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Technology Executive Committee

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Draft policy brief on integrating hard-to-abate industries in updated NDCs

Concept note

I. Background

1. As per activity C.3.1 of its rolling workplan (2023–2027), the TEC works to promote low and near zero emission production and products, including in the steel and cement industries, through the support of innovation, enabling environments, sustainable purchasing commitments, and financing to inform the preparation and implementation of NDCs.

2. At TEC 28, the TEC considered a draft annotated outline for a policy brief on hard-to-abate industries in updated NDCs[1] and provided guidance to the activity group on transformative industry to revise the annotated outline. The TEC further requested the activity group to prepare a draft policy brief based on the revised annotated outline for consideration at TEC 29.

3. The TEC activity group continued working intersessionally and, based on the revised annotated outline, developed the draft policy brief with the support of a consultant and UNIDO.

4. At TEC 29, the co-leads of the activity group, supported by a consultant, will present the draft policy brief contained in the annex.

II. Scope of the note

5. The annex to this note contains the draft policy brief on integrating hard-to-abate industries in updated NDCs.

III. Expected action by the Technology Executive Committee

6. The TEC will be invited to consider the draft policy brief contained in the annex and provide guidance to the activity group with a view to finalizing the draft after TEC 29.

[1] See TEC document TEC/2024/28/10.

Annex

Draft policy brief on integrating hard-to-abate industries in updated NDCs for deep industrial decarbonization

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1. Why this TEC Brief?

Confronting climate change is an urgent and complex challenge that has been widely acknowledged and prioritized by the global community. Central to these efforts is the latest IPCC assessment report, which concludes that global greenhouse gas (GHG) emissions must peak by 2025 at the latest and be reduced by 43% by 2030, relative to 2019 levels, to limit warming to 1.5°C (IPCC, 2022). Achieving the 1.5°C target has been underscored in the outcome of the first global stocktake (GST).[1] Achieving this ambitious goal requires deep, rapid and sustained reduction in GHG emissions and comprehensive international action in this regard. There is a growing recognition of the necessity to adopt transformative zero-emission solutions across all sectors worldwide.

Accounting for 34% of all emissions in 2019 and considering the duplication of the demands of its key products over the past two decades, there is an urgent need for comprehensive adoption of zero-emission pathways in industry, particularly the hard-to-abate industries (HAI) (Dhakal et al. 2022). Achieving the Paris Agreement targets demands a sweeping, systemic shift towards a sustainable, zero-emission future, especially given current trends, where emissions from HAI are expected to increase significantly, particularly in developing countries (IEA, 2023).

The urgency of integrating low and net-zero emission technologies in industry and in particular in HAI into the update of Nationally Determined Contributions (NDCs) for the period 2025-2035 is paramount. This policy brief builds on the TEC background paper on mapping of initiatives that promote low and near zero emission production and products in HAI, leveraging the findings into recommendations that can be considered when updating the NDCs and in National Reports to attract further support (TEC, 2023).

By providing detailed guidance and actionable recommendations, this TEC policy brief aims to support countries in effectively integrating industries and in particular HAI when developing their updated NDCs. This integration is expected to lead to substantial reductions in GHG emissions, helping to keep the 1.5-degree target within reach and securing a sustainable, zero-carbon future.

2. Highlights

Incorporating low and zero-emission technologies when developing the NDCs for the 2025-2035 period is crucial. These technologies are vital for reducing emissions in steel, cement, chemicals, non-ferrous metals, aluminium, and paper industries, which are major contributors to global industrial CO2 emissions. To achieve significant emission reductions and keep the 1.5-degree target within reach, transforming these industrial

[1] Decision 1/CMA.5, paragraph 4.

sectors is imperative. This includes the transition to net-zero fossil fuel-free approaches, energy and material efficiency, circularity, and sector-specific technologies. Electrification, hydrogen-based steelmaking, carbon capture and storage (CCS), electric boilers, and renewable energy-based high-efficiency electric kilns are all critical solutions that demand a concerted effort to mobilize finance, engage in policy making, and foster international cooperation. The findings of this policy brief highlight the following key areas of intervention to drive deep decarbonization of HAI:

a) **Integration of Industries, in particular Hard-to-Abate Industries, in the update of NDCs to Drive Decarbonization.** Countries with a significant and growing share of emissions from HAI are encouraged to prioritize targeted mitigation actions in industries such as steel, cement, chemicals, non-ferrous metals, aluminium, and paper when developing their updated NDCs for the 2025–2035 period, as well as their Long-Term Low Emission Development Strategies (LT-LEDS) toward net-zero emissions. This includes phasing out the unabated use of coal in HAI and transitioning away from fossil fuels. The transition to net-zero emissions in HAI should be supported by policies that encourage the deployment of renewable energy, electrification, and other low-carbon technologies, along with the establishment of clear milestones for each major production sector (UNFCCC, 2023).

b) **Transforming Key Industrial Sectors to Achieve Significant Emission Reductions.** Transforming key industrial sectors, such as steel and cement, is crucial for achieving deep emissions reductions. This involves accelerating the development and deployment of net-zero emission steel and net-zero emission cement production technologies.

c) **Tracking Progress through Roadmaps and Milestones for Emission Reduction.** Roadmaps and milestones can benefit from robust monitoring and verification systems to help ensure that emission reduction targets are met. These systems should feature transparent measurement, reporting, and verification (MRV) processes, aligned with national inventories, to track emissions and assess the effectiveness of technologies (Singh & Levin, 2016).

d) **Collaborative Efforts between Industries, Research Institutions, Financial Institutions and Governments to Accelerate Development and Deployment of Low and Net-Zero Emission Technologies.** Support for effective collaboration between industries, research institutions, financial institutions, and governments is crucial to accelerate the development and deployment of low and net-zero emission technologies. Such partnerships could drive innovation, facilitate the exchange of best practices, and create synergies that enhance decarbonization efforts, including the transition to net-zero alternatives for high embodied carbon materials.

e) **International Cooperation and Knowledge Sharing as Catalysts for Innovation, Technology Transfer and Capacity-building.** Fostering international cooperation and knowledge sharing is vital for innovation, technology transfer, and capacity-building. This global effort is crucial for the successful integration of technologies into the update of NDCs and achieving global emission reduction targets.

3. Introduction

3.1. Background

The industrial sector is a significant contributor to global GHG emissions. Three primary sectors—cement, chemicals & petrochemicals, and steel industries—are notably referred to as "hard-to-abate industries". These industries are responsible for nearly 60% of total industrial energy consumption and contribute approximately 70% of industrial CO2 emissions. These sectors have a high reliance on fossil fuels, long facility lifetimes (20-50 years), and significant capital expenditures for deploying net zero emission technologies. Acknowledging the historical rise in global demand for steel (2.1 times), cement (2.4 times), and plastics (1.9 times) over the past two decades, there is an urgent need to stabilize or reduce current production levels and associated emissions. Transforming the industry sectors, including but not limited to steel, cement and concrete, chemical industries, and non-ferrous metals, aluminium, and paper, is crucial to substantially reducing emissions of the industry sector to keep the Paris Agreement 1.5-degree target within reach (IEA, 2021).

In 2021, the International Energy Agency (IEA) reported a dramatic annual increase of over 6% in global emissions, primarily driven by the resurgence of coal, oil, and gas as economies recovered from the pandemic. In 2023, emissions grew by 1.1% compared to 2022, increasing by 410 million tonnes (Mt) to reach a new record high of 37.4 billion tonnes of CO2eq (Gt). This surge highlighted the persistent challenge of managing rapidly rising GHG emissions, particularly in sectors essential to economic growth (IEA, 2024).

Given the IPCC's Sixth Assessment Report’s call to reduce all emissions by at least 43% by 2030, the industrial sector is crucial in meeting this target. Achieving these reductions depends significantly on the sector's shift to cleaner practices and technologies, requiring substantial investments in new technologies and processes, such as hydrogen-based steelmaking, carbon capture and storage, and bio-based chemicals (IPCC, 2023).

The outcomes of the first Global Stocktake at COP28 also highlighted the critical need for collaborative approaches to climate technology research, development, and demonstration, including in hard-to-abate sectors.[2] Such approaches are essential for deploying mature climate technologies and developing emerging technologies on a large scale. By leveraging international cooperation and knowledge sharing, countries can enhance their capacity to develop and implement effective decarbonization strategies and achieve their climate goals.

3.2. Objectives and Scope

The Technology Executive Committee (TEC) has developed this policy brief to provide guidance and support to countries integrating actions to mitigate industrial emissions into the process for updating their NDCs. This effort aligns with the overarching guidance provided by the Technology Framework to the Technology Mechanism[3] and directly supports accelerating climate action during this critical decade, in line with the outcome of the first global stocktake. The primary objectives include:

- **Informing countries about technology and policy options for HAI**: The brief covers the latest innovations and decarbonization strategies for the industry, with a focus on the steel, cement, and chemical sectors, which are major contributors to global industrial emissions. Recognizing the rapidly closing window of opportunity to limit warming to 1.5°C, the brief emphasizes the urgent need for immediate action and highlights solutions that are ready for deployment within this decade.

- **Providing examples of implementable policies for integration into NDCs**: The brief offers actionable approaches and policies that can be adopted and adapted by different countries to meet their specific needs, accelerating progress toward achieving net-zero industrial emissions by mid-century, as called for in the outcome of the first global stocktake, while recognizing that delaying action will significantly increase the difficulty and cost of achieving the Paris Agreement's goals (UNFCCC, 2023).

- **Offering recommendations that help attract finance and mobilize investments**: By showcasing investable, low-carbon technologies and recommending clear policy signals for industry decarbonization, the brief aims to attract more sustainable investments and mobilize climate financing.

The policy brief covers the available technologies and approaches to decarbonize Industry, in particular HAI, the barriers for these technologies to be deployed and the existing or possible policies that can be used to enable these technologies. The policy brief will also look at the means of implementation for these policies, including finance, and capacity building.

[2] Decision 1/CMA.5, paragraph 107.

[3] Decision 15/CMA.1, Annex, paragraph 8 (c).

4. Policy options for decarbonizing hard-to-abate industries

4.1. Low Emission and Net-Zero Technologies for Decarbonizing hard-to-abate Industries

Several cross-sectoral technologies are being implemented to support decarbonization across multiple industries. By applying these emergent technologies, we can achieve a reduction of CO2 emissions from HAI by two Gt of CO2eq by 2030, representing a significant 20% decrease in CO2 equivalent emissions from this sector (UNIDO, 2022; IEA, 2021).

The **electrification of industrial processes** and fuel switching—transitioning from fossil fuel-based energy to renewable electricity and lower or zero GHG intensity energy carriers when electrification is not feasible—is a key strategy for emissions reduction across all hard to abate sectors, including heat and power processes as well as transportation within industrial operations. There is significant potential for electrifying low-temperature and some medium-temperature heat applications using highly efficient industrial heat pumps, with other electric heating technologies and thermal energy storage further extending electricity's reach.

Energy efficiency improvements are universally applicable, involving process optimization, equipment upgrades, and the implementation of energy management systems to reduce overall energy consumption and emissions. Digitalization and smart technologies further enhance these efforts by enabling process optimization, predictive maintenance, and energy management, leading to reduced emissions and improved efficiency.

Material efficiency involves producing the same end-use service with fewer GHG-intensive materials. This can be achieved through eco-design, which assesses and reduces a product's environmental footprint over its life cycle via conscious design and revised building codes. Improving material efficiency can also be accomplished by extending the lifespan and reusability of materials. Strategies include extending product lifespans, minimizing rebuild cycles, and promoting adaptability for other end-uses, allowing for non-destructive reuse and effective recycling. Additionally, **switching to less GHG-intensive materials**, such as wood, local natural materials, and cementitious substitutes, can reduce overall emissions.

Another approach to mitigating emissions from HAI is fostering **circularity**, which focuses on closing the loop for materials and energy flows by incorporating policies and strategies for more efficient energy, materials, and water consumption, while emitting minimal waste to the environment. This can be achieved by increasing both the quantity and quality of recycling materials with high GHG emissions, including metals like iron, aluminium, and copper, and plastics such as polyethylene, polyvinyl chloride, and polypropylene (UNIDO, 2023). However, to fully realize the potential of circularity, it is essential to ensure a sufficient and consistent supply of scrap material, which is crucial for the effective use of electric furnaces in recycling processes. Demand for materials is a key driver of energy consumption and CO2 emissions in the industrial sector. The approaches referenced previously can decrease it, but it also can be influenced through urban planning, building codes and related socio-cultural norms that shape the overall demand for square meters per capita of floor space, mobility and transport (IPCC, 2023).

Decarbonizing production processes is also crucial, achieved through the research, development, and commercialization of emerging and near-commercial technologies that produce zero or very low emissions. *Near-commercial technologies*, such as electric boilers are often already in use but are limited by high electricity costs or regulatory issues. Natural refrigerants can be combined with heat pumps and with refrigeration systems. *Emerging technologies*, still in the research and development phase such as induction and plasma heating rely on low GHG electricity. Others depend on low emission hydrogen, and carbon capture and storage or utilization, like hydrogen direct iron steel or post-combustion carbon capture, utilization, and storage (CCUS).

Industries and in particular HAI also have available or in different stages of development **sector-specific technologies** tailored to the unique processes and challenges of the decarbonization of each sector.

In the **steel industry**, hydrogen-based steelmaking is emerging as a ground-breaking approach, utilizing green hydrogen instead of coal in the direct reduction of iron ore, significantly reducing CO2 emissions. Complementing this, the adoption of Electric Arc Furnaces (EAFs) that recycle scrap steel and are powered by renewable electricity offers substantial emissions reductions compared to traditional blast furnaces. The electrification of steelmaking through EAFs, particularly when powered by renewable energy, is a crucial step toward decarbonization. Additionally, the Direct Reduced Iron-Electric Arc Furnace (DRI-EAF) process, which uses a blend of hydrogen and carbon monoxide, presents another viable pathway for reducing emissions. Expanding renewable energy capacity and ensuring the availability of scrap material are essential for maximizing the impact of these technologies (UNECE, 2022). Furthermore, implementing CCUS technologies can capture up to 90% of CO2 emissions from steel production, providing a crucial tool for mitigating the industry's carbon footprint that can be combined with blast furnace-basic oxygen furnace with top gas recirculation and HIsarna.[4] New technologies are emerging such as Aqueous or Molten Oxide Electrolysis.[5]

In the **cement sector**, similar innovative approaches are being employed. Utilizing alternative clinker materials, such as calcined clay or slag, can further reduce CO2 emissions associated with traditional clinker production. Upgrading cement plants to improve energy efficiency, through high-efficiency kilns and waste heat recovery systems, significantly lowers fuel consumption and emissions. One of the simplest and most effective ways to reduce cement and concrete emissions is to make stronger concrete through better mixing and aggregate sizing and dispersal. In addition, CCS technologies can help capturing CO2 emissions from the cement production process, addressing emissions from the calcination process. Promising new technologies in development are magnesium and ultramafic cements (Haque & Zhao, 2024).

For aluminium and other non-ferrous metals new technologies are near the commercial stage, such as inert electrodes combined with green electricity. Hydro or electrolytic smelting with CCUS if necessary is in different stages of development and cost depending on the specific ore.

The **chemicals and petrochemicals sector** is also seeing transformative changes with the integration of biomass feedstocks, which replace fossil fuel-based feedstocks, reducing the carbon footprint of chemical production. This shift to bio-based chemicals, sourced from agricultural waste, forestry residues align with sustainability goals, whereas dedicated energy crops can result in synergies or trade-offs depending on context-specific conditions (Vera et al., 2022). Catalysis of ammonia from low- or zero-GHG hydrogen is another available technology for the chemical sector. Electrification of chemical processes, powered by renewable energy, offers another pathway for emissions reduction, as does the development, and use of advanced catalysts that enhance the efficiency of chemical reactions, thereby lowering energy consumption and emissions. Technologies in development include electrocatalysis and alternatives for end use plastics, mainly through recycling and CCUS.

For pulp and paper production in addition to the general approaches and technologies included at the beginning of this section full biomass firing, including lime kilns is a technology available for emission reductions.

4.2 Implementation Barriers

Despite the promising potential of decarbonization technologies, several challenges must be addressed to achieve widespread implementation and effectiveness of the above technologies:

[4] The HIsarna ironmaking process is a direct reduced iron process for iron making in which iron ore is processed almost directly into liquid iron (pig iron).

[5] Molten oxide electrolysis steelmaking is an electrolytic smelting process for transforming iron oxide into liquid metal and oxygen.

- **Technological Maturity:** Some technologies, particularly those involving hydrogen and advanced catalysts, are still in the development or early deployment stages, requiring further research and innovation to enhance their efficiency, reliability, and scalability. In other cases, the technology and facilities are available, but the limiting factor is the availability of resources. For example, natural gas, which is considered an important transition fuel, can already be used in facilities coupled with CCUS, but its availability may be a constraint.

- **High Capital Costs:** Many decarbonization technologies, such as energy efficient cement kilns, require significant upfront investment. These high capital costs can be a barrier for industries, particularly in regions with limited access to financing.

- **Infrastructure Development:** Building the necessary infrastructure for hydrogen distribution, CO2 transportation and storage, and upgraded electrical grids is a complex and resource-intensive process. The difficulty of replacing existing assets and the supply availability of alternative materials and energy sources further complicate this challenge. Additionally, CCS-related challenges, including transport infrastructure and liability issues, must be addressed to ensure effective CCS. Renewable energy infrastructure, such as electricity and green hydrogen, also requires significant investment and development. Delays or insufficient investment in these areas can hinder the adoption of decarbonization technologies, making it crucial to prioritize and streamline infrastructure projects to support a sustainable transition.

- **Regulatory Hurdles**: Inconsistent or unclear regulatory frameworks can create uncertainty for industries looking to invest in new technologies. Harmonizing regulations across regions and ensuring clear, long-term policy signals are essential for fostering investment and innovation. In addition, carbon pricing is considered among the key actions to effectively address the challenge of a net-zero future, a consequence when pricing emissions in industry is "leakage," where emitting industrial activities move to regions with less stringent or no carbon pricing. The trade exposure of the steel and chemical industries complicates the establishment of decarbonization policies. Regulating emissions in one country or region will likely require protective measures against cheaper, higher-emission products from elsewhere, affecting both imports and exports.

- **Lack of Transparency and Monitoring:** Effective decarbonization efforts require robust MRV systems to ensure transparency and accountability. The Paris Agreement established universal MRV provisions, but many countries and industries still struggle with implementing these mechanisms comprehensively. Without clear MRV processes, it is difficult to accurately track emissions trends, evaluate the effectiveness of mitigation efforts, and build confidence in climate actions (Singh & Levin, 2016).

- **Market Volatility:** Fluctuations in the prices of carbon credits, renewable energy, and raw materials can impact the economic viability of decarbonization projects and introduce the risk for countries to lose export competitiveness. Stable and predictable market conditions are necessary to encourage long-term investments.

- **International Coordination:** Effective decarbonization requires coordinated efforts across borders to ensure uniformity and efficiency. Currently, multiple regulatory frameworks and certification systems are being developed in parallel to define the environmental performance of fuels and materials. However, inconsistencies in these approaches pose a significant risk of market fragmentation, excessive administrative burdens for companies, and a confusing landscape for customers and suppliers. As an example of efforts to address these challenges, the IEA has proposed net-zero principles for emissions measurement methodologies in materials production (IEA, 2023).

- **Public Acceptance:** Gaining public support for new technologies and infrastructure projects as well as changing product composition and design is crucial. This includes addressing concerns about safety, environmental impact, and economic implications for local communities. Additionally, engaging both public and private sector stakeholders is essential to ensure a comprehensive approach that considers the interests and concerns of all parties involved, facilitating smoother implementation and greater acceptance of decarbonization initiatives.

- **Socially and Economically Just Transitions**: Transitioning from traditional carbon-intensive industries to sustainable alternatives is crucial but challenging. While some communities benefit from reduced emissions and economic gains, others face job losses and inequality. It is crucial that this transition is gender-responsive, addressing women's unique challenges and making gender equality central to new opportunities and protections. A just transition requires retraining, equitable policy frameworks, and targeted support to ensure all communities share in the benefits of decarbonization.

Addressing these various challenges requires targeted actions from governments, industry stakeholders, financial institutions, and the global community. By designing policies that tackle these issues and integrating them into updated NDCs, a legislative and financial environment can be created that fosters large-scale investments and innovative approaches to industrial decarbonization.

4.3 Enabling Policies for Decarbonization Technologies

Policies and initiatives to decarbonize HAI should avoid a "one-size-fits-all" strategy. Instead, they could incorporate a variety of technologies and solutions tailored to the unique industrial structures, resource availability, and political and economic conditions of different countries and regions. To effectively deploy existing and emerging technologies for decarbonizing HAI, robust policy tools are required at both national and international levels. Key policies that have proven effective in various contexts include:

1. Economic and Regulatory Incentive Policies

Carbon Pricing Mechanisms assign a cost to carbon emissions, encouraging investments in low-carbon technologies and processes. A carbon price can be introduced through a carbon tax, which charges a fee per unit of emissions, providing certainty about the cost of carbon but leaving emissions levels from covered industries uncertain. Alternatively, a cap-and-trade system can be used, where industries need to buy credits in a market or at auction to be allowed to emit.

To support the deployment of emerging decarbonization technologies like CCUS, electric boilers, and alternative clinker materials, governments could consider subsidies and tax breaks for renewable energy projects and energy efficiency improvements. These incentives may lower financial barriers to adopting innovative technologies across sectors such as steel, cement, and chemicals.

Additionally, simplifying procedures for obtaining licenses for captive electricity generation from waste heat recovery could encourage companies to deploy these technologies more widely.

Regulations aimed at phasing out high global warming potential gases like F-gases and Sulfur Hexafluoride (SF6), in alignment with international agreements and commitments, such as those discussed at COP 28, can accelerate the adoption of cleaner technologies (CTCN, 2023).

Box 1: Vietnam's Market-Based Instruments in the Steel Industry

As part of the Vietnam Green Growth Strategy, which aims to improve energy efficiency and reduce energy consumption in the steel industry, the Vietnam Partnership for Market Readiness Project supported the development of a pilot crediting program. This initiative included assessing the program's readiness, piloting it, and identifying feasible carbon pricing instruments (CPIs). The project aimed to strengthen Vietnam's capacity to reduce greenhouse gas emissions through market-based instruments (MBIs). As a result of this intervention, the project successfully enhanced Vietnam's readiness and capacity for implementing carbon pricing and market-based instruments, laying a strong foundation for future GHG emission reduction initiatives in the steel industry. (The World Bank, 2021)

Developing regulations for sustainable forest management and incentivizing investments in the biomass value chain can elevate other materials as alternatives for carbon intensive materials in HAI.

Lastly, deposit schemes and producer end-of-life responsibility policies can support the increased circularity of products like steel, concrete, and plastics, minimizing their use and increasing both the quantity and quality of recycling of materials with high GHG emissions (e.g., iron, copper and polyethylene) (TEC, 2023).

2. Electrification and Decarbonizing Policies

In the near term, the decarbonization of HAI is expected to be largely propelled by the shift to renewable energy sources and the electrification of industrial heating. (IEA, 2023; Thiel & Stark, 2021). While electrification technologies are mature and already widely available, their broader implementation will require upgrading infrastructure, grid integration and supportive policies to incentivize adoption.

Electrification needs to be paired with a transition to ultra-low GHG-emitting fuels and feedstocks, and the adoption of carbon management strategies such as carbon capture and storage. The adoption of green hydrogen as an energy carrier and feedstock will require supportive policies, investment in infrastructure and scaling up renewable hydrogen production. As mentioned in Section 4.1, emerging technologies, such as hydrogen-based steelmaking and electric boilers, may benefit significantly from these policy supports.

Electrification can synergize with renewable energy integration, creating opportunities for using renewable electricity in the industry. The shift from fossil fuel-based energy to renewable electricity should be supported by government subsidies, schemes, projects, grants, and tax incentives to support the expansion and enhancement of grid infrastructure to accommodate increased electrification. Substantial budgets are already dedicated to boosting the share of clean energy in primary energy production in many Parties to the Paris Agreement, either through direct government initiatives or by incentivizing private sector involvement (World Economic Forum, 2023). The newly established IEA Working Party on Industrial Decarbonisation, The Climate Club, the International Partnership for Hydrogen and Fuel Cells in the Economy, and the Clean Energy Ministerial Hydrogen Initiative are relevant fora in which governments can collaborate on this topic (IEA, 2023).

3. Policies for Research, Development, and Demonstration

Policy support for research, development, and demonstration (RD&D) is deemed essential for decarbonizing HAI by improving existing processes and accelerating their deployment. New technical challenges arise at each market development stage. While companies can tackle some issues through their own research, policies and programs that support RD&D can accelerate technological advancements. Effective innovation also requires coordination across academia, industry, and government.

To achieve this, policies could focus on allocating dedicated budgets for innovation and R&D programs tailored to national priorities. Offering incentives to private sector actors in HAI sectors could stimulate investment in decarbonization research, with enhanced incentives for collaborative R&D efforts across sectors. Additionally, countries could seek guidance from international bodies like the bodies under the UNFCCC Technology Mechanism to align R&D initiatives with global climate objectives and share good practices.

These policies could support the adoption of emerging technologies such as hydrogen-based direct reduced iron (DRI) and Limestone Calcined Clay Cement (LC3) through targeted funding and development programs. Moreover, the continued development of energy-efficient technologies like high-efficiency kilns and heat recovery systems in the cement sector, as well as advanced catalysts in the chemical sector, could also be bolstered through RD&D initiatives.

Box 2: Limestone Calcined Clay Cement's development in Switzerland

The pursuit of sustainable alternatives to clinker, a primary component of cement, began in 2004 when Professors Karen Scrivener and Fernando Martirena discussed using calcined clays. Their initial research from 2005 to 2008, supported by Swiss agencies, revealed the potential of Limestone Calcined Clay (LC3). Subsequent projects from 2009 to 2020, also supported by Swiss funding, focused on verifying LC3's technical and economic viability, involving experts from Switzerland, Cuba, and India. Successful trials led to the first large-scale LC3 production in Colombia. Since 2020, efforts have continued to scale LC3 globally, gaining significant media attention. (Limestone Calcined Clay Cement (n.d))

4. Green Public Procurement Policies

Governments play a crucial role in the development and commercialization of new technologies, especially those that reduce emissions and benefit society. For low-carbon alternatives to move from the lab to the market, they need sufficient demand; without it, producers lack the incentive to invest, and these technologies won't benefit from economies of scale. As significant purchasers of industrial goods, with procurement accounting for an average of 12% of GDP in OECD countries and up to 30% in many developing nations, governments can create substantial markets for low-carbon products through preferential purchasing policies. Such policies can help reduce the costs of new technologies by overcoming market barriers. Notable examples of government procurement programs include the United States' Buy Clean California Act, Japan's Act on Promoting Green Purchasing, and India's Ujala program for efficient lighting. By 2013, 95% of products purchased by the Japanese government under their green purchasing program met green criteria, saving 210,000 tons of CO_2e annually (Rissman et al., 2020).

5. Policies for Definitions and Standards

Carbon labelling schemes can increase the market value of low-carbon products by informing buyers about their reduced carbon impacts, thereby boosting their willingness to pay. Labels for materials like steel, cement, and chemicals can support public procurement programs favouring lower emission products.

Two of the greatest challenges of carbon labelling are the variability of the accounting methodology and the scarcity of data necessary to assess a product's holistic GHG impacts**. Product Carbon Footprint (PCF) and Life Cycle Assessment (LCA) Standards** can provide comprehensive assessments of the ecological footprint of products and processes within these industries. Design standards on different products can enable their adequate recycling or repurposing as well as maximize their lifetime by extending their lifespan and allowing for other potential end uses. Regulatory standards and building codes can also help to create markets for low carbon alternatives to high embodied carbon materials (Clean Air Task Force, 2023). Several carbon labelling schemes, such as the Environmental Product Declaration (EPD), adhere to ISO standards. Supporting energy management systems like ISO 50001 can promote continuous improvement plans for energy. However, past labelling schemes have often failed due to incomplete adoption and the complexity of calculating LCA values. Implementing labels at the manufacturer level, rather than at the retailer or reseller level, can help address these challenges.

Box 3: Canada's Energy Star Certification

The ENERGY STAR® certification is available to seven industrial sectors in Canada, including cement and steel, as part of the country's efforts to improve energy performance. Natural Resources Canada (NRCan) administers the program in coordination with the U.S. Environmental Protection Agency (EPA). The program aims to enhance energy performance, recognize industrial achievements, and share best practices. It includes two components: ENERGY STAR Certification and ENERGY STAR Challenge. For certification, manufacturing plants must achieve an ENERGY STAR score of 75 or higher, based on an industry-specific Energy Performance Indicator (EPI) developed jointly by NRCan and the EPA. This benchmarking tool compares a plant's energy performance with similar plants in Canada and the U.S. The ENERGY STAR Challenge encourages plants to reduce their energy intensity by 10%, with successful participants receiving recognition from NRCan.

6. Capacity Building

Strengthening institutional and governmental capacity can play a significant role in supporting the adoption of low-carbon technologies within the industrial sector. Enhancing the ability of governments to implement and align policies with low-carbon development goals could facilitate smoother transitions. Approaches such as voluntary agreements and international support might contribute to building the necessary institutional frameworks, aiding industry in moving towards more sustainable and efficient practices (IPCC, 2023).

5. Implementation

The successful transition to a low-carbon industry hinges not only on the development of technologies and supportive policies but also on their effective implementation. This section outlines the crucial steps and collaborative efforts needed to ensure that decarbonization initiatives are realized efficiently and effectively. Implementation of these policies requires the involvement of various stakeholders, including governments, the industrial sector, financial and research institutions, and international organizations.

Developing **Roadmaps and Milestones**: Roadmaps should be aligned with the 1.5°C target and the global net-zero goal, including clear milestones for phasing out unabated fossil fuel use in HAI. For example, the Global Cement and Concrete Association's 2050 Net Zero Roadmap demonstrates how the cement industry can achieve carbon-neutral concrete by 2050 through collaboration with stakeholders and policymakers (Global Cement and Concrete Association. (n.d.)). Such roadmaps should outline specific targets and timelines for each sector, ensuring that progress is measurable and regularly monitored. Regular updates and adjustments based on ongoing evaluations will help maintain alignment with overall climate goals. Additionally, definitions and standards that embody measurement protocols and environmental performance thresholds can establish a common framework for advancing various technologies and sectors. It may also be beneficial to include a broader range of technologies and approaches in these roadmaps, such as electrification, energy efficiency, and circularity, to support a more holistic approach to decarbonization across different industries.

Box 4: Identification and Evaluation of Cement Industry Technologies in the Republic of Congo

The Climate Technology Centre and Network (CTCN) conducted a study in the Republic of Congo to modernize the cement sector, emphasizing emissions transparency and annual audits. The project included a general and detailed energy audit of cement plants, identification of key operational data, and development of audit protocols. The focus on adopting efficient technologies aimed to enhance emissions reporting and reduce GHG emissions, improving the sector's sustainability. As a result of this intervention, the project enabled more accurate GHG emissions calculations and enhanced the sector's capacity to implement effective emission reduction strategies (CTCN, 2020).

Clearly defining **Roles and Responsibilities:** Clearly defining the roles and responsibilities of each stakeholder is critical for successful implementation. Governments need to establish regulatory frameworks and provide financial incentives. Industries should, in line with their respective country-contexts, invest in and adopt new technologies, such as green hydrogen-based steelmaking, electric arc furnaces, high-efficiency kilns and waste heat recovery systems amongst others contained in this brief. Financial institutions should offer funding and risk mitigation solutions. International organizations can support capacity-building and facilitate global cooperation.

Developing Investment Plans for Industrial Decarbonisation: To make financial flows consistent with low- and net zero emission pathways, countries need clear industrial decarbonization roadmaps, along with well-developed and aligned public and private financing propositions. Additionally, they may need to demonstrate specific institutional capacities and improve the environment for policy implementation and private sector engagement. Issuing national green bonds for decarbonization technologies in HAI and creating green loan financial mechanisms with de-risking components for energy efficiency and renewable energy measures are crucial steps. These investment plans should also focus on providing green energy for electrification and hydrogen production. They should help connect buyers of new energy projects with project developers and support the deployment of technologies like recycled materials, alternative clinkers, and CCUS ensuring a comprehensive approach to decarbonization.

Leveraging the strengths of UN multilateral institutions and international finance organizations can create a 'chain reaction' to overcome investment bottlenecks and establish the necessary policy and financial environment for large-scale financing. Ambitious NDCs, by setting clear milestones, and National Reports by specifying the relevant policies, plans and needs can increase certainty and help catalyse investment, mobilizing substantial capital and directing it towards impactful decarbonization initiatives. This strategy not only supports the achievement of climate goals but also enhances the attractiveness of investments in green technologies and projects, ensuring they align with long-term economic and environmental objectives (Industrial Decarbonization Accelerator, 2023).

Using **Blended Finance:** Blended finance, which combines public sector grants and concessional loans with private capital, is an effective strategy to scale up investment in industrial decarbonization projects. This approach leverages public funding to attract private investment, enabling the scale-up of innovative technologies and projects, including those involving emerging technologies like advanced catalysts, electric boilers, and high-efficiency kilns. Building on previous work of the TEC on technology financing, including TEC brief #6, which outlines the challenges in financing climate technologies faced by developing countries, to review good practices and lessons learned, and to highlight the roles of different stakeholders in facilitating access to climate technology finance, blended finance mechanisms can play a pivotal role in supporting the transition to a low-carbon economy (UNFCCC, 2015).

Taking advantage of **International Cooperation and Knowledge Sharing:** Developing effective collaboration models between industry, research institutions, and governments is crucial to accelerate the development and deployment of essential decarbonization technologies. These models should emphasize joint research initiatives, technology demonstration projects, and knowledge exchange platforms, leveraging the TEC mapping on HAI (TEC, 2023). International cooperation and knowledge sharing are equally vital, fostering innovation, technology transfer, and capacity-building. Engaging in multilateral agreements and partnerships, such as the Industrial Deep Decarbonization Initiative (IDDI), the Climate Club and the Leadership Group for Industry Transition (LeadIT), can enhance global coordination and commitment to decarbonization goals. Facilitating market linkages between industry players, technology providers, and financial institutions is also key to supporting the commercialization and scaling of decarbonization technologies, including those identified in Section 4.1.

Integrating Industry in the Update of NDCs: Updated NDCs and LT-LEDS are pivotal in guiding countries' climate actions and commitments under the Paris Agreement. Given the significant impact of industry on GHG emissions, it is essential to integrate sector-specific and cross-sectoral decarbonization strategies into these updates to ensure coherent and ambitious climate action plans. Updated NDCs should clearly articulate policies for industrial decarbonization and demonstrate how these align with long-term net-zero strategies, as emphasized in the UAE Consensus.[6] Countries are encouraged to adopt the approaches outlined in this brief when updating their NDCs for the 2025-2035 period and their LT-LEDS. Additionally, aligning these strategies with international frameworks and agreements will enhance their effectiveness, foster global cooperation, and strengthen support for implementation.

6. Recommendations

Based on the findings of the previous sections, the following recommendations are provided.

6.1. National-Level Policy Recommendations

To enhance industrial decarbonization, particularly in HAI, while accelerating progress towards net-zero emissions in line with the UAE Consensus, countries are encouraged to consider the following approaches:

1. **Phasing out unabated coal:** Prioritizing the rapid phase-down of unabated coal power used in industrial processes, particularly in the steel, cement, and chemicals sectors. This involves establishing clear targets and timelines for the phase-out and implementing supportive policies to ensure a just transition for workers and communities.

2. **Scaling up renewable energy:** Making the tripling of renewable energy capacity globally by 2030 a priority, also by providing clean power to industrial facilities. This includes developing policies that incentivize direct electrification of industrial processes with renewable energy, including through power purchase agreements and on-site renewable energy generation.

3. **Enhancing energy efficiency:** Recognizing that doubling the global average annual rate of energy efficiency improvements by 2030 is essential across all industrial sectors. This can be achieved by implementing policies that promote energy efficiency audits, best practice sharing, and the adoption of energy-efficient technologies in industrial processes.

Further, countries are invited to consider the approaches and technologies contained in section 4.1, the enabling policies in section 4.3 and the actions for implementation in section 5 to enhance industrial decarbonization, particularly in HAI.

6.2. International Development Organizations

International development organizations are invited to consider the following recommendations to enhance industrial decarbonization, particularly in HAI by:

1. **Fostering Market Linkages between industry sector players, low-carbon technology providers, and donor organizations and Collaborative R&D Programs.** Encouraging the creation of market linkages between industry, in particular HAI sector players, low-carbon technology providers, and donor organizations can help in developing large-scale R&D programs with clear agendas. Ideally, these efforts could involve multiple countries with similar technology interests, promoting synergy and fostering innovation.

2. **Enhancing Global Cooperation between global industry players, technology providers, initiatives, and funding bodies Through Strategic Linkages.** Establishing connections between global industry players, technology providers, initiatives, and funding bodies could enhance global cooperation in technology

[6] Decision 1/CMA.5, paragraph 40.

development and deployment. By fostering these linkages, international efforts may be better synergized, contributing to more effective large-scale industrial decarbonization.

3. **Supporting Cross-Border Green Energy Purchases.** Where countries face challenges in producing sustainable energy, international bodies might consider encouraging the purchase of green energy from other nations. International development organizations could facilitate this by conducting global studies to identify suitable buyer and supplier countries, helping to foster match-making and long-term purchase agreements.

4. **Developing Harmonized Standards for Decarbonization Technologies.** Prioritize the development and adoption of harmonized international standards for measuring and reporting emissions from HAI, including standardized methodologies for LCAs.

5. **Promoting Peer-to-Peer Knowledge Exchange between countries with similar technology interests.** International development organizations may find it beneficial to develop peer-to-peer knowledge exchange programs between countries with similar technology interests. These programs could include study tours, technology transfer initiatives, and joint collaboration plans, all aimed at sharing experiences and accelerating the global deployment of decarbonization technologies.

6. **Facilitating Support from Developed to Developing Countries And South-South And Triangular Cooperation.** Encouraging the provision of financial, technical, technological, and capacity-building support from developed to developing countries in accordance with the requirements under the UNFCCC and the Paris Agreement, and fostering South-South and triangular cooperation can play a crucial role in advancing global decarbonization efforts. Such support could be tailored to meet the specific needs and contexts of developing countries.

7. **Promoting Transparency and Monitoring Systems.** Support developing countries in building robust MRV systems for tracking progress on industrial decarbonization, ensuring transparency and accountability in the implementation of NDCs and LT-LEDS.

Abbreviations and acronyms

CCS - Carbon Capture and Storage

CCUS - Carbon Capture, Utilization, and Storage

CO2 - Carbon Dioxide

CPI - Carbon Pricing Instruments

CPIs - Carbon Pricing Instruments

DRI - Direct Reduced Iron

DRI-EAF - Direct Reduced Iron-Electric Arc Furnace

EAF - Electric Arc Furnaces

EAFs - Electric Arc Furnaces

EPD - Environmental Product Declaration

EPI - Energy Performance Indicator

GCCA - Global Cement and Concrete Association

GDP - Gross Domestic Product

GHG - Greenhouse Gas

HAI - Hard-to-Abate Industries

IDDI - Industrial Deep Decarbonization Initiative

IEA - International Energy Agency

IPCC - Intergovernmental Panel on Climate Change

IRENA - International Renewable Energy Agency

ISO - International Organization for Standardization

LCA - Life Cycle Assessment

LC3 - Limestone Calcined Clay Cement

LeadIT - Leadership Group for Industry Transition

LT-LEDS - Long-Term Low Emission Development Strategies

MPP - Mission Possible Partnership

MRV - Monitoring, Reporting, and Verification

NDCs - Nationally Determined Contributions

NOx - Nitrogen Oxides

PCF - Product Carbon Footprint

RAC - Recycled Aggregate Concrete

RCA - Recycled Concrete Aggregate

R&D - Research and Development

RD&D - Research, Development, and Demonstration

SF6 - Sulfur Hexafluoride

SOx - Sulfur Oxides

TEC - Technology Executive Committee

UN - United Nations

References

Clean Air Task Force (2023). *Building demand for low-carbon materials: How market demand can accelerate cement and steel decarbonisation in Europe*. Authors: Hans Bolscher, Perla Torres, Jules Schers, Andrea Finesso, Aurora Miari, Liliana Guevara Opinska. Available at: https://www.catf.us/wp-content/uploads/2023/09/CATF_Building-Demand-for-Low-Carbon-Materials.pdf

Climate Technology Centre and Network (CTCN) (2020). *Study on the identification and evaluation of technologies and industrial processes used in cement producing industries in Congo*. Available at: https://www.ctc-n.org/technical-assistance/projects/study-identification-and-evaluation-technologies-and-industrial

Dhakal, S., J.C. Minx, F.L. Toth, A. Abdel-Aziz, M.J. Figueroa Meza, K. Hubacek, I.G.C. Jonckheere, Yong-Gun Kim, G.F. Nemet, S. Pachauri, X.C. Tan, T. Wiedmann (2022). *Emissions Trends and Drivers.* In IPCC (2022): *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA. Available at: https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter02.pdf

Global Cement and Concrete Association (n.d.). *The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete*. Available at: https://gccassociation.org/concretefuture/

Haque, M.A., Dai, J.G., & Zhao, X.L. (2024). *Magnesium cements and their carbonation curing: a state-of-the-art review.* Low-carbon Materials and Green Construction, 2(2). doi: 10.1007/s44242-023-00033-3. Available at: https://doi.org/10.1007/s44242-023-00033-3

Industrial Decarbonization Accelerator (2023). *How to unlock the finance needed to decarbonize heavy industries.* Available at: https://www.industrialenergyaccelerator.org/general/how-to-unlock-the-finance-needed-to-decarbonize-heavy-industries/

International Energy Agency (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector.* Available at: https://www.iea.org/reports/net-zero-by-2050

International Energy Agency (2023). *CO2 Emissions in 2023.* IEA, Paris. License: CC BY 4.0. Available at: https://www.iea.org/reports/co2-emissions-in-2023

International Energy Agency (2023). *Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach.* IEA, Paris. License: CC BY 4.0. Available at: https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach

Intergovernmental Panel on Climate Change (2022). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA. Available at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/

Intergovernmental Panel on Climate Change (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II, and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115. Available at: https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf

Limestone Calcined Clay Cement (n.d.). Available at: https://lc3.ch/

Rissman, J., Bataille, C., Masanet, E., Aden, N., Morrow III, W. R., Zhou, N., Elliott, N., Dell, R., Heeren, N., Huckestein, B., Cresko, J., Miller, S. A., Roy, J., Fennell, P., Cremmins, B., Koch Blank, T., Hone, D., Williams, E. D., de la Rue du Can, S., Sisson, B., ... & Helseth, J. (2020). *Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070.* Applied Energy, 266, 114848. https://doi.org/10.1016/j.apenergy.2020.114848

Singh, N., Finnegan, J., & Levin, K., with contributions from Damassa, T., Elsayed, S., Mitra, A., Rich, D., Sotos, M., Tirpak, D., & Wood, D. (2016). *MRV 101: Understanding Measurement, Reporting, and Verification of Climate Change Mitigation.* World Resources Institute, August 2016. Available at: https://transparency-partnership.net/sites/default/files/mrv_101_0.pdf

TEC (2023). *Transformative industry: Mapping of initiatives that promote low and near zero emission production and products in hard-to-abate sectors.* Available at: https://unfccc.int/ttclear/tec/transformativeindustry.html

Thiel, G. P., & Stark, A. K. (2021). *To decarbonize industry, we must decarbonize heat.* Joule, 5(3), 531-550. doi: 10.1016/j.joule.2020.12.007. Available at: https://doi.org/10.1016/j.joule.2020.12.007

UN Climate Technology Centre and Network (2023). *Global Collaboration at COP28: Advancing the Phasing Out of SF6.* Available at: https://www.ctc-n.org/news/global-collaboration-cop28-advancing-phasing-out-sf6

United Nations Economic Commission for Europe (UNECE) (2022). *Technology Brief: Carbon Neutral Energy Intensive Industries.* Available at: https://unece.org/sites/default/files/2022-11/Industry%20brief_EN_2.pdf

United Nations Framework Convention on Climate Change (UNFCCC) (2015). *Technology Executive Committee: Enhancing Access to Climate Technology Financing*. Available at: https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/TEC_documents/5be1bf880cc34d52a4315206d54a711b/c9efe76199fb43bc8cfc8dee1e5c2863.pdf

United Nations Framework Convention on Climate Change (UNFCCC) (2023). *Conference of the Parties serving as the meeting of the Parties to the Paris Agreement. Decision 1/CMA.5 Outcome of the first global stocktake.* Available at: https://unfccc.int/documents/637072

United Nations Industrial Development Organization (UNIDO) (2022). *International Year Book of Industrial Statistics 2022.* Vienna. Available at: https://stat.unido.org

United Nations Industrial Development Organization (UNIDO) (2023). *Policy Packages for Decarbonizing Heavy Industry.* Policy Brief Series: Insights on Industrial Development. Available at: https://www.unido.org/sites/default/files/unido-publications/2023-12/IID%20Policy%20Brief%209%20-%20Policy%20packages%20for%20decarbonizing%20heavy%20industry.pdf

Vera, I., Wicke, B., Lamers, P., Cowie, A., Repo, A., Heukels, B., Zumpf, C., Styles, D., Parish, E., Cherubini, F., Berndes, G., Jager, H., Schiesari, L., Junginger, M., Brandão, M., Bentsen, N.S., Daioglou, V., Harris, Z., & van der Hilst, F. (2022). *Land use for bioenergy: Synergies and trade-offs between sustainable development goals.* Renewable and Sustainable Energy Reviews, 161, 112409. https://doi.org/10.1016/j.rser.2022.112409

The World Bank (2021). *Vietnam-Partnership for Market Readiness.* Available at: https://documents1.worldbank.org/curated/en/343091624562711541/pdf/Implementation-Completion-and-Results-Report-ICR-Document-Vietnam-Partnership-for-Market-Readiness-P152797.pdf

World Economic Forum (2023). *Transitioning Industrial Clusters towards Net Zero: National Policy Enablement for Industrial Decarbonization – Part II.* Available at: https://www3.weforum.org/docs/WEF_Transitioning_Industrial_Clusters_towards_Net_Zero_2023.pdf

About the Technology Executive Committee

The Technology Executive Committee (TEC) is the policy component of the Technology Mechanism, which was established by the Conference of the Parties in 2010 to facilitate the implementation of enhanced action on climate technology development and transfer. The TEC analyses climate technology issues and develops policies that can accelerate the development and transfer of low-emission and climate resilient technologies.