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Capitalizing on AI's Potential to Help Tackle the Climate Crisis

The pace of technological change hits me at least once a week. I might be scrolling through Twitter or perusing an article, and something comes along that astounds. As the Head of the U.K. government's Office for Artificial Intelligence, I see this most often through the application of AI technologies, as computers learn to diagnose cancer [1], beat humans at highly sophisticated games [2], or solve one of the longest-standing predicaments in the scientific community [3]. The pace of these achievements dwarfs anything we as a society are reasonably prepared for, and fortunately many of these advances tilt toward innovations that aim to improve the world.

This is the promise of the Fourth Industrial Revolution. The scale of investment in these advances in the past few years alone has been immense: worldwide spending on AI was approximately $35.8 billion in 2019, with a 44% increase from 2018 [4]; the Big Data market has almost doubled in size in three years, with a total global revenue of $49 billion in 2019 [5]; and in the U.K., recent research estimates that the digital sector is contributing £4700 (U.S. $5800) every second to the U.K. economy, accounting for 7.7% of gross value added in 2018 [6].

The uptake of these technologies means the world is accelerating even faster towards a future where breakthroughs are commonplace, and where emerging technology shapes the world we live in. My son is a Rubik's Cube fanatic, so you can imagine my fascination when researchers at OpenAI in San Francisco revealed an algorithm (through reinforcement learning — trial and error) capable of manipulating the pieces of a Rubik's Cube using a single robotic hand [7]. This is no mean feat: researchers also created environments like friction, elasticity, and dynamics to make it as real-world as they could, beating the dexterity of children by years.

But there is an impact to these breakthroughs that often gets glossed over amid the excitement — training artificial intelligence is very energy intensive. The computing power required for the Rubik's Cube training would have required more than 1000 desktop computers and a dozen machines running specialized graphics chips, crunching intensive calculations, for several months. For deep learning to grasp something as complex as language, models typically have to be provided with billions of written articles in order to understand the meanings of words and how sentences are constructed.

We see this similarly in emerging technologies. Bitcoin, in creating ever more complicated algorithms to mine, currently uses more energy than Switzerland does in a year, or

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as much energy as all the tea kettles in the U.K. use over 11 years [8]. This will only increase.

This issue has traditionally gone unaddressed in the AI community; the energy required to power cutting-edge AI has been on a steep upward curve for some time. OpenAI has shown that the computing power required for DeepMind's Go-playing program AlphaZero, has doubled every three months, increasing 300 000 times between 2012 to 2018 [9]. This is faster than the rate at which computing power has historically increased [10].

As these technologies grow faster — with all their positive transformative capabilities — so too does the risk of their becoming a significant environmental problem [11]. We are warned by history: in creating unprecedented human welfare over the past century, we have also been left with a planet that scientists warn is under unprecedented environmental strain. The article from Luccionni *et al.* in this issue, "Estimating Carbon Emissions of Artificial Intelligence," explores this issue with clarity.

From the U.K., the government is embarking on a push to acknowledge the scale of the environmental challenge ahead of us. This year has been hailed as a Year of Climate Action by the Prime Minister [12], and there are a whole host of positive contributions AI and emerging technologies can and are making to tackle the climate crisis. But we must not lose sight of the whole system. The intersection between the AI and climate worlds has not been adequately addressed. If we do not act to change that now, it is our present society, not just future generations, that will experience the impact of rapid digital transformation — positive and negative — alongside the impact of climate change.

If balanced correctly, this intersection promises a wealth of solutions that can help tackle our most pressing challenges — from decarbonizing energy and transport, to predicting forest fires, to more accurate and local climate monitoring solutions. This calibration also needs to be approached with a sober sense of the scale required to achieve these goals [13]. Just as the U.K. works to decouple carbon emissions and economic growth on the path to net zero emissions — so-called "clean growth" — we must also meaningfully deliver sustainable, inclusive growth with emerging technologies.

U.K.'s Place in Decarbonization and Digitization

Climate change is one of the most urgent and pressing challenges we face today, and one where more action is desperately needed. We must recognize and welcome pressure for action to cut emissions, and push to build consensus around change so that communities across the U.K. — and across the world — are secure, optimistic, and involved in our shifts to decarbonize the entire economy.

In the U.K., it has been twelve years since Parliament passed the seminal Climate Change Act, which introduced legally binding long-term emissions reduction targets. Last year the U.K. went even further and became the first major economy in the world to pass laws to end its contribution to global warming by 2050 [14]. It was an effective way of ensuring climate action survives the political cycle, moving away from climate advocacy and into climate action. In doing so, the U.K. has taken action without impacting quality of life: since 1990, emissions in the U.K. have been cut by 42% while the economy has grown by 72% [15]. The U.K. has been independently assessed as the leading G20 country to decarbonize since the year 2000 [16].

As we now reach the mid-point between 1990 and 2050, we have reason to take stock and reflect on how the U.K. was able to drive the decarbonization push among the 25 major economies in the world. Low-carbon innovation and rapid growth in renewables, particularly offshore wind, helped to set the trajectory. Thanks to a rich geographic position and the U.K.'s subsidy schemes encouraging renewables [17], offshore wind capacity has surged more than seven-fold from when the Climate Change Act was introduced [18]. The year 2019 was the cleanest year on record for Britain as the amount of zero carbon power outstripped fossil fuel power for a full twelve months for the first time ever [19].

In response to this, the Queen's Speech in December 2019 called for 40 GW of offshore wind by 2050 [20]. To put that scale of investment in context, the total electricity demand of the U.K. is currently at around 50 GW. Recent analysis suggests that offshore wind prices are now so low that the wind farms could generate electricity more cheaply than existing gas-fired power stations as early as 2023 [21].

In concert with the rise of renewables is a sharp fall in coal power. The year 2013 saw Britain as the first EU country to announce a carbon price support of £18 per ton of carbon dioxide [22], paid for by fossil fuel companies. In 2015 the U.K. announced it would stamp out coal power entirely within a decade [23]; this ambition was recently ratcheted up by the Prime Minister to 2024. The effect has been a radical transformation of the energy mix: whereas in 1990 coal made up 75% of the grid, it constituted only 2% of 2019's energy output [19] and

last year achieved the first coal-free fortnight since the first industrial revolution (24).

These are some wins for the U.K., but what comes next is the hard part: an economy-wide overhaul towards net zero, according to the Committee on Climate Change, the independent non-departmental public body formed under the Climate Change Act (25). This is not to be underestimated, and for the country that powered the first industrial revolution, this will require decisive action.

The U.K. government built a modern industrial strategy for the country that nominated itself as a vehicle for economy-wide transformation, choosing to squarely embrace the fourth industrial revolution (26). This was reflected in the grand challenges it set for itself: Artificial Intelligence (AI) and data, aging society, future of mobility, and clean growth.

These grand challenges were chosen to represent larger global megatrends that can supercharge existing strengths throughout the country. In 2017, Professor Dame Wendy Hall and Jerome Pesenti led an independent review of how the AI ecosystem could be further developed in Britain (27). The review made a number of important recommendations to improve access to skills and data, maximize AI research, and support the uptake of AI.

Following the Hall-Pesenti review, the nearly £1billion (U.S. $1.2 billion) AI Sector Deal was published in 2018 (28), which made clear the huge global opportunity in AI, and the U.K. government declared its intention to become a global leader in AI and data-driven technology. The AI Sector Deal led to the creation of three new institutions: a U.K. government Office for AI; a U.K. industry-led AI Council; and the U.K. Center for Data Ethics and Innovation.

As part of that first institution, I'm deeply proud of what my team of fewer than 20 civil servants have been able to achieve. We are working to build the enabling foundations for AI and data driven technologies to be expressed in a myriad of ways, and have since delivered on the commitments set out in both the Review and Sector Deal (29). We also work closely with colleagues across the U.K. government who are looking at various applications of AI; the Center for Connected and Autonomous Vehicles and its Future of Mobility Grand Challenge are a natural fit, and teams in the Government Digital Service are looking at how government itself can use AI in the most appropriate and responsible way.

The U.K. finds itself in a strong position to capitalize on the opportunities of AI. Based on recent estimates, the U.K. is third in the world for investment, innovation, and implementation of AI (30). On skills, the U.K. is seen as the leader in Europe (31), is third in research talent and published research papers (32), and third in raising investment in AI (33). The prize is significant: embedding AI across the U.K. has the opportunity to create thousands of high-quality jobs and drive economic growth — potentially contributing an estimated £232 billion to the U.K. economy by 2030 (34).

As the political tide rises on the need for increased action on climate change, there is a need to consider how these Grand Challenges intersect, and we must take a fresh look at how our collective national efforts can apply themselves across shared global threats, and in concert with the national efforts of others who acknowledge the same.

The Challenge Ahead

To get the intersection right and capitalize on the full potential that emerging technologies can bring to tackle the climate crisis, a number of important — and systemic — barriers must be overcome. These are barriers that exist globally and across domains, and while we cannot hope to solve this particular Rubik's cube ourselves, we in the U.K. Office for AI have been applying our efforts to help find useful solutions to a couple of issues: access to data, and the supply of AI skills.

As AI technologies grow faster — with all their positive transformative capabilities — so too does the risk of their becoming a significant environmental problem.

Access to data is fundamental to any technology, but with AI the need is critical. AI technologies can scale innovation and unlock insights that can optimize systems or generate breakthrough discoveries to help tackle climate change, but scaling up to meet this challenge is difficult, and the true value of data often goes unrealized (35). Public trust and confidence in how data is used is also a significant factor, explored in the recent report by the U.K. Center for Data Ethics and Innovation (36). Business models for data collaboration and interoperability therefore remain greatly underutilized. This is often caused by a lack of capacity to collect data, unclear data ownership structures, and

a lack of commercial incentive to obtain or share data.

The Office for AI has been working with the Open Data Institute to explore how access to data can be improved, through Data Trusts [37]. By demonstrating the benefits of sharing data — including non-personal data — such as our pilot projects in illegal wildlife trade and food waste, we may be able to start building thriving AI and data technology ecosystems that can step up to the challenge of climate change.

Tackling this multifaceted challenge requires drawing on a huge range of disciplines and skills, which means both institutional expertise and human skills. The most successful in this pursuit will need to understand the promise of emerging technologies in reaching net zero, but also in understanding the language around these technologies. The pool of individuals is currently too small and not representative of our diverse society to develop the correct technology at scale to attack this problem.

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In the U.K. this is reflected by an imbalance of supply to meet the demand for AI technologies. The Office for AI has sought to address this by developing a talent and skills pipeline to enable as many people as possible to benefit from the opportunities presented by AI [38].

The U.K. government is also supporting new U.K. Research and Innovation Centers for Doctoral Training in AI [39], which will train 200 new Ph.D. students per year until 2025 with a multi-disciplinary approach, and two of these Centers are focused explicitly on AI and sustainability issues.

On its own, this won't be enough to draw the best and brightest into the net zero challenge, but once these foundations are enabled, the opportunity to plug into this challenge is what comes next. But we cannot afford to wait for long. The Intergovernmental Panel on Climate Change has warned that our current trajectory of decarbonization means that the "safe limit" of 2°C will have been breached by 2036 [40]. Though there has been political and technological progress, the rate of global decarbonization required is increasing each year, which puts in sharp focus the need to bring every technological solution to bear on accelerating the decarbonization of the economy.

Transformative Potential of AI

AI technologies provide a host of applications to mitigate and adapt to the issue of climate change, and many qualified individuals, including Luccionni *et al.* in this issue, have opined on this [41]. Some estimates have put the potential of applying AI to clean growth as bullish: globally, AI can help deliver a reduction in GHG emissions of up to 4% by 2030 with a concurrent uplift of 4.4% to global GDP [42].

In order to illustrate how AI can be used to transform our sectors, energy is perhaps the most practical lens through which to focus. AI applications in energy provide the largest global impact on greenhouse gas (GHG) emissions [42], but this should not discount the system-wide importance of applying technological solutions to a wide range of sectors with the intent to help mitigate and adapt.

The U.K. energy system, much like others around the world, is transitioning from being centralized and fossil-fuel dominated, to being increasingly decentralized and renewables dominated, and with new demands from transport and heat. As this happens, there is an increasing need to optimize and manage the many complex constituents of the energy system, including renewables, electric vehicle charging, and battery storage. AI will not only be a useful tool in optimizing and managing future electricity systems, but will also be essential in managing increased complexity, whether in relation to solar and wind forecasting, grid management, battery management, or analyzing smart meter data.

Perhaps one of the most important roles AI could play in this space is in optimizing electricity dispatch. Electricity dispatch is the short-term allocation of the optimal amount of generated electricity that is required to meet the demand of the overall system, and to do so at the lowest cost. All else being equal, systems that have large amounts of intelligence — and the capacity to update quickly in light of real-world conditions — are systems that are a lot more efficient.

In contrast, the more uncertainty grid operators have in their forecast of electricity supply or demand, the more backup power, typically provided by fossil fuel generation, is required. AI, alongside improved data collection, can much more closely forecast in real time the right balance of renewables supply with demand, to optimize the role of renewables on the system [43].

This can reduce the need for reserve power and reduce the loss of excess renewable power, which would otherwise be lost.

In the U.K., this opportunity is being approached with an open data mindset. A former DeepMind employee has spun up OpenClimate Fix, a non-profit research lab creating open datasets for machine learning researchers and startups to benefit from solar "nowcasting." These algorithms will forecast electricity production from solar power up to a few hours ahead, and the open nature of the data will enable others to develop new technologies far more easily [44].

Low carbon innovation is also at the heart of the government's approach to net zero, with over £3 billion (U.S.$3.6 billion) of government investment from 2015 to 2021 [45], [46]. The economic benefits associated with AI in energy are significant — the ability to optimize current grid efficiency and avoid constraints can save billions of pounds on building new grid capacity. This is reinforced by the U.K. Energy Innovation Needs Assessment, which supports evidence and analysis on the role of different technologies in the U.K.'s future energy system. Using AI to optimize the electricity system, and in the design of nuclear and offshore wind development, carries an innovation value of £8.7 billion (U.S.$ 10.5 billion) up to 2050, and an export potential of £3.5 billion (U.S.$4.2 billion) by 2050, topping the list of priority innovations they identified [47].

Opportunities of Applying AI to Net Zero

The energy sector, like any other, is faced with technical, regulatory, financial, commercial, and political barriers to overcome before being able to harness the full spectrum of AI opportunities. But the potential for an economic revolution is there. If we can square up to this challenge, the low carbon economy in the U.K. could grow four times faster than the rest of the economy until 2030, and could deliver between £60 billion (U.S.$73 billion and £170 billion (U.S.$205 billion) in exports by 2030 [48].

The demand for data science skills in the energy sector has always been present, but with the push towards net zero the ability to harness AI to maximize the reliability, responsiveness, and accuracy of the U.K.'s energy system will need to attract experts in machine learning. Digital skills and data analytics will eventually become core skills for the net zero energy workforce, with big data used for network planning, maintenance, and risk mitigation. National Grid has suggested that more than half of the 117 000 jobs required this decade (65 000) by the energy industry to reach its net zero goals will be data analysts and renewables specialists [49].

While machine learning offers powerful solutions, there is still a need for a coordinated effort to identify how these tools — particularly next-gen tools — may best be applied to tackle climate change. Many AI practitioners wish to act; clean energy and climate related workshops were oversubscribed at the 2019 NeurIPS Conference, the largest AI research conference of the year.

If we are to make meaningful progress in this space in this Year of Climate Action, researchers must continue to apply their enthusiasm for this topic through presentations and papers in a concerted way throughout the year, and must be empowered to do so. I sincerely hope that, by the next NeurIPS Conference in November, the volume of energy and climate workshops are significantly increased and will still be very much oversubscribed.

Where the U.K. Government and U.K. Ecosystem Can Lead

For all the historic gains that have brought the U.K. to its present place in the AI and decarbonization races, the renewed challenge of net zero has focused minds and invigorated others to join. Action is required from the entire economy, from technological innovation to business leadership and international fora.

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Technologically, the U.K.'s Met Office has recently announced £1.2 billion to develop a supercomputer for improved severe weather and climate forecasting [50]. On innovation, the government announced a £1 billion Ayrton Fund, using the best of British science to tackle climate change in developing countries [51]. In energy, the regulator Ofgem has announced a nine-point plan to challenge the energy industry to rise to the challenge alongside government to decarbonize the energy system [52], and government is working with industry to build a platform that helps innovators find pre-existing open energy data

projects and applications to build on the progress of others (53).

As a government, we are also committed to contributing and influencing the global narrative on AI, and specifically around safe and ethical AI, climate change, and sustainability. We do this through our participation in multilateral fora, including the Global Partnership on AI (GPAI), the G7 and G20, and United Nation bodies such as UNESCO.

GPAI is a new multilateral, multistakeholder forum, which seeks to connect policy and research experts with those who will directly benefit from AI related technologies to tackle some of the world's biggest problems, including the UN Sustainable Development Goals. The U.K. will do this through practical guidance that countries will be able to implement at various stages of their journey with technology.

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A number of fora, including the current Saudi Arabian Presidency of the G20, are looking at how the OECD AI Principles can be practically implemented. Included in these is the principle that "AI should benefit people and the planet by driving inclusive growth, sustainable development and well-being" (54). I will be calling upon these fora to approach sustainability by design, in the same way as one might factor in ethical approaches to AI from the outset. I would love to see participants pledge to bake in climate-friendly approaches at the beginning rather than retrofitting at the end.

Next year the U.K will host COP26, the U.N. climate summit, in Glasgow. In the run up to this, businesses and charities have been encouraged to participate and we are poised to see a greater focus on climate and sustainability across the country. The goals for COP26 are to hold every Paris signatory to their commitments and set net zero as the clear science-based target for all climate ambition from countries, businesses, states, and cities, and many others besides, as we seek to underscore the seriousness with which we should all be moving forward in our journey on climate action.

The Real Work Lies Ahead

The U.K. has begun to move its own dial on decarbonization, but the real work lies ahead. With a profusion of AI technologies, we must find sustainable ways to embrace the rapidly approaching fourth industrial revolution and consider how AI might help accelerate our progress. In all of this, we must turn back to the impact of the fourth industrial revolution on the planet, and do more to change this trend.

Change means adjusting to the global megatrends present in our lives; adapting to the impacts of climate change; harnessing the exponential potential of AI technologies underpinned by increasing compute power; and responding to new global markets created by emerging technologies. These in themselves are incredible shifts that have the potential to supercharge clean growth and push us closer to a net zero world. But AI is not the panacea, and we must consider how to use AI as a tool to enable other tools across domains.

By enhancing how we view AI, and placing it instead in a holistic, tech-first narrative on our most pressing environmental challenges, we may benefit society and advance the studies of AI in one fell swoop. To do this meaningfully, we will need to inject machine learning into traditionally untrammeled domains, communicating across disciplines that require a wide range of skills, and do so with innovative approaches to data sharing.

If we succeed, and are able to diffuse innovations and build on research on the shared environmental challenge we all face, we may begin to move beyond change to an extensive and lasting transformation towards something more complete. I encourage you all to join me in this transformation.

Author Information

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