological formations, such as oil fields, gas fields, or saline aquifers, or converted into products like fuels and building materials.

The commercial viability of CCUS faces challenges due to the high costs of capturing, transporting, and storing CO_2. Capture costs for industrial processes range from USD 50 to 150 per ton, and direct air capture can cost up to USD 600 per ton.[87] An extensive CO_2 pipeline network is mainly used to transport the captured CO_2 from emission sources, such as industrial hubs or power plants, to storage sites, such as oil fields or saline aquifers. Both ends of the pipeline may be separated by a remote distance, representing a substantial cost.

In cases where pipelines are unavailable, shipping CO_2 is also an alternative to islands and coasts.[87] To find a reliable geological formation to permanently store CO_2, an upfront investment is also required.

US$ 50-150 per ton

Capture costs for industrial processes

Given the private sector's struggle to justify these projects based on market returns alone, the policy and regulatory support heavily influence CCUS's viability. The United States encourages CCUS implementation by providing up to USD 50 per ton of CO_2 stored and USD 35 for enhanced oil recovery through a 45Q tax credit.[88] The EU Emissions Trading System attaches costs to carbon emissions, promoting CCUS by making it financially appealing. Beyond financial support, leading conglomerates also directly invest in large-scale CCUS projects. For example, the Northern Lights Project in Norway, invested by TotalEnergies, Equinor, and Shell, captures CO_2 from European industrial sources, transports it by ship to Norway, and injects it into a storage site under the North Sea. This project plans to store up to 1.5 million tons of CO_2 annually,[89] with potential for expansion. Long-term regulatory stability is necessary to de-risk the long-term CCUS investment. Favorable incentives will help make CCUS commercially viable earlier, such as tax credits, carbon credits, public investment, carbon taxes, or cap and trade systems.

As the material research develops, there are also options to use materials absorbing CO_2 when exposed to the air to avoid CO_2 transportation. One prominent example is biochar, produced through the pyrolysis of organic waste, which is another promising method for CCUS.[85] Apart from absorbing CO_2, biochar also improves soil fertility and promotes microbial activity,[86] contributing to climate resilience and other sustainable development goals.

Modernization of Grids and Energy Storage

Power grids must be modernized as renewable energy rises in the global energy mix. Traditional grids are designed based on relatively stable fossil fuel power generation and struggle with the intermittent nature of certain clean energy sources, such as wind and solar. Grids in the era of clean energy require digitalization and involve more adjusting features to reduce usage peaks and valleys.

Digitalization in modern power grids automates, monitors, and controls the capacity across various power grid units. Such controls traditionally take place in a passive model when certain fluctuations are observed and measured by the digital facilities. However, leading digitalization uses AI to forecast demand and react to adjust production and balance supply in advance, thereby reducing fossil fuel dependency. With such capability, modern grids can also orchestrate crowdsourced energy facilities, such as rooftop solar and home batteries, to optimize the grid as a holistic system in terms of efficiency and emission reduction.

As another key component in modern power grids, energy storage in the virtual power plant (VPP) stores and releases energy to reduce the volatility incurred by clean energy. Pumped hydro storage and flywheel are the two most valued mechanisms for energy storage due to their scalability and straightforward principles for implementation. Pumped hydro, now making up over 90% of global long-duration energy storage, anticipates a further significant composite annual growth rate (CAGR) of approximately 30% over the next 5 years with an incremental 69 GW in pumped storage capacity by 2030.[90,91,92] To support the growth and reduce the investment burden, opportunities exist for retrofitting infrastructure, such as disused mines and non-powered dams. Flywheel energy storage system (FESS) is also a key form of energy storage. Though the physical mechanism for FESS is straightforward and even old-school, the competency of FESS is increasing with the recent ClimateTech innovations, mainly on improving flywheels' storage capacity, energy density, safety, and efficiency. One remarkable innovation is to reduce friction and energy loss in FESS by adopting magnetic levitation and superconducting materials. The latest development also highlights other mechanisms, such as lithium-ion battery clusters and thermal storage.

While generators, users, and energy storage form a simple producer-consumer model, optimizing modern grids can be complicated. Many more factors shall be considered: energy balance, priority of users, resilience, and so on. In the context of decarbonization, many policy-driven factors also create additional green dimensions in grid management, such as Renewable Energy Certificates (REC) and other green assets, along with carbon pricing and accounting of subsidies or tax incentives. In the United States, policies like Renewable Portfolio Standards (RPS) and Clean Energy Standards (CES) also require grids to retain data for compliance and traceability regarding the minimal renewable energy usage threshold.

Green Hydrogen & Primary Chemicals

> *International businesses are working with their supply chains to reduce their reliance on fossil fuel powered electricity, or inefficient uses of energy, to bring costs down and help decarbonise the overall supply chain.*
>
> **Helen Clarkson, OBE**
> Chief Executive Officer, Climate Group

Green hydrogen is produced by electrolyzing water using solar, wind, or other renewable energy. It is possibly an efficient fuel for transportation and logistics due to its high theoretical energy density and also a primary material for synthesizing other chemicals, which decarbonizes the chemical industry by reducing dependence on fossil fuels.

Future of Hydrogen Fuel

Hydrogen has been widely used with industry consensus in certain processes, such as producing direct reduced iron (DRI). However, debates are heated regarding hydrogen's main destiny in fueling—whether it should be a prevalent direct fuel or a precursor to producing other fuels.

Hydrogen as a direct fuel has a high performance yet is concerned mainly with safety and infrastructure. Theoretically, combusting hydrogen yields zero emissions and an energy density of 33.33 kWh/kg, surpassing that of gasoline and diesel threefold. However, specialized storage methods must be employed to address hydrogen's wide flammability range of 4% to 75% in air, rendering a far lower practical energy density. These storage methods include pressurized tanks at 35-70 MPa,[95] which is a mainstream way, and also less developed methodologies such as liquefaction, metal hydride storage, and adsorption. Before technology further advances to improve security, personal hydrogen-powered vehicles may still hold safety concerns, especially storage in insufficiently ventilated spaces like underground parking.[96,97] Beyond its explosive nature, hydrogen can also compromise the ductility of metals, a phenomenon known as hydrogen embrittlement (HE) or hydrogen-induced cracking (HIC). Also, building refueling infrastructure requires extensive costs. By the end of 2023, there has been 1,100 hydrogen refueling stations globally compared to 2.7 million EV charging points. A standard hydrogen fueling station requires a capital of approximately USD 1.9 million, surpassing EV charging stations by nearly 20 times. Certain academics suggest that the cost gap between hydrogen-powered vehicles and EVs might remain unresolved permanently, as the early inception of EVs may have left insufficient available resources for cities to develop another charging network.[93,94,95]

As an essential material in the electrolysis facility to produce hydrogen, membranes provide electrical insulation and conduct ions between electrodes. Traditionally, without membranes, hydrogen was generated via alkaline water electrolysis with inherent explosion risks caused by dissipated hydrogen. Proton exchange membrane (PEM) and anion exchange membrane (AEM) are deployed to drastically enhance safety, prevent leaks, and increase efficiency for electrolysis. As ClimateTech advances, more novel alternative options appear, such as solid oxide electrolyzers (SOE).

Recent advancements in PEM aim to boost proton conductivity, mechanical durability, and chemical resistance, improving the longevity and efficiency of fuel cells. However, the mainstream material for PEM, perfluorosulfonic acid (PFSA), is identified as a persistent environmental pollutant under the EU Chemicals Strategy for Sustainability due to its resistance to degradation and potential health risks such as carcinogenicity and endocrine disruption. As a result of environmental, policy, and economic considerations, the market calls for innovation on safer, more efficient, and more sustainable alternatives to PFSA for use in PEM fuel cells. Researchers are exploring alternative materials such as sulfonated hydrocarbon-based polymers or composite materials.

ClimateTech regarding hydrogen-powered vehicles is rapidly advancing despite the challenges, especially in Asia, based on patent filing statistics. Many contributors to this report are prudently optimistic about the adoption of hydrogen-powered vehicles restricted to certain geographic areas and applications. For example, hydrogen is promising in the use case of heavy-duty commercial trucking in industrial settings such as factories, ports, and logistics hubs, where infrastructure is controllable, safety measures are more ready, and safety concerns are mitigated by always ensuring open-air space for hydrogen to dissipate upward in case of leakage.[98,99]

Green Ammonia and Methanol

Green ammonia and methanol are also promising green fuels. They can be generated from green hydrogen and CCUS-captured CO or CO_2 named Renewable Fuels of Non-Biological Origins (RFNBOs) or "electrofuels." In addition, they can also be generated by other green approaches, such as biomass and employment of CCUS in the fossil-fuel-based traditional process using natural gas, bunker fuel, and naphtha. Dr. Ramon Gonzalez, Program Director of the U.S. Department of Energy Advanced Research Projects Agency-Energy, explains that the choice among these methods depends on the expected target products, "When producing soluble feedstocks from CO_2, chemistry currently has a significant advantage. However, for more complex molecules like those in SAF, biology can simplify the process significantly by reducing the number of steps required."

Among all trajectories, the biomass method shows general economic viability for several reasons. The method uses low-cost, common raw materials such as crop residues, forest waste, or municipal solid waste. The first phase of the biomass method, transforming biomass into syngas (a mixture of H_2, CO, and CO_2) from anaerobic digestion, is a common and historic process. The second phase involves converting syngas chemically into ammonia or methanol, resulting in lower net carbon emissions than fossil fuel methods. However, the biomass method is not a 100% zero-carbon trajectory. Also, the supply of raw materials is heterogeneous - for example, municipal solid waste or biomass can contain various components. Resolutions to these challenges should be prioritized as they hinder the scaling of biomass methods. In contrast, methanols produced with hydrogen and CCUS have relatively high prices but offer a zero-carbon pathway. Therefore, in certain cases, an innovative co-production mechanism can simultaneously generate bio-methanol and green methanol.

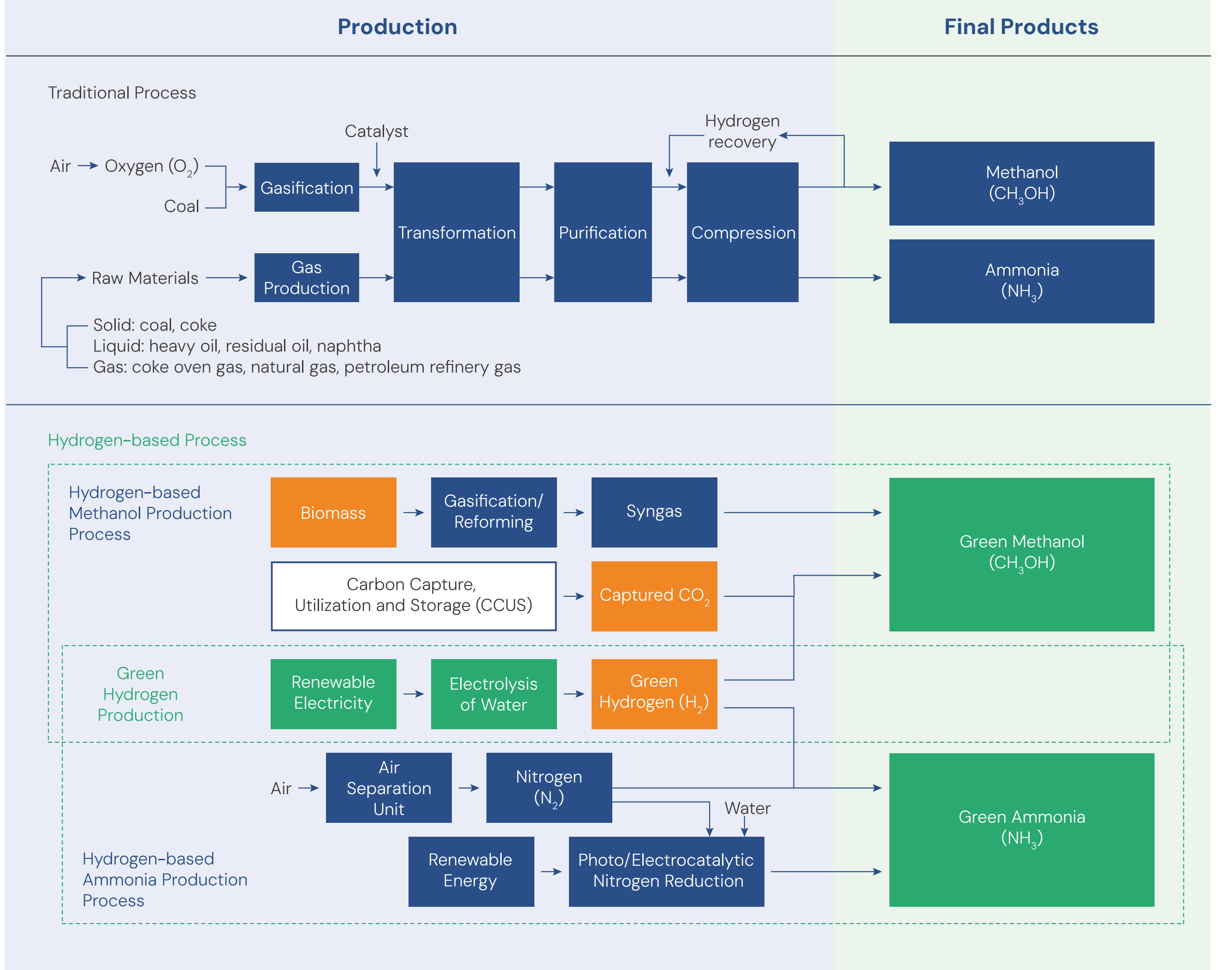
A geographic study shows Europe holds over 80% of global green ammonia[102] and methanol production capacity, largely due to their supportive policies such as the Revised Renewable Energy Directive (RED II) and the Fuel Quality Directive (FQD). In the Middle East, the NEOM Green Hydrogen Project is projected to produce 640 tonnes of green hydrogen and 1.2 million tonnes of green ammonia daily by 2026.[100] Aramco, and ENOWA, NEOM's energy and water company, are working to establish a synthetic electrofuel demonstration plant at ENOWA's Hydrogen Innovation and Development Center (HIDC), targeting an annual output of over 12,000 barrels of low-carbon gasoline.[101]

Use cases of green ammonia and methanol are primarily related to shipping, while they can also be chemical feedstocks for industries such as textiles, plastics, agriculture, and pharmaceuticals. Green ammonia alone is a suitable short-sea shipping fuel reducing emissions by 40% to 70%.[104] Green methanol can replace or be blended with conventional fuels such as bunker fuel, diesel, kerosene, or gasoline in shipping, ground transportation, and aviation, where it is classified as sustainable aviation fuel (SAF). In 2023 and 2024, Maersk completed the first voyage of a methanol-powered container vessel and supported an ammonia-fueled ship with early regulatory approvals. IRENA projects a 500Mt market demand for ammonia and methanol-related biofuels by 2050.[103] However, further widespread adoption only happens when their cost is reduced to a competitive level compared with other fuels.

500Mt

market demand for ammonia and methanol-related biofuels by 2050

FIGURE 3.7 **Production, Process, and Utilization of Ammonia and Methanol**



Source: WeCarbon analysis based on various sources[105,106,107]

Traceability Dilemma and Solutions

In terms of a chemical as a commodity, there is little compositional distinction between green products and their traditional counterparts. Although there are very expensive laboratory testing methods for differentiating green and non-green, such as including isotopic signature analysis (C-12, C-13, and C-14) and trace contaminant detection, they are economically infeasible as a way of widespread, reliable physical or chemical authentication of green attributes.

Therefore, data traces related to the production process become the only justification for their premium market value and other preferential policies, such as carbon market advantages, supply chain mandate compliance, or the pursuit of a sustainable brand image and improved ESG outcomes. The data needs to be certified by a trustable third party to gain trust from procurers.

As a traditional practice, the government provides a certificate only specifying the type, mass, and carbon footprint of the products. Without traceability measures, the certificate may be misused in irrelevant products and lose track when green and non-green fuels are blended. The International Sustainability and Carbon Certification (ISCC) is a primary international framework to certify the adherence to green fuel standards throughout the supply chain with improved traceability, transparency, integrity, and accountability. ISCC tracks the full documentation of a product from origin to delivery in a Chain of Custody approach and allows controlled blending of certified and non-certified goods. As an ongoing tracking measure, the ISCC requires periodic audits by accredited third-party bodies to ensure compliance with standards and address any non-conformances. Other frameworks like the Roundtable on Sustainable Biomaterials (RSB) and Renewable Energy Directive Certification (REDcert) also support European sustainable practices.

Apart from certification, there are also instances of market and financial tools. The European Hydrogen Bank employs a market-based mechanism to connect buyers and sellers, efficiently allocate subsidies to producers, and eventually ensure genuineness in green hydrogen or RFNBO. The European Climate, Infrastructure and Environment Executive Agency (CINEA) has set up Innovation Funds to evaluate bids and grant winners with fixed subsidies for up to 10 years if they start production within 5 years.[108] To extend the scope of support, Germany has also introduced an "Auction as a Service" (AaaS) scheme as an additional financial subsidy for top projects that did not qualify for EU-level support.

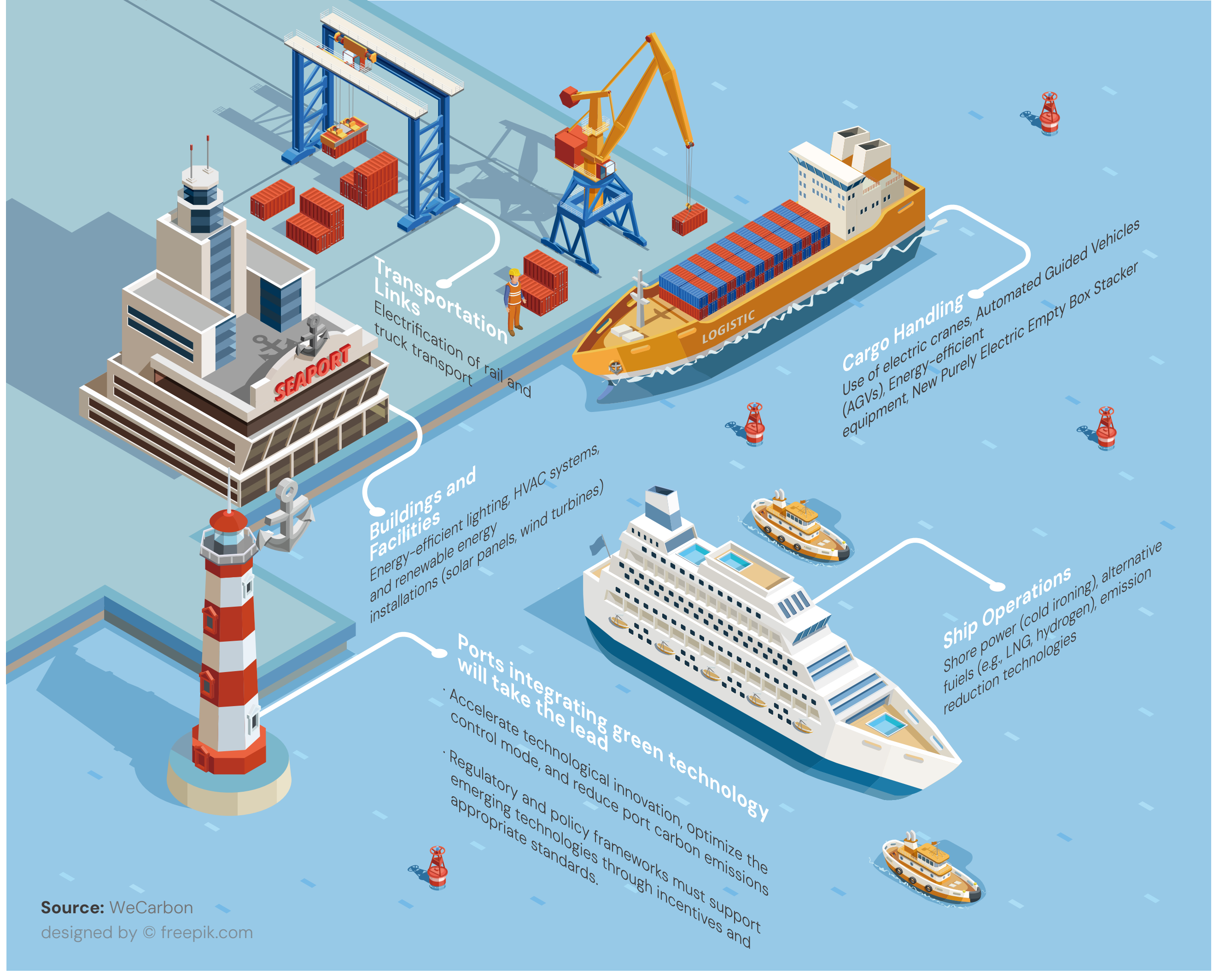
Clean Energy in Logistics, Shipping, and Aviation

"Regarding AI and logistics, efficiency-driven solutions are highly optimized, resulting in more fluid processes. Technology now helps us monitor and gain a better understanding of ship quality, ship efficiency, and ship capabilities with real-time information globally. Smart technology, as a whole in the oil and maritime industry, is very effective. We're seeing more ports and logistic centers almost operated by AI-controlled processes, enhancing efficiencies and optimizing operations.

H.E. Khamis Juma Buamim
Chairman, Dubai Council for Marine & Maritime Industries

Transport Hubs and Units: Who is the Priority for Decarbonization?

FIGURE 3.8 **Decarbonization of Transport Hubs**



Source: WeCarbon
designed by © freepik.com

Transport hubs and units are the main venues for emissions. Consensus has been established on decarbonization pathways of transport units, including alternative fuels and electrification. However, contributors to this report also call for emphasis on decarbonizing transport hubs, including ports and cargo stations, where there is still large room for improvement, such as by adopting renewable energy, advanced cargo handling technologies, and sustainable infrastructure. Ports that integrate sustainable practices and ClimateTech are also better positioned to comply with global green supply chain standards and improve their competitive edge. Tackling dust, pollution, and oil discharge can improve ports' ecological state and may be more cost-efficient than decarbonizing transport units. Installing shore power facilities can also cut emissions from port operations. Globally, these changes could significantly decrease carbon emissions in shipping and logistics.

Heavy-duty vehicles (HDVs) comprise 10% of the global fleet but are significant emission contributors, with 28% of greenhouse gas emissions, 45% of nitrogen oxide emissions, and 57% of particulate matter emissions from on-road vehicles.[109] Electrification, as a major focus of the green transition, will result in 63% less greenhouse gases than diesel, with a maximum of 92% reduction possible using 100% renewable electricity.[110] Electrification also resolves other environmental impacts, such as pollution from particulate matter. However, transitioning HDVs to electric power presents at least three challenges regarding constraints in the driving range. Zhang Junyi , Founding Managing Partner of NIO Capital, observes that current battery technology struggles to improve energy density, resulting in heavy batteries carried and lower loading efficiency compared to fossil-fuel-powered HDVs. Slow charging also constrains the efficiency of these vehicles. Leading ClimateTech focuses on advancing materials and design to reach lightweight, thereby improving fuel efficiency and reducing carbon footprints. Certain innovations in powertrains not only deliver environmental impact but also enhance performance, including ride quality, handling, braking, and increased towing and payload capacities.

Electrification will not only require investment but also incur job disruptions and employment shifts. A study[111] indicates increased electromobility will eliminate 84,000 jobs in the EU by 2030, productivity improvements will cut another 222,000 jobs, while 200,000 permanent jobs will be created, such as maintenance of charging and refueling networks, maintaining electrified powertrains, and so on. Social and psychological factors, such as consumer reluctance, ingrained habits, and a lack of public understanding may also hinder the adoption of new technologies.[112]

Promotion of Alternative Fuels: LNG and SAF

Liquefied natural gas (LNG) and SAF are promising fuels to decarbonize the transportation and aviation sectors. LNG produces a notable emission reduction of approximately 40% less CO_2 than coal and 30% less than oil,[113] making it one of the cleanest fossil fuels. LNG is also clean in other ways, generating less soot, dust, particulate matter, and other harmful atmospheric compounds relative to coal and oil. Consequently, LNG represents a cleaner alternative to conventional marine fuels and serves as a transitional solution toward achieving zero-emission technologies. Isaac Smith, Managing Director of Clarendon Capital, proposes that LNG is viewed as a transitional "bridge fuel," offering a cleaner alternative to coal, particularly in manufacturing and energy production. While it's not the greenest option, it is better than coal and can help facilitate the shift to renewables over the next 10 to 15 years, especially in major manufacturing regions like China. This aligns with the concept of the 'energy trilemma,' which emphasizes balancing affordability, energy security, and carbon emission reduction.

In the aviation industry, SAF provides a potential reduction in CO_2 emissions of up to 80% compared to traditional jet fuel[114] and has been the most highlighted theme in the aviation sector's decarbonization efforts. SAF is produced from various culinary, municipal, or forest wastes. Its production process recycles CO_2 absorbed by biomass, unlike fossil fuels that release sequestered carbon. Given aviation's limited incentive for refining aircraft design solely due to environmental reasons and the slow adoption of low-carbon alternative energy like batteries or hydrogen fuel expected only by the late 2030s, SAF stands as the immediate solution for existing aircraft. The International Air Transport Association (IATA) estimates a need for nearly 450 billion liters of SAF annually by 2050, a significant increase from the current 125 million liters,[115] underscoring the necessity for expansion in SAF production.

450billion

liters estimated annual demand for SAF by 2050

Both LNG and SAF are integral in mitigating environmental impacts within their respective sectors and contribute to the broader objective of achieving net-zero emissions. As advancements in technology and infrastructure continue, LNG and SAF will further contribute to advancing a more sustainable future for global transportation and aviation.

IV

Powering the Progress: Infrastructure, Finance, and Education

© A Vision of the Future City, Xu Kangning, finalist of 2024 Climate and Sustainability Photography Awards

> *"The climate file is witnessing rapid developments on the global stage. This imposes on us the responsibility of uniting and enhancing efforts to keep youth at the heart of change.*

H.E. Dr. Sultan Saif Al Neyadi
Minister of State for Youth Affairs, United Arab Emirates

Climate change mitigations, particularly those through technological advancement, require strategic investment across infrastructure, finance, and education. Infrastructure forms the bedrock for developing, promoting, and expanding climate technologies; financial endorsement, meanwhile, offers capital support for advancing these technologies toward maturity. A robust education sector is for cultivating future leaders, experts, and a skilled workforce necessary for developing and deploying effective ClimateTech.

Policy & Infrastructure

Robust infrastructure, including tangible assets (urban developments, power grids) and intangible elements (exchanges, certification bodies, policy frameworks), cultivates innovation, offering platforms for development and ensuring streamlined connectivity. As the backbone of the sector, infrastructure facilitates the efficient scaling and adoption of new technologies through established standards and regulations, thereby promoting sustainable growth.

Building a Trustable Certification Network

In green supply chains, certification, including verification and conformity assessment, is a crucial infrastructure to ensure adherence to regulations and standards. Certifications can be either mandatory, aligning with governmental directives and standards, or voluntary, driven by producers seeking to highlight their sustainability credentials. Considering that sustainable products appear difficult to distinguish and can even be physically or chemically identical to their non-green counterparts—especially commodities such as steel, aluminum, hydrogen, or primary chemicals—certification is the primary mechanism to verify environmental claims, ensure transparency, and maintain credibility. For each supply chain participant, certification is a pillar of many value propositions. For producers, certification paves the way toward a fairly competing market. In a green supply chain context, certification also protects the equality and game rules for financial, commercial, and regulatory incentives. For customers, certification becomes a credible source to validate the sustainability, health, or performance expectations and justifies the pricing premium of green products in customer's purchase decisions. For governments, certification is also a pillar to support the governmental directives and mandates on products that can be implemented at technical levels. Zhao Bingbing, Chief Representative of Greater China at London & Partners, observes that products with green certification are more likely to be recognized by the industry and market. Green labels help consumers identify products, boosting a company's market competitiveness, especially with rising environmental awareness.

> “
> *Despite the existence of numerous recognized metrics and standards within national and regional APEC communities, inconsistencies in definitions and reporting standards can create significant barriers.*
>
> **Alex Parle**
> Executive Vice President, National Center for APEC

Several contributors to this report note significant challenges to diverse implementation and interpretations of established standards and certification schemes among verifiers, across jurisdictions, and also within individual organizations. This renders it difficult to recognize data and certification across jurisdictions of the supply chain. Even if the interpretation is aligned, residual risk—the risk remaining after mitigation efforts—remains. Certifiers face limitations in their capacity to review documentation, conduct on-site visits and sample tests, and significantly depend on client-supplied documentation and selective, rather than comprehensive, testing. Such limitations can lead to occasional oversight, compromising the certification process's overall effectiveness. As preferential benefits are accorded to products with green claims, opportunities exist for deceptive practices, including greenwashing and outright fraud, to circumvent inspections and exploit residual risks. A European Commission study[116] indicated that 53.3% of environmental claims analyzed in the EU were vague, misleading, or unfounded, with a further 40% lacking substantiation.

53.3%

environmental claims in the EU found to be unreliable

To address the residual risk, leading ClimateTech offers innovative mechanisms. For example, blockchain technology maintains the accuracy and integrity of data sourced from upstream vendors. Xu Qiuming, General Manager of Sustainability Services from TÜV Rheinland, emphasized blockchain's capacity to strengthen supply chain transparency, enhance traceability, and reduce associated costs. A critical challenge, however, is the data reliability before its blockchain inscription. To address this concern, TÜV Rheinland partners with blockchain service providers to guarantee data legitimacy and quality, particularly in the green electricity industry. Through this partnership, such blockchain services can achieve legal data authentication, ensuring conformity with regulatory instruments such as green electricity certifications.

A further challenge arises from excessive voluntary green certification programs developed by international bodies, industry associations, and even private companies, each with varying levels of authoritative accreditation. Therefore, certain companies resort to establishing their own certification systems and logos, motivated by self-interest, hindering consumer attempts to verify legitimate green claims. This excess of certification schemes reduces the credibility of authoritative standards, allowing less confirmed assertions to obscure genuinely sustainable practices. Public consultations regarding the EU product policy framework[117] emphasize these concerns, highlighting the difficulties procurers encounter when evaluating and comparing the plethora of green claims.

To uphold the integrity of certification programs and combat deceptive "green" marketing, countries and regions are implementing regulatory frameworks governing the veracity and trustworthiness of environmental certifications and claims. China, for instance, employs the China National Accreditation Service for Conformity Assessment (CNAS) to formally review and recognize such programs, thereby promoting standardization. In the EU, directives such as Directive 2024/825 ("Empowering Consumers for the Green Transition through better protection against unfair practices and through better information") establish regulations for green claims on consumer products. In the United States, the Federal Trade Commission (FTC) offers guidance and legal parameters for green claims. These regulatory structures represent a government-backed force to ensure ethics and prevent fraud in the green supply chain transition.

AI significantly contributes to workload management and mitigating human error risks in staffing. The increasing complexity and volume of regulations require support for engineers, and AI offers this by facilitating laboratory operations, testing, report generation, and certification. Heuristic algorithms in Natural Language Processing (NLP), coupled with layout processing models such as LayoutLM, facilitate the identification of errors and minor issues, including deviations from established standards. Such proactive identification enables certification bodies to address these concerns preemptively, safeguarding their credibility against potential damage.

Integrating certification processes into the supply chain significantly reduces transaction costs while enhancing transparency and traceability. One common strategy is the incorporation of testing facilities directly into manufacturing processes. Major manufacturers frequently collaborate with leading certification bodies to establish joint laboratories, enabling immediate product testing upon completion and ensuring prompt adherence to relevant standards. In the ClimateTech sector, this integrated approach shows its value as industries seek to mitigate carbon emissions and satisfy increasingly stringent environmental regulations. Ready access to onsite certification ensures the verification of sustainable practices throughout the production cycle, thereby facilitating regulatory compliance and enhancing a company's demonstrable environmental responsibility, a factor that can translate into a significant competitive advantage. Dr. Herman Sun, Deputy General Manager at ICAS, emphasizes the corporate imperative to strengthen compliance systems through external partnerships, achieve alignment with global standards, and leverage digital and intelligent methodologies to drive advancements in compliance certification and comprehensive supply chain development.

Establishing Sustainable Urban Infrastructure

The long-term health and resilience of both our planet and its urban communities require designing sustainable cities and achieving urban green transitions. Expanding urban areas intensifies the demand for resources and energy, exacerbating environmental challenges, including air pollution, greenhouse gas emissions, and resource depletion. Addressing such issues requires evidence-based urban design principles that prioritize both sustainability and resilience.

The transition to greener urban components must circumvent the "Not In My Backyard" (NIMBY) effect. Opposition from actions, movements, and governmental decisions against high-polluting industries in urban infrastructure development can result in industrial relocation rather than genuine transformation. Therefore, these industries are inclined to migrate to less developed and regulated regions. This geographic shift can create a misleading impression of reduced environmental impact, as emissions and pollution, potentially under-reported due to insufficient data collection and infrastructure, fail to reflect the true global scope of environmental challenges.

Waste management can be considered as an example. Decades of landfill opposition and closure advocacy by environmentalists in certain Global North cities have redirected waste to external facilities. This redirection disproportionately affects economically disadvantaged areas in the Global South, which receive a significant influx of hazardous materials, particularly electronic waste. Agbogbloshie, Ghana, in West Africa, exemplifies this trend, having become a major global e-waste repository. Therefore, while ClimateTech solutions reduce such environmental consequences, the potential displacement of harmful activities during the transition requires careful consideration.

Transportation, energy, and industry are fundamental urban sectors. Public transit electrification and digitalization offer significant emissions reductions. Electrification's contribution to decarbonization is twofold: non-fossil-fuel-based electricity directly reduces fossil fuel use, and even electricity derived from fossil fuels centralizes combustion, enabling management through air pollution control and CCUS.

Public transit must offer a positive experience while reducing emissions to cultivate a shift away from private vehicles. Digitalization, facilitated by Mobility as a Service (MaaS) and AI algorithms, optimizes routes, enhances passenger comfort, and lessens environmental effects. Intelligent systems minimizing wait times, preventing congestion, and optimizing routes contribute to the attractiveness of sustainable transportation choices. Urban mobility is being transformed by integrating diverse transportation modes, particularly through innovations such as MaaS. The MaaS platform facilitates access to numerous transportation services—buses, trains, bikes, and ride-sharing—in a single, user-friendly system, thereby increasing efficiency and reducing reliance on private vehicles. To fully realize the advantages, robust measures, and collaborative efforts must address data privacy and cybersecurity challenges. For instance, robust data encryption protocols and regular security audits protect sensitive user information on these platforms. Federated learning, edge computing, and other privacy-preserving AI methods can enhance data privacy while maintaining the benefits of AI. Through federated learning and edge computing, AI algorithms are trained across decentralized devices or servers; data remains local, and only model updates are exchanged. This approach ensures that sensitive user data remains on users' devices, reducing the risk of data breaches. In addition, incorporating differential privacy, which introduces noise into datasets, hinders the extraction of individual user information, enhancing privacy protections.

Energy-efficient buildings are transforming the architecture and construction sectors. Energy savings can be achieved through advanced design principles and technologies, including features such as intelligent lighting and climate control systems, reducing overall energy consumption. Cities striving for similar outcomes should strategically invest in green technologies and enforce stringent energy efficiency standards. Rigorous criteria for energy-efficient building design, for instance, can minimize energy expenditure for heating and cooling by maximizing insulation and airtightness. Such improvements reduce energy consumption and enhance sustainability. To reduce the challenges of retrofitting existing buildings, municipalities ought to implement streamlined regulations and incentivize the integration of energy-efficient features. In addition, incorporating intelligent building technologies allows for energy optimization based on real-time data analysis. Effective management of these technologies requires partnerships and proactive maintenance. Finally, advanced storage solutions and improved grid integration should complement on-site renewable energy solutions to address fluctuations in energy production.

CASE STUDY 8 | **Pathway to Net-zero Industrial Park**

Jinwan InnovDock Park is an industrial park in Shanghai, China, focused on the new materials and healthcare sectors. Golden Bridge Group, the park's developer, aims to build a green industrial community and achieve harmonious coexistence between humans and nature, reflecting the national climate strategy. As the park transitions into an industrial community, it emphasizes integrating and enhancing functions within urban renewal and development as well as prioritizes how its construction can contribute positively to China's green and low-carbon development goals.

The park integrates cutting-edge artificial intelligence technologies to establish Jinwan InnovDock Park as a low-carbon benchmark. The developer researches the integration of green, low-carbon practices with digital AI technologies, reducing carbon emissions through artificial intelligence and intelligent building systems, especially through innovative technologies like the Internet of Things and data-driven models. Building Integrated Photovoltaic (BIPV) is the technical means for energy conversion in the park, using surplus clean energy in energy storage and mobile energy. The park has innovatively introduced four major carbon reduction strategies:

1. Passive energy-saving design
2. Active energy regulation
3. Efficient utilization of renewable energy
4. Creating a healthy and perceptible environment

This 100,000-square-foot park is expected to reduce carbon emissions by approximately 3.76 million tonnes annually and generate around 900,000 kWh of renewable energy annually. The park's carbon reduction efforts are ongoing, with the project expected to reach peak carbon by 2027 and achieve carbon neutrality by 2028, setting a leading sustainability practice. Jinwan InnovDock Park has embedded the concept of carbon neutrality throughout its life cycle, from future planning and construction to ongoing management. By leveraging artificial intelligence and intelligent building technologies to lower carbon emissions, the park aims to distinguish itself as the first Net-zero Industrial Park in Shanghai.

Source: Golden Bridge Group, 2023

"

Digital and Smart technologies not only empower the construction of the Jinwan InnovDock Park towards its sustainability goal, but also enable net-zero operations over its lifecycle.

Zhu Lili, Vice General Manager, Golden Bridge Group

As the Parisian "15-Minute City" model exemplifies, integrating services in a convenient radius cultivates sustainable urban living by reducing automobile reliance. Achieving such integrated, mixed-use development requires comprehensive community engagement and adaptable strategies. Transit-Oriented Development (TOD), by integrating public transportation with residential and commercial spaces, enhances accessibility while reducing car dependency. Successful TOD implementation, however, depends on effective collaboration between urban planners and transit authorities to address potential overcrowding and ensure equitable growth. Adaptive reuse projects, meanwhile, offer an approach to modernization, demonstrating the viability of repurposing existing structures while protecting their historical value. Innovative design and considered solutions can address the challenges of modernization while preserving the vibrance of historical landmarks.

Manufacturing represents a powerful engine for urban economic growth but also can be perceived as a source of pollution and resident opposition by the community. Eco-conscious plants employing zero-carbon technologies offer a path toward harmonious urban integration. The Integrated Coal Gasification Combined Cycle (IGCC) technology, for instance, facilitates the transformation of coal power plants into zero-emission, zero-waste facilities. Leading IGCC implementations situated near beaches, parks, residential areas, and other urban settings exemplify this potential. Across various manufacturing sectors, the exploration of urban compatibility and enhanced neighborhood integration is gaining momentum.

CASE STUDY 9 | **Neighborhood Friendly Pulp & Paper Production**

Asia Symbol, a prominent global pulp and paper producer under the Royal Golden Eagle (RGE) group, has successfully integrated its operations within urban environments and fostered positive relationships with the local community. Despite operating in a traditional manufacturing sector, Asia Symbol has achieved a greenhouse gas (GHG) emission intensity of 0.44t CO_2e per ton of product in 2023, setting a benchmark for low emissions in the industry. This achievement underscores the company's commitment to sustainable practices and its ability to coexist harmoniously with urban communities.

Typically, manufacturing plants face the "Not In My Backyard" (NIMBY) effect, leading to complaints and dissatisfaction among residents, which can jeopardize normal operations and damage the brand's reputation. However, Asia Symbol excels in promoting positive externalities through community-friendly practices:

1. Conducted the 1st integration project of in-depth flue gas treatment and waste heat recycling in China's pulp and paper industry. Nearly USD 57 million was invested to recover waste heat from power plants. This investment enables the capture of waste heat and water vapor from chimneys, providing winter heating for an area of 6 million square meters in the community around the mill. By reducing coal use, it could cut 0.38 million tonnes of CO_2 emissions every year.

2. Continuously increase the proportion of renewable energy (biomass and solar power) and clean energy in production. In 2023, renewable and clean energy accounted for 71.53% of its energy consumption.

3. Built the 1st urban reclaimed water reuse project in China. By converting municipal sewage into clean water for reuse in production, it can save more than 10 million cubic meters of water resources every year.

4. Established the 1st full-process zero-emission wastewater treatment station in China with a daily processing capacity of 30,000 cubic meters. The project transforms effluent into reusable reclaimed water, industrial salt, sludge suitable for use as a construction material additive etc., promoting the resource utilization of by-products in effluent treatment.

To further enhance its environmental stewardship, Asia Symbol has pledged to reduce GHG emissions per product unit by 30% by 2030. The company has allocated nearly 25% of typical project investments to environmental protection and collaborates with various universities to enhance pollutant removal through physical treatment during aeration in the wastewater treatment process.

Source: Royal Golden Eagle China, 2023

"*In the green supply chain transformation, RGE leverages its scale and influence in implementing latest technologies to go from environment friendly to neighborhood friendly.*"

Dr. Shu Landen, Financial Vice President, Royal Golden Eagle China

Exchanging Financial and Green Assets

Amid growing calls for corporate accountability, financial exchanges, particularly stock exchanges, are evolving into central actors in promoting environmental responsibility in supply chains. Nearly every exchange enforces ESG criteria regulations, with requirements becoming increasingly stringent. In addition, a recent development involves the expansion of ESG standards by certain exchanges to include climate disclosure. Stock exchanges thus act as regulatory bodies ensuring listed companies' adherence to ESG and climate disclosure mandates and cultivating a sustainable business ecosystem.

Another emerging concept is the role of exchanges as architects of industry standards and motivators for collaborative action. The NYSE's support for "Climate Action 100+," which mobilizes investors to incentivize improved environmental performance among companies, exemplifies this innovative approach to sustainability. Similarly, the LSE's "Sustainable Stock Exchanges Initiative" collaborates with global exchanges to create and communicate best practices for sustainable supply chain management. Such collaborations facilitate corporate alignment with evolving standards and propel industry-wide progress toward greater sustainability.

Besides traditional financial instruments such as stocks and bonds, a diverse range of tradable assets and their equivalents has proliferated, notably in "Green Asset Exchanges." Carbon assets constitute a significant portion of these green assets, categorized into voluntary and mandatory markets. Voluntary markets facilitate the exchange of offset assets derived from sustainability-driven mechanisms, whereas, mandatory markets impose regulatory carbon caps upon entities, enabling the trade of credits to fulfill these legal obligations. In established markets, "allowances" or "negative externalities" typically denote mandatory market assets, whereas "credits" or "positive externalities" designate those in voluntary markets. Dr. Lan Hong, Deputy Director of Eco-Finance Research Center points out, "Through the optimized allocation of resources across different industries, market entities automatically seek out the sectors with the lowest carbon reduction costs, forming a cost-effective emission reduction path. In this process, the efficiency of resource allocation continues to improve, while also fostering the development of new low-carbon industries."

Renewable energy can be traded as assets on green exchanges. Renewable Certificates or Credits, including RECs and I-RECs (now I-TRACK), are issued commensurate with renewable energy generation, offering organizations a mechanism for measuring and exchanging their contributions to renewable energy production. Novel biofuels, such as fatty acid methyl ester (FAME) and bioethanol, are also subject to exchange trading.

These green asset exchanges strengthen the liquidity of green assets, benefiting established manufacturers and sustainable innovators. Companies demonstrating exemplary sustainable practices can generate revenue from the trade of carbon credits and renewable energy certificates, creating a powerful incentive for continued investment in green initiatives. Simultaneously, manufacturers and emitters gain efficient access to necessary credits and allowances through these exchanges, facilitating compliance with regulatory mandates. This streamlined acquisition process promotes the adoption of sustainable practices, enabling them to achieve their regulatory objectives. In sum, green asset exchanges offer a scalable market-based mechanism for efficiently distributing environmental resources.

Ensuring the credibility and effectiveness of these green assets requires robust data interconnection and genuineness verification. Effective interconnection requires smooth integration with government registries or authorized databases during asset trades. This integration guarantees transparent and accurate tracking of ownership, authenticity, and provenance. For instance, trading RECs should trigger immediate updates to these registries, thus precluding double-counting and preserving system integrity.

Verifying genuineness requires robust mechanisms ensuring that data underpinning green assets, such as carbon credits or biofuels, accurately represent their environmental benefits and sustainability. The mechanisms are particularly important for voluntary carbon assets. Inaccurate or fraudulent data used for credit issuance justifies and indeed mandates revocation, highlighting the importance of a framework for continuous monitoring and reevaluation. Likewise, assessment checks for biofuels should include detailed lifecycle analyses, independent third-party audits, and certifications, confirming that production processes adhere to established sustainability standards and significantly reduce carbon emissions.

Decentralized solutions, including blockchain, enhance data connectivity and authenticity surpassing centralized trading mechanisms. Two primary strategies involved are notarization and tokenization of certificates. Notarization ensures data authenticity and integrity by smart contract and cryptography, creating a secure, tamper-resistant record that confirms the data's origin and integrity. This method assures traders of the precision and stability of information, thereby strengthening certification processes. Tokenization, particularly through the issuance of Real World Asset (RWA) tokens, involves creating digital tokens for each unit of green electricity produced, emissions reduced, or products manufactured. These tokens represent distinct, verifiable units of sustainable activity or production, allowing for tracking and validation of sustainability claims even if the product undergoes further transformation. Each token serves as an irrefutable proof of sustainable practice, ensuring transparency and credibility throughout the supply chain.

In blockchain contexts, Real World Assets (RWA) can act as a valuable credit source, addressing the financial obstacles faced by small and medium enterprises (SMEs). Traditional financing often requires high creditworthiness, typically more accessible to large businesses, posing substantial challenges for SMEs in obtaining necessary funding. RWAs facilitate asset verification, proof of ownership, and credit evaluation, bridging the gap between blockchain technology and tangible assets. Frank Zhang, President of Metaverse Green Exchange Tech (MVGX) in Singapore, highlights the use of Non-fungible Digital Twins and Carbon Neutrality tokens. These technologies, following blockchain principles, ensure transparency, traceability, and permanence in green asset exchanges. Such adherence allows for thorough data tracking, verification, oversight, and management, optimizing data flow and connectivity with external systems. This guarantees verification, registration, and transaction compliance for carbon credits across the green industry supply chain.

In conclusion, green asset exchanges signify a transformative evolution toward sustainable finance. This evolution, however, requires rigorous data interconnection and robust genuity checks to preserve market integrity and effectiveness. Secure trading environments, accurate asset tracking, and transparent validation processes empower these exchanges to contribute significantly to global sustainability objectives while simultaneously creating novel investment avenues.

Finance & Investment

Advancing Green Finance

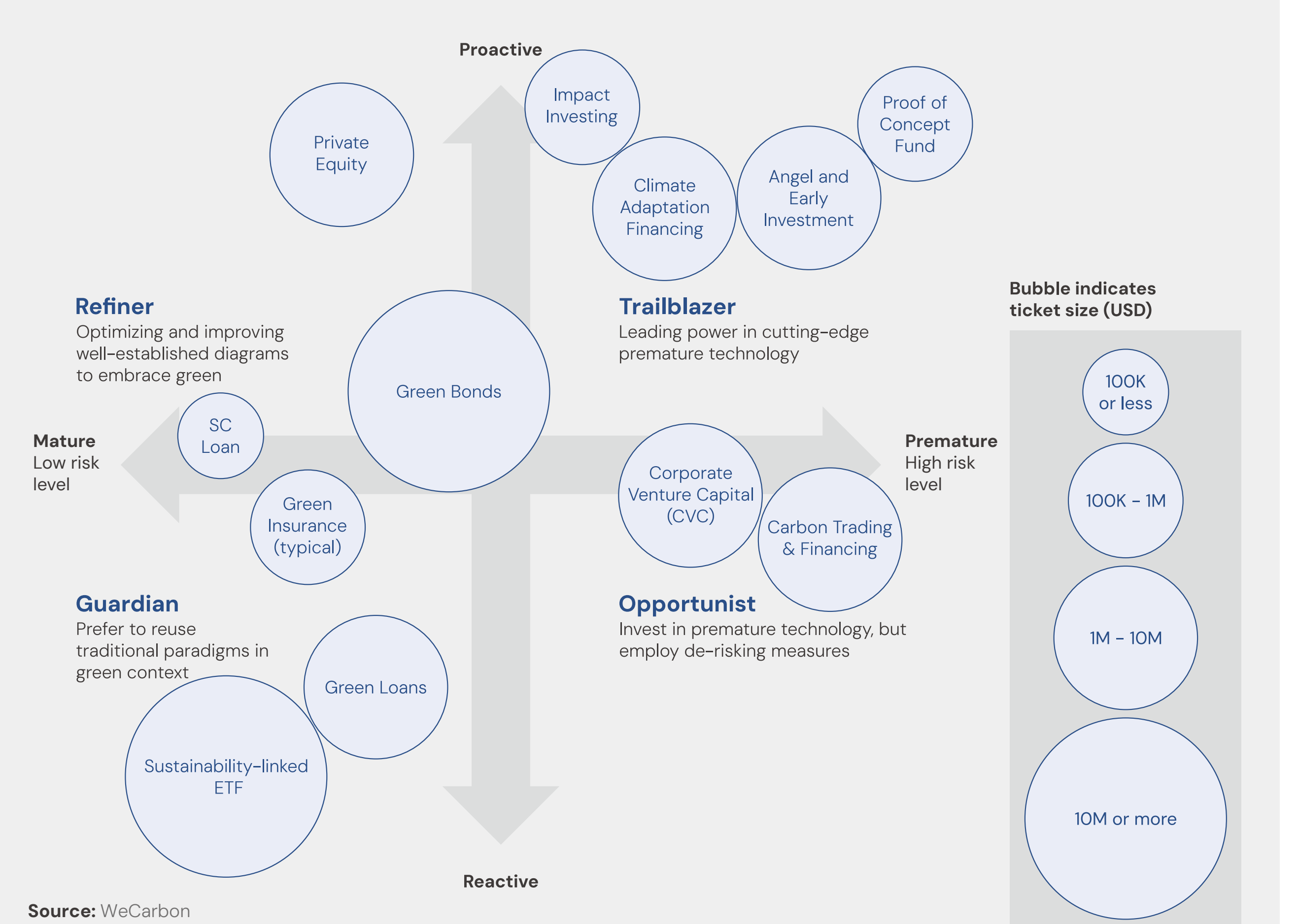
Green finance comprises structured financial activities that channel capital toward environmentally beneficial areas. As the flow of capital dictates the course of technological and human resource allocation to a great extent, green finance is expected to assume a formative role in shaping supply chain practices, behaviors, and technologies. For instance, the proactive leadership of MDBs is evident in their rigorous project loan standards, which promote the adoption of advanced technologies that are otherwise not used due to cost reasons. In addition, access to early-stage investment is a key success factor for leading ClimateTech companies, directly influencing their capacity for sustained green innovation.

While pursuing proactive green finance is an ideal objective, the tension between such an approach and the risk-return profiles of financial institutions requires careful consideration. Academic research[118] suggests that financial system characteristics, such as policy uncertainty and focusing on short-term gains, significantly impede green finance investment. A leading role invariably requires investments in sectors with less certainties and industry consensus, thus increasing uncertain exposures, whereas, green finance frequently involves reduced rates or preferential terms, intrinsically prioritizing lower risk in a balanced risk-return profile. In markets where green finance remains early and immature, there may not be visible, secure, robust financial evidence demonstrating superior returns from green projects. Therefore, proactively assuming leadership in green finance demands innovative financial instrument design and presents a challenge for financial institutions.

Traditional green finance instruments, rather than being proactive, address green-related needs with established financial tools. Green loans, for instance, offer marginally reduced interest rates yet still require significant collateral. While ClimateTech holds promise for private equity, valuations remain tethered to conventional indicators, such as cash flow and revenue.

A typology of green financial mechanisms, based on proactivity and maturity, indicates four quadrants for ClimateTech financing. Trailblazers spearhead investment in new technologies. Opportunists thus enter upon the demonstration of technological viability. Refiners offer large-scale support as technologies mature. Guardians, despite offering substantial funding, prefer traditional methods and risk management protocols, including collateral requirements and bank-based risk assessments, albeit adapted for green contexts.

FIGURE 4.1 **Quadrants on the Maturity, Proactiveness, and Ticket Size of Different Financial Instruments**



Source: WeCarbon

A sustainable supply chain requires equilibrium between proactive and reactive green finance approaches. Reactive models, commonplace in financial institutions and existing schemes, generally produce stable returns and predictable risks, yet their adherence to established industry norms and conventional risk assessments can be limiting. This reliance on the status quo restricts their capacity to adequately address the challenges and opportunities in new green technologies and practices, potentially hindering innovation and impeding progress in reducing climate change, whereas, proactive support cultivates innovation by offering ClimateTech startups and early adopters with the necessary financial resources to reduce risk before achieving positive cash flow. However, undue proactive support risks disrupting the supply chain by incentivizing reckless behaviors and the premature implementation of underdeveloped technologies, potentially culminating in market instability.

For financial institutions to achieve equilibrium, the strategic design of green finance tools empowers competent ClimateTech companies and users to reduce risk and cultivate long-term competency. Integral to these tools is an assessment framework that identifies suitable investment targets. Traditional frameworks, reliant on discounted cash flow and financial projections, prove inadequate in this context, failing to capture climate-related risks and opportunities. Dr. Gu Wei, President of the Sino Research Institute of Green Finance, observes that risk-prudent management through pricing or mitigation is a function of financial institutions. Therefore, the necessity arises to demonstrate that green and low-carbon supply chains present lower developmental risks than their brown or black counterparts. Superior performance, enhanced strategic advantage, and broader market acceptance are necessary for persuading investors that these supply chains warrant lower-risk premiums.

Innovations in traditional financial instruments, from the Quadrant Guardian to the Quadrant Refiner, display encouraging improvements. Traditional green insurance, while involving green assets, typically relies on conventional actuarial models. Parametric insurance, however, represents a departure: by incorporating and measuring climate-related parameters, such innovations accurately reflect climate risk. This enhanced accuracy in risk assessment and pricing enables a closer alignment between financial products and climate change realities, further expanding insurance's role.

CASE STUDY 10 | **Parametric Insurance for Climate Risks**

With the impact of climate change, extreme weather events that used to be rare and isolated have become more frequent, concurrent, and intense. Facing the evolving risk landscape, traditional insurance solutions do not always meet the needs of corporations. Parametric insurance is an effective innovation that complements traditional insurance programs and offers the insured a wide range of applications including non-damage business interruption, hard to insure physical risks, or pure financial loss covers.

AboitizPower is a major Philippine power generator and utility company with one of the nation's largest distribution networks. AboitizPower adopted parametric insurance from Swiss Re Corporate Solutions to produce its transmission and distribution (T&D) lines vulnerable to typhoons, which are typically uninsurable under conventional policies due to their location in areas prone to severe storms.

Typhoon Rai (Odette) devastated the Philippines in December 2021, impacting 10.6 million people and inflicting an estimated USD 900 million in infrastructural and agricultural damage. The year's most powerful typhoon, Rai, caused widespread destruction in the Cebu area, where AboitizPower holds significant assets. The typhoon's sustained winds activated the parametric insurance policy. Swiss Re Corporate Solutions made a payout to AboitizPower within 33 days of landfall and a mere 12 days after the reporting agency confirmed wind speeds.

Different from traditional insurance, which assesses actual loss, parametric insurance triggers payment upon the occurrence of a pre-defined event meeting specific parameters, such as wind speed. The parametric insurance from Swiss Re Corporate Solutions for AboitizPower features the "Cat in a Box" structure, a transparent framework, which covers the primary value concentrations of its T&D lines in Cebu and Mindanao. A meteorological event, such as a typhoon, reaching a designated wind speed threshold in a predetermined geographical "box" activates this policy. In the case of Typhoon Rai, wind speeds approximating 190 km/hour in Cebu triggered the policy. This rapid payout facilitated AboitizPower's swift power grid repairs, thus contributing to the island's economic resurgence.

The parametric insurance solution offered by Swiss Re Corporate Solutions to AboitizPower in the wake of Typhoon Rai demonstrated the effectiveness of alternative risk transfer solutions. With the simple and effective claims process, the insured could focus on efforts to mitigate the event impact and resume operations as quickly as possible. It also showcased the capacity of parametric insurance to bridge the protection gap left by traditional policies. With the growing impact of climate change, the value of alternative risk transfer and innovation in risk management has become increasingly evident in building resilience and addressing climate risks.

Source: Swiss Re Corporate Solutions, 2022

Climate change continues to be one of the most pervasive threats we face. It is one of the biggest risks for the insurance industry and a top priority for us and our customers. We are committed to developing insurance solutions that meet the dynamic needs of businesses in this evolving risk landscape and in the future.

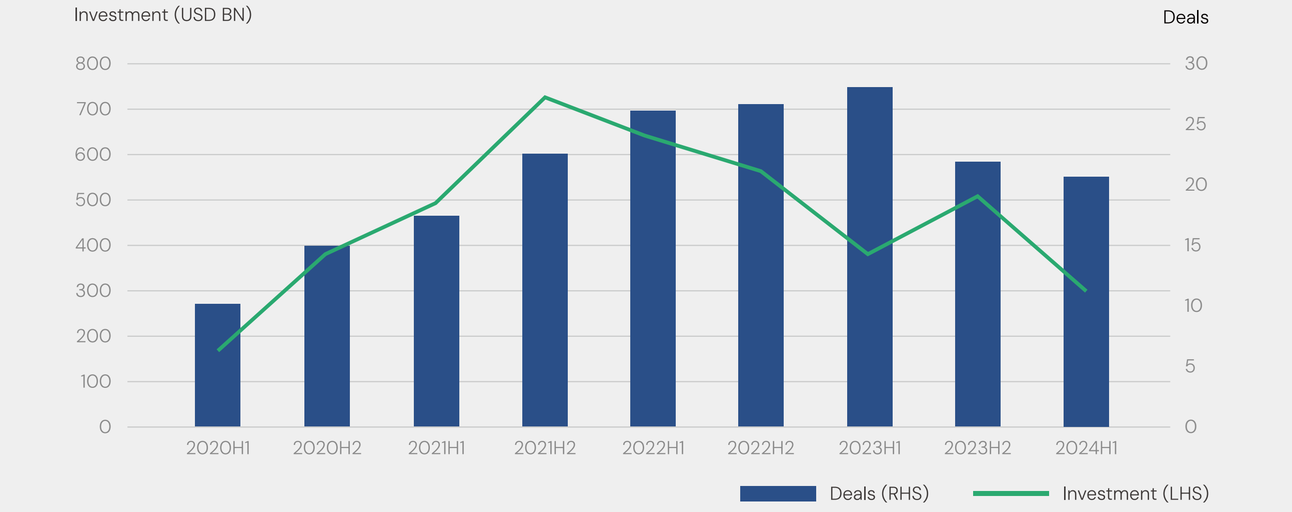
Jonathan Rake, Regional CEO Asia Pacific, Swiss Re Corporate Solutions

Besides commercial initiatives, multilateral development banks (MDBs) have also developed customized parametric insurance products. One prominent example is World Bank's customized parametric catastrophe risk insurance product for the Philippines, which provides significant post-disaster payouts for both national and local governments, with annual coverage increasing from US$206 million to US$406 million, and is also adopted by other countries like Mexico, Uruguay, Pacific Island nations, Caribbean countries, and select South American nations.[119]

Synergizing Policy and Venture Capital

Venture capital offers early-stage funding and can be the key success factor, especially for ClimateTech projects lacking sufficient TRL. Many innovative companies rely significantly on venture capital support for growth. This dependence is particularly acute in the ClimateTech sector, where long-term development cycles and policy dependencies require venture capital to sustain innovators and propel their advancements. The prevailing global economic downturn, however, has reduced global climate investment. Therefore, an enhanced understanding of market factors and effective collaboration between ClimateTech innovators and investors is significant for achieving growth.

FIGURE 4.2 | **Semiannual Climate Investment, 2020-2024 (USD BN)**



Source: Sightline Climate

Incentives and policy measures significantly affect ClimateTech venture capital investment patterns. The American ClimateTech market, exemplified by the post-Inflation Reduction Act (IRA) expansion, illustrates this influence. With its tax credits for renewable energy, CCUS, and other clean technologies, the IRA has spurred significant growth. Data from the Clean Investment Monitor, a collaborative project of the Rhodium Group and the MIT Center for Energy and Environmental Policy Research, indicates a dramatic rise in clean energy and transportation technology manufacturing investments. These investments surged from USD 22 to 89 billion in the two years following the IRA's enactment, representing a 156% annual increase in 2023.[120] This report's contributors frequently note that burgeoning ClimateTech firms typically experience a critical policy shift that propels them from stagnation to growth.

The alternatives of "Business as Usual" (BAU) present a significant common obstacle to ClimateTech product adoption necessitating a clear demonstration of their economic viability. Customer adoption depends on this comparative advantage. Policy interventions, however, can significantly expedite this process. Through incentives, subsidies, or regulatory mandates, such interventions enhance the attractiveness or even require the use of ClimateTech solutions. Effective policy cultivates market entry and scalability for these innovative technologies by reducing financial risks and costs for businesses and consumers. A greener supply chain finally depends on the synergy between economic viability and supportive policy frameworks.

As a result, such interaction between policy measures and market factors thus drives ClimateTech innovation and adoption. Collaborations between venture capitalists and innovators are also required. Such partnerships furnish strategic direction, market analysis, and networks, beyond the fundamental funding, thereby facilitating access to further resources and prospects. As the sector develops, successful ClimateTech companies demonstrate capabilities for resolving these issues, aligning technological progress with shifting regulatory environments and market needs. Xu Jieping, Chief Executive Officer of Plug and Play China, further notes that prominent venture capitalists and incubators deliver comprehensive open innovation services. These services strengthen ClimateTech adoption among large enterprises, cultivate a sustainable ecosystem, and guarantee the continued development and validation of ClimateTech, propelled by policy directives and industry resources.

Moreover, fostering such collaborations can initiate a virtuous cycle, attracting increased venture capital investment to successful ClimateTech firms and accelerating sector-wide innovation. Venture capitalists with an in-depth understanding of both market factors and policies can significantly enhance a startup's capacity for effective strategy planning. This alignment ensures that startups are not merely technologically sophisticated but well-positioned to capitalize on and influence policy trends. Therefore, their attractiveness to the following funding rounds and further investment is magnified. Moreover, numerous venture capital firms offer supplementary support through portfolio management, facilitating companies' adaptation to regulatory shifts. Therefore, these partnerships strengthen the financial resilience and growth prospects of individual ClimateTech firms and propel broader industry progress toward the overarching goals of carbon footprint reduction and climate change mitigation.

> *Beyond funding, the most important support for the green transformation supply chain, will be local and international regulations that favor green transition.*
>
> **Nabil Al-Khowaiter**
> Former Chief Executive Officer, Aramco Ventures

Education & Talents

Increasing environmental challenges have spurred global awareness of sustainable development among governments, organizations, businesses, and the public, creating a surge in demand for ClimateTech professionals. LinkedIn's 2023 Global Green Skills Report indicates a 22.4% average increase in jobs requiring at least one green skill across 48 countries and regions between 2022 and 2023. While the green talent pool has expanded, growing from 9.6% in 2015 to 13.3% in 2021 and further increasing by 12.3% between 2022 and 2023,[121] the supply of these professionals meets only half the demand. Education plays a critical role in addressing this talent deficit. It offers a foundation for cultivating environmental awareness among younger generations, imparting knowledge, nurturing a responsible mindset, and optimizing relevant skills. Through these efforts, education promotes innovation and technological progress, finally forging a path toward a sustainable future. Dr. Zhang Junjie, Director of the Sustainable Investment Research Program at Duke Kunshan University, notes that universities are the key forces in promoting the development of these cutting-edge technologies and achieving breakthroughs from zero to one.

22.4%

rise in green-skill jobs across 48 regions between 2022 and 2023

Both ClimateTech advancement and green supply chain development require talent cultivation. As industries adopt sustainable practices and seek to minimize environmental impact, demand surges for professionals capable of supply chain management and optimization. These professionals require expertise in environmental impact assessment, sustainable sourcing, and eco-friendly logistics management.

ClimateTech education transcends traditional social group boundaries. While public perception pivots to university climate schools cultivating future leaders for global dialogues and entrepreneurial ventures, professionals also need education to implement sustainability principles in companies regardless of their scale. Moreover, the contribution of skilled workers, integral to implementing and maintaining ClimateTech infrastructure and facilities, must be recognized.

Rising of Climate Change Natives to Future Leaders

Youth inherits not only the world as it exists today with its current climate issues, but also represents the future leadership in achieving intergenerational sustainability. Born in the age of growing climate consciousness, this new generation can be termed "climate change natives." Educated on the subject from their early years and beneficiaries of economic progress cultivating a broader global understanding, they differ significantly from preceding generations. This expanded worldview allows them to look beyond traditional cultural and industrial demarcations, embracing instead a more holistic approach to climate concerns. While global opinions on climate change remain diverse, the ingrained awareness of this generation offers promise for a more sustainable future as they assume positions of influence.

A multi-pronged approach, including education, practical application, and policy advocacy, cultivates meaningful youth engagement in climate action. University curricula should be broadened to include environmental science, policy development, economics, sustainable practices and management, and social justice, offering a systematic approach for the youth to understand the complex mechanism underlying sustainability efforts. The UNFCCC's Youth Constituency (YOUNGO) offers an example of promoting environmental awareness through webinars, workshops, and events such as the Conference of Youth. By exchanging novel concepts and pragmatic strategies, YOUNGO advances the United Nations' objectives and empowers youth to spearhead initiatives addressing global environmental concerns.

Reducing climate change impact requires more than mere pronouncements; it frequently involves the complex redistribution of resources among countries, regions, industries, and socioeconomic strata. Such redistribution requires careful consideration. University curricula must prepare future climate leaders to prioritize marginalized populations burdened by climate change consequences among the most significant proportion, including displacement from climate-related catastrophes and unemployment from policy adjustments. Youth leaders require education regarding the grave implications of climate change and the development of robust societal and economic structures that guarantee equitable outcomes throughout the transition.

Moreover, climate leadership education, in addition to establishing a technical foundation through knowledge and skills transfer for future leaders, should, according to a large number of contributors, offer young people avenues for expressing their perspectives. It should also facilitate the meaningful integration of their insights into wider climate strategy networks and policy development. Experiential learning, including internships and mentorships, allows direct engagement with cutting-edge sustainability practices, empowering young individuals to apply their knowledge in the collaborative development of solutions for complex, real-world environmental problems. This approach ensures that students, alongside understanding global climate challenges, develop an understanding of local and ethical dimensions. Therefore, they acquire the skills and knowledge necessary to effect positive change in ClimateTech, while simultaneously cultivating self-effectiveness in environmental stewardship.

Effective climate leadership education programs can prepare future leaders. Equitable and inclusive access, however, remains paramount, particularly regarding national, regional, and gender parity. The stereotype associating men primarily with ClimateTech fields, such as science, technology, engineering, and mathematics (STEM), overlooks the complexity of climate issues, which frequently incorporate both STEM and liberal arts disciplines. Rather than simply discouraging women from exploring ClimateTech interests, this misconception also restricts their entry into professional fields such as natural sciences, environmental engineering, and other areas related to climate leadership. In addition, in certain regions, including several BRICS countries, as noted by Alexander Kormishin, Chairperson and Director-General of BRIC Youth Energy Agency, women encounter barriers to leadership, sometimes exhibiting a greater inclination toward traditional domestic roles. This gender bias, constraining women's involvement in the energy sector and leadership positions, consequently limits their potential contributions to national economies and environmental initiatives.

Due to the interdisciplinary character of climate issues, equitable access to STEM knowledge and opportunities should be afforded to all, irrespective of gender. To reduce existing disparities and ensure continued advancement in climate leadership education, a focus on the social empowerment of youth and women is critical. This focus requires specialized training to secure their robust representation in sustainable development initiatives and provide equal opportunities for their emergence as future climate leaders and contributors to the energy transition.

CASE STUDY 11 **Impact-oriented Arab Youth Empowerment**

The Arab Youth Center (AYC) is extensively involved in empowering youth across the Arab world. Its unique impact evaluation framework, combined with a focus on entrepreneurship, professional development, community engagement, and research, has positively influenced over 30,000 individuals through various transformative programs.

AYC's evaluation framework is notable for its data-driven and youth-oriented strategy. By incorporating young people's perspectives, AYC ensures its programs are engaging and tailored to their specific needs. For instance, during the data collection phase, AYC uses the Net Promoter Score (NPS) to gauge youth satisfaction and expectations, allowing for effective tracking and quantification of program success.

The Arab Youth Council for Climate Change (AYCCC), a key initiative under AYC, recruits climate leaders for a two-year membership, providing intensive training and supporting them in executing community projects. The Center promotes these leaders by connecting them with opportunities, advocating for them in international forums, and linking them with decision-makers and peers in the region. According to the AYC Impact Assessment Report, 78% of respondents reported increased climate change awareness following their engagement with AYCCC, and nearly 40% actively participated in climate change mitigation activities, demonstrating the substantial impact of AYC's initiatives.

AYC demonstrates measurable youth empowerment by equipping young people with knowledge, skills, and opportunities to address climate change. This approach actively fosters a generation of Arab youth committed to environmental stewardship.

Source: Arab Youth Center, 2024

"Through listening to their insights and benefiting from their recommendations, we can design and implement innovative solutions that effectively reduce the challenges of climate change and capitalize on future opportunities.

H.E. Dr. Sultan Saif Al Neyadi, Minister of State for Youth Affairs, United Arab Emirates

Leadership skills can be cultivated among youth, whereas youth across diverse geographical locations and socioeconomic backgrounds should have equitable access to climate leadership education. Balancing the commercial aspects with the educational objectives of such programs presents a significant challenge. While commercialization has propelled the development of diverse youth-oriented initiatives—including volunteer opportunities, summer camps, forums, and internships—an overemphasis on profit can exacerbate disparities in access. International organizations, governments, and large corporations should prioritize equitable practices in their commercial partnerships. When selecting program participants, beyond their financial affordability, educators must also consider a candidate's potential for climate leadership and alignment with program values. In addition, scholarships offered by numerous organizations effectively support access to climate leadership education.

Learning Beyond the Mold

With sustainable development a focal point of higher education, an increase in green degree programs across universities is evident. The UN Environment Programme (UNEP) reports that approximately 1,050 universities in 68 countries and regions have committed to net zero emissions by 2050,[122] demonstrating a growing dedication to sustainable development initiatives. Such initiatives frequently include green degrees and research projects covering popular fields such as artificial intelligence and green energy, with a core focus on sustainable development. The University of Oxford, for instance, is implementing initiatives to enhance climate change literacy among both undergraduate and graduate students. In addition, as noted by Dr. Andrew Lee, Associate Fellow of UCL Center for Climate Change and Sustainability Education, the relevant question is not whether individuals believe in climate change but rather their understanding of the underlying science. By offering relevant courses and research resources, "green universities" equip youth and professionals with the knowledge to address challenges, prompting solution-oriented approaches. This cultivation of individuals with strategic vision and management skills offers enterprises a robust pool of highly qualified personnel, driving advancements in ClimateTech and cultivating sustainable supply chains.

1,050

universities in 68 regions pledged net zero by 2050

Green education in universities, similar to climate leadership education, requires enhanced adaptability in its curricular design. Rigid, textbook-centric approaches need to be revised to meet the evolving demands of the relevant industries, cultivate meaningful student engagement, and cultivate a comprehensive understanding of contemporary climate-related challenges. Meanwhile, educational experiences should transcend the confines of traditional classrooms, emphasizing professional skill development and holistic growth through practical, interdisciplinary frameworks. Institutions must prioritize problem awareness and cultivate problem-solving aptitudes, encouraging student involvement in scientific research and internships to enhance future competitiveness. Simultaneously, teacher training programs and textbook revisions align teaching with industry progress.

While universities offer sustainability-focused curricula, students must still be equipped with the practical skills necessary for impactful careers advancing sustainable development. A significant demand exists for globally-minded ESG professionals with interdisciplinary expertise in finance, management, and operations. Leading organizations actively recruit individuals capable of integrating international ESG standards into strategic planning. From these professionals, complex systemic thinking, diverse stakeholder engagement, and a commitment to long-term sustainable innovation are expected, skills largely cultivated through university education and experience. This context explains the role of universities not only in delivering sustainable education but also in cultivating the broad skill sets and global perspectives required to meet the practical demands of integrated ESG leadership.

Green higher education extends beyond the classroom, particularly through the reconstruction of university infrastructure and the creation of green campuses. Employing eco-friendly construction materials and integrating environmental awareness into daily life, these campuses immerse students in an atmosphere conducive to environmental consciousness. The National University of Singapore (NUS), for instance, demonstrates significant progress with initiatives such as Carbon Neutral NUS, Cool NUS, and Zero Waste NUS. Redesigned teaching buildings at NUS have achieved an 80% reduction in carbon emissions. In addition, the campus features around 35,100 trees and buildings with cooling paint to reduce heat absorption and air conditioning needs. These infrastructure changes support the "zero waste" movement, with resource sorting stations enhancing waste segregation and recycling.[123] This holistic transformation of physical spaces and student routines cultivates a widespread culture of environmental responsibility, nurturing awareness and motivating concrete action among youth.

Modern universities actively promote interdisciplinary environmental education, cultivating collaboration among diverse academic departments and external organizations, including businesses. This cooperative approach, including internal and external partnerships, equips students with diverse backgrounds to gain sustainability knowledge and cultivate a comprehensive understanding of, and skill set in, ClimateTech, while aligning academic curricula with industry needs. For instance, King Abdullah University of Science and Technology (KAUST) collaborates with local and global companies, such as Saudi Aramco, Saudi Electricity Company, and Longi Solar, to secure research funding while simultaneously advancing market-relevant technologies in carbon capture, low-carbon hydrogen, and advanced transport.

CASE STUDY 12 **Climate Education Beyond Classrooms**

The Global Alliance of Universities on Climate (GAUC) was established during the World Economic Forum in 2019 with eight leading universities, spearheaded by Tsinghua University and London School of Economics and Political Science, to lead global higher education efforts in addressing climate change.

GAUC empowers youth globally by enhancing international dialogue across various sectors, equipping students with the skills to address climate issues. The alliance has formed a global cross-university network consolidating climate education resources from 15 universities and networks in nine countries and regions across six continents, offering students unrestricted access to expert-led lectures and pioneering research.

Beyond theoretical online courses, GAUC has championed Climate X flagship projects and practical events in collaboration with industry, non-profit, and governmental bodies. These initiatives, such as the Global Youth Summit and Youth Delegation to COP25, aim to cultivate future climate leaders. To further engage youth in climate action, GAUC proposed a one-week event before the UNFCCC COP to gather youth and discuss climate-related topics. The 2023 event saw youth organizations from six continents advance numerous climate innovation and policy advocacy projects.

GAUC acknowledges the critical skills needed in the climate sector. As ClimateTech advances, data analysis and artificial intelligence proficiency have become essential for young individuals addressing climate issues. Additionally, constructing green supply chains requires a solid understanding of green finance principles. To address these needs, GAUC leverages internal resources providing climate x finance and climate x AI & Innovation training courses, enabling young people to acquire cutting-edge technological expertise.

Source: Global Alliance of Universities on Climate, 2023

The young generation often has a broader global perspective and can see climate issues in a more integrated way across traditional cultural and industrial boundaries. Youth can be seen as "catalysts" in climate issues, accelerating the formation of diverse needs and solutions and playing an important role in understanding and addressing climate issues. Ensuring young people participate in climate action requires a joint effort through education, practice, and policy advocacy.

Alice Ho, Chief Youth Officer, Global Alliance of Universities on Climate

Transforming Vocational Education

The growing integration of sustainability into educational curricula at all levels, including technical and vocational education in environmental consciousness, cultivates the green skills demanded by the contemporary labor market. Interviews indicate that educators and entrepreneurs acknowledge shortcomings in traditional vocational training, including a lack of practical experience with industrial settings and extended integration timelines for graduates transitioning into employment. Therefore, a new model is developed blending green education with technical and vocational training through cooperative alliances.

To cultivate "industry-education integration," educational institutions and local businesses have forged collaborative partnerships. Vocational schools offer their expertise, complemented by the financial support and practical environments furnished by enterprises. This synergistic approach facilitates academic events, forums, and competitions, equipping students with advanced skills and knowledge in intelligent manufacturing and energy management. Schneider Electric represents a prime example, having hosted the Go Green competition since 2011. This competition has attracted more than 160,000 students from 200 countries and regions, encouraging innovations in digitalization and energy management through a sustainability perspective. In China, Schneider Electric's collaborations extend to over 100 vocational schools through initiatives such as the "BipBop Plan" and the "Green Industry-Education Integration Project," training thousands of teachers and benefiting more than 100,000 students. In addition, numerous universities partner with international organizations to elevate the global quality of vocational education. Such international collaborations advance the exchange of environmental technology and knowledge, significantly improving the professional capabilities and marketability of vocational graduates.

While university-level climate education flourishes, green vocational training faces challenges in standardization and funding. Government subsidies, a frequent source of vocational education support, pose a barrier for certain developing countries and regions, thus exacerbating regional inequalities. Moreover, a comprehensive and structured curriculum is absent from existing green vocational training, resulting in a shortage of skilled workers to meet market demands. This deficiency of advanced vocational institutions, specialized training programs, and qualified educators limits frontline workers' understanding of green skills and reduces their inclination toward sustainable practices. Dr. Ese Owie, Chief Executive Officer of Oxford Climate Alumni Network (OxCAN), highlights that, regarding the deployment of clean energy components and other installations, while individuals in the Global South demonstrate both the aptitude and the desire for skills enhancement, investment in this region remains urgent for further capacity building.

Recent regulations in the US offers significant incentives to enhance vocational education to support the transition to a renewable energy economy. This creates a virtuous cycle where communities and states compete to attract investments in renewable energy, such as battery and electric vehicle manufacturing plants. As states vie for these investments, they invest in vocational training to ensure the local workforce has the necessary skills.

Dr. Stan Meiburg
Executive Director, Sabin Family Center for Environment and Sustainability

International collaboration and technology transfer enhance vocational education, particularly in economically disadvantaged regions. CAMFED (Campaign for Female Education), beginning in 2013, established an innovative program for young women from marginalized, impoverished farming communities throughout sub-Saharan Africa. Equipping over 8,500 individuals with climate-smart agricultural methods,[124] the initiative transformed a significant number of participants into "agripreneurs," thereby generating economic value. Greater engagement from international organizations and non-profit funders with vocational training is strongly recommended, considering its capacity to significantly accelerate community development and empowerment. Such training, emphasizing practical skills and sustainable practices, not only strengthens agricultural productivity but also cultivates economic resilience and independence in participating communities. Therefore, this approach advances broader socio-economic progress, addressing immediate needs while promoting long-term growth.

In conclusion, despite advancements, sustainable vocational education requires continued attention and improvement, while academics and educational institutions collaborate and innovate to develop environmentally conscious individuals whose skills align with the educational system's requirements.

V

Conclusion: What's Next?

© Duku Highway Under the Evening Glow, Chang Kaifeng, finalist of 2024 Climate and Sustainability Photography Awards

> *"While technology can enable a zero-carbon economy, it may lead to a green cost premium in many sectors. This means that we will not achieve decarbonization just by a free market. We will need regulation, quantitative targets, carbon pricing, or public policy instruments that level the competition between traditional and cleaner technologies.*

Lord Adair Turner
Chairman, Committee on Climate Change

For Governments and International Organizations

First, prioritize science, stakeholder engagement, and synergy in international climate goal-setting by recognizing leading and lagging factors and facilitating multilateral discussions on climate transition strategies and financial responsibilities.

Second, implement stable, consistent policies to nurture a virtuous green economy cycle. Encourage investment with market-based benefits for green supply chain participants through government mechanisms like regulatory sandboxes and Proof of Concept Fund (PoCF). Enhance public awareness and manage awareness regressions/fluctuations to maintain policy effectiveness.

Third, craft green regulations to close the gap with non-green alternatives, avoiding trade barriers and inequalities. Recognizing issuing regulations is just the beginning, with enforcement and public education equally essential for effective policy implementation, especially in managing the credibility of environmental claims. Evaluate green labels to prevent self-certification, misinformation, and greenwashing, using blockchain and traceability tech to enhance credibility and prevent fraud.

Fourth, reduce bureaucracy and educate officials on green knowledge. Match international green standards, market mechanisms, and regulations in the supply chain to enhance efficiency and reduce risks.

Lastly, circumvent the "Not In My Backyard" (NIMBY) effect by focusing on urban decarbonization rather than relocating non-green industries.

For NPOs and Education Institutions

First, develop mechanisms, including Technology Transfer Offices (TTOs), to move innovations from the lab to the factory.

Second, bridge gaps in knowledge, standards, and compliance across multi-jurisdictional supply chains to establish trust, standardized metrics, and mutual recognition.

Third, speak their language when educating the young generation as "climate change natives." Multi-level and multi-disciplinary programs should be developed beyond textbooks and classrooms to nurture future climate leaders, professionals, and skilled workers while ensuring gender and social equity.

For Large Enterprises

Firstly, move beyond compliance for sustainability excellence by aligning with customer and employee values, enhancing brand competency, and increasing investor and customer confidence through high perceived green value (PGV) and reduced risk. Support socially responsible job impacts by monitoring job loss and offering training for transitions to skilled roles.

Secondly, establish infrastructure for traceable supply chain data to ensure compliance and influence. Collaborate to provide testing facilities and integrate innovative technologies into large supply chains.

Thirdly, carefully assess AI use in supply chains, targeting small-scale, quick-win scenarios while considering data quality and algorithm limitations.

Lastly, for hard-to-abate sectors and traditional energy operators, adopt flexible, cost-effective transition strategies like in-situ retrofitting and CCUS. Balance costs and sustainability for alternative fuels, ensuring proper certification and data traceability for value protection.

For Financial Institutions

First, analyze technological, financial, regulatory, and social factors influencing ClimateTech adoption across different TRLs and ARLs. ClimateTech products, alongside their Business as Usual (BAU) scenarios should be evaluated for a comprehensive assessment.

Second, identify the risk appetites of financial institutions within trailblazers, opportunists, refiners, or guardians, and adopt the appropriate proactive or reactive strategy. Integrating climate-related risks and opportunities into financial and risk projection models is needed.

Third, offer best practices and network support beyond just funding to enhance ClimateTech initiatives.

For SMEs, Startups, and Individuals

First, develop a diverse skill set within management teams in ClimateTech firms that goes beyond technical expertise to include sales, government relations, and investor relations. Remain ever-learning, agile, and responsive to the latest green supply chain trends and policy changes by quickly adapting strategies to capitalize on policy advantages is necessary.

Second, establish a competitive edge by considering differentiating factors from peers, competitors, and also the Business as Usual (BAU) case.

Third, cultivate entrepreneurial acumen by embracing the "fail fast, fail well" mindset, allowing for rapid testing and iteration of ideas to gain valuable insights and accelerate learning.

Institutions

United Nations Institute for Training and Research (UNITAR) provides innovative learning solutions to individuals, organizations, and institutions to enhance global decision-making and support country-level action for shaping a better future. With a strategy fully focused on achieving the Sustainable Development Goals (SDGs), UNITAR supports Governments in implementing the 2030 Agenda.

Website: www.unitar.org

Pacific Economic Cooperation Council (PECC) is an independent, regional mechanism with 23 member countries and 2 institutional members that advances economic cooperation and market-driven integration. It has served as a regional forum for cooperation and policy coordination to promote economic development in the Asia-Pacific region since 1980. As APEC's only non-government official observer, PECC provides information and analytical support to APEC ministerial meetings and working groups in facilitating private sector participation in the formal process.

Website: www.pecc.org

Shanghai Climate Week (SHCW) is a global non-profit platform for governments, businesses, academic institutes, and social institutions to communicate & collaborate on climate actions under the support of the UN & Chinese governments. It aims at "China Action, Asia Voice, Global Standard," pushing social forces of engagement in China's commitment to carbon peaking and neutering goals, amplifying Asia's voice for green transformation, enhancing international communication & collaboration in response to climate change, and participating in design & implementation of international standards.

Website: www.shanghaiclimateweek.org.cn

Knowledge Partner

WeCarbon is a global leading ClimateTech company dedicated to delivering AI-powered solutions and pioneering insights to promote ESG and sustainability within the global supply chain, focusing on green transitions in compliance, manufacturing, certification, cross-border trade, and management.

Website: www.we-carbon.com

Supporting Organization

(Listed in alphabetical order)

Arab Youth Center
Asian Development Bank
Asia Green Fund
Atlantis Blu Group
Baowu Group
Bosch
Global Alliance of Universities on Climate
Golden Bridge Group
Green Finance Forum of 60
London & Partners
Lotus
National Center for APEC
New Energy Nexus
Nike
Oxford Climate Alumni Network (OxCAN)
Roca
Royal Golden Eagle Group
Schneider Electric
Sino Research Institute of Green Finance
Swiss Re Corporate Solutions

Legal Advisor

Light & Bright

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