Tackling Climate Change with Machine Learning

Priya L. Donti
Carnegie Mellon University
Climate Change AI

Nov 17, 2021 @ IAPA "Festival of Analytics Goodness"

Climate change

Increasingly severe effects

- Storms, droughts, fires, flooding, extreme heat, etc.
- Uneven impacts

Feedbacks (e.g. albedo, permafrost)

Need net-zero greenhouse gas emissions by 2050 (UN Intergovernmental Panel on Climate Change)

- But emissions still increasing each year




What it means to tackle climate change

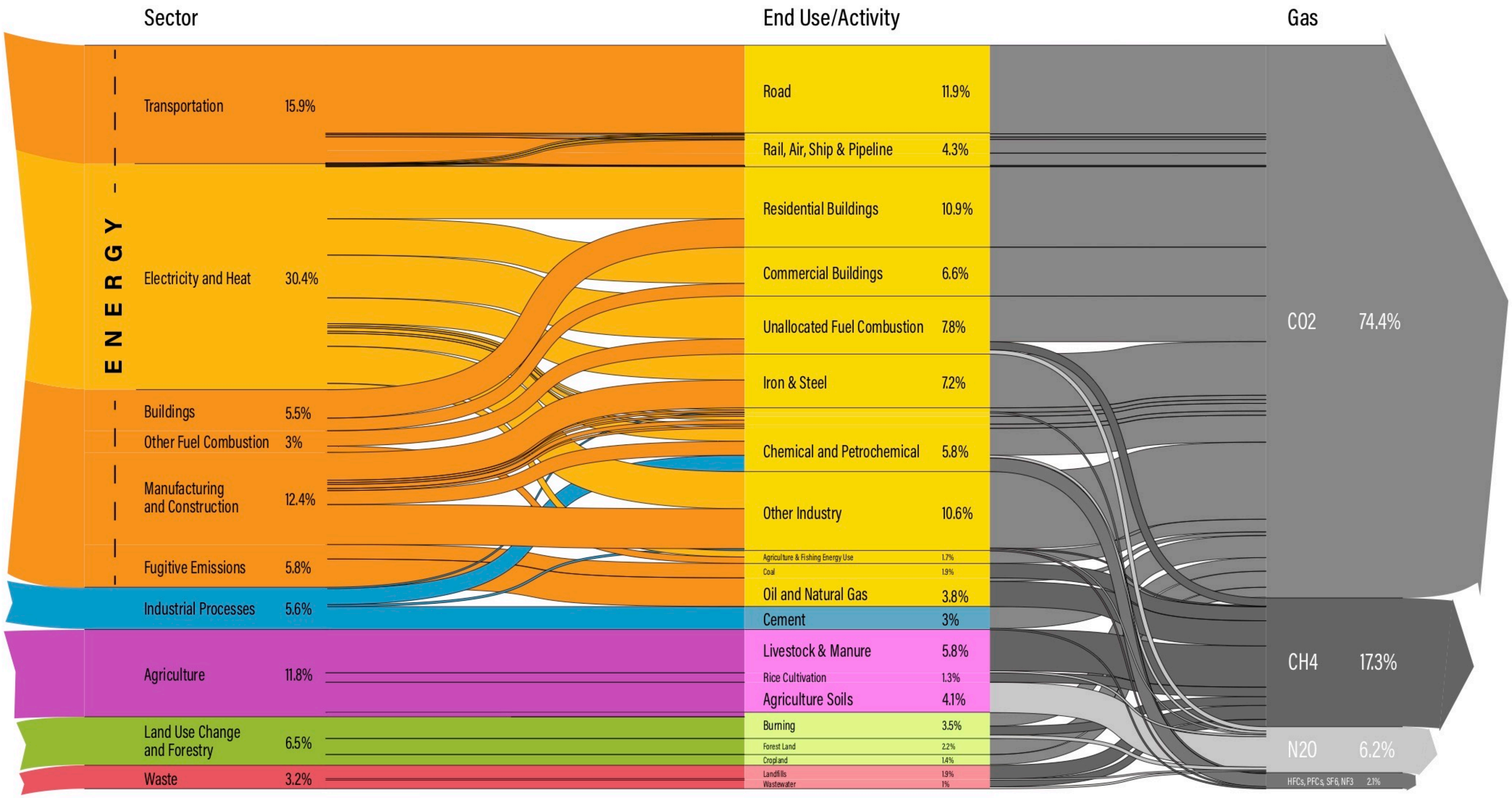
Climate change is not an on/off switch

Mitigation: Reducing greenhouse gas emissions

Adaptation: Resilience to consequences of climate change

World Greenhouse Gas Emissions in 2016

Total: 49.4 $GtCO_2e$

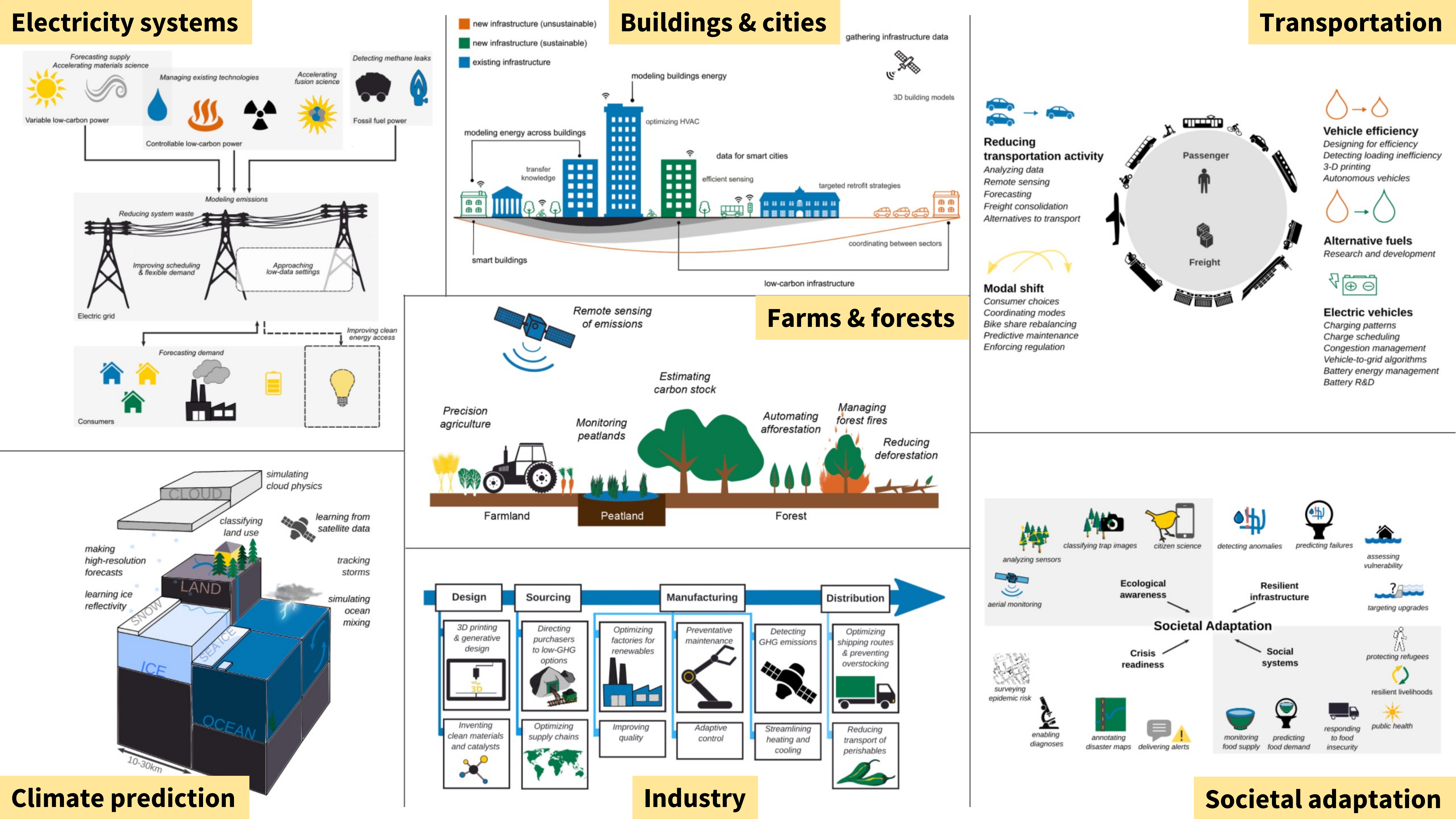


Source: https://www.wri.org/resources/data-visualizations/world-greenhouse-gas-emissions-2016

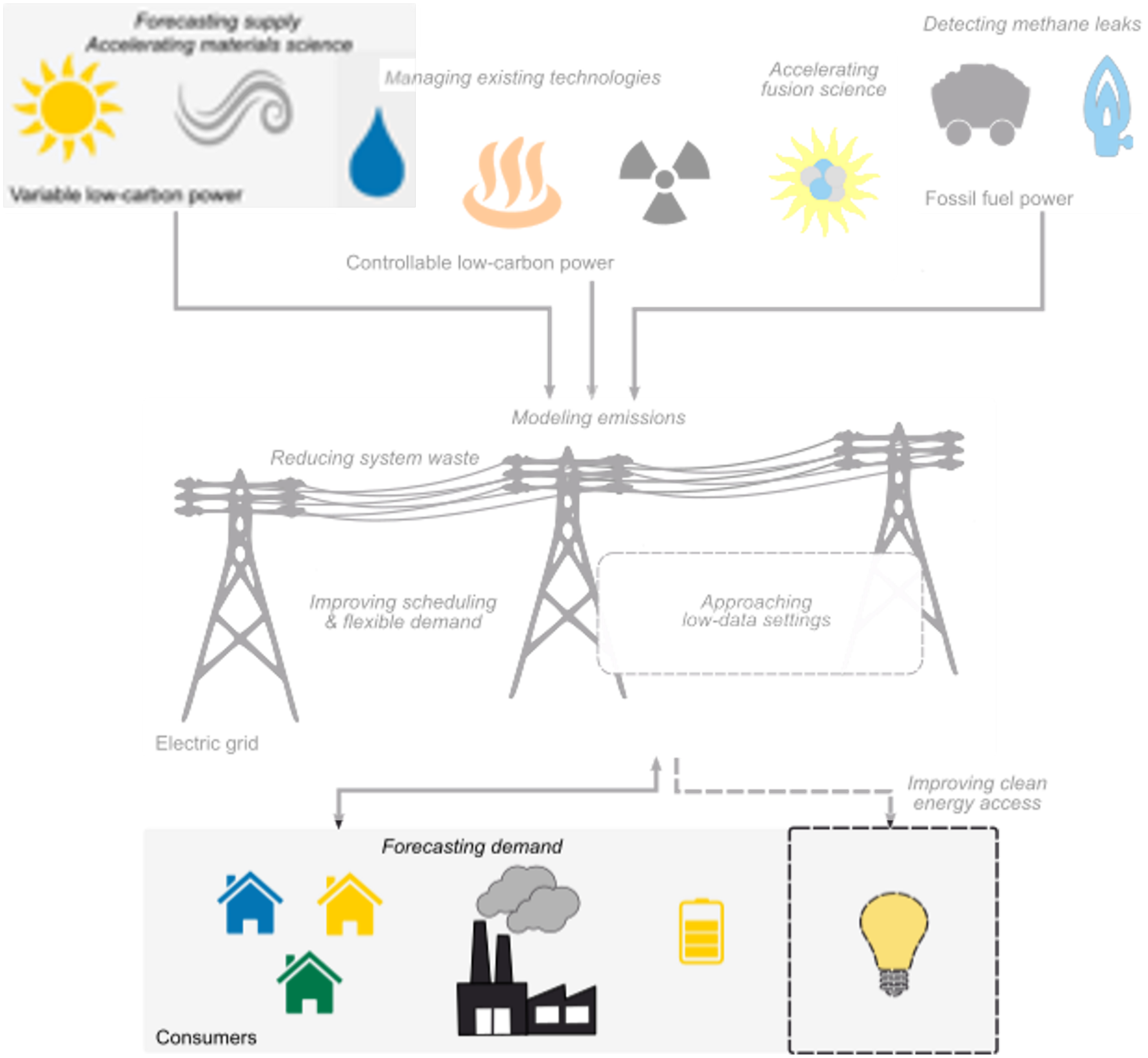
Tackling Climate Change with Machine Learning

David Rolnick[1*], Priya L. Donti[2], Lynn H. Kaack[3], Kelly Kochanski[4], Alexandre Lacoste[5], Kris Sankaran[6,7], Andrew Slavin Ross[8], Nikola Milojevic-Dupont[9,10], Natasha Jaques[11], Anna Waldman-Brown[11], Alexandra Luccioni[6,7], Tegan Maharaj[6,7], Evan D. Sherwin[2], S. Karthik Mukkavilli[6,7], Konrad P. Kording[1], Carla Gomes[12], Andrew Y. Ng[13], Demis Hassabis[14], John C. Platt[15], Felix Creutzig[9,10], Jennifer Chayes[16], Yoshua Bengio[6,7]

[1]University of Pennsylvania, [2]Carnegie Mellon University, [3]ETH Zürich, [4]University of Colorado Boulder, [5]Element AI, [6]Mila, [7]Université de Montréal, [8]Harvard University, [9]Mercator Research Institute on Global Commons and Climate Change, [10]Technische Universität Berlin, [11]Massachusetts Institute of Technology, [12]Cornell University, [13]Stanford University, [14]DeepMind, [15]Google AI, [16]Microsoft Research


Electricity systems
Forecasting supply
Accelerating materials science
Variable low-carbon power
Managing existing technologies
Accelerating fusion science
Controllable low-carbon power
Detecting methane leaks
Fossil fuel power
Modeling emissions
Reducing system waste
Improving scheduling & flexible demand
Approaching low-data settings
Electric grid
Improving clean energy access
Forecasting demand
Consumers
Buildings & cities
new infrastructure (unsustainable)
new infrastructure (sustainable)
existing infrastructure
gathering infrastructure data
3D building models
modeling buildings energy
optimizing HVAC
modeling energy across buildings
transfer knowledge
data for smart cities
efficient sensing
targeted retrofit strategies
coordinating between sectors
smart buildings
low-carbon infrastructure
Transportation
Reducing transportation activity
Analyzing data
Remote sensing
Forecasting
Freight consolidation
Alternatives to transport
Passenger
Freight
Vehicle efficiency
Designing for efficiency
Detecting loading inefficiency
3-D printing
Autonomous vehicles
Alternative fuels
Research and development
Modal shift
Consumer choices
Coordinating modes
Bike share rebalancing
Predictive maintenance
Enforcing regulation
Electric vehicles
Charging patterns
Charge scheduling
Congestion management
Vehicle-to-grid algorithms
Battery energy management
Battery R&D
Remote sensing of emissions
Farms & forests
Estimating carbon stock
Precision agriculture
Monitoring peatlands
Automating afforestation
Managing forest fires
Reducing deforestation
Farmland
Peatland
Forest
simulating cloud physics
CLOUD
classifying land use
learning from satellite data
making high-resolution forecasts
tracking storms
learning ice reflectivity
simulating ocean mixing
LAND
SNOW
SEA ICE
ICE
OCEAN
10-30km
Climate prediction
Design
Sourcing
Manufacturing
Distribution
3D printing & generative design
Inventing clean materials and catalysts
Directing purchasers to low-GHG options
Optimizing supply chains
Optimizing factories for renewables
Improving quality
Preventative maintenance
Adaptive control
Detecting GHG emissions
Streamlining heating and cooling
Optimizing shipping routes & preventing overstocking
Reducing transport of perishables
Industry
analyzing sensors
classifying trap images
citizen science
detecting anomalies
predicting failures
assessing vulnerability
aerial monitoring
Ecological awareness
Resilient infrastructure
targeting upgrades
Societal Adaptation
Crisis readiness
Social systems
protecting refugees
surveying epidemic risk
resilient livelihoods
enabling diagnoses
annotating disaster maps
delivering alerts
monitoring food supply
predicting food demand
responding to food insecurity
public health
Societal adaptation

Electricity systems >> Forecasting supply and demand



Need: Scheduling and planning

ML: Short- and medium-term forecasts

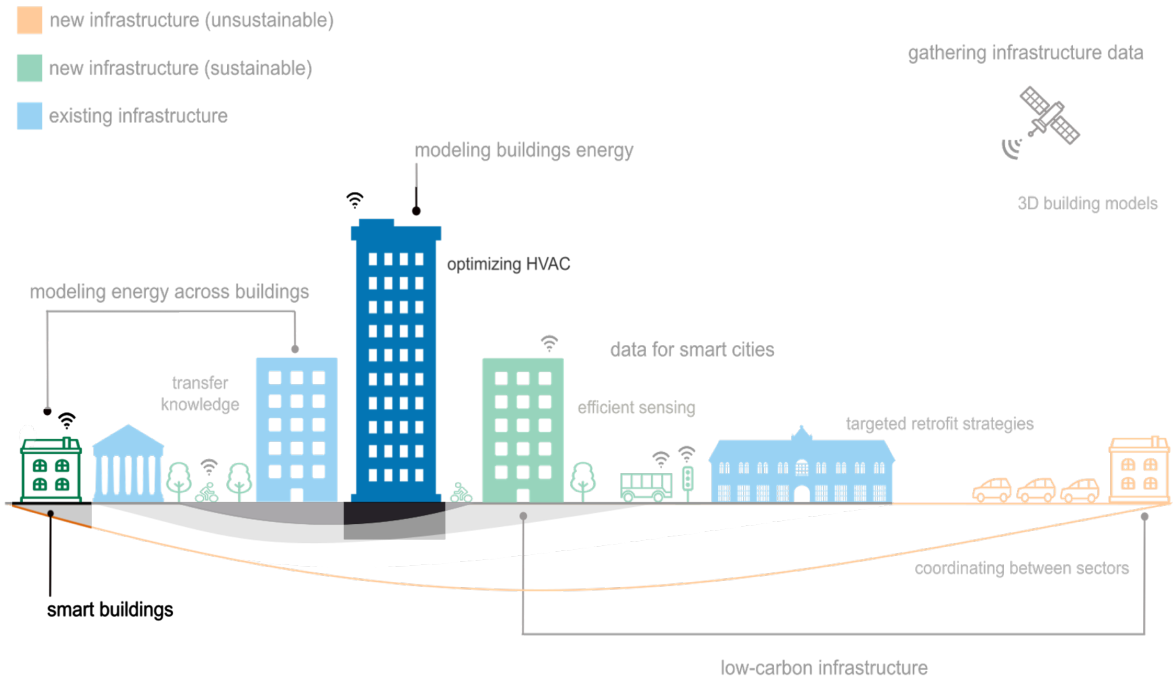
- Historical data, physical model outputs, image/video data

Stakeholders: System operators, power producers, demand aggregators, ...

Important considerations:

- Incorporate system physics & goals
- Characterize uncertainty
- Interpretable forecasts

Buildings and cities >> Building energy use optimization



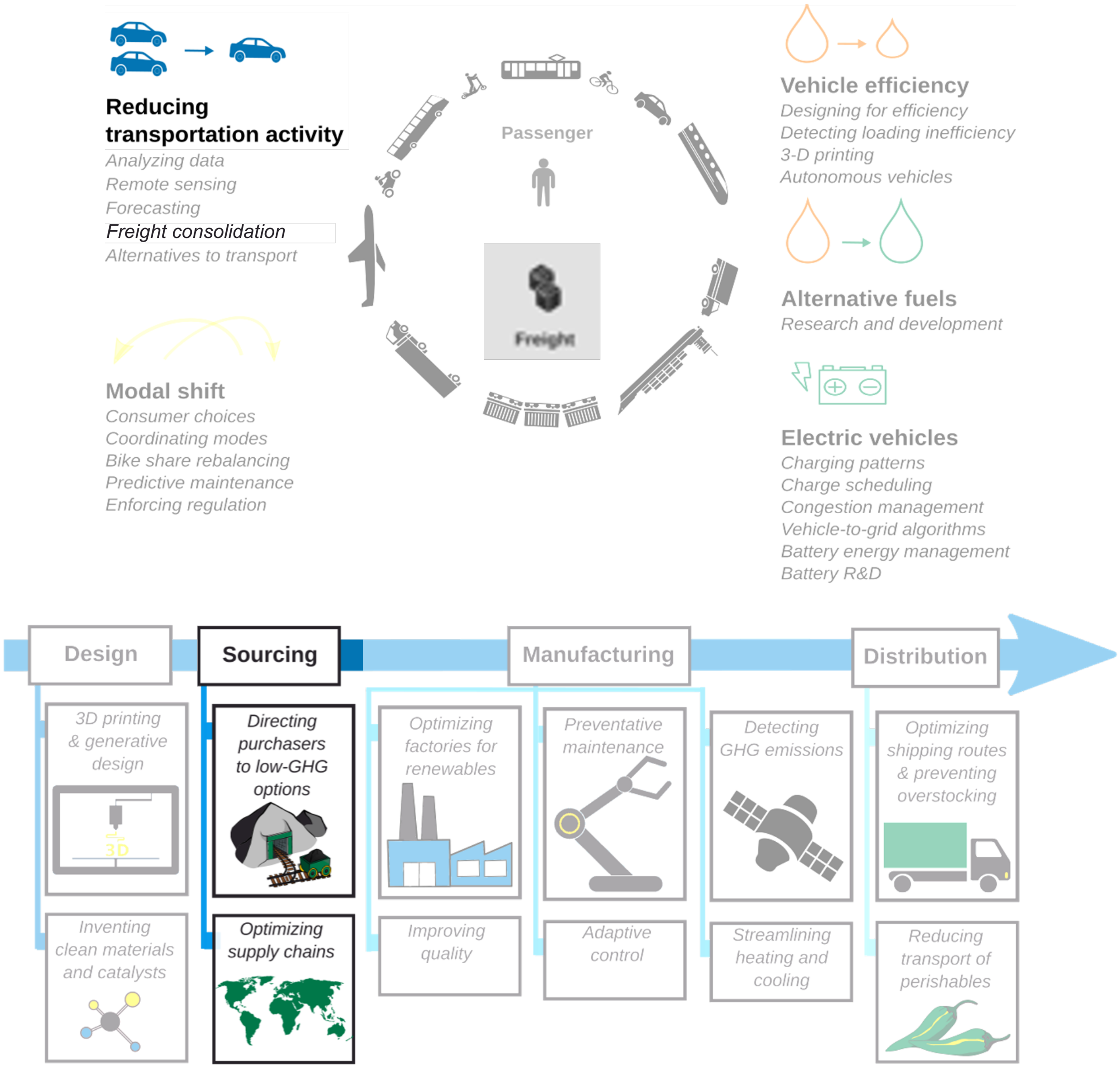
Need: Increased energy efficiency in both existing and new buildings

ML: Smart equipment control (coupled with base measures such as insulation)

- Heating and cooling (HVAC)
- Lighting
- Industrial equipment

Stakeholders: Building managers, city planners, equipment manufacturers, ...

Transportation/Industry >> Optimizing supply chains



Need: Decrease emissions associated with sourcing of goods

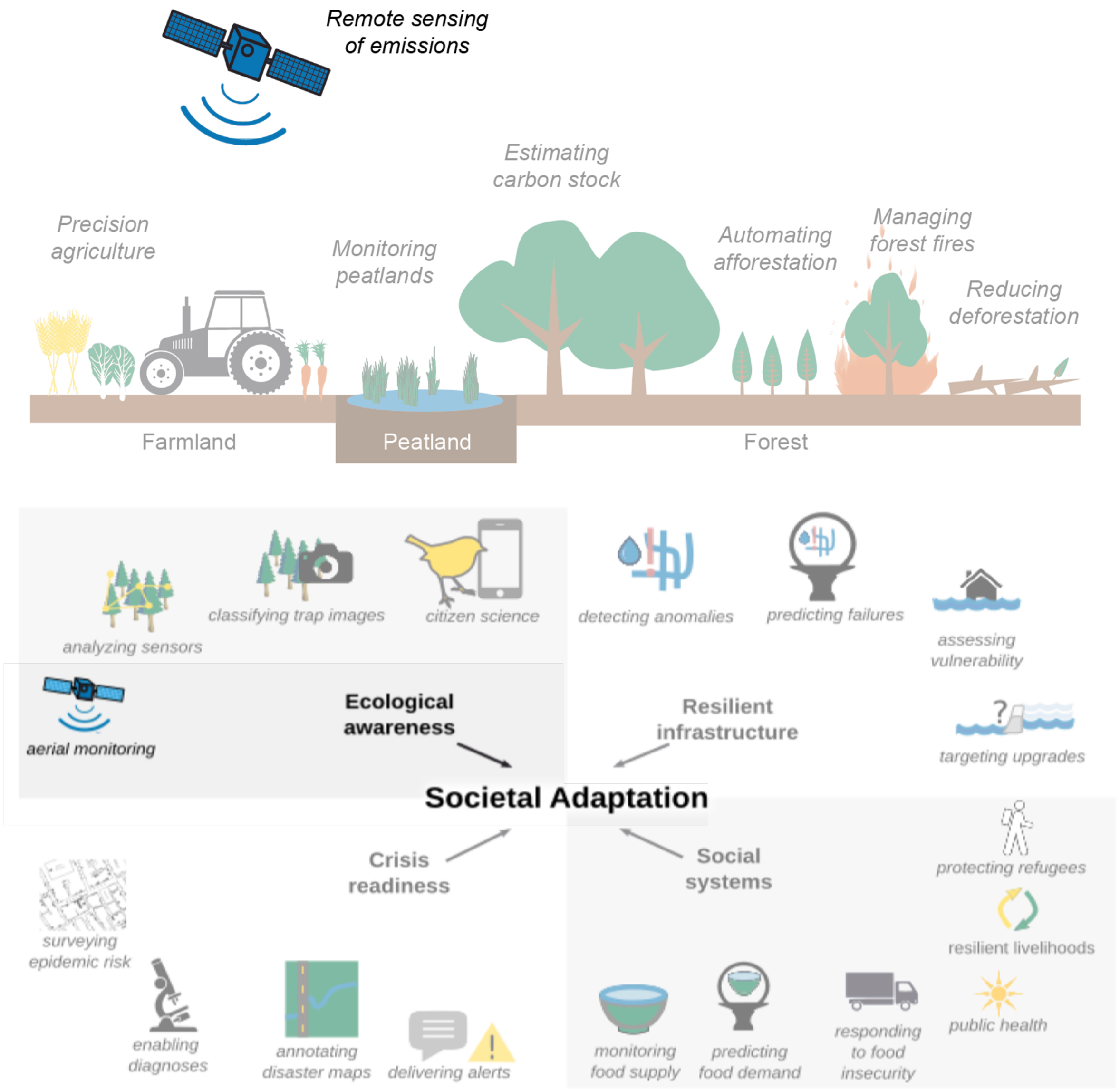
ML:

- Cluster suppliers (bundle shipments)
- Improve routing and auctions
- Predict demand (reduce overproduction)

Stakeholders: Logistics management companies, rail/freight companies, ...

Note: Beware the Jevons paradox

Farms and forests >> Gathering land use data



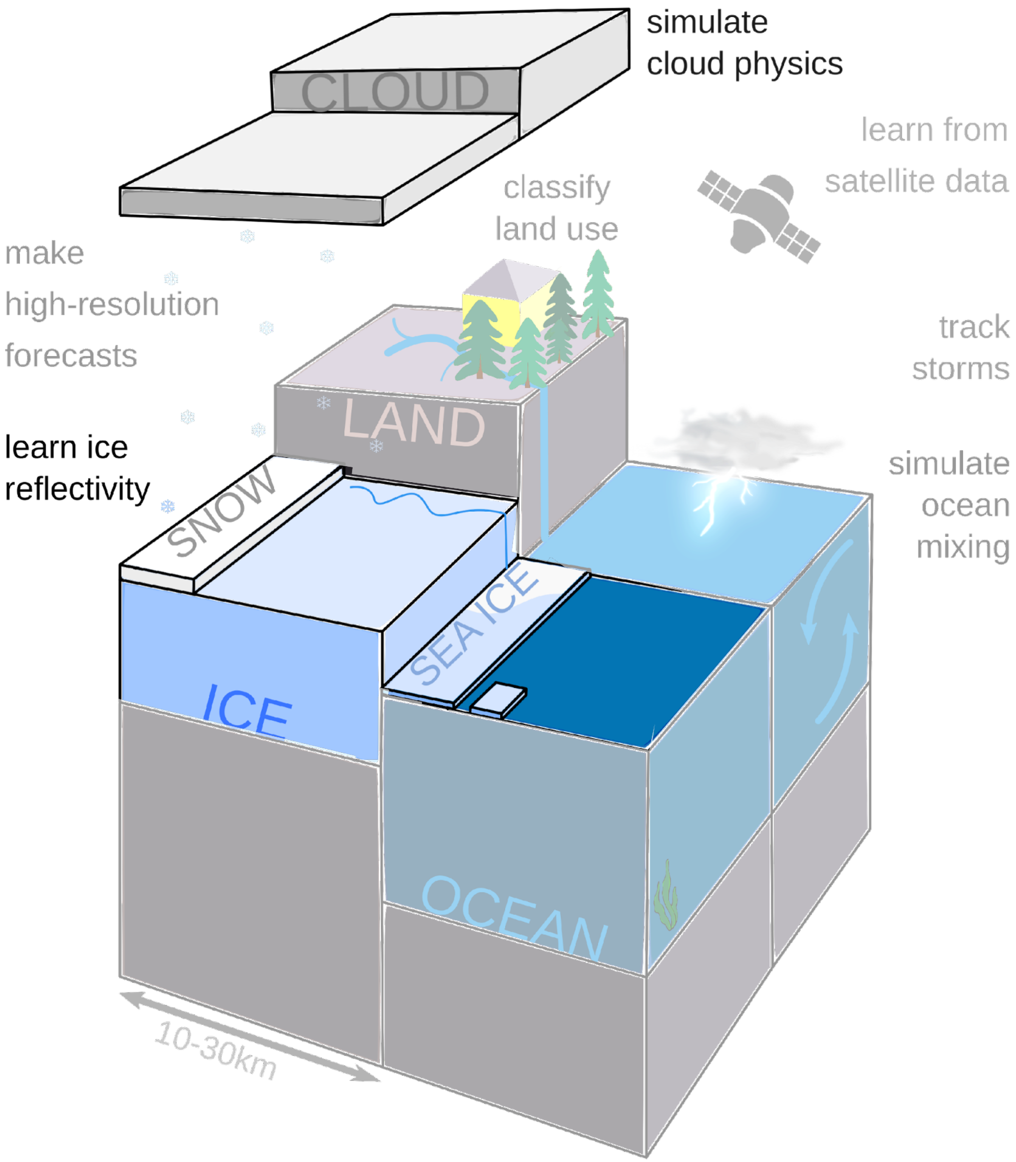
Need: Model emissions and land use for simulation, accounting, policy

ML: Remote sensing

- Data: Satellite, aerial, or drone imagery (color images, LiDAR, etc.)
- Object detection, semantic segmentation, spatio-temporal forecasting, super-resolution,...

Stakeholders: Farmers, NGOs, gov programs, agriculture startups, ...

Climate prediction >> Accelerating climate simulations



Need: Efficient, accurate climate simulations

ML: Improve portions of simulations

- Approximate cloud physics through reduced-form models
- Gather data about ice sheets and sea level rise from satellite imagery

Stakeholders: Climate scientists, local governments

Collective decisions >> Analyzing policies

Need: Evidence-based decision-making based on analysis of climate-relevant policies

ML: Natural language processing to classify, cluster, and otherwise analyze text corpora

Stakeholders: National and local governments

Table 5. Error analysis.

SENTENCE	LABEL	CONTAINS	BERT	STUDENT	EXPERT
It is envisaged that **emission** reduction will be achieved through the **mitigation** actions in the sectors.	MITIGATION	MITIGATION	MITIGATION	MITIGATION	MITIGATION
The Steering Committee is the supreme body for **decision making** and sectoral **implementation**.	STRATEGY	MITIGATION	STRATEGY	STRATEGY	STRATEGY
The **mitigation** actions that enhance **afforestation** are projected to result in the **sequestration** of 1 mtCO2e annually.	LAND USE	LAND USE	AGRICULTURE	MITIGATION	LAND USE
In the absence of project activity, **fossil fuels** could be burned in **power plants** that are connected to the grid.	STRATEGY	EQUITY	ENERGY	INDUSTRY	ENERGY
Due to the outbreak of the Ebola Virus the development gains made after a 10-year civil war were rudely reversed.	ENVIRONMENT	NO LABEL	MITIGATION	NO LABEL	NO LABEL

Source: Corringham et al., 2021

Recurring themes

Gathering information (GHG emissions, deforestation, infrastructure, crops)

Forecasting (renewable energy, transportation demand, extreme events)

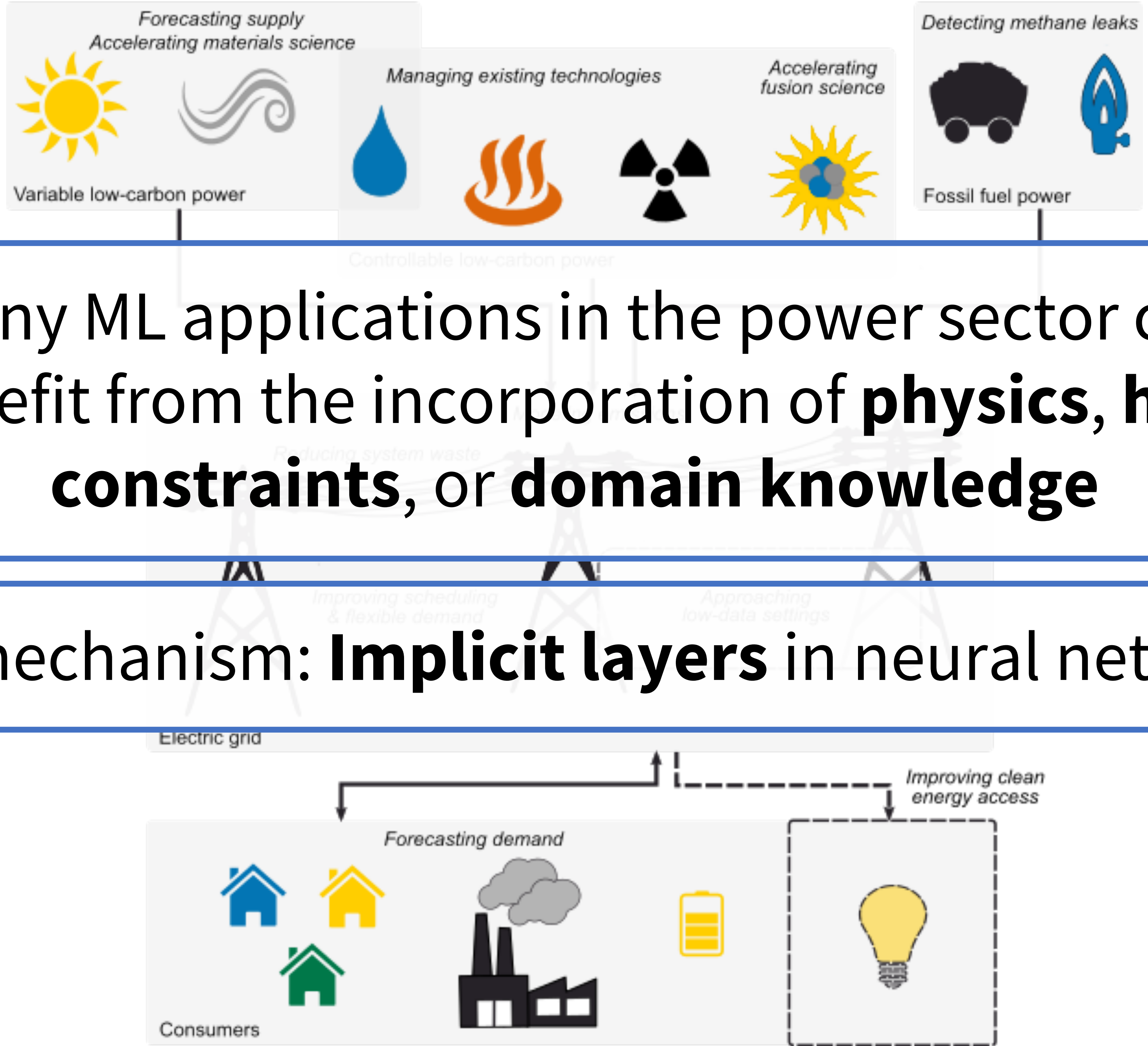
Improving operational efficiency (heating and cooling, freight, food waste)

Predictive maintenance (methane leaks, resilient infrastructure)

Accelerating scientific experimentation (batteries, electrofuels)

Approximating time-intensive simulations (climate, energy, city planning)

Quick Dive: Electric Power Systems



Many ML applications in the power sector can benefit from the incorporation of **physics**, **hard constraints**, or **domain knowledge**

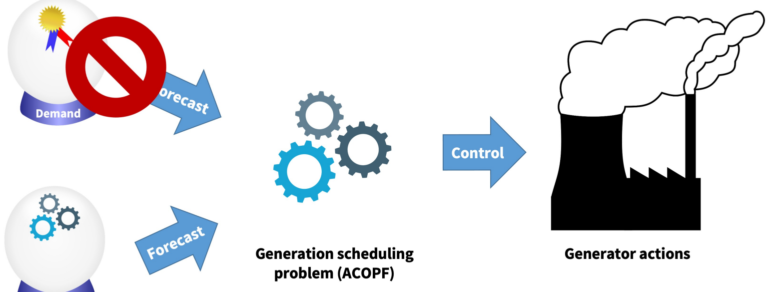
One mechanism: **Implicit layers** in neural networks

Paradigms for implicit layers in power systems

Enable **decision-driven models** (e.g., demand forecasting)

Provide **inductive biases** (e.g., inverse optimal power flow)

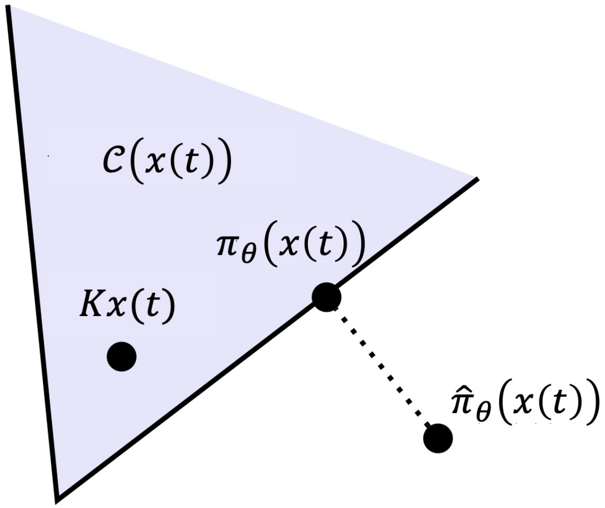
Enforce hard constraints (e.g., robust control via DL; approximating ACOPF)

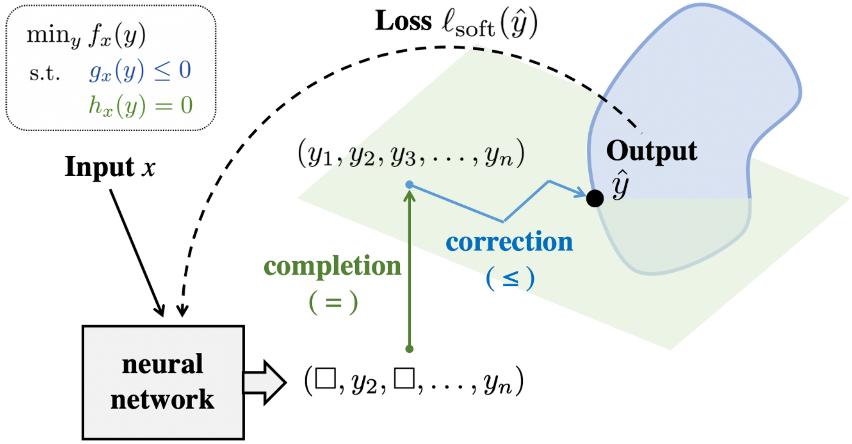


Inverse optimal power flow

$$\underset{\hat{c},\hat{Y}}{\text{minimize}} \quad \ell\left((p_g,\lambda),(\hat{p}_g,\hat{\lambda})\right)$$

$$\text{subject to} \quad \hat{p}_g,\hat{\lambda} = \mathbf{ACOPF}(\hat{c},\hat{Y},p_d)$$





Important Considerations

Machine learning: Strengths & limitations

Machine learning (ML): Group of techniques that automatically extract patterns from (large amounts of) data

STRENGTHS

- **Scaling human insight** by analyzing patterns in large amounts of data
- **Optimizing complex systems**
- **Generating “new” (derived) data** from other sources of data
- **Integrating with other methods**, e.g. domain and physical models

LIMITATIONS

- **“Garbage in, garbage out”**
  - Does not work on bad or overly limited data
- **Inherits biases in data/design/use**
  - Not “objective”
- **Assumes patterns are persistent**
  - Difficulty with e.g. long-term forecasts
- Finds **correlation, not causation**

Machine learning is not a silver bullet

- Not applicable everywhere
- Where applicable, only one part of the strategy
  - E.g. insulation more important than smart buildings!
- Impactful applications are often not flashy
- Work needs to be driven by end users

Important considerations for deployment

- Sometimes simple methods work
- Rebound effects: Efficiency does not always translate to climate impact
- Equity in scoping, deployment, and access
- Partnerships are key: researchers, implementing industries, end users, policymakers, other affected parties

ML's multi-faceted impact on climate change

ML applications in mitigation & adaptation

ML applications that increase emissions

ML applications w/ uncertain or systemic impacts

Energy use of ML itself

What you can do

General

- Check out Climate Change AI resources & community: www.climatechange.ai
  - Virtual happy hour (fortnightly) and Circle discussion platform
  - Newsletter, tutorials, Wiki, talk recordings
  - Workshops and webinars

Students

- Contact potential mentors & collaborators in the space
- Take classes in multiple disciplines

Professionals

- Join community meetings
- Leverage your network
- Engage with technology-policy interface

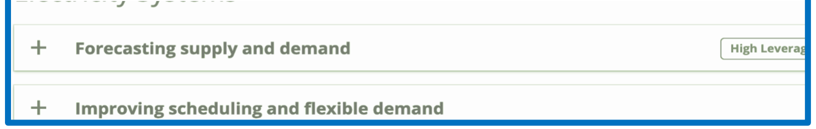
Climate Change AI

Catalyzing impactful work at the intersection of climate change and AI

Digital resources

Foundational report on climate change and AI

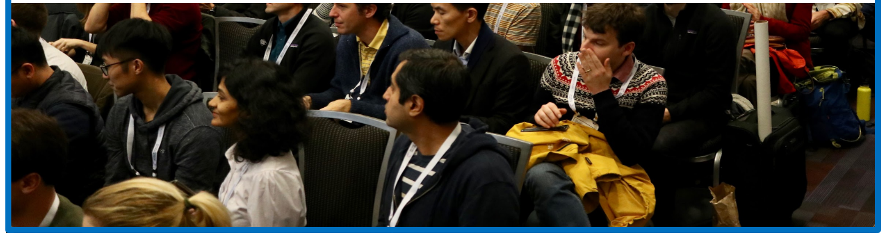
Resource Wiki w/ datasets and additional resources



Conferences and events

Next workshop (virtual) @ NeurIPS

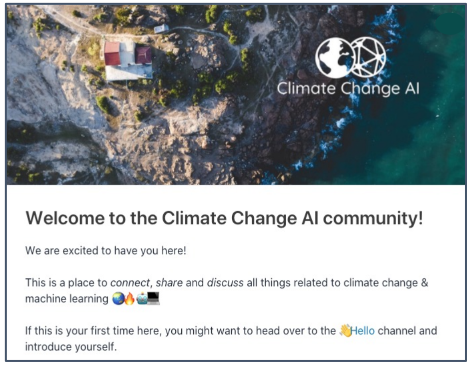
- Attend: Dec 14



Funding programs

Global research funding for impactful projects

Newsletter and community



Calls for Submissions

Funding

Projects & Courses

Readings

Jobs

Webinars and happy hours

Next webinar: Nov 19

Machine learning for carbon capture and sequestration

Next happy hour: Nov 17

Learn more:

www.climatechange.ai

@ClimateChangeAI