HEINRICH BÖLL STIFTUNG
ECOLOGY

E-PAPER

Artificial Intelligence and Climate Change

Opportunities, considerations, and policy levers to align AI with climate change goals

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Published by Heinrich-Böll-Stiftung, December 2020

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Foreword

The use of digital technologies towards a sustainable economic transformation has become a key point of discussion in European and German policymaking.

Recent breakthroughs in machine learning have raised hopes that artificial intelligence (AI) can bring us closer to achieving the United Nations' Sustainable Development Goals. On the other hand, there are worries that AI or AI-driven technologies can also become drivers of global resource consumption and emissions, depending on the types of applications and the circumstances of their deployment.

Many factors will play a role in shaping the actual outcome. For example, remote sensing algorithms for satellite image analysis can be used to gather information on agricultural productivity or predict building energy consumption, but can also be used to accelerate oil and gas exploration. Self-driving cars can make driving more efficient, but they could also increase the amount people drive.

The authors of this report are machine learning and policy experts at leading research institutions in North America and Europe who are committed to identifying and facilitating those uses for machine learning technologies that are beneficial for the climate, and to warning of those that might harm our planet. This report provides an overview of specific benefits AI applications can bring to climate modelling, battery development, electricity networks, and food security, to name just a few areas, as well as ways in which AI can also be detrimental to efforts addressing climate change.

The authors steer clear of touting technology as a panacea for the problems plaguing our planet, reminding us that the role of artificial intelligence in ushering in a more sustainable future ultimately relies on human decisions. Whether or not the use of AI can reduce – rather than increase – resource consumption and emissions will depend on smart policies, regulatory frameworks, and incentives.

We are thankful to the authors – Priya Donti, Lynn Kaack, David Rolnick, and Emma Strubell – for updating us on the most recent developments in their field and for providing ideas for how to assess the environmental as well as broader societal impact of these technologies. We hope that this report can help create a common baseline for an evaluation of existing policies – as well as a starting point for an informed discussion over future policy options.

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Summary

With the increasing deployment of artificial intelligence (AI) technologies across society, it is important to understand in which ways AI may accelerate or impede climate progress, and how various stakeholders can guide those developments. On the one hand, AI can facilitate climate change mitigation and adaptation strategies within a variety of sectors, such as energy, manufacturing, agriculture, forestry, and disaster management. On the other hand, AI can also contribute to rising greenhouse gas emissions through applications that benefit high-emitting sectors or drive increases in consumer demand, as well as via energy use associated with AI itself. Here, we provide a brief overview of AI's multi-faceted relationship with climate change, and recommend policy levers to align the use of AI with climate change mitigation and adaptation pathways.

1. What is AI?

Artificial intelligence (AI) refers to any algorithm that allows a computer to perform a complex task. Recently, there have been advances in a sub-area of AI called machine learning (ML), a set of techniques for automatically extracting patterns from data. Particularly successful areas of AI include computer vision (interpreting the content of images), natural language processing (parsing words and text), time-series analysis (e.g., forecasting), and control (operating complex systems). Many AI tools are currently available out of the box for each of these functionalities. Cutting-edge areas of research in AI include cross-cutting topics such as interpretability (explaining why predictions are correct), uncertainty quantification (calibrating the confidence of predictions), and few-shot learning (gaining insights when little data is available).

AI methods are now employed extensively for applications such as assisting doctors in labeling medical images, detecting obstacles for self-driving cars, and predicting consumer patterns for advertising. Like other fundamental tools across engineering and science, AI can be used to accelerate and enable a wide variety of applications.

2. Artificial intelligence and climate change

Given their broad applicability, AI and ML have impacts that depend heavily on how society chooses to use them. As such, due to the importance of addressing climate change, the potential implications of AI for climate progress should be assessed.

AI applications for climate change mitigation and adaptation

AI can be applied to address climate change by providing methods that are useful for research, engineering, and policy for both mitigation and adaptation. Here, we introduce several overarching ways in which AI can be helpful, and provide a deep dive into one specific example for each area.

- **Gathering information:** In cases where policy-relevant information is not otherwise available, AI can help obtain estimates for some of this information by analyzing large amounts of raw data (such as geospatial imagery, text documents, or sensor data). For instance, AI can be applied to satellite imagery to help pinpoint sources of greenhouse gas emissions, gather information about building efficiency characteristics, and track deforestation.

Example: Using AI to improve food security

Climate change is increasingly impacting agriculture via more frequent and severe storms, droughts, flooding, and the increased spread of disease and pests. With the widespread availability of high-resolution satellite and aerial imagery, it has become possible to monitor crop conditions and agricultural yield at scale, and to devise early warning systems to forestall crises. AI is being used to automate this process, vastly scaling up the number of images that can be analyzed as well as picking up on subtle cues in images that humans might not notice. For instance, with AI, it is possible for experts to label crop cover in a few images and have the algorithm learn to extrapolate that automatically over a wide area. Major players in this space include governmental programs (e.g. NASA Harvest[1] and Copernicus Land Monitoring Service[2]), NGOs (such as GEOGLAM[3]), and a large number of private companies (such as Indigo Atlas Insights[4]).

1 NASA Harvest: https://nasaharvest.org/
2 Copernicus Land Monitoring Service: https://www.copernicus.eu/en/services/land
3 GEOGLAM: http://earthobservations.org/geoglam.php
4 Indigo Atlas Insights: https://www.indigoag.com/atlas-insights

- **Forecasting:** AI can help provide forecasts of quantities such as wind power production, transportation demand, and extreme events by analyzing patterns in historical data. These forecasts can in turn provide much-needed foresight in contexts such as power system optimization, infrastructure planning, and disaster management.

Example: Solar PV nowcasting

Power system operators are increasingly relying on short-term forecasts – or "nowcasts" – of power production in order to manage grids with large amounts of solar and wind. Using historical data, AI can help learn correlations between power production and factors such as localized weather, and then apply these insights to forecast future power production. For instance, the non-profit Open Climate Fix[5] is developing open source nowcasting models that identify cloud cover in satellite imagery and combine this with other weather and locational data in order to more accurately forecast solar power a few hours ahead. As another example, the US Department of Energy and the National Center for Atmospheric Research led a collaboration to develop probabilistic, multi-timescale solar power forecasts up to 72 hours in advance [Haupt et al. 2016].

- **Improving operational efficiency:** AI can help improve the efficiency of real-world systems by improving how these systems are optimized. Examples include managing industrial heating and cooling systems, consolidating freight shipments, and reducing waste in the food industry.

Example: Control of heating, ventilation, and cooling (HVAC) systems

Heating, ventilation, and cooling (HVAC) systems are responsible for more than half of the energy consumed in buildings, and current systems leave large room for improvement in terms of accounting for actual building thermodynamics, usage patterns, and equipment constraints. AI-based control strategies can help improve the operation of HVAC systems, in order to increase their efficiency. For example, techniques such as reinforcement learning[6] [Wang and Hong 2020] and AI combined with model-predictive control[7] [Drgoňa et al. 2020, Drgoňa et al. 2018] have been used to find optimal HVAC control strategies in commercial and residential buildings. AI-driven control strategies can also be employed in industrial contexts; for example, the UK AI company DeepMind developed such an approach for HVAC in Google's data centers that resulted in large efficiency gains [Gamble and Gao 2018].

5 Open Climate Fix: https://openclimatefix.org/

6 Reinforcement learning refers to an area of machine learning where the algorithm tries to learn strategies to maximize the chances of a desirable outcome by interacting with some surroundings.

7 Model predictive control is a method to control processes, taking into account also future states of the process. It is widely applied across industries.

- **Predictive maintenance:** By detecting faults early, AI can help increase infrastructure safety, drive down costs, and increase the energy efficiency of systems. For instance, AI has been used to detect leaks in natural gas pipelines, identify anomalies in solar panel outputs, and forecast faults in infrastructure or industrial equipment.

Example: Maintenance of rail systems

Railway systems play a critical role in decarbonizing passenger and freight transportation. While many kinds of approaches will be needed to increase the competitiveness of railway systems against high-carbon modes of transport, predictive maintenance techniques can play a role by improving efficiency and reducing the need for costly repairs. AI can inform predictive maintenance systems by analyzing sensor data at scale in order to detect present or future anomalies. For instance, Deutsche Bahn[8] is developing AI techniques to analyze data from acoustic sensors and video equipment in order to predict mechanical faults and monitor the status of railway equipment. Other work has looked at combining large-scale analysis of vibration data and video images with prior knowledge of track characteristics in order to guide railway maintenance decisions [Jamshidi et al. 2018].

- **Accelerating scientific experimentation:** AI can help accelerate the process of scientific discovery, e.g., by learning from past experiments in order to suggest future experiments that are more likely to be successful. As such, AI can help accelerate the development of clean technologies such as batteries or next-generation solar cells.

8 Deutsche Bahn: https://www.deutschebahn.com/en/Digitalization/technology/New-Technology/artificial _ intelligence-3520346

Example: Research and development of electric storage technologies

Battery-electric storage is considered a key building block of decarbonization strategies in the transportation and electricity industries, and the technology still has significant need for performance and cost improvements [Beuse et al. 2020]. AI is starting to be successfully used for research and development (R&D) in the battery industry. For example, researchers have demonstrated that data analysis using AI can be employed to assess the capacity degradation of batteries, which is still poorly understood [Severson et al. 2019]. AI can also be used to accelerate the discovery of new battery materials [Jain, et al. 2013], for instance by analyzing large databases of materials in order to recommend which potential materials to try next. Such AI-driven approaches are beginning to be deployed in the battery industry.[9]

- **Approximating time-intensive simulations:** AI can help speed up computationally intensive simulations that are used to model climate physics or in engineering systems. For example, AI can help approximate portions of climate models and power system optimization models, and is already being used to speed up city planning tools to aid real-time decision-making.

Example: Localized climate models

Climate scientists have a very accurate picture of the factors involved in how the climate changes (such as atmospheric and ocean physics), but running physics-based climate models can be very time- and compute-intensive, with some simulations requiring massive supercomputers. While AI cannot replace physics-based models, it can in some cases provide fast approximations to particularly time-intensive parts of these models. For example, AI can learn a rough model for cloud physics (an important component of climate simulations) by observing the predictions of a more exact model, which can help the overall climate model run more efficiently. This can, for instance, enable granular predictions of the changing climate at an exact location on Earth, which could be prohibitively time-consuming with full physical simulations. This allows for more informed decision-making at local levels – e.g., the planning of infrastructure that is resilient to extreme events – as well as potentially saving the energy that would be required to run supercomputers for exact climate models. Increasingly, climate scientists are incorporating AI into their computational pipelines (see e.g. [Reichstein et al. 2019] and the AI2ES initiative[10]).

9 See for example players such as Aionics, Accure, and Twaice.
10 NSF AI Institute for Research on Trustworthy AI in Weather, Climate, and Coastal Oceanography (AI2ES): https://www.ai2es.org/

AI applications increasing emissions or with uncertain impact

Given the broad applicability of AI, it can also be used to accelerate various applications that negatively affect climate change mitigation and adaptation strategies. For example, AI is applied widely to facilitate oil and gas exploration and extraction. Autonomous vehicles, which rely heavily on AI, may result in increased emissions from the transportation sector depending on the conditions under which they will be deployed, while AI-driven innovations in marketing or manufacturing could increase consumption of goods and services, and raise associated emissions. The effects of these applications of AI on the climate are not well researched, but the potential impacts could be large.

Example: Oil and gas exploration and extraction

AI has been used extensively within the fossil fuel industry. For instance, a recent report detailed ways in which large tech companies are using AI to help oil and gas companies identify and model extraction sites, optimize pipelines to expand fossil fuel transportation and storage capabilities, improve refining processes, and facilitate the marketing and sale of fossil fuel-derived products [Greenpeace 2020]. Some reports estimate that AI and other digital technologies could generate as much as USD 425 billion in value for the oil and gas sector by 2025 [Spelman et al. 2017]. This has direct implications for increasing emissions, and it may also increase the competitiveness of fossil fuel technologies, thereby slowing the transition to low-carbon technologies [Victor 2019].

Example: Autonomous vehicles

AI is a key element of autonomous vehicle (AV) technologies, enabling the development of autonomous cars, trucks, delivery robots, drones, etc. AVs could bring fundamental changes to passenger and freight transportation, and affect vehicle design, traffic flow, and transportation demand. While some aspects of autonomous vehicles could reduce the energy consumed when driving (such as platooning,[11] eco-driving, and integrating AVs with low-carbon transportation), it is possible that AVs could actually lead to higher energy consumption, for instance by lowering the barriers to using individualized transportation, increasing the number of miles traveled, and shifting passengers and freight away from low-carbon options such as rail [Wadud et al. 2016].

11 Platooning refers to trucks driving very close together, which is facilitated by AI technologies and provides better fuel economy by reducing the air resistance.

Energy use of AI

Running an AI algorithm uses energy directly, with the amount varying dramatically between different algorithms. Most widely used AI systems use very little power, and can run on a standard laptop or smartphone. Some systems, largely confined to research, use larger amounts of energy, with estimated carbon impacts for the biggest such models comparable to the lifetime emissions of a car [Strubell et al. 2019]. Figures on the total power consumption of AI do not exist, but the International Energy Agency reports that currently data centers consume around 1 percent of global electricity [IEA 2019], of which AI represents a limited fraction. In addition to electricity use, it may also be important to consider the embedded emissions associated with the hardware used. While measuring the energy consumption of single AI models is relatively easy compared to estimating the climate impacts of AI-driven applications, we anticipate that the latter will have much larger effects (both positive and negative) on GHG emissions. Trends in this area should continue to be monitored.

3. Policy levers

In order to best align the use of AI with climate change mitigation and adaptation pathways, we believe policy makers will need to take action in three main areas: (a) fostering the research, development, and deployment of AI in applications explicitly aimed at addressing climate change, (b) regulating the impacts of AI-driven technologies that are emerging or already in use across many sectors of the economy, and (c) increasing public sector capacity for regulation and innovation at the intersection of AI and climate change. We suggest potential policy levers in these areas below. Overall, we emphasize that policy-making in both climate change and AI will be critical in properly shaping incentives and progress.

Foster AI research, development, and deployment to benefit the climate

- Facilitate interdisciplinary and applied research at the intersection of computer science and climate-relevant fields (e.g., engineering, economics, or urban planning).
- Develop pathways for advancing the technical readiness of AI applications for climate change mitigation and adaptation, through research, development, and demonstration (RD&D) programs.

- Reduce regulatory hurdles to the deployment of AI technologies in sectors and industries relevant to climate change mitigation and adaptation (such as the electricity sector).

Regulate emissions impacts of AI-driven technologies

- Incorporate considerations of climate impact into regulations of AI-driven emerging technologies (such as autonomous vehicles or shared economy applications) to better align such technologies with climate change mitigation and adaptation pathways.
- Create economic incentives and regulatory requirements (e.g., through carbon taxes or cap-and-trade programs) for GHG emissions reduction and avoidance of rebound effects when AI is applied for efficiency gains in industry.
- Where applicable, mandate transparency and reporting of greenhouse gas emissions or energy consumption impacts of AI, including life-cycle impacts and externalities.

Facilitate AI and data sharing in the public sector

- Where beneficial, develop or enhance in-house AI implementation capacity within public entities.
- Develop processes to incorporate feedback from stakeholders who are involved in or impacted by AI technologies (e.g., civil society, industry, etc.) throughout the process of scoping, designing, and deploying relevant projects.
- Develop standards and best practices to guide decisions around when and how AI should be used, including criteria for determining in which situations AI (as opposed to simpler alternatives) is most appropriate.
- Facilitate and develop standards around data collection, management, and sharing that are mindful of concerns over privacy and control over data.

4. Policy-relevant considerations

AI systems may have risks and unintended consequences. For instance, the High-Level Expert Group on AI of the European Commission defined seven requirements for Trustworthy AI [AI HLEG 2019]; these considerations apply to climate-change related applications of AI just as much as elsewhere. With respect to climate strategies, the following issues are particularly relevant:

- **Criteria for impact assessment:** There is a fundamental asymmetry in terms of the data available on AI's climate impacts: in particular, the energy consumption of AI models is relatively easy to estimate, but there is very little data on the impact of use cases. Nonetheless, policy in this area should be proactive in addressing both energy use and application-specific impact, especially given the fast pace at which the AI sector is evolving.
- **Equity:** Equity is a central consideration in climate change mitigation and adaptation strategies at all levels of governance. AI-driven approaches may lead to the exacerbation of inequities, e.g., by widening the digital divide or through issues such as algorithmic bias.
- **Power shift:** The use of AI may shift power structures among public and private entities by virtue of who controls relevant data, the (uneven) distribution of capacity and intellectual capital for AI-driven analyses of these data, and the conditions for access to and maintenance of these analyses. As many climate strategies are implemented by and in the public sector, public entities looking to employ AI should take these factors into consideration when making decisions around building in-house capacity.
- **Critical infrastructure:** The energy sector is central to climate change mitigation, and much of it is regarded as critical infrastructure. AI applications to critical infrastructure must incorporate considerations of safety and security.

5. Conclusion

The ways in which we choose to employ AI in the coming years will have significant impacts on societal progress towards climate change goals. As a broadly powerful engineering tool, AI can be used to accelerate a wide variety of applications - both those that help and those that impede climate change mitigation and adaptation. Policy can serve an important role to ensure AI is applied in a way that aligns with climate change strategies and with the present and future well-being of society.

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Policy-relevant considerations

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Imprint

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Place of publication: https://www.boell.de/ | https://us.boell.org/ | https://eu.boell.org/

Release date: December 2020