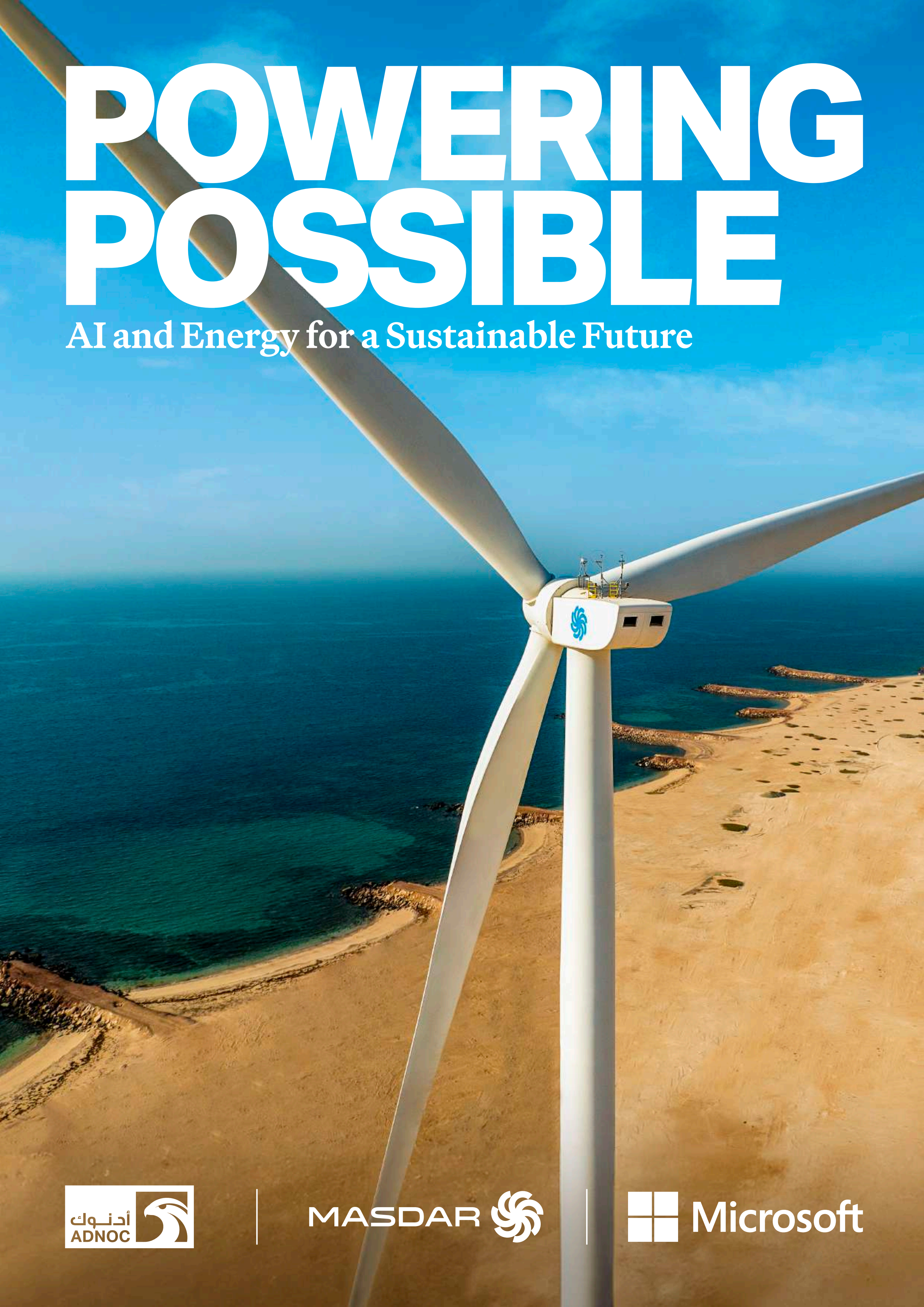
POWERING POSSIBLE

AI and Energy for a Sustainable Future



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We are at a pivotal moment for human progress driven by three megatrends, the rise of the Global South, the accelerated energy transformation, and the rapid growth of AI.

AI is an era-defining innovation that is altering the pace of change itself - resetting the boundaries of productivity and the possibilities of progress. But in doing so, it is also creating a power surge that nobody accounted for just 18 months ago.

By collaborating to solve AI's near-term challenges, we can also unlock AI's long-term benefits across the energy value chain – helping to secure a sustainable and prosperous future for generations to come.

Dr. Sultan Al Jaber
Managing Director and Group CEO, ADNOC
and Chairman, Masdar

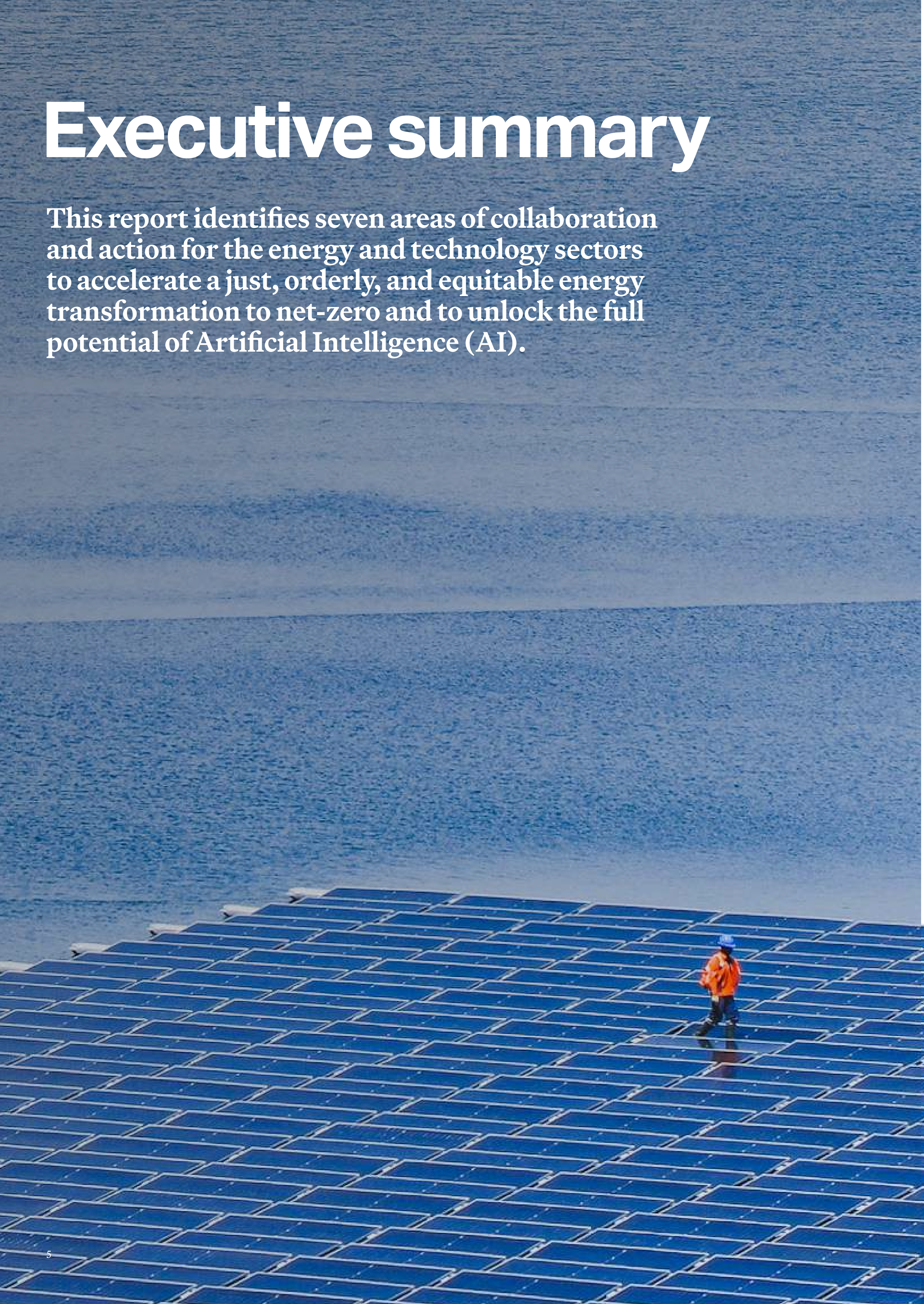
This new era calls on us to do two things at once:

Meet the AI moment while transitioning to a more sustainable economy.

In a world that will need more electricity, not less, it's imperative that we generate more carbon free energy to power AI and use that very same technology to increase capacity, optimize transmission, and expand energy access to communities around the world.

This isn't a journey any of us can take alone. It requires working across technology, energy, science, and policy sectors to find solutions and accelerate our collective progress.

Brad Smith
Vice Chair and President, Microsoft



Executive summary

This report identifies seven areas of collaboration and action for the energy and technology sectors to accelerate a just, orderly, and equitable energy transformation to net-zero and to unlock the full potential of Artificial Intelligence (AI).

Energy and technology, longtime drivers of humanity's progress and prosperity, have powered the world's industrialization and enabled dramatic improvements in living standards. In just the past 40 years, the global energy system has contributed to lifting over 1 billion people out of poverty,[1] a 10-year increase in life expectancy,[2] and a rise in literacy rates from 70% to 90%.[3] **Yet these benefits have not been experienced equally; nearly 750 million people still lack access to electricity, particularly in the Global South, where expanding energy access is fundamental to fostering economic prosperity.[4]**

Since the 1960s, global energy demand has quadrupled (despite increased energy efficiency) and technological advancements have surged.[5] The global economy now stands at a crossroads: the imperative to accelerate the net-zero energy transformation, growing energy demand, particularly in the Global South, and the expected development and growth of AI. Convergence of these three megatrends represents an opportunity to shape a sustainable and equitable future.

The UAE Consensus, agreed to by 198 parties[6] at COP28, laid out a path to achieve a just, orderly, and equitable transition to a net-zero energy system. Amongst other things, that requires tripling renewable energy capacity and doubling the rate of energy efficiency by 2030, while accelerating new carbon-free technologies. AI has emerged as one enabling technology that has the potential to support the achievement of these objectives whilst meeting rising energy demand.[7]

AI's recent advancements and increased adoption suggest it can help accelerate the global energy system's transformation to net zero whilst meeting the projected 3–4% per year increase in global electricity demand through 2030.[8] However, to realize AI's full potential, much more is needed, and much more is possible. The electricity needed to power the data centers critical to AI and other digital services is expected to grow between 8–23% per year through 2026, bringing AI use to 0.24% of global electricity demand.[9] Despite $250 billion in private investments in AI between 2017 and 2023, only 5% of that funding went to the energy sector. Much more investment is urgently needed in this area to leverage AI's potential for driving innovation and sustainability in energy systems.[10]

Of course, even the most effective and widespread deployment of AI must be combined with other enablers of the transition, including policy and regulation, public and private investment, and support for the Global South.

SURVEY INSIGHT

Of executives surveyed

92% by 2030

believe AI will have a transformative impact on the energy system and it increases to

97% by 2050

According to the International Renewable Energy Agency (IRENA), the annual rate of deployment of renewable generation must grow by 16% every year through 2030 to meet the tripling target.[11] To achieve this target, it is critical to address key challenges such as permitting, grid infrastructure, financing, and supply chain bottlenecks. For instance, permitting constraints can delay utility-scale projects by seven to 12 years. AI could help to streamline data workflows and speed up permitting and siting by up to 40%.[12]

By 2040, electricity grids will need to add or refurbish 80 million kilometers of network in order to connect rising demand and more diversified supply.[13] AI is already playing a role. For example, companies in India and Ghana are using it to support the expansion of transmission networks and the integration of renewable energy.[14]

To achieve the goals of the UAE Consensus and the Paris Agreement, methane emissions must fall by over 30% by 2030 under the Global Methane Pledge.[15] AI tools are already being deployed to detect methane with greater accuracy at a fraction of the cost. Although AI can help, methane reduction can only be delivered with stricter regulation and enforcement; 50% of methane emissions come from 11 countries where significant progress is needed.[16]

For this report, ADNOC surveyed approximately 400 global leaders from different sectors on AI and Energy. Among the executives surveyed, 92% by 2030 and 97% by 2050 believe that AI will have a transformative impact on the energy system, with a focus on improving energy efficiency in the short term and advancing emerging energy solutions (e.g., small modular nuclear reactors, carbon capture) in the longer term. Despite the enthusiasm shown by senior leadership, conventional energy has been slower to adopt AI than other industries (e.g., 23% of conventional energy organizations allocate more than five percent of their annual budget to implementation and development of AI-based solutions, compared to 56% of the renewable sector who allocate more than five percent of their annual budget to implementation and development of AI-based solutions).[17]

The energy system of the future will need to rely more on electrification and distributed generation and place a premium on flexibility, efficiency, and resilience. AI's capabilities in analytics and optimization can help to manage this variability and complexity, on both the supply and the demand side.

For example, AI can be used to model how distributed sources like rooftop-solar affect grid capacity. It can also help match variable supply with evolving demand, which will be essential in the renewables-dominated electricity system of the future.

Specifically, AI can dynamically simulate grid load and transmission capacity to improve transmission and distribution efficiency. AI can also support a more resilient grid. For example, smart grids that link sensors and GIS data with AI can better predict disruptions from wildfires, floods, and storms. Finally, AI is already accelerating research and development into new materials that could increase the capacity and stability of energy storage and carbon removal, amongst other areas.[18,19]

AI capabilities have matured rapidly in recent years, and expectations are high. Investment in AI is projected to rise to $150 billion in 2025.[20] Technology and energy leaders must work together to ensure access to reliable carbon-free energy, a critical enabler for AI's continued development and growth. Together they are well positioned to make this happen.

The electricity needed to power the data centers is expected to grow between

8-23%

bringing AI use to 0.24% of global electricity demand [9]

SURVEY INSIGHT

Conventional energy companies have been slower to adopt AI-based solutions than renewable energy counterparts

AI depends on data centers and other critical infrastructure. Data centers account for approximately 1–1.3% of global electricity demand, and this is expected to almost double to 2% by 2026.[21] Of global electricity demand, AI-driven data centers account for a small but growing share: 0.02% in 2022 and 0.24% in 2026.[22] Demand growth for continuous and reliable power can put pressure on electricity grids where data centers are concentrated. In the European Union (EU), electricity demand for data centers is expected to increase at ~9% per year, due to digitalization including AI, and could exceed 5% of total EU electricity demand by 2026. In the U.S.—the largest data center market globally—data centers represented about 4% of the nation's electricity demand in 2022 and that is expected to rise to nearly 6% by 2026.[23] This demand growth can be challenging in regions with aging transmission infrastructure and growing competing demands for new, carbon-free generation.

MASDAR

"As the UAE's renewable energy champion and a global clean energy leader, Masdar has a proven track record in pioneering clean energy projects for nearly two decades. But AI has changed the game, and it represents one of the greatest opportunities to transform the global clean energy industry in history. AI – and the data centers it requires - will serve as an increasingly important driver of global energy demand. Meeting this demand sustainably will require a multifaceted approach, and it is up to all of us to work together to unleash its full potential and build a more sustainable future."

Mohamed Jameel Al Ramahi
CEO, Masdar

We see huge potential for collaboration between the energy and technology sectors to accelerate a just, orderly, and equitable energy transformation to net zero and manage the energy system of the future whilst unlocking the full potential of AI with carbon-free electricity.

Specifically, we see seven priority areas:

01 Increase collaboration between technology and energy companies to deploy more carbon-free energy while making it more available and more affordable for all.

02 Invest in AI for the energy transformation, with a focus in four key areas: tripling the availability of renewable energy, building resilient grids, reducing methane emissions, and utilizing carbon capture and storage.

03 Expand and enhance grid capacity, increase availability of carbon-free electricity, especially in locally stressed grids or regions—while continuing to innovate to increase energy efficiency.

04 Build capacity in the workforce to leverage AI for energy transformation.

05 Develop AI with and for emerging economies, to meet their unique needs.

06 Establish data standards and protocols for AI to better support the energy sector.

07 Advance policy and governance for responsible, sustainable AI and a secure and inclusive transformation to a net-zero energy system.

The challenge and opportunity for ENERGY AND AI

Energy, innovation, and growth

The world has witnessed how technological innovation and access to affordable energy have delivered global growth and socio-economic progress for two centuries. Billions have been lifted out of poverty as a result, though millions are still without access to electricity and are at a disadvantage because of it.

> "AI will be the catalyst for transforming energy systems globally. By harnessing advanced AI solutions, we can expand energy access, accelerate economic development, and enable adopting nations to spearhead the worldwide shift toward sustainable energy practices. This integration promises not only to optimize current systems but also to innovate new pathways for environmental stewardship and energy efficiency."

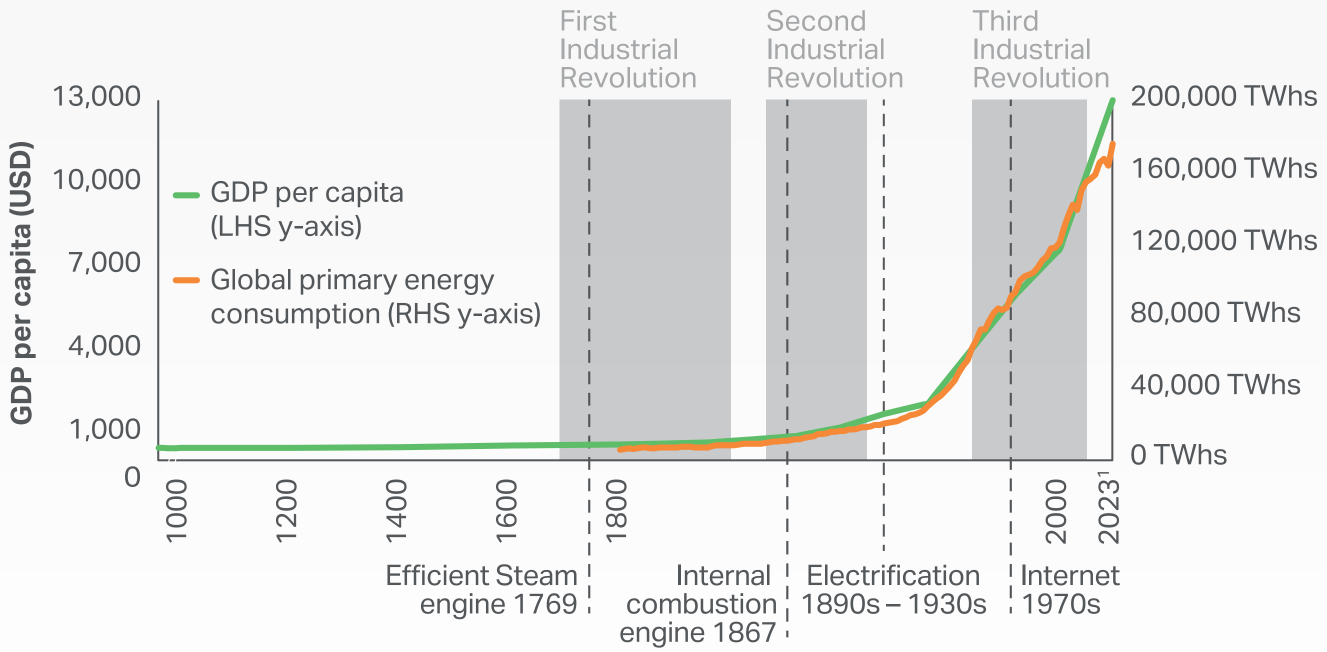
Peng Xiao
GCEO, G42

Energy and technology have underpinned two centuries of global economic growth and prosperity. From the steam engine of the early 19th century through the internal combustion engine of the mid-20th century to the internet of the late 20th century, successive waves of technological innovation have enabled humanity to produce more output with less input. Global GDP per capita—after a long stagnation that may have lasted many thousands of years—took off in the 19th century. Today, it has reached $13,000 per person, a 13-fold increase in a little over two centuries.

The widespread adoption of the technological innovations driving that growth relied upon access to affordable and reliable energy in ever-greater quantities. In 1800, primary energy demand was 6,250 TWh per year; today, it is 180,000 TWh.[24] It was technological innovation that unlocked that energy—from the introduction of coal-powered steam engines in the coal mines of the late 18th century to the fracking revolution of the 1990s. It has been a cycle of positive reinforcement (see Figure 1).

Figure 1

Technological innovation and energy have underpinned economic growth



Note: GDP per capita data for year 0 – 1980 based on data from Maddison Project Database and University of Gronigen; 1980-present based on data from IMF
Source: Our World in Data, World Bank, "World Bank World Development Indicators", 2023; Bolt and van Zanden - Maddison Project Database 2023, University of Gronigen; Maddison Database 2010; Oxford Economics (GDP data from IMF Data Portal-1980 onwards); ADNOC Analysis

More recently, primary energy demand has begun to decouple from economic growth in more mature markets. Global GDP has almost tripled since 1990, while energy intensity has fallen 34% (see Figure 2), driven by a shift from industry to services, as well as steady improvements in energy efficiency.

Related, the emissions intensity of the global economy has declined by c. 60% since 1970, even whilst absolute emissions have continued to grow (see Figure 3).

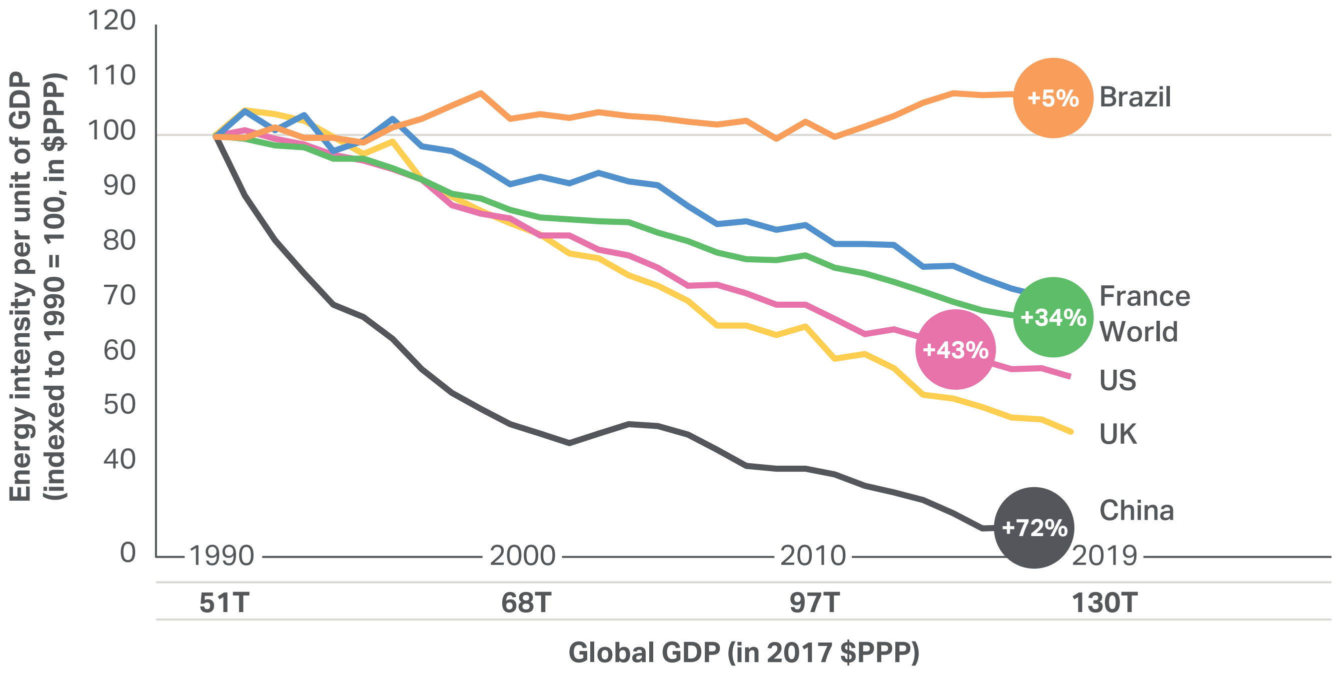
Technological innovation has helped

reduce the energy and emissions intensity

of economic output

Figure 2

Economic output has become less energy-intensive since 1990

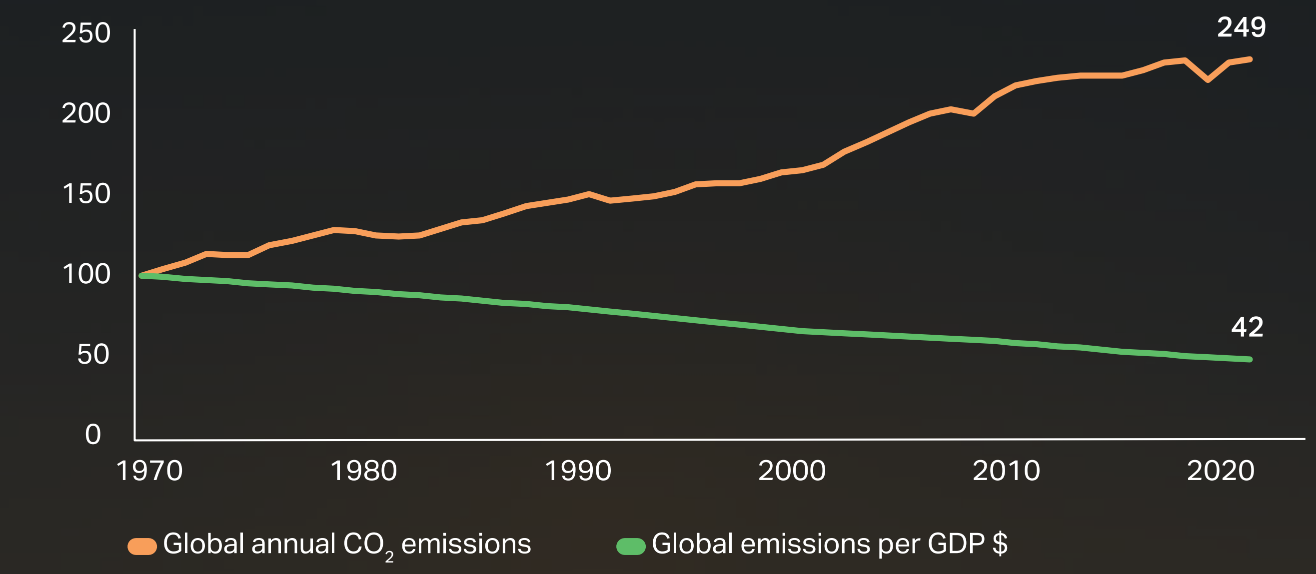


Note: PPP = purchasing power parity; T = trillion
Source: BCG, A Blueprint for the Energy Transition, 2023.

Figure 3

Global emissions continue to grow, even as emissions per capita fall

Global emissions 1970 onwards [All values indexed to 1970 (1970 = 100)]

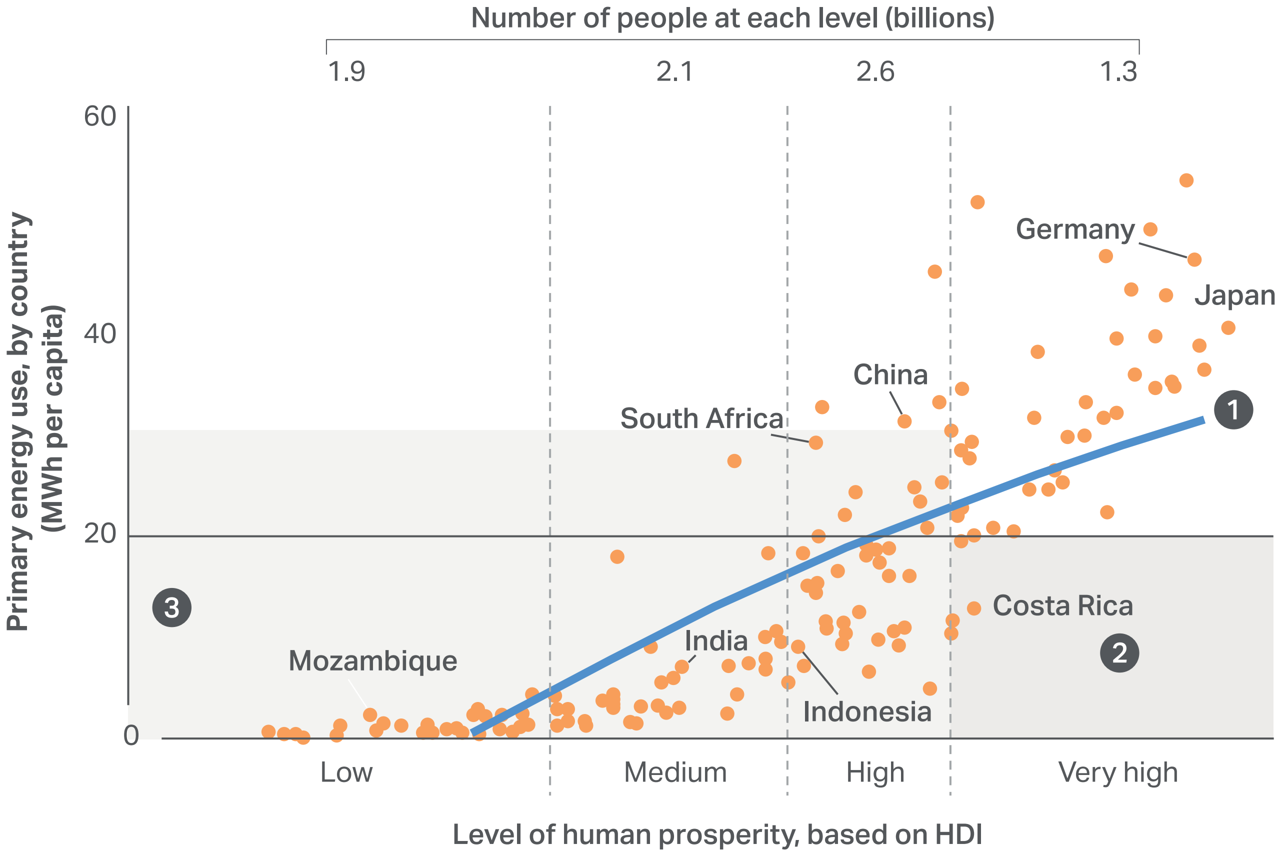


All values indexed to 1970 (1970 = 100).
Source: Global Carbon Budget (2023) – with major processing by Our World in Data

But the availability of energy remains strongly correlated to prosperity (see 1 in Figure 4). In just the past 40 years, the global energy system has contributed to lifting over 1 billion people out of poverty, a 10-year increase in life expectancy, and a rise in literacy rates, from 70% to 90%. Approximately 60 countries that rank low or medium on the UN Human Prosperity Index, rely on less than 20 MWh of primary energy consumption per capita per year (see 2 in Figure 4). Moreover, 750 million people still lack any access to electricity at all (see 3 in Figure 4).[25] Closing this access gap would be a major contribution toward alleviating poverty, particularly in sub-Saharan Africa.

Figure 4

Human prosperity remains highly correlated to primary energy demand



Note: Countries with HDI >0.8 and with per capita energy consumption >60MWh are not shown. HDI = Human development index. HDI measures acountry's performance in terms of life expectancy at birth, average years of schooling, and gross national income. Low, HDI <0.55; medium, HDI ≥0.55 but <0.7; high, HDI ≥0.7 but <0.8; very high, HDI ≥0.8.
Source: BCG, A Blueprint for the Energy Transition, 2023.

> "The close interaction between energy and AI marks a transformative moment in our pursuit of a sustainable future. By harnessing the power of AI to optimize energy systems, we can accelerate the global transition to net-zero, while driving innovation, improving efficiency, and ensuring that clean energy is accessible to all. This is not just an opportunity—it's a responsibility we must embrace to secure a prosperous future for generations to come."

UNITED ARAB EMIRATES
MINISTER OF STATE OFFICE

H.E. Omar Al Olama
Minister of State, Ministry of AI,
Digital Economy and Remote Work Applications Office

Energy and AI at the crossroads

Today, the global economy is at a crossroads, and energy and AI are at the center of developments.

AI is one of the latest technological innovations with the potential to make a significant contribution to economic growth through its emergent abilities to measure, predict, and optimize systems; accelerate innovation; and empower the workforce.

Estimates of AI's potential contribution to global economic output by 2030 vary from $1 trillion to $7 trillion.[26]

Energy and technology companies have the potential to drive this economic opportunity together. For example, technology companies can serve the latent demand for digitalization and deployment of AI in the energy sector; energy companies, on the other hand, can help technology companies with their net-zero goals by serving the necessary demand for carbon-free electricity.

AI could contribute between

$1 trillion

to

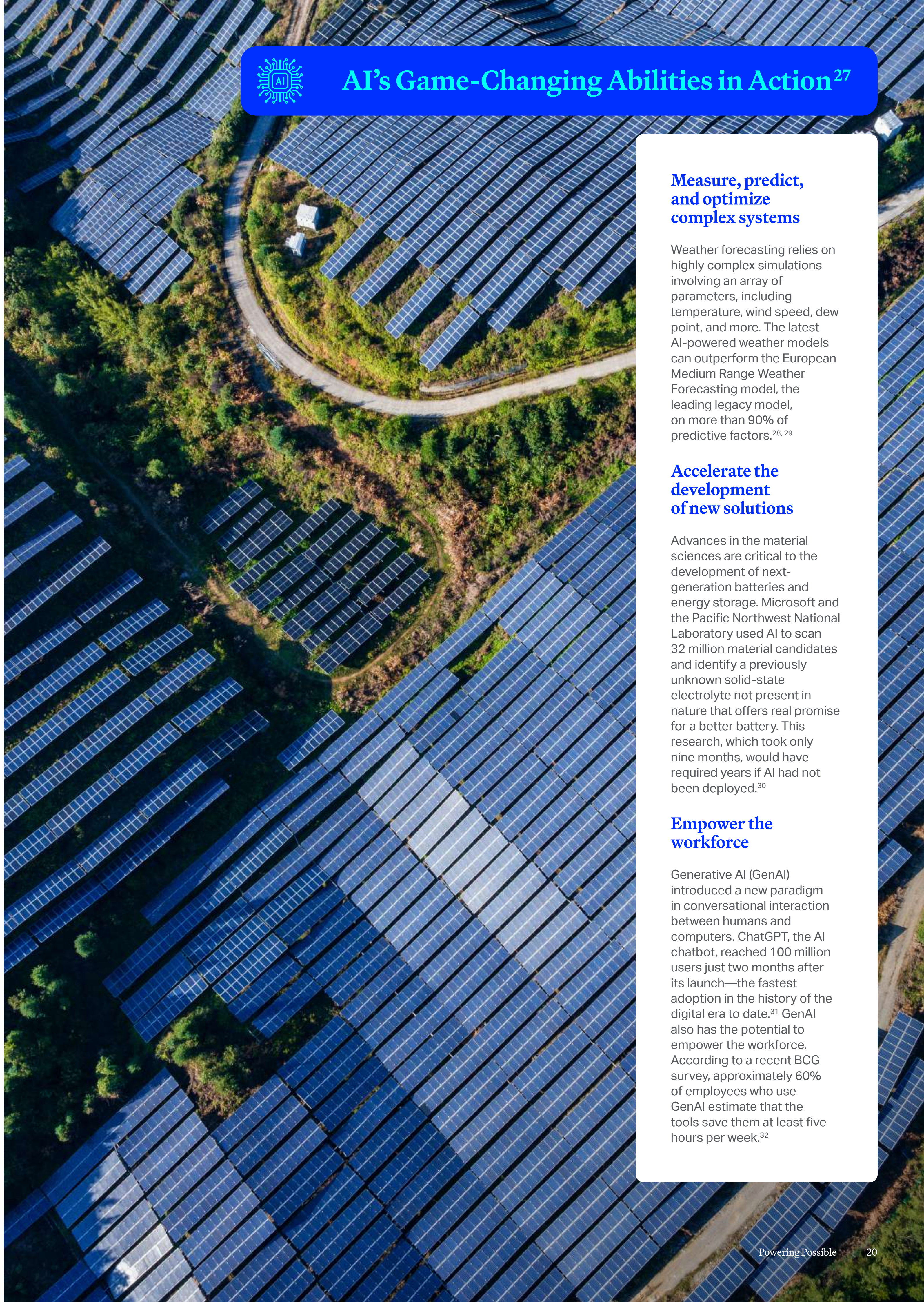
$7 trillion

to the global economic output by 2030[26]

"The rise of AI requires significant infrastructure to support it. Private capital can finance critical investments in data centers as well as energy infrastructure and decarbonization technology needed to meet growing power demand. These investments can help power economic growth, create jobs, and drive AI innovation."

BlackRock

Larry Fink
Chairman and CEO, BlackRock



AI's Game-Changing Abilities in Action[27]

Measure, predict, and optimize complex systems

Weather forecasting relies on highly complex simulations involving an array of parameters, including temperature, wind speed, dew point, and more. The latest AI-powered weather models can outperform the European Medium Range Weather Forecasting model, the leading legacy model, on more than 90% of predictive factors.[28, 29]

Accelerate the development of new solutions

Advances in the material sciences are critical to the development of next-generation batteries and energy storage. Microsoft and the Pacific Northwest National Laboratory used AI to scan 32 million material candidates and identify a previously unknown solid-state electrolyte not present in nature that offers real promise for a better battery. This research, which took only nine months, would have required years if AI had not been deployed.[30]

Empower the workforce

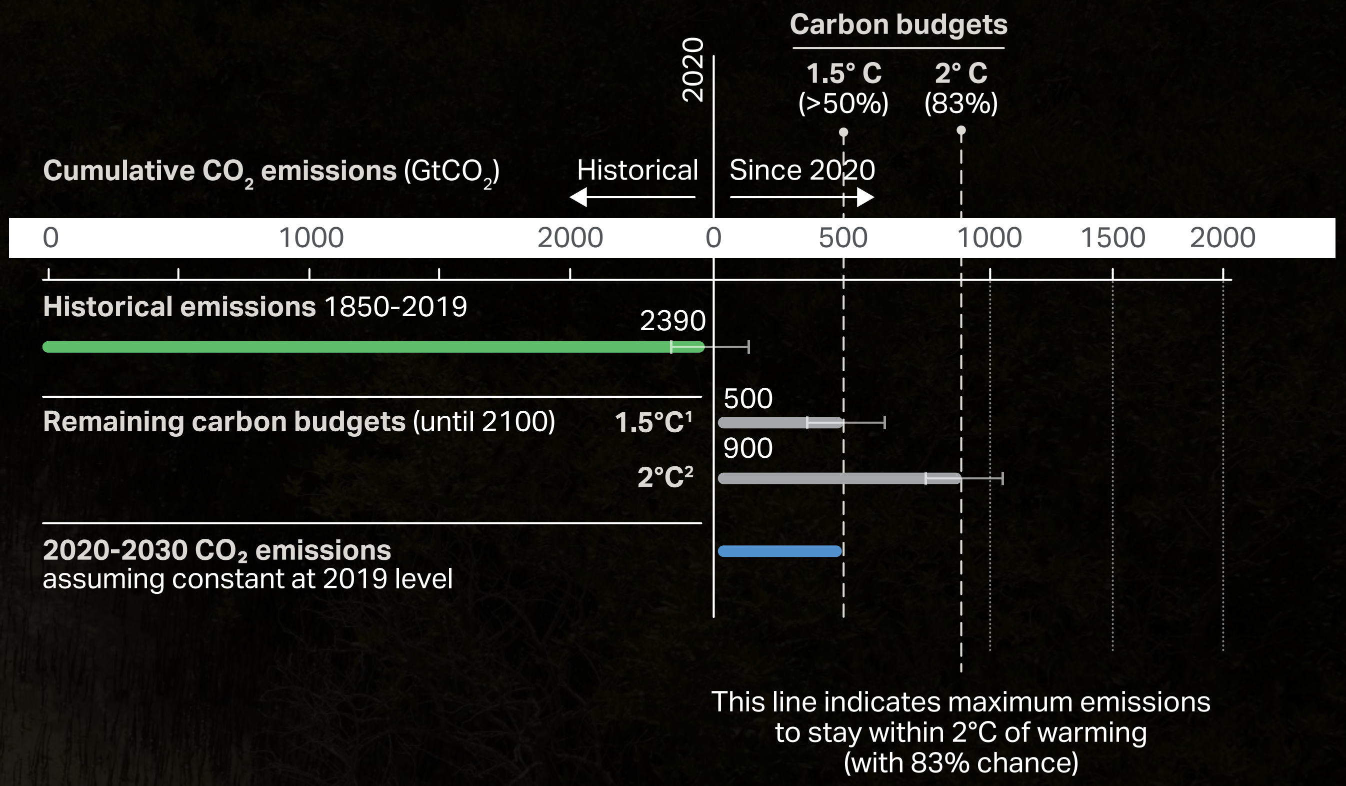
Generative AI (GenAI) introduced a new paradigm in conversational interaction between humans and computers. ChatGPT, the AI chatbot, reached 100 million users just two months after its launch—the fastest adoption in the history of the digital era to date.[31] GenAI also has the potential to empower the workforce. According to a recent BCG survey, approximately 60% of employees who use GenAI estimate that the tools save them at least five hours per week.[32]

Meanwhile, climate change threatens to further undermine economic growth. As a result of anthropogenic greenhouse gas emissions, global average temperatures have risen 1.2°C since the pre-industrial period.[33] This rise has led to climate-related natural disasters causing significant and rising socio-economic impacts.

If we want an even chance of limiting global temperature rise to 1.5°C by 2100, cumulative emissions since 1850 must be limited to c. 2,900 $GtCO_2$; as of now, we have emitted more than 80% of that. If not controlled, we will exhaust the rest of it by 2030 (see Figure 5).[34] The energy system, consisting of producers and consumers, accounts for approximately 75% of greenhouse gas emissions and has a central role to play. For context, this rate of emissions reduction implies an energy transformation roughly three times the speed of any previous one, and from a far larger base.[35]

Figure 5

Global remaining carbon budget dictates that this decade is critical



Note: Figures in parentheses denote level of confidence;
1. 1.5°C with >50% level of confidence; 2. 2°C with 83% level of confidence
Source: IPCC AR6 Synthesis Report; ADNOC Analysis

The potential for partnership between the energy and technology sectors

Greater collaboration between the energy and technology sectors has the potential to unlock progress across this global agenda. Fortunately, AI has become a higher priority over the last three years for 66% of energy companies, according to our survey.

The following three chapters cover three specific areas:

Chapter 2

explores the potential for AI's current and emergent abilities to support a just, orderly, and equitable energy transformation toward net-zero.

Chapter 3

explores the potential for AI's emergent and potential abilities to support the operation of the energy systems of the future.

Chapter 4

explores the small but growing energy demand for AI, and the role energy and technology companies can play in meeting that demand with carbon-free supply.

SURVEY INSIGHT

AI has become a higher priority for

66%

of energy companies over the last 3 years

SURVEY INSIGHT

82%

of leaders believe AI can increase the speed at which energy companies become more sustainable

02

THE POTENTIAL FOR AI

to accelerate the energy transformation

The potential for AI to accelerate the energy transformation

The world requires a just, orderly, and equitable transition to a net-zero energy system.

Last year in Dubai, UAE, world leaders aligned on the pathway to decarbonizing the current energy system and building a system for the future. The COP28 UAE Consensus requires, amongst other things, tripling renewable energy capacity and doubling the rate of energy efficiency by 2030, as well as accelerating the deployment of new carbon-free technologies (see Figure 6).

AI's emergent abilities could make a significant contribution to delivering on these challenging but critical commitments. According to the ADNOC global survey, more than 90% of business leaders believe AI will have a transformational impact on the energy transformation by 2030, and even more believe it will by 2050 (see Figure 7).

AI could play a significant role both in decarbonizing the current energy system and building the energy system of the future. 82% of leaders from the same survey believe AI can increase the speed at which energy companies become more sustainable.

Figure 6

COP28 delivered major commitments across renewable energy, energy efficiency, and more—laying the groundwork for the net-zero system of the future...

28. *Further recognizes* the need for deep, rapid and sustained reductions in greenhouse gas emissions in line with 1.5 °C pathways and *calls* on Parties to contribute to the following global efforts, in a nationally determined manner, taking into account the Paris Agreement and their different national circumstances, pathways and approaches:

(a) Tripling renewable energy capacity globally and doubling the global average annual rate of energy efficiency improvements by 2030;

(b) Accelerating efforts towards the phase-down of unabated coal power;

(c) Accelerating efforts globally towards net zero emission energy systems, utilizing zero- and low-carbon fuels well before or by around mid-century;

(d) Transitioning away from fossil fuels in energy systems, in a just, orderly and equitable manner, accelerating action in this critical decade, so as to achieve net zero by 2050 in keeping with the science;

(e) Accelerating zero- and low-emission technologies, including, inter alia, renewables, nuclear, abatement and removal technologies such as carbon capture and utilization and storage, particularly in hard-to-abate sectors, and low-carbon hydrogen production;

(f) Accelerating and substantially reducing non-carbon-dioxide emissions globally, including in particular methane emissions by 2030;

(g) Accelerating the reduction of emissions from road transport on a range of pathways, including through development of infrastructure and rapid deployment of zero-and low-emission vehicles;

(h) Phasing out inefficient fossil fuel subsidies that do not address energy poverty or just transitions, as soon as possible;

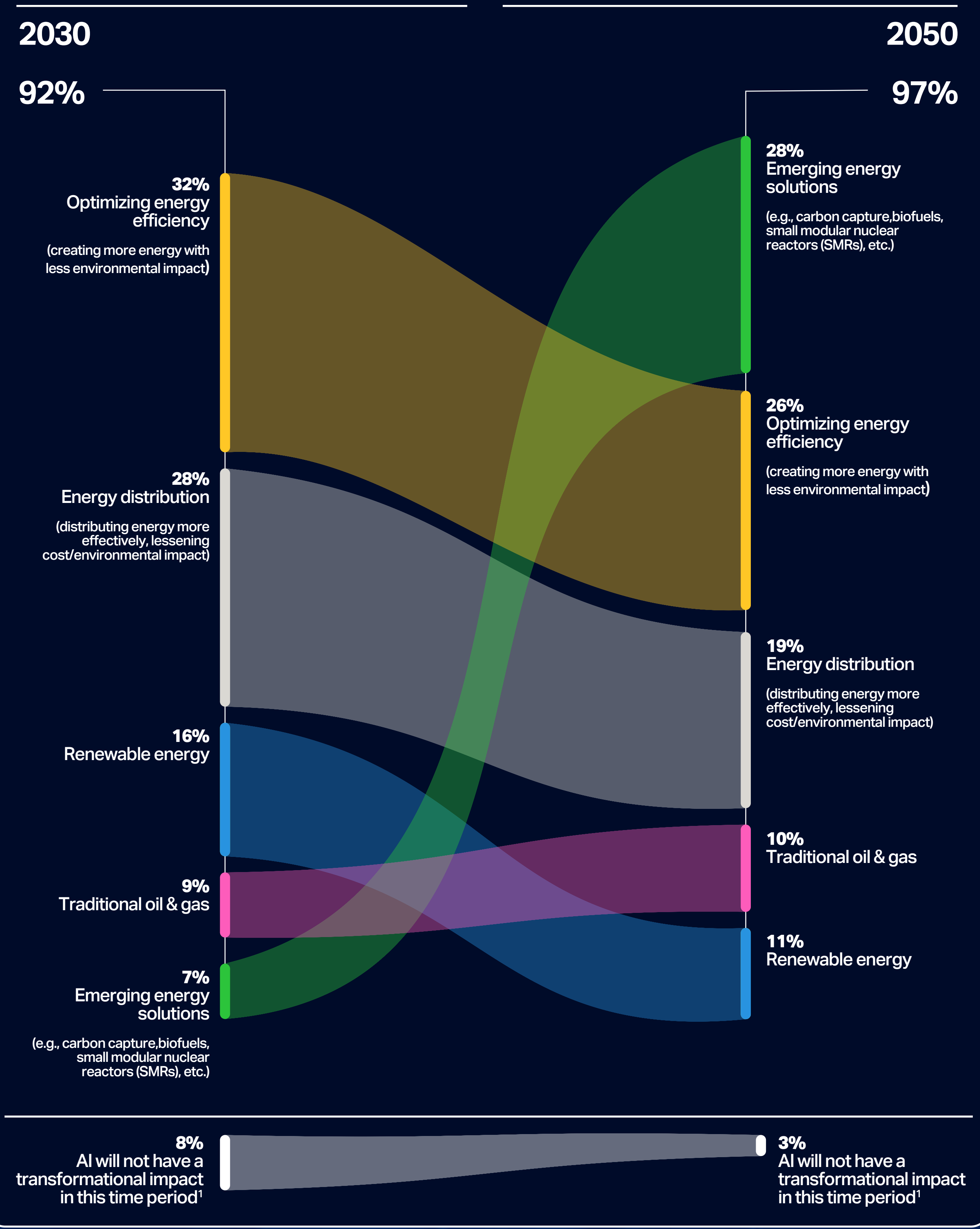
...but bold commitments need to be supported by bold action.

UAE CONSENSUS | COP28 UAE

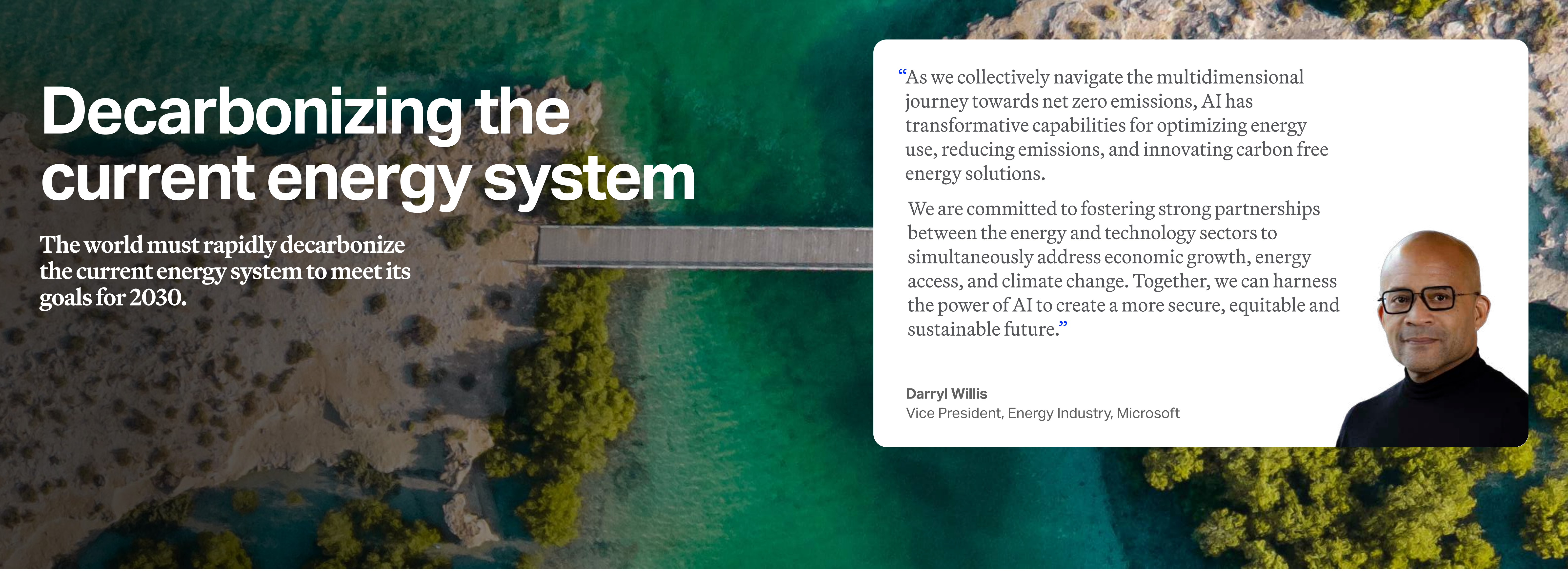
SURVEY INSIGHT

Figure 7

Leaders' confidence in AI driving innovative energy breakthroughs for emerging energy solutions like carbon capture and SMRs quadruples in the long term



Note:1% of respondents responded 'Don't know' are included;
Source: ADNOC AI Survey; Respondents were asked in which area of energy production do they feel artificial intelligence (AI) will have the most transformational impact by 2030 and by 2050.



Decarbonizing the current energy system

The world must rapidly decarbonize the current energy system to meet its goals for 2030.

> "As we collectively navigate the multidimensional journey towards net zero emissions, AI has transformative capabilities for optimizing energy use, reducing emissions, and innovating carbon free energy solutions.
>
> We are committed to fostering strong partnerships between the energy and technology sectors to simultaneously address economic growth, energy access, and climate change. Together, we can harness the power of AI to create a more secure, equitable and sustainable future."

Darryl Willis
Vice President, Energy Industry, Microsoft

According to the International Energy Agency (IEA), demand for coal, oil, and gas will peak this decade based on current policies and fall to 56% by 2050. Even under its Net Zero Scenario, fossil fuels supply would remain 14% of energy supply by 2050, though coal would decline to near zero.[36] In short, oil and gas coupled with carbon capture and storage (CCS) wherever possible, will continue to be a significant proportion of the energy system through the middle of the century, and with significant regional variation in the pace and scale of decline.

The use of oil and gas in the energy system will need to be decarbonized to achieve the goals of the Paris Agreement. The emissions associated with both the production and use of oil and gas must be abated. Methane abatement and CCS are priorities.[37]

Early developments suggest that AI has the potential to play a valuable but supporting role in both methane abatement and CCS.

Role of AI in reducing methane emissions

Methane is approximately 80 times more potent than carbon dioxide (CO_2) at trapping heat in the atmosphere over a 20-year period. It is the second-most abundant anthropogenic greenhouse gas after CO_2, accounting for about 20% of global emissions.[38, 39]

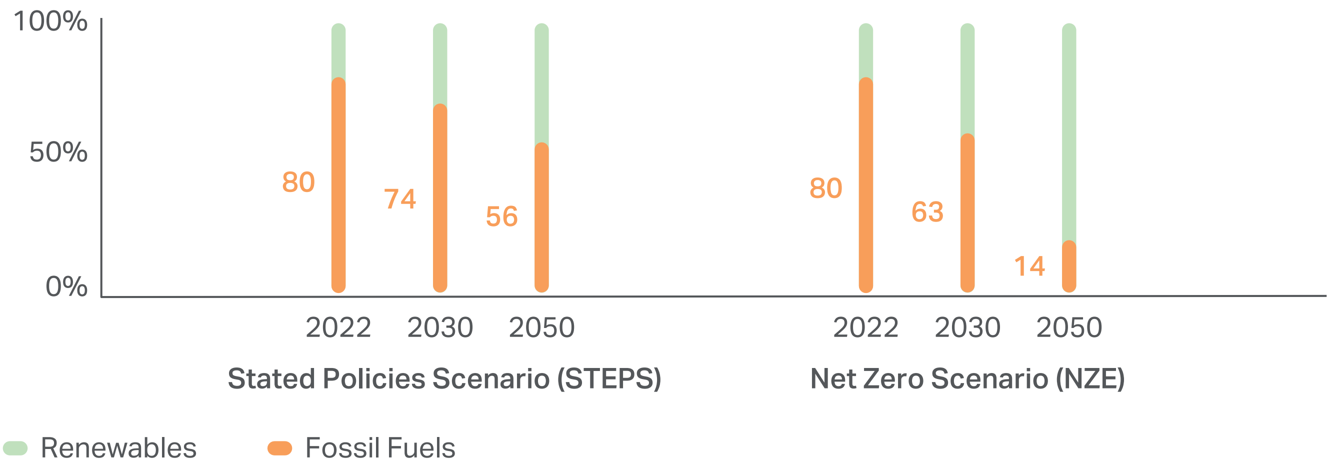
The Global Methane Pledge commits 111 countries that account for 45% of the world's methane emissions to reduce their emissions by at least 30% by 2030.[40] The Oil and Gas Decarbonization Charter, launched at COP28, commits 30 national oil companies and 20 international oil companies, or more than 43% of global oil production, to achieve near-zero methane emissions by 2030 from their upstream operations.[41]

One challenge is that methane leaks are notoriously difficult to detect and manage: methane is invisible to the naked eye and leaks intermittently from a range of point sources.[42] Once leaked, methane disperses rapidly and often escapes detection.[43] This leads to potential under-reporting.[44] The IEA notes that methane emissions from the energy sector could be up to 70% greater than government estimates.[45]

Figure 8

Fossil fuels, coupled with CCS wherever possible, will continue to remain a critical fuel in the future across different scenarios

Total fossil fuel supply (% of total supply)



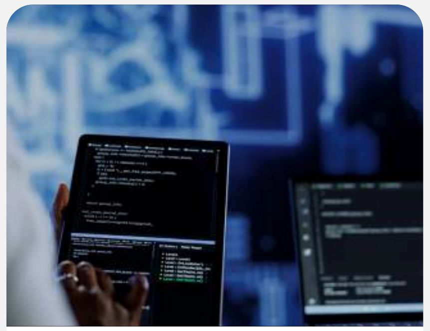
Source: IEA, Net Zero Roadmap: A Global Pathway to Keep the 1.5˚C Goal in Reach; IEA, WEO 2024

Recent developments suggest that AI's emergent abilities could support oil and gas players' endeavors to measure, predict, and optimize complex systems to improve methane management.

Potential opportunities include:

AI-generated insights

AI-generated insights from geospatial, meteorological, and historical leak rate data, used in conjunction with atmospheric dispersion models, can optimize sensor placement for maximum coverage and the timely detection of leak emissions.[46]



Algorithm analysis

Algorithms that analyze data from internet of things (IoT) sensors can detect and even quantify leaks in near real time.

Automated generation

Automatic generation of incident reports and the identification of available technicians and materials can expedite repair work.

Progress is being made. For example, Oxford University has developed an AI tool that scans geospatial data to detect leaks 20% more accurately than legacy tools.[47] The model was trained on large volumes of data from NASA satellites. The researchers have made the base data and code open-source so that the tool is available to others.

ADNOC is also developing and deploying a range of AI-based tools for managing methane that have shown early promise (see Figure 9).

Figure 9

ADNOC AI use cases for methane emissions and flaring reduction have shown early promise

Methane detection

1. Methane Detection and Monitoring Pilot

- ADNOC has launched a pilot project using methane detection technology for enhanced environmental management with high accuracy compared to the industry standard.
- The initiative uses passive FTIR spectroscopy, computer vision, and deep learning to monitor large areas (in combination with sensor networks)
- The technology provides real-time observation and remote operations.
- The system offers reliable alerts, 24/7 detection, and validation of methane, CO, CO_2, TVOC, and H_2S. It supports LIDAR efforts, identifies emission sources, and uses AI for plume modeling and heat mapping.

Flaring management

2. Real-Time Flare Combustion Monitoring

- ADNOC has implemented an AI-based solution for real-time flare combustion monitoring
- Using cost-effective CCTV cameras and deep learning, ADNOC assesses combustion efficiency (CE) with Temporal Standard Deviation (TSD) and flare event detection networks.
- The system provides reliable real-time data, supporting emission control strategies, aligning with environmental regulations, and enhancing sustainability by reducing emissions cost-effectively.

3. Lab-Scale Flare Stack System

- ADNOC has developed a lab-scale flare stack system for studying and optimizing combustion, emissions, and safety protocols in industrial processes.
- This prototype simulates real-world conditions for systematic data collection and AI-driven flare management testing.
- Detailed monitoring and manipulation of combustion parameters generate high-quality data for AI models.
- This initiative can enhance the understanding of flare dynamics, reduce environmental impacts, and offer actionable insights for optimizing flare operations.

Role of AI in improving CCS

CCS is an essential tool for decarbonizing sectors where emissions are hard to abate otherwise (such as cement, steel, and chemicals) and for producing carbon-free hydrogen from fossil fuels.

To reach net zero by 2050, CCS deployment must increase significantly. By 2030, global CCS capacity needs to be more than 40 times larger than it is today.[48] Greater scale and increased efficiency will be critical.[49] The IEA highlights the need for continued innovation in CCS to improve its effectiveness (for example, increasing capture rates from 90% to 98%) and reducing costs. This requires advancements in capture technologies, transportation methods, and storage solutions. Moreover, CCS needs to be integrated across various sectors, including power generation, industry, and fuel transformation, with a particular focus on scaling in regions with large industrial bases.[50]

"As a solution, CCS represents a measurable undertaking that can help move us towards a decarbonised energy system. Through increased adoption of AI, we can significantly improve CO_2 capture efficiency, rapidly identify and map optimal storage sites and closely monitor injected CO_2 behavior. Today, we are only scratching the surface of AI's potential. Energy players must continue to innovate the solutions they are offering through technological partnerships in order to meet the energy needs of the present without compromising future generations as part of a just and responsible energy transition."

Taufik Tengku
President & GCEO, Petronas

AI has the potential to support innovators in building scale and improving the efficiency of CCS projects in both the capture and sequestration phases:

Capture

AI could help identify new materials that will support higher capture rates.[51] Material properties related to CO_2 binding and kinetics determine the performance of CCS hardware. Using AI and supercomputers to design materials with optimal carbon capacity, researchers at Argonne National Laboratory identified 120,000 promising new material candidates in only 30 minutes.[52]

Storage

AI might also provide operational support in the sequestration phase of deployments.[53] It can simulate pressure levels during carbon storage, aiding in the identification of optimal injection rates and sites for carbon sequestration. Stanford University, California Institute of Technology, Purdue University, and NVIDIA have developed an AI-based tool that doubles accuracy in certain simulation tasks.[54]

AI can be used for rapid screening of potential CCS site locations and assessing trap and seal integrity. For example, Geoteric is using AI to address the challenge of identifying suitable storage sites for carbon sequestration projects.[55] AI tools can support comprehensive CCS planning by identifying the optimal pathways between sequestration sites and emission sources, considering factors like distance, transportation options, and volume.

Building the energy system of the future

The energy system of the future will be built from development and deployment of new technologies. AI has a supporting role to play.

The energy system of the future will be built from many technologies available today—such as wind, solar, and batteries—and some that require further development—such as advanced geothermal, small, modular nuclear reactors, advanced nuclear, and green hydrogen. To be successful, we must continue pushing these technologies down the cost curve and accelerating the speed of their deployment. AI is not a silver bullet in this, but it has a role to play.

Role of AI in renewables build-out

According to the IRENA, the rate of deployment for renewables must accelerate to meet the target of tripling renewable energy capacity by 2030, as required by the COP28 UAE Consensus. Specifically, annual rate of wind deployment needs to increase by 16.9% and solar-PV deployment by 18.4%.[56] AI can contribute to this effort, including by accelerating site selection and permitting.

Site selection

When identifying a site for new renewable energy projects, developers optimize for a range of factors, including weather patterns, topography, grid connectivity, and transmission congestion.[57] These factors are vital to consider because they influence deployment lead time and cost effectiveness, both factors in the return on investment.

AI-based optimization tools could prove helpful.[58] They can assess weather patterns, analyze benchmark data from other projects in similar environments, and streamline interconnection studies to understand how rapidly and efficiently a project could be linked to the grid. For example, the World Bank's REZoning tool is an open-source platform that uses advanced analytics to identify optimal locations for solar and wind installations.[59]

Permitting

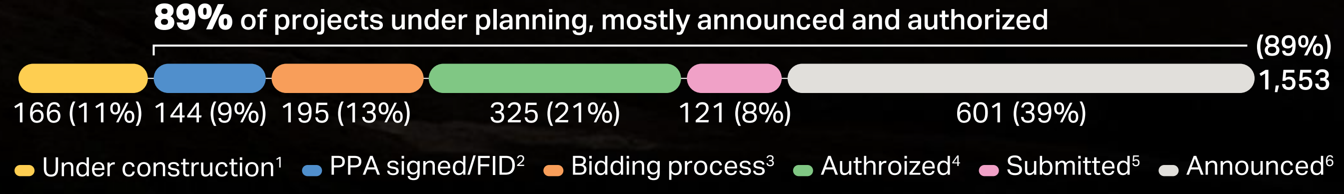
The build-out of renewables has slowed because of the permitting process. All told, the permitting and approval of renewable energy projects can take seven to 12 years, creating a major bottleneck in the planning stage. Today, nearly 90% of renewable energy projects worldwide are somewhere in the planning stage—construction is still in the future (see Figure 10).

AI and GenAI can expedite various parts of the permitting process. For example, AI can analyze satellite imagery and geospatial data for environmental impact assessments to support in expediting the process by up to 40%, from five years to three years,[60] while GenAI's language processing and text classification capabilities can help streamline documentation processes.[61]

Figure 10

Accelerated permitting is critical to near-term deployment

Global under construction and planned solar and wind projects as of February 2023, in GW



1. All consents received, preliminary work has commenced, and placing main contracts has occurred and/or project under synchronization.
2. The project company has signed an offtake agreement, the project company has made the final investment decision.
3. Authorized project with an order has been placed for main equipment and/or major site work.
4. Project has received public/statutory consents by national authorities.
5. Project has been submitted to national authorities.
6. Project announced by company or planned in a national development plan.

Source: Enerdata February 2023.

Role of AI in reducing downtime

Once renewable projects are operational, it is crucial to maximize both emissions reduction and business value. Investments in renewables, grids, and battery storage need to double through 2030 to meet the COP28 target of tripling capacity.[62] One attractive aspect of the investment proposition for renewables is that, after the initial capital outlay, projects have relatively low operating costs.[63]

AI helps maintain low operating costs for renewable projects by minimizing the amount of downtime due to planned or unplanned maintenance. AI-driven predictive maintenance can reduce downtime by 10% to 20% at the asset level, significantly lowering maintenance costs.[64] Reduced downtime also allows projects to supply more clean power to the grid, potentially replacing energy from emission-intensive sources. For example, a 10% to 20% reduction in downtime across the asset base of a 1 GW wind farm could translate to emissions savings of approximately 5T CO_2 per year (see Figure 11). Presight, a leading big data analytics company powered by GenAI, has developed an asset management tool for its renewable energy projects around the globe.

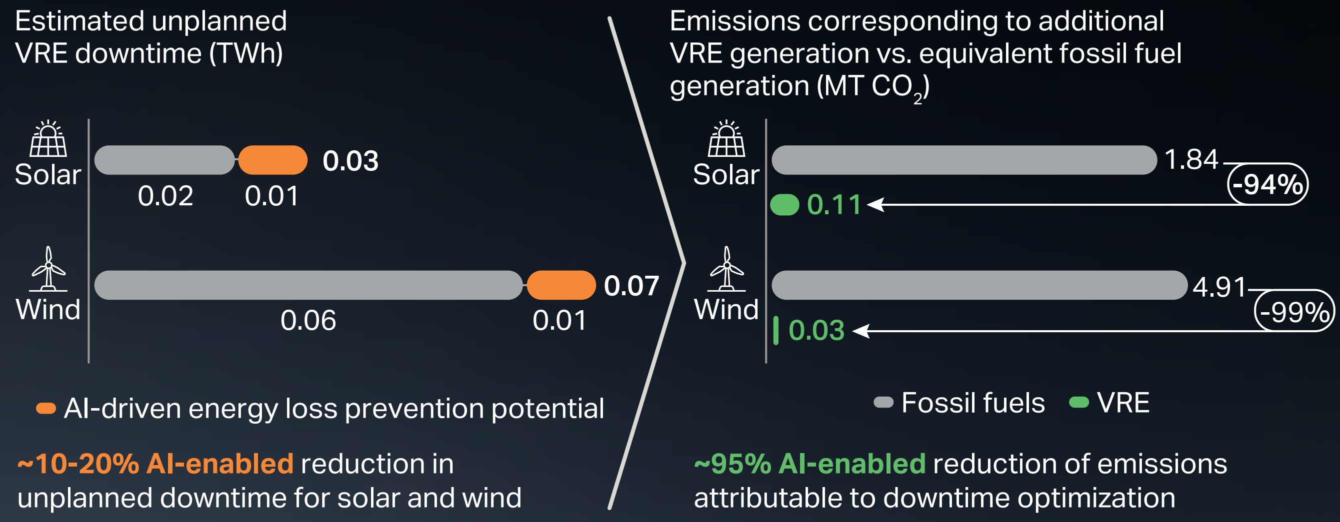
AI-driven predictive maintenance capability can reduce downtime by

10%–20%

at the asset level [64]

Figure 11

AI applications to reduce downtime in variable renewables



Note: Methodology used 1GW as representative of an average solar/wind farm capacity, potential impact is estimated based on the real-world deployment of 10-20% downtime reduction with the upper end of the range being used in the analysis on the page.
Source: NREL, Life Cycle Greenhouse Gas Emissions from Electricity Generation: Update 2021; IPCC - Emission Factor Database (2023) – with minor processing by Our World in Data; Expert interviews; ADNOC analysis

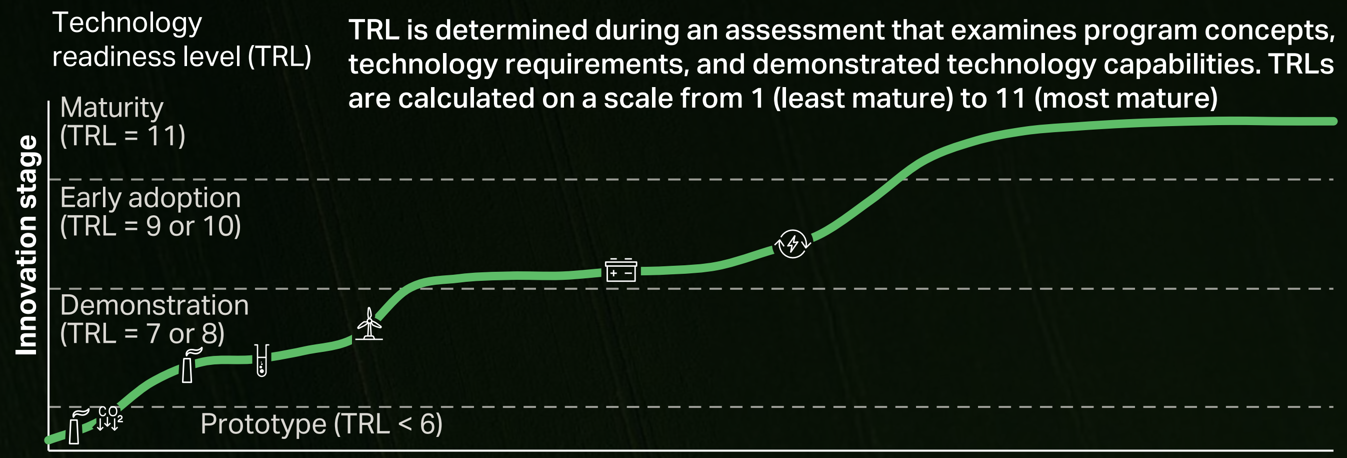
Role of AI in green-technology innovation

Continued innovation will be needed to develop and commercialize new technologies and eliminate the "green premium," which is the cost difference between legacy carbon-intensive and newer, low-carbon technologies. New technologies that are not yet at scale will account for 35% of the emissions reductions needed to achieve net zero by 2050.[65] Bringing these technologies to scale is achievable but will require concerted effort.

The IEA has highlighted hydrogen electrolyzers, direct air capture (DAC), and next-generation batteries as three of the most critical innovations along the path to net zero.[66] However, these innovations, along with other nascent technologies, face a steep climb to technological maturity, reducing costs, and scalability (see Figure 12).

Figure 12

Several technologies must climb the technological readiness curve toward maturity before they can be deployed at a global scale



- Low-carbon hydrogen and synfuels
- Bioenergy
- Carbon removal (incl. DAC)
- Energy storage
- Green factory technologies
- Distributed energy

Key challenges to technological maturity include:

Product development | Factory setup | Talent sourcing | Supply chain | End-system integration | Funding

Source: BCG, Fast-Tracking Green Tech: It Takes an Ecosystem, 2023.

"Electricity and renewable energies are digital ready: AI enables us to accelerate and optimize their integration along the entire electricity chain. AI technology will play a key role in the transition to a net-zero energy system!"

Patrick Pouyanné
Chairman and CEO, TotalEnergies

AI's game-changing ability to accelerate innovation shows particular promise in six key areas:

Green hydrogen

Developing membrane-less technology for hydrogen production is critical for the technology's ability to scale. Researchers from Harvard, EPFL, and HPE have developed AI-enabled digital twins for membrane-less electrolyzers, with the potential to boost efficiency by up to 20% and cutting costs by up to 25%.[67]

Direct Air Capture (DAC)

Researchers from Microsoft, MIT, and UC Berkeley are developing an AI model to accelerate the discovery of new materials for cost-effective carbon dioxide removal.[68] The AI-driven model aims to identify materials capable of capturing large amounts of CO_2 from the atmosphere while minimizing the energy required to release it for storage or reuse.

Next-gen battery materials

Battery storage faces challenges due to rising costs and limited supply of critical minerals like lithium. AI is helping to address these constraints. Microsoft and Pacific Northwest National Laboratories used AI to discover new battery materials with reduced lithium dependence in weeks instead of years.[69]

Storage

Octopus Energy's Kraken platform is a powerful deep-tech solution designed to optimize the management of energy resources, particularly for energy storage systems. It leverages advanced analytics, real-time data monitoring, and machine learning to balance supply and demand, especially with the integration of renewable energy sources.

Small modular nuclear reactors (SMRs)

Researchers at Purdue University and Argonne National Laboratory have developed an AI algorithm that predicts changes in SMR performance with 99% accuracy, potentially lowering costs and improving reactor efficiency, which would make nuclear energy more viable and easier to manage.[70] These efficiency improvements and cost reductions are anticipated to make these technologies more economically viable, potentially attracting more capital and hence more adoption.

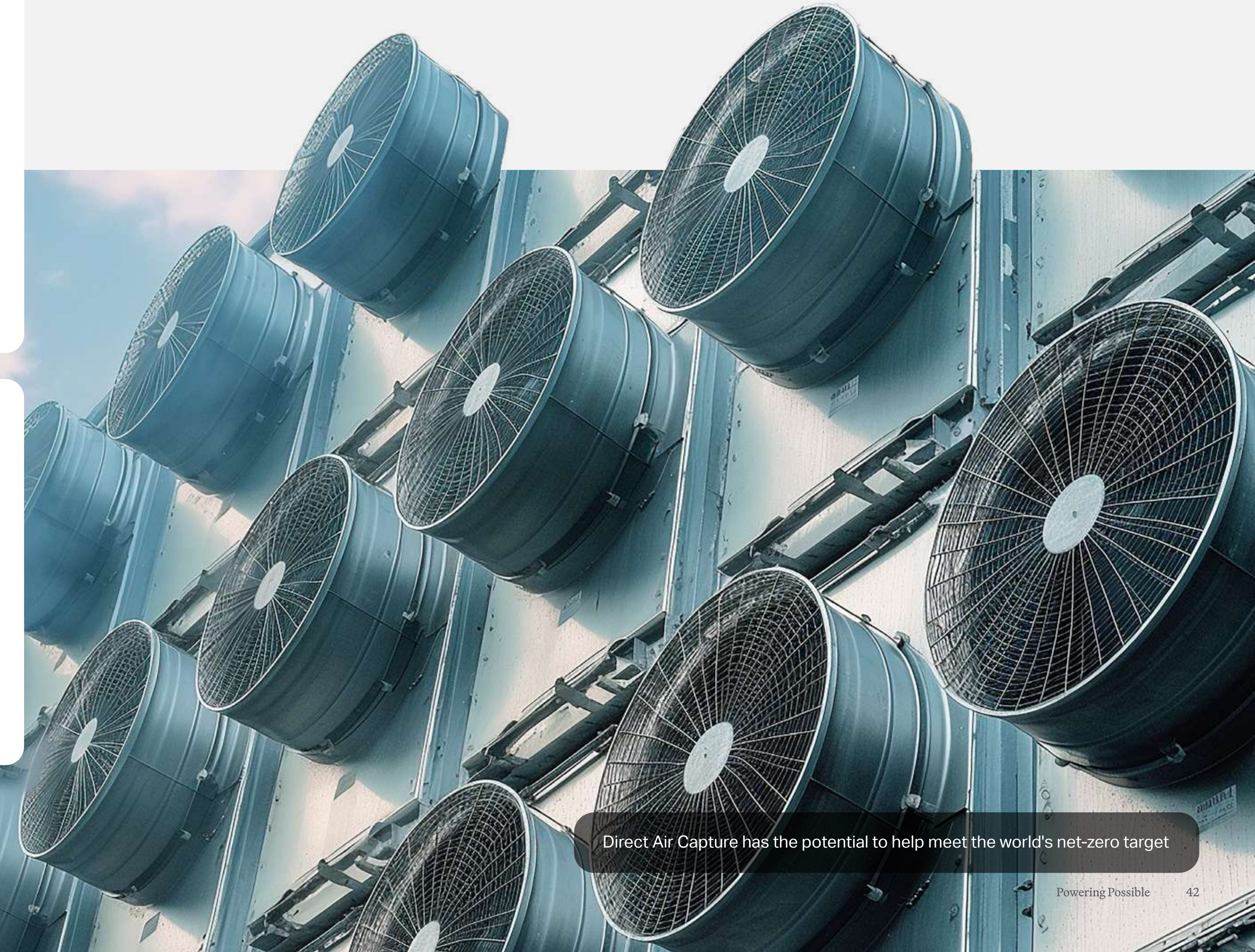
Nuclear fusion

At Princeton Plasma Physics Laboratory, AI is accelerating nuclear fusion development by predicting and mitigating plasma instabilities, optimizing complex computational tasks, and reducing computation time from tens of seconds to milliseconds.[71] These advancements are key to making fusion a scalable and reliable energy source.

CREATED WITH AI

Conclusion

AI has the potential to support a just and equitable transition to a net-zero energy system. To maximize its impact, AI must develop its capabilities and overcome obstacles to implementation. For example, the integration of AI into permitting processes will require improvements in the reliability and transparency of GenAI, significant process changes and the upskilling of personnel. Moreover, AI is not a silver bullet. Alone, it cannot address all the challenges associated with the energy transformation. For example, any new materials for direct air capture will still need to be commercialized and funded at scale. Nonetheless, given the scale and urgency of the climate challenge, it would be remiss not to comprehensively explore and fully exploit the potential of AI.



Direct Air Capture has the potential to help meet the world's net-zero target

AI and the

FUTURE ENERGY SYSTEM

The energy system of the future and AI

For the world to deliver a just, orderly, and equitable energy transformation, the energy system of the future will need to look very different than it does today. It will need to be fundamentally transformed on three levels (see Figure 13 overleaf). At the systems level, energy must become more electric, distributed, and variable in both supply and demand. At the operational level, energy must become more efficient, resilient, and supported by sufficient and robust infrastructure. And at the global level, the Global South will need to play a far greater role, as it is expected to be responsible for nearly 80% of the new electricity demand between now and 2050.[72]

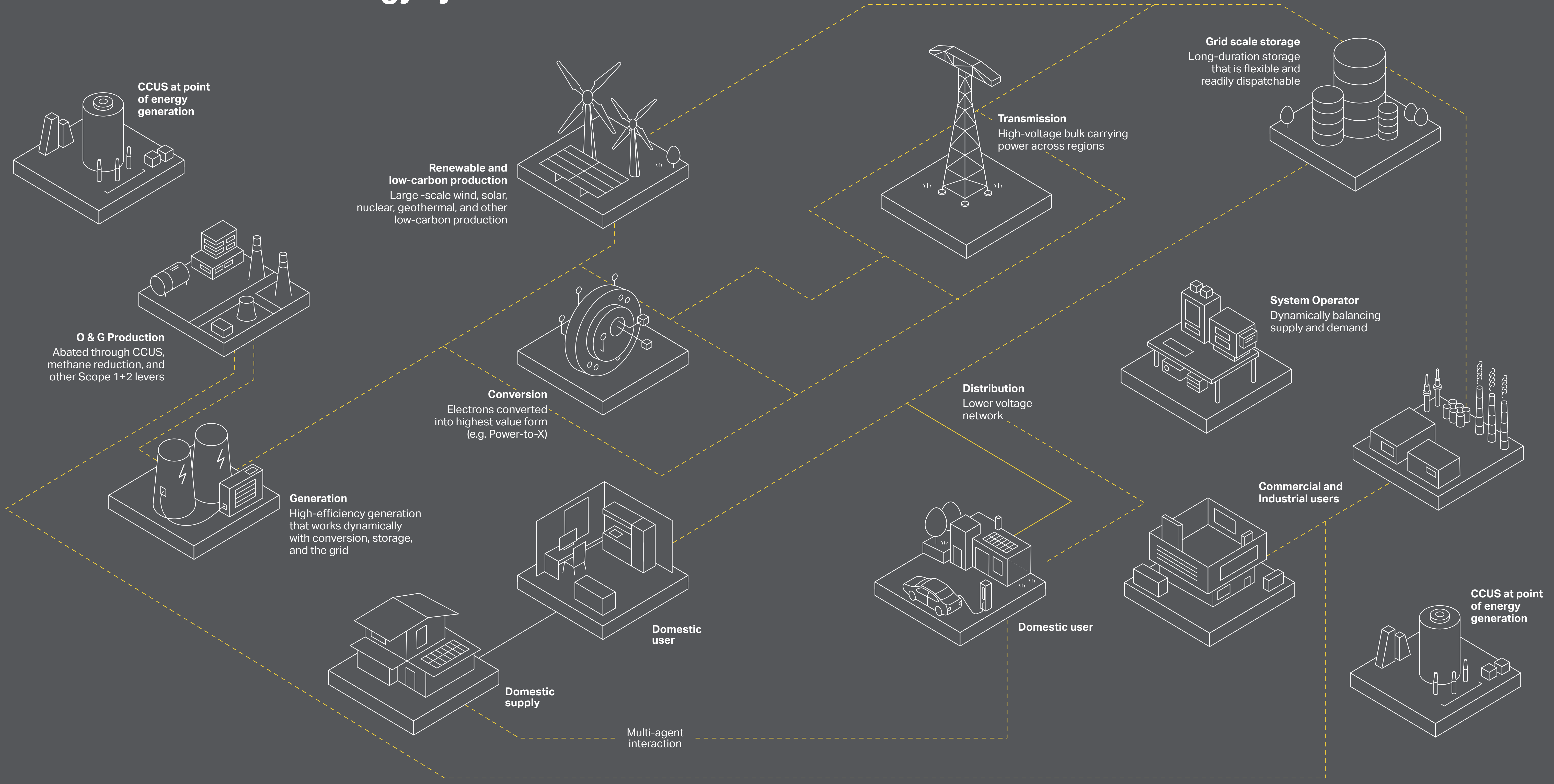
AI can play a valuable role at all three levels, as its capabilities become more refined and barriers to implementation are overcome.

"AI is transforming our understanding of the physical world, and it will have a transformative impact on how science and engineering are done."

Anima Anandkumar
Bren Professor of Computing and Mathematical Sciences, Caltech

Figure 13

A vision of the future energy system



Three transformations that will characterize the future energy system

1. At the **systems level,** the future of energy system will become more electric, distributed, and variable.
2. At the **operational level,** it will need to be efficient, resilient, and supported by the right infrastructure.
3. At the **global level,** EMDCs have the potential to play a central role in the energy system of the future.

AI can help to orchestrate the future energy system, leveraging its abilities for complex analysis and optimization

SYSTEMS LEVEL

Energy will become more electric, distributed, and variable in supply and demand

AI may have a valuable role in prediction, simulation, and optimization of this new system.

Electricity will be the core energy vector of the net-zero system, accounting for approximately 50% of total energy demand by 2050, up from 20% today.[73] However, the primary energy mix behind electricity must diversify, with nearly 90% coming from renewable sources.[74] Seven different energy sources (solar, wind, solid bioenergy, nuclear, oil, hydro, natural gas with CCS) will provide at least 20 exajoules (EJ) of energy each, compared with six (oil, unabated coal, unabated natural gas, solid bioenergy, nuclear, hydro) providing that level today.[75]

With the uptake of weather-dependent energy sources, the variability of energy generation will significantly grow. Nearly 70% of global electricity generation in 2050 is expected to come from variable solar and wind.[76]

The geographic dispersion of energy generation will increase as well, and distributed power generation will play a major role. The IEA estimates that distributed solar PV generation could increase more than 20 times by 2050, going from 320 TWh in 2020 to around 7,500 TWh.[77] That would account for roughly one-third of today's total global electricity demand.[78]

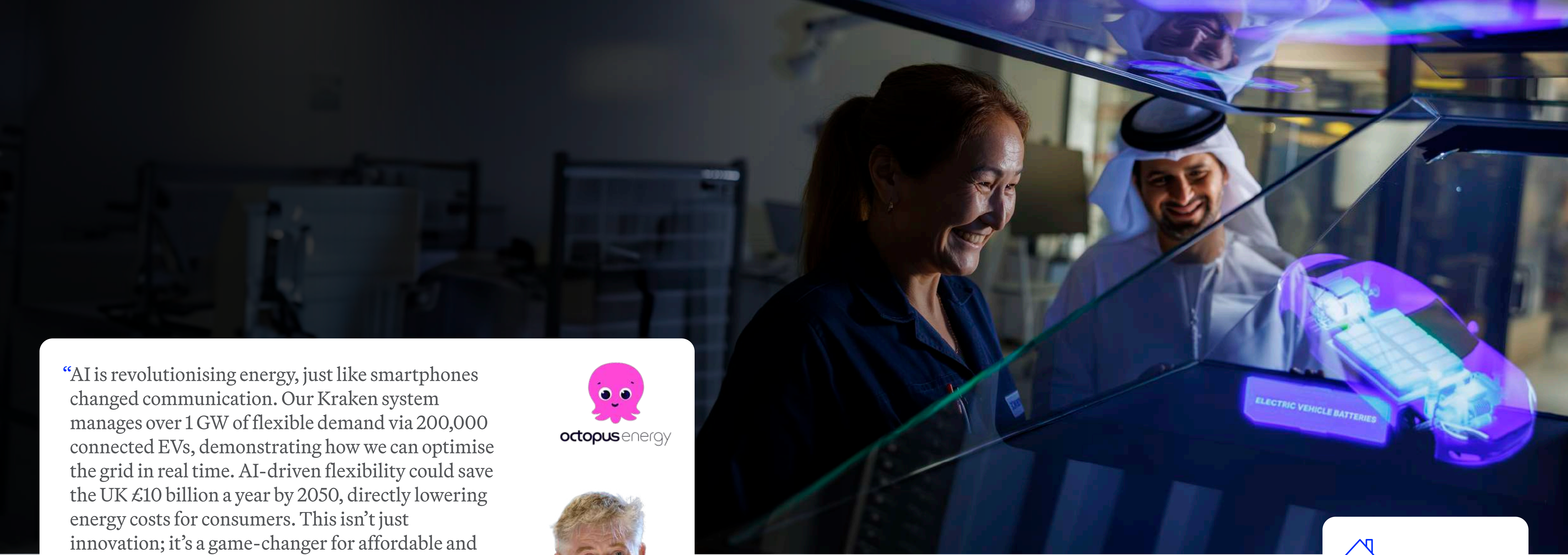
With the introduction of two-way power flows, distributed generation will have implications for the shape of the energy system. In some instances, bulk power—large, centralized generators—may be augmented with smaller, variable generators.[79] In the residential sector, the source of power will primarily be solar PV. In the industrial sector, sources will include solar PV, wind, and combined heat and power systems.[80]

Energy systems and regulation will need to evolve to support two-way power flows. Already today, leading distribution networks, such as those in South Australia and Queensland, are becoming net exporters to the energy system because of the high penetration of rooftop solar.[81] These systems have introduced dynamic operating envelopes to ensure they can maintain grid stability while maximizing solar output.

Nearly

70%

of global electricity generation in 2050 is expected to come from variable solar and wind [76]



"AI is revolutionising energy, just like smartphones changed communication. Our Kraken system manages over 1 GW of flexible demand via 200,000 connected EVs, demonstrating how we can optimise the grid in real time. AI-driven flexibility could save the UK £10 billion a year by 2050, directly lowering energy costs for consumers. This isn't just innovation; it's a game-changer for affordable and resilient energy."

Greg Jackson
Founder and CEO, Octopus Energy

"AI promises transformational advances across industries, societies, and the environment, but its rapid growth and energy demands strain an already overstretched energy system. Closer collaboration between the AI and energy sectors, alongside governments and civil society, is crucial to unlock sustainable solutions. A multistakeholder approach will accelerate progress, ensuring AI's full potential is realised in a way that creates inclusive value and leaves no one behind."

Badr Jafar
CEO, Crescent Enterprises

Individuals and organizations with distributed energy resources, storage, and flexible demand (including EVs) will continue to go from being electricity customers to being active participants in grid dynamics and energy markets, using millions of digital devices to connect their distributed energy resources to the grid. These devices will enable them to generate, sell, store, and optimize their own electricity profiles.[82] On the demand side, up to 1 billion households and 11 billion appliances could contribute to flexibility via demand response and multi-agent systems.[83]

Balancing supply and demand in these future systems will be far more complex than today. On the supply side, variable sources like solar and wind are intermittent, both regularly (seasonal and diurnal) and irregularly (weather). On the demand side, intraday load variability will be amplified by changes in the location and timing of EV charging.

As the amount of dispatchable firm power in energy systems declines, the ability to predict generation and load will be critical to maintaining the stability of energy systems.[84]

Flexibility management—the ability to balance intermittent supply with variable demand—will also be critical. By shifting intraday load profiles—via storage and demand response, for example—grid operators can reduce peak demand and ensure the optimal load to maintain stability and power quality.

The IEA estimates that the energy system's flexibility must quadruple in a net-zero system.[85] This would have the beneficial effect of making power systems more economical, because it would limit the need for additional grid investments and generation sources.[86]

Up to

1 billion

households and

11 billion

appliances could contribute to flexibility via demand response[83]

AI's capabilities in prediction, simulation, and optimization

AI has already demonstrated game-changing abilities to predict, simulate, and optimize highly complex systems in several fields.

As these abilities continue to develop, there is significant potential for them to build on the value of existing information technology solutions in the energy sector. Of course, as with any new technology, there will be implementation challenges.

Prediction

Improved forecasting could address many challenges related to energy system variability. Anticipating changes on the supply side (such as the impact of weather on wind output) and the demand side (such as changes in consumption at five-to-ten-minute intervals) could provide significant value for generators, grid operators, and consumers.

AI-based weather models are improving rapidly and—in combination with physics-based models—have the potential to issue more precise and more reliable forecasts of renewable generation and load demand.[87] For example, Amperon, an analytics platform that partners with Microsoft, provides reliably accurate forecasts related to grid demand, meter demand, and asset-level renewable generation forecasts, with the latter able to forecast at sub-hourly intervals.[88]

Simulation

AI could simulate the impact of potential scenarios across different components of a future energy system. Digital twins, currently deployed across several industries, could be a major enabler for these simulation use cases to flourish, with AI being used to predict how energy systems will behave under different conditions. By integrating and leveraging data from smart meters and other sources, AI could help gain detailed insights into the energy networks, right down to local distribution networks. This capability would support several operations, including the definition of location-specific, dynamic operating envelopes for distributed energy resources. Collecting and processing myriad data in near real time, running simulations of likely outcomes down to local distribution networks and customer resources, and suggesting optimal demand response interventions to support grid stability and power quality—all of these will be impossible without new AI abilities.[89] Enerjisa Üretim, Turkey's leading power generator, leveraged Microsoft's cloud and AI capabilities to create 3D digital twins of its power plants to assess plant health (e.g., turbines, heat pumps) and risks in real time.[90]

Solar PV could grow to

100 million

by 2023, from
25 million today [85]

Optimization

AI could help play an important role in optimizing and integrating distributed energy resources into virtual power plants (VPPs), collecting many distributed energy resources, including solar PV, EVs, and chargers, energy storage, and smart buildings. Like traditional power plants, VPPs can provide utility-scale grid services, so they will be increasingly important as demand increases and transmission is constrained.

AI could help integrate energy resources into VPPs in a range of ways, including identifying potential participants and facilitating enrollment. Additionally, AI could enhance VPP performance by analyzing the vast and fragmented data generated from extensive portfolios of distributed energy resources.[91] Uplight is one example of a VPP platform in the U.S. that is using AI's powers for optimization to enhance VPP performance and user engagement.[92]

Case in point: The airline industry operates within a highly complex and demanding environment. There is a need to optimize across many dimensions in this industry, including flight schedules, aircraft maintenance, weather conditions, and air traffic control—all while ensuring safety, regulatory compliance, and customer satisfaction. Recently, leading airlines have started using AI-based platforms to optimize flight routes, reduce fuel consumption, predict delays and technical issues, and provide 24/7 support services to customers.[93]

Data complexity

As we have already discussed, the structure of the future energy system will be significantly more complex.

To cite a few examples:
Smart power meters worldwide exceeded 1 billion in 2022, a tenfold increase over the previous decade; connected devices in power systems currently number approximately 13 billion, 13 times more than in the last decade; and grids have approximately 320 million distribution sensors deployed globally today, a number that will likely increase. In the IEA's Net Zero Scenario, the number of homes relying on solar PV could grow from 25 million today to 100 million by 2030. All these pieces of hardware generate and rely on data.

This structural and data complexity could increase volatility in the energy system. Without effective management, we could see price fluctuations, increased outages, and a heavy strain on energy infrastructure.

How AI's optimization and analytic capabilities can help

Advanced AI-based management tools could mitigate these challenges. For example, AI algorithms have the potential to significantly enhance grid management by assessing real-time weather data, forecasting supply and demand, and automating control systems. U.S.-based LineVision uses AI and computational fluid dynamics to integrate weather data with real-time sensor measurements, providing dynamic line rating. This capability helps power companies maximize the carrying capacity of grid infrastructure and integrate renewable energy supplies. Using LineVision tools, in just one instance, the UK's National Grid has unlocked up to 600 MW of offshore wind capacity, increasing line capacity by up to 60%.[94]

"The build out of AI needs close cooperation with the energy sector. The data centres need reliable power infrastructure and clean power supply. However, AI will also play a crucial role to accelerate the energy transition. It will help to integrate more renewables into the grid, will help to make the grids more efficient and stable. AI will also improve the prediction of renewable generation profiles as well as the respective response from storage, flexible generation and the full utilization of demand side response."

Markus Krebber
CEO, RWE AG

OPERATIONAL LEVEL

The energy system will need to be more efficient and resilient, and supported by the right infrastructure

AI can play an important role in building resilience and efficiency of energy infrastructure.

The efficiency premium

Every unit of energy must be used (for example, on-site data center), distributed (for example, over the grid), converted to storage (for example, long-duration batteries), or converted to a new vector (for example, hydrogen). Distribution and conversion cost energy—with some conversions being much less energy-efficient than others.

A more complex energy system will place a premium on efficiency. There is significant potential. The IEA estimates that more efficient systems could reduce energy losses in transmission and distribution in today's energy system to 5% worldwide, compared with as much as 18% in some regions today.[95] This improvement could reduce energy-related emissions by over 400 MT,[96] roughly equivalent to Australia's total annual emissions today.

Identifying and ensuring the next-most-efficient source for a unit of energy is highly complex. The optimal solution in each instance must account for the level and location of current and future demand and supply, the energy efficiency of the alternative options, multi-commodity energy prices and market conditions, grid stability, and carbon efficiency. All these considerations imply an immense complexity with a very large decision space for how to operate our energy system.

Adopting more efficient systems can reduce energy-emissions by over

400 MT

roughly equivalent to the total annual emissions of Australia today[96]

How AI could help improve efficiency

AI's ability to drive efficiency through power-market optimization is improving. In the future, AI's new and improved abilities could help market participants optimize consumption, costs, and revenues as system complexity rises.

For example, industrial players could use AI to navigate multiple commodity markets and optimize participation, while smaller players like small and medium-sized enterprises (SMEs) and households would benefit from enhanced consumption management and domestic supply (e.g., distributed solar electricity generation) export. Additionally, AI could play a central role in market-making, facilitating coordination and negotiation to meet individual participants' needs while optimizing overall network performance. The data platforms that optimize these systems will be critical, enhancing operational efficiency and providing clear price signals.

Initiatives like Denmark's DataHub, Germany's SMARD platform, and frameworks proposed by the UK's Energy Data Taskforce demonstrate the potential for information technology to improve efficiency.[97] Of course, the potential for AI to improve efficiency will be constrained, at least in part, by the underlying infrastructure and market structures and where the incentives of players are well aligned. These must be improved in parallel.

"We are at the beginning of a new industrial revolution, one that will capitalize on the twin technologies of accelerated computing and artificial intelligence. Artificial intelligence is already beginning to transform the energy grid, driving improved grid reliability and energy efficiency, and also supporting integration of renewable energy sources. AI is a critical solution for modern energy production and delivery, enabling greater productivity and economic growth."

NVIDIA

Jensen Huang
Founder and CEO, NVIDIA

The resilience imperative

According to an S&P study cited by the United Nations Environment Programme (UNEP), in a moderate climate-change scenario, utilities will be the most exposed economic sector in 2050.[98] The energy sector is exposed to both chronic risks like rising temperatures and water scarcity and acute risks like storms and wildfires. Rising temperatures can impact capacity for power plants, which experience reductions of up to 10% on days hotter than 27°C.[99] Meanwhile, wildfires can create massive damages for utilities, with trees and debris collapsing onto infrastructure like transmission lines and substations. In the U.S., wildfires over the last half century have cost power companies an average of $1 billion per year.[100] Clearly, the energy system will need to become more resilient.

In the U.S., wildfires over the last half century have cost power companies an average of

$1 billion

per year [100]

How AI can help improve resiliency

AI's capabilities for risk and prediction analytics will be vital both for anticipating events before they occur and responding dynamically after they do.

AI-powered risk tools can integrate company- or region-specific parameters with larger climate and weather models. Algorithms then construct risk portfolios by approximating the eventuality of different scenarios—for example, estimating if and where an extreme weather event will occur.[101]

In Canada, Alberta Wildfire is using a tool built by AltaML and powered by Microsoft Azure Machine Learning to help duty officers make strategic decisions and allocate resources to combat wildfires. The AI tool can predict wildfires with 80% accuracy, providing vital intelligence in an increasingly severe environment.[102]

The infrastructure requirements

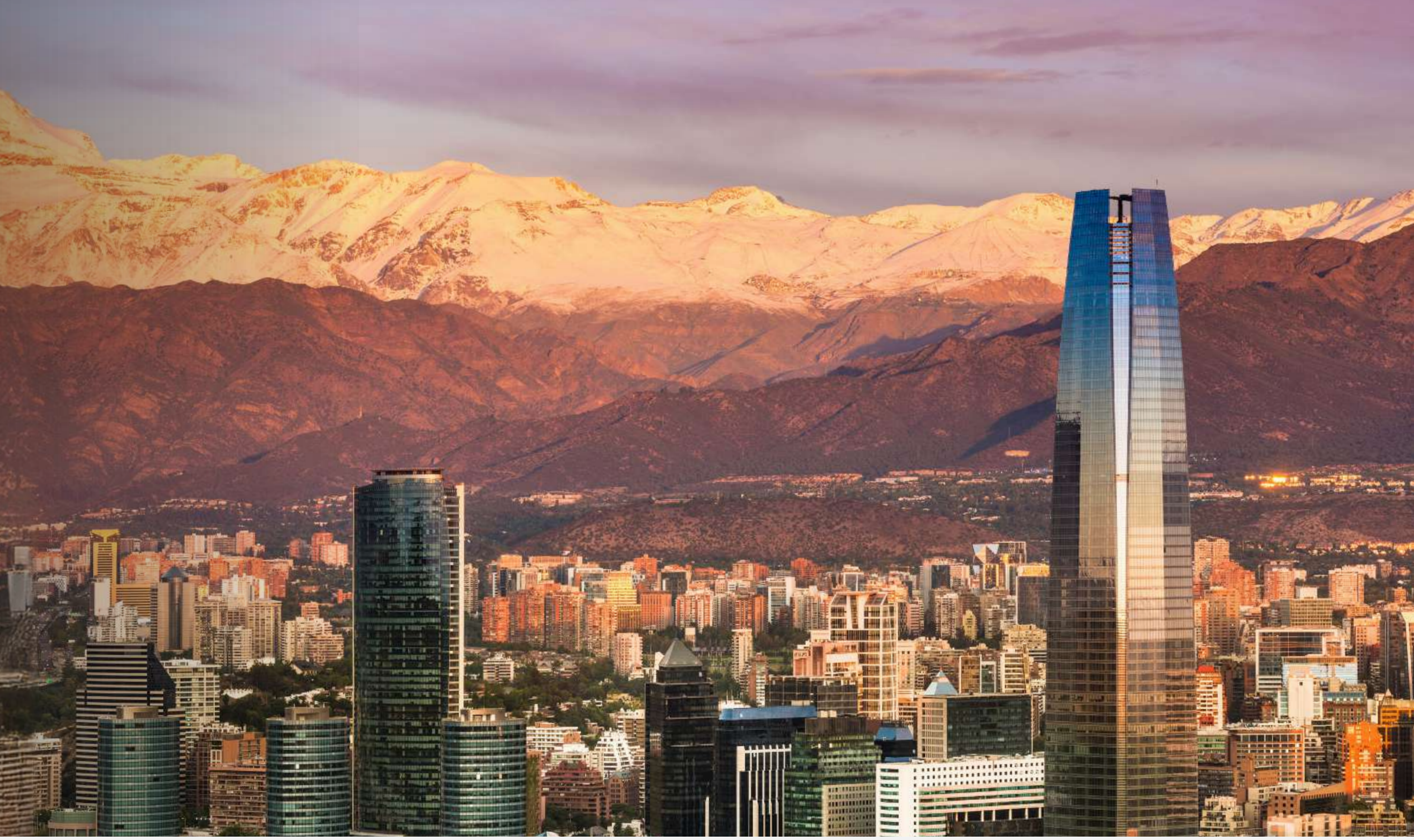
As the energy system becomes increasingly electrified and interconnected, it will require a robust infrastructure capable of handling greater loads, enhanced digital connectivity, and a growing number of supply and demand points.

Developing and building energy systems requires complex planning and a wide set of stakeholders, so strategic decision-making will be essential. Additionally, grid upgrades will be needed to accommodate EV charging, data centers, and other new electricity demands. One approach is minimizing network upgrades through market signals to locate demand near generation and storage, and vice versa, where possible, as well as flexibility management.

How AI can help with planning

AI-driven forecasting, simulation, optimization, and visualization tools could support better and quicker decision-making for the next generation of infrastructure planning. This is based on AI's proven ability to simulate multiple scenarios and intervention options despite high uncertainty, across different time horizons, and with fine geographical detail.

EV charging station



GLOBAL LEVEL

Emerging markets and developing countries will play a far greater role in demand and value chains

Meeting the energy demand of emerging markets and developing countries (EMDCs), and realizing their potential in energy value chains will be critical to global growth and prosperity.

Today, EMDCs, excluding China, account for 38% (160 EJ) of the total final global energy demand. By 2050, according to IEA's Stated Policy Scenario, they will account for 50% (252 EJ) of primary global energy demand.[103] Meeting that demand with reliable, affordable, and sustainable energy is a defining challenge for the energy industry and the global economy.

In parallel, EMDCs have the potential to play a central role in the energy value chains of the future, including critical materials, green tech manufacturing, renewable generation, transmission, and storage. Realizing that potential will give EMDCs a greater stake in the energy transformation and have the potential to reduce energy costs for all.

For example, Chile holds a third of the world's supply of lithium and is the largest producer of copper. Both materials are critical to green technologies like solar PV and battery storage, and they position Chile in the global energy transformation.[104]

Africa holds 60% of the world's solar resources but currently accounts for just 1% of solar power generation.[105] India has the potential to generate 750 GW of solar capacity, roughly nine times what it currently generates.[106] In fact, renewables account for nearly two-thirds of all new power capacity additions in EMDCs (again, excluding China) in the IEA's STEPS by 2030[107] (see Figure 14).

Similarly, EMDCs will have a critical role to play in energy storage and transmission. Energy value chains are expected to be more fragmented and more regional than those of today. In the Middle East, green hydrogen capacity doubled year-on-year from 2022 to 2023.[108] Oman, the UAE, and Saudi Arabia are positioning themselves as global leaders in hydrogen production.

EMDCs will account for

50%

primary global energy demand by 2050 up from

38%

today [103]

"The promise of AI in energy is about deliberate and informed technological advancement to create a more equitable and sustainable world.

By investing in scalable AI solutions tailored to the Global South - such as the power of AI for distributed energy systems and microgrids, we can bring reliable, clean power to hundreds of millions of people across the Global South - powering dreams, fueling innovation, and ultimately unlocking economic potential."

World Wide Technology

Omar Mir
International & Special Advisor, WWT

Figure 14

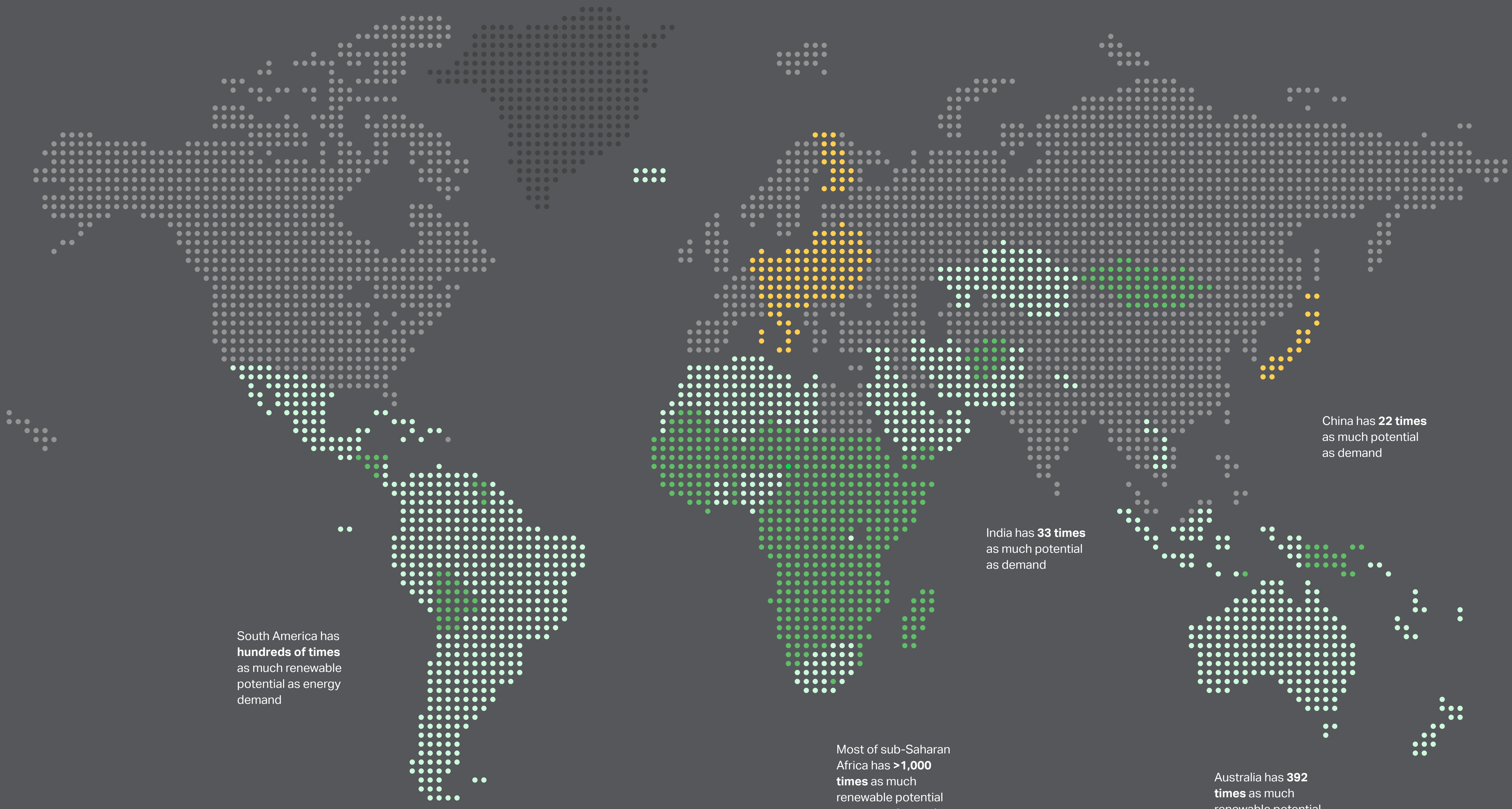
The Global South is abundant with renewables

SUPERABUNDANT
RE potential
>1,000x
of total energy demand

ABUNDANT
RE potential
100–1,000x
of total energy demand

SUFFICIENT
RE potential
10–100x
of total energy demand

STRETCHED
RE potential
<10x
of total energy demand



Sources: Rocky Mountain Institute, The Energy Transition and Global South, Carbon Tracker

EMDCs will need to overcome significant challenges to meet their demand and achieve their potential. For instance, the extraction and processing of critical minerals can be inefficient and damaging to the local environment. Transitioning away from fossil fuels poses particular challenges for workers and consumers in EMDCs without social safety nets and the fiscal capacity to support them. Moreover, EMDCs are more likely to lack access to the capital and technology needed for such intensive transitions (see Figure 15).

By 2050

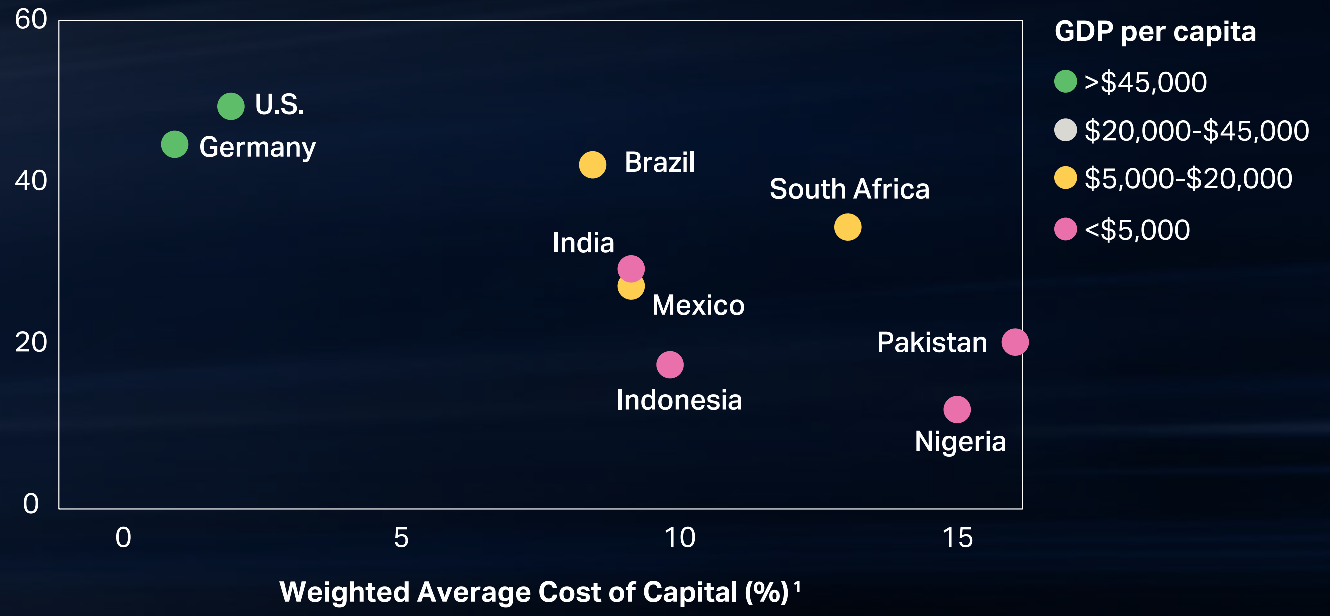
85%

of firms are expected to adopt AI systems and workers are more optimistic and more experienced than their peers in the Global North.[109]

Figure 15

The high cost of capital makes financing the energy transformation harder for developing economies

Government spending as a percentage of GDP (%)



1. Indicators of economy-wide cost of capital for debt (government bond + debt risk premium), nominal values, 2020.
Note: Countries with available data in the IEA Cost of Capital Observatory.
Source: BCG, "A Blueprint for the Energy Transition", 2023 (with data from International Monetary Fund 2023, Refinitiv); IEACost of Capital Observatory 2023.

How AI Can Help

AI cannot solve all the challenges faced by EMDCs, but it can play as important a supporting role for them as in advanced economies. In fact, leaders based in EMDCs are even more optimistic about the potential for AI in the energy system than their advanced economy counterparts (see Figure 16). As per a global survey of 13,100 employees conducted by BCG, by 2050, 85% of Global South firms are expected to adopt AI systems, and workers in these locations are more optimistic and more frequent users than their peers in the Global North.[109] Together, this points to huge potential for leadership and skills. Indeed, technology pioneers in the Global South are already using AI in distributed generation, microgrids, and more.

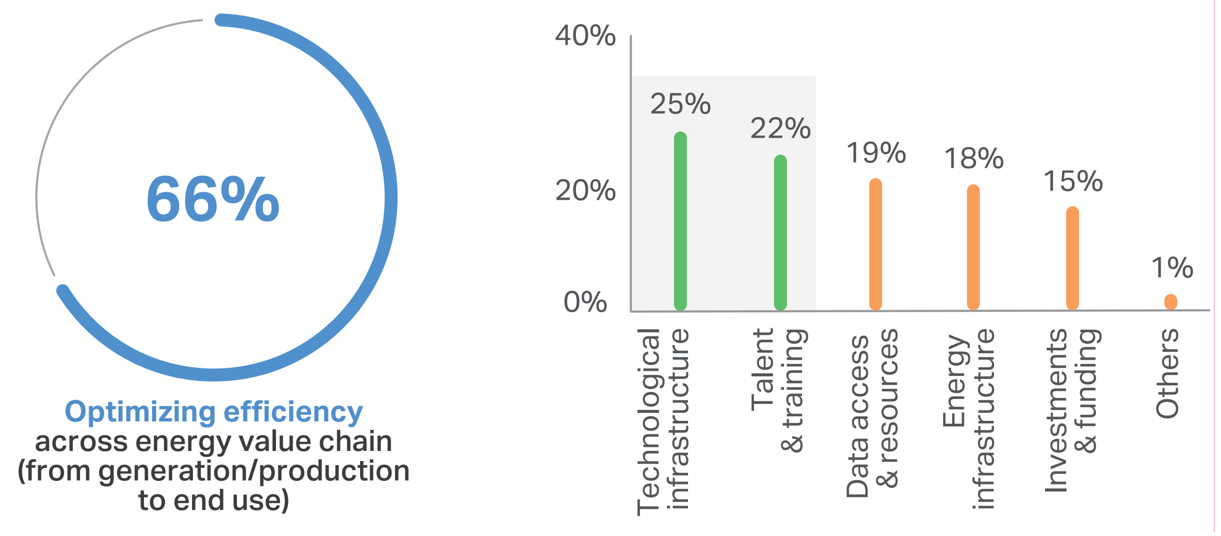
SURVEY INSIGHT

Figure 16

Two-thirds of EMDC leaders believe AI can optimize energy efficiency across the value chain, and they highlight talent and training along with technology infrastructure as critical for success

Respondents from Global South considering AI adoption and use to have an impact on (%)¹

Respondents considering importance of different enablers (%)²



Source: ADNOC AI Survey
1. Respondents were asked how significant an impact they believe the adoption and use of AI will have on optimizing efficiency across the energy value chain, from generation and production through distribution to eventual use.
2. Respondents were asked which areas should be prioritized to support the greater use of AI in emerging markets, given its expected positive economic benefits in these regions.

Partnerships will be essential to ensure AI is available in EMDCs. For instance, as part of an initiative with the Republic of Kenya's Ministry of Information, Communications and the Digital Economy, Microsoft and UAE-based G42 recently announced a $1 billion digital investment in Kenya. With the help of local partners, they plan to build a cutting-edge data center, create a digital innovation lab, and develop AI models in local languages (see Figure 17 for further examples).[110]

A digital investment between partners Microsoft and UAE-based G42 of

$1 billion

in Kenya to build innovative AI-enhanced system [110]

Sources: IEA

"Access to AI and other advanced technologies that support cleaner energy and lower-carbon growth are essential to levelling the playing field and ensuring a just and equitable energy transition."

Proscovia Nabbanja
CEO, Uganda National Oil Company

Figure 17

Pioneers have already started driving the energy transformation in the Global South

Husk Power Systems

Leveraging AI to support clean microgrids in the Global South

Builds and operates mini-grids that supply clean, reliable electricity in remote and rural areas.

AI supports grid layout and predictive maintenance, renewable energy forecasting, demand forecasting, and more.

Currently has major operations in India, Nigeria, and Tanzania and is poised to expand further in the Global South.

HUSK.

Zola Energy Storage and Management

Managing hybrid solar and energy storage systems with the help of AI

Zola manages smart microgrids that combine solar and battery storage to provide stable power to remote areas.

Leverages AI and advanced analytics to predict energy consumption and optimize battery capacity levels.

Based in Arusha, Tanzania, with operations in Rwanda, Ghana, Cote D'Ivoire, and Nigeria.

ZOLA

SOLShare

Winner of the Zayed Sustainability Prize 2022 in 'Energy'

Connects homes with distributed generation to microgrids and uses AI to optimize peer-to-peer energy trading

SOLBox, the company's core innovation, is a bi-directional energy meter that connects homes to the grid; it also links to an app and online platform that use advanced analytics to monitor generation and facilitate trading

Headquartered in Dhaka, Bangladesh; has established over 50 microgrids that connect over 6.5K households

solshare

SunCulture

Using IoT and advanced analytics to optimize solar-powered irrigation systems for farmers

Develops and deploys distributed solar systems that connect to battery-powered water pumps, used for irrigation.

IoT-enabled equipment collects data related to solar generation patterns and water usage, supported by analytics.

Based in Nairobi, Kenya, with products currently used in Ethiopia, Zambia, Togo, Cote D'Ivoire, and more.

SunCulture

G42 in partnership with global and local tech players

Collaborating with Microsoft and local innovators to build AI capacity in Kenya

Joint investment with Microsoft to build comprehensive AI ecosystem in Kenya, totaling $1B.

Plans to build state-of-the-art data center campus in Olkaria, Kenya, run entirely on geothermal energy.

Partnering with local Kenya organizations to build local-language AI models, and E. Africa innovation hub and more.

G42

AI's potential to evolve more advanced abilities

AI has the potential to develop entirely new abilities that—if realized—would position it to play an even greater role in the energy system of the future.

Beyond the development and deployment of AI's current abilities, entirely new abilities are on the horizon. One example is agentic operation: autonomous or semiautonomous systems designed to make decisions and accomplish goals—on behalf of an individual—within specific environments.[111] Technical research in the field of agentic systems has advanced greatly in recent years, and they are significantly more sophisticated than assistive systems, such as ChatGPT, that rely on human guidance to retrieve and process information. With the help of agentic AI, autonomous systems are rapidly advancing in areas like self-driving vehicles, complex games, and research assistance.[112, 113, 114]

With appropriate safeguards in place, agentic AI has the potential to unlock value in the vastly complex future energy system, particularly in grid management and demand response. In these areas, decisions must be made rapidly and accurately based on vast amounts of dynamic and interconnected data at a scale not possible today, even with assistance from AI.

For example, in grid management, today's AI can predict demand across various loads and forecast power availability based on factors like weather and grid congestion. Agentic systems could enable going one step further, assisting humans to automatically activate alternative power sources or storing surplus energy for future use.

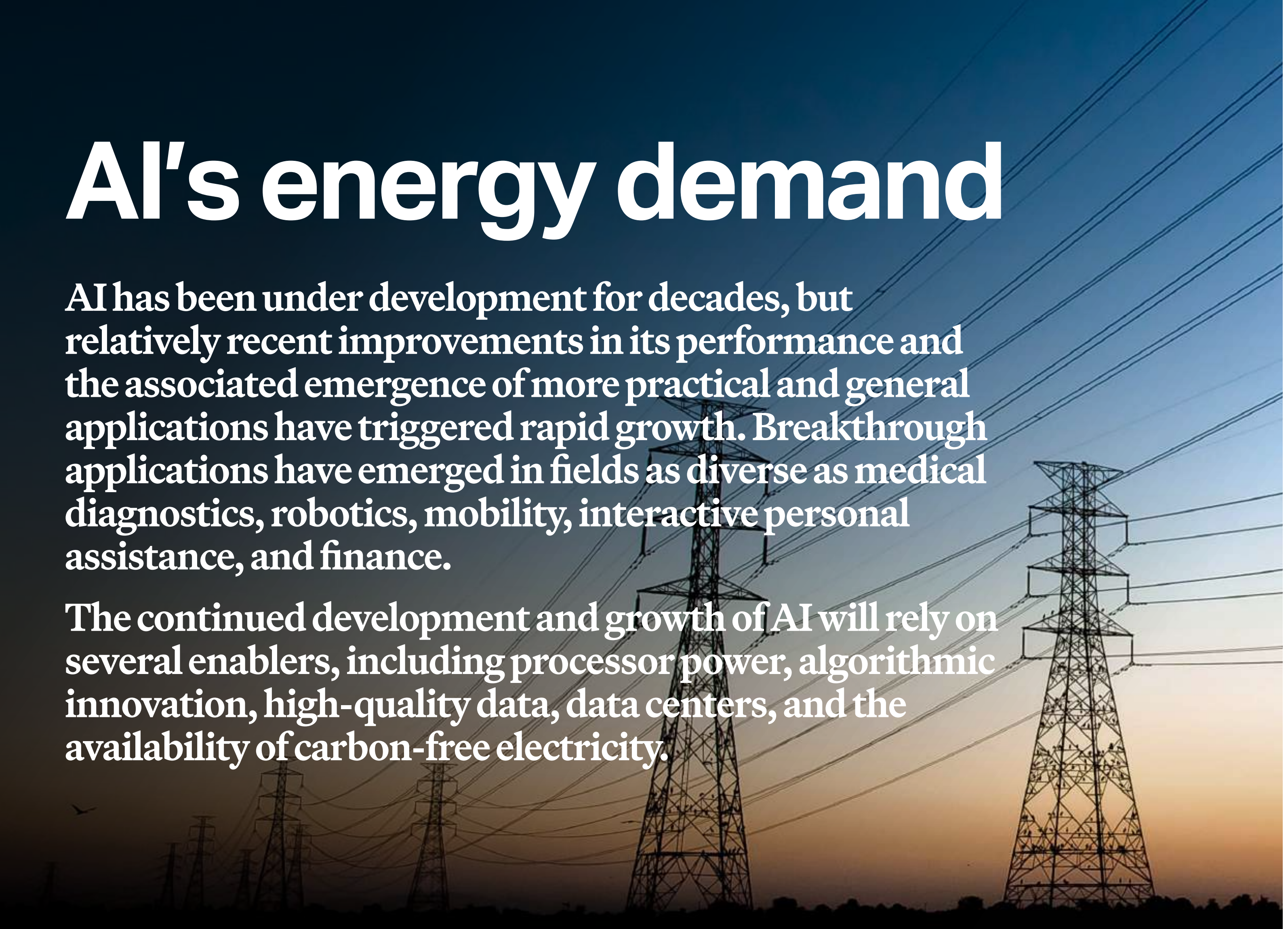
When it comes to demand response, today's AI can gather data from devices like EVs, appliances, and smart meters to help human operators allocate power more effectively. Agentic systems, by contrast, could be instructed by humans on when to directly control devices, curbing energy use during demand spikes or charging batteries when energy is abundant.

While agentic AI has the potential to provide many opportunities, the potential applications in the energy sector are still in their infancy. More research and learning is needed to understand and refine its potential. For agentic AI systems to scale, especially in complex and technical fields like energy, they must undergo robust testing and be equipped with strong safeguards.

The EU Artificial Intelligence Act, which regulates AI models and systems, sets forth specific requirements for "high risk" AI systems, which include those used in the management and operation of safety components of critical infrastructure, like the energy sector. These requirements include obligations around risk assessments, data governance, transparency, and human oversight.[115] In the energy sector, therefore, it is possible that certain agentic AI systems may need some level of human oversight, making them semi-autonomous rather than fully autonomous.

As it continues to evolve with new and improved abilities, AI has the potential to play an even more valuable role in the energy system of the future.

Meeting THE ELECTRICITY NEEDS OF AI with carbon-free energy



AI's energy demand

AI has been under development for decades, but relatively recent improvements in its performance and the associated emergence of more practical and general applications have triggered rapid growth. Breakthrough applications have emerged in fields as diverse as medical diagnostics, robotics, mobility, interactive personal assistance, and finance.

The continued development and growth of AI will rely on several enablers, including processor power, algorithmic innovation, high-quality data, data centers, and the availability of carbon-free electricity.

Data centers are key infrastructure for hosting AI. Despite the rapid growth in data center operations and AI applications, AI's energy demand is likely to remain minor on a global scale in the near term. However, this demand growth for continuous and reliable power is beginning to strain certain local grids where data centers are concentrated, making it crucial to plan how energy supply will meet this demand.

Global electricity demand is expected to rise at 3–4% per year through 2030, which is approximately equivalent to the total annual electricity demand of Japan.[116, 117] The growth of electricity demand is largely driven by increased electrification in households and commercial buildings as well as in transport and industry. Nearly 80% of this demand growth is from EMDCs.[118] Electrification is a critical part of the energy transformation because it makes it easier to power sectors like transport, heating, and industry with carbon-free energy. According to the IEA STEPS, global electricity capacity will need to increase 1.7 times by 2030, as compared to 2023.[119] In addition to the significant financial investment in power production to meet this rapid rise in demand, upgrades to transmission infrastructure will be necessary to reliably deliver electricity.

Data centers, critical infrastructure for AI, are driving part of this growth. Today, data centers account for approximately 1–1.3% of global electricity demand—about 1.5 times the total annual electricity demand of Spain[120]—crypto adds another 0.4% (see Figure 18). As the infrastructure needed to support AI expands, electricity demand from data centers will rise, though the extent of the increase remains uncertain.[121] History suggests that innovation can slow that demand. Between 2010 and 2020, global data center workloads increased by approximately 840%, while data center electricity demand increased by only 10%.[122]

While the electricity consumption of GPU chips has been increasing on a per unit basis, it has been decreasing on a per compute basis, which is expected to continue (see Figure 19 and Figure 20).
In the short term, electricity demand for data centers is expected to grow 8–23% per year through 2026, doubling its share of global electricity demand to 2.65%.[123] Looking forward to 2030, based on IEA and Goldman Sachs data, we have projected that electricity demand for data centers will potentially grow 3–20% per year, equivalent to 1–6 times the global electricity demand growth rate over 2023-2030.[124] While AI is emerging as a new driver for data center electricity demand, its current impact remains relatively small, accounting for about 0.02% of global electricity demand in 2022. At current rates of growth, AI is expected to account for 0.24% of global electricity demand in 2026 (see Figure 18).[125, 126]

Data center electricity demand growth rate is expected to be

3–20%

per year between 2023 and 2030 [124]

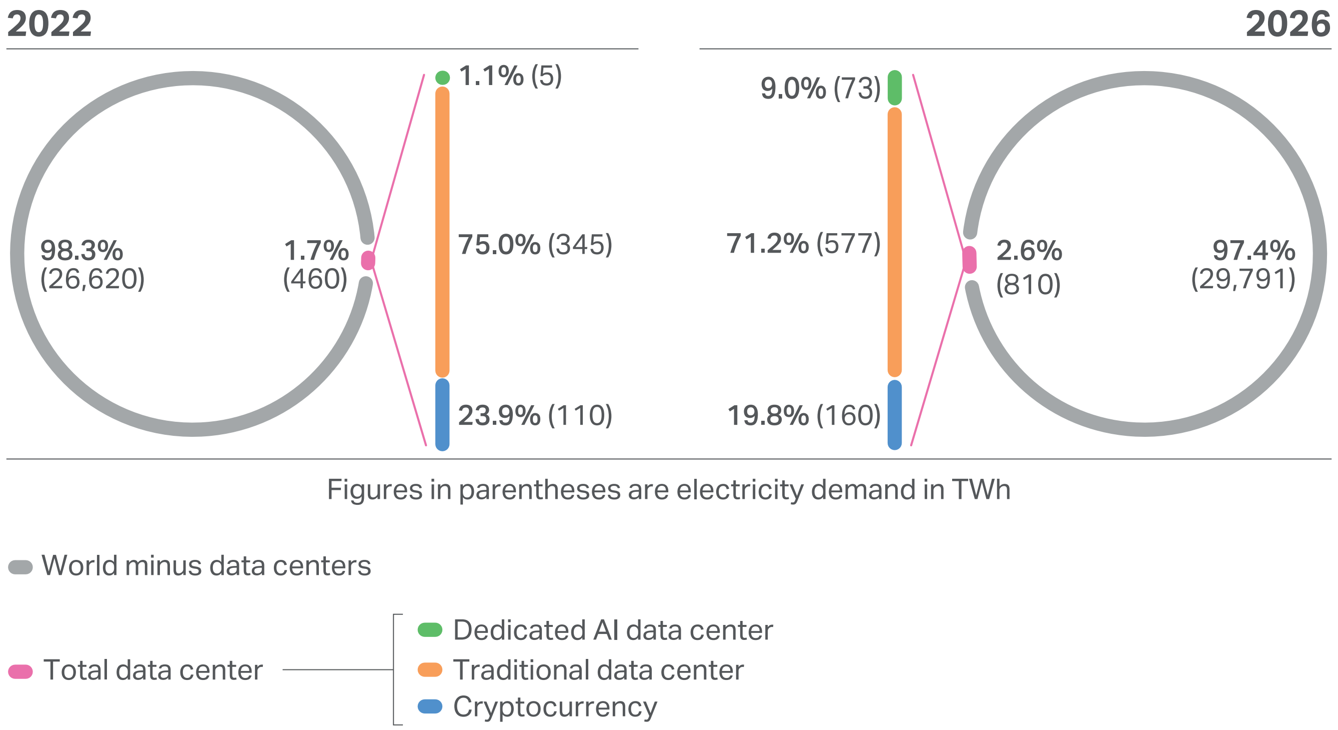
Data center electricity demand growth is

1–6 times

the global electricity demand growth rate [124]

Figure 18

AI and data center proportion of global electricity demand



Source: IEA, Electricity 2024: Analysis and Forecast to 2026, 2024
Methodology: The pie chart was develop based on data from the IEA Electricity Report 2024 (see figure on page 35), AI-related energy consumption in 2022 is estimated at approximately 5 TWh, and at around 73 TWh by 2026. The other data presented in the pie chart are either explicitly provided in the report or calculated based on these two AI energy consumption estimates.

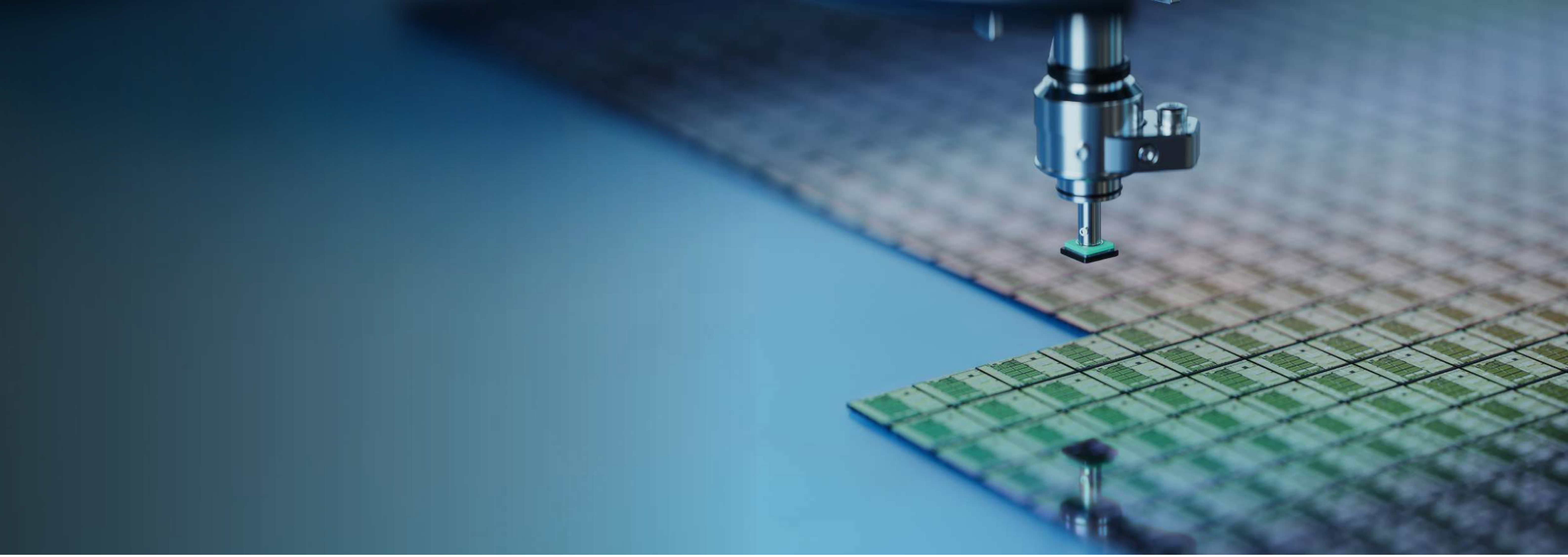
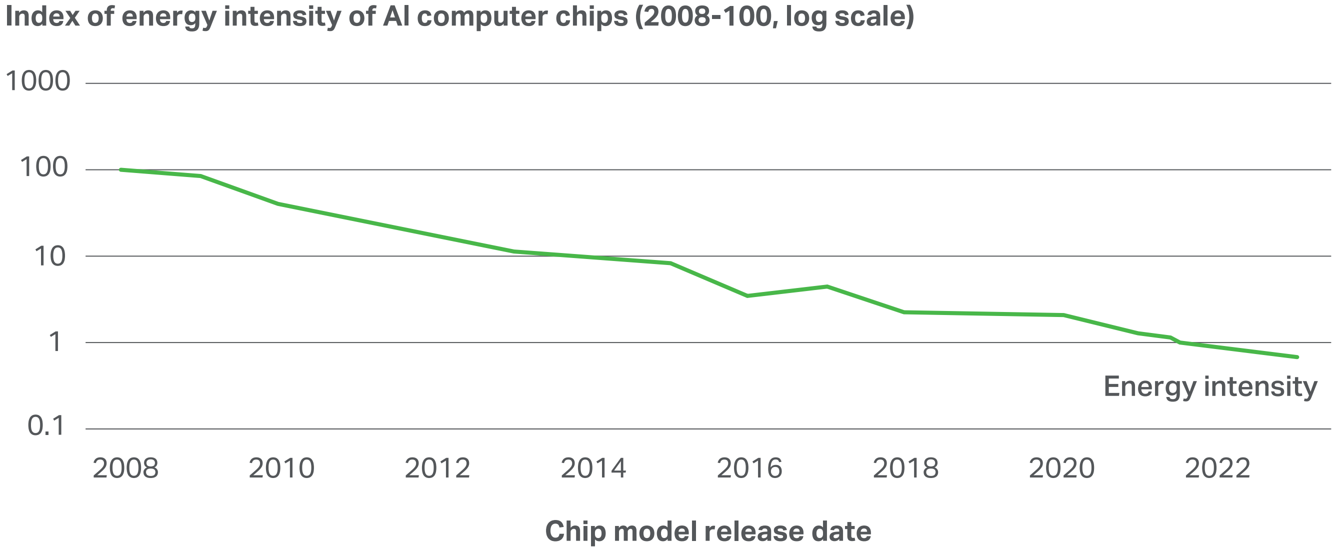


Figure 19

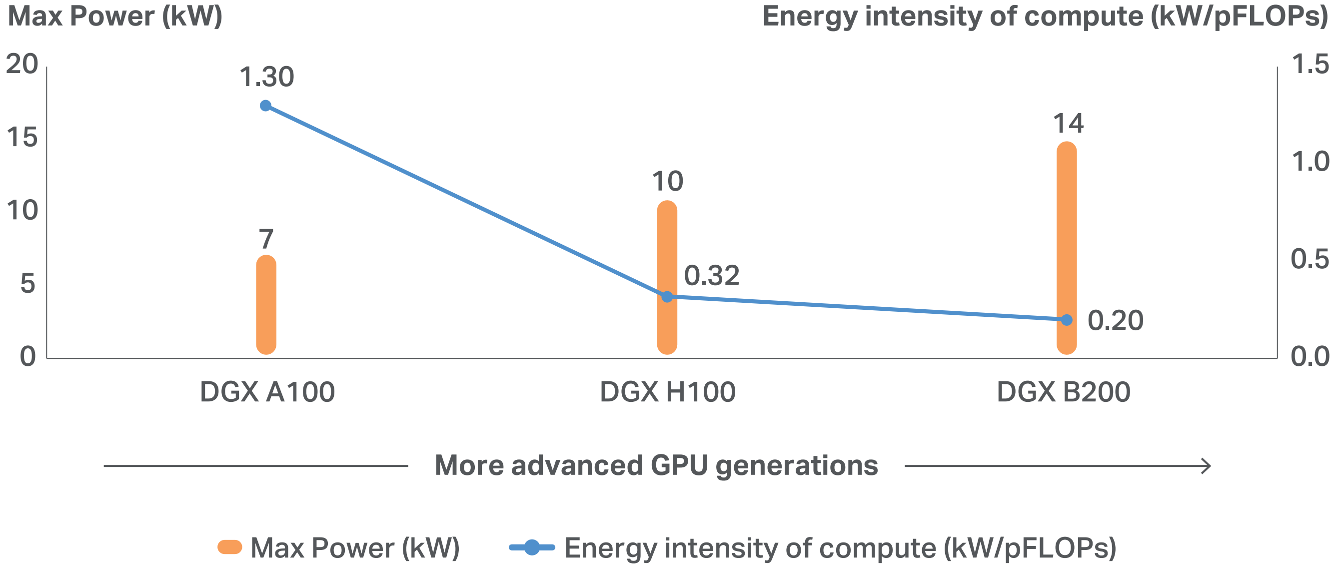
Energy intensity of AI computer chips has been improving historically



Source: IEA, *What the data center and AI boom could mean for the energy sector*, October 2024

Figure 20

Energy intensity of compute is decreasing even as energy consumption of AI chips is increasing on a per unit basis



Source: Nvidia, DGX Station A100 Hardware Specifications; Nvidia, H100 Tensor Core GPU Datasheet; Nvidia, DGX B200 Datasheet; ADNOC Analysis.

Reliably forecasting AI electricity demand beyond a few years is extremely difficult.[127] It will depend on how AI models are developed and operated, how technologies advance, and how models evolve. Innovations will be critical to increase energy efficiency in data center design and operations. But according to IEA projections, data centers will remain a relatively small driver of overall electricity demand growth at the global level in the decade to come (see Figure 21).

In certain regions, the speed and scale of AI and data center growth has the potential to put more pressure on local electric supplies due to rapid connection requirements that outpace historic planning timelines. The high demand for reliable carbon-free power further intensifies these challenges, requiring careful coordination and strategic planning to ensure that both AI and data centers can effectively integrate into the evolving energy landscape.

For example, in regions where data centers are concentrated, they can account for a significant percentage of the total electricity demand load (see Figure 22). In the EU, electricity demand for data centers is expected to increase at ~9% per year due to digitalization, including AI, and could exceed 5% of the EU electricity demand by 2026. In the U.S.—the largest data center market globally—data centers represent about 4% of the nation's electricity demand; that is expected to rise to nearly 6% by 2026.[128]

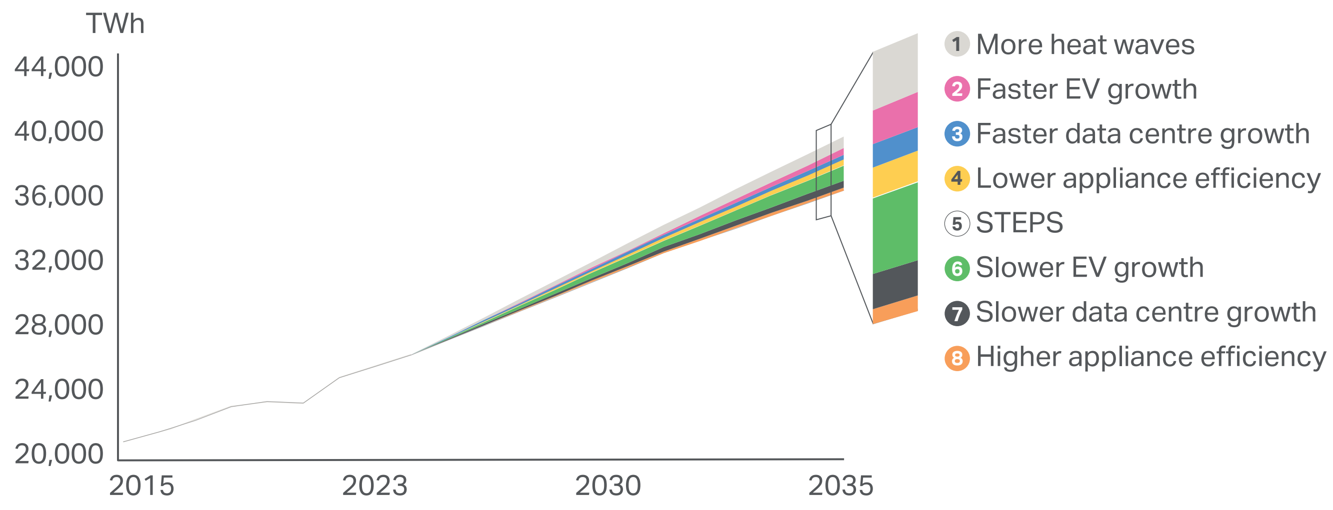
These rates of growth can be challenging in regions with aging transmission infrastructure and growing competing demands for carbon-free generation. In certain markets, that growth will potentially translate into a large share of grid demand.

In the U.S., electricity demand has stayed relatively flat since the turn of the century but is now expected to grow at 1–2% per year, resulting in an overall increase of 15–20% from 2023 to 2030.[129] According to the Electric Power Research Institute (EPRI), data center electricity demand is expected to grow 5–15% annually and can potentially account for 5.0–9.1% of U.S. electricity demand by 2030, up from nearly 4% in 2022.[130]

Power producers and technology companies are building generation capacity in response. American Electric Power is adding 20 GW over the next decade, 15 GW of which is to meet demand from data centers.[131] Technology companies are partnering in building capacity with utilities—for example, in Nevada with advanced geothermal and in Virginia with SMR.[132]

Figure 21

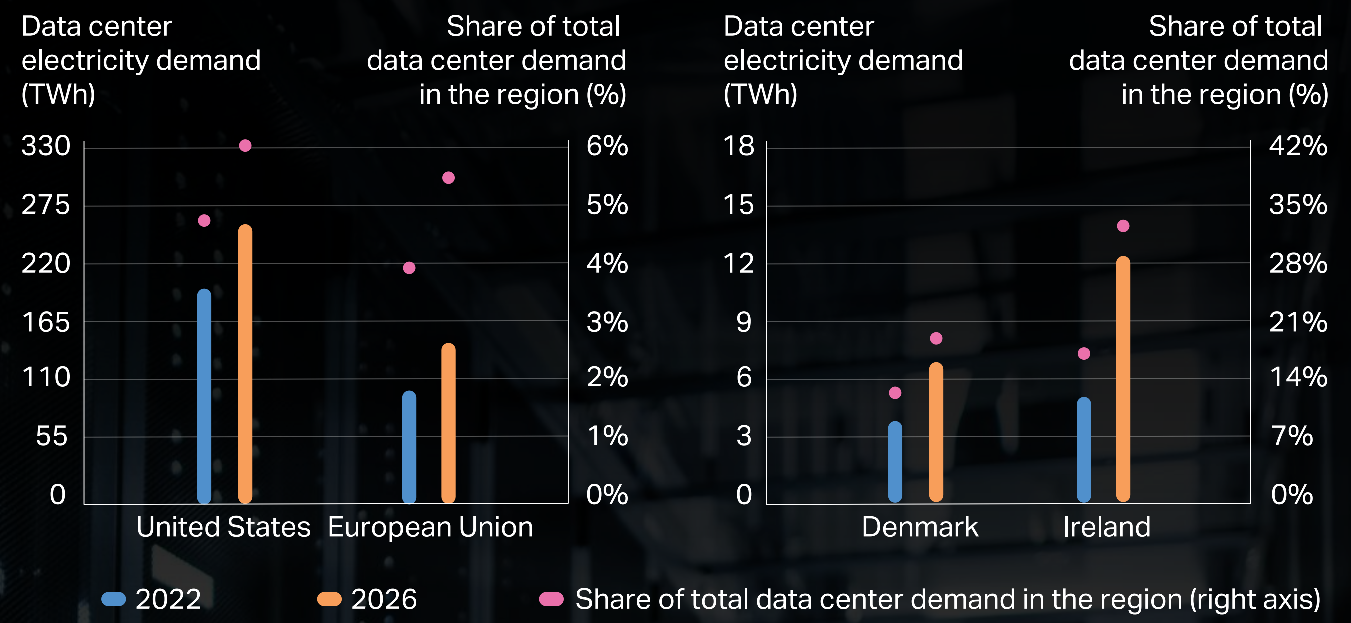
While electricity demand increases strongly in IEA's Stated Policy Scenario (STEPS), uncertainties could push demand further, by up to 15%.



Source: IEA, WEO 2024

Figure 22

Data center electricity consumption and growth across markets with high data center concentration



Source: IEA, Electricity 2024.

Data center electricity demand is expected to account for

5–9.1%

of U.S. electricity demand by 2030 [130]

“As AI continues to drive growth in data centers, it's clear that the future of energy must be carbon-free. At Quantum Switch, we're committed to ensuring our infrastructure supports this shift. AI demands stable, scalable energy, and investing in carbon-free power sources—like wind, solar, and storage—will not only help meet this demand but also ensure that our data centers remain efficient, sustainable, and resilient in a net-zero world.”

Timothy Bawtree
Chairman, Quantum Switch Group

Total U.S. data center electricity demand could grow between 30–90 GW between 2023 and 2030.[133,134] Estimates suggest that addressing this incremental demand could require $4–$9 billion in investment per year from 2023 to 2030.[135]

In the EU, data centers could account for about 17% of incremental electricity demand from 2024 through 2026.[136] In certain markets, that growth would translate into a large share of national demand. For example, the IEA forecasts that data centers could account for 28% of Ireland's demand by 2026 and approximately 20% of Denmark's by 2026.[137] In some countries, the possibility to develop data centers further has been limited due to concerns on grid and clean energy capacity availability.

Keeping up with this growing demand for carbon-free energy in the regions that support data centers will be critical to ensure that AI growth is aligned with, and helps to accelerate, the global race to net zero.

Growing renewable generation can deliver a significant share of this rising demand, but the intermittency of renewables will need to be addressed with storage or reliable non-intermittent energy sources. Further developing such solutions is critical to meet the growing electricity demand, including those of AI with carbon-free energy.

We see two main areas of opportunity for energy players to work with technology players: improved data center efficiency and new sources of carbon-free electricity.

Improving the efficiency of AI and data centers

The IEA has called for energy efficiency to be the "first fuel of choice." The COP28 UAE Consensus calls for the annual rate of energy efficiency to double by 2030.[138]

Meanwhile, AI's energy efficiency has improved, and there is potential for further improvement in these areas:

Hardware

Investing in the latest energy-efficient processors and storage devices can greatly reduce the energy required to perform computational tasks. One strategy is to optimize the hardware mix, using high-power GPUs for intensive computations and low-power CPUs for other tasks. A future possibility is to use quantum computers, which have the potential to perform some compute-intensive tasks more efficiently.[139]

While the absolute electricity demand per GPUs is increasing, they are becoming more efficient, meaning they use less electricity per unit of processing power basis, and this trend is expected to continue.[140]

Smaller models

Small language models (SLMs) are designed to perform simpler tasks than large language models (LLMs). They can be more accessible to organizations with limited resources and may be more easily fine-tuned to specific needs.[141] SLMs are also more energy-efficient because of their lower compute requirements, thereby providing a viable option for users that do not need the power of an LLM.[142]

Cooling

Replacing traditional air cooling with liquid cooling systems, where coolants are circulated directly to hot components like CPUs and GPUs, can significantly reduce energy use for cooling. Liquid cooling is more efficient at transferring heat, reducing the need for extensive air conditioning. While some liquid cooling systems use a considerable amount of water, many do not. A focus on minimizing both water and energy use is essential, as there is often a trade-off between these resources in cooling strategies. Water-free cooling systems can be a strong option, especially when surplus carbon-free energy is available to power them. Leveraging environmental conditions, such as using cool outside air, can further reduce reliance on energy-intensive mechanical cooling. Segregating hot and cold air streams within the data center to prevent mixing can also improve cooling efficiency.

Data

Electricity use can be minimized by reducing the amount of data that needs to be processed or stored through compression techniques and by optimizing storage systems. It is possible, for example, to reduce the amount of "dark data" held on servers, such as obsolete data like unused backups. Another strategy is edge computing, which moves some processing tasks closer to the source of data. Edge computing is designed to reduce the amount of data transmitted to and from data centers, thus lowering energy usage by both networks and data centers.

Energy management

AI can help monitor and optimize energy usage in real time, adjusting cooling systems, workload distribution, and other parameters dynamically to minimize energy consumption. AI systems can also predict when equipment is likely to fail or require maintenance, allowing for proactive intervention that both ensures systems run at peak efficiency and reduces energy waste due to malfunctioning equipment.

Demand response

This term refers to the practice of balancing power grids by incentivizing customers to shift demand to times when supply is available or utilizing electricity generation or storage on-site to reduce demand from the grid at certain times.[143] Technology companies have launched pilot programs, with promising early results. And select Microsoft and Google data centers in the EU used demand response to support the grid during periods of energy scarcity in the winter of 2022 to 2023.[144] More research is being done on opportunities for grid operators to optimize grids with greater granularity and efficiency offered by AI.

Developing new sources of carbon-free electricity

Although AI is projected to be about 0.24% of total global electricity use by 2026, the broader cross-sectoral load growth necessitates the build-out of carbon-free electricity and additional sources of carbon-free energy generation.

The technology and energy industries must work to meet the evolving demands on the world's grids and this build-out of carbon-free energy sources through a combination of direct investment and green procurement (e.g., power purchase agreements).

In addition, new sources of energy will need to be connected to new sources of demand through increased transmission and distribution capacity. The integration of software that increases grid transparency and accuracy can help.

SURVEY INSIGHT

83%

of leaders in energy companies and

75%

of leaders in technology companies surveyed are willing to pay more for carbon-free energy

Cooling towers of a nuclear plant

Wind and solar

Wind and solar are expected to provide about 30%–41% of future generation by 2030, according to the IEA.[145] Power purchasing agreements (PPAs) with renewable energy providers can signal demand but it will need support from energy industry participants and regulators to ensure expedited build-out. The technology companies that build and run AI models are among the top six corporate buyers of solar and wind PPAs in 2021.[146] Masdar has a number of PPAs supplying electricity generated from offshore and onshore wind with hyperscalers in the U.S., Germany, and Spain. Large consumers have the potential to expand the use of PPAs via novel engagements, but grid operators, utilities, utility regulators and others in the electricity industry must also work to bring more carbon-free electricity online to meet the needs of the future grid. In particular, it is crucial to ensure that new capacity is developed in EMDCs to increase electricity access for local communities.

Bioenergy and gas with CCS

In the short term, new large-scale natural gas and bioenergy plants will potentially be necessary in some markets to meet rapidly growing demand. These plants should be equipped or retrofitted with CCS technologies whenever feasible.

Long-duration energy storage

Long-duration energy storage (i. e., for eight hours or more) is particularly well-suited to complementing renewables and can be cheaper than increasing solar capacity to cover mornings and evenings. Microsoft and Google recently collaborated with Nucor to accelerate development of carbon-free energy solutions such as long-duration energy storage.[147]

Geothermal

Geothermal power plants have a high-capacity factor of 90% or more and can provide firm, dispatchable electricity all year long.[148] Microsoft and UAE-based G42 have made plans to set up a geothermal-powered data center in Kenya with a potential capacity of 1 GW.[149] Similarly, Sage Geosystems will provide Meta's data centers with 150 MW of geothermal power by 2027.[150]

Nuclear fission

Nuclear fission generates carbon-free firm electricity. Microsoft and Constellation Energy have entered into a power purchase agreement to restart the Three Mile Island nuclear power plant. This plant will supply power to data centers for 20 years, starting in 2028, pending regulatory approvals.[151] Additionally, there has been progress in developing next-generation nuclear technologies, including small modular reactors with Kairos power and X-energy.[152, 153]

Nuclear fusion

Another potential source of sustainable energy is nuclear fusion.[154] In 2022, a team at U.S.-based Lawrence Livermore National Laboratory's National Ignition Facility conducted the first controlled fusion experiment that produced more energy from fusion than the laser energy used to drive it. The path to market-ready fusion energy will depend on partnerships and the ability to mobilize resources for scaling.[155] In 2023, Microsoft formed the world's first nuclear fusion power purchase agreement with Helion to buy 50 MW of fusion power, with deployment starting in 2028, when the plant becomes operational.[156]

> "With renewed momentum and support for deploying nuclear plants across countries, financial institutions and the international civil nuclear sector, driven by the strong market signals from technology companies urgently requiring large amounts of clean, baseload electricity, there is a clear opportunity for nuclear energy to sustainably power digital transformation globally."

Mohamed Al Hammadi
CMD & CEO, ENEC

05

Recommendations for

REALIZING AI'S POTENTIAL

for the energy transformation

Recommendations for realizing AI's potential for the energy transformation

The potential for the energy and technology sectors to accelerate a just, orderly, and equitable energy transition to net-zero whilst minimizing the emissions footprint of AI is huge. But success is not inevitable: It requires collaboration between both sectors, along with academia, governments, and others to develop the abilities of AI and effectively deploy them in the energy sector.

Seven priority areas include:

Increase collaboration between technology and energy companies to deploy more carbon-free energy while making it more available and more affordable for all.

01

Invest in AI for the energy transformation with a focus in four key areas: tripling the availability of renewable energy, building a resilient grid, reducing methane emissions, and utilizing carbon capture and storage.

02

Expand and enhance grid capacity and increase availability of carbon-free electricity, especially in locally stressed grids or regions—while continuing to innovate to increase energy efficiency.

03

Build capacity in the workforce to leverage AI for the energy transformation.

04

Develop AI with and for emerging economies, to meet their unique needs.

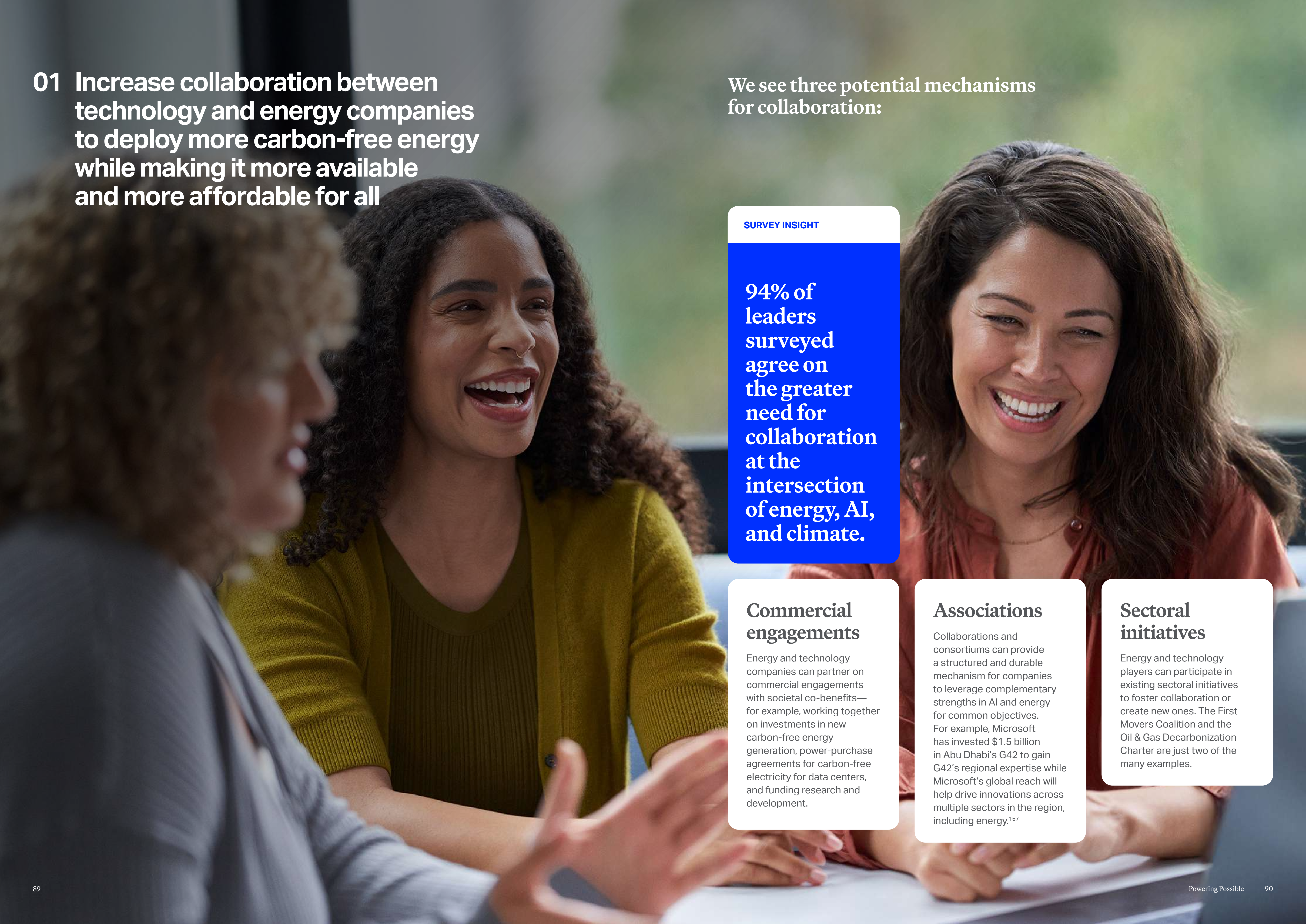
05

Establish data standards and protocols for AI to better support the energy sector.

06

Advance policy and governance principles targeting for responsible, sustainable AI development and a secure and inclusive transition transformation to a net-zero energy system

07



01 Increase collaboration between technology and energy companies to deploy more carbon-free energy while making it more available and more affordable for all

We see three potential mechanisms for collaboration:

SURVEY INSIGHT

94% of leaders surveyed agree on the greater need for collaboration at the intersection of energy, AI, and climate.

Commercial engagements

Energy and technology companies can partner on commercial engagements with societal co-benefits—for example, working together on investments in new carbon-free energy generation, power-purchase agreements for carbon-free electricity for data centers, and funding research and development.

Associations

Collaborations and consortiums can provide a structured and durable mechanism for companies to leverage complementary strengths in AI and energy for common objectives. For example, Microsoft has invested $1.5 billion in Abu Dhabi's G42 to gain G42's regional expertise while Microsoft's global reach will help drive innovations across multiple sectors in the region, including energy.[157]

Sectoral initiatives

Energy and technology players can participate in existing sectoral initiatives to foster collaboration or create new ones. The First Movers Coalition and the Oil & Gas Decarbonization Charter are just two of the many examples.

02 Invest in AI for the energy transformation with a focus in four key areas: tripling the availability of renewable energy, building a resilient grid, reducing methane emissions, and utilizing carbon capture and storage

The rate of new energy patents has halved since the 1970s.[158] In addition, private investment in AI for energy declined by over 30% in the last three years.[159]

Technology and energy collaboration can lean in to assist in three areas.

R&D

Energy and technology companies should openly collaborate in mapping emergent AI abilities to the four key focus areas named above, and then partner in developing practical solutions that will accelerate their development and deployment for the energy transition. For example, energy companies can use their R&D resources to provide opportunities for real-world testing of new materials for carbon capture and storage. Companies can include targets for their company's particular investment in related R&D in their annual budgets.

Commercial-ization

Energy and technology companies should collaborate on the commercialization of proven AI-applications for the energy transformation to make them more broadly available in the market.

Scaling

Licensing new technologies can accelerate adoption and lower costs for all participants. Open-source sharing is particularly suitable for large problems that require market-wide collaboration to accelerate innovation. This can include technologies with significant societal co-benefits, but also commercial endeavors that demand a shared technical foundation on top of which companies can compete.

03 Expand and enhance grid capacity and increase availability of carbon-free electricity, especially in locally stressed grids or regions—while continuing to innovate to increase energy efficiency

Energy and technology companies are well placed to collaborate on reducing the carbon footprint of data centers. Two priorities stand out:

Energy efficiency

Technology players should continue to invest in the energy efficiency of data centers and their constituent technologies to minimize the energy demand of AI and its associated emissions.

Carbon-free electricity

Energy and technology players should collaborate on increasing the availability of carbon-free electricity to data centers and increasing the reliability of the grid. For example, joint investment and power-purchasing agreements in collaboration with grid operators and regulators can be effective means to accelerate build-out of generation capacity and transmission infrastructure.

04 Build capacity in the workforce to leverage AI for the energy transformation

Energy companies cannot benefit from AI unless they have the skills to identify and implement solutions. Technology companies cannot deliver AI solutions without a better understanding of energy systems and the energy transformation. Joint training and workforce development could accelerate this agenda.

AI training for energy companies

Energy companies have long prioritized technology training. Training on the potential for AI in the energy transformation should be available to a wide range of personnel in both technical and nontechnical functions. By mainstreaming AI, leaders can build a culture of innovation within their organizations—key for attracting and retaining talent. Approximately 80% of AI talent leaves organizations because they want a more dynamic role or do not see opportunities for advancement.[160] Energy leaders that build AI-ready organizations will be more successful when it comes to retaining talent and driving their organizations into the future. Leading institutions such as the UAE's Mohamed bin Zayed University of Artificial Intelligence (MBZUAI) can serve as hubs for advancing AI knowledge and skills within the energy sector.

Energy training for technology companies

This training should start from the top at technology companies, with leaders establishing carbon-free electricity as the "fourth pillar" of AI development, along with computing, data, and algorithmic innovation. At the product development level, technology companies need to understand AI's potential for applications in the energy transformation. This will require training in the key challenges of the energy transformation, as well as in the operating environment of energy companies (such as technical standards for efficiency, product quality, and safety).

SURVEY INSIGHT

78% of leaders consider talent and training a challenge to adopting and using AI.

05 Develop AI with and for emerging economies to meet their unique needs

Approximately 80% of electricity demand growth through 2050 is expected to come from EMDCs, who are also expected to play a key role in new green energy value chains.[161] AI solutions must be designed with and for these markets.

The areas to concentrate on are:

Data centers

Today, approximately 85% of data centers are outside EMDCs. This disparity will grow unless corrective action is taken: By 2030, it is expected that the developed economies will add 1,800 data centers, and the EMDCs only 300.[162]

There has been concentrated data center development in just a few markets. Expanding into emerging markets will enhance sustainability and foster innovation in these new regions.

Talent

As highlighted in Chapter 3, talent is one of the most important enablers for AI development in EMDCs. It can be fostered through talent exchange programs, networks and mentorship, and the sharing of best practices.[163] Both energy and technology companies will find that EMDCs contain pools of ambitious talent. Survey analysis found that the five countries with the highest confidence in the future of AI are all located in EMDCs.[164] Training programs should incorporate talent from EMDCs.

Models

The vast majority of AI models are developed in the Global North, but local data is required to ensure they can be adapted to local realities, which can be highly constrained.[165] Technology leaders should partner with EMDCs to design and deploy AI models and solutions that meet the needs and reflect the circumstances of EMDCs.[166]

Approximately

80%

of electricity demand growth through 2050 is expected to come from EMDCs [161]

06 Establish data standards and protocols for AI to better support the energy sector

Data standards and protocols are necessary for the efficient flow of data across the energy system. Protocols should focus on pre-competitive zones of the data layer,[167] ensuring that proprietary data remains protected. Some sectors have succeeded in balancing data mutualization and competition. Take, for example, software's Linux open-source operating system, weather forecasting's public weather databases, and commercial air travel's open data for aviation safety.[168]

Unified data formats

Establishing standardized data formats for energy sector-related data (such as consumption patterns, generation data, and grid status) will be critical. Such formats ensure that AI systems can effectively analyze and share data across different platforms, devices, and segments of the value chain.

Communication protocols

Standardized Application Programming Interfaces (APIs) and communication protocols will be needed to facilitate seamless data exchange between AI systems, smart devices, grid operators, and other stakeholders in the energy ecosystem. This includes protocols like MQTT or OPC-UA for industrial IoT devices.

Interoperability frameworks

Creating frameworks that allow for the interoperability and integration of disparate types and sources of data (such as weather data, market data, and grid status data) into AI models will enable more comprehensive analysis and decision-making. Such frameworks will be critical for grid operators that sit at the nexus of supply and demand and receive data from many sources.

07 Advance policy and governance for responsible, sustainable AI and a secure and inclusive transformation to a net-zero energy system

Governments have an opportunity to accelerate the energy transition by crafting standards and policies that harness the capabilities of AI and help ensure alignment with sustainability outcomes as well as its safe, secure and responsible use.

Frameworks and policies for AI in the energy sector

It will be important to develop thoughtful standards and policy frameworks that govern the use of AI in the energy sector, ensuring compliance with existing energy laws, safety standards, and environmental regulations, following industry best practices for AI and implement government-led AI safety standards and policies.

Enhanced reporting protocols

Policies that encourage and leverage AI and digital tools for energy and environmental-related reporting can enhance accuracy, reduce costs and quickly adapt to shifts and differences in metrics and accounting.

Greater collaboration

Facilitate collaboration and partnerships among companies, AI researchers, scientists, and policymakers by creating a regulatory sandbox to address sustainability challenges collaboratively and by funding interdisciplinary projects that combine AI expertise with policy, sustainability, and social justice.

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