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Task Force 4
Refuelling Growth: Clean Energy and Green Transitions

ADVANCING AI FOR CLIMATE ACTION: GLOBAL COLLABORATION ON INTELLIGENT DECARBONISATION

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Abstract

Artificial Intelligence (AI) combined with cyber-physical systems (CPS) can play a vital role in eliminating greenhouse gas emissions across sectors. The transition from fossil fuels to renewables is achieved through electrification, introducing complexity in systems deployment, integration, and efficient orchestration of electrified economic systems. AI-driven CPS are uniquely suited to manage this complexity, potentially accelerating decarbonisation efforts. This Policy Brief advocates for the mainstreaming of AI-driven CPS for climate change risk mitigation.

To effectively realise the Intelligent Decarbonation (IDC) potential, AI-driven CPS must be elevated to a global level of collaboration and coordination, fostering clear IDC principles and guidelines, capacity building and technology transfer. The importance of IDC governance is emphasised to avoid unwanted path dependency and to avert a technology-centric approach, which has proven to yield limited results. A shift from trustworthy to sustainable AI is necessary to eliminate AI's own carbon footprint.

The Challenge

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Artificial Intelligence (AI) has the potential to contribute to the UN Sustainable Development Goals (SDGs).[1] The International Telecommunication Union (ITU) has identified 281 AI projects by 40 different UN entities addressing various urgent issues, including climate action (SDG 13), which is the focus of this brief.[2] Outside the UN context, an increasing number of promising studies also highlight the use of AI in achieving carbon-neutral transformation goals. Specifically, the Cambridge Centre for Advanced Research and Education in Singapore (CARES) analysed projects across sectors, demonstrating that cyber-physical systems in combination with AI offer a substantially higher potential for emissions reduction and lower costs of reducing CO_2 compared to conventional approaches.[3]

As detailed in this brief, the main reason for such abatement potential relates to the capability and high efficiency potential of AI-enabled CPS that are capable of integrating, operating, and managing increasingly more complex and fully electrified economic systems. Based on these promising developments, this brief advocates for the mainstreaming of AI-driven CPS, or what will be referred to here as Intelligent Decarbonisation (IDC), as a vital technology for climate change risk mitigation and adaptation efforts. To understand the full potential of IDC, the brief outlines its key components, with a focus on AI-enhanced CPS and their applications across multiple sectors.

While recognising IDC's potential, the limitations of relying solely on climate technology as a remedy for climate change must be acknowledged. An overreliance on technology as the primary solution has demonstrated limited success, as evidenced by repeated warnings from the UN and IPCC.[4] IDC faces its own limitations, such as lack of data, absence of CPS and AI solutions, and unintended reverse effects of optimisations. Furthermore, IDC is still in its early stages, making any exploration of its long-term impacts merely speculative. AI research also scarcely focuses on climate change. However, the issue of technology solutionism is not just about engineering bottlenecks; technology itself can be part of the problem.

As certain technologies from previous industrial revolutions contribute to today's climate crisis, AI might become part of a future crisis. This concern is not solely about AI's own immense energy and water consumption, which yet must be addressed by the G20. Rather, it is more about the longer-term risks attributed to widespread AI adaptation, which are not inherent to the technology, but rather how it is used and regulated. Like climate action, AI presents a critical juncture, giving policymakers the opportunity to steer AI towards benefiting people and the planet. To effectively address opportunities and risks, this policy brief proposes a G20 Intelligent Decarbonisation Action Initiative (IDC AI) to foster collaboration and offer clear principles and guidelines for integrating sustainable AI into climate action.

Background

Cyber-Physical Systems at the Centre of IDC

To scale AI and generative models in conjunction with other digital technologies that are critical for climate change mitigation, and to set the technology on a path that serves people and planet, it is important to identify the major components of intelligent decarbonisation (IDC). At the centre of IDC are cyber-physical systems (CPS) which connect the physical with the virtual/digital world through integrating computations, physical objects and processes. They monitor and control physical processes through advanced sensors and actuators, with feedback loops where the physical processes affect computations and vice versa. IDC is engineered to improve efficiency, performance, safety, and reliability through real-time data capture, exchange and analysis, as well as through self-regulation and decision automation. CPS is enabled by a combination of advanced technologies that facilitate such integration, information exchange, and control between digital and physical components. Those enabling technologies include mobile communication networks (5G/6G, Wi-Fi, low-power wide-area networks); cloud computing; edge computing; blockchain/smart contracts; Internet of Things (advanced sensors and actuators); smart metering; semantic web/knowledge graphs; digital twins; big data; as well as machine learning.[5]

Over the past decade, CPS has emerged as a vital technological component in the industry sector, forming the basis of the 'Industry 4.0' vision to transform traditional manufacturing into intelligent, adaptive, and efficient systems. Today, the initial scope of CPS is expanding towards increasing connectivity and data exchange vertically and horizontally, not only within but also between the industry and other sectors. The aspiration behind establishing a digitally networked industry is not just to enhance operational efficiencies and competitiveness, but also to systematically reduce emissions holistically and transform the industry into a circular economy.[6]

The dual objectives of growth and sustainability have often been seen as conflicting when transitioning from a linear to a circular economy. However, this seems less of a case with CPS, particularly in light of the sharply declined levelised cost of renewable electricity. CPS aligns with the requirements of net-zero transformation efforts. The high capability of efficiently optimising inputs and costs, combined with that of coordinating large systems, make CPS well-suited for the green transformation. Such capability is not limited to Industry 4.0 but can also be employed within other emissions-intensive sectors, including electricity and heat production, transportation, buildings and cities, and agriculture. All sectors must undergo transformation to meet net-zero targets. The substitution of fossil fuels is achieved through the electrification of all economic systems with renewable energy; and electrification precisely requires the integration and efficient orchestration of the cyber and physical dimensions. Thus, the implementation of CPS not only serves internal efficiency targets of individual organisations but also is an enabler for the transformation towards a low carbon economy.

AI-enhanced Cyber-Physical Systems

Renewable power generation, electrification, and digitalisation lead to the coupling of organisations and sectors into integrated, trans-sectoral systems with feedback loops, facilitating decarbonisation. CPS combined with AI capabilities are ideal for efficiently deploying and managing such complex systems. CPS functions as an overarching architecture and governance structure, ensuring integration, computing, and communication functions for its subsystems, as well as operational monitoring, control, and optimisation of processes. AI operates as a standalone or embedded technology, optimising parts or the entire system through predictive analytics, adaptive control, and decision optimisation and automation capabilities. AI technologies, which are increasingly applied within CPS, include computer vision, time series analysis, reinforcement learning and control, uncertainty quantification, unsupervised learning, natural language processing, transfer learning, interoperable models, and causal inferences.

Table 1 proposes specific intelligent IDC application areas for each sector, which are derived from two in-depth studies on application of CPS and AI in relation to decarbonisation and climate change mitigation efforts, including actual case studies.[7]

Table 1: Sector-specific Application Areas of AI-driven Cyber-physical Systems

Sector	Application Areas	Selected Case Studies
Electricity and Heat Generation	**Renewable energy transition and system integration**: enable transition to and enhance integration and management of intermittent renewable energy sources; optimises energy storage systems and supports decentralised energy generation. **Smart grid management and sector coupling**: improve grid and management of demand-supply matching, efficient load management, demand response, and grid stability; integrate energy systems (electricity, heating, and transportation); harmonise planning and operations. **Predictive maintenance and asset management**: analysis of sensor data from power generation equipment to optimise asset planning, operations, maintenance, performance monitoring. **Enhanced capturing of carbon dioxide**: optimise performance and processes of carbon capture, utilisation, and storage (CCUS) technologies in power plants and large-scale industrial processes; integration with energy systems; leakage detection and mitigation.	The J-Park Simulator in Singapore: cross-domain modelling and data storage with an ontology-based expert system for eco-industrial parks. Distribution grid monitoring for loss identification and minimisation at Liechtensteiner Kraftwerke. Predicting grid impacts from decarbonisation in the city of Lucerne, Switzerland. The World Avatar (TWA) agents for OPEX and CO_2 reduction in district heating (Pirmasens, Germany)

Sector	Application Areas	Selected Case Studies
Trans- portation	**Intelligent traffic management**: advanced prediction and management of traffic patterns through senor data, reducing congestion, shorter travel times, fuel consumption and emissions, enabling modal substitution and enhancing parking management. **Electrification and charging infrastructure**: enable and support adoption of electric vehicles (EVs); optimise charging infrastructure, prediction and management of EV fleet and charging demand; ensure optimised integration with the power grid. **Connected and autonomous vehicles**: facilitates communication between vehicles and infrastructure; optimise routes/scheduling for vehicles, adapt to traffic conditions; improve driving behaviour and traffic safety. **Integrated multimodal transportation**: flexible provision and consumption of alternative modes of transportation, including public transit, biking, walking, and shared mobility services.	Catena-X: collaborative, open data ecosystem for the automotive industry in Germany and with global hubs. Transportation CPS with cases studies on different transportation scenarios and technology approaches.
Buildings and Cities	**Optimised urban planning and design**: enables creation of integrated urban designs that minimise resource consumption, promote efficient transportation system, and enhances green spaces. **Enhanced construction processes and materials**: improve the design and construction process by automating repetitive tasks, optimising the use of materials, reducing waste and human error; assists in developing sustainable, energy-efficient, zero-carbon materials and techniques; enables predictive maintenance to optimise resource allocation and reduced downtime. **Prefabrication, modular construction and reuse**: facilitate the design and production of prefabricated and modular construction component, which reduces material waste, shortens construction times, and minimises on-site environmental disruptions. **Smart building management**: optimises asset utilisation, energy use, reduces waste, and minimises overall energy consumption through real-time analysis of sensor data from building systems; enhances efficiency through integration with IoT devices and smart grid infrastructure.	Cooling Singapore is a multi-disciplinary research project developing solutions for mitigating urban heat. Multi-stage stochastic programming in the UK for optimal phasing of district heating network investments.

Sector	Application Areas	Selected Case Studies
Industry	**Electrification and energy efficiency**: enable electrification of industrial systems with renewable energy; efficient onsite energy generation, storage and grid integration; virtual power plants or microgrids; real-time energy monitoring and control of energy usage across facilities; surplus and demand balancing; integrated planning and operation. **Smart manufacturing and process optimisation**: processes automation; IT-OT convergence; predictive analytics; incremental real-time quality monitoring, performance optimisation, zero-error production, and self-regulation. **Smartly networked industry**: enables autonomous and shared data spaces across the entire production and supply chain in cross-sectoral value networks for end-to-end solutions, enhanced resilience, sustainability and competitiveness.	Green, lean and digital transformation for decarbonisation of chemical industries. Industry 4.0 projects and R&D cluster in Germany. CReDo, a UK-based connected digital twin for cross-sector (telecoms, power and water networks) climate adaptation and resilience.
Agriculture and Land use	**Precision farming**: enhanced crop health monitoring and disease detection; yield prediction and optimisation; precision irrigation and nutrient management; weed control and pest management; real-time monitoring of weather, temperature, water usage, or soil conditions for enhanced farm management and decision support. **Livestock management and feed production**: precision livestock farming; feed optimisation and enhanced nutrition management; early sign disease detection; breeding and genetic improvement; smart grazing and pasture management. **Crowd-farming and ecosystem integration**: enable multi-local production model; enhanced harvest planning; supply chain efficiency; food waste reduction; platform-based pooling of smallholders and livestock producers to make technologies affordable; data and application sharing; new business models, incl. precision agriculture and farming-as-a-service. **Deforestation and land-use**: enhanced monitoring and detection through remote sensing; forest and ecosystem health assessment; optimise land use for sustainability, productivity, and ecosystem health; supply chain traceability and certification; carbon sequestration and ecosystem services valuation.	Leveraging automation in agriculture for transforming agrifood systems by FAO. ITU Connect2Recover case on Botswana's digitalisation of the primary sector. List of major applications of AI in agriculture.[8]

Source: Authors' own, using various open sources

AI can also be employed across sectors for climate change adaptation, helping to optimise decision-making around climate events, such as climate science and extreme weather occurrences. Additionally, AI can assist in navigating markets, policies, and behaviours related to climate change, as well as supporting geoengineering and disaster recovery efforts. Overall, despite such sectoral and functional perspectives, the application of intelligent CPS for electrification has the potential to lead to trans- and cross-sectoral integrations and optimisation.[9]

Climate Change and AI: The Twin Juncture

Since the first IPCC report in 1990, technology has been assigned a dominant role in tackling climate change. New technologies – such as carbon capture and storage; plant-based and geological carbon sinks; mitigating overshoot scenarios with geoengineering; or models to estimate the impact of investments and technology on GHG emissions – play a crucial role in climate change mitigation and has led to avoided, and in some cases reduced or removed emissions. Nevertheless, technology-focused climate policies have demonstrated little success as evidenced by the ongoing warnings and increasing frustration with the inability to tackle the climate crisis more rapidly.[10]

Technology solutionism has falsely led to an oversimplification of a complex issue while omitting or accepting that existing technology, together with capitalist expansion and institutional legacies, have created a path dependency from which humanity cannot simply depart primarily based on the introduction of new technologies. Climate action is at a critical juncture, which yet opens up the space for far-reaching political action, urgently needed to prevent large sets of system elements from turning into climate tipping points. Surpassing 1.5°C of global warming may lead to the activation of multiple tipping points, beyond which humanity loses control, and the consequences of severe global warming become inevitable.

In this context of prevailing climate action, this policy brief advocates for the use of technology in climate change mitigation, while also cautioning against technology overreliance and uncontrolled proliferation of AI. Like climate change, widespread AI-driven digitalisation has reached a critical juncture that makes possible and necessitates political intervention to steer AI development towards societal and environmental benefits. For some AI critics, the deployment of large generative AI models might be considered as AI's "tipping point."[11] Beyond this point, it could become increasingly challenging to alter the trajectory of rapidly advancing AI. At this juncture, policymakers face a dilemma. On one hand, regulating a new technology at an early stage of its proliferation is relatively easier, while its long-term consequences remain a matter of speculation. On the other hand, waiting for a technology to mature leads to clearer consequences, but attempts to regulate a mature technology and mitigate these consequences often fail.

Policymakers must strike a balance: regulate AI at an early stage while avoiding over-regulation, which could stifle innovation, competitiveness, and the realisation of AI's tremendous efficiency potential for the green transformation. Importantly, AI and other digital technologies have their own carbon footprint, which is expected to grow considerably in the future. The estimated contribution of the ICT sector to global GHGs lies between 1.8 and 3.9 percent, potentially surpassing global air traffic. At this dual critical juncture, the global community faces not only a climate action gap, but also an AI governance gap, indicating a lack of global collaboration and coordination to ensure that AI primarily serves the benefits of society and nature.

The G20's Role

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In this policy brief, the G20's role is relevant from three perspectives: climate change; knowledge and technology transfer; and digitalisation and AI. The G20 recognises the massive concern for climate change and actively pursues initiatives and policies to address it. With its member countries accounting for approximately 80 percent of GHG emissions, the G20 plays a crucial role in driving progress towards a more sustainable future. The group includes both fossil energy exporters and importers, and they share a commitment to achieving net-zero emissions. Recognising the importance of innovative solutions, the G20 promotes collaboration on research, development, and deployment of clean technologies, as well as investments in clean energy infrastructure and renewable energy technologies.

Second, The G20 Development Working Group supports capacity building and the transfer of knowledge and technology to the developing economies to fight climate change through various mechanisms and collaborative efforts. This includes mobilising financial resources, collaborating with multilateral development banks, establishing or joining clean technology partnerships that include provisions for technology transfer and capacity building; bilateral and regional cooperation with developing countries; and the work through international frameworks, such as the United Nations Framework Convention on Climate Change (UNFCCC), which facilitate the transfer of technology and knowledge.

Finally, the G20 also supports responsible and inclusive digital transformation and human-centred AI. The G20 Roadmap for Digitalisation[12] and the G20 AI Principles[13] demonstrate the group's commitment to these goals. In 2019, the G20 Leaders recognised the potential of AI in achieving the UN SDGs. The G20 AI Principles highlight the importance of collaboration in realising a sustainable and innovative global society through digital technologies and technological transformation. However, the G20 Leaders did not provide specific actions or strategies addressing the intersection of digital and green transformations, including the role of AI and other digital technologies in driving effective climate change mitigation and adaptation strategies.

Recommendations to the G20

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Given the convening power of the G20 members, their commitment to leveraging AI and CPS for climate change risk mitigation and net-zero transformation is crucial. The following five recommendations outline actionable steps the G20 can take to promote the responsible and effective use of AI and CPS in addressing climate change.

Table 2: Recommendations to the G20

	Recommendation	Description
1	Establish a dedicated IDC action initiative	Create a G20 Intelligent Decarbonisation Action Initiative (IDC AI) to foster collaborative IDC efforts, establish shared goals, and provide guidelines for integrating AI into climate action. This involves aligning IDC-related policies between all G20 working groups, and piloting ICD projects for a shared understanding.
2	Global toolbox for intelligent decarbonisation	Create an IDC Toolbox aimed at providing guidance, resources, and best practices for the implementation of IDC technologies. It should include sustainable AI-CPS standards, repository of use cases, capacity building programmes, PPP collaboration framework, and regulatory and policy guidance, including on avoiding emissions and water consumption caused by AI-CPS.
3	Foster Public-Private Partnerships for research and innovation	Encourage G20 countries to establish PPPs to accelerate research and innovation of sector-specific application as outlined in Table 1. Partnerships help mobilise investments and create synergies between sectors. They help support academic institutions, research centres, startups, and the transfer of academic knowledge via spin-offs.
4	Encourage IDC capacity building and knowledge transfer	Establish an IDC Capacity Building, Knowledge & Technology Transfer Initiative to enable the Global South with developing and using AI and CPS technologies, overcome barriers to climate change mitigation, and align with climate goals. Programmes could encompass financial support, technical assistance, investment in training initiatives to equip local workforces with necessary skills.
5	Promote global collaboration on responsible and sustainable AI	Establish a G20 coordinating committee for the governance of trustworthy and sustainable AI. The committee should coordinate the transition towards an equitable and low-carbon digital economy; the mitigation of AI risks; and the reduction of the carbon emission impact of AI and CPS. The G20 should collaborate with the G7 Hiroshima AI process, the UN, and GPAI.

Attribution: Thorsten Jelinek et al., “Advancing AI for Climate Action: Global Collaboration on Intelligent Decarbonisation,” *T20 Policy Brief*, June 2023.

Endnotes

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