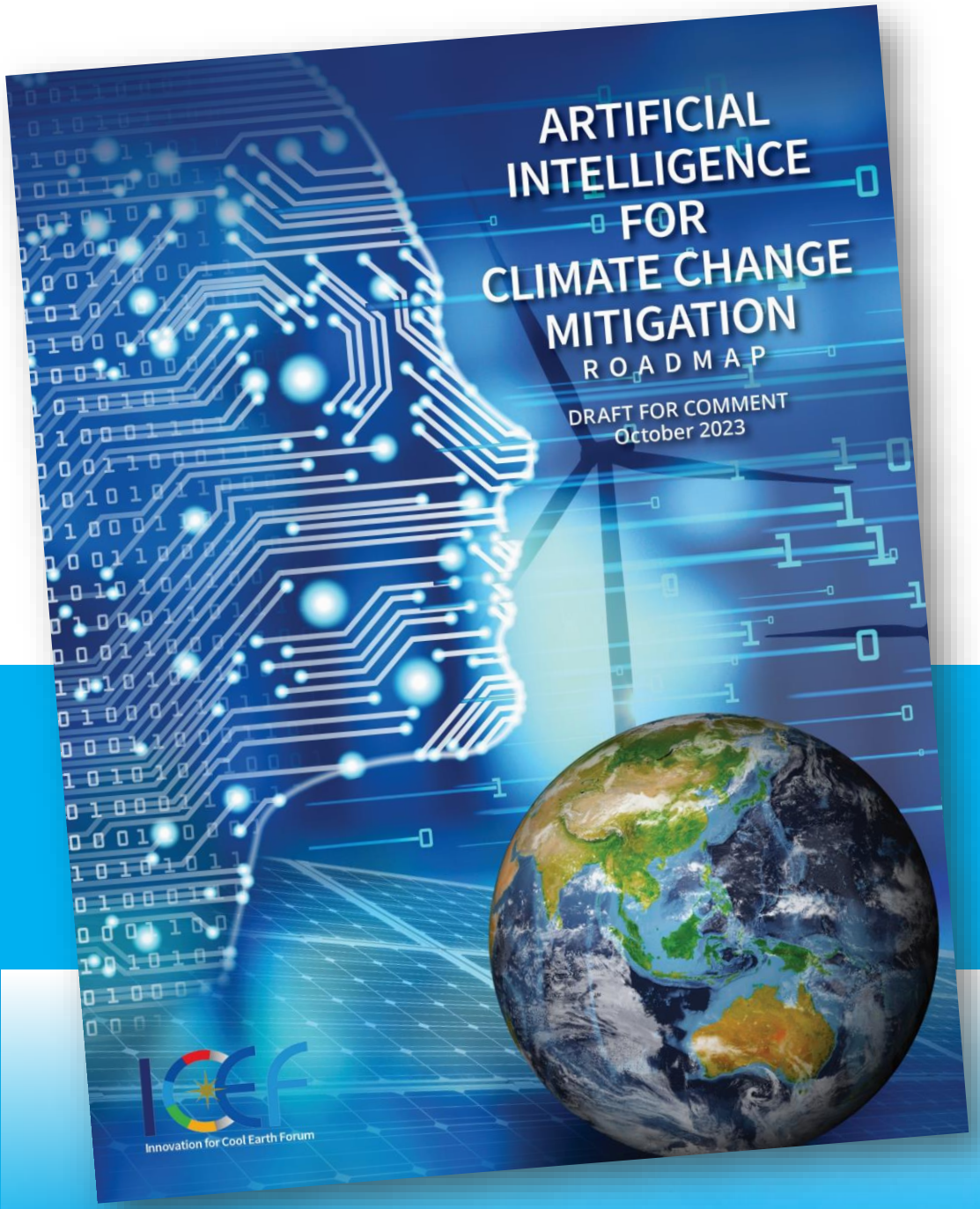


Innovation for Cool Earth Forum

David **Sandalow**, Colin **McCormick**, Alp **Kucukelbir**, Julio **Friedmann**, Trishna **Nagrani**, Zhiyuan **Fan**, Antoine **Halff**, Alexandre **d'Aspremont**, Ruben **Glatt**, Elena **Méndez Leal**, Kevin **Karl,** Alex **Ruane**

Innovation for Cool Earth Forum

INNOVATION ROADMAP PROJECT

Artificial Intelligence for Climate Change Mitigation
(draft for comment released today)

- Low-Carbon Ammonia (2022)
- Blue Carbon (2022)
- Carbon Mineralization (2021)
- Biomass Carbon Removal & Storage (BiCRS) (2020)
- Industrial Heat Decarbonization (2019)
- Direct Air Capture (2018)
- Carbon Dioxide Utilization 2.0 (2017)
- Energy Storage Roadmap (2017)
- Carbon Dioxide Utilization (2016)
- Zero Energy Buildings (2016)
- Solar And Storage (2015)

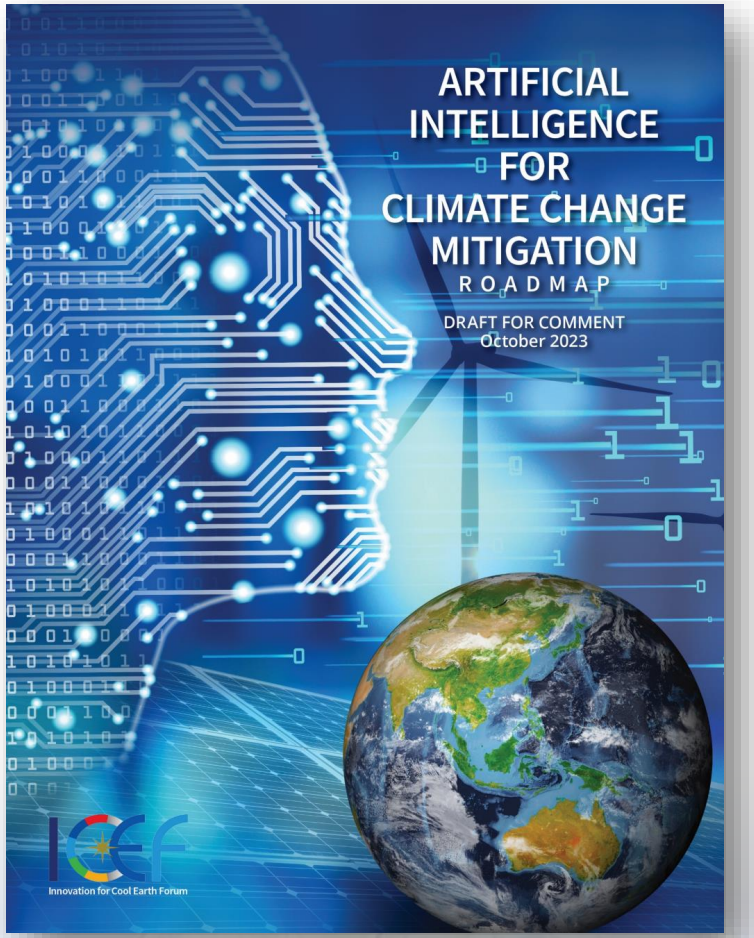
ICEF AI FOR CLIMATE CHANGE MITIGATION ROADMAP

Topic:

- ***HOW CAN AI HELP REDUCE EMISSIONS OF GREENHOUSE GASES?***

(Not:

- *How can AI help adapt to climate change?*
- *On balance, will AI help or hinder the fight against climate change?)*



ICEF AI FOR CLIMATE CHANGE MITIGATION ROADMAP

PART I: **BACKGROUND**

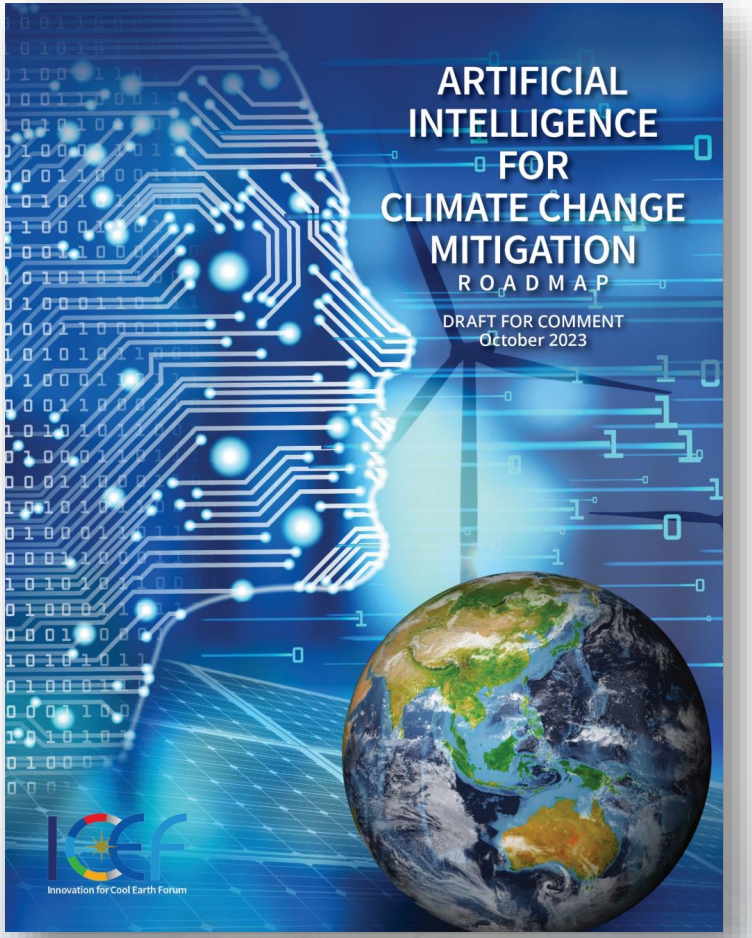
- Chapter 1. INTRODUCTION TO ARTIFICIAL INTELLIGENCE
- Chapter 2. INTRODUCTION TO CLIMATE CHANGE

PART II: **HIGH-POTENTIAL OPPORTUNITIES**

- Chapter 3. GHG EMISSIONS MONITORING
- Chapter 4. POWER GRID
- Chapter 5. MANUFACTURING
- Chapter 6. MATERIALS INNOVATION
- Chapter 7. FOOD SYSTEMS
- Chapter 8. ROAD TRANSPORT

PART III: **CROSS-CUTTING TOPICS**

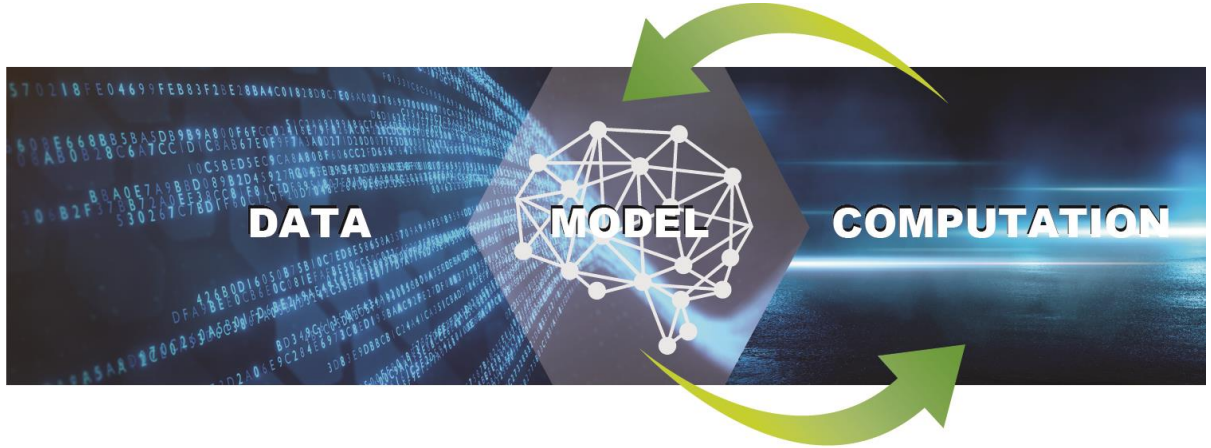
- Chapter 9. BARRIERS
- Chapter 10. RISKS
- Chapter 11. POLICY
- Chapter 12. FINDINGS AND RECOMMENDATIONS



Part I: BACKGROUND

Chapter 1: INTRODUCTION TO AI

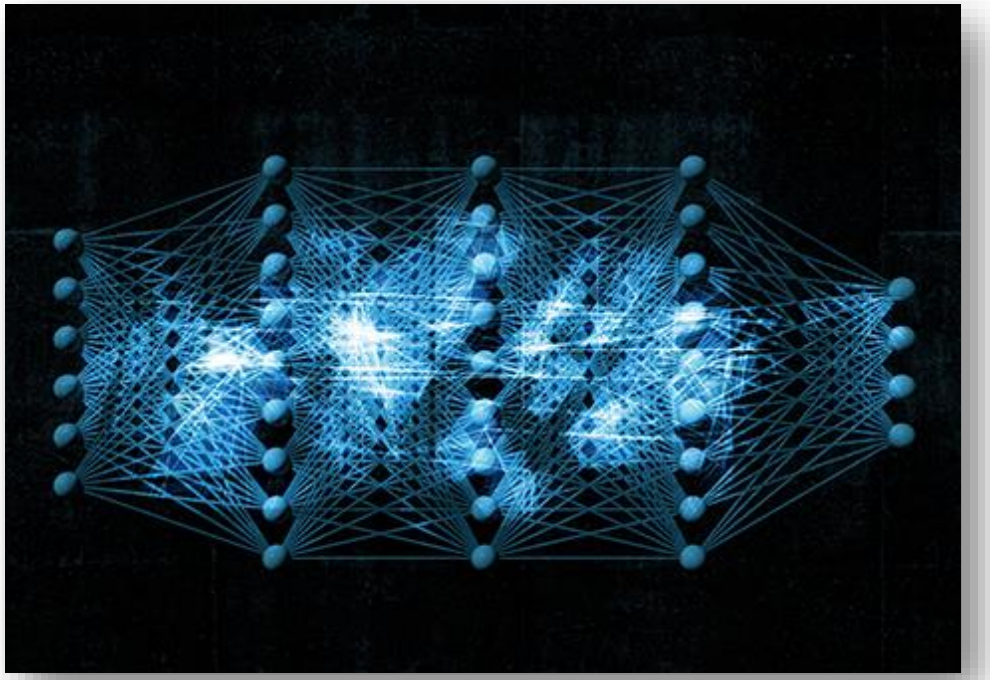
- Artificial Intelligence (AI) is the science of making computers perform complex tasks
- AI relies on machine learning (ML) to detect patterns from large datasets
- AI differs from traditional software
  - Instead of relying on explicit programming, AI replies on historical data and simulation to “train” models and “learn” patterns



Chapter 1: **INTRODUCTION TO AI**

AI/ML rely on three things:

- Data
  - Observations that pertain to a problem at hand
  - Example: historical weather patterns
  - Data availability and accessibility are essential
- Model
  - Describes the objective of the AI system
  - Describes patterns that lie in data
  - Enables the detection of patterns from data to achieve its objective
- Computation
  - Set of mathematical and statistical algorithms and computer hardware
  - “Trains” the model on the data



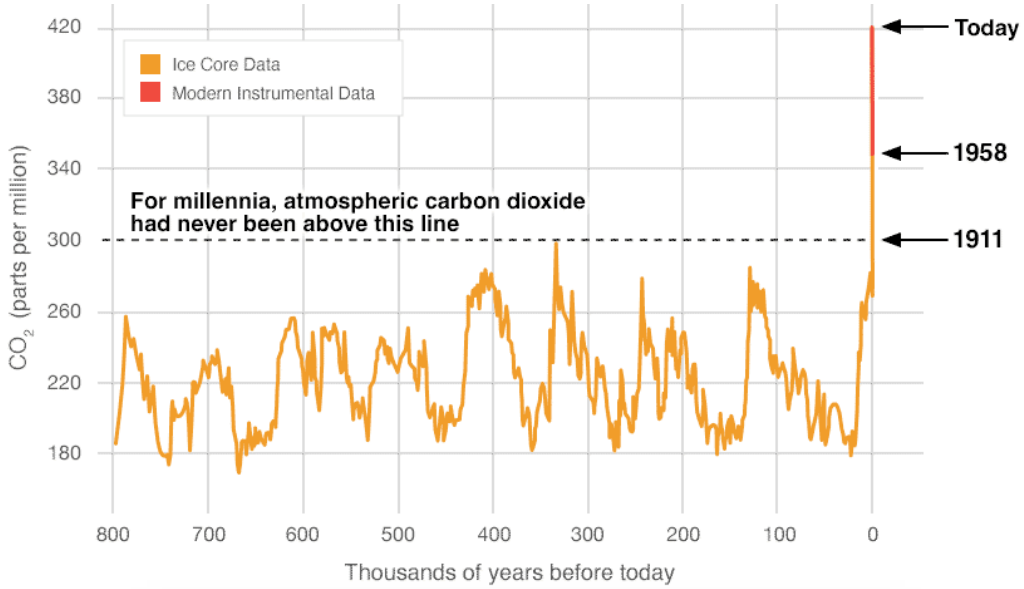
Chapter 2: INTRODUCTION TO CLIMATE CHANGE

- Atmospheric concentrations of heat-trapping gases are now higher than any time in human history.

- In terms of global average temperatures:
  - July 6, 2023 was the warmest day ever recorded
  - July 2023 was the warmest month ever recorded
  - The warmest 9 years ever recorded were the last 9 years

- This summer's heat waves, drought, fires and floods are all consistent with scientists' predictions of the impacts of climate change.

- Policies currently in place are not sufficient to reach the goals set in the Paris Agreement result – and those policies are not being fully implemented. The world is not on a path to meet its climate-related goals.



Chapter 2: **AI CONTRIBUTIONS TO CLIMATE SCIENCE**

AI is making important contributions to understanding climate change:

- improving climate model performance
- identifying new climate processes and feedback
- attributing extreme events to human influence, and
- revealing additional climate drivers.

Part II:
HIGH-POTENTIAL OPPORTUNITIES

Chapter 3: GHG EMISSIONS MONITORING

AI is helping to significantly improve information on sources of greenhouse gas (GHG) emissions.

- *Analyzing vast amounts of data* from earth-observation satellites, airplanes, drones, land-based monitors, the Internet of things, social media and other technologies

AI has been particularly important in improving *methane emissions* monitoring.

- Processing data from methane sensors at scale
- Combining input from multiple satellites
- Integrating satellite information with data generated by other types of sensors

AI is also being used to better understand sources of CO_2 *emissions*.

- AI algorithms can be trained to survey the world's vegetation at high spatial resolution.

Japanese IBUKI-2 GHG monitoring satellite

Chapter 3: **GHG EMISSIONS MONITORING**

Barriers to using AI for emissions monitoring include

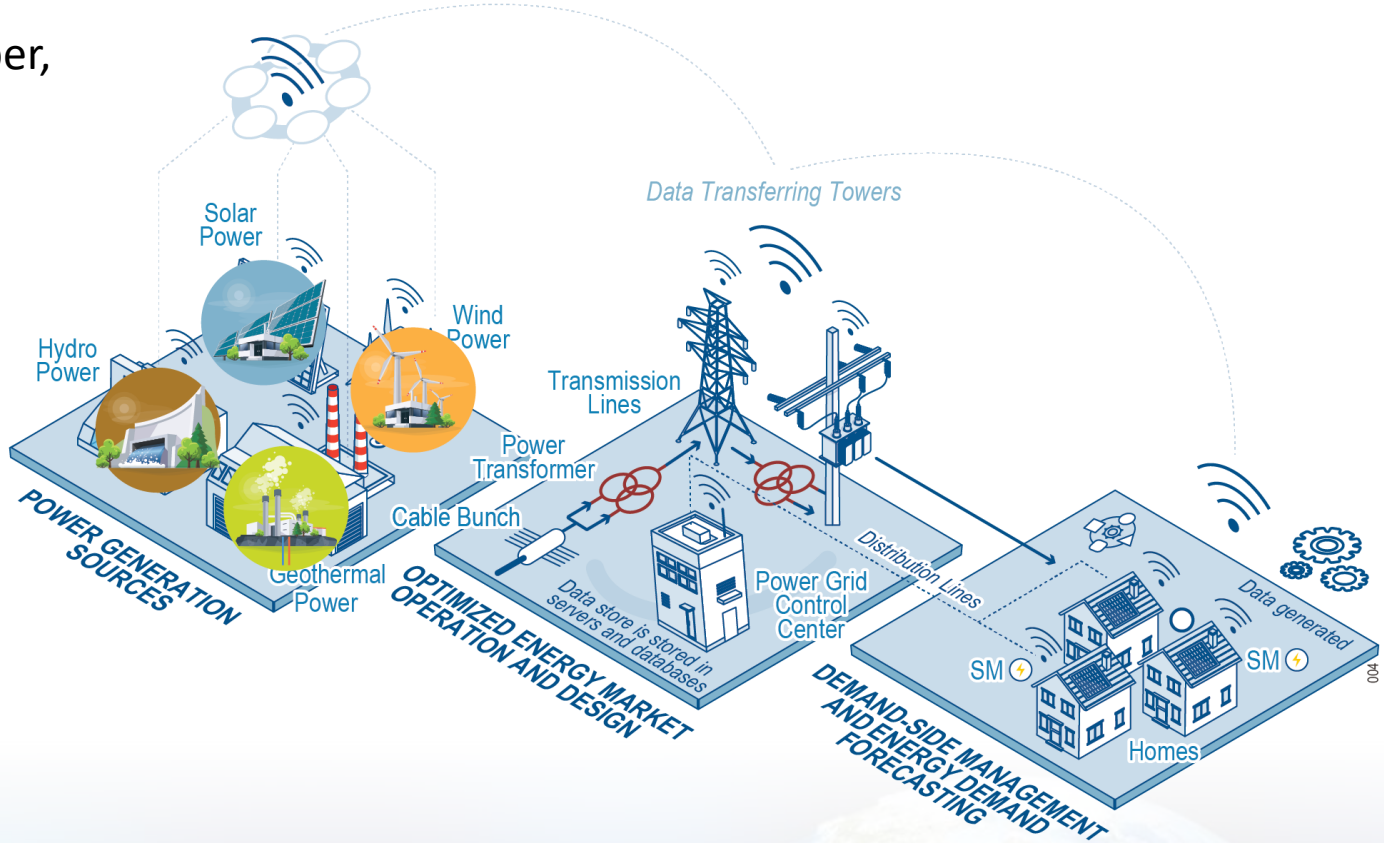
- lack of AI literacy,
- conflicting data,
- sovereignty concerns, and
- uncertain financial models.

Measures to help address these barriers include

- promoting AI literacy,
- establishing mechanisms to validate AI-enabled GHG emissions data,
- setting up one or more global “owners” of AI-enabled GHG emissions data, and
- elevating AI for climate in international dialogue, and negotiations.

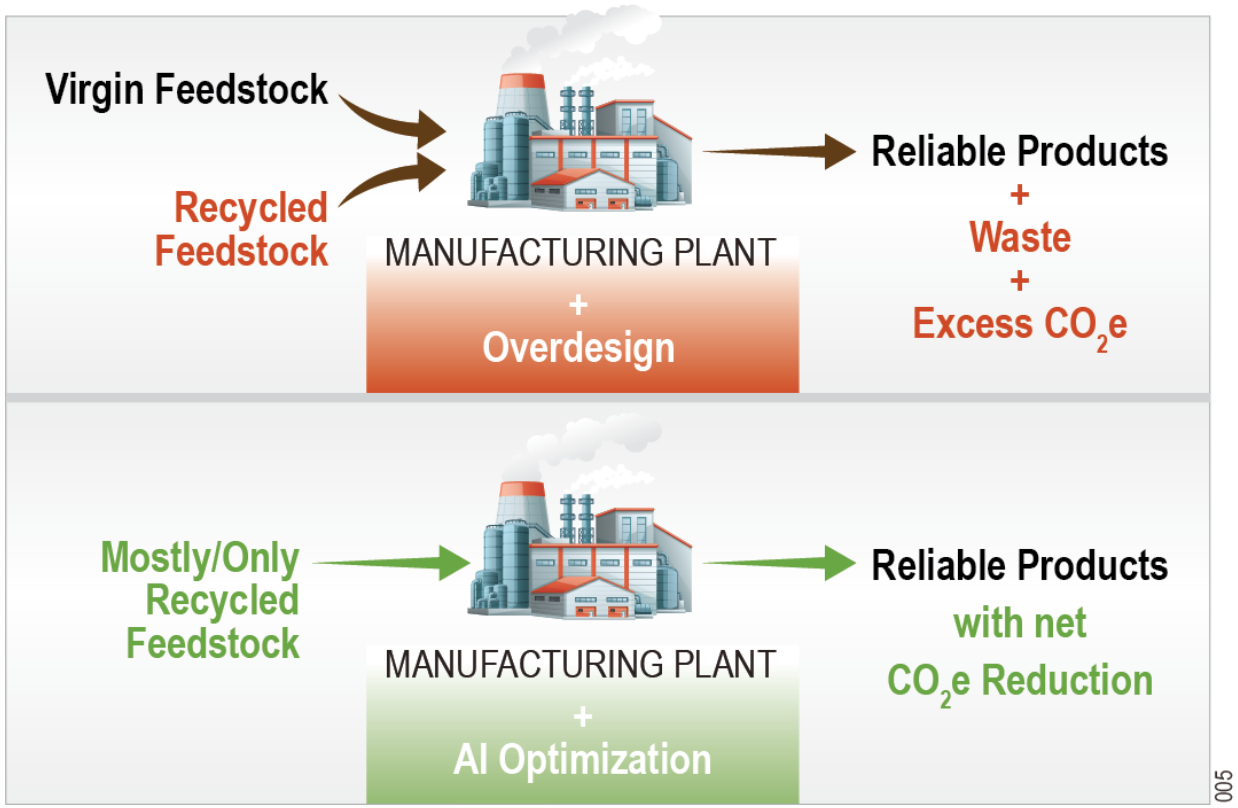
Chapter 4: **POWER GRID**

- AI is becoming an essential part of power grid infrastructure.
- AI can make decarbonization of the power grid cheaper, faster and smoother, helping with:
  - predictions,
  - scenario generation,
  - optimization, and
  - system planning and integration.
- AI can help in all parts of the power grid, including:
  - generation,
  - transmission and distribution
  - end use, and
  - energy storage.
- Barriers include:
  - lack of well-developed models, and
  - lack of trained personnel.
- Using AI in real-time operations creates security and safety risks.



Chapter 5: MANUFACTURING

- Manufacturing responsible for ⅓ of global emissions
- Decarbonizing manufacturing is hard because of physical (e.g., heat) and chemical (e.g., reactions that produce CO_2) constraints
- Decarbonizing manufacturing requires long-term investment like:
  - hardware changes / carbon capture
  - process changes (e.g., recycled feedstock)
  - switch to electrification
- But, AI can provide a complementary benefit today on existing hardware



Chapter 5: **MANUFACTURING**

AI can help in many ways:

- Decarbonizing the process of making things
  - Enabling recycling/circular feedstock
- Decarbonizing supply chains
  - Optimizing manufacturing schedules
- Implementing dematerialization strategies
  - Designing stronger/lighter materials
- Decarbonizing maintenance of equipment
  - Forecasting process conditions

Important barriers and risks include:

- Lack of manufacturer incentive to decarbonize
- Additional safety risk of adopting AI-based workflows

Chapter 6: MATERIALS INNOVATION

- High-performance materials are essential for decarbonization
- Historically, new materials were discovered by accident or exhaustive, expensive experiments (e.g. Edison's light bulb)
- In recent decades, it has become possible to computationally predict whether new materials will have useful properties - but it is slow
- AI can dramatically accelerate this capability

The incredible durability of Roman concrete is why the Pantheon has stood for almost two millennia.

Chapter 6: **MATERIALS INNOVATION**

- AI can be used to
  - screen millions of possible materials for important properties,
  - dramatically accelerate materials experiments, synthesize published research, and
  - generate new materials concepts

- To accelerate the use of AI for materials innovation, we need
  - better harmonization of materials databases,
  - semi-automated high-throughput materials testing facilities, and
  - more focus on embedded (manufacturing) emissions and life-cycle assessment.

Chapter 7: **FOOD SYSTEMS**

- Food systems account for over 30% of human-caused global greenhouse gas emissions.
- Climate change impacts including droughts, floods, heat waves and the spread of pests threaten food systems.
- AI can contribute to more sustainable food systems in many ways, including:
  - integrating data from soil sensors and satellites to create fertilizer management plans that minimize NOx emissions while maximizing crop yields, and
  - creating virtual farms that simulate different crops, weather conditions and soil properties to help optimize agriculture practices.

Chapter 8: ROAD TRANSPORT

- 18% of global energy-related CO_2 emissions.

- AI has significant potential to help reduce CO_2 emissions by accelerating innovation in:
  - batteries
  - sustainable biofuels
  - intelligent transportation systems, and
  - shifts towards modes of transportation that emit less carbon.

- Barriers include a lack of data, the lack of uniform standards for data and a shortage of personnel with AI training.

- Risks include bias, invasions of privacy and increases in greenhouse gas emissions caused by the deployment of autonomous vehicles.

Part III: CROSS-CUTTING ISSUES

Chapter 9: BARRIERS

Five groups of barriers impede the use of AI for climate change mitigation:

- data
- people
- computation
- cost
- institutions

Chapter 10: **RISKS**

Risks from AI can include:

- bias,
- invasions of privacy,
- security threats,
- safety issues, and
- increased greenhouse emissions.

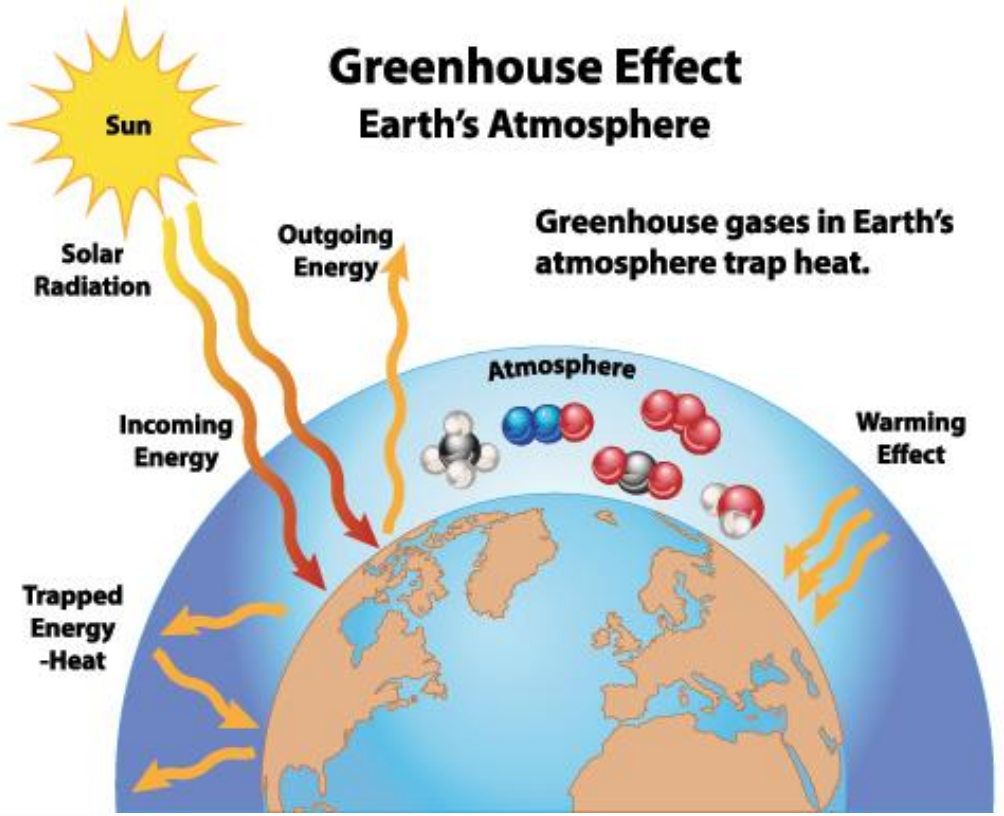
These risks exist when using AI for climate change mitigation.

Chapter 10D: GREENHOUSE GAS EMISSIONS FROM COMPUTING OPERATIONS FOR AI

- Currently modest—less than 1% of the global total and likely much less than 1% of the global total.

- Future GHG emissions are very uncertain—could be even more modest or could be substantial. Depends on:
  - processes used to manufacture AI equipment
  - energy efficiency of AI equipment
  - optimization techniques in AI models
  - use of zero carbon electricity in AI operations, and
  - demand for AI applications.

- Much better data collection and assessment methodologies are needed



Chapter 11: **POLICY**

Government policies with respect to AI are evolving rapidly, addressing topics including bias, privacy, security, safety and job displacement.

Very few policies that specifically address the use of AI for climate.

We explore two broad categories:

- *policies that promote* the use of AI for climate change mitigation, and
- *policies that manage risks* related to the use of AI for climate change mitigation

Chapter 11: **POLICY**

Governments could promote the use of AI for climate change mitigation with that include:

- launching AI skills development programs
- funding the collection of climate-related data
- encouraging or requiring the standardization of climate-related data
- creating AI offices within government ministries and
- using international institutions such as the Clean Energy Ministerial and World Meteorological Organization as platforms for international cooperation on AI for climate change mitigation

Chapter 11: **POLICY**

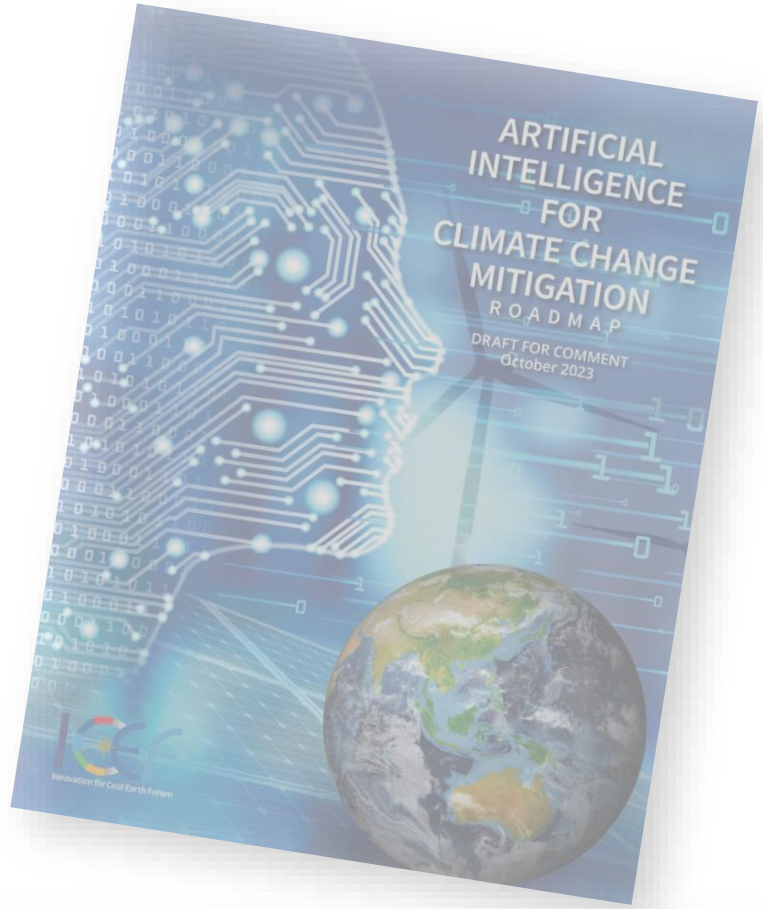
Governments could help manage risks related to the use of AI for climate change mitigation with policies that include:

- standards requiring diverse and representative data sets for AI models.
- legal frameworks that hold entities accountable for biased outcomes from AI applications,
- independent oversight boards responsible for monitoring privacy protections,
- R&D on energy-efficient AI algorithms and hardware, and
- tax incentives and other policies promoting low-carbon data centers.

Chapter 12: **FINDINGS AND RECOMMENDATIONS**

FINDINGS

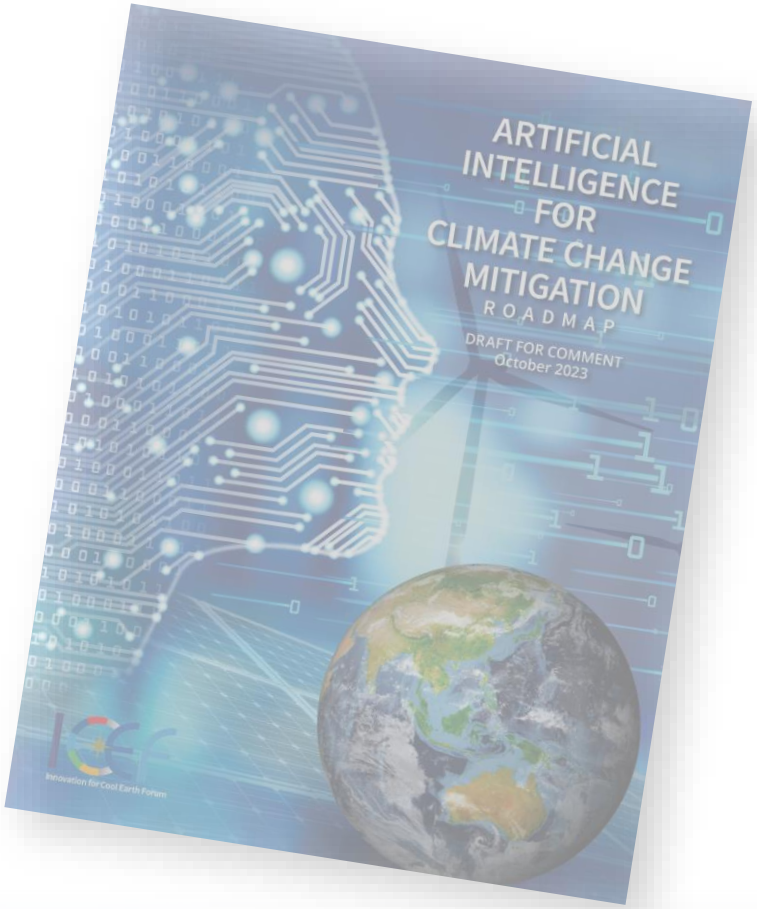
1. Artificial intelligence is currently contributing to climate change mitigation and has the potential to make significant additional contributions in the years ahead.
2. Artificial intelligence is not a panacea when it comes to climate change.
3. The lack of trained personnel and lack of high-quality data are critical barriers to the use of AI for climate mitigation.
4. Significant resources will be required for artificial intelligence to reach its potential in helping mitigate climate change.



Chapter 12: **FINDINGS AND RECOMMENDATIONS**

FINDINGS

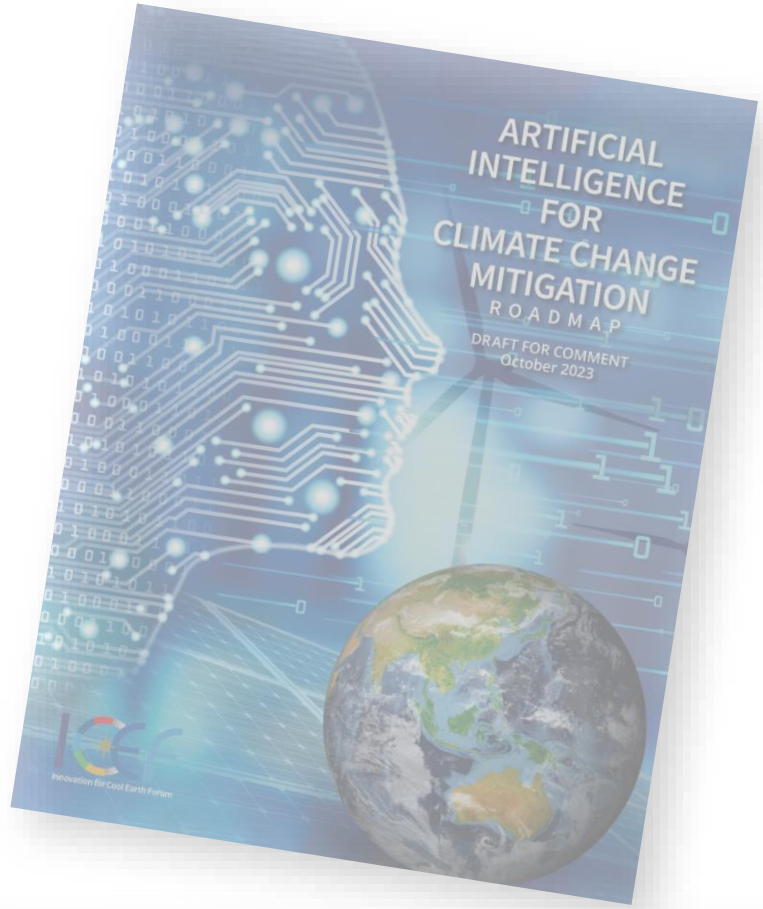
5. Risks of using AI include bias, invasions of privacy and security issues. These risks exist when using AI for climate mitigation.
6. Greenhouse gas emissions from computing infrastructure for AI are currently modest – significantly less than 1% of the global total.
7. The amount of future greenhouse gas emissions from AI computing infrastructure is highly uncertain.



Chapter 12: **FINDINGS AND RECOMMENDATIONS**

RECOMMENDATIONS

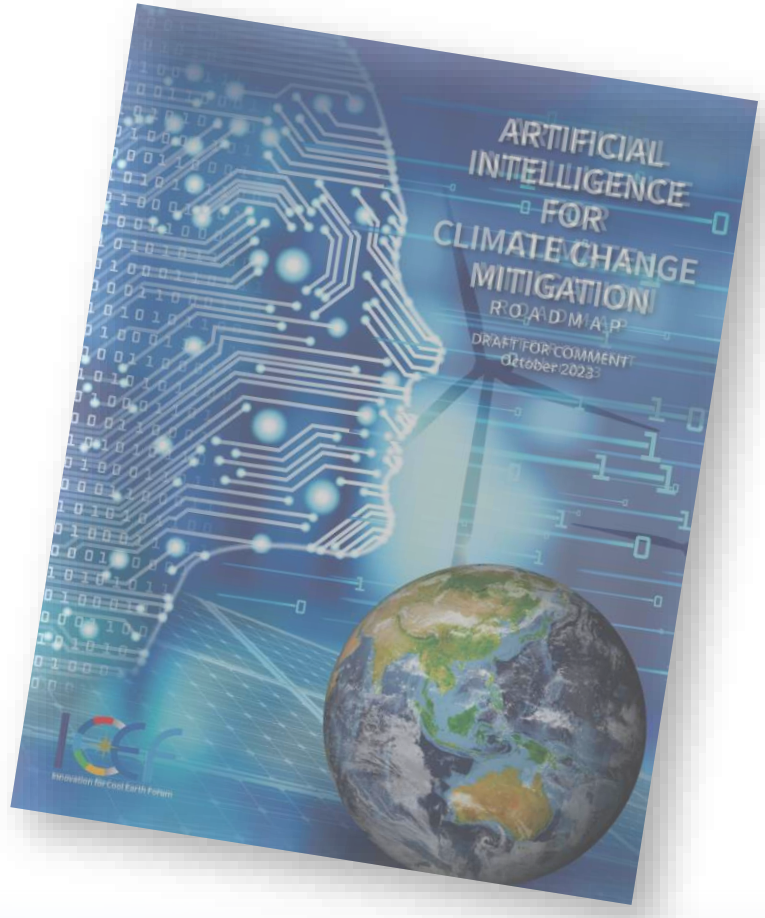
1. AI tools should be integrated into many aspects of climate change mitigation.
2. AI skills-development should be a priority in all institutions with a role in climate mitigation.
   - Educational institutions at all levels should offer courses relevant to AI.
   - Government agencies, businesses and civil society should regularly review the capabilities of their staffs with respect to AI.
3. Governments should assist in the development and standardization of data for AI applications that mitigate climate change.
4. All government agencies with responsibility for climate change should create an AI Office.

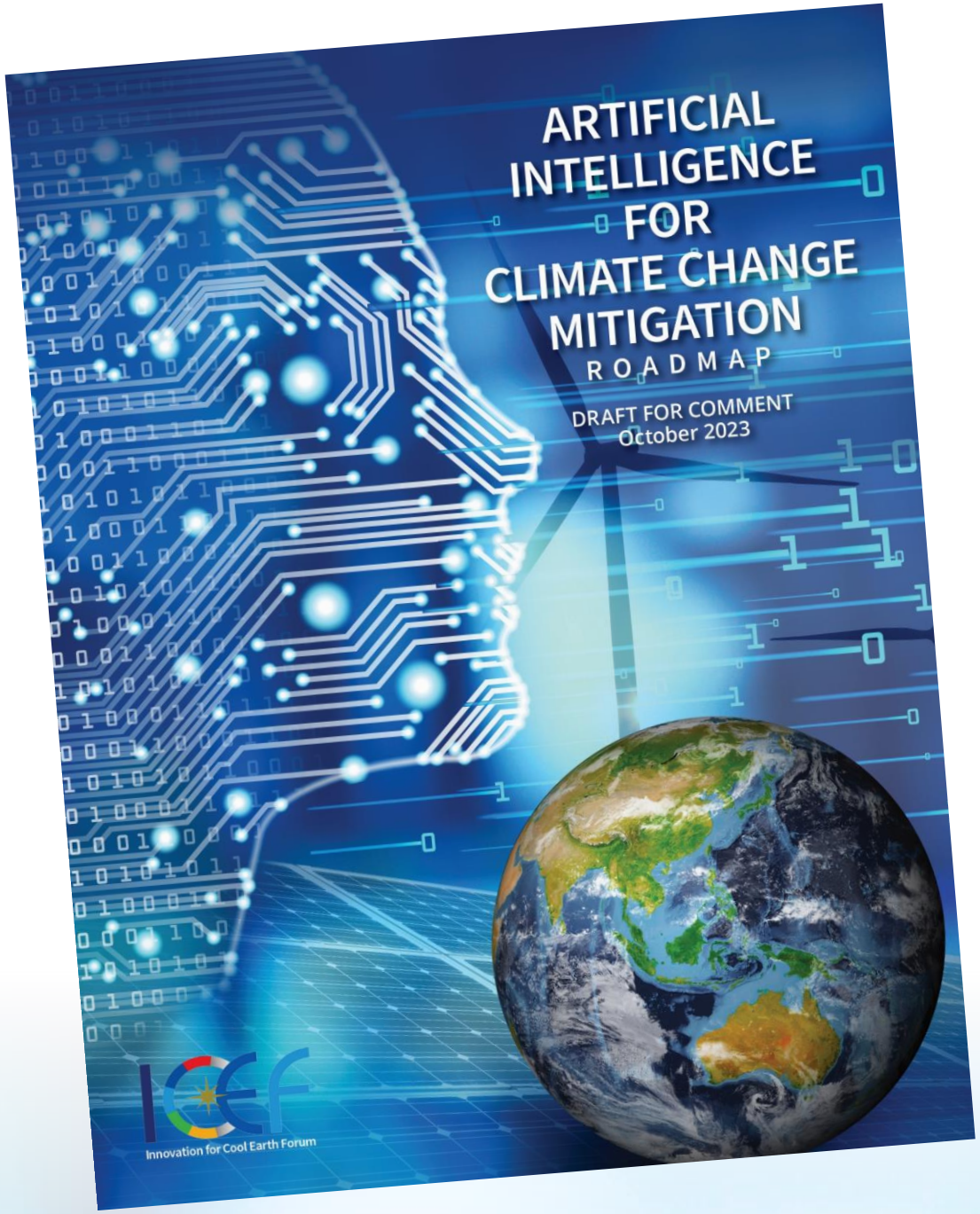


Chapter 12: **FINDINGS AND RECOMMENDATIONS**

RECOMMENDATIONS

5. Electric utilities should be incentivized to deploy artificial intelligence, with regulated returns for investments in AI and other tools.
6. Governments should launch international platforms to support cooperative work on AI for climate change mitigation.
7. Governments should work to minimize greenhouse gas emissions from AI's computing infrastructure.
8. Avoiding unfair bias should be a core, high-priority principle guiding the development of all AI tools for climate change mitigation.





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Innovation for Cool Earth Forum

This roadmap was prepared to facilitate dialogue at the Tenth Innovation for Cool Earth Forum (October 2023), for final release at COP28 in December 2023. We are deeply grateful to the Ministry of Economy, Trade and Industry (METI) and New Energy and Industrial Technology Development Organization (NEDO), Japan, for launching and supporting the ICEF Innovation Roadmap Project of which this is a part.

Ruben Glatt contributed to the technical evaluations in this document.
The policy recommendations were prepared by other contributors.

INNOVATION ROADMAP PROJECT

HOESUNG LEE—former Chair, IPCC: "The ICEF roadmaps provide important research on a wide range of technologies for helping achieve net zero emissions. They are an important resource for anyone working on these issues."

VACLAV SMIL—energy historian: The ICEF roadmaps "provide essential information on different aspects of our energy systems and how they might change over time. I recommend them for anyone interested in this challenging topic."

ALISSA PARK—Dean, UCLA School of Engineering: "The ICEF roadmaps...are an excellent resource for researchers and practitioners who cross disciplinary boundaries to develop transformative solutions for climate change."

www.icef.go.jp/roadmap