Cities & decarbonization
MIT 11.165/477, 11.286J

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September 10, 2022

Preparing for class

1. Introductory reading
   - short & skimmable, so easy to catch up (but you should catch up!)
   - particularly important to look at Mackay chapter 2

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5. As you read and watch, write down the questions that you have for discussion.

Materials for today

- James H. Williams et al. Carbon-Neutral Pathways for the United States. AGU Advances, 2(1), 2020 doi. URL.
- David Roberts. Cities are beginning to own up to the climate impacts of what they consume, July 2019. URL.
- Angel Hsu et al. A research roadmap for quantifying non-state and subnational climate mitigation action. Nature Climate Change, 9(1):1117, January 2019. doi. URL.
- Dan Tong et al. Committed emissions from existing energy infrastructure jeopardize 1.5 C climate target. Nature, 572(7769):373377, August 2019. doi. URL.
- C40 Cities et al. Consumption-based GHG emissions of C40 cities. Technical report, C40 Cities Climate Leadership Group, 2019. URL.
- Samuel A Markolf et al. Pledges and progress: Steps toward greenhouse gas emissions reductions in the 100 largest cities across the United States. Technical report, Brookings Institution, October 2020.

Mackay chap. 2: "the balance sheet"

Energy consumption versus energy production

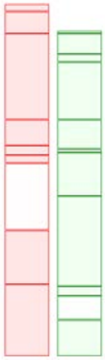

Figure from Mackay

Figure courtesy of David MacKay.

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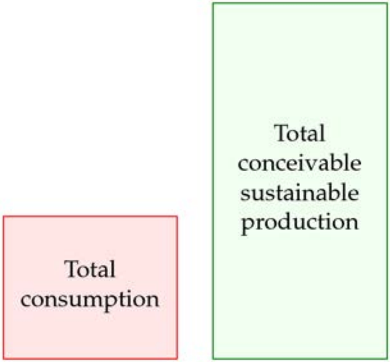

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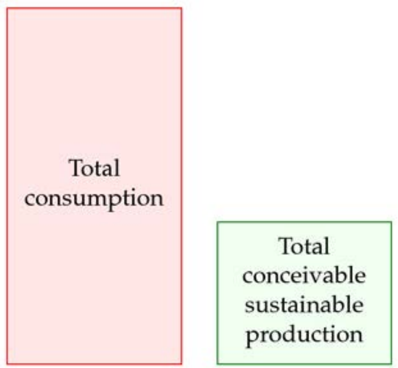

Figure from Mackay

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Mackay chap. 2: "the balance sheet"

Some key forms of consumption for the left-hand stack will be:

- transport
  - cars, planes, freight
- heating and cooling
- lighting
- information systems and other gadgets
- food
- manufacturing

In the right-hand sustainable-production stack, our main categories will be:

- wind
- solar
  - photovoltaics, thermal, biomass
- hydroelectric
- wave
- tide
- geothermal
- nuclear? (with a question-mark, because it's not clear whether nuclear power counts as "sustainable")

Figure from Mackay

Figure courtesy of David MacKay.

Mackay chap. 2: key physical concepts

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- units: kilowatt-hour (kWh); also BTU, therms, joules, calories
  - fossil fuels: barrels, short tons, cubic feet

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- example 1: "I worked out for an hour and it was only equivalent to 3 Oreos!"
- example 2: the average American household uses, per year, about 11,000 kWh in electricity. Each person uses 300 MBTUs total per year, which is approximately 2.3 gallons of oil, 7.89 pounds of coal, and 252 cubic feet of natural gas per day.

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- example: "My workout maintained a steady output of 3 Oreos per hour!"

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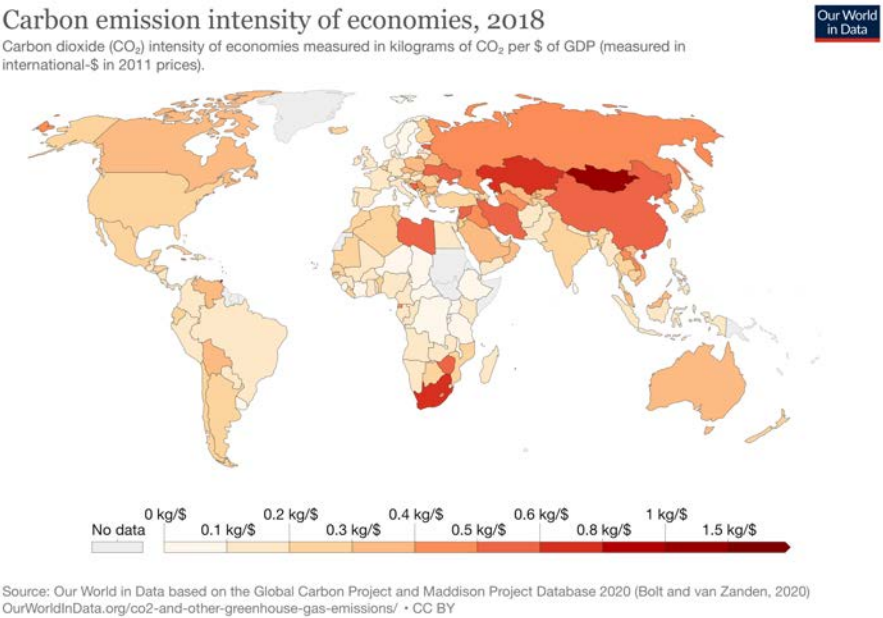
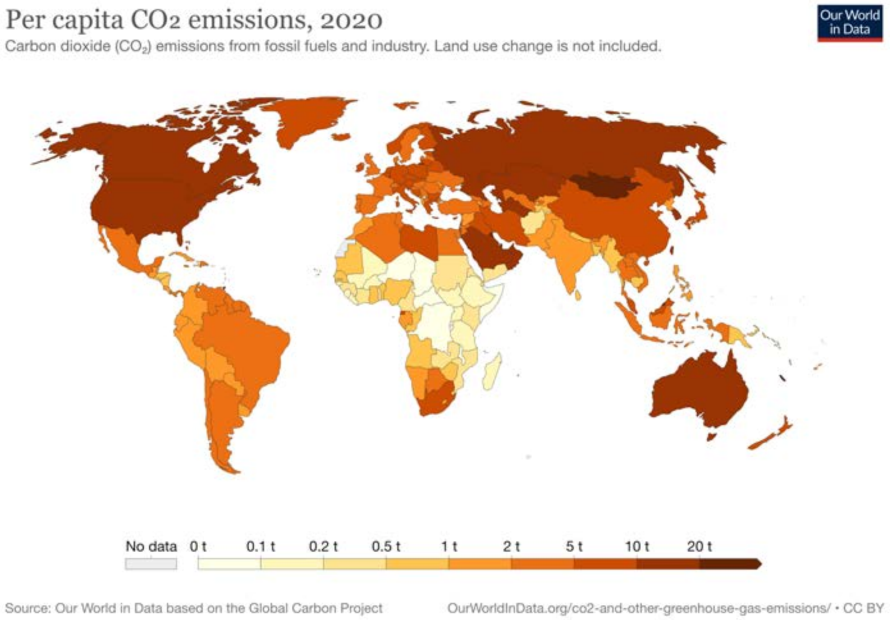
- examples: UNFCCC reporting inventories; source; electricity; air quality;



Map from Our World in Data



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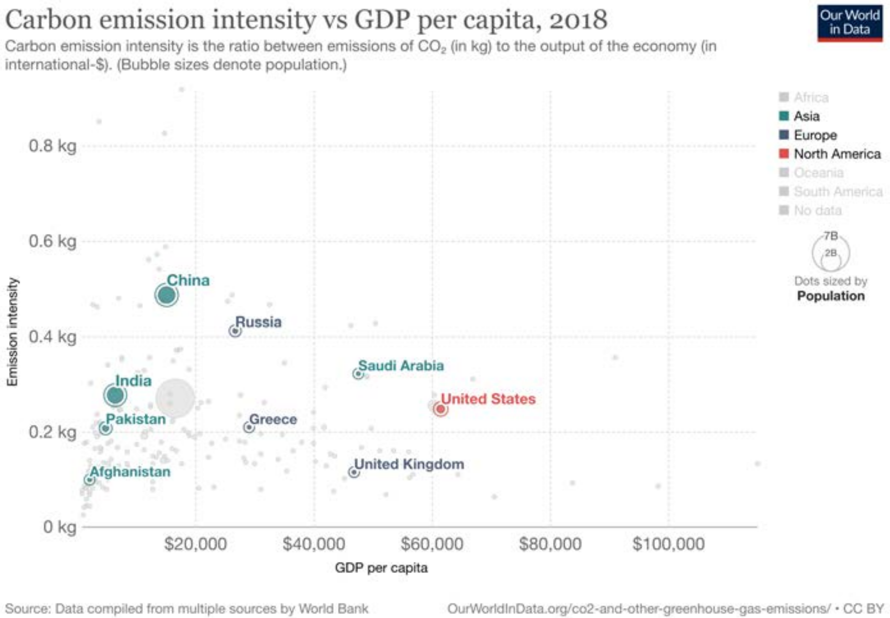
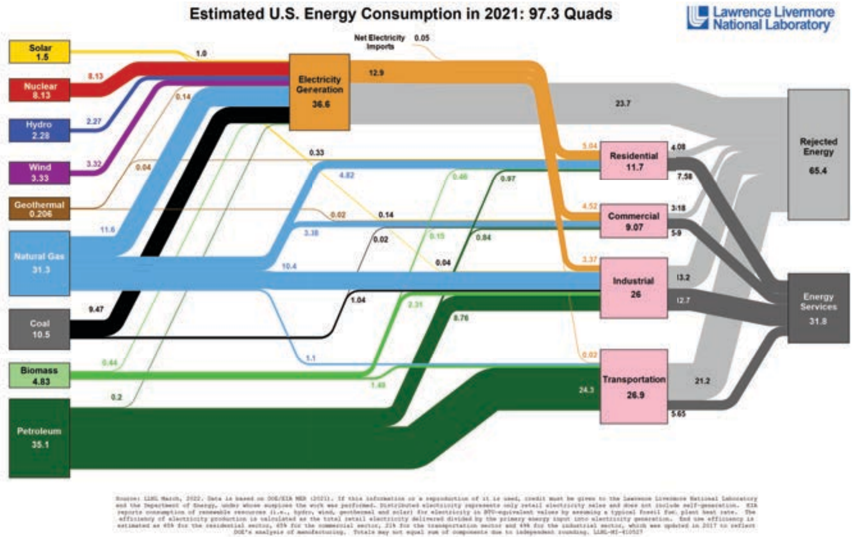


Map from Our World in Data

Sankey diagrams



Sankey diagrams for the US and every state at flowcharts.LLNL.gov

Figure courtesy of LLNL / US Department of Energy. This image is in the public domain.

Deep decarbonization

US economy-wide decarbonization plans:

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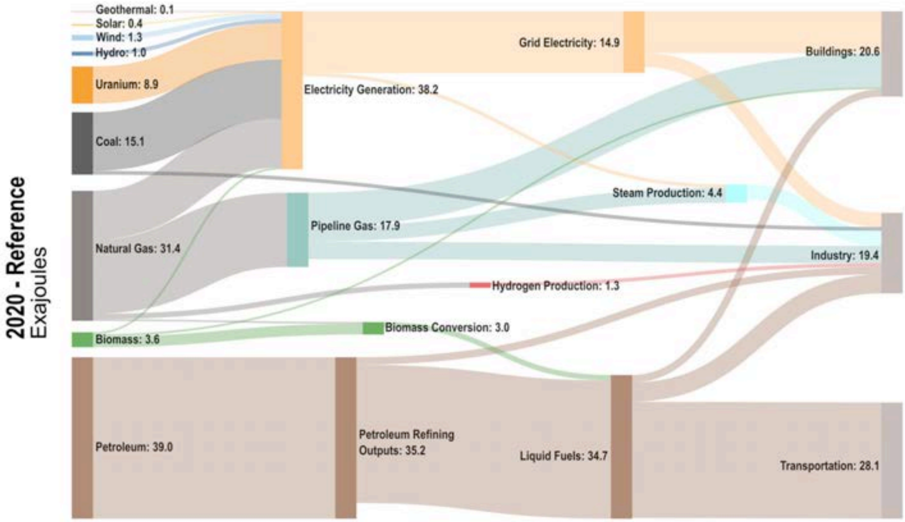
Many plans agree on the technology pathways, so we can later focus on implications for:

- implementation
- geography
- politics
- land use and the built environment

Williams et al, 2020



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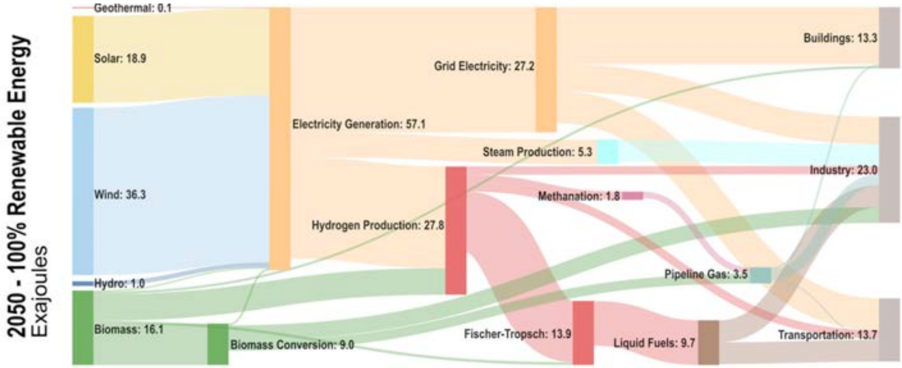

Williams et al, 2020

All numbers in quads (.9478 quad = EJ)
Total US economy in 2020 uses 100.8 quads;
100% RE economy in 2050 uses 72.8 quads

	WILLIAMS ET AL 2020			
	2020 Reference	2050 100% Renewable	Total % growth, 2020-2050	Notes
Electric power sector				
Primary energy supply				
Petroleum	37.0	-	-100%	Eliminate
Natural gas	29.8	-	-100%	Eliminate
Coal	14.3	-	-100%	Eliminate completely
Biomass	3.4	15.3	347%	Growth by 3.5X
Nuclear	8.4	-	-100%	Eliminate completely
Solar	0.4	17.9	4625%	Growth by 46X
Wind	1.2	34.4	2692%	Growth by 27X
Hydro	0.9	0.9	0%	No growth
Geothermal	0.0	0.1	120%	Minor factor
TOTAL PRIMARY ENERGY	95.5	68.6	-28%	

Williams et al, 2020

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WILLIAMS ET AL 2020	2020 Reference	2050 100% Renewable	Total % growth, 2020-2050	Notes
Buildings (residential + commercial)				
Primary energy supply				
Electricity	20.2	12.9	-36%	Decline in total use
Pipeline natural gas	9.5	-	-100%	Eliminate completely
Biomass conversion	1.6	3.6	130%	(Via electricity)
TOTAL PRIMARY ENERGY	31.3	16.6	-47%	Reduce by half
Final demand (use)	19.9	13.1	-34%	
Implied losses	-36%	-21%		
Gain in efficiency		15%		

Tong et al *Nature* 2019

Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target

Dan Tong[1,2], Qiang Zhang[2]*, Yixuan Zheng[2,3], Ken Caldeira[3], Christine Shearer[4], Chaopeng Hong[1], Yue Qin[1] & Steven J. Davis[1,2,5]*

Net anthropogenic emissions of carbon dioxide (CO_2) must approach zero by mid-century (2050) in order to stabilize the global mean temperature at the level targeted by international efforts[1–5]. Yet continued expansion of fossil-fuel-burning energy infrastructure implies already 'committed' future CO_2 emissions[6–13]. Here we use detailed datasets of existing fossil-fuel energy infrastructure in 2018 to estimate regional and sectoral patterns of committed CO_2 emissions, the sensitivity of such emissions to assumed operating lifetimes and schedules, and the economic value of the associated infrastructure. We estimate that, if operated as historically, existing infrastructure will cumulatively emit about 658 gigatonnes of CO_2 (with a range of 226 to 1,479 gigatonnes CO_2, depending on the lifetimes and utilization rates assumed). More than half of these emissions are predicted to come from the electricity sector; infrastructure in China, the USA and the 28 member states of the European Union represents approximately 41 per cent, 9 per cent and 7 per cent of the total, respectively. If built, proposed power plants (planned, permitted or under construction) would emit roughly an extra 188 (range 37–427) gigatonnes CO_2. Committed emissions from existing and proposed energy infrastructure (about 846 gigatonnes CO_2) thus represent more than the entire carbon budget that remains if mean warming is to be limited to 1.5 degrees Celsius (°C) with a probability of 66 to 50 per cent (420–580 gigatonnes CO_2)[5], and perhaps two-thirds of the remaining carbon budget if mean warming is to be limited to less than 2 °C (1,170–1,500 gigatonnes CO_2)[5]. The remaining carbon budget estimates are varied and nuanced[14,15], and depend on the climate target and the availability of large-scale negative emissions[16]. Nevertheless, our estimates suggest that little or no new CO_2-emitting infrastructure can be commissioned, and that existing infrastructure may need to be retired early (or be retrofitted with carbon capture and storage technology) in order to meet the Paris Agreement climate goals[17]. Given the asset value per tonne of committed emissions, we suggest that the most cost-effective premature infrastructure retirements will be in the electricity and industry sectors, if non-emitting alternatives are available and affordable[4,18].

International efforts to limit the increase in global mean temperature to well below 2 °C, and to 'pursue efforts' to avoid a 1.5 °C increase, entail a transition to energy systems with net-zero emissions by mid-century[1–5]. Yet recent decades have witnessed an unprecedented expansion of historically long-lived, fossil-fuel-based energy infrastructure—particularly associated with the rapid economic development and industrialization of emerging markets such as China and India[9,10]—and a shift towards natural-gas-fired power plants in the USA. Although

Tong et al 2019

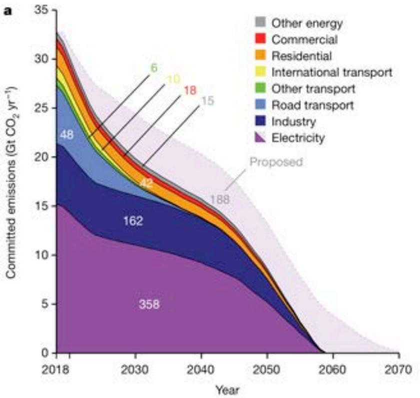

Fig. 1 | Committed annual CO_2 emissions from existing and proposed energy infrastructure. a, b, Estimates of future CO_2 emissions by industry sector (**a**; see also Supplementary Tables 1, 2) and country/region (**b**), assuming historical lifetimes and utilization rates. Emissions from existing infrastructure are shown with darker shading, and emissions from proposed power plants (that is, electricity) are more lightly shaded. Numbers within graphs show total amounts of emissions over the period shown.

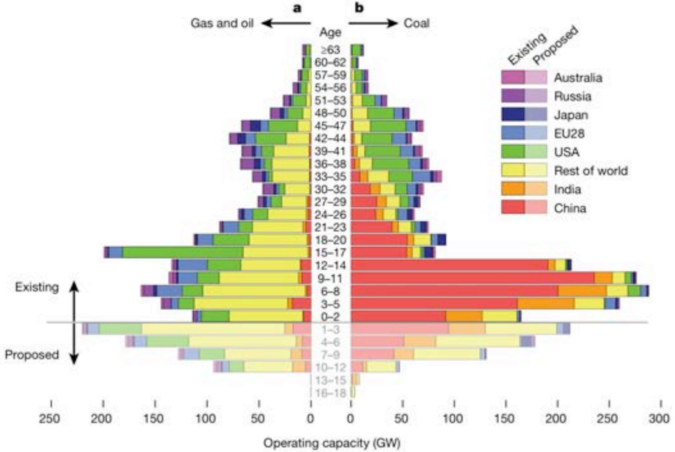

Fig. 2 | Age structure of global electricity-generating capacity. a, b, The operating capacity of gas- and oil-fired electricity-generating power units (**a**) and coal-fired units (**b**). The youngest existing units are shown at the bottom of the 'existing' section. The more lightly shaded bars underneath show proposed electricity-generating units according to the year (from now) that they are expected to be commissioned. The recent trends in Chinese and Indian coal-fired units (red and orange at the lower right) and US gas-fired units (green at the left) are easily apparent. '0 years old' means that the power units began operating in 2018.

GHG emissions from cities

Numerous recent studies show that most US GHG emissions are from cities, but the exact proportion depends on how and where you count:

- Jones et al 2018
- Goldstein et al 2020
- Gurney et al 2018, 2020, 2021
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- city, urban definitions
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- (not always accounted for: how cities shape local microclimates; affluence in terms of wealth and income)

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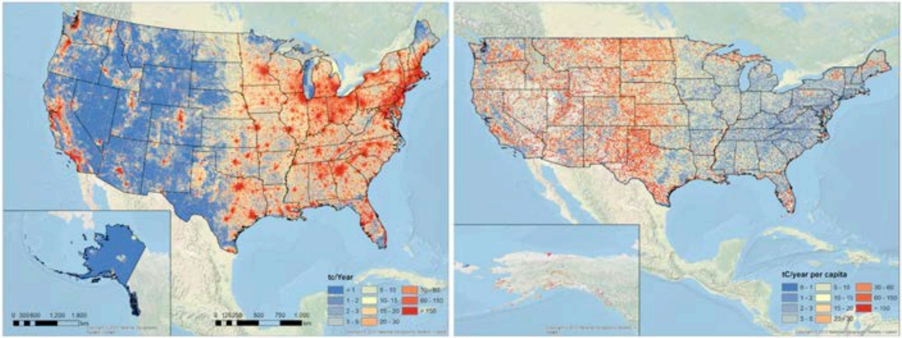


(a) (b)

Figure 3. Vulcan v3.0 2011 $FFCO_2$ emissions for the United States. (a) Absolute emissions (1 km × 1 km resolution, tC); (b) per capita emissions (0.1° × 0.1° resolution, tC; different resolution and projection required for integration with population data).

Screenshot from Gurney et al 2020

Hsu et al, 2019

nature climate change

PERSPECTIVE

https://doi.org/10.1038/s41558-018-0338-z

A research roadmap for quantifying non-state and subnational climate mitigation action

Angel Hsu[1,2*], Niklas Höhne[3,4], Takeshi Kuramochi[4,5], Mark Roelfsema[6], Amy Weinfurter[7], Yihao Xie[7], Katharina Lütkehermöller[4], Sander Chan[8], Jan Corfee-Morlot[9], Philip Drost[10], Pedro Faria[11], Ann Gardiner[12], David J. Gordon[13], Thomas Hale[14], Nathan E Hultman[15], John Moorhead[16], Shirin Reuvers[11], Joana Setzer[17], Neelam Singh[18], Christopher Weber[19] and Oscar Widerberg[20]

Non-state and subnational climate actors have become central to global climate change governance. Quantitatively assessing climate mitigation undertaken by these entities is critical to understand the credibility of this trend. In this Perspective, we make recommendations regarding five main areas of research and methodological development related to evaluating non-state and subnational climate actions: defining clear boundaries and terminology; use of common methodologies to aggregate and assess non-state and subnational contributions; systematically dealing with issues of overlap; estimating the likelihood of implementation; and addressing data gaps.

PERSPECTIVE NATURE CLIMATE CHANGE

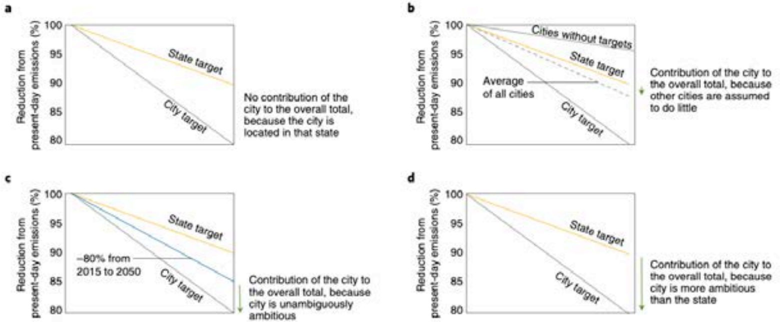


Fig. 1 | Different ways of comparing city non-state climate action with state targets. a, No additional reductions in a case with 100% geographical overlap. **b**, Additional action compared to the average of all cities (with and without targets) in the state. **c**, Additional action compared to an average long-term target for all cities with targets in the state. **d**, Full effect (assuming 100% attribution). Panel **a** adapted from ref. [35], NewClimate Institute, 2013.

PLEDGES AND PROGRESS

Steps toward greenhouse gas emissions reductions in the 100 largest cities across the United States

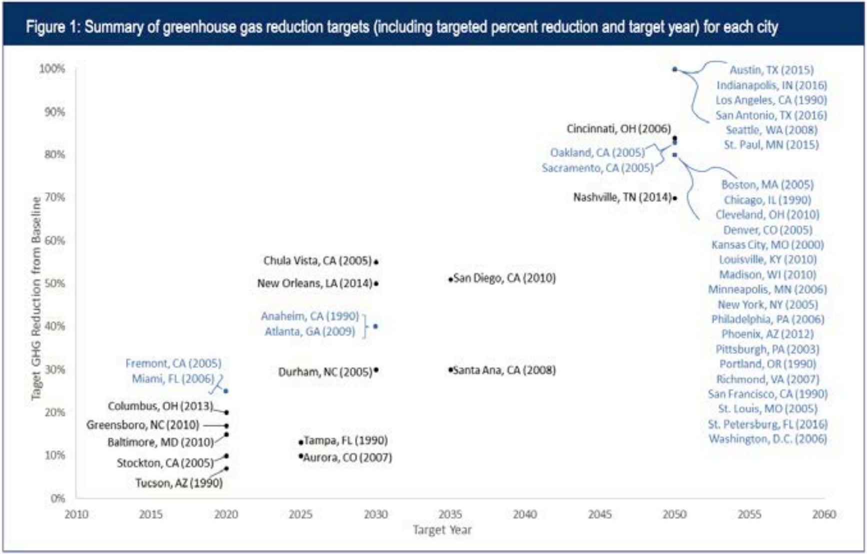
Samuel A. Markolf, Inês M. L. Azevedo, Mark Muro, and David G. Victor

EXECUTIVE SUMMARY

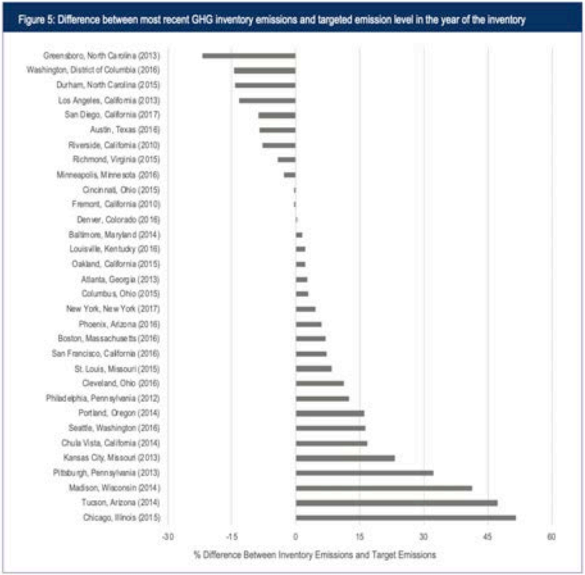
The COVID-19 crisis has precipitated the largest decline of global greenhouse gas (GHG) emissions on record.[1] Those massive current declines are likely temporary, but they raise important questions about the trajectory of emissions as the economic crisis abates and economic activity resumes.

Since 1991, over 600 local governments in the United States have developed CAPs that include GHG inventories and reduction targets.[2]

These local plans — which entail a GHG emission inventory and the establishment of reduction targets, reduction strategies, and monitoring efforts — have been celebrated as an important counterpoint to federal drift.



Notes: The numbers in parentheses represent the baseline year of their climate action plans. Values in blue indicate multiple cities with the same reduction target and target year. The figure solely depicts the final targets for each city — not any interim targets.



Notes: The numbers in parentheses next to the city name represent the year of the most recent GHG inventory. Positive values mean that the emissions from the city were higher than the targeted emissions for that year.