Introduction and class policies

Purdue ME 597, Distributed Energy Resources

Kevin J. Kircher

Outline

What are DERs?

Why study DERs?

Class outline

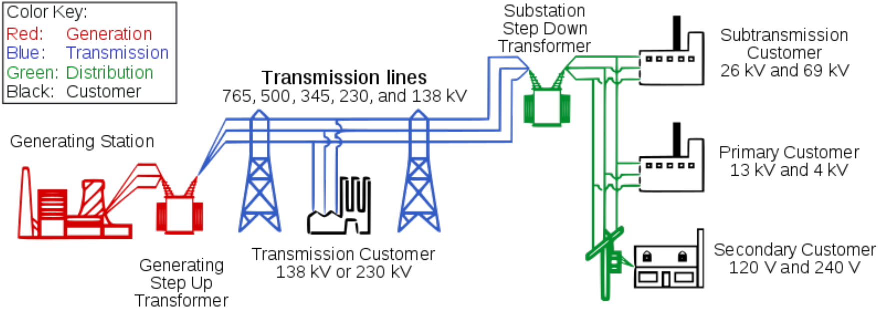
Class policies

What are Distributed Energy Resources (DERs)?

controllable electrical devices that plug in at the edge of the grid

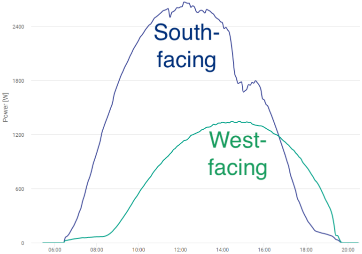
DOE Loan Programs Office: Posters

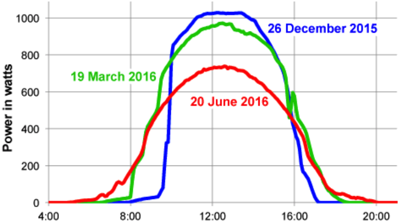
The power grid

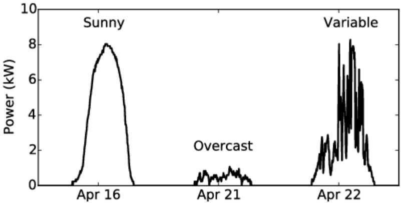


Wikipedia: Electrical grid

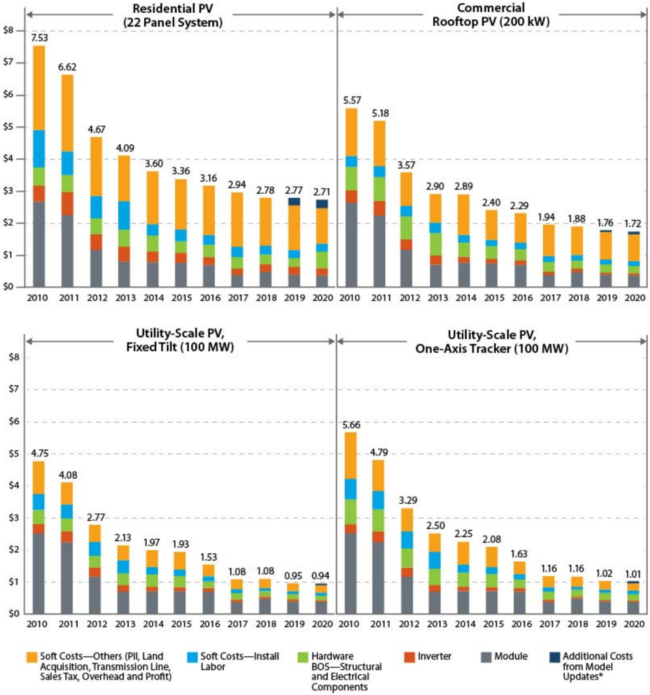
Solar photovoltaics





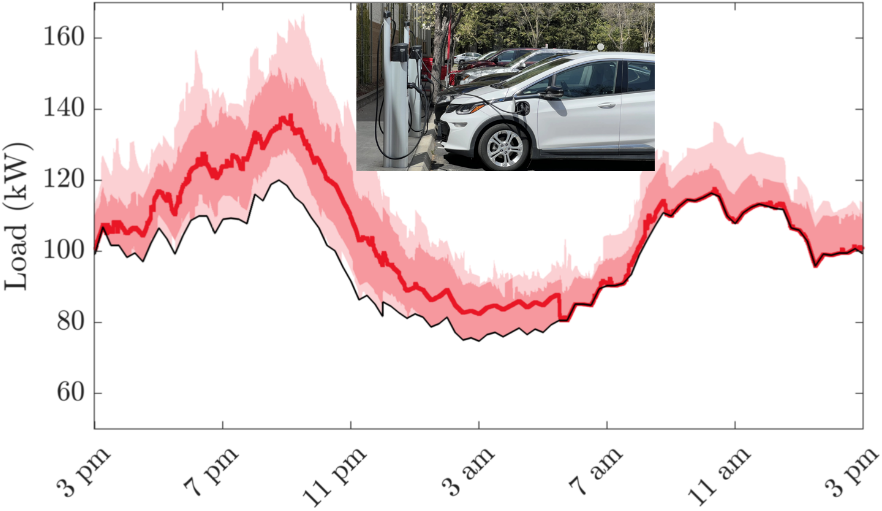


Getty Images; Solar Talk: Solar panel direction; Dan's Diary: A Year of Solar Data; Lee et al. (2017): *Distributed Rate Control for Smart Solar Arrays*


Residential PV
(22 Panel System)
Commercial
Rooftop PV (200 kW)
Utility-Scale PV,
Fixed Tilt (100 MW)
Utility-Scale PV,
One-Axis Tracker (100 MW)
$0
$1
$2
$3
$4
$5
$6
$7
$8
7.53
6.62
4.67
4.09
3.60
3.36
3.16
2.94
2.78
2.77
2.71
5.57
5.18
3.57
2.90
2.89
2.40
2.29
1.94
1.88
1.76
1.72
4.75
4.08
2.77
2.13
1.97
1.93
1.53
1.08
1.08
0.95
0.94
5.66
4.79
3.29
2.50
2.25
2.08
1.63
1.16
1.16
1.02
1.01
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Soft Costs—Others (PII, Land Acquisition, Transmission Line, Sales Tax, Overhead and Profit)
Soft Costs—Install Labor
Hardware BOS—Structural and Electrical Components
Inverter
Module
Additional Costs from Model Updates*

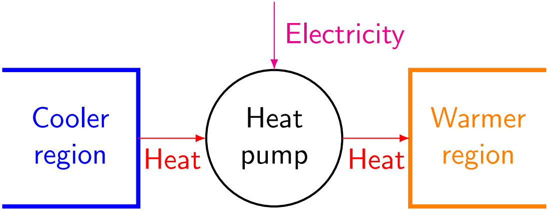
Getty Images; BloombergNEF: Lithium-ion battery prices

Electric vehicles



Alexeenko et al. (2023): *Achieving reliable coordination of residential plug-in electric vehicle charging*; Pew Research Center: How Americans view EVs

Heat pumps and air conditioners



Elephant Energy: Guide to Cold Climate Heat Pumps; ACHR News: NYC's 'Clean Heat For All Challenge'

Thermal storage and water heaters

Green Energy Times: Electric Thermal Storage; MA Clean Energy Center: Heat pump water heaters

Outline

What are DERs?

Why study DERs?

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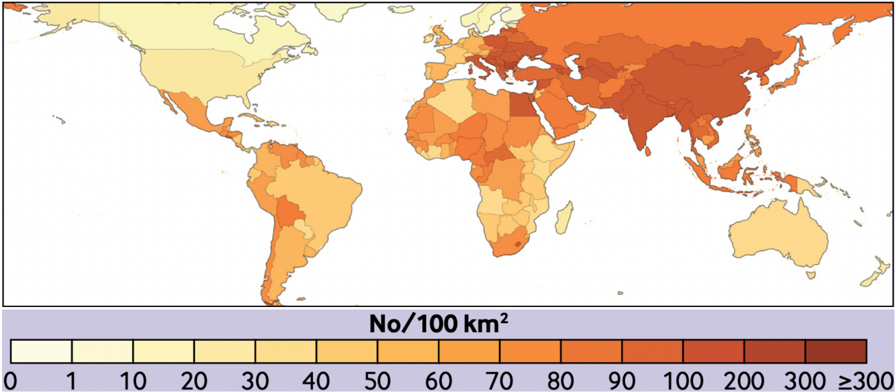
Why study DERs?

- fossil energy systems worsen
  - public health (fossil air pollution: 7–10% of deaths globally)
  - affordability (residential electricity prices: up ~25% since 2020)
  - climate change (75–80% of climate pollution)
- DERs will feature prominently in energy transitions
- DER adoption is already taking off
- good design and control can make DERs much more valuable
  - improve user experiences
  - deepen emission reductions
  - reduce installation and operating costs
  - unlock participation in (& revenue from) power grid operations

Fossil air pollution: 4–6 million avoidable deaths per year

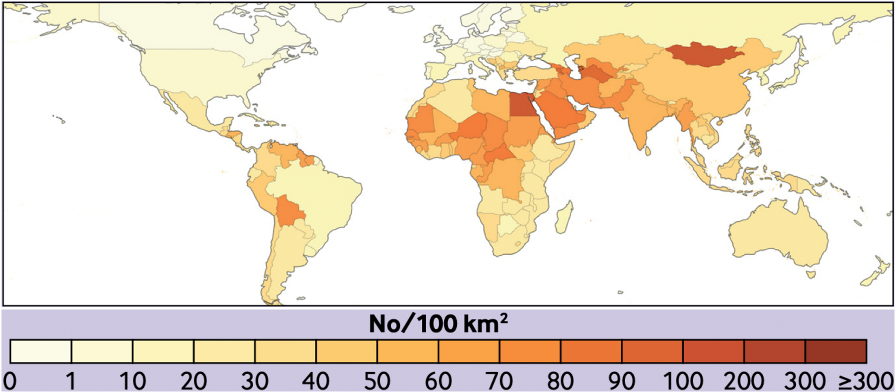
annual deaths from fine particulate and ozone per 100,000 people



Lelieveld et al. (2023): Air pollution deaths attributable to fossil fuels: Observational and modelling study

Fossil air pollution: 4–6 million avoidable deaths per year

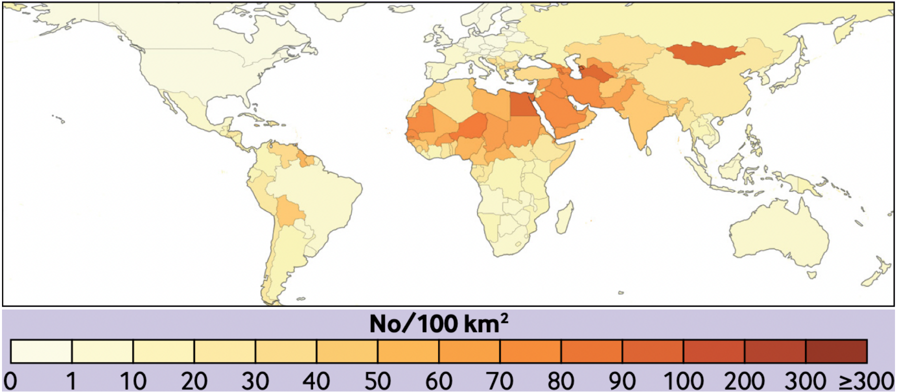
with fossil fine particulate and ozone removed



Lelieveld et al. (2023): Air pollution deaths attributable to fossil fuels: Observational and modelling study

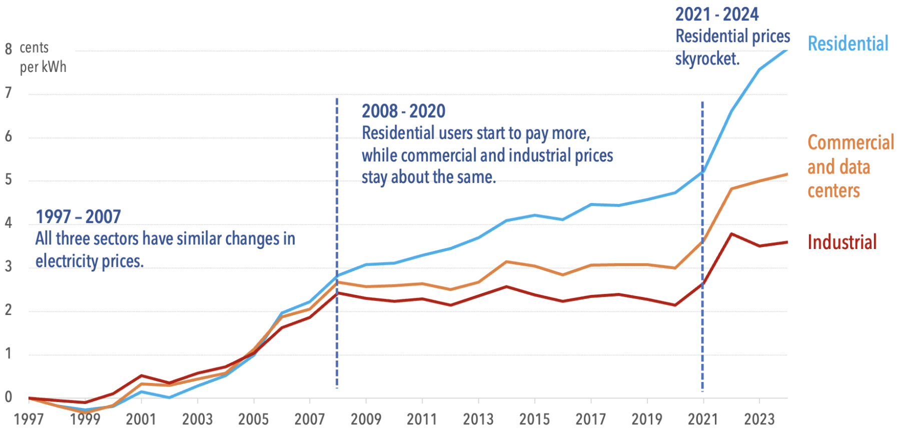
Fossil air pollution: 4–6 million avoidable deaths per year

with all human-caused fine particulate and ozone removed



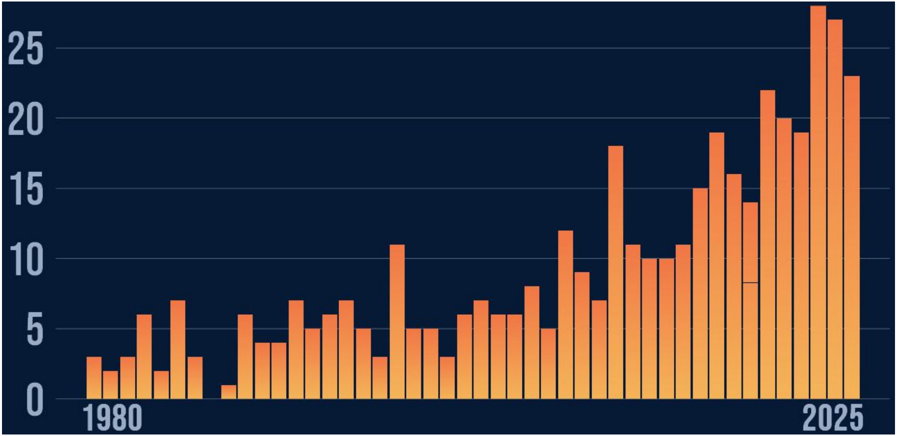
Lelieveld et al. (2023): Air pollution deaths attributable to fossil fuels: Observational and modelling study

Household electricity prices are rising



Karin Kirk (2026): Home electricity bills are skyrocketing. For data centers, not so much

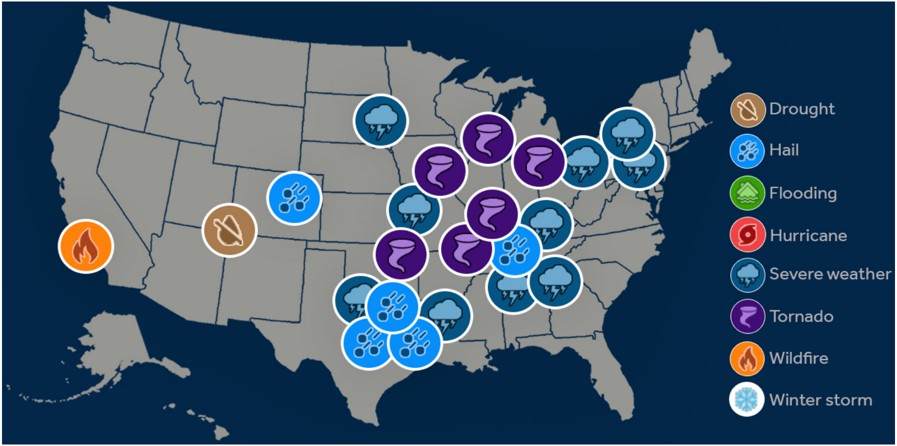
Humans have changed the climate



US inflation-adjusted billion-dollar disasters

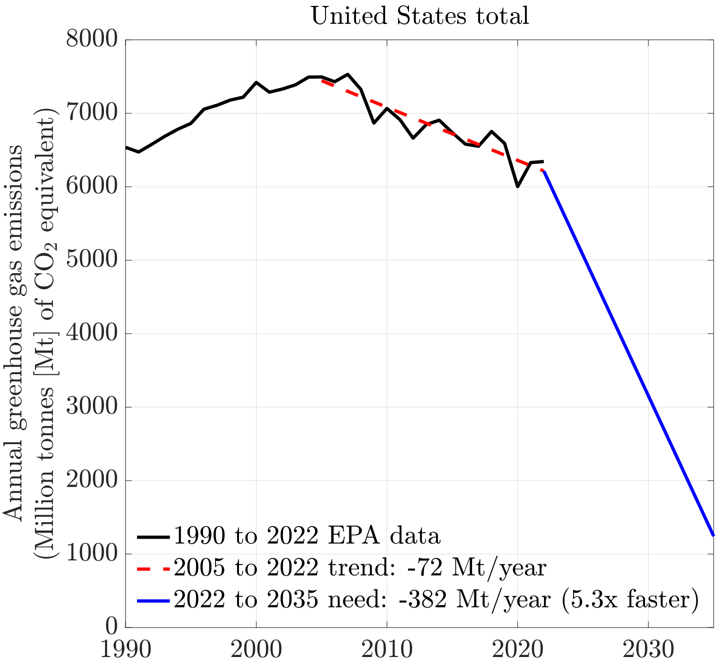
Climate Central: US Billion-Dollar Weather and Climate Disasters

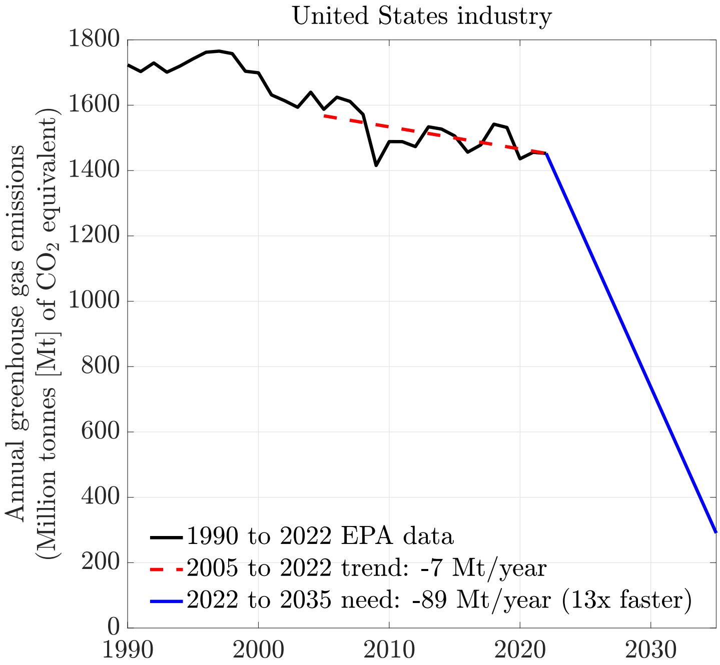
Humans have changed the climate

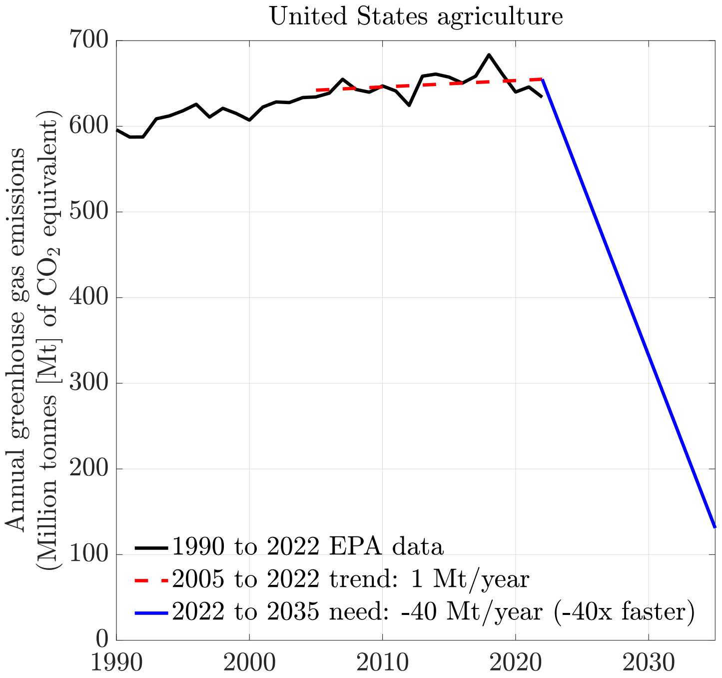


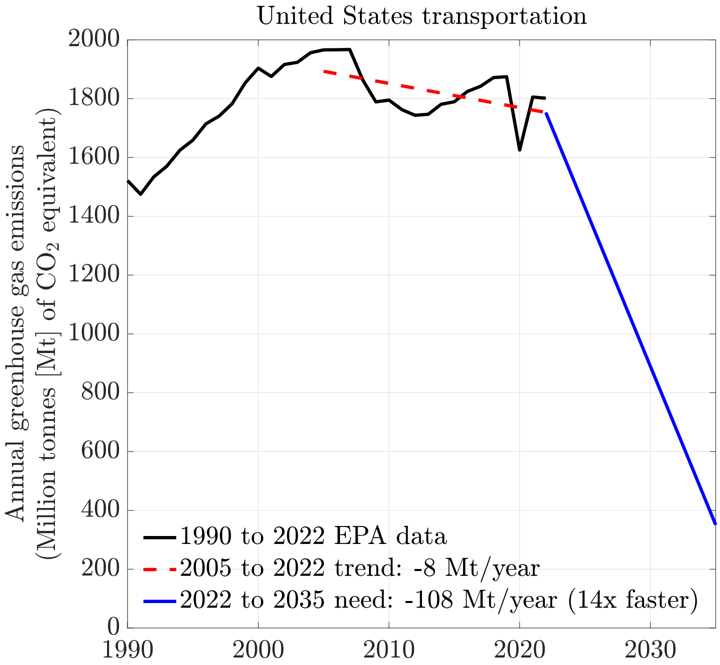
23 billion-dollar disasters in 2025, totaling $115 billion

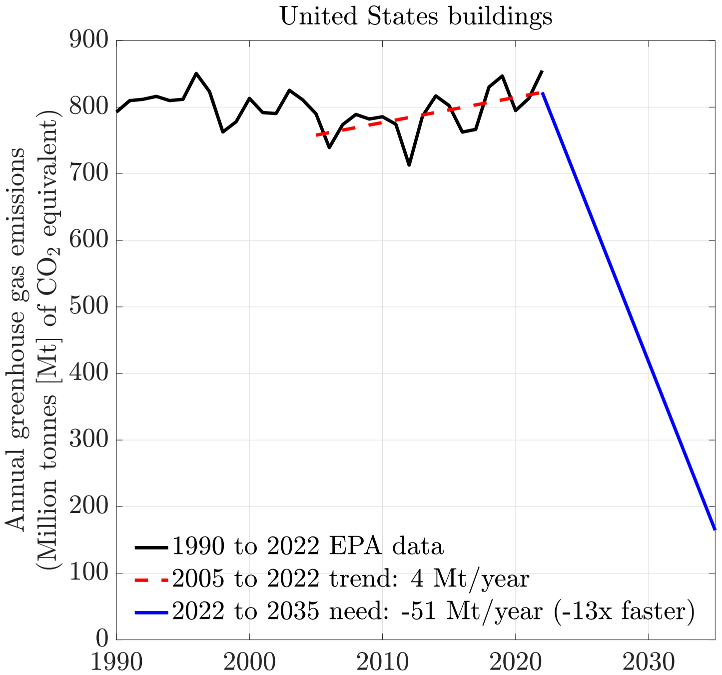
Climate Central: US Billion-Dollar Weather and Climate Disasters

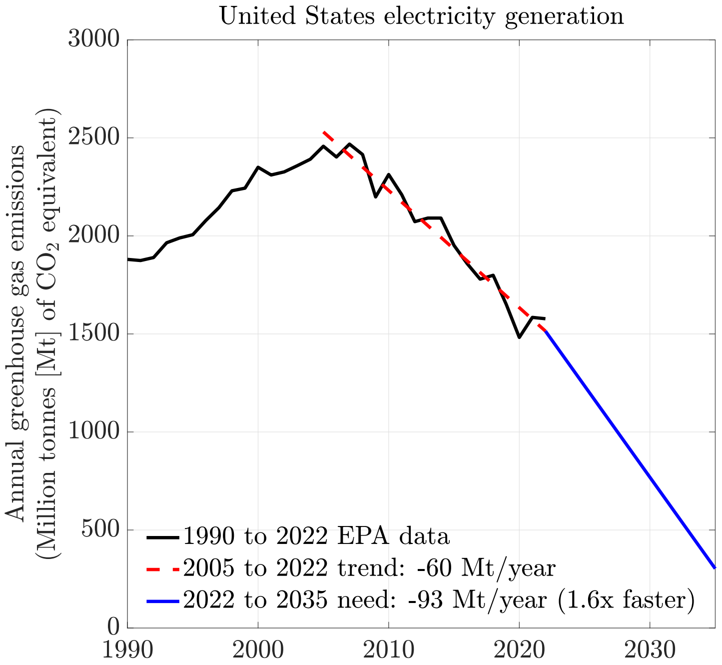

United States total
Annual greenhouse gas emissions
(Million tonnes [Mt] of CO_2 equivalent)
8000
7000
6000
5000
4000
3000
2000
1000
0
1990
2000
2010
2020
2030
1990 to 2022 EPA data
2005 to 2022 trend: -72 Mt/year
2022 to 2035 need: -382 Mt/year (5.3x faster)


United States industry
Annual greenhouse gas emissions
(Million tonnes [Mt] of CO_2 equivalent)
1800
1600
1400
1200
1000
800
600
400
200
0
1990
2000
2010
2020
2030
1990 to 2022 EPA data
2005 to 2022 trend: -7 Mt/year
2022 to 2035 need: -89 Mt/year (13x faster)

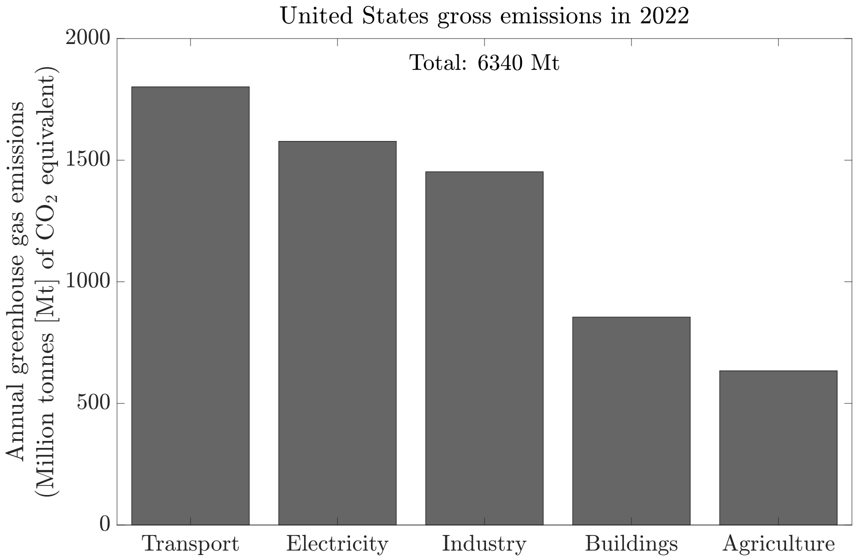

United States agriculture
Annual greenhouse gas emissions
(Million tonnes [Mt] of CO_2 equivalent)
700
600
500
400
300
200
100
0
1990
2000
2010
2020
2030
1990 to 2022 EPA data
2005 to 2022 trend: 1 Mt/year
2022 to 2035 need: -40 Mt/year (-40x faster)


United States transportation
Annual greenhouse gas emissions
(Million tonnes [Mt] of CO_2 equivalent)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1990
2000
2010
2020
2030
1990 to 2022 EPA data
2005 to 2022 trend: -8 Mt/year
2022 to 2035 need: -108 Mt/year (14x faster)

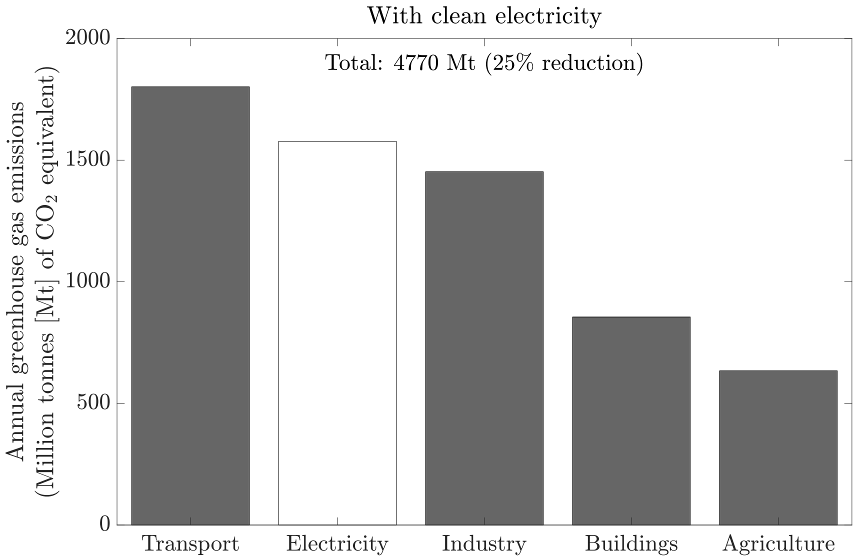

United States buildings
Annual greenhouse gas emissions
(Million tonnes [Mt] of CO_2 equivalent)
900
800
700
600
500
400
300
200
100
0
1990
2000
2010
2020
2030
1990 to 2022 EPA data
2005 to 2022 trend: 4 Mt/year
2022 to 2035 need: -51 Mt/year (-13x faster)


United States electricity generation
Annual greenhouse gas emissions
(Million tonnes [Mt] of CO_2 equivalent)
3000
2500
2000
1500
1000
500
0
1990
2000
2010
2020
2030
1990 to 2022 EPA data
2005 to 2022 trend: -60 Mt/year
2022 to 2035 need: -93 Mt/year (1.6x faster)

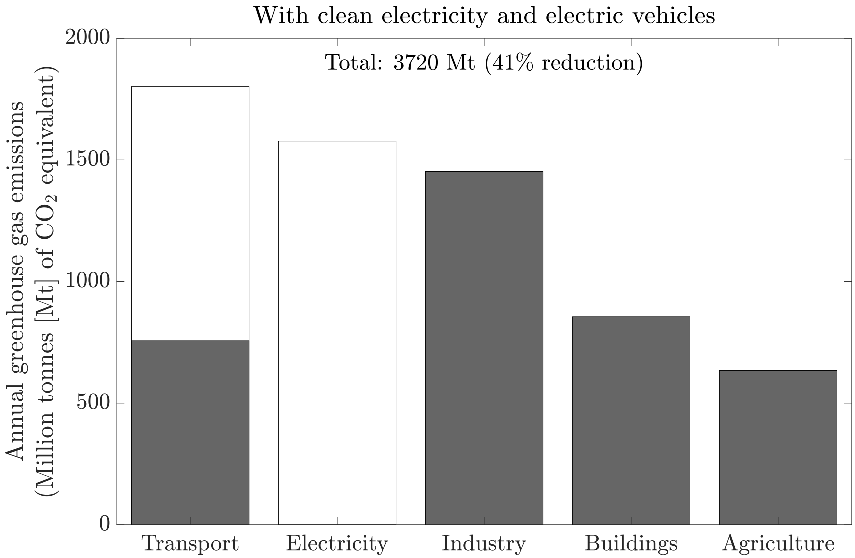
A two-step strategy for deep decarbonization

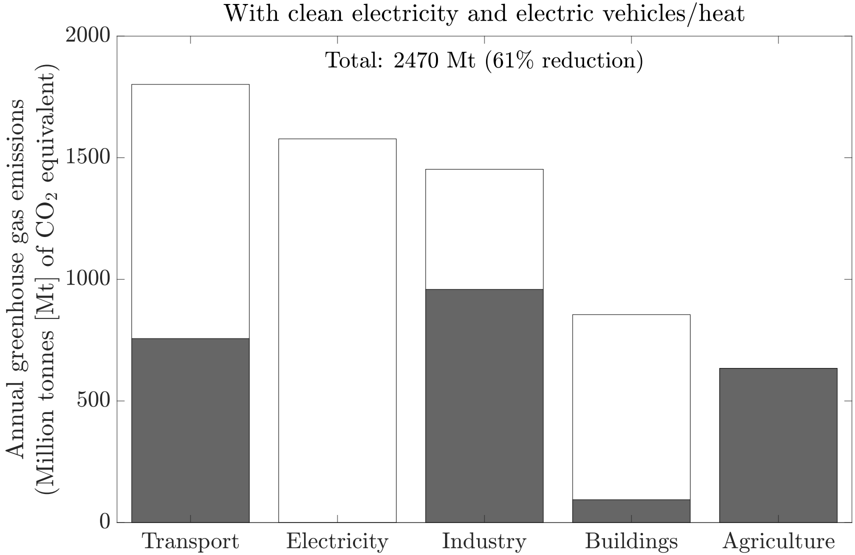


1. Decarbonize electricity generation

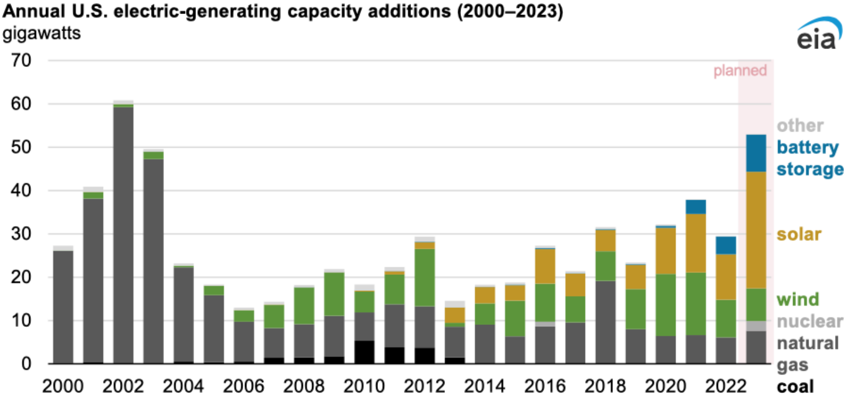


2. Electrify light-duty vehicles...




With clean electricity and electric vehicles/heat
Total: 2470 Mt (61% reduction)
Annual greenhouse gas emissions
(Million tonnes [Mt] of CO_2 equivalent)
2000
1500
1000
500
0
Transport
Electricity
Industry
Buildings
Agriculture

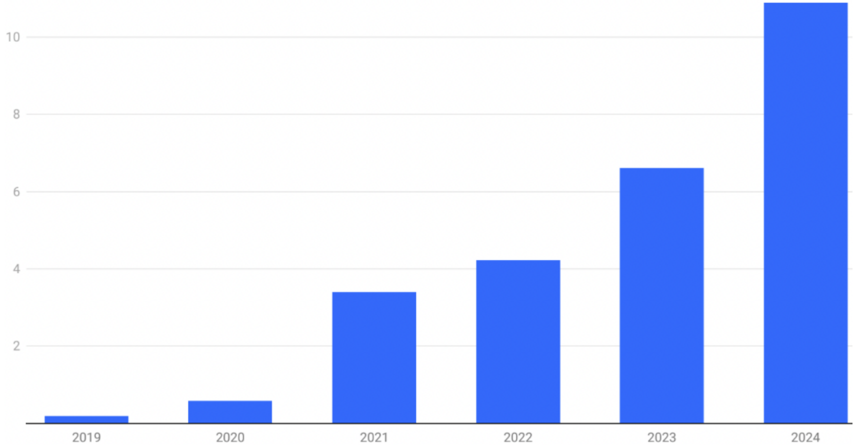
Most new electrical capacity is now wind, solar, or batteries



Energy Information Administration: Today in Energy (March 6, 2023)

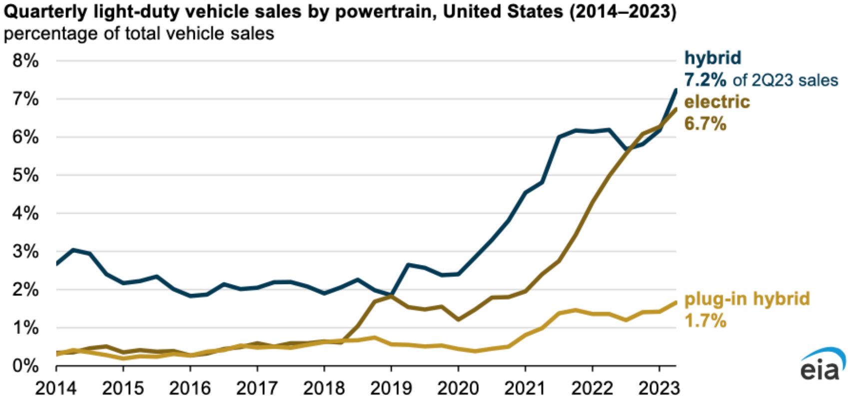
Battery installations are accelerating

new battery capacity additions (GW)



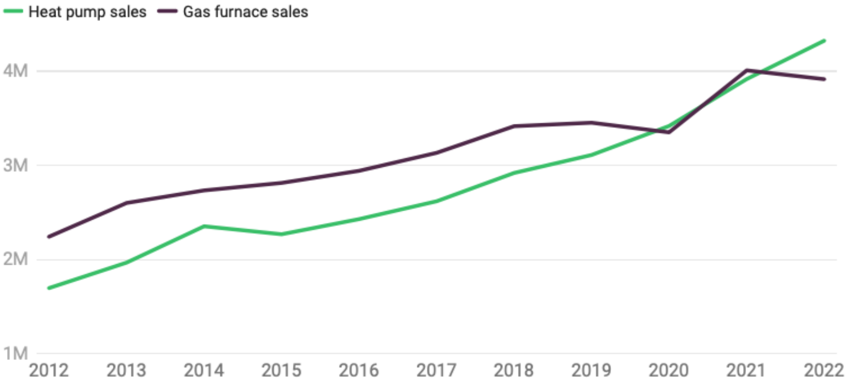
Michael Thomas/Cleanview: America's Grid Battery Boom is Just Getting Started

Electric vehicle sales are growing quickly



Energy Information Administration: Today in Energy (September 7, 2023)

Heat pump sales have outpaced gas furnaces



Canary Media: Americans bought more heat pumps than gas furnaces last year

Outline

Modeling and simulation

- review of linear differential equations
- introduction to linear dynamical systems
- (semi-)physical models of and data sources for
    - ◇ batteries and electric vehicles
    - ◇ solar photovoltaics
    - ◇ buildings
    - ◇ heat pumps and air conditioners
    - ◇ thermal storage and water heaters

Optimization and control

- convex sets and functions
- convex optimization problems
- disciplined convex programming
- model predictive control
- applications to DER design, operation, model fitting, ...

Supervised machine learning

- brief introduction to machine learning
  - predictors
  - validation
  - features
  - empirical risk minimization
  - regularization
- DER applications
  - time-series forecasting
  - system identification

Outline

Prerequisities

- ordinary differential equations
- linear algebra
- programming in **Matlab** or **Python**
- not required, but may enhance appreciation:
  - energy systems
  - optimization
  - control systems
  - probability and statistics
  - machine learning

Homework

- 20% of grade
- 6–8 problem sets with a mix of math and coding
- done individually or in teams
- everyone submits their own write-up
- outside resources are okay, but you must **cite them**
  (to really learn, *try homework with no outside help*)
- homework front-loaded in first ∼half of semester
- second ∼half: focus on semester projects

Midterm exam

- 30% of grade
- take-home over 24 hours
- taken ~halfway through semester
- no final exam

Semester project

- 50% of grade
- done individually or in teams of up to 4
  (expectations scale with team size)
- each team gives one ∼5 minute idea pitch
  - one presenter only (but whole team helps prepare)
  - whole team fields questions for ∼2 minutes
- each team gives one ∼10 minute conference-style talk
  - one presenter only (but whole team helps prepare)
  - whole team fields questions for ∼4 minutes
- each team writes one ∼6 page conference-style final paper
- each team member verbally assesses their own contributions
  (in a meeting with me and their team)

Websites

- Kevin's website
  - ◇ download lecture slides and videos
  - ◇ download homework assignments and midterm
- Gradescope
  - ◇ upload completed homeworks and midterm
  - ◇ view grades

Online participation

- view lecture slides and videos whenever
  (or join class in real time via Zoom if you prefer)
- upload homeworks and midterm when in-person class does
- join Zoom office hours if helpful
- work remotely with project team (or work alone if you prefer)
- join Zoom for your team's project presentations

Survey

please take two minutes to tell us a bit about yourself
(one page, five questions)