A Socio-technical Analysis on the Role and Implications of Climate-AI Technology in the U.S. and India

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

The threat of climate change is no longer a threat but a reality; hotter temperatures, frequent extreme weather events, rising ocean levels and acidification, and more have been well-documented as the result of human-caused greenhouse gas (GHG) emissions from burning fossil fuels, deforestation, material pollution, and the like. Time is ticking as the world must reach net-zero emissions by 2050 to limit temperature rise to 1.5°C above pre-industrial levels as defined by the IPCC (2018). Tackling the crisis will require government policy, behavioral change, and new technologies. This paper evaluates the role, social and ethical implications of one such technology jumping into the climate fight: artificial intelligence (AI) and machine learning (ML).

AI and ML (used interchangeably here) encompass a set of software-based techniques to gain valuable insights from large swaths of data. Applications into fields such as healthcare, education, and criminal justice are increasingly common. The technology's growth is inevitable and fueled by American tech companies; company initiatives like Microsoft's AI for Earth prove AI is now entering the climate crisis.

America and India are explored for several reasons. The U.S. is the global leader in AI, as measured by their venture capital, number of startups, quality of publications, etc. (Castro & McLaughlin, 2021). However, as a superpower the country has been notably rocky in its climate endeavors, the topic being one of political divisiveness within its borders. This makes America a compelling country of consideration as it ranks 4th in the world for per-capita CO_2 emissions and 2nd for total emissions as of 2018 (Union of Concerned Scientists, 2020).

India, on the other hand, is just blossoming in its AI foothold. The country's AI Standardisation Committee published a paper (2020) proposing an AI "stack" or infrastructure setup for the nation. The preface concedes "AI is the main driver for the desired socioeconomic

transformation of India" (p. 2) along with the competitive motivation of other nations' developing national AI strategies (p. 14). In parallel, India models climate action for the rest of the world as one of only eight countries and the only major country whose actions are compatible with warming of less than 2°C or better (comparatively, the U.S. is considered "critically insufficient") (Climate Action Tracker, 2020). Additionally, India is particularly vulnerable to climate impacts like flooding, droughts, heatwaves, and water shortages; despite this, in 2018 it was also the third greatest emitter of CO_2 (Union of Concerned Scientists, 2020). Transformative change is needed to meet the country's emissions-reduction targets (McCarthy, 2021), and several indicators suggest AI may help close that gap.

Together, the countries will exert much influence, both on each other and the rest of the world. This assertion is timely with the recent announcement of the "U.S.-India Climate and Clean Energy Agenda 2030 Partnership" on Earth Day 2021 (Office of the Spokesperson).

This paper will: (1) evaluate the role, limits, and potentials of AI in the climate fight; (2) characterize the socio-technical system in India and America and evaluate the influence of such a system on the direction of AI-climate technology; and (3) consider the social and ethical implications present with such direction within such system.

STS Framework and Research Method

The Large Technological System framework (Hughes, 1987) conceptualizes this research by highlighting influential components within each country's sociotechnical system. This conceptualization reveals messy and deep-rooted complexities, perfect for a systemic phenomenon such as climate change. Mediation theory conceptualizes the social and ethical

implications of climate-AI technological, namely the definition and interpretation of sustainability that arises through society members' interaction with climate technology.

Document analysis is my primary method of research. This fast-paced topic lends a variety of contemporary news articles, including opinion pieces and the like. Data collection from government regulations, mandates, and frameworks; reports and analyses from large and reputable organizations; and some academic papers contextualizes this novel and complex issue.

Literature Review

Little literature covers the intersection of AI, climate, and ethics. However, Coeckelbergh explores this topic in his paper, *AI for climate: freedom, justice, and other ethical and political challenges* (2020). He concludes AI for climate should be pursued but not without close attention to ethical and political issues, which he deems as being "political problems concerning freedom and justice, and the challenge of using AI given the problem of (hyper)agency in the Anthropocene" (sect. Conclusion). This paper fails to contextualize the state of climate change and AI within a framework that reveals its complexities. Additionally, my paper takes a deep look at the U.S. and India specifically, both of whom are major players in the game.

AI's Technical Role in Climate Change

For tech enthusiasts, AI's potential for climate aid is generally well-regarded. The prominent paper *Tackling Climate Change with Machine Learning* (Rolnick et al., 2019) was written by experts from institutions like Stanford and MIT as well as researchers from Google and Microsoft. It is an extremely thorough evaluation of climate issue areas amenable to machine learning. Some examples they denote as "high-leverage" are:

- enabling low carbon electricity;
- reducing transport activity, improving electric vehicles, and enabling low-carbon transportation options;
- smart buildings, gathering infrastructure data, and data for smart cities;
- reducing food waste and monitoring food security;
- monitoring peatlands, ecosystems, and biodiversity and managing forests;
- sequestering CO2;
- forecasting extreme weather events and aiding in disaster response;
- facilitating behavior change;
- and informing policy.

The paper in total details 33 applications across 13 solution domains. Similar reports include *Harnessing Artificial Intelligence for the Earth* (World Economic Forum, 2018) and *How AI can enable a Sustainable Future* (Herweijer et al., 2018).

While enthusiasm is high in these papers, caution must be exercised on AI's true potential. Vinod Khosla, a prominent venture capitalist and engineer by education, expresses his hesitations in a fireside chat *AI, Can it be a climate changer?* at the 2020 NeurIPS Conference. He starts, "The basic question to ask is: Can AI make a material difference in climate trajectory? There's a lot of well-intentioned efforts, but mostly very little impact" (1:18). Khosla asserts the largest carbon-reduction technology falls into one of a dozen or so categories (4:50) which, give or take, are:

- electric vehicles and automotive batteries;
- food, meat, and agriculture;
- low-carbon air transport and shipping;

- cement or equivalent substitute construction material;
- dispatchable renewable energy;
- public transit;
- grid storage and long-duration battery storage;
- HVAC systems;
- industrial processes;
- fertilizer;
- and water.

Most papers, talks, and articles that tout AI's ability don't address these key problems areas according to Khosla. He says,

> I googled AI for climate technologies—what came up: almost completely worthless when it comes to really affecting change, reducing carbon. It does help us understand things better, build better models, but it's not going to reduce the amount of carbon we're emitting in the air, because it's not going to let us come up with radical technologies that dramatically improve the cost comparativeness of these alternatives (10:18).

Khosla calls the 2019 Rolnick et al. paper, specifically, unfocused (12:01). He believes AI can tackle very distinct problems in the climate context: materials design, high dimensionality problems, complex systems design, and (necessary) optimizations (12:17). In essence, AI is best at "capturing the science we cannot yet model economically" (12:57). Khosla says these capabilities can and should complement other technologies, because a combination of radical technologies is far more powerful than AI alone (14:01).

This brings up an excellent point: current AI can provide insight into challenging issues, but alone it does not affect change. This has two implications. First, as Khosla states, AI must be

used in conjunction with other engineered technologies to create effective climate solutions. Secondly, AI-climate solutions must be assessed in light of their surrounding socio-technical system. The societal construction of AI is equally important to the AI itself in weighing its climate impact and understanding how it contributes to the aspirations of sustainability.

Kate Maher, associate professor of Earth system science at Stanford University, believes in the ability of AI to make meaningful change through insights on arbitrarily complex problems. In an article recounting a Stanford HAI (human-centered artificial intelligence) workshop focused on environmental intelligence (Maher, 2020), she says, keenly:

> A substantial barrier to development of sustainable societies arises from the complexity of socio-economic-environmental systems, complexity that can surpass the ability for a human to understand all interactions and causations. A common approach to make sense of this complexity is to develop indexes, or collections of indicators. Although useful as a metric for evaluation, when applied as a tool for decision making, a strong reliance on indices can lead to unintended consequences because a static index cannot fully account for uncertainty associated with human behavior and community-driven priorities. Reliance on indices can also incentivize certain metrics with negative consequences for other components of the system and obscure the correlation among indicators. Most important, indexes can be influenced by deeply embedded social and cultural preferences and local political action. To address these limitations requires an intelligent system, human or machine, that can deeply understand multi-dimensional problems and solutions in complex socio-economic-environmental systems.

Maher acknowledges limitations of AI sustainability management: machine learning on single indices are definitionally unable to model complex environmental systems. But she is hopeful

and specific about how that can change; AI models have the unique ability to fathom complexities beyond a human brain if trained on numerous, representative data streams.

What may come of such a diversely educated and informed AI? The workshop evoked three overarching themes:

1. *Predicting, detecting, and mitigating or incentivizing environmental transitions*: Knowledge of past environmental changes (such as land use or misuse, pest management, etc.) and resulting consequences can ensure early detections and aid preparedness.
2. *Quantifying well-being and compatibility with one's environment*: AI may help optimize human-environment compatibility to develop a definition of environmental good minimizing need for human self-sacrifice.
3. *Environmental justice and human rights*: Vulnerable communities face disproportionate burden of the climate crisis, such as human rights abuses in industries like mining, agriculture, and industrial processes. Data capturing human health and well-being could help meaningfully link environmental justice to carbon-intensive activities, which may ultimately influence policy and regulations.

In essence, the technical role of AI in climate change is founded but its potential impact is still unclear. Machine intelligence can produce optimizations, garner insight from big data, and model predictions. Therefore, climate applications from AI alone may include energy and grid management; building efficiency; food, water, and ecosystem oversight; extreme weather forecasts; and the like. However, more carbon-reducing applications exist in the collaboration of AI with other engineering technologies: through modeling complex equations, materials, and systems. Regardless, understanding the sociotechnical system becomes paramount in uncovering AI's relation to sustainability; hopefully, as Maher suggests, as one beneficial and just.

AI and Climate Change in the United States

Political energy and promises

Climate momentum in the U.S. has shifted starkly after the 2020 election of President Joe Biden. Trump, notoriously anti-climate, weakened environmental protections from the Obama-era over 74 different actions (Gross, 2020) and removed America from the Paris Climate Agreement. In opposition, President Biden re-entered the Paris Agreement on his first day in office and held a two-day Leaders Summit on Climate beginning on Earth Day 2021 to reestablish the United States as a global leader in climate change.

While ambivalent about climate change, the Trump administration had a keen interest in artificial intelligence. His executive order *Maintaining American Leadership in Artificial Intelligence* (Exec. Order No. 13859, 2013) was spurred by competition with China, who unveiled their own national AI plan in 2017 (Ghaffrey, 2019). As such, national security was a top priority of the order; in a press release Trump says, "Continued American leadership in Artificial Intelligence is of paramount importance to maintaining the economic and national security of the United States" (Office of Science and Technology Policy, 2019). The executive order overview website covers four broad categories: AI for American Innovation, AI for American Industry, AI for the American Worker, and AI with American Values (Trump White House, 2019). In furtherance of innovation, President Trump committed to doubling nondefense AI R&D over two years, with nationally-vital applications being "science, medicine, communication, manufacturing, transportation, agriculture, and security." Investments are guided by the National AI R&D

Strategic Plan: 2019 Update (Select Committee on AI) which identifies 8 priorities for federal funding:

1. Make long-term investments in AI research.
2. Develop effective methods for human-AI collaboration.
3. Understand and address the ethical, legal, and societal implications of AI.
4. Ensure the safety and security of AI systems.
5. Develop shared public datasets and environments for AI training and testing.
6. Measure and evaluate AI technologies through standards and benchmarks.
7. Better understand the national AI R&D workforce needs.
8. Expand public-private partnerships to accelerate advances in AI (p. iii, Executive Summary).

To spur R&D, the Trump administration also sought to make federal data, models, and computing resources available to the public (sect. Data Resources for AI R&D). A Vox opinion piece comments, "Tech giants like Google, Apple, Microsoft, and Amazon, to name just a few, should welcome this potential treasure trove of wide-reaching government data that is necessary to train AI algorithms" (Ghaffary, 2019).

The AI for American Industry section begins with the assertive commentary,

> AI innovation can be hampered or driven overseas by overly restrictive government regulations. We will create a national climate where scientists and technologists successfully develop their new AI inventions here in the United States. Under this Administration, we are removing regulatory and other barriers to the safe development and testing of AI technologies, to enable the creation of new AI-based industries and the adoption of AI by existing industries.

The industries elaborated on are:

- transportation, including autonomous vehicles;
- healthcare;
- manufacturing;
- financial services;
- agriculture, some uses being ecosystem management, water system resilience, and crop health analysis;
- weather forecasting, “to better understand and predict the dynamic environment we live in”;
- and national security and defense.

Though climate benefits are inherent in some of these efforts, climate change is intentionally not mentioned in the AI plan.

The Trump administration also established the National Artificial Intelligence Initiative Office in January 2021, established the Select Committee on AI in 2018, released AI regulatory guidance to ensure the technology embodies “American values”, and held a White House Summit on AI for American Industry in May 2018 (sect. Executive Order on AI). Summit attendees included government officials, academic and research experts, and American business leaders (Office of Science and Technology Policy, 2018, p. 2). Key takeaways from the summit were: supporting the national AI R&D ecosystem, developing the American workforce to take full advantage of the benefits of AI, removing barriers to AI innovation in the United States, and enabling high-impact sector-specific applications of AI (p. 3).

With the COVID-19 pandemic still raging, revisiting AI guidance is not a priority for new President Biden. However, his campaign was run on the promise of elevating science-backed policy, including investments in climate technology and innovation. The Climate Summit hosted by the United States on Earth Day 2021 was an energizing and acute representation of America's desired leadership role in the climate crisis. A culmination of leaders from 40 countries virtually convened to share concerns, hopes, and ambitions for the crisis. Among key themes were mobilizing public and private sector finance to drive the net-zero transition, the economic benefits of climate action, and spurring transformational technologies to build industries of the future (U.S. Department of State, 2021). In the session "Unleashing Climate Innovation," Secretary of Energy Jennifer Granholm pointed to the potential $23 trillion global market in the clean energy transition by 2030 ([EN] Leaders Summit on Climate - Day 2, 2021, 25:25). Bill Gates, also present, emphasized the need for technological breakthroughs in key areas (30:10).

The summit highlighted innovation, economic opportunity, and jobs creation as the key drivers for American climate action. Biden seeks to leverage the private sector to develop changes needed for a cleaner world. Secretary Gina Raimondo, Biden's new Secretary of Commerce, affirmed this demand: "The government can't do it alone, we need the private sector, we need private sector innovation, we need entrepreneurialism, and we need academic research and academic research institutions to play a huge role in uncovering and developing new technologies and innovations, investments that can unlock massive economic opportunities as well" (1:06:32). Known, well-developed technologies exist to mitigate climate change, but thus far the United States has been slow to adopt them. A prime example is solar and wind energy production, where in 2020 just over 10% of America's electricity was generated from solar or wind (U.S. Energy Information Administration, 2021). However, this summit chose to focus on

the challenges that yet remain, invigorating the private sector to tackle those challenges, and the economic opportunity that lies ahead. According to Fatih Birol from the International Energy Agency, just under half of emissions reductions in 2050 must come from technology that is still under development (1:11:03).

Addresses by private sector players affirmed the discussion. Two, whose work alluded to AI involvement, were,

- GE Renewables (1:18:25): Seeks to digitize and modernize the grid to ensure reliable delivery of electricity with improved security and lower operational costs (1:20:37).
- X, the Alphabet Moonshot Factory (1:23:04): Believes software will make the grid more reliable by managing demand, noting weather conditions in California and Texas which made manual grid-management risky and unreliable. Their spokesperson said, "Our team has been working with partners to develop tools required to move our grids out of the industrial age and into the age of intelligence" (1:25:58).

The Biden-Harris administration's climate action plan also intimately couples the relationship between jobs creation and addressing the climate crisis through a $100 million funding opportunity from the Department of Energy, creating Climate Innovation Working Group towards their Advanced Research Projects Agency-Climate (ARPA-C) commitment, and other similar endeavors (The White House, 2021). In a statement regarding the plan, Gina McCarthy, President Biden's National Climate Advisor, says:

> We are tapping into the imagination, talent, and grit of America's innovators, scientists, and workers to spearhead a national effort that empowers the United States to lead the world in tackling the climate crisis. At the same time, we are positioning America to create good-paying, union jobs in a just and equitable way in communities across the

> nation that will be at the forefront of new manufacturing for clean energy and new technology, tools, and infrastructure that will help us adapt to a changing climate. (The White House, 2021).

The previous administration affirmed incentivizing strong machine intelligence efforts. Now, the current administration builds on those calls for innovation and drives it towards the climate crisis, where the opportunities for AI involvement are still-to-be-defined—likely by the private sector—but very much visible.

Defining the socio-technical system

Since the industrial revolution, America has relied on the private market to spur technological change, which provides foundation for the sociotechnical system at play: system builders in the climate AI boom will be the technological innovators who spark remarkable transformations. Vinod Khosla, in his fireside chat, refers to these people as instigators; "It only takes one scientist-entrepreneur to actually disrupt one of these areas. What matters is one person taking the handles, solving the scientific, technical problem, hopefully with the help of AI, and then making it happen. Even if they fail, they will change the whole industry" (2020, 8:09). Instigators radically shift the idea of what is possible. Climate tech examples include electric vehicles and plant-based meats.

Between 2006-2011, over $25 billion of venture capital was invested in clean energy technology (Horowitz, 2021), meaning this is not the first time America has tackled clean tech. The boom quickly turned into a bust; but now, the wave is back and hopefully here to stay. There are many reasons (PwC, 2020) why now is different, all relating to the momentum of the current

sociotechnical system. Firstly, contemporary climate tech encompasses more applications than just energy. Secondly, new technologies such as AI, advanced materials, and blockchain have become cheaper and more widespread since 2011. Next, there is greater consumer demand for sustainable products. Additionally, the regulatory environment on the whole favors sustainable development, along with growing corporate demand as many companies make net-zero commitments. Lastly, the few success stories from the first clean tech wave attracts enthusiasm and investment.

In the United States, climate AI is on trend to be governed by social and cultural means rather than political, with tech companies taking a particular interest. At the start of 2020 Apple, Facebook, Microsoft, Google, and Amazon promised ambitious climate commitments (Reuters Staff, 2020). Since then, more tech companies have joined the list and raised ambitions. In Amazon's Climate Pledge, signatories commit to net-zero carbon emissions by 2040, ten years earlier than the Paris Agreement. Over 105 tech and non-tech companies have signed, including Microsoft, Verizon, Uber, IBM, Coca-Cola, PepsiCo, Best-Buy, and VISA (The Climate Pledge, 2021).

Though climate leadership now exists under Biden—with goals to halve 2005-level emissions by 2030—tech companies are not letting up. In fact, they are calling for consistency of GHG emissions reporting as the SEC collects public input (Weiss, 2021). Arvin Ganesan, the global head of energy and environmental policy at Apple, tweeted, "Disclosure is an important tool in the fight against climate change. Measuring and mapping carbon emissions enables companies to understand their footprint, develop strategies to reduce emissions and, ultimately, achieve decarbonization" (Weiss, 2021). Ceres, a sustainable investing nonprofit, calls this the first time a major U.S. public company has back climate-disclosure regulations (Weiss, 2021).

A deep-dive into the US sociotechnical system on climate-AI reveals profit and the market economy as the primary momentum for change. In a culture hailing technological prowess, tech giants bore responsibility amid shifting politics. Even under Biden, they will continue to have political influence. Indeed, polarized views make it impossible for the government to enact sweeping changes across the country, making political resistance a reverse salient of the sociotechnical system. Additionally, instigators bear the burden of having to disrupt an established carbon-intensive infrastructure in the U.S., making that issue another reverse salient. As AI's role in climate-tech increases, tech companies and "instigators" will be the biggest players on the chessboard.

Technology examples and trends

A PwC report *State of Climate Tech 2020* expresses the urgency facing the planet and reports data on venture capital (VC) in climate tech. 2013 to 2019 saw a 3750% increase in venture funding for climate tech, roughly three times that seen for AI (sect. Foreword). The top region of investment in this same period was North America at $29 billion, and mobility and transport were most funded at 63% of investment dollars (p. 4). The following charts from the report showcase the United States as the biggest player in the arena.

Top 10 climate tech investment hubs

China and the USA and Canada dominate investment in Mobility and Transport, the most heavily invested challenge area, and so it's no surprise they feature heavily in our list of top 10 investment hubs. India and Germany are the only countries to feature cities in the top 10 outside of the US and China.

Startup HQ	Funding raised
San Francisco Bay Area, United States	$11.7B
Shanghai, China	$7.5B
Beijing, China	$6.6B
Los Angeles, United States	$3.5B
Boston, United States	$2.1B
Guangzhou, China	$1.7B
Nanjing, China	$1.2B
Hangzhou, China	$1.0B
Berlin, Germany	$930M
Bengaluru, India	$870M

Top 10 climate tech investment hubs (excluding Mobility and Transport)

Given the dominance of the electric vehicle and micro-mobility levers in our data set – which are no doubt important, but perhaps not reflective of overall trends – it is useful to examine funding outside the Mobility and Transport challenge area.

Here we see notably different results for top climate tech investment hubs. No Chinese cities feature, and the US dominates. However, three of the top 10 cities only have one startup in their jurisdiction, indicating the nascency of investment outside of established hubs.

The disproportionate investment in the San Francisco Bay area suggests that investor hubs can create a positive feedback loop of investment as startups and investors congregate, even for new areas such as climate tech.

Startup HQ	Funding raised
San Francisco Bay Area, United States	$6.9B
Boston, United States	$2.1B
Berlin, Germany	$650M
New York, United States	$650M
Sioux Falls, United States	$370M
London, United Kingdom	$350M
Labège, France	$300M
Boulder, United States	$300M
Chicago, United States	$240M
Pittsburgh, United States	$220M

Figure 1. Charts from a PwC report noting the climate-tech startup headquarters of the world, most of which are in the United States (PwC, 2020, p. 33).

Overall breakdown of investment by startup region

The geographical split shows that nearly half of all venture dollars in climate tech startups, $29 billion, went to startups in the USA and Canada. China is the second most significant region at $20 billion. The European market is approximately a third of China's at $7 billion invested.

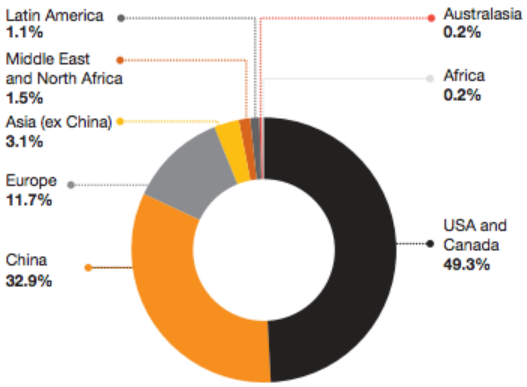


Figure 2. A graph from the PwC report showing the disproportionate concentration of VC in certain regions, namely the US and China (PwC, 2020, p. 33).

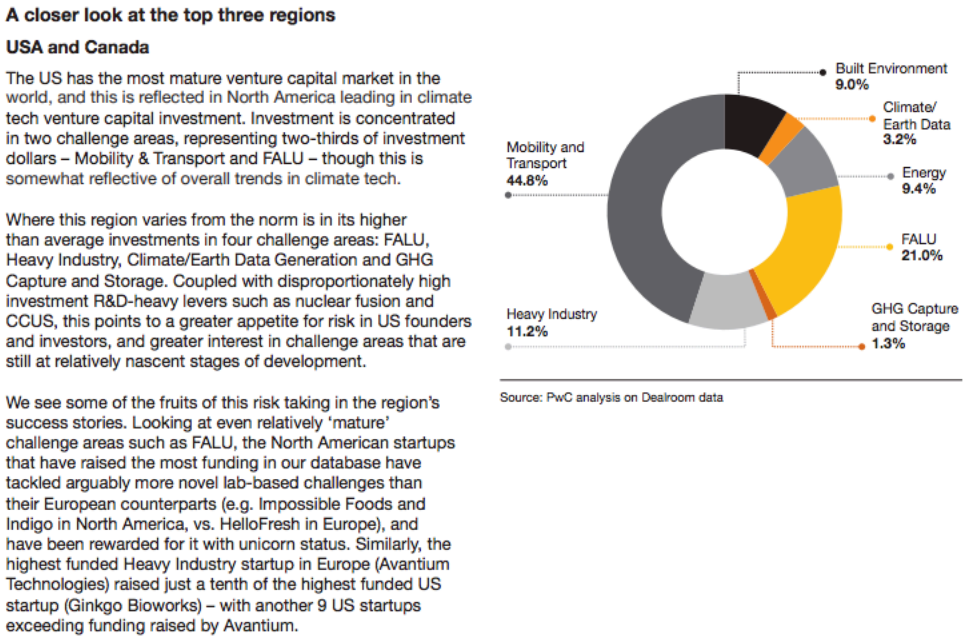
Dollars concentrated in mostly American startup capitals signifies the U.S.'s major role. AI as a technology will be used across a multitude of sectors for greater carbon reduction, evidenced by its breadth of technological capability. According to the report, "PwC/Microsoft analysis suggests that just AI, and in just 4 sectors of the economy, could reduce annual global emissions by 2.4 gigatons of CO_2e in 2030. This is equivalent to the emissions of Australia, Canada and Japan combined, and would represent an overall reduction in carbon intensity of 4.4 – 8.0% relative to business as usual" (p. 7).

The following examples of specific, contemporary use-cases of climate AI rounds out the previous discussion:

1. IBM Research Team using AI to accelerate discovery and design of polymer membranes for capturing CO_2, as well as simulating CO_2 flow through different types of rocks to evaluate their trapping ability (Assefa, 2021).
2. Examining road conditions with AI in Montgomery, AL to prevent the need for manual maintenance inspection, saving emissions and adding to the many smart-enabled technologies transforming the city (Brereton, 2019).
3. Using machine learning to improve charging times and lifespan of electric vehicle batteries from researchers at General Motors, Panasonic, IBM, MIT, Stanford, and more (Oliver, 2020).
4. The Climate TRACE coalition, made up of global nonprofits and former U.S. Vice President Al Gore, developing an AI-based analytics tool to track worldwide pollution in real time (Time, 2020).

5. USDA Agriculture Research Service training AI models to recognize stress indicators in plants, such as soil and water levels, to provide specific and individual recommendations to farmers (Voigt, 2021).

Steep uptick of VC funding indicates climate change-fighting innovation is on the rise. Though AI has an important role to play across a variety of sectors, with some examples above, the PwC report indicates there is disproportionate funding for climate issue areas.



A closer look at the top three regions

USA and Canada

The US has the most mature venture capital market in the world, and this is reflected in North America leading in climate tech venture capital investment. Investment is concentrated in two challenge areas, representing two-thirds of investment dollars – Mobility & Transport and FALU – though this is somewhat reflective of overall trends in climate tech.

Where this region varies from the norm is in its higher than average investments in four challenge areas: FALU, Heavy Industry, Climate/Earth Data Generation and GHG Capture and Storage. Coupled with disproportionately high investment R&D-heavy levers such as nuclear fusion and CCUS, this points to a greater appetite for risk in US founders and investors, and greater interest in challenge areas that are still at relatively nascent stages of development.

We see some of the fruits of this risk taking in the region's success stories. Looking at even relatively 'mature' challenge areas such as FALU, the North American startups that have raised the most funding in our database have tackled arguably more novel lab-based challenges than their European counterparts (e.g. Impossible Foods and Indigo in North America, vs. HelloFresh in Europe), and have been rewarded for it with unicorn status. Similarly, the highest funded Heavy Industry startup in Europe (Avantium Technologies) raised just a tenth of the highest funded US startup (Ginkgo Bioworks) – with another 9 US startups exceeding funding raised by Avantium.

Source: PwC analysis on Dealroom data

Figure 3. A chart from the PwC report shows the breakdown of investment dollars into different climate-issue areas. Most funding went into Mobility and Transport (PwC, 2020, p. 34).

This figure shows climate tech is concentrated heavily in mobility and transport, such as electric vehicles, self-driving cars, and micro-mobility. AI-climate endeavors will also naturally concentrate in areas of high funding, an example seen in the many companies and institutions researching EV battery advancements using AI.

Conclusion

The United States experienced a 180-shift in federal administrative attitudes towards climate change. However, living out America's culture of entrepreneurialism, tech companies quickly filled the void of the previous administration and, along with ambitious net-zero targets for their own company, began investing in climate tech. Biden is now fueling the effort as he equates solving climate change with economic prosperity and creating jobs. The government will not make judgement calls about what is good for the environment, but will let details be settled by the market itself. To this end, "There is, therefore, a huge gap between the rhetoric of the 'climate emergency' and the reality of an inadequate global response. The startup world has a critical role to play in bridging this gap: there is a key window over the 2020s to channel the best entrepreneurs, and crucial venture capital, into developing the transformational solutions needed to decarbonise our industries" (PwC, 2020, p. 6). AI will likely be used across a variety of sectors relative to each sector's funding.

AI and Climate Change in India

Political energy and promises

Unlike the United States, India has had consistent leadership under Prime Minister Narendra Modi since 2014 and is on track to meet their nationally determined contributions (NDC) under the Paris Climate Agreement (Jaiswal & Joshi, 2020), which are:

(a) reduce emissions by 33% to 35% of its GDP by 2030 from 2005 levels;

(b) achieve 40% of installed power capacity from non-fossil fuels by 2030;

(c) and create an additional carbon sink of 2.5 to 3 billion tons of CO_2e through tree cover by 2030 (NRDC, 2020, p. 1-2).

India has already reduced emissions by 21% and installed 38% generation capacity from non-fossil fuels (Jaiswal & Joshi, 2020). 23.5% of India's generation capacity, or 88 GW, comes from renewables specifically as of July 2020 (NRDC, 2020, p. 1). The country aims to install 175 GW of renewables by 2022 and 450 GW by 2030, which is 20% more than India's current total grid capacity (Jaiswal & Joshi, 2020). Although making headway, comprehensive plans on climate change from the national government have been vague. In 2008, the *National Action Plan on Climate Change* outlined eight climate-related missions:

1. National Solar Mission
2. National Mission for Enhanced Energy Efficiency
3. National Mission on Sustainable Habitat
4. National Water Mission
5. National Mission for Sustaining the Himalayan Ecosystem
6. National Mission for a "Green India"
7. National Mission for Sustainable Agriculture
8. National Mission on Strategic Knowledge for Climate Change (Talanoa, 2008).

The aspirations of the report are lofty, but it has not been updated since 2008. Rattani et al. argue the plan was created in response to pressure from developed countries to reduce emissions, China releasing a national climate plan in 2007, and wanting a policy before the 2008 Tokyo G8 Summit and 2009 Conference of Parties at Copenhagen (2018). However, as a country with an emissions-per-capita less than half the global average, India has challenged the world for years saying it is the developed world's responsibility to tackle the crisis they caused. Prakash Javadekar, Indian Minister of Environment, Forest and Climate Change, says,

> Historically it's the developed countries that have been major contributors to carbon emissions with the United States with the highest historical emissions at 25 per cent, followed by the EU at 22 per cent and China at 13 per cent. Historically India has a low carbon emission contribution of only 3 per cent. Even presently, our carbon emissions remain restricted at 6.8 per cent of global emissions and the per capita emissions is only 1.9 tonnes per capita. Thus, our historic, as well as present contribution to greenhouse gas emissions, is low. Despite the fact that India has not been the reason for climate change, we have responsibly addressed the issue and have taken strong measures to curb our carbon emissions and to meet goals set by the Paris Agreement (Express News Service, 2020).

Regardless of this truth, India is one of the most at-risk countries for climate disaster. The Germanwatch Global Climate Risk Index ranks India as the 7th most affected country in the world for extreme weather events in 2019 and 5th in 2018 (Eckstein et al., 2021). Because of this, the developing country has a huge potential for gains from climate change mitigation strategies. Especially given the new US-Indian climate partnership, the coming decade will see India as an active climate player.

Like with climate, India's AI potential is primed for explosion. The country recognizes its need for AI advancement in the increasingly intelligent world:

> Technological, economic and military supremacy can only be achieved with access to AI related resources and development of relevant AI solutions. As with any other technological advancement, AI brings numerous opportunities as also challenges. For adapting AI to the Indian environment, across sectors, it is required to evolve uniform

> standards in this field. This is the only way forward for a more effective adoption by all stakeholders and this also is the biggest challenge facing us" (AI Standardisation Committee, 2020, p. 2).

This paper, *Indian Artificial Intelligence Stack*, along with the *National Strategy for Artificial Intelligence* by NITI Aayog in 2018, make up the foundation of India's approach to artificial intelligence. India is motivated by AI strategies from the developed world, referencing the 2019 American AI Initiative under Trump along with others (AI Standardisation Committee, 2020, p. 14, 39). Additionally, India seeks to align itself as the provider for other developing nations. NITI Aayog acknowledges India's unique position:

> A national AI strategy needs to be premised on a framework which is adapted to India's unique needs and aspirations, while at the same time, is capable of achieving the country's full potential of leveraging AI developments. Such a framework could be seen as an aggregation of the following three distinct, yet inter-related components:
>
> a) Opportunity: the economic impact of AI for India
>
> b) AI for Greater Good: social development and inclusive growth
>
> c) AI Garage for 40% of the world: solution provider of choice for the emerging and developing economies (ex-China) across the globe (2018, p. 18).

Both papers specifically name the following sectors that could be beneficially impacted by AI (NITI Aayog, 2018, p. 20; AI Standardisation Committee, 2020, p. 10-12):

1. Healthcare.
2. Agriculture: meeting increased demands for food, addressing demand prediction, irrigation, and pesticide use, improving crop yield, detecting pest attacking, and predicting crop prices.

3. Smart mobility, including transportation and logistics: autonomous fleets for ride sharing, driver assist, predictive maintenance, autonomous trucking and delivery, and improved traffic management.
4. Retail.
5. Manufacturing.
6. Energy: energy system modelling and forecasting, enabling energy storage in intelligent, renewable grids, and predictive maintenance.
7. Smart cities: traffic control, garbage disposal management, and crowd management.
8. Education and skilling.

Unlike the initiative under President Trump, the NITI Aayog report explicitly mentions climate change in relation to these sectors as an example issue primed for AI-intervention. The AI Standardisation Committee also notes the potential pitfalls of AI:

> There is an increasing realisation that AI could also exacerbate problems for people, without proper safeguards. For AI to be the sustainable revolution there is a need to provide an open environment with safeguards and oversight to guide the future that is being built. Support and partnerships will be required to be unlocked and the scale of innovation on emerging technologies and solutions to be considered (2020, p. 8).

The paper seeks to define a comprehensive framework for the country on the best utilization practices for artificial intelligence to "enable [an] environment [that will] exploit AI productively in various walks of life" (p. 2). Specifically, the AI stack intends to address and tackle central control of data, unbiased open architecture, and proper storage frameworks (sect. 4). The revolutionary transformation may include "smart dust, smart drones, futuristic farming, smart

aerospace and smart energy networks" (p. 9). However, NITI Aayog identified following barriers:

- Lack of broad based expertise in research and application of AI,
- Absence of enabling data ecosystems – access to intelligent data,
- High resource cost and low awareness for adoption of AI
- Privacy and security, including a lack of formal regulations around anonymisation of data, and
- Absence of collaborative approach to adoption and application of AI (p. 7).

In response to these bottlenecks, the AI Standardisation Committee was formed to create the proposed Indian AI Stack, shown below:

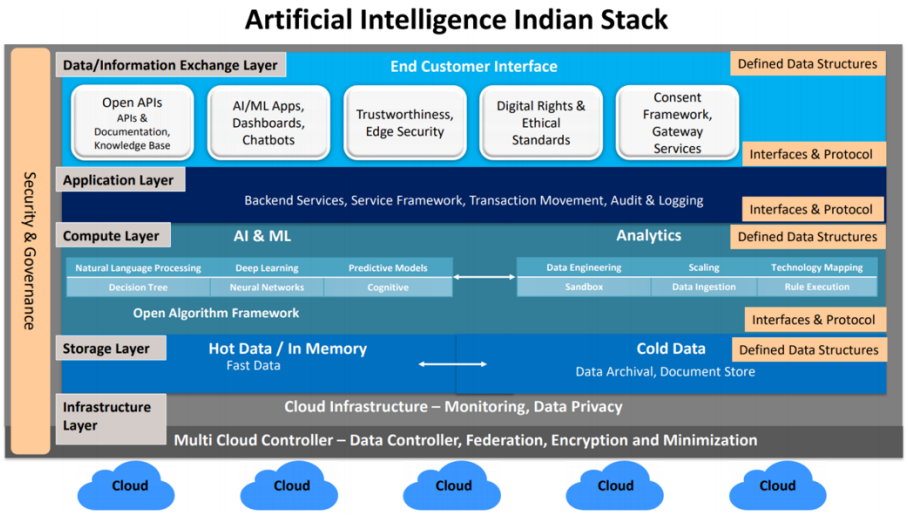


Figure 1: Proposed Indian AI stack

Figure 4. The proposed Indian AI stack (AI Standardisation Committee, 2020, p. 21).

Defining the socio-technical system

India's dire climate situation needs addressing, but as a developing nation, India must also tackle poverty, food insecurity, etc. Climate change intimately intertwining with these other

systemic issues is particularly obvious in the developing and vulnerable country. Unlike the United States where climate change can be afforded its own concentration, India must tackle the crisis alongside and as part of other issues. National efforts around science, technology, innovation, and private sector involvement, as detailed by the Paris Agreement goals and AI reports discussed above, will guide India's endeavors. Additionally, India's spiritual roots yield a fundamentally different perspective on climate change than the Western world. Prime Minister Modi at the Climate Adaptation Summit 2021 said,

> India's civilizational values teach us that importance of living in harmony with nature. Our ancient scripture Yajurveda teaches us that our relationship with planet earth is that of a mother and her child. If we take care of mother earth, she will continue to nurture us. To adapt to climate change, our lifestyles must also adapt to this ideal (HT Correspondent, 2021).

This attitude is further evidenced in India's non-actionable Paris Agreement goals (NRDC, 2020, p. 1-2):

- To put forward and further propagate a healthy and sustainable way of living based on traditions and values of conservation and moderation.
- To adopt a path that is climate-friendly and cleaner than the one followed hitherto by others at a corresponding level of economic development.
- To better adapt to climate change by enhancing investments in development programs in sectors vulnerable to climate change, particularly agriculture, water resources, the Himalayan region, coastal regions, health, and disaster management.

Also shaping India's sociotechnical system is its history of engineering and its relation to British colonialism. The military engineers of the East India Company were the first in India; then, in the Public Works Department engineers worked on fast-growing railroads (Ramnath, 2016). The prestige and identity of the engineering profession in India comes from association with government work and nation-building (Ramnath, 2016).

Modern Indian engineers are still building the nation, especially in light of the climate crisis. Increasingly ravaged by climate disaster and frustrated by lack of resources compared to the developed world, Javadekar asks for advanced countries to provide financial and technological support in the endeavor (PTI, 2019). Modi, at the G-20 Summit, reiterated this call (PTI, 2020). Additionally, at the Climate Adaptation Summit, Modi spoke about disaster resilience specifically: "I call upon the Global Commission on Adaptation to work with Coalition of Disaster Resilient Infrastructure (CDRI) to enhance infrastructure resilience globally" (HT Correspondent, 2021).

India's system builders are climate-AI engineers, similar to the US, however motivations and momentum differ greatly. Though private sector involvement and startup culture is present, the country as a whole seeks to build the nation by tackling issues to improve quality of life. Sustainability will be integrated into that development from the ground, enforced through the country's spiritual beliefs. Unfortunately, India faces many reverse salient: the gravity of the climate crisis, lack of time for affecting change before matters worsen, and lack of resources.

Technology examples and trends

A Green Tech Media article acutely defines India's clean-tech culture:

> It's easy to see what's motivating India's emerging ecosystem of sustainable technology startups with a glance out the window from the office of Sangam Ventures in Gurugram, just outside of Delhi. Several floors below the firm's balcony, power lines crisscross over piles of garbage, a fleet of rickshaws, and cow patties on a rooftop that are being dried for use as cooking fuel. Above it all lies a blanket of yellowish smog (Pyper, 2021).

This description fits the characterization of India's sociotechnical system and momentum. Though in its infancy, growing interest and investment bodes well for India and other nations. Shailesh Vikram Singh, an angel investor at the GoMassive Earth Network, said "If we can solve it, we won't just solve it for India. We will solve it for the whole Global South" (Pyper, 2021).

However, climate tech investment goes beyond the private sector. Microsoft's AI for Earth grants are given to researchers using machine learning for climate-gain, and many are offered to projects in India. Below are five examples (Microsoft News Center India, 2018):

1. Dr. Muneeswaran Mariappan: Cataloguing the rich ecosystem of Northeast India with AI-enabled tools.
2. Archana Chaudhari: Monitoring real-time energy use, streamlining energy distribution, and cutting carbon emissions through data analytics on smart meter readings.
3. Dr. Yogesh Simhann: Deploying IoT, machine learning, predictive analytics, and big data for fair and efficient water distribution in major Indian cities.
4. Dr. Himanshu Agarwal: Monitoring the purity of urban water, air, and soil through a network of IoT-enabled water sensors and ML algorithms.
5. Dr. Mamta Sharma: Predicting weather conditions and pest migration patterns for farmers with AI.

Conclusion

India is on the cusp of a thriving AI infrastructure as documented in the two papers discussed. The papers mention climate-related use cases which will certainly expand as the country's technology matures. The country has made great progress on climate goals but has much work to do to maintain stability in the coming decades. A dive into the sociotechnical system in India highlights nation-building and climate desperation as the main momentums for change. A startup culture of climate tech is growing in response; but many projects in India are still funded from the West, such as the Microsoft AI for Earth projects.

Discussion

Climate-AI technology in the United States and India is characterized by a vastly different ecosystem of system builders, momentum, and reverse salient. This has implications on the direction of that climate-AI technology.

Seen through its urgent calls to developed nations and its insistence for disaster resiliency, India is forced to work on mitigating climate realities they face presently, evidenced by the emphasis on fields like agriculture and energy in the AI reports discussed. However, because the country is still developing, sustainability will be integrated into new infrastructure from the start. This includes their creation of AI infrastructure throughout the country; the ingredients for a recipe of AI-climate integration are present, so an intimate relationship will build between the two phenomena. We see this in the growing climate tech scene in India.

However, as seen with the Microsoft AI for Earth grants and calls from Javadekar to the Western world for technology and financial supports, developed countries, especially the U.S.,

will have large influence in the direction of climate-AI technology in India. The U.S., too, hopes to exert influence: "This is a once in a generation opportunity to produce advanced technologies, export them around the world, and speed global net-zero transitions" ([EN] Leaders Summit on Climate - Day 2, 2021, 1:07:19). The new U.S.-India climate initiative proves this further. Additionally, India itself wants to influence the global south as a role model and solution-provider for the growing climate crisis, seen in part in the three components laid out in the NITI Aayog AI report, specifically being the "AI Garage for 40% of the world" (2018, p. 8).

However, influence from an aggressively capitalistic and individualistic culture like the U.S. may be at odds with India's values and goals. In America, individualistic culture will fuel consumer-driven climate-AI products. This may look like smart personal or home devices, public transportation tailored on individual rather than collective schedules (as suggested by Khosla in his fireside chat), resource-use optimizations, etc. The U.S. has an established, unsustainable infrastructure and consumerism culture; therefore, "green-products" must disrupt and replace carbon-intensive norms, so that the status-quo can continue as normal. However, this is fundamentally different than projects necessary for India, which are focused on clean water, energy, and food access. India has explicitly stated lifestyle adaptation must also be part of the solution, which is at odds with America's view.

In America, tech companies exert the most influence on the direction of climate-AI technology, politically and culturally. Due to the erratic nature of contemporary American politics, with polarization on the rise and climate action quite dictated by party lines, the market is a more constant force and better predictor of climate technology. Therefore, the ethical and social implications are that technology created for American consumerism culture mediates a definition of sustainability that is seen and tackled as a market issue. Climate-AI may prioritize

convenience and maintenance in the status quo. This means that sustainable changes in infrastructure will come only as necessary and as defined by technology, such as the rise in popularity of electric vehicles necessitating charging stations. In contrast, Indian efforts to nation-build and influence from spiritual roots create a definition of sustainability that is holistically integrated into infrastructure. Because of this, India is more poised than the U.S. to develop or adopt radical, sustainable changes that are influenced or built by technology. Additionally, the Indian government has more vested oversight on national infrastructure than the U.S. as it seek to build the nation. This difference in attitude is evident even in the scope of national reports from each country; in India, these reports are lengthy and discuss development of infrastructure. However, American initiatives under both Biden and Trump have focused on technology innovation, jobs creation, security, and the private market.

Conclusion

This paper sought to:

(1) evaluate the role, limits, and potentials of AI in the climate fight. AI's role in climate change is yet to be completely defined, but it is clear that its carbon-reduction potential is highest when integrated with other engineering technologies. Its use is undoubtedly increasing in the climate fight. Additionally, AI has the potential to accelerate just and equitable climate action through insights in relevant data.

(2) characterize the socio-technical system in India and America and evaluate the influence of such a system on the direction of AI-climate technology. America's sociotechnical system is one of political strife and entrepreneurial spirit. The hype of innovation yields the responsibility of the direction of AI-climate technology to American tech companies. In contrast,

India is characterized by their need to develop their nation holistically, and climate change mitigation is intertwined with other systemic issues. As its AI potential blossoms, the country will use the technology in furtherance of their nation-building goals.

(3) consider the social and ethical implications present with such direction within such system. The United States and India are bound to influence each other's future of climate technology and climate-AI, but each country's vastly different sociotechnical system may reveal itself as a point of friction. Sustainability is America is mediated by green-consumerism and must disrupt existing carbon-intensive infrastructure. The goal of sustainability in America is to claim it without altering the status quo; as such, climate-AI technology will be built towards American values of individualism. On the other hand, India has the opportunity to integrate sustainability natively into the country's development as they continue to build themselves. For India, sustainability is a necessity to create a developed country and climate technology can and will help them achieve that goal. Regarding AI specifically, both countries understand and respect its power, but the U.S. is similarly hands-off in creating regulatory standards beyond broad claims of embedding American values, whereas India seeks to build national infrastructure for intelligent systems with a very intentional approach to AI that makes sense for India. However, both countries have acknowledged in some respect the potential hazards of the technology.

AI will play a significant role along with many other technologies in solving climate change. We've seen that the technology will influence and be influenced by the sociotechnical systems of each country and the resulting definition of sustainability that arises. Because of the broad potentials for AI involvement, as a technology it can be molded to be in furtherance of any defined or assumed national goals.

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