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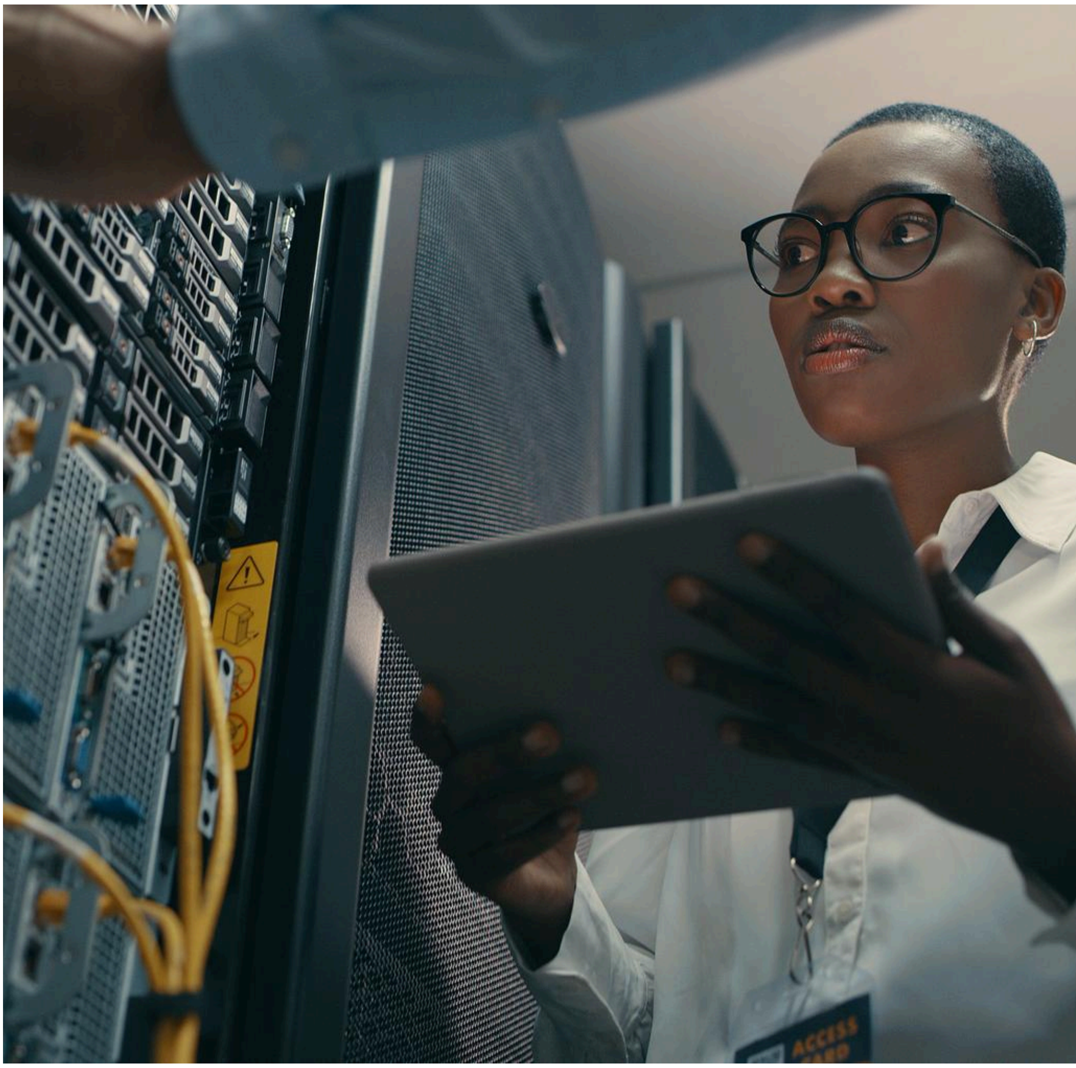

Greening AI: A Policy Agenda for the Artificial Intelligence and Energy Revolutions

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Executive Summary

We are at the beginning of a new age. The accelerating pace of artificial-intelligence development presents new opportunities. Every industry will be profoundly reshaped by this general-purpose technology, and discovering novel solutions to the world's most intractable challenges, such as climate change, will become possible. Governments have a unique opportunity to take action.

As demand for AI has grown, so too has demand for energy. This has created strains on national energy networks, which need to be managed in the short term. But in the medium to long term, the two systems need not be in tension. Instead, each can offer the chance of success in the other. The revolutions taking place in AI and energy are interconnected.

With the right strategy, these twin transitions can create a positive loop in which AI speeds up the energy transition while subsequent clean-energy production fuels further technological innovation, unleashing investments into compute infrastructure and clean technologies.

Many actors in the private sector are already aware of this interplay between clean-energy developments and innovation advancements. Developers are intensely focused on cutting energy demand, while companies such as Nvidia, Microsoft and Google are investing heavily in reducing consumption and increasing clean energy. Political leaders need to continue to create the incentives for companies to move in the direction of the twin transitions with a policy agenda that aims to minimise AI's energy and carbon costs while maximising its benefits.[1]

Unlocking the positive loop at scale requires a bargain between the public and private sectors: governments need to make it easy for companies to innovate and adopt greener AI techniques and the private sector needs to rachet up investments in clean-energy development and energy-efficiency R&D. This focus has to be emphasised across the whole AI value chain – from the electricity grid and power sources to hardware, software and end use – to bend the energy demand curve and unlock the positive loop.

While circumstances and priorities will vary from country to country, it is clear that governments pursuing success in AI and in climate policy face similar challenges. Practical action is needed in five core areas:

1. **Build foundational government capacity:** This should include mechanisms at the centre of government that drive national AI efforts and integrate green AI. Investing in collaboration between government, academia and the private sector will also help governments build the right technical expertise and governance frameworks to unlock the positive loop. To meet AI's growing energy requirements, governments also need to build energy infrastructure and power generation that incorporates AI energy-demand forecasts.
2. **Identify the scale of the problem:** Governments need to establish and adopt best-practice metrics for reporting on carbon emissions and energy consumption across the AI value chain. Doing so can fill existing measurement and accountability gaps that currently hinder governments' abilities to create the right kinds of policies and R&D investments needed to unlock the positive loop.
3. **Use agile policies and targets to incentivise greener practices:** Because the AI revolution is progressing rapidly, governments need to develop innovative, flexible planning and permitting criteria that support private-sector investment in and adoption of clean-energy technologies, while also creating a green-AI certification scheme that incentivises environmentally friendly practices through evidence-based targets. Elements of this could be made mandatory over time if incentives and supportive regulatory environments prove insufficient.
4. **Create better alternatives:** Governments need to facilitate private-sector innovation in advanced energy solutions like nuclear and geothermal to ensure AI and energy-system investments go hand in hand. Governments also need to increase R&D investments in green-AI hardware and software to identify new energy-efficient solutions; promote open-source AI models to reduce resource-intensive training phases; and dedicate a portion of the national compute pool for green-AI research.
5. **Collaborate and coordinate internationally:** By engaging across borders, governments can accelerate and deliver global progress on green AI. Leaders should look to the COP Breakthrough Agenda to convene and coordinate high-level international collaboration, agenda-setting and delivery for green AI.

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A New Policy Agenda

Even as AI sheds light on the possibility of a carbon-neutral future, it is taxing existing resources and adding to emissions in the short term. Despite commitments by many tech companies and utility providers to reduce carbon emissions and add new clean-power sources, companies[2] and governments[3] alike are turning to less climate-friendly solutions, including the construction of new gas plants, to deal with spikes in compute demand.

Slowing down the development of compute infrastructure while clean energy supply catches up is not a sensible option. As laid out in TBI's *State of Compute Access: How to Bridge the New Digital Divide* report, this delays digital connectivity and the provision of digitally enabled public services, creating a new digital divide.

This challenge is already surfacing in countries such as Ireland, Singapore and the Netherlands, which have instituted moratoriums on the construction of new data centres in certain regions to limit strains on the grid. In the United States, construction timelines for data centres have been extended by between two and six years[4] because of power-supply delays and grid-capacity constraints.

The Direct Climate and Energy Impacts of AI

- Training an AI model like GPT-3 is estimated to emit 552 tonnes of carbon-dioxide equivalent (GtCO2e).[5]
- Data centres (excluding those for cryptocurrency) currently account for 1 to 1.5 per cent of global electricity use.[6]

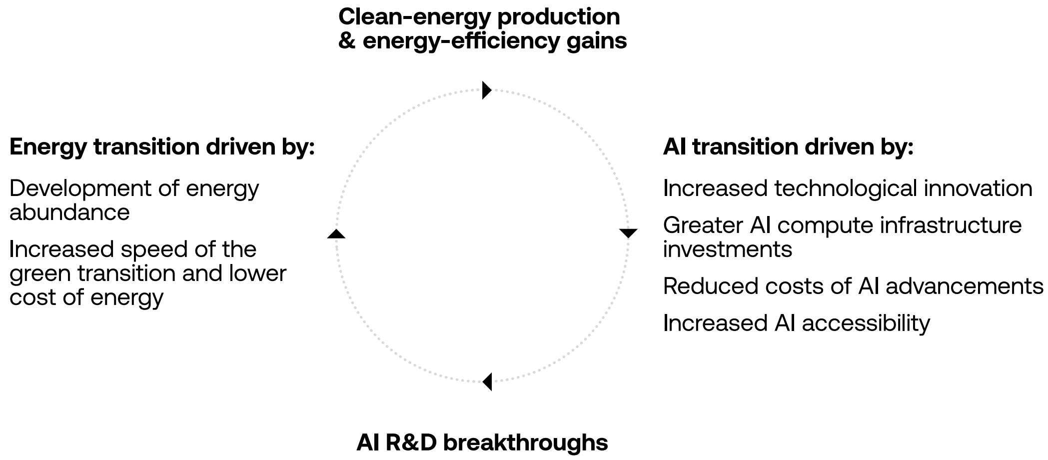
- AI is estimated to account for less than one-fifth[7] of overall data-centre energy demand today, but this share is likely to grow quickly over the next few years with the International Energy Agency (IEA) projecting that global electricity demand from data centres could double between 2022 and 2026.[8]
- One industry analyst projects that data-centre energy use could triple between 2023 and 2030, with AI accounting for 90 per cent of the growth.[9] In some countries with heavy concentration of tech activity such as Ireland, this could account for up to a quarter of a country's electricity use if power generation capacity does not increase.[10]

Despite heavy energy consumption, AI is enabling breakthroughs across the climate and energy sectors and accelerating climate-science research at scale. Google DeepMind researchers have recently discovered[11] 2.2 million crystal structures, including 380,000 stable materials that could power future technologies such as batteries, computer chips and solar panels. This discovery is equivalent to about 800 years' worth of knowledge and demonstrates an unprecedented scale and level of accuracy in predictions.

Governments that enable the rapid development of zero- and low-carbon power will attract investment into compute infrastructure and clean-power technologies from hyperscalers, the world's largest data centres with extensive cloud-computing services. Run by companies with household names such as Google, Amazon, Meta and Microsoft – all of which are working to achieve net zero in the next ten to 20 years – this investment can translate the positive loop into a competitive advantage.

FIGURE 1

Leveraging the twin transitions to unlock the positive loop



For countries early in their AI journeys, there is a clear opportunity to establish the foundational capabilities for green AI from the outset, generating investment from hyperscalers seeking new growth markets. For those more advanced in their AI journeys, and those with significant compute resource, the development of green AI presents a significant opportunity to reduce the costs of AI advancements through cleaner, cheaper renewable energy – a critical factor for highly cost-sensitive data-centre operators and developers downstream. In essence, more energy-efficient AI unlocks additional carbon headroom for countries to pursue further information and communication technology (ICT) growth and maximise their compute regardless of their starting point, and while keeping on track with decarbonisation and climate targets.

Green AI

The development and operation of AI that is energy-efficient and uses zero- and low-carbon energy.

Governments need to accelerate clean-grid infrastructure and power generation and drive the development of low- and zero-carbon compute infrastructure. But they also need to create the environment for the private sector to enhance AI's energy efficiency at the technical level. How countries approach this will vary depending on local contexts and capacities.

Zero- and low-carbon approaches to AI do not have to entail compromises on the quality of AI models. Researchers from Google and the University of California, Berkeley, have shown that the carbon footprint of large language models (LLMs) can be reduced by 100 to 1,000 times[12] with the appropriate algorithms, customised hardware and energy-efficient cloud-data centres. Support for existing efforts and accelerating new approaches in this space will deliver benefits for stakeholders across the AI value chain.

FIGURE 2

The AI value chain

Energy Infrastructure & Generation	Hardware	Software	Operations
Grid infrastructure serves as the backbone for powering data centres and compute infrastructure, ensuring reliable energy supply for AI training and operations. The source of power generation determines the grid's carbon intensity and AI's emission levels.	Hardware refers to the physical components needed for AI computations, from facilities such as data centres to equipment such as processors and storage devices. The energy consumption of the hardware, along with the required cooling systems, represents a significant portion of AI's carbon emissions. Factors critical to minimising this impact include the physical layout of data centres, the modularity of equipment and effective inventory-lifecycle management.	Sustainable AI development involves designing robust algorithms and keeping source code "neat and clean". The choice of programming language and the algorithm complexity are crucial drivers of AI energy consumption.Efforts in software optimisation involve refining code and algorithms to decrease computational loads and, consequently, the environmental impact of running AI applications.	Operations relate to the practical aspects of training and using AI models including advanced analytics, machine learning, deep learning and large language models.Strategic decisions regarding the location of compute (edge versus core) or practices such as batch optimisation and caching can minimise redundant data transfer and computations, further conserving energy.

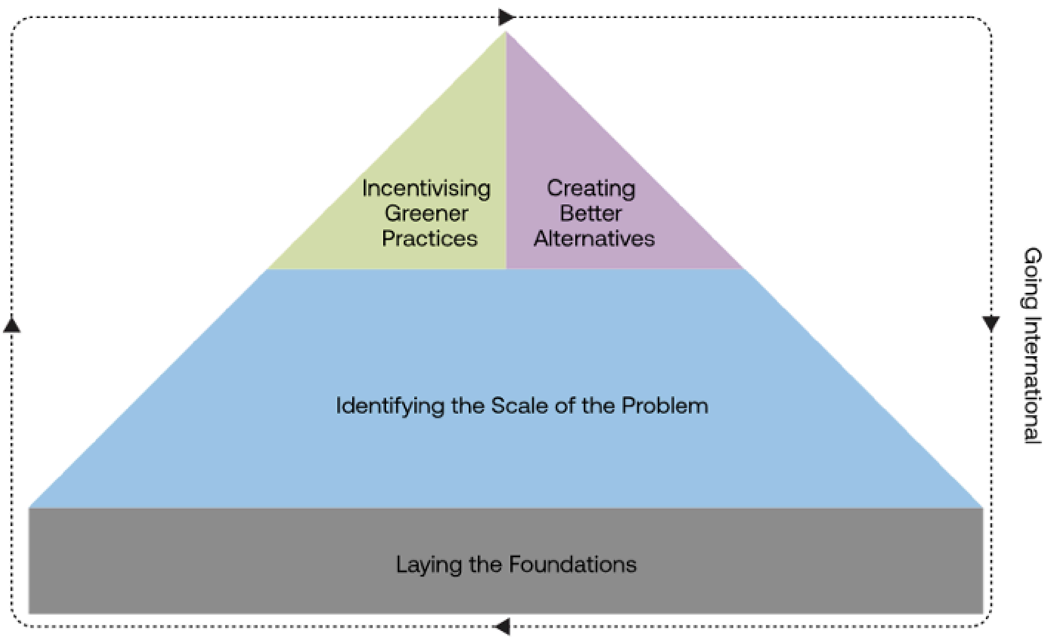
While some governments, including those in Singapore, Finland and the EU, are responding to the need to invest in green AI to varying degrees, most governments face significant hurdles in developing effective policies that tackle the pace and scale of AI's energy demand.

Importantly, leaders do not need to reinvent the wheel in this space but can build upon existing efforts.

Singapore in particular has been a pioneer in advancing research and policy that supports sustainable digital economic growth. A comprehensive case study at the end of this paper offers strong examples of best practice that other governments can learn from as well as valuable insights that can be leveraged to advance green-AI innovation.

FIGURE 3

A new policy agenda for green AI



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Laying the Foundations

Governments need to develop the capacity to address the dynamic and interdisciplinary nature of the climate and AI nexus. Building this "green-AI muscle" is critical to accelerating private-sector innovation and adoption across the AI value chain – from measuring AI-related carbon emissions and incentivising green-AI practices to strategically identifying and allocating funding for better alternatives. This capacity has to be complemented by strategic government investment in the foundational energy infrastructure needed to meet AI's energy demands.

ESTABLISHING INSTITUTIONAL MECHANISMS

Driving technological transformation requires strong political leadership and clarity of priorities. At present, most governments treat AI and decarbonisation as two separate agendas and have few – if any – people working at their intersection. This leads to disjointed policy and failure to harness the opportunities presented by green AI.

Recommendation: Establish a mechanism at the centre of government to coordinate priorities between the AI and climate transitions. As governments integrate AI at the heart of government to improve public services, as recommended in *Governing in the Age of AI: A New Model to Transform the State* these teams should appoint a specialist with skills at the intersection of climate and AI, or at a minimum, appoint a climate expert. Recruiting this expertise at the heart of government will help break down silos, ensure accountability and build the government's multidisciplinary capacity to drive the twin transitions. There is more guidance on how governments can cultivate this specific skillset below.

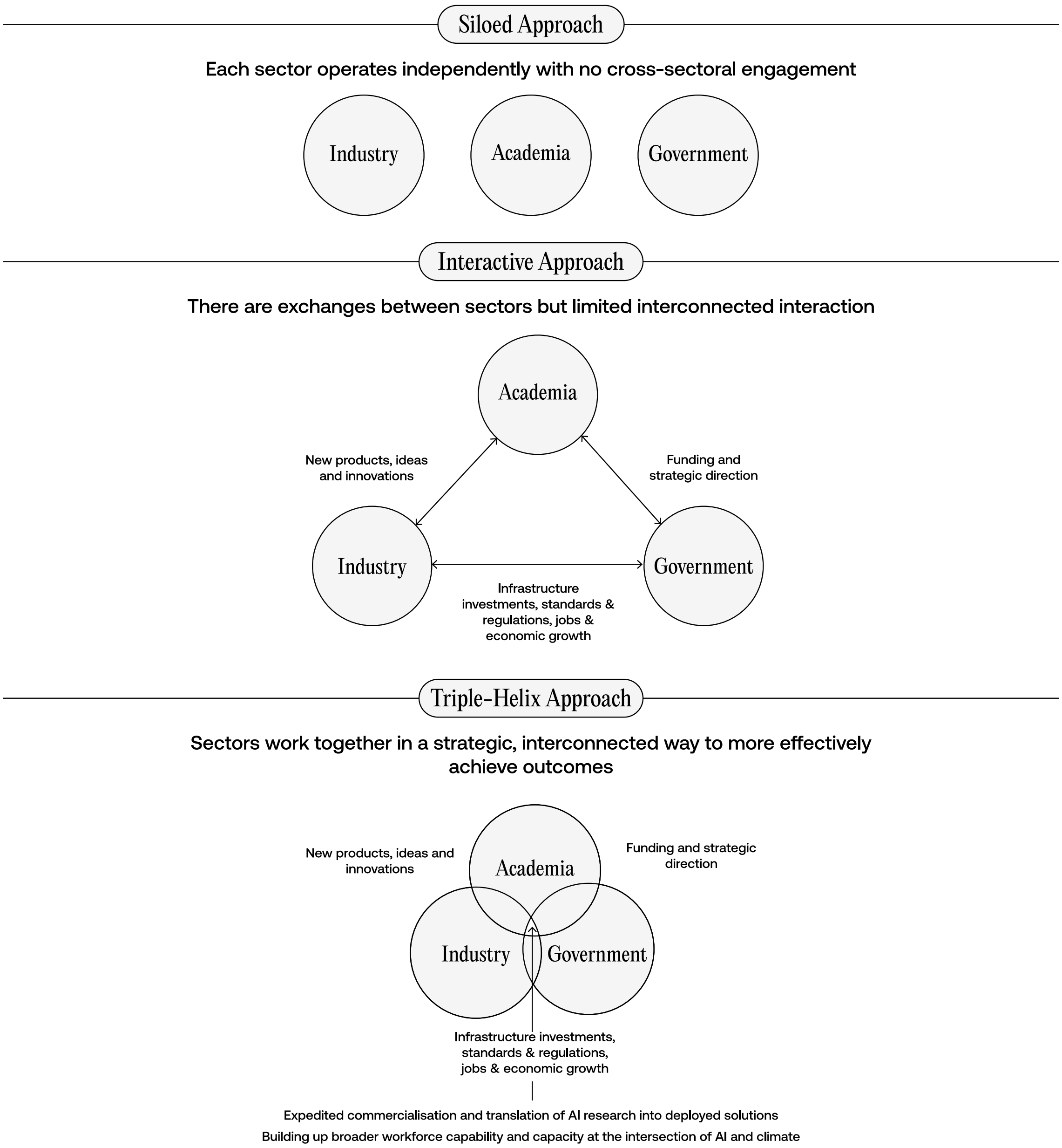
CREATING "TRIPLE-HELIX PARTNERSHIPS"

Triple-helix partnerships that interconnect and enhance collaboration between government, academia and the private sector are crucial to greening AI. When tightly interconnected, the three entities act as complementary gears in the machinery of innovation. Governments play a central role by setting strategic direction, providing funding and acting as a connecting node;

academia contributes by conducting cutting-edge research and developing foundational knowledge; the private sector brings practical expertise, market insights and the ability to translate research into viable solutions. When these gears move seamlessly, they accelerate the deployment of marketable green-AI solutions.

FIGURE 4

The triple-helix approach to partnerships



Recommendation: Expedite the commercialisation and translation of foundational AI research into deployed solutions. Governments should use targeted public-funding programmes to bring green-AI research out of the lab and into the market. Programmes should foster greater collaboration between academia and the private sector to enable co-development of zero- and low-carbon digital solutions. Governments should consider specialised pots of funding, with a focus on green-AI market gaps to drive forward these efforts.

Recommendation: Scale skills at the intersection of AI and climate and establish a long-term talent pipeline. To build out the skillset needed to get the twin transition right, governments should leverage the triple-helix model to map future demand and then establish cross-disciplinary training programmes. Regular assessments with industry and academia of such programmes and curricula will ensure their continued relevance and avoid an over- or under-supply of such skills. To develop green-AI talent, governments should consider:

- Expanding formalised programmes at the undergraduate and graduate level by increasing degree modules that bridge the gaps between AI, climate change and sustainability. This will provide students with a strong foundation in green AI and enhance their ability to integrate green perspectives when developing AI systems.
- Increasing the availability of professional-development programmes with industry partners to provide aspiring green-AI professionals with relevant progression pathways. These programmes should also include joint workshops or training sessions that offer practical exposure to green-AI technologies and their specific application to climate challenges. Strong baseline programmes are already in place and can be continually assessed and updated with further industry and academic views. These include the Green Software Foundation's Green Software Practitioner[13] training and the Linux Foundation's Green Software for Practitioners[14] training course.
- Establishing polymath fellowships that enable existing climate or AI professionals to pivot into the complementary field. This approach would cultivate a steady pipeline of interdisciplinary professionals equipped to meet future green-AI demand and a greater culture of sustainability at leading AI labs.

BUILDING GRID INFRASTRUCTURE

Many companies working in AI, particularly hyperscalers and telecommunications operators, have made commitments to dramatically reduce their carbon emissions. For example, Google aims to achieve 24/7 clean energy for their operations by 2030, and together with Microsoft have signed the 24/7 Carbon-Free Energy Compact,[15] which aims to secure renewable energy matched to demand at all times. Similarly, Amazon and Meta are members of the Emissions First Partnership,[16] which strives to make the most significant emissions reductions possible, irrespective of geographical and market boundaries. These initiatives are not mutually exclusive and show the motivation across industry to support decarbonisation and increase the availability of renewable energy.

Interviews and roundtable conversations with hyperscalers confirmed that renewable-energy capacity is a major factor in where data centres are placed. To attract more compute and clean-tech investment, governments will need a clear path to providing sufficient clean energy, including a grid that can manage the new supply and demand and has the capability to balance, store and manage intermittent renewables.

These plans will need to take into account AI's energy-demand forecasts. Implementing these plans will require governments to think through near- and long-term approaches akin to Norway's second data-centre strategy[17] and Singapore's National AI Strategy 2.0[18]. Governments need to ensure carbon-budget and power allocation to process AI workloads in the near term, while mapping out the growth of net-zero, green data centres powered by renewable energy in the medium to long-term. Few are currently doing this.

Recommendation: Conduct AI-related energy-demand forecasts. To address the AI energy demand and consequent impact on national and global emissions, it is crucial to have strong calculations of current use and future projections. Forecasts need to not solely extrapolate past AI energy use into the future, but include social, economic and technological factors that influence future demand.[19] For example, extrapolations based on recent data-centre energy use overlook countervailing energy-efficiency trends.[20] Research on the energy usage of inference (the process of running data through a trained AI model to draw conclusions) is even more nascent than on the training side of AI energy demand and requires additional attention. Countries and international institutions at the frontier of carbon accounting and reporting should drive this agenda, sharing methodologies that can be adopted across contexts.

Recommendation: Integrate AI-related energy-demand forecasts into national-grid decarbonisation planning and investments. Governments should use strategic spatial energy plans to identify clean-energy investments needed for future zero- and low-carbon AI growth, including assessing the baseload power for data centres. This would allow governments to anticipate grid-capacity needs and invest in clean grid infrastructure. Government-sponsored digital-twin technology could simulate energy supply and demand scenarios to optimise data-centre siting for renewable-energy access and opportunities for heat-waste harnessing as well as help with strategic decisions around grid development and future energy-infrastructure investments. Although not all countries will have the data needed for digital twins, it is imperative that future energy infrastructure investments and plans go hand in hand with AI demand forecasts.

Recommendation: Invest in modern grid infrastructure. Foundational investments in modern grid infrastructure[21] is essential for flexibility and optimisation. A smarter, digitised grid can better integrate different sources of energy, including renewables and storage. This allows for a more flexible and responsive system that can handle the fluctuations of renewable-energy production and leverage additionality from advanced electricity technologies. It also makes it easier for data-centre operators and AI companies to optimise load-shifting strategies. Moreover, government investment in smart-grid technologies can ensure a stable and efficient clean-energy system that can more effectively meet AI’s growing energy demands.

04

Identifying the Scale of the Problem

Governments cannot manage what they do not measure. Leaders need an accurate picture of the scale and scope of AI's emissions and energy usage to formulate the right policy interventions. This is critical for driving AI-related innovation by helping developers and users understand the link between AI and emissions, encouraging greener practices, and identifying opportunities for energy-saving innovations. Enhanced transparency is also key in tackling greenwashing and fostering accountability in AI development. Importantly, standardising metrics would streamline the reporting process for companies working across international jurisdictions, easing both financial- and non-financial-resource burdens for companies and normalising information-sharing practices.

Moreover, in other sectors the simple act of mandating emissions reporting has been found to lead to reduced emissions, even when reductions are not mandated.[22]

But despite increasingly stringent energy-reporting requirements for grid infrastructure and data centres, there is a lack of understanding and consensus around which aspects of AI's energy-related impacts, especially regarding compute operations, should be monitored. Many of these data are also not publicly accessible. For example, Microsoft's sustainability calculator provides a macro-level overview of Azure's energy impact, but does not release granular data on computing workloads, AI-model energy use or data-centre operations. Moreover, existing methodologies for assessing the environmental impact of ICT are too inconsistent to form a cohesive framework. A more comprehensive measurement framework that spans AI's value chain is needed.

ASSESSING GRID CAPACITY AND CARBON INTENSITY

Information and transparency regarding the grid's capacity and carbon intensity are essential for calculating the carbon emissions of activities further downstream. Reporting at the grid level can also help attract investment in AI compute infrastructure, particularly from companies with ambitious renewable-energy ambitions, and is important for accelerating the development of greener techniques across hardware, software and operations. It can also allow investors and developers to ensure that both energy needs and climate commitments will be met.

Recommendation: Require reporting of the capacity and carbon intensity of the grid. Governments should require electricity grids to report their total capacity and carbon intensity, with granular data specified to the unit of an hour. This is already done in many countries across the world, but a large number of developing countries are yet to provide this information.[23]

ASSESSING DATA-CENTRE ENERGY CONSUMPTION AND CARBON EMISSIONS

Greenhouse-gas-emission and energy-consumption reporting is becoming increasingly common.[24] The most commonly used data-centre efficiency and sustainability measurement is Power Usage Effectiveness (PUE) – the ratio of total data-centre energy use to IT-equipment energy use – but this provides an inaccurate picture of AI's sustainability and climate impact and limits governments' ability to drive greener behaviour. Additionally, there are limited data that isolate how much energy is being used and emissions are being generated specifically by AI.

Recommendation: Establish and adopt best-practice metrics for data-centre energy consumption and carbon emissions, isolating information related to AI. Governments should look towards best practice in measuring data-centre efficiencies and emissions like the European Energy Efficiency Directive (EED) (see below) and regulatory-reporting requirements like the EU's CSRD and EED, the UK's SECR and California's SB253 as well as legislation recently proposed in the US on the investigation and tracking of the environmental impacts of AI. Reporting requirements should be mandatory for data centres above a certain threshold size (for example 300 kilowatts (kW)) and voluntary for smaller-scale data centres. Governments should consider integrating more specific metrics that provide a holistic overview of data-centre energy efficiency and climate impact, such as the carbon intensity of the energy used (including hourly data); scope 1, 2 and 3 emissions; and inventory age and status. Emissions specific to AI development and deployment should also be identified and reported separate from other ICT uses and services. This would enable data centres to more effectively implement load shifting and could help developers create more energy-efficient and cost-effective alternatives.

The European Energy Efficiency Directive (EED)

The EED was adopted by the European Commission in March 2024 with an aim to reduce both energy consumption and carbon emissions. Applying to data centres above 500 kW, from September 2024 operators are required to report on: floor area, installed power, data volumes, energy consumption, PUE, temperature set points, waste-heat utilisation, and water and renewable-energy usage. Germany was the first European country to incorporate the EED into law,[25] adding the requirement that data centres with 300 kW capacity or more cover 50 per cent of their electricity consumption using renewable sources from January 2024 and 100 per cent from January 2027.

ASSESSING THE ENERGY CONSUMPTION AND CARBON EMISSIONS OF AI SOFTWARE

Governments need to measure the energy consumption and carbon emissions of AI software to develop the right set of green-AI policies. This is particularly pertinent for countries leading in AI development and deployment. Singapore has made a strong head start in tackling this measurement challenge through the Infocomm Media Development Authority's (IMDA's) green software trials, which will bring together industry partners to test carbon-reduction techniques in real-world settings and report on those that are successful in lowering AI compute resources.

When the trials conclude later this year, the insights and data will be critical in formulating guidelines for industry – particularly on the ability of these carbon-reduction techniques to deliver cost and energy efficiency without affecting performance.

Recommendation: Adopt best-practice metrics on energy consumption and carbon emissions for AI software. Until findings from the green software trials are released, the Software Carbon Intensity (SCI) specification[26] developed by the ISO in collaboration with the Green Software Foundation presents a strong starting point for calculating a software system's carbon-emission rate – termed the "SCI score" – with the purpose of raising awareness and transparency of a particular application's level of energy use and carbon intensity. To support the implementation of the SCI standard and ensure comprehensive emissions assessment, governments can use various open-source and commercial software benchmarks. These can help measure the energy consumption and carbon emissions of AI models and applications throughout the entire AI lifecycle. Such standards need to be constantly examined to identify gaps or shortcomings, given their relatively nascent nature and the rapid pace of AI development.

FIGURE 5

Open-source and commercial software benchmarks

Tool Name	Description	Utilisation Phase
CarbontrackerCodeCarbon	Estimate the carbon footprint of AI training models during the development process	Model training
MLPerfImpact FrameworkKepler	Measuring the post-deployment (inference) energy consumption of AI	Post-deployment
GreenPixieWebsite CarbonCloud Carbon Footprint	Identify, analyse and reduce carbonisation of cloud and web platforms that host AI applications	Post-deployment

05

Incentivising Decarbonisation and Energy Efficiency

Governments need to ensure energy investment and AI development are moving together. To do this, leaders need to make it easy for companies to align clean energy and AI goals. They also need to drive the adoption of best practice across the AI value chain through a range of voluntary and mandated policies. Governments can initially use incentives and voluntary actions to nudge behaviour change. If, over the long term, these measures are shown to be insufficient in curbing energy demand and emissions, governments can consider progressing to increasingly stringent penalties to ensure the adoption of greener practices. This ladder-like approach provides governments with a range of tools and approaches – increasing in scale and severity – to achieve AI decarbonisation and energy efficiency.

ACCELERATING PRIVATE-SECTOR-LED ENERGY-INFRASTRUCTURE INVESTMENT

Licencing and permit processes for renewable energy projects in most countries are lengthy and difficult, hindering efforts to align the rapid build out of AI compute and clean-energy infrastructure. This can also inhibit data centres from leveraging existing renewable-energy sources and impede investments in clean on-site generation. For example, while nuclear small modular reactors (SMRs)[27] are touted as one solution for future on-site energy sources, nuclear power is subject to notoriously slow permit processes.

Recommendation: Create flexible planning and permit processes that are faster, more streamlined and in line with strategic AI and clean-energy goals. Governments need to make it easier for data-centre sites to connect directly with renewable-energy sites and ease the planning-application process for data-centre development in areas with plenty of renewable energy or waste-heat-recovery opportunities. For smaller data-centre operators with smaller budgets, governments can also use tax incentives to encourage the use of renewable-energy sources and waste-heat recovery. Permit criteria should be updated to ensure new developments are pursued in tandem with investments in wider energy infrastructure and that they're using state-of-the-art technology and the best sustainability practices.

Recommendation: Leverage time-of-use tariffs to support and encourage flexibility. Governments should use flexible tariff schemes to support load shifting and to encourage software design and applications to be flexible, reducing demands on the grid and enabling data centres to make better use of renewable-energy sources, which may only be able to provide power intermittently. Ireland's state-owned power operator, EirGrid, has flexible demand arrangements that serve as a good example of this. While flexibility is not feasible for all data centres due to sensitive data, there is significant opportunity to optimise renewable-energy availability and shift data-centre energy demand across the grid. Further research and development support is still required on this, as outlined below in the Creating Better Alternatives chapter.

Recommendation: Companies need to match government-driven flexibility by integrating data-centre flexibility requirements into service-level agreements between data-centre operators and customers. This is important in creating demand and awareness among customers for greater flexibility.

INITIATING A GREEN-AI CERTIFICATION SCHEME

While many data centres are already very energy-efficient, not all operators follow the same standard. Specifically, non-hyperscale data centres such as co-location facilities face economic pressures to maximise rack-space utilisation. As a result, they may prioritise selling space over achieving optimal energy efficiency. Additionally, these operators are often hesitant to pay a green-energy premium due to their cost sensitivity.

To incentivise practices that better align with the green transition, it is critical that governments set targets based on the metrics and reporting outlined above, raise awareness of best practice across the AI value chain, and put pressure on low performers to improve. Doing so can have important co-benefits across the ICT sector, as targets do not apply only to AI but to all services within the data centre.

Certification can also help developers and users make informed choices about the services they use, whether that is data-centre space or a particular AI application. Research shows that consumer behaviour is influenced by green labels and certificates,[28] with consumer pressure and brand reputation consequently driving corporate action. In part because of these pressures, management-consulting company Gartner predicts 75 per cent of organisations will have implemented a data-centre infrastructure-sustainability programme by 2027,[29] a significant improvement from less than 5 per cent in 2022.

Recommendation: Establish a publicly accessible repository of best green-AI practices and case studies. Based on existing data and novel trials, this repository should serve as a common reference point to demonstrate successful implementations of green AI. For data centres, the European Code of Conduct for Energy Efficiency in Data Centres and Singapore's tropical data-centres standard provide existing examples for data centres, while similar efforts should be established for software and operations.

Recommendation: Create targets for energy consumption, energy efficiency and carbon emissions for data centres and software through a green-certification scheme. Governments should base targets on best-practice examples and "green by design" criteria (see below) that balance energy-efficiency improvements with emissions reductions and do not compromise on the good service of the data centre or software. Requirements within the schemes should become more stringent over time to keep pushing innovation and efficiency improvements.

Data Centres

While many countries have their own sustainability accreditation systems for data centres or buildings more generally, existing certification schemes should be expanded to not only focus on internal optimisation but also on renewable-energy use, additionality and integration with the grid for energy export. Further criteria governments can consider include local land availability for on-site renewable-energy generation, site location and investments in innovative energy sources.

Leadership in Energy and Environmental Design (LEED) and Excellence in Design for Greater Efficiencies (EDGE) are the leading examples of international green-building certifications that can be easily utilised, implemented and added to by governments and organisations, particularly for those early in their AI trajectory, rather than spending additional resources on establishing their own version.

Software

It is more difficult to judge best practice and provide targets for software because of its context-specific nature and because there has historically been little attention on the intersection between AI software and energy. Yet governments must start building efficiency and carbon footprints into AI-software assessment criteria.

Governments should work to include these targets in frameworks that govern responsible and transparent AI, such as the AI Verify framework, to underscore that responsible use and deployment of AI includes environmental considerations. AI Verify is the first AI governance-testing framework and software toolkit supporting responsible AI. It validates AI systems against the principles of transparency, reproducibility, safety, fairness and accountability. Frameworks like this should be expanded to include measures that will be identified through green software trials along with "green by design" AI-model criteria.

Recommendation: Introduce public awards to recognise outstanding performance in green AI. If a certification scheme alone results in limited adoption of greener practices, governments should introduce public awards or recognition schemes based on certification and incentive programmes that recognise, validate and reward organisations adhering to established green-AI practices and further incentivises these actions. Awards enhance transparency and public awareness of this issue, further enabling and incentivising organisations and individuals to make informed decisions of the services they select.

Recommendation: Explore the gradual introduction of more mandatory standards and requirements across the AI value chain. If the data show that incentives and supportive regulatory environments are insufficient, governments should begin making previously voluntary standards and best practice mandatory, including introducing initially small fines to incentivise compliance, with the possibility of increasing severity. If mandatory measures are needed, governments could consider mandating a certain threshold for energy efficiency and carbon emissions for different sizes of data-centre providers; requiring a certain standard of efficiency and renewable-energy use for new data-centre builds; using the green by design criteria and accreditation system to establish a minimum level of accreditation; and increasing efficiency and emissions thresholds and financial penalties over time. These interventions should be considered as options of last resort if incentives and enablers prove insufficient. They are also dependent on the evolution of a country's AI capability and should only be considered in countries where this is advanced.

Potential Green-by-Design Criteria

Hardware: Green-by-Design Data Centres

Core elements[30] of "green by design" for data centres could include:

- Prioritising green approaches in determining data-centre siting
- Increasing demand flexibility and load shifting
- Shifting from diesel to renewable back-up generators
- Utilising energy storage and energy management to integrate with the grid for energy export
- Reporting inventory age and status
- Investing in 24/7 renewable-energy matching through power-purchasing agreements
- Using state-of-the-art technologies and best practice for data-centre sustainability
- Modular infrastructure, allowing for more efficient utilisation of resources by enabling scalability and flexibility in data-centre operations
- Integrated data-centre flexibility requirements in service-level agreements

Software: Green-by-Design AI Models

Core elements of "green by design" for AI models could include:

- Requiring emissions tracking and carbon-footprint measurement in the AI-application-development process
- Limiting the need for duplicated processes by using caching to avoiding redundant recomputes
- Reducing "code bloat"
- Certifying AI models for energy efficiency, carbon emissions and water impact
- Using agreed standards and specs for the green AI across industries
- Using lower-level programming languages that have fewer memory-management requirements and thus are less energy-intensive

06

Creating Better Alternatives

Innovation lies at the heart of the positive loop between the AI and energy transitions. It enables reductions in emissions and energy consumption across the AI value chain and accelerates AI advancements. For instance, it is through continued innovation and improvement in data-centre operations and hardware efficiencies (such as using AI to optimise processes[31] and make advancements in chips) that total global data-centre electricity use increased by only 6 per cent from 2010 to 2018,[32] even as the number of data-centre compute instances (that is to say, virtual machines running on physical hardware) rose to 6.5 times over the same period.[33]

The private sector is largely driving these energy-efficiency and decarbonisation efforts, investing in innovations that are critical to both accelerating AI advancements and the energy transition. AI companies are some of today's biggest clean-energy investors. For example, Microsoft has created the $1 billion Climate Innovation Fund to accelerate climate technology development and deployment and corporate clean-energy power-purchase agreements (PPAs)[34] accounted for more than 10 per cent of all new renewable capacity added in 2021.

FACILITATING PRIVATE-SECTOR INNOVATION IN ADVANCED ENERGY-SOURCE SOLUTIONS

Data centres require a power supply that provides consistent, reliable energy to prevent shutdown and overload. This means the infrastructure behind AI has a relatively unique baseload-power requirement compared to most other industries, and companies are investing heavily in advanced clean-electricity technologies needed to complement intermittent solar and wind power.

For instance, by 2022 Google had invested $3.5 billion in renewable energy globally,[35] and it has recently partnered with a clean-energy startup Fervo to develop a geothermal power project in the US that is now contributing carbon-free energy to the electricity grid.[36] Microsoft is investing in new approaches that shift back-up generators from diesel to zero- and low-carbon alternatives, such as green hydrogen[37] and modular nuclear reactors,[38] and is using lithium-ion batteries and a grid-interactive uninterruptible power supply to share energy with the local grid when needed.[39]

In addition to advanced electricity technology, companies are also testing ways to integrate more intermittent renewable energy and increased flexibility into AI operations. For example, by using intelligent design, instrumentation, control and automation, companies are increasingly experimenting with demand flexibility and load shifting to schedule non-time-sensitive tasks for off-peak periods, or even shift workloads to different data centres and geographies.

Recommendation: Build a suite of financial vehicles to accelerate the commercialisation of clean-energy advancements. Governments should focus on paving the way for the production of nuclear (specifically SMRs) and geothermal energy due to their ability to provide baseload power. Mechanisms governments could pursue include:

- A loans-programme office to de-risk investments until they become bankable for private investment. The US Department of Energy's Loan Program Office provides a good example other countries could replicate. It is investing in micronuclear reactor advancements while investor confidence builds.[40]
- Contracts-for-difference (CfD) schemes to attract private investment in clean-energy projects. In the UK, CfDs are used for a range of renewable-energy sources including wind, solar, tidal and geothermal and can serve as a model for other countries to drive the commercialisation of geothermal and nuclear.[41]
- Sophisticated PPAs to help advance 24/7 renewable-energy matching, drive innovation and make a significant emissions impact.[42] Companies like Google and Microsoft are piloting 24/7 clean PPAs[43] that incorporate a portfolio of clean-energy sources, integrate energy-storage solutions and match clean-energy generation with consumption on an hourly basis.[44] To facilitate these more complex PPAs, governments should develop standardised contractual templates that streamline negotiation processes and reduce transaction costs for both clean-energy developers and potential buyers; offer credit enhancements or loan guarantees to clean-energy developers entering into PPAs; or facilitate programmes that aggregate the demand from multiple small clean-energy projects.[45]
- Offtake agreements whereby the government serves as a backstop offtaker for renewable-energy generators at a pre-determined price. State-guaranteed revenue improves investor and lender confidence, facilitates greater access to project financing and boosts competition in PPA markets

with private-sector participants by enabling more generators and offtakers to participate confidently.[46] This is particularly critical for emerging economies to de-risk hyperscaler investments and support the adoption of clean-energy infrastructure.

ALLOCATING R&D INVESTMENT TO IMPROVE ENERGY EFFICIENCIES

Countries at the technological frontier are in an advantageous position to explore and research cutting-edge green-AI technologies. By drawing on insights from prior research and trials, they can accelerate the development of these technologies. Through targeted and strategic investments, governments play a pivotal role in advancing these efforts. Collectively, these advancements contribute to a growing pool of climate-friendly, open-source AI resources accessible globally.

Recommendation: Accelerate R&D into hardware energy efficiencies through sandbox trials. Governments can drive innovation and test new data-centre efficiency and sustainability approaches through data-centre specific sandbox trials that could mirror Singapore's Sustainable Tropical Data Centre Testbed (see case study for details).[47] Efforts could focus on determining and deploying optimal data-centre equipment change-out rates, balancing financial viability with sustainability and ensuring that computing infrastructure remains both efficient and performance-optimised. Research on frontier energy-efficient technologies could also include the developmentof new materials, testing of reversible computing approaches, and the creation of Data Processing Units (DPUs) that are specifically designed for AI applications.

Recommendation: Establish outcome-oriented national grants or prizes to incentivise innovation. These could take the form of a national challenge prize, which offers rewards to whoever can solve a discrete, well-defined problem first or most effectively.

Recommendation: Accelerate software energy efficiencies through trials. Governments should learn from IMDA's green-software trials once findings are published. Through triple-helix partnerships, further software trials should focus on uncovering additional energy-efficient techniques and could include experimenting with synthetic data generation, which would reduce the need for redundant data pre-processing tasks and allow for AI models to be trained in more energy-efficient ways.

PROMOTING OPEN-SOURCE RESOURCES

Open-source resources are critical to facilitating the adoption of energy-efficient AI-development practices. Access cuts down the need for resource-intensive training phases, while still providing developers with a base that can be further fine-tuned for their application development.

Examples of such AI models include the SEA-LION (Southeast Asian Languages In One Network) LLM and the VGG16 and VGG19 (16- and 19-layer Convolutional Neural Networks developed by the Visual Geometry Group at the University of Oxford) computer-vision models. These resources can be accompanied by others including optimised software libraries like TensorFlow Lite that support the creation of more energy-conscious AI applications. These libraries are engineered to minimise the computational load, facilitating the deployment of AI in environments where energy utilisation may be a concern.

Recommendation: The mechanism at the centre of government responsible for coordinating AI and climate priorities should establish a curated list of publicly available, open-source AI resources that it updates on a regular basis. Given the pace of AI-model development, various open-source AI models run the risk of becoming outdated if not updated accordingly, which would reduce their effectiveness and hinder their public uptake. A curated and updated list would serve as a comprehensive repository of tools and models that are vetted for their efficiency and sustainability, offering developers easy access to the best available resources for green-AI development and serve as a benchmark for sustainable development practices within the AI community. For instance, the US recently introduced the 2024 Artificial Intelligence Environmental Impacts Act, which includes provisions for the development or cataloguing of open-source software and hardware tools with the aim of facilitating the measurement of environmental impact of AI models, systems and hardware.[48]

FIGURE 6

Open-source models and the rationale for updating them

Model	Update Rationale
Open-source natural language processing (NLP) models	Earlier versions of large NLP models such as the Bidirectional Encoder Representations from Transformers (BERT) require longer training times and, by extension, larger amounts of computational resources. Such models could benefit from updates using techniques like distillation or pruning to create smaller, more efficient versions.
Open-source computer-vision models	Models such as VGG19, while foundational in the field of computer vision, are known for their large size and computational intensity. Updating these models to more efficient architectures such as MobileNet or EfficientNet can reduce computational load and energy consumption without significantly compromising accuracy.
Generative adversarial network (GAN) models for image recognition and generation	The earlier variations of DCGAN (Deep Convolutional GAN) are based on architectures that are, by today's standards, not optimised for computational efficiency or energy consumption during training and inference. Newer GAN models have incorporated architectural improvements that allow for less training time, reduced energy consumption and more efficient image generation.

Recommendation: Promote or incentivise gradual climate-friendly shifts within the developer community. This includes transitioning mindsets and practices away from high-level languages like Java to more efficient, lower-level languages such as C++. This shift enables developers to write code that is more directly aligned with hardware operations, enhancing the overall energy efficiency of AI systems by optimising resource usage.

MAKING SOVEREIGN COMPUTE MORE ACCESSIBLE FOR GREEN-AI RESEARCH

TBI's report on the *State of Compute Access* recommends that governments build out their national compute infrastructure as a means of providing high-performance computing (HPC) resources to academics and AI start-ups. Establishing this public AI infrastructure is crucial not just to spur AI development across various sectors but to ensure that research in key areas, particularly those aligned with governmental priorities such as energy efficiency and climate change, is adequately supported.

Recommendation: Governments at the technological frontier should dedicate a portion of their national compute pool specifically for green-AI research. This dedicated compute pool would serve as a national “green-AI resource”, ensuring that researchers focused on green-AI challenges have adequate access to the computational power necessary for their work. For example, JASMIN is a supercomputer facility in the UK that is specifically designed to provide substantial compute resources to the environmental science research community. It supports large-scale data analysis, simulation and modelling efforts that are crucial for advancing understanding and actions regarding climate change and environmental sustainability.

07

Going International

Both AI and climate change are borderless. The most efficient way to harness the positive loop between the green and AI transitions is to collaborate internationally – to shortcut learning by doing, efficiently allocate scarce R&D funding, ensure consistency and interoperability of green-AI regulations standards, and encourage best practice.

To do this, it is essential to get international buy-in through forums in both the ICT and climate sectors, and to build a network across these sectors. As highlighted in the 2023 Breakthrough Agenda Report,[49] co-authored by the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA) and the United Nations (UN) Climate Change High-Level Champions, international collaboration is not yet strong enough to deliver climate goals; AI coordination at the global level is also nascent. Specifically, international-level efforts are needed to:

1. **Create an international peer-learning network for governments**, co-developing policy frameworks and sharing best practice.
2. **Adopt common metrics and reporting frameworks**, ensuring cohesion and comparability across efforts. Without this, it is difficult to understand the global scale and scope of AI's energy use and carbon footprint, forecast trends and enable comparability – all of which can hamper innovation and action.
3. **Coordinate horizon scanning, monitoring and forecasting** to track progress and identify persisting or emerging challenges, enabling robust policy evaluation.
4. **Collaborate on R&D** to support technology transfer and capacity-building mechanisms for green-AI compute infrastructure and skills development, particularly in emerging economies.
5. **Coordinate on standards and regulations for green-AI practices** to limit carbon leakage by preventing AI compute infrastructure from shifting to countries with more relaxed policies. Transparency and coordination of standards and regulations also supports the development and adoption of best practice, creating greater international cohesion and putting public pressure on organisations and countries to adhere to green practices.

Recommendation: Leverage the Conference of the Parties (COP) and its Breakthrough Agenda to coordinate high-level collaboration and agenda-setting for green AI. The Breakthrough Agenda brings together stakeholders to decarbonise specific sectors. Data centres are included within Buildings Breakthrough, established at COP28 in 2023.[50] A distinct AI Breakthrough should be established to conduct specific monitoring, forecasting and strategising on emissions across the AI value chain. Reporting from the AI Breakthrough to COP will reveal if the sector is on track to meet global climate goals, and more stringent measures can be introduced by governments if it is not.

Recommendation: Work through international institutions to support technical-level delivery. Many existing international institutions and networks are well-suited to support and deliver the technical aspects of high-level international collaboration and coordination across the five areas outlined above. Some of these organisations are already performing this function but require broader buy-in and support from across the international community. The table below lays out which existing international institution is best suited to address each of these different action areas:

FIGURE 7

International-organisation green-AI capabilities

UNITED NATIONS

Relevant mechanisms: International Telecommunication Union (ITU), Conference of the Parties (COP), Breakthrough Agenda, 24/7 Carbon-Free Energy Compact, Climate Technology Centre and Network (CTCN), Technology Executive Committee (TEC)

Expansion areas: All actors should engage and adopt

AI value chain
Grid
Hardware
Software
Operations

Green AI functions
Capacity building
Peer learning
Tech transfer
R&D
Monitoring trends
Common metrics

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD)

Relevant mechanisms: The expert group on compute and climate OECD.AI can serve as an example of an international policy working group that conducts analysis on the energy consumption and environmental impact of domestic AI compute capacity

Expansion areas: While OECD.AI can serve as a model for other non-OECD countries, data-sharing and horizon-scanning efforts should be global in nature

AI value chain
Grid
Hardware
Software
Operations

Green AI functions
Capacity building
Peer learning
R&D
Common metrics
Reporting frameworks
Standards
Joint compute

OPEN COMPUTE PROJECT (OCP)

AI value chain
Hardware

Green AI functions
Capacity building
Peer learning
Common metrics

GREEN SOFTWARE FOUNDATION (GSF)

AI value chain
Software

Green AI functions
Peer learning
R&D
Common metrics
Reporting frameworks
Standards

AI VERIFY FOUNDATION

Expansion areas: Incorporate green AI into principles and best practice for responsible use of the technology

AI value chain
Hardware
Software

Green AI functions
Capacity building
Peer learning
Common metrics
Standards

CLIMATE NEUTRAL DATA CENTRE PACT (CNDCP or The Pact)

Relevant mechanisms: The Pact and working groups

AI value chain
Hardware

Green AI functions
Capacity building
Peer learning

CLIMATE CHANGE AI (CCAI)

Relevant mechanisms: Community platform, workshops

AI value chain
Software
Operations

Green AI functions
Capacity building
Peer learning
R&D

WORLD BANK

Relevant mechanisms: Guide to Green Data Centres, the International Finance Corporation's (IFC) Excellence in Design for Greater Efficiencies (EDGE) building certification

AI value chain
Grid
Hardware

Green AI functions
Peer learning
Tech transfer
R&D
Standards

SCIENCE BASED TARGETS INITIATIVE (SBTi)

Expansion areas: Establish a specific AI pathway

AI value chain
Grid
Hardware

Green AI functions
Peer learning
Common metrics
Reporting frameworks
Standards

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

Relevant mechanisms: Software Carbon Intensity (SCI) specification

AI value chain
Grid
Hardware
Software
Operations

Green AI functions
Standards

INTERNATIONAL ENERGY AGENCY (IEA)

Relevant mechanisms: Annual tracking and forecasting of global data-centre energy use and emissions,
Technology Collaboration Programme (TCP)

AI value chain
Grid

Green AI functions
Capacity building
Peer learning
Tech transfer
Monitoring trends

GREENHOUSE GAS PROTOCOL (GHG Protocol)

Relevant mechanisms: Corporate Accounting and Reporting Standard

AI value chain
Grid
Hardware

Green AI functions
Common metrics
Reporting frameworks
Standards

INTERNATIONAL FINANCIAL REPORTING STANDARDS FOUNDATION (IFRS Foundation)

AI value chain
Grid
Hardware

Green AI functions
Standards

ASSOCIATION OF SOUTHEAST ASIAN NATIONS (ASEAN)

Relevant mechanisms: ASEAN Working Group on Environmentally Sustainable Cities (AWGESC), ASEAN Working Group on Climate Change (AWGCC)

AI value chain
Grid
Hardware
Software
Operations

Green AI functions
Capacity building
Peer learning
Common metrics
Standards
Joint compute

Recommendation: Governments should collaborate and coordinate on green-AI research to reduce R&D costs, share information and drive further green AI research, innovation and deployment. Specifically:

- Replicate the Breakthrough Energy Ventures Europe approach,[51] pooling resources to establish a "Breakthrough Green AI Ventures". Such a fund would leverage the significant investments hyperscale data-centre operators and large AI companies are already investing in this space.
- Provide dedicated funding for Focused Research Organisations (FROs) working on specific green computational research and commercialisation issues. There is more information on FROs below. Different countries could prioritise different kinds of FROs, but they could exist as part of an international umbrella network run by a philanthropic organisation, with joint funding from governments.
- Contribute to a joint compute fund to finance challenges in strategically important aspects of climate tech where compute power has the potential to unlock big breakthroughs. Leading AI and quantum companies would be paid to allocate part of their compute capacity towards supporting funded research. This differs from the sovereign compute pool in that it is targeted at more specific problems and resources and data are coordinated and shared across countries. This mitigates the risk of duplicative efforts by researchers. For many countries this will be more accessible than substantial sovereign compute pools.
- Establish an international data-centre experimentation hub modelled on the Interuniversity Microelectronics Centre (IMEC), the global centre for semiconductor innovation, which provides space to test, experiment and commercialise new innovations. The hub should utilise triple-helix partnerships to ensure commercial viability and adoption of any innovative solutions that are generated.

Focused Research Organisations: A Deeper Dive

What Are FROs?

FROs undertake projects that are too big for a single academic lab, too complex for a loose multi-lab collaboration and not directly profitable enough for a venture-backed startup or industrial R&D project. They are run by full-time technicians who oversee ten to 30 employees and who pursue specific, quantifiable technical milestones rather than doing blue-sky research. They are also finite in duration, usually lasting five to seven years. As they near completion, they translate what they have built into venture-backed startup spinouts and/or longer-lived nonprofits.

Suggested Research Areas for FROs

Although breakthroughs in the AI ecosystem can be profitable, there are particular challenges that FROs could address, including:

- Developing ultra-efficient AI architectures, for instance research into novel neural-network architectures that prioritise computational efficiency without compromising on performance.
- Developing and open sourcing advanced optimisation algorithms, for instance model pruning, quantisation and knowledge distillation, that make models lighter and faster.
- Establishing comprehensive benchmarks and standards for measuring and reporting the energy efficiency of AI models.
- Compiling and releasing large, high-quality datasets designed to train AI models more efficiently.
- Prioritising different kinds of FROs in different countries and contexts, all of which are part of an international umbrella network run by a philanthropic organisation with joint funding from governments.

08

Greening AI in Practice: Lessons From Singapore

From its work optimising energy efficiency for data centres in tropical climate countries[52] to its more recent efforts focused on greening AI software,[53] Singapore provides strong examples of green-AI best practices across the value chain. Governments across country-income level can learn from its experience and leverage valuable insights to advance green-AI innovation.

Laying the Foundations

Central to Singapore's success in advancing green AI is its application of triple-helix partnerships. Singapore led the application of the triple-helix model of innovation in its first national AI strategy in 2019,[54] recognising the critical importance of interconnecting government, the private sector and academia to enable the development and deployment of AI solutions.

Singapore's IMDA has put this into practice, leveraging its role as connector to help bring researchers and industry together to collaborate on pilot projects and validate their technologies in a real-world setting, with the aim of supporting the translation of research into market-ready solutions.[55] Such partnerships also serve as platforms for ongoing dialogue among government agencies, academic institutions and industry firms to help the government formulate guidelines and regulations that support innovation while balancing the risks.

IMDA's Green Computing Funding Initiative (GCFI) exemplifies the effectiveness and impact of such partnerships in support of green AI.[56] An SGD 30 million funding pool for research to optimise the design and function of energy-efficient software, it enables researchers from institutes of higher learning to collaborate with industry to solve problems related to green computing. The GCFI is targeting its funding on use cases not served by existing commercial solutions and will be accompanied by further efforts to bring together researchers and industry to co-develop low-carbon digital solutions for the technology industry. Governments can use the GCFI as a model to develop similar funds.

IDENTIFYING THE SCALE OF THE PROBLEM

Singapore leads the way in setting sustainability standards for AI, with the world's first sustainability standard for green data centres in tropical settings. Additionally, as a member of the Green Software Foundation, Singapore contributes to initiatives like the SCI specification, promoting transparency of and accountability for the carbon emissions of AI software.

INCENTIVISING AI DECARBONISATION AND ENERGY EFFICIENCY THROUGH TARGETS AND POLICY

In 2022, following its four-year temporary pause on new data centres, Singapore's Economic Development Board and IMDA announced a pilot for companies to set up data centres with more sustainable energy use and more efficient cooling methods.[57] The criteria for new data centres prioritised ones that utilised "state of the art technologies and best practices for sustainability, particularly in the areas of energy efficiency and decarbonisation", as well as investment in wider national benefits, such as energy infrastructure.

Singapore is taking this a step further with the upcoming release of a "Green Data Centre Roadmap", which is set to unlock additional green data-centre capacity in the coming years. The roadmap calls on industry players to play a catalytic role in fostering partnerships across the ecosystem in order to accelerate data centres' use of green and efficient energy in both hardware and software to realise the broader goal of sustainable development.

CREATING BETTER ALTERNATIVES

Singapore is particularly advanced in its R&D capacity and contributions to innovation in both hardware and software through initiatives such as the Sustainable Tropical Data Centre Testbed and green software trials.

The Sustainable Tropical Data Centre Testbed was set up at the end of 2023.[58] It is funded by the National Research Foundation with Meta as an anchor industry partner and research led by the National University of Singapore and Nanyang Technological University with support from IMDA. The Centre focuses on surfacing sustainable and efficient data-centre solutions specific to the context of the region's high-temperature and humid operating environment. Countries with similar conditions can build on progress made by Singapore's testbed and assess the feasibility of applying these solutions to their own local contexts.

On the software side, Singapore's green software trials are a first-of-its-kind effort led by IMDA to invest in exploratory research into the tangible energy efficiency and cost savings of greening AI software. Industry players are participating in trials to better understand how to develop green software and reduce energy use and IT costs. The trials will see industry players apply carbon-reduction techniques to digital applications and measure their impact and effectiveness in operational contexts and their ability to increase energy and cost efficiencies without compromising performance. Data from the trials will inform guidelines and best practice for green software development within the industry, which companies will be able to use at scale. They will also provide a basis for incentivising the adoption of green-AI software by providing evidence for the cost savings associated with operations-optimisation strategies.

Finally, to further support research and innovation that would provide societal benefits such as green AI, in its National AI Strategy 2.0 Singapore has also committed to allocating a proportion of high-performance compute to support meritorious use cases, including for the public good.

GOING INTERNATIONAL

Singapore actively engages in the growing international community around AI through participation in the Global Partnership on AI, the World Economic Forum AI Governance Alliance and the UN High-Level Advisory Body on AI. IMDA also produced the world's first AI governance-testing framework and software toolkit, AI Verify, in 2022 to help companies and other builders of AI systems to validate their performance against a set of internationally endorsed principles. The AI Verify Foundation was then established as an open-source community to forge partnerships that drive momentum around the development of trustworthy AI.

Singapore is also engaged in green AI. It became the first country to join the Green Software Foundation through IMDA to work jointly with key technology partners on promoting greener software practices and contributing to building consensus around measuring the environmental impact of AI software. By sharing its expertise, Singapore contributes to a sustainable digital future on a global scale.

09

Conclusion

AI will have a transformational impact across the climate and energy sectors. Governments have a critical role to play in unlocking the positive loop between the AI and energy revolutions. AI can fuel the scientific and R&D breakthroughs needed to accelerate the energy transition; the energy transition in turn can drive clean-energy production, energy-efficiency gains and cost savings critical to accelerating technological innovation. In this way, the AI and energy revolutions can become force multipliers. Governments that can harness this dynamic will find advantage.

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10 Annex

FIGURE 8

Recommendations for different infrastructure-development levels

Countries with advanced compute ecosystems

- Establish institutional mechanisms at the heart of government
- Invest in clean grid infrastructure
- Establish "triple-helix partnerships"
- Require reporting on grid capacity and carbon intensity
- Establish and adopt best-practice metrics for data-centre energy consumption and carbon emissions
- Incentivise best practice by creating a green-AI certification scheme
- Integrate coordination and collaboration on green AI into existing international forums

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- Establish and adopt best-practice metrics for the energy consumption and carbon emissions of AI software
- Incentivise best practice by creating a green-AI certification scheme
- Increase R&D investment in green-AI hardware and software
- Promote open-source resources
- Dedicate a portion of the national compute pool to green-AI research
- Integrate coordination and collaboration on green AI into existing international forums

Countries with emerging renewable-energy infrastructure

Countries with advanced renewable-energy infrastructure

- Establish institutional mechanisms at the heart of government
- Invest in clean grid infrastructure
- Establish "triple-helix partnerships"
- Require reporting on grid capacity and carbon intensity
- Establish and adopt best-practice metrics for data-centre energy consumption and carbon emissions
- Create an innovation-responsive environment
- Incentivise best practice by creating a green-AI certification scheme
- Explore the introduction of more mandatory standards and requirements
- Facilitate and scale private-sector innovation in advanced energy-source solutions
- Integrate coordination and collaboration on green AI into existing international forums

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- Increase R&D investment in green-AI hardware and software
- Promote open-source resources
- Dedicate a portion of the national compute pool to green-AI research
- Integrate coordination and collaboration on green AI into existing international forums

Countries with emerging compute ecosystems

Endnotes

1 While this paper is focused on AI's energy demand and carbon emissions, it is important to note a myriad of broader climate impacts are nevertheless equally important and require additional study and consideration. For instance, the ways in which AI is used by end users can have far-reaching impacts for broader climate action – for better or for worse – from their use to further fossil-fuel exploration and extraction on the one hand, to helping illuminate climate, conservation, and humanitarian risks and realities as never before on the other. As governments continue to develop national AI strategies and build out their green AI capabilities, it is important that both governments and other actors across the whole AI value chain consider these broader climate impacts.

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