

CCAI Summer School 2024

Tackling Climate Change with Machine Learning

Priya L. Donti, David Rolnick, Lynn H. Kaack

Climate change warrants rapid action



Filippo Monteforte | AFP | Getty Images



David Mcnew | Getty Images



NASA



Pivaset | Shutterstock.com

Impacts felt globally

Disproportionate impacts on most disadvantaged populations

Need net-zero greenhouse gas emissions by 2050 (IPCC 2018)

- ▶ Across energy, transport, buildings, industry, agriculture, forestry, etc.

How does ML fit into this picture?

Lecture outline

Introduction to climate change

Opportunities for ML in climate action

Considerations for research and deployment

Is ML a help or hindrance for climate action?

Takeaways and how to get involved

Lecture outline

Introduction to climate change

Opportunities for ML in climate action

Considerations for research and deployment

Is ML a help or hindrance for climate action?

Takeaways and how to get involved

State of
climate change

Approaches for
climate action

The state of climate change

Earth has already warmed over 1°C, compared to pre-industrial period

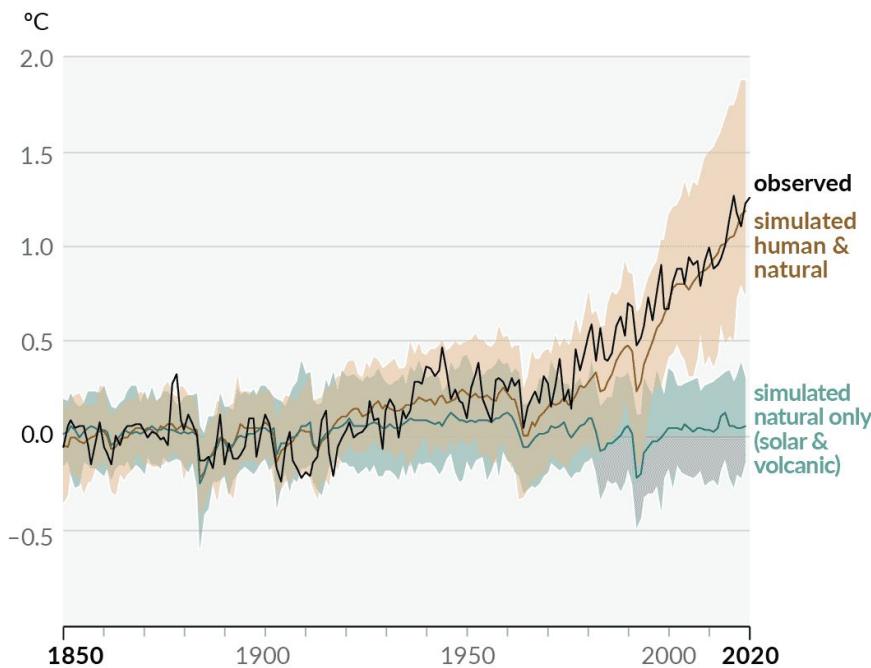
Due to excess greenhouse gas (GHG) emissions from human activities

- ▶ E.g., carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O)

Has induced major changes in climate

- ▶ Climate = “average weather”
- ▶ Extreme heatwaves, precipitation, droughts, hurricanes, etc.

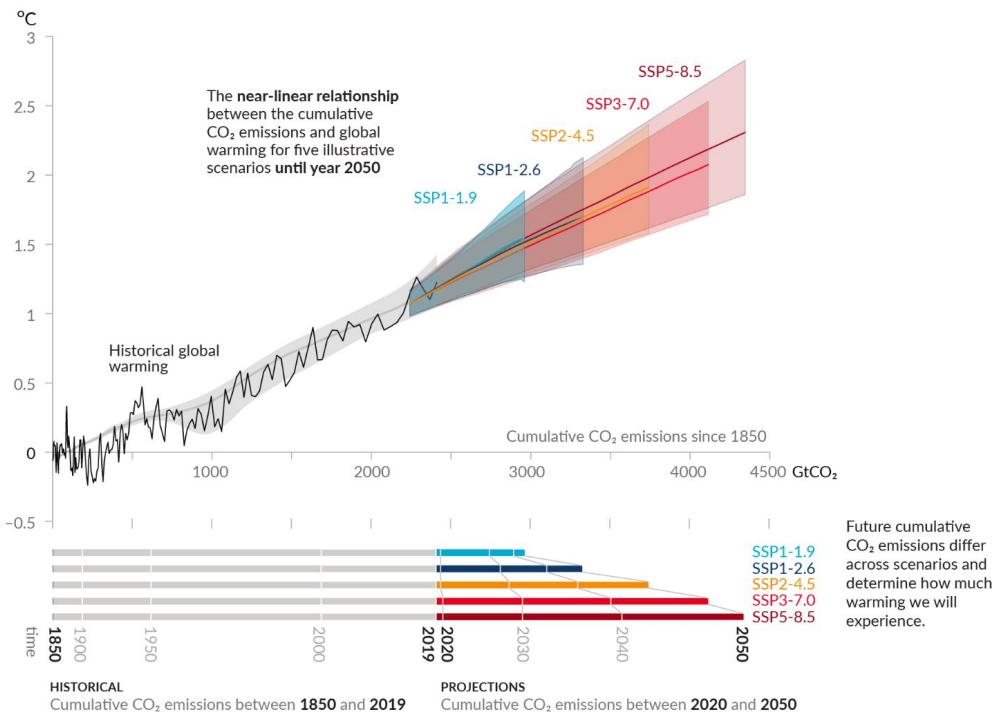
Change in global surface temperature (annual average) as **observed** and simulated using **human & natural** and **only natural** factors (both 1850–2020)



Rapid action is needed to limit warming

Every tonne of CO₂ emissions adds to global warming

Global surface temperature increase since 1850–1900 (°C) as a function of cumulative CO₂ emissions (GtCO₂)



Speed and scale of systemic changes affects total warming

Net-zero by 2050 (**SSP1-1.9**) limits warming to ~1.5°C

Climate change is **not an on/off switch** - every unit of GHG emissions reduction matters

Approaches to addressing climate change

Axes of action

- ▶ **Climate science:** Understanding and predicting climate change
- ▶ **Mitigation:** Reducing or preventing greenhouse gas emissions
- ▶ **Adaptation:** Responding to the effects of a changing climate

Important frameworks

- ▶ **Climate justice:** An equity-centered approach to climate change
- ▶ **Co-benefits:** Explicitly considering linkages between climate action and other UN Sustainable Development Goals (SDGs)

Approaches to addressing climate change

Axes of action

- ▶ **Climate science:** Understanding and predicting climate change
- ▶ **Mitigation:** Reducing or preventing greenhouse gas emissions
- ▶ **Adaptation:** Responding to the effects of a changing climate

Important frameworks

- ▶ **Climate justice:** An equity-centered approach to climate change
- ▶ **Co-benefits:** Explicitly considering linkages between climate action and other UN Sustainable Development Goals (SDGs)

Approaches to addressing climate change

Axes of action

- ▶ **Climate science:** Understanding and predicting climate change
- ▶ **Mitigation:** Reducing or preventing greenhouse gas emissions
- ▶ **Adaptation:** Responding to the effects of a changing climate

Important frameworks

- ▶ **Climate justice:** An equity-centered approach to climate change
- ▶ **Co-benefits:** Explicitly considering linkages between climate action and other UN Sustainable Development Goals (SDGs)

Climate change mitigation

Mitigation: Reducing or preventing GHG emissions

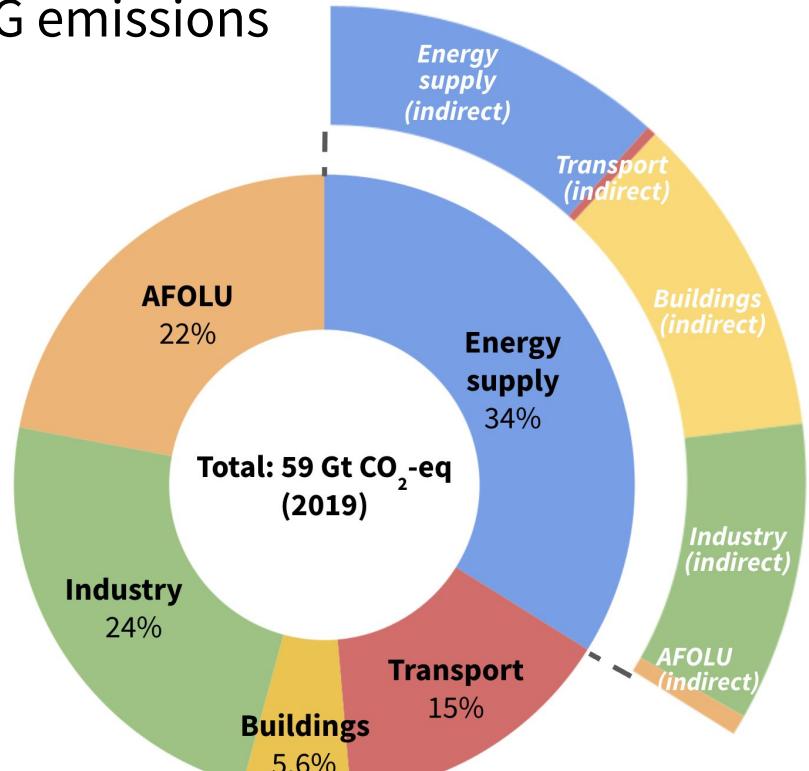


Figure data based on IPCC AR6 WG3 Report (2022). Percentages shown do not add to exactly 100% due to rounding to two significant figures.

Climate change mitigation

Mitigation: Reducing or preventing GHG emissions

Sectors

- Energy supply
- Transportation
- Buildings
- Industry
- Agriculture
- Forestry
- Other land use
- CO₂ removal

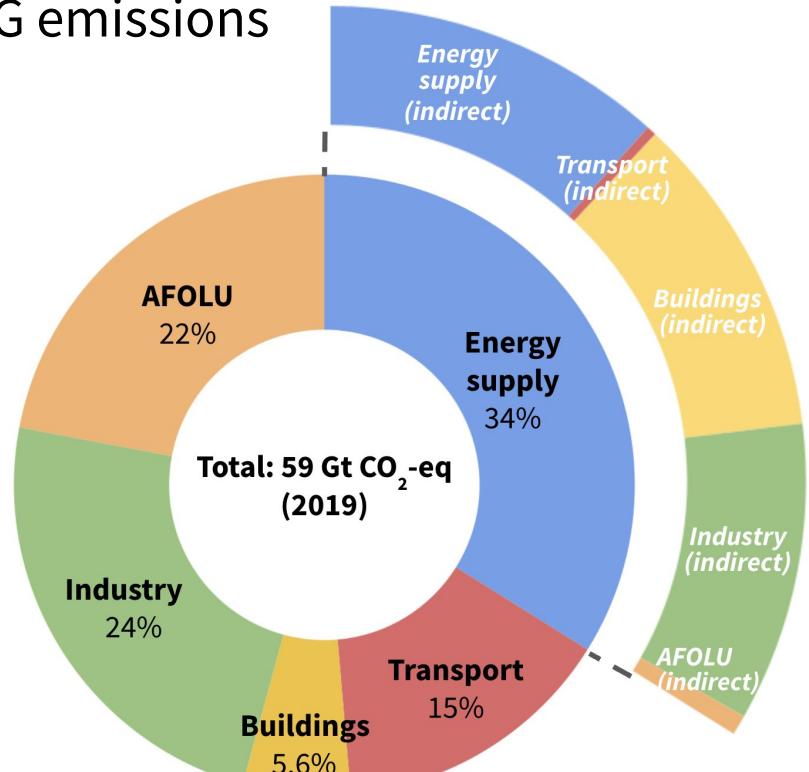


Figure data based on IPCC AR6 WG3 Report (2022). Percentages shown do not add to exactly 100% due to rounding to two significant figures.

Climate change mitigation

Mitigation: Reducing or preventing GHG emissions

Sectors

- Energy supply
- Transportation
- Buildings
- Industry
- Agriculture
- Forestry
- Other land use
- CO₂ removal

**Energy-related
emissions**

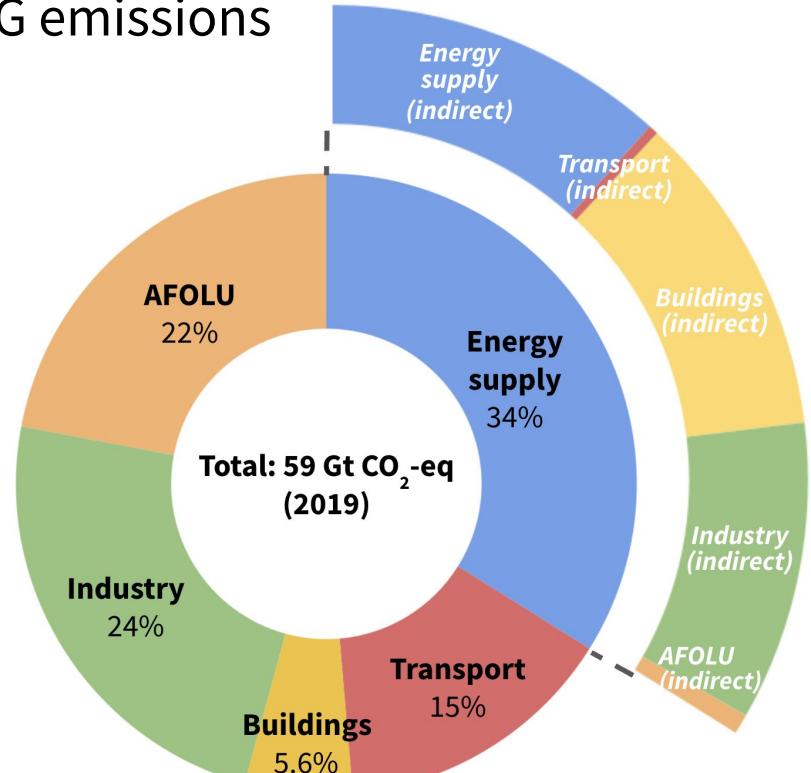


Figure data based on IPCC AR6 WG3 Report (2022). Percentages shown do not add to exactly 100% due to rounding to two significant figures.

Climate change mitigation

Mitigation: Reducing or preventing GHG emissions

Sectors

- Energy supply
- Transportation
- Buildings
- Industry
- Agriculture
- Forestry
- Other land use
- CO_2 removal

**Land use
(AFOLU)
emissions**

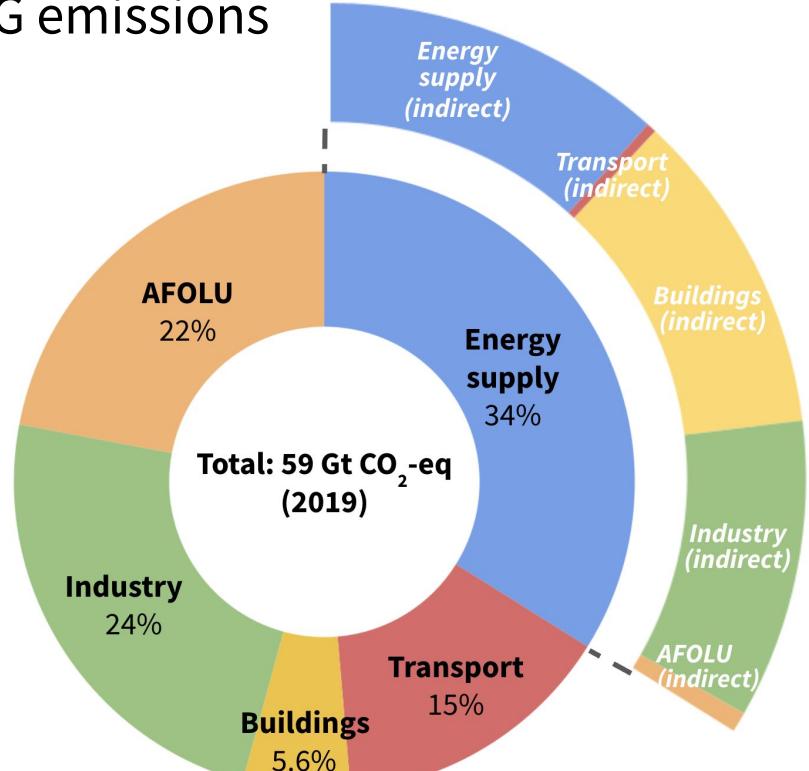


Figure data based on IPCC AR6 WG3 Report (2022). Percentages shown do not add to exactly 100% due to rounding to two significant figures.

Approaches to addressing climate change

Axes of action

- ▶ **Climate science:** Understanding and predicting climate change
- ▶ **Mitigation:** Reducing or preventing greenhouse gas emissions
- ▶ **Adaptation:** Responding to the effects of a changing climate

Important frameworks

- ▶ **Climate justice:** An equity-centered approach to climate change
- ▶ **Co-benefits:** Explicitly considering linkages between climate action and other UN Sustainable Development Goals (SDGs)

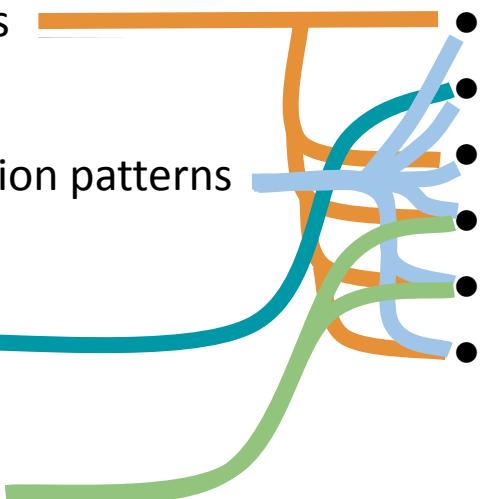
Climate impacts and downstream effects

Climate impacts

- Rising temperatures
- Changing precipitation patterns
- Rising sea levels
- Ocean acidification

Downstream effects

- Droughts and heatwaves
- More intense storms and flooding
- More frequent wildfires
- Loss of ecosystem services
- Biodiversity loss
- Spread of disease vectors and pests



Climate change adaptation

Adaptation: Responding to the effects of a changing climate

Climate change adaptation

Adaptation: Responding to the effects of a changing climate

1. Measuring and predicting risks
 - **Risk:** Impact x probability

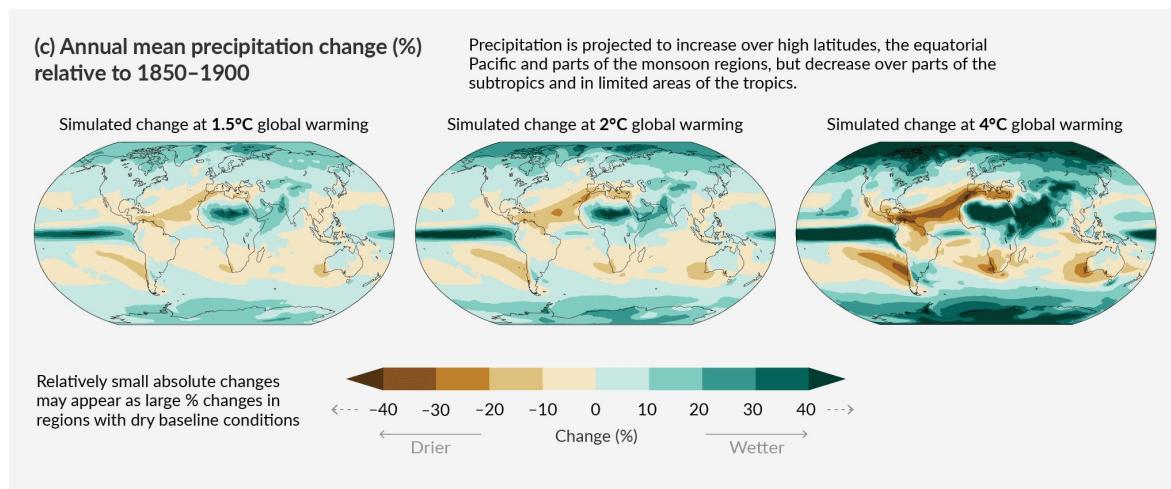


Figure source: IPCC AR6 Summary for Policymakers (2021)

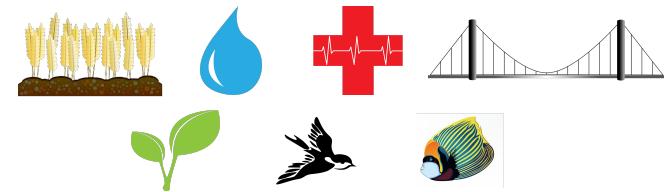
Climate change adaptation

Adaptation: Responding to the effects of a changing climate

1. Measuring and predicting risks

- ▶ **Risk:** Impact x probability

Human & ecological systems



2. Strengthening adaptive capacity

- ▶ **Robustness:** Withstanding a range of outcomes with no/minimal impact
- ▶ **Resilience:** Recovering quickly after impact

Connections with UN SDGs



Approaches to addressing climate change

Axes of action

- ▶ **Climate science:** Understanding and predicting climate change
- ▶ **Mitigation:** Reducing or preventing greenhouse gas emissions
- ▶ **Adaptation:** Responding to the effects of a changing climate

Important frameworks

- ▶ **Climate justice:** An equity-centered approach to climate change
- ▶ **Co-benefits:** Explicitly considering linkages between climate action and other UN Sustainable Development Goals (SDGs)

Takeaways: Introduction to climate change

Rapid action is needed on climate change

- ▶ **Climate science:** Understanding and predicting climate change
- ▶ **Mitigation:** Reducing or preventing greenhouse gas emissions
- ▶ **Adaptation:** Responding to the effects of a changing climate

Important frameworks

- ▶ **Climate justice:** An equity-centered approach to climate change
- ▶ **Co-benefits:** Explicitly considering linkages between climate action and other UN Sustainable Development Goals (SDGs)

Lecture outline

Introduction to climate change

Opportunities for ML in climate action

Considerations for research and deployment

Is ML a help or hindrance for climate action?

Takeaways and how to get involved

Roles for ML in
climate action

Considerations
in evaluating
applications

What is AI?

Artificial intelligence (AI): Any computer algorithm that makes predictions, recommendations, or decisions on the basis of a defined set of objectives.*

Machine learning (ML): AI algorithms that infer patterns from data.

Especially popular / effective recently, thanks to deep learning / neural networks.

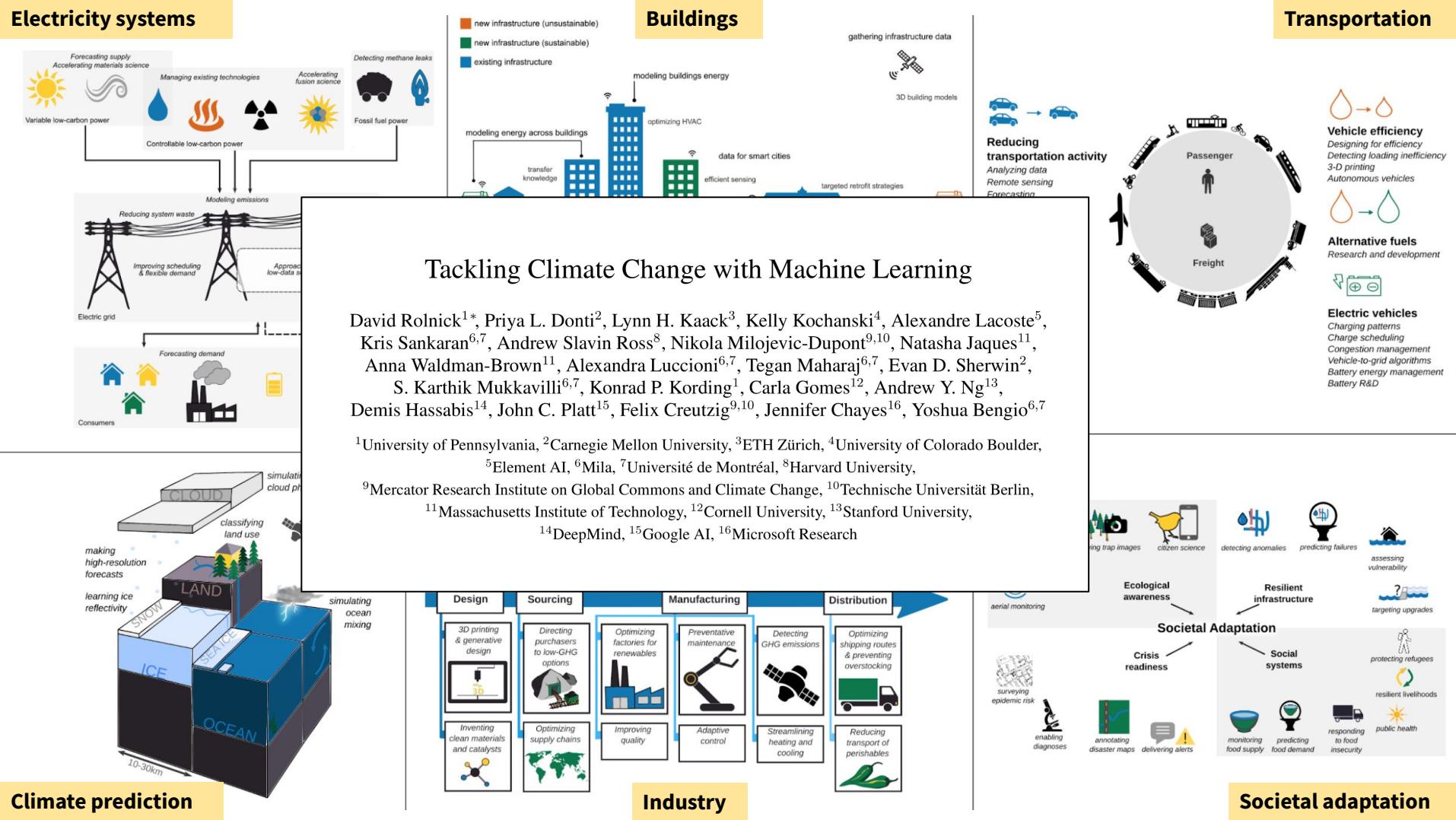
Example areas: Computer vision, optimization, natural language processing, reinforcement learning and control

Some buzzwords: Foundation models,

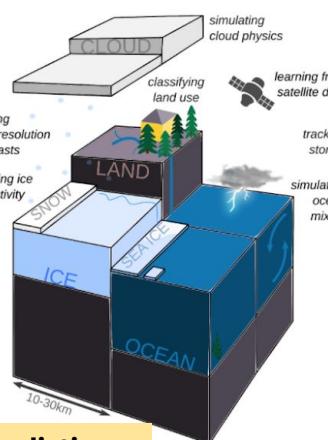
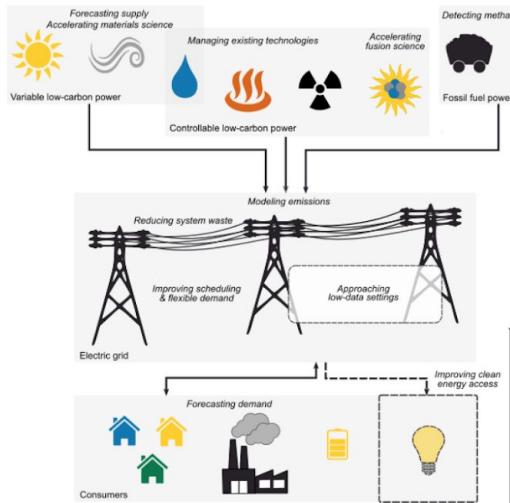
generative AI, large language models

(most of AI is not these things)

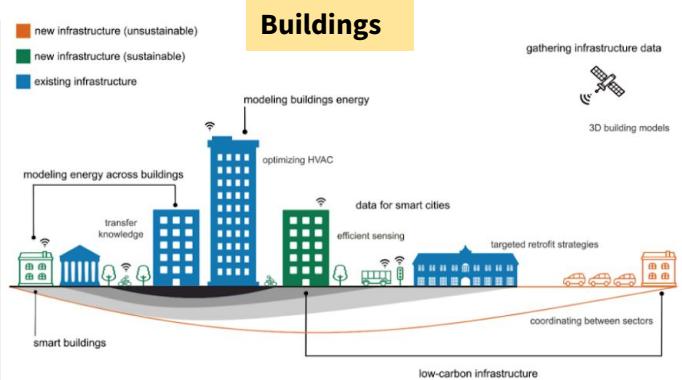
*OECD AI Principles.



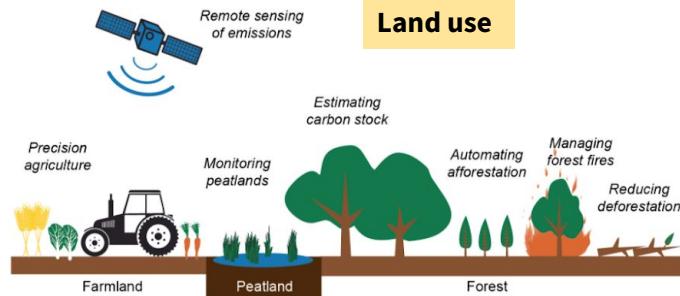
Electricity systems



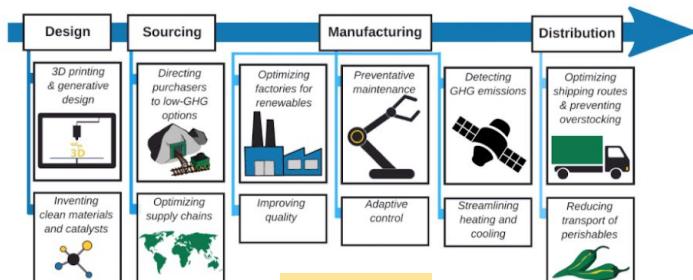
Buildings



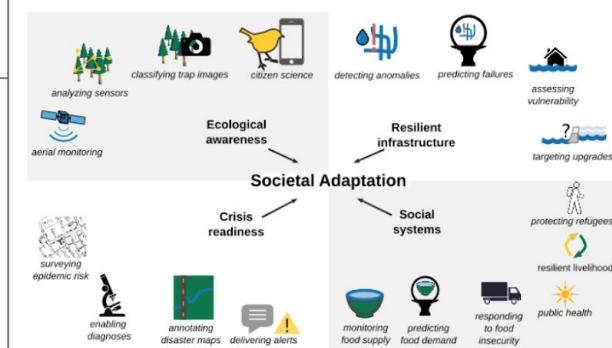
Land use



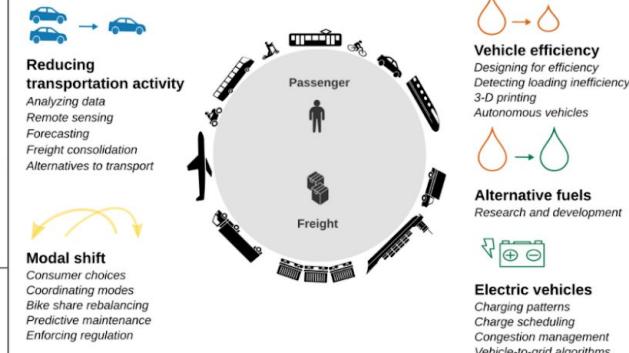
Industry



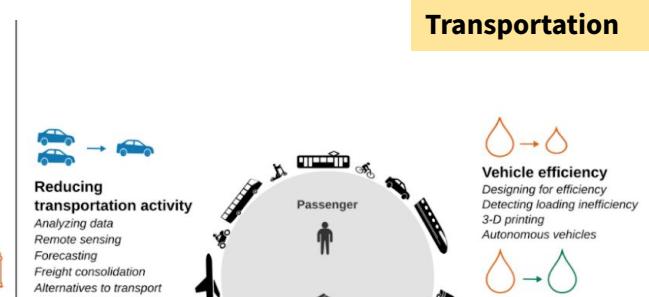
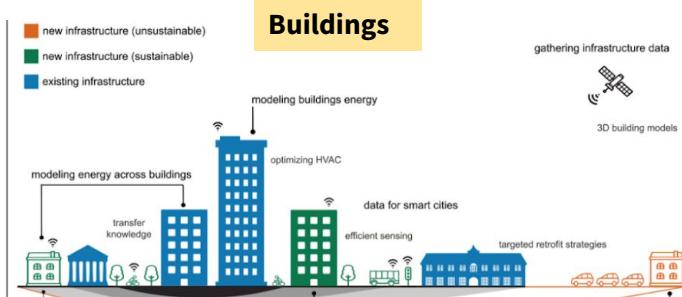
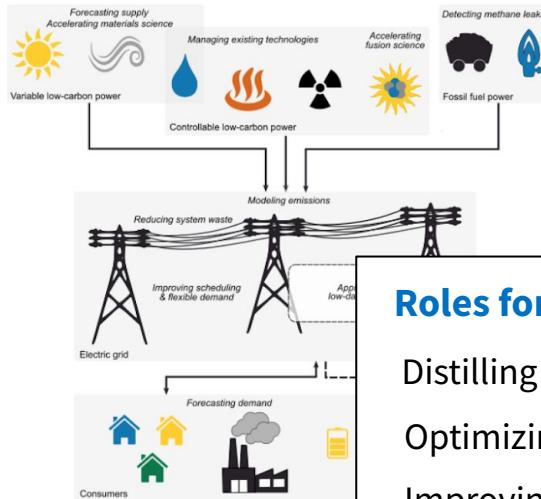
Societal adaptation



Transportation



Electricity systems



Roles for ML in mitigation, adaptation, & climate science

Distilling raw data into actionable information

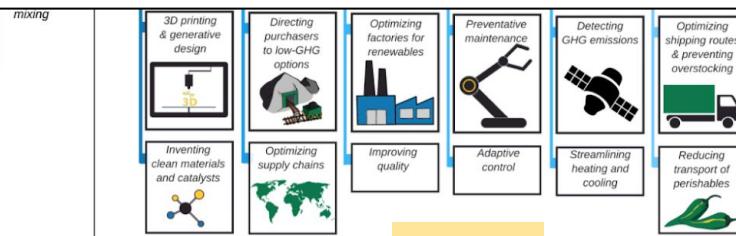
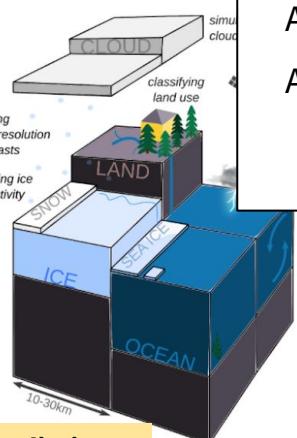
Optimizing complex systems

Improving predictions

Accelerating scientific discovery

Approximating time-intensive simulations

See also: <https://www.climatechange.ai/summaries>



Industry



Societal adaptation

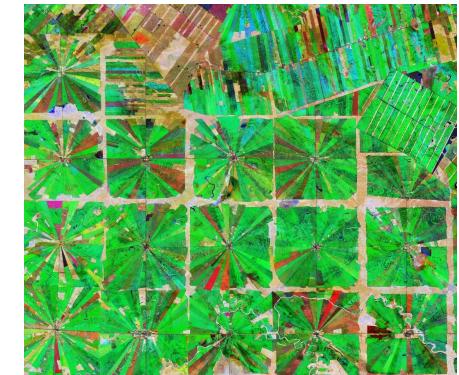
1. Distilling raw data

Role: Distilling raw data into actionable information

Some relevant ML areas: Computer vision, natural language processing

Examples

- ▶ Mapping deforestation and carbon stock [M]
- ▶ Gathering data on building footprints/heights [M]
- ▶ Evaluating coastal flood risk [A]



2. Optimizing complex systems

Role: Improving efficient operation of complex, automated systems

Some relevant ML areas: Optimization, control, reinforcement learning

Examples

- ▶ Controlling heating/cooling systems efficiently [M]
- ▶ Optimizing rail and multimodal transport [M]
- ▶ Demand response in electrical grids [M]



Note: Beware of misaligned objectives and rebound effects

3. Improving predictions

Role: Forecasts and time series predictions

Some relevant ML areas: Time series analysis, computer vision, Bayesian methods

Examples

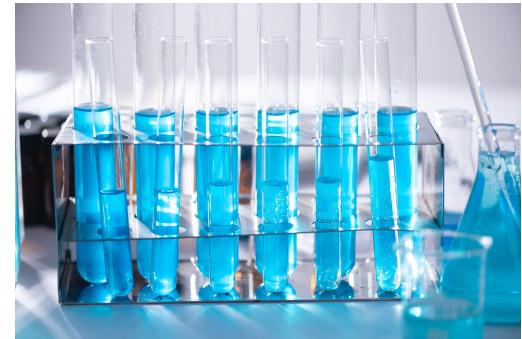
- ▶ “Nowcasting” for solar/wind power [M]
- ▶ Forecasting electricity demand [M]
- ▶ Predicting crop yield from remote sensing data [A]



4. Accelerating scientific discovery

Role: Suggesting experiments in order to speed up the design process

Some relevant ML areas: Generative models, active learning, reinforcement learning, graph neural networks



Examples

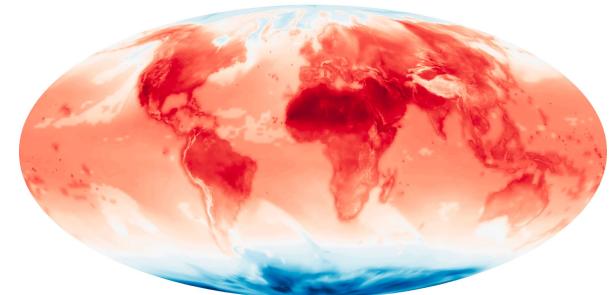
- ▶ Identifying candidate materials for batteries, photovoltaics, and energy-related catalysts [M]
- ▶ Algorithms for controlling fusion reactors [M]

5. Approximating simulations

Role: Accelerating time-intensive, often physics-based, simulations

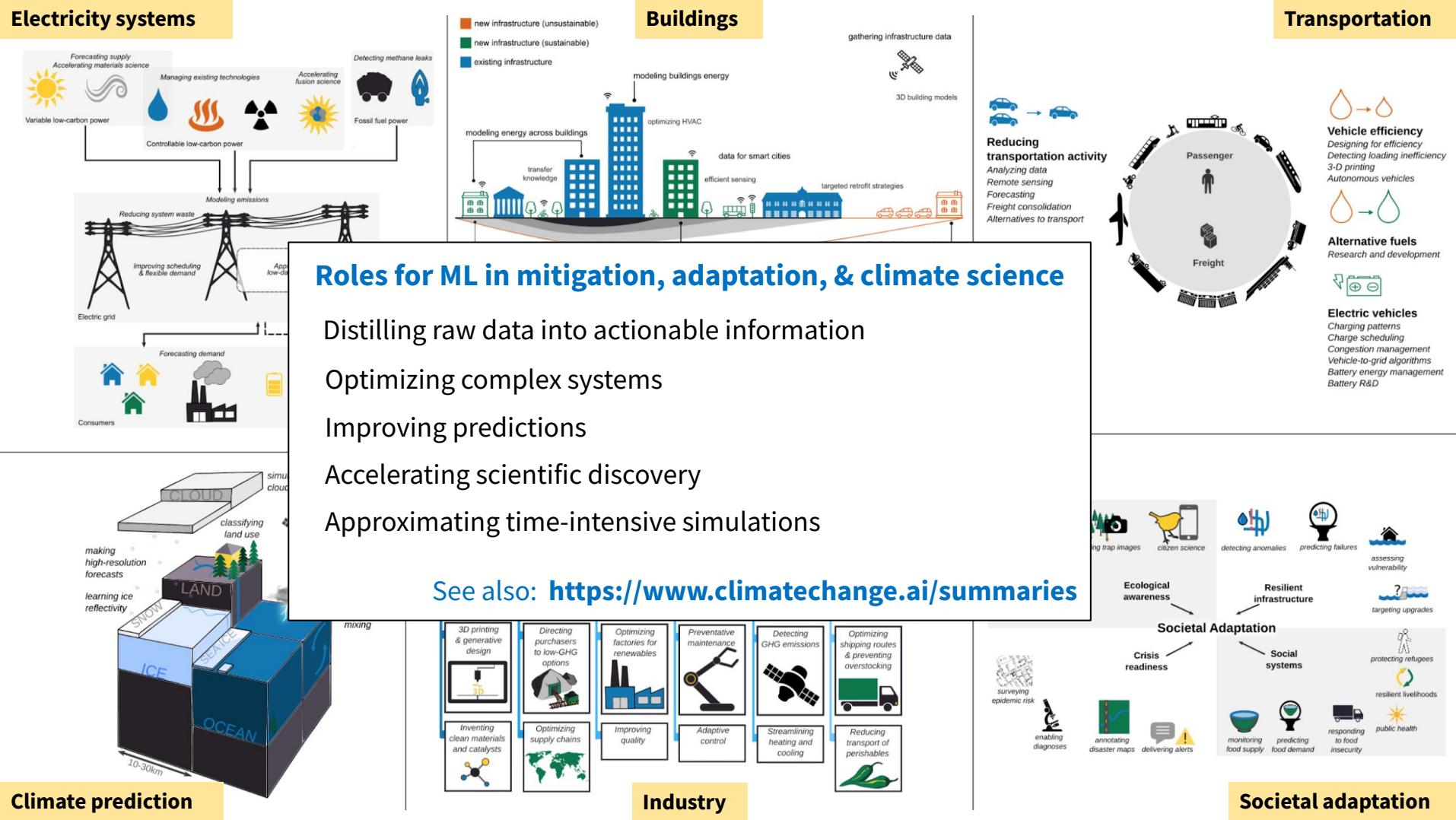
Some relevant ML areas:

Physics-informed ML, computer vision,
interpretable ML, causal ML



Examples

- ▶ Superresolution of predictions from climate models [A]
- ▶ Simulating portions of car aerodynamics [M]
- ▶ Speeding up planning models for electrical grids [M]



Questions that we asked in identifying priorities

- ▶ Is ML **needed** to address the problem?
- ▶ What is the **scope** of the impact? (in rough terms)
- ▶ What is the **time horizon** of the impact?
- ▶ What is the **likelihood** that a solution can be found?
- ▶ Can a solution feasibly be **deployed**?
- ▶ What are the potential **side effects** of deploying the candidate solution?
- ▶ Who are the **relevant stakeholders** who are involved in or affected by the application?

Key considerations

ML is not a silver bullet and is only relevant sometimes

High-impact applications are not always flashy

Interdisciplinary collaboration

- ▶ Scoping the right problems
- ▶ Incorporating relevant domain information
- ▶ Shaping pathways to impact

Equity considerations

- ▶ Empowering diverse stakeholders
- ▶ Selecting and prioritizing problems
- ▶ Ensuring data is representative

Opportunities for innovation in ML

Sophisticated algorithms may be required, but aren't always

Any innovations should be shaped by needs of the relevant application

- ▶ Physics/engineering constraints or robustness guarantees
- ▶ Interpretability or causality
- ▶ Uncertainty quantification
- ▶ Generalization, e.g. across geographies, under non-stationarity, or with limited data

See our [ICML 2022 tutorial](#)

Lecture outline

Introduction to climate change

Opportunities for ML in climate action

Considerations for research and deployment

Is ML a help or hindrance for climate action?

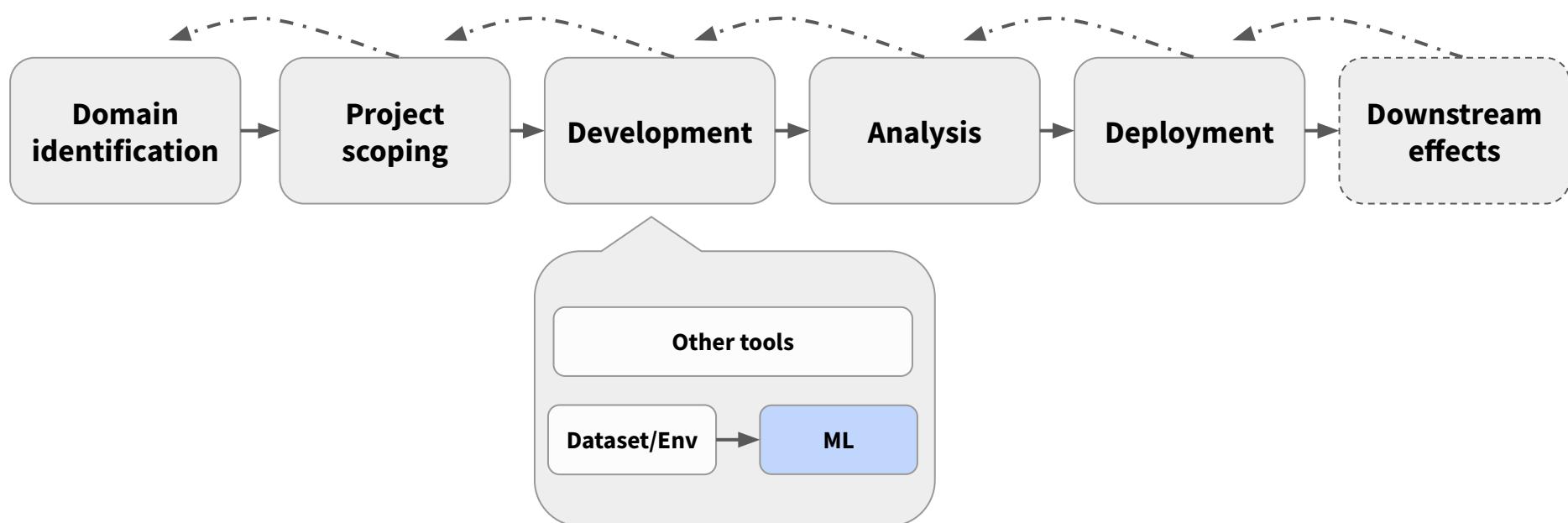
Takeaways and how to get involved

Data & metrics

Stakeholder engagement

Responsible AI considerations

ML-for-climate: Pathway to impact



Developing data, simulators, and metrics

Data: Collection, annotation, collation, inference, and/or licensing

- ▶ Note: “Data” can mean different things to different communities

Simulators: Needed for innovations in physical domains

- ▶ E.g., power systems, transport, buildings, heavy industry

Evaluation metrics: Need agreement and iteration from ML researchers, domain researchers, deployers, and other affected stakeholders

Resources and venues

- ▶ CCAI Dataset Wishlist (www.climatechange.ai/dataset-wishlist.pdf)
- ▶ Lacuna Fund funding for climate datasets
- ▶ NeurIPS Datasets and Benchmarks track

Responsible AI for climate action

Mitigating biases in data and models

- ▶ E.g., Buildings data: Housing discrimination, geographic disparities in availability
- ▶ E.g., Weather models: Calibration may be optimized for particular regions

Improving trustworthiness and accountability

- ▶ Safety and robustness: Critical in, e.g., power systems and industrial operations
- ▶ Interpretability and auditability: Critical in, e.g., policymaking contexts

Centering equity and climate justice

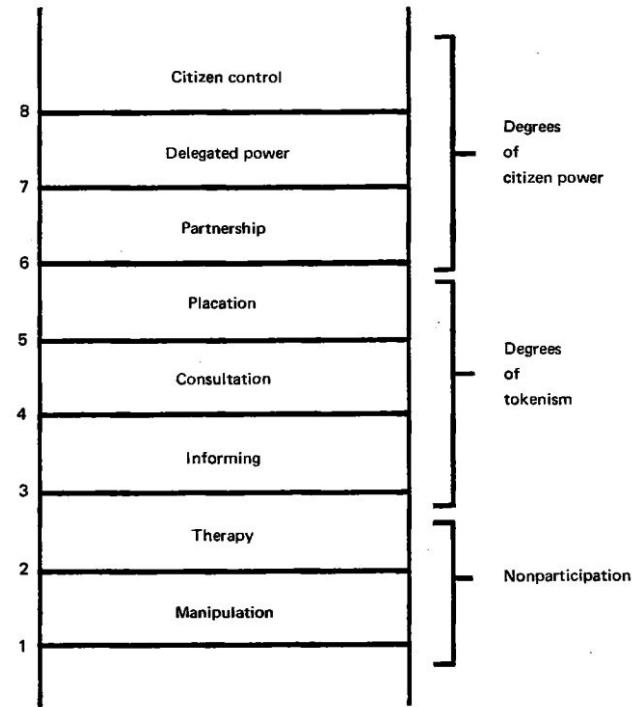
- ▶ Centering diverse stakeholders: E.g., industrial ag vs. smallholder farmers
- ▶ Avoiding centralization: Democratized capacity and compute, digital divide
- ▶ Avoiding digital colonialism: E.g., smart meters, analysis of remote sensing data

Importance of stakeholder engagement

Stakeholder types (e.g.)

- ▶ Researchers (tech & social sciences)
- ▶ Implementing entities and industries
- ▶ End users
- ▶ Policymakers
- ▶ Other affected parties

Meaningful engagement required

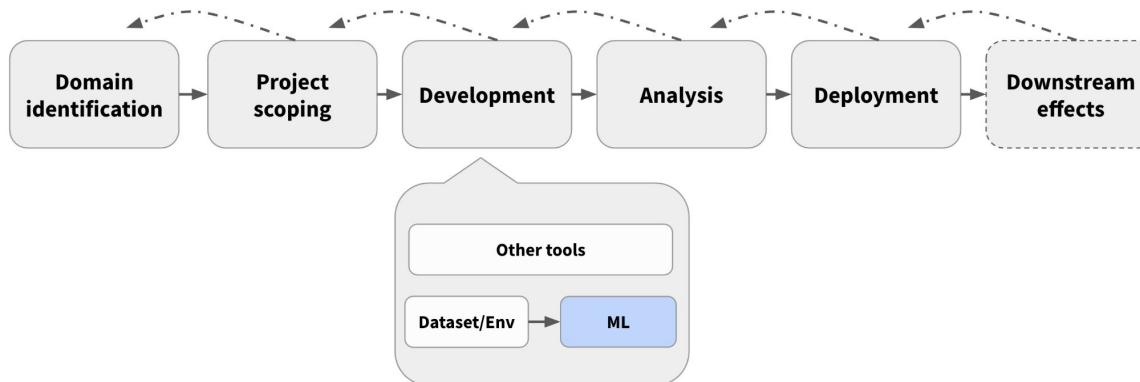


Arnstein's Ladder of Citizen Participation

Takeaways: Considerations for research & deployment

Consider the full pathway to impact, including

- ▶ Data, simulators, metrics
- ▶ Responsible AI & climate considerations
- ▶ Stakeholder engagement



Lecture outline

Introduction to climate change

Opportunities for ML in climate action

Considerations for research and deployment

Is ML a help or hindrance for climate action?

Takeaways and how to get involved

What is ML's carbon footprint?

What can one do to shape the overall impact?

ML's carbon footprint

Emissions from
ML computation
& hardware

ML applications
in climate change
mitigation

ML applications
that increase
emissions

ML's system-level
impacts

ML's carbon footprint

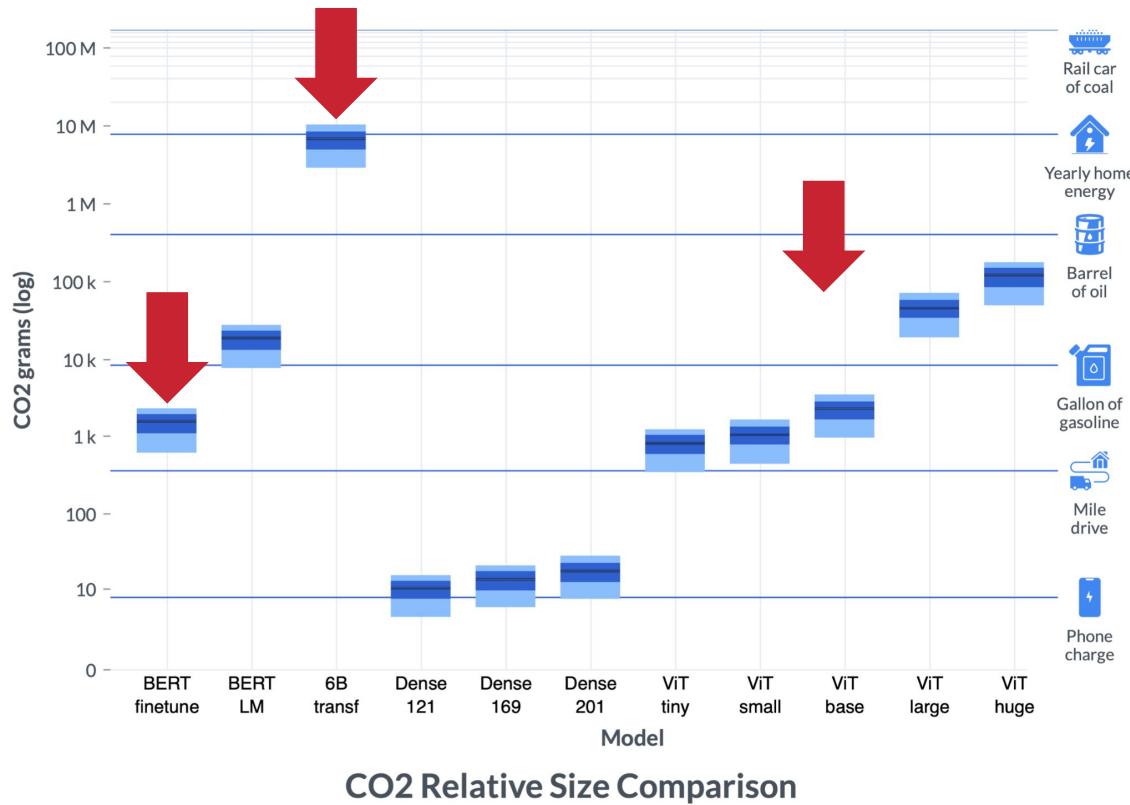
Emissions from
ML computation
& hardware

ML applications
in climate change
mitigation

ML applications
that increase
emissions

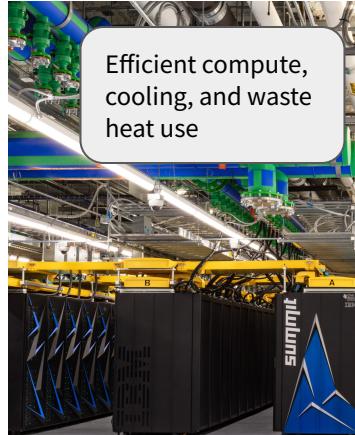
ML's system-level
impacts

Emissions from ML computation



Impacts from ML computation & hardware

Operational emissions from energy consumed during computation



Embodied emissions from production and end-of-life of hardware



ML's carbon footprint

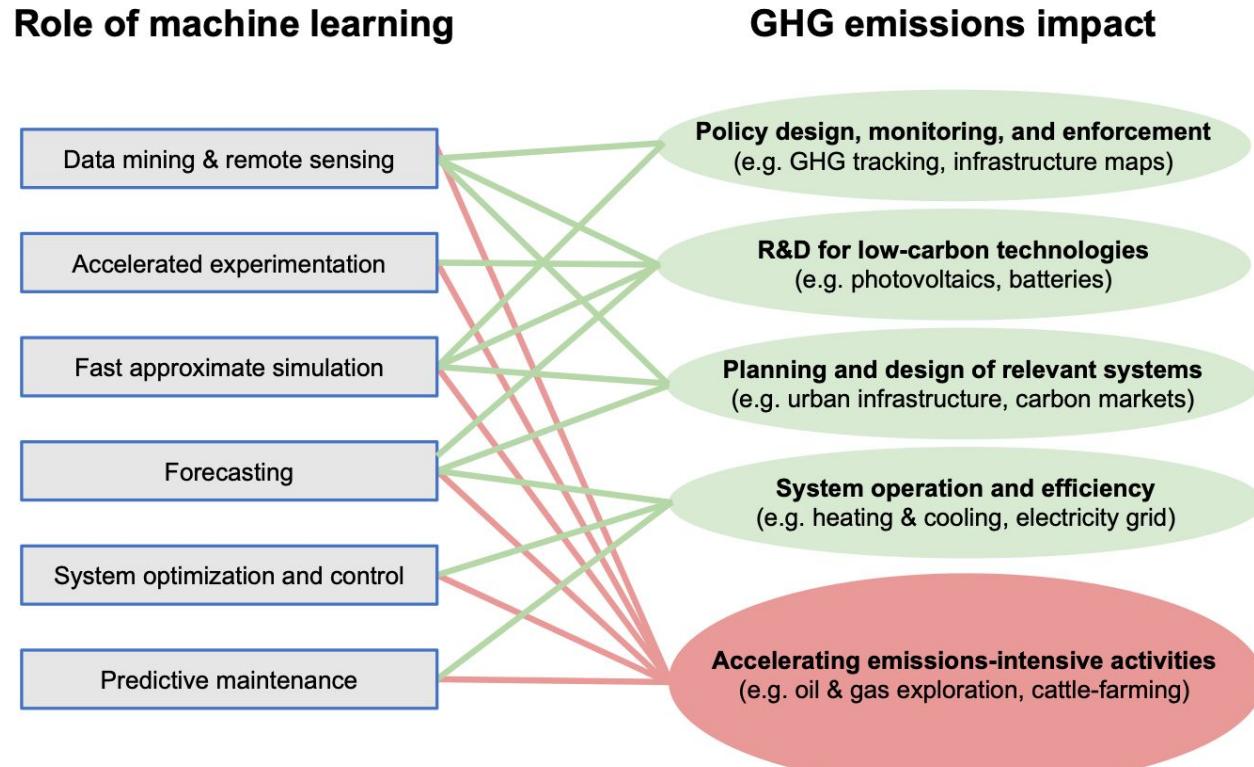
Emissions from
ML computation
& hardware

ML applications
in climate change
mitigation

ML applications
that increase
emissions

ML's system-level
impacts

Immediate application impacts



Broader scope of application impacts

Example: Efficiency improvements in crude oil refining

- ▶ Crude oil is turned into lighter hydrocarbons by heat from coker units
- ▶ Accurately predicting coke buildup in pipes with ML can help **maintain equipment and reduce energy consumption**
- ▶ This ML application reduces emissions in the refinery
- ▶ The application is also **reducing costs** - making oil more competitive relative to cleaner alternatives
- ▶ Need to consider how the ML application affects emissions from the energy & economic system overall



ML's carbon footprint

**Emissions from
ML computation
& hardware**

**ML applications
in climate change
mitigation**

**ML applications
that increase
emissions**

**ML's system-level
impacts**

System-level impacts of ML applications

Potential **rebound** and **lock-in** effects

- Oil refining, autonomous vehicles

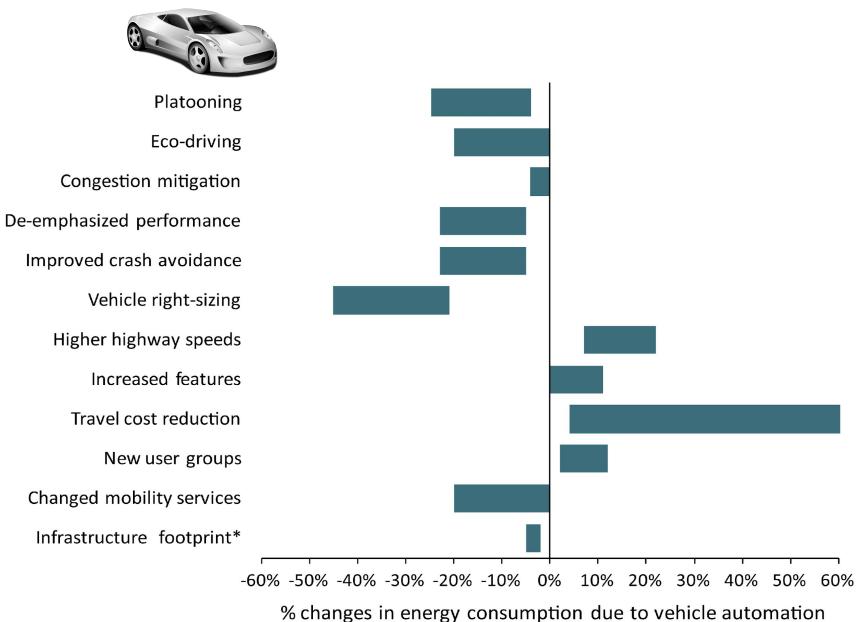


Image source: Wadud et al. 2016

System-level impacts of ML applications

Potential **rebound** and **lock-in** effects

- Oil refining, autonomous vehicles

Increasing **societal consumption**

- Personalized ads, on-demand delivery



Image credit: Megan_Rexazin_Conde / Pixabay.com

System-level impacts of ML applications

Potential **rebound** and **lock-in** effects

- Oil refining, autonomous vehicles

Increasing **societal consumption**

- Personalized ads, on-demand delivery

(Mis)information and polarization

- Content personalization/amplification



Image credit: Rose Wong / for NBC News

System-level impacts of ML applications

Potential **rebound** and **lock-in** effects

- Oil refining, autonomous vehicles

Increasing **societal consumption**

- Personalized ads, on-demand delivery

(Mis)information and polarization

- Content personalization/amplification

Inducing **societal power shifts**
due to access and agency

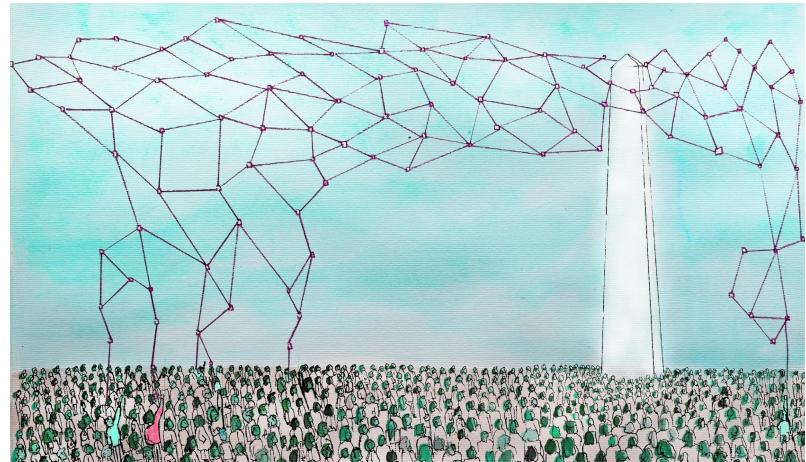


Image credit: Jamillah Knowles & We and AI / Better Images of AI / People and Ivory Tower AI / CC-BY 4.0

ML's carbon footprint

**Emissions from
ML computation
& hardware**

**ML applications
in climate change
mitigation**

**ML applications
that increase
emissions**

**ML's system-level
impacts**

Climate change impacts of your ML work

Computing-related:

- ▶ **Measure** your footprint with tools such as [ML CO2 Impact](#), [CodeCarbon](#), [Carbontracker](#), or tools specifically for [Azure](#) or [Hugging Face](#)
- ▶ **Reduce** your impacts by choosing more efficient models, and reducing wasteful model retraining and execution

Application-related:

- ▶ **Quantify and evaluate** the application impacts where possible
- ▶ Be **transparent** about impacts in publications and with stakeholders (quantitatively and qualitatively)
- ▶ Choose **what** you (or the ML community) works on

Lecture outline

Introduction to climate change

Opportunities for ML in climate action

Considerations for research and deployment

Is ML a help or hindrance for climate action?

Takeaways and how to get involved

Ways to be involved in ML + climate change

Many job opportunities exist in this space, including in academic research, focused institutes, startups, tech companies, tech non-profits, AI teams in non-tech companies, and public bodies for funding, data, procurement, & policy

ML-focused folks can **include climate-relevant applications** in the set of problems that motivate their work & **build collaborations with domain experts**

Climate-focused folks can **learn about relevant ML methods** and where they may be applicable & can **build collaborations with ML experts**

From ML and tech, working explicitly on climate problems isn't the only way to help - consider how to better **align your existing projects** with climate goals

Consider becoming a bridge btw. specific fields or sectors (e.g. ML + agriculture)

Other relevant resources

Selected communities & events

- ▶ **Energy:** ACM e-Energy, IEEE Power & Energy, PSCC, BuildSys, AI.EPRI
- ▶ **Land use:** GRSS-IEEE, Int'l Soc. of Precision Ag, Restor, Global Forest Watch
- ▶ **Climate & Earth science:** Climate Informatics, AGU/EGU, Phi-Week
- ▶ **Biodiversity:** AI for Conservation slack, WILDLABS, GEO BON
- ▶ **General:** CompSustNet (community & doctoral consortium)

Publication venues: ICML/NeurIPS/ICLR/CVPR/etc, special track of JMLR on climate, Environmental Data Science, ACM COMPASS, many domain-specific and general interest venues

More info in the [Climate Change AI monthly newsletter](#)

Datasets and challenges

Energy: CityLearn, OPFLearn, ARPA-E GO, PowerGridworld, L2RPN, BeoBench, Building Data Genome, bbd.labworks.org, COBS, BOPTEST/ACTB, Open Catalyst

Land use: TorchGeo, blutjens/awesome-forests, CropHarvest, Radiant ML Hub, LandCoverNet, Agriculture-Vision, chrieke/awesome-satellite-imagery-datasets

Climate & Earth science: mldata.pangeo.io, ClimateBench, ClimART, CauseMe

Adaptation: wandb/droughtwatch, Global Flood Database, FloodNet, ITU GEOAI

Biodiversity: iNat dataset, LifeCLEF, FGVC, iWildCam, Movebank

More info climatechange.ai/reports/grandchallenges and practice with
climatechange.ai/tutorials

CLIMATE CHANGE AND AI

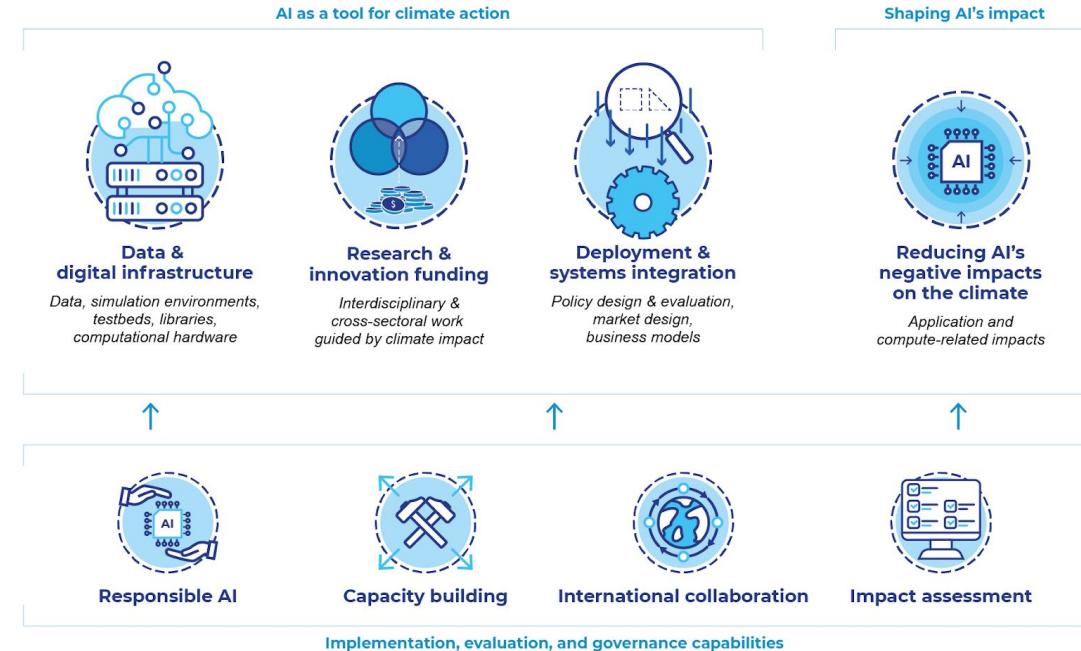
Recommendations for
Government Action

Global Partnership on AI Report

In collaboration with Climate Change AI and
the Centre for AI & Climate

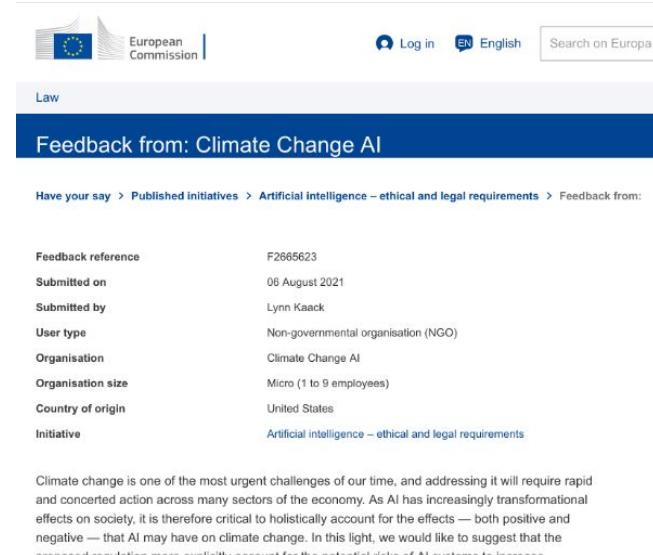


Policy



AI and climate in policy

- ▶ See for example **CCAI feedback** to the European Union's AI Act
- ▶ The final EU **AI Act** (2024) includes reporting requirements on the energy use of high-risk systems and large models
- ▶ Proposed US **Artificial Intelligence Environmental Impacts Act** of 2024
- ▶ US **Executive Order** on the Safe, Secure, and Trustworthy Development and Use of Artificial Intelligence (2023) includes a focus on energy



The screenshot shows a feedback submission page on the European Commission's website. The header includes the European Commission logo, a 'Log in' button, a language selector set to 'English', and a search bar. The main content area has a blue header bar with the text 'Feedback from: Climate Change AI'. Below this, a breadcrumb navigation shows 'Have your say > Published initiatives > Artificial intelligence – ethical and legal requirements > Feedback from: Climate Change AI'. The main body contains a table with the following data:

Feedback reference	F2685623
Submitted on	06 August 2021
Submitted by	Lynn Kaack
User type	Non-governmental organisation (NGO)
Organisation	Climate Change AI
Organisation size	Micro (1 to 9 employees)
Country of origin	United States
Initiative	Artificial intelligence – ethical and legal requirements

Below the table, a text box states: 'Climate change is one of the most urgent challenges of our time, and addressing it will require rapid and concerted action across many sectors of the economy. As AI has increasingly transformational effects on society, it is therefore critical to holistically account for the effects — both positive and negative — that AI may have on climate change. In this light, we would like to suggest that the ~~government~~ regulation ~~more~~ ~~continually~~ ~~assess~~ ~~the~~ ~~potential~~ ~~of~~ ~~AI~~ ~~systems~~ ~~to~~ ~~influence~~'.



Climate Change AI

Catalyzing impactful work at the intersection of climate change and AI

Educational resources

Summer school in AI & climate

- ▶ Virtual program (Jun-Jul)
- ▶ In-person program (Aug)

Tutorials & other “entry points”

Electricity Systems

+ Forecasting supply and demand

High Leverage

+ Improving scheduling and flexible demand

Conferences & events

Workshop series

- ▶ Submit and/or attend
- ▶ Mentorship programs

Events at UN Climate Change Conf.



Funding programs

Global research funding for impactful projects

Climate Change AI Innovation Grants

Announcing a **\$1.8M grants program** for projects at the intersection of AI and climate change

- Funding of up to **\$ 150K** for **year-long** research projects
- Supporting projects involving AI or machine learning that address problems in **climate change mitigation, adaptation, or climate science**
- Focus on fostering **pathways to impact** and the creation of catalytic datasets

Community



Welcome to the Climate Change AI community!

We are excited to have you here!

This is a place to connect, share and discuss all things related to climate change & machine learning.

If this is your first time here, you might want to head over to the [Hello channel](#) and introduce yourself.



Calls for Submissions



Funding



Projects & Courses



Readings



Jobs

Thought leadership

Reports aimed at researchers, practitioners, and policymakers

CLIMATE CHANGE AND AI

Recommendations for
Government Action

Climate Change AI

www.climatechange.ai



@ClimateChangeAI