

Macroeconomic Implications of Decarbonization Policies and Actions: A Workshop

Invited Poster Presentations

September 12, 2:30-3:45 PM ET

(Poster Abstracts and Presenter biosketches may be found in the Briefing Book on the [workshop event page](#))

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MOTIVATION

- There is a need to decarbonize the U.S. multi-modal freight network (i.e., truck, rail, and barge) to help reduce greenhouse gas emissions
 - Transition to renewable energy sources (i.e., electrification)
 - Shift from higher-carbon modes of transport to lower-carbon modes (e.g., truck to barge)
- These changes will also affect the resilience of supply chains, potentially increasing it in some areas and decreasing it in others
- The primary goals of this project are twofold:
 - Find optimal ways of decarbonizing the US multi-modal freight network
 - Assess how these changes affect the resilience of the network under current and future climate scenarios

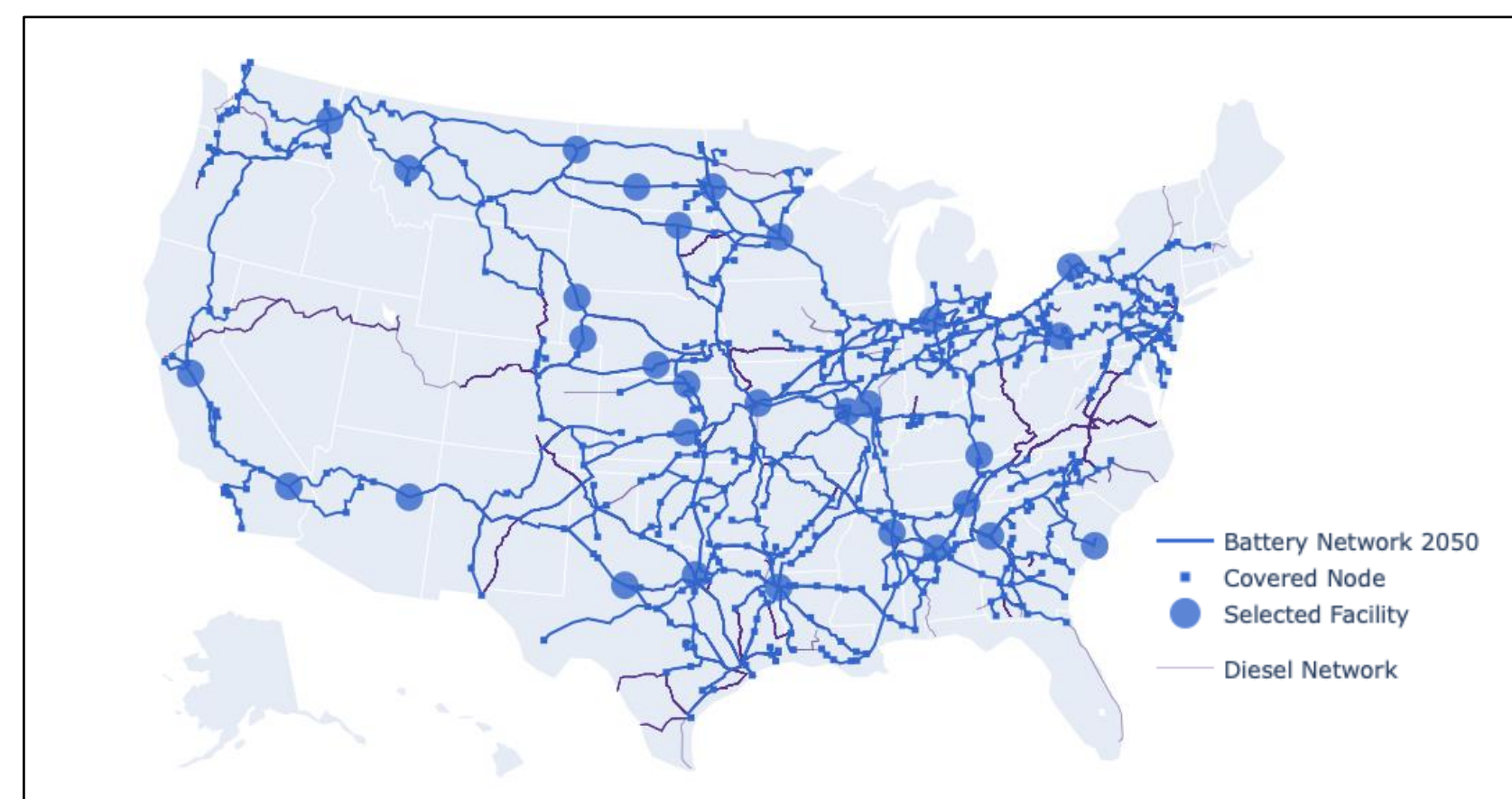


Figure 1: Example decarbonization of freight rail network – rechargeable stations deployed at optimally selected facilities overlayed onto current network¹

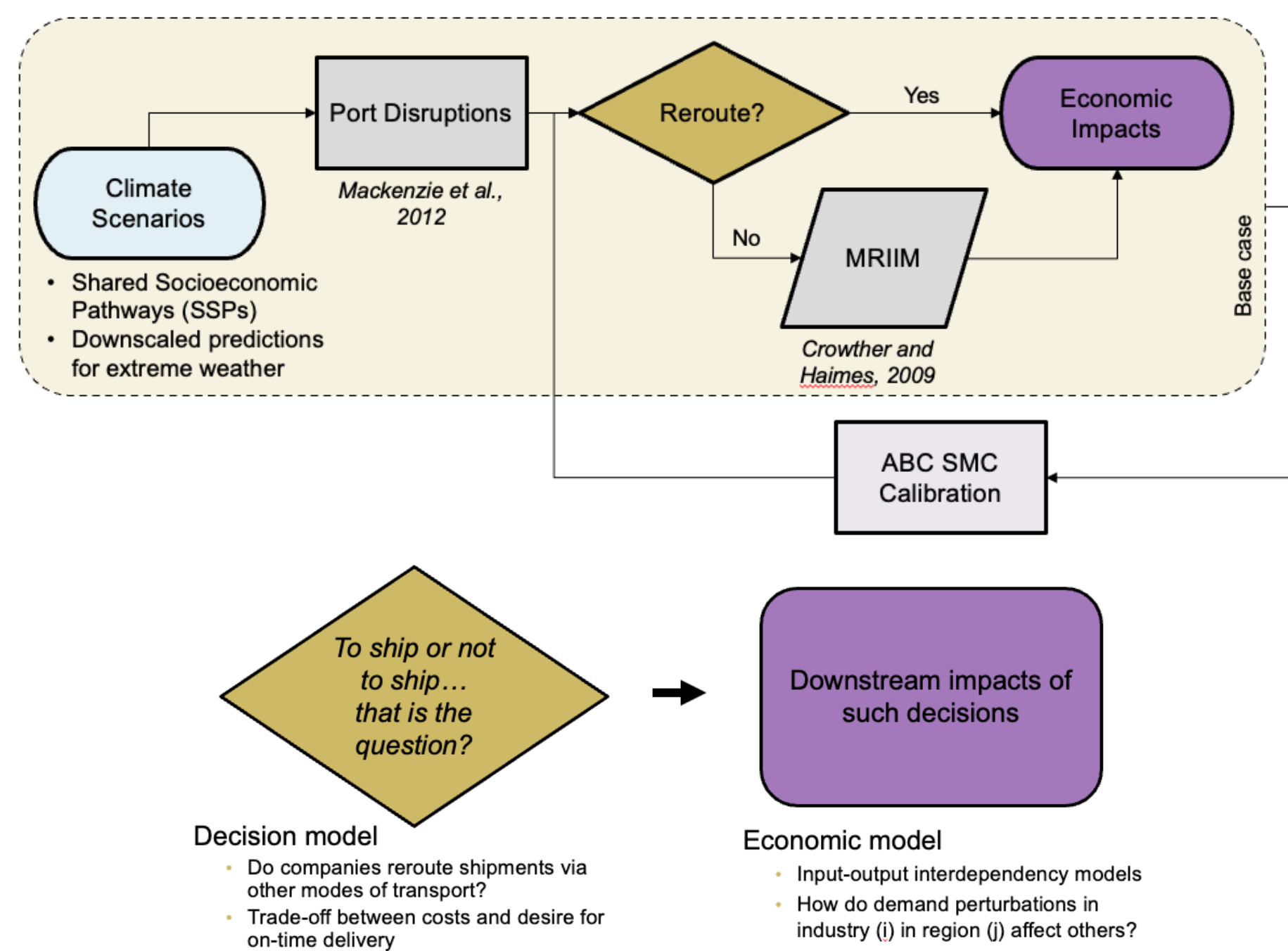


Figure 2: Flowchart of integrated approach to assessing resilience of freight network under future climate scenarios (e.g., inland waterways)

APPROACH

- Integrated platform to optimally decarbonize multi-modal freight network (*work in progress*)
 - Network and traffic assignment models facilities and modes of transport
 - Simulations model operations within facilities, including automation and electrification
 - Analytics to rollout vehicle fleets and infrastructure developments
 - Freight routing logistics to help monitor performance

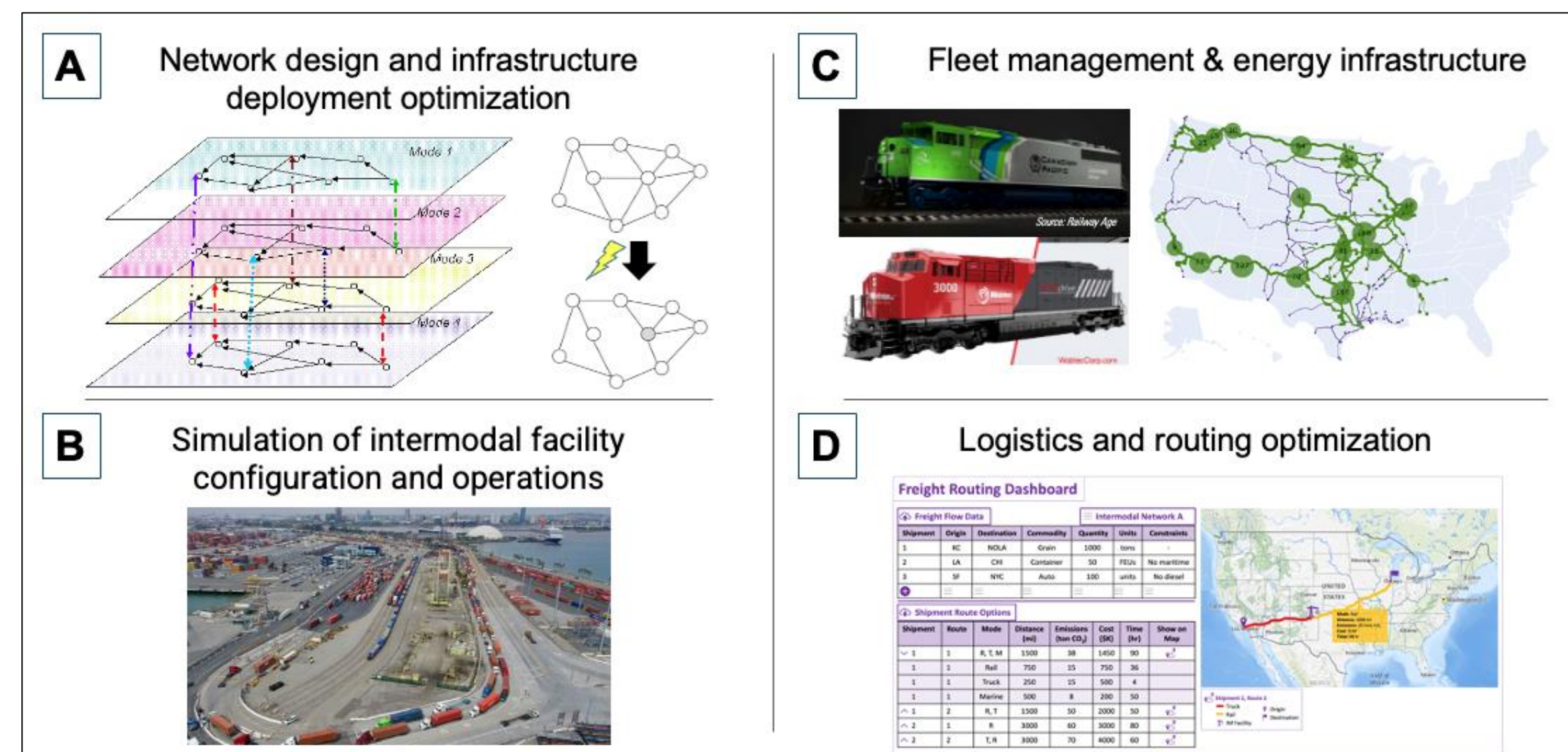


Figure 3: Diagram of multi-modal freight network decarbonization platform

- Assess vulnerabilities in the decarbonized freight network to help inform infrastructure investments
 - Network analysis to evaluate disruption and cascading failures (*work in progress*)
 - Integrated climate, agent-based, and economic modeling to estimate impacts of disruptions from disasters under future climate scenarios (e.g., below and Results)

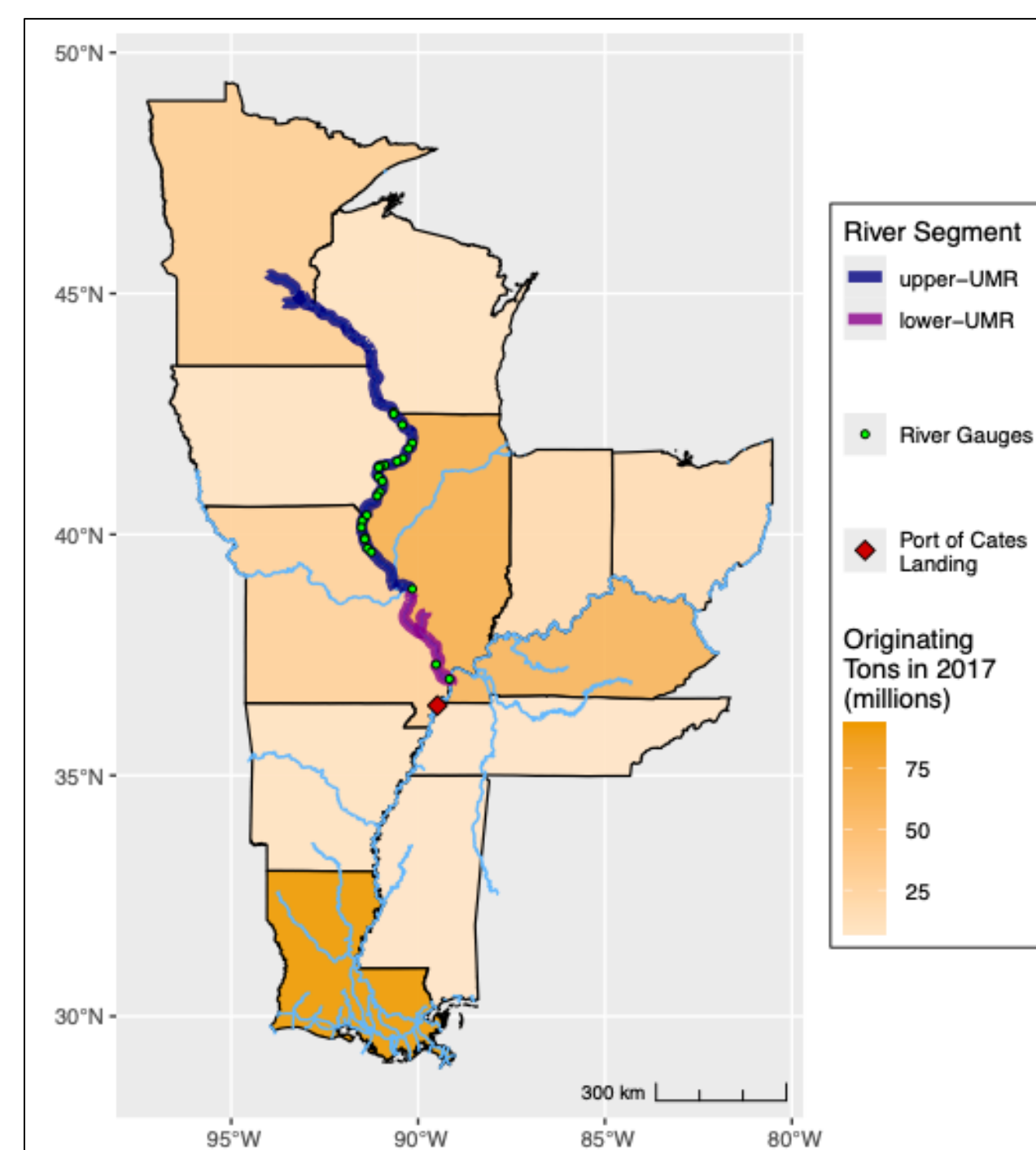


Figure 4: Case study area - Upper Mississippi River (UMR)

upper-UMR	10yr	20yr	50yr	100yr	500yr
SSP126	6.4	8.8	10.5	12.2	16.2
SSP245	6.4	8.7	10.4	12.1	16.1
SSP370	6.4	8.7	10.4	12.1	16.0
SSP585	8.0	10.9	13.1	15.2	20.1

lower-UMR	10yr	20yr	50yr	100yr	500yr
SSP126	16.7	22.8	27.4	32.0	42.5
SSP245	20.8	28.2	33.7	39.2	51.9
SSP370	19.8	26.9	32.2	37.4	49.5
SSP585	23.5	32.0	38.2	44.4	58.8

Figure 5: UMR river segment disruptions by flood return period under various climate scenarios

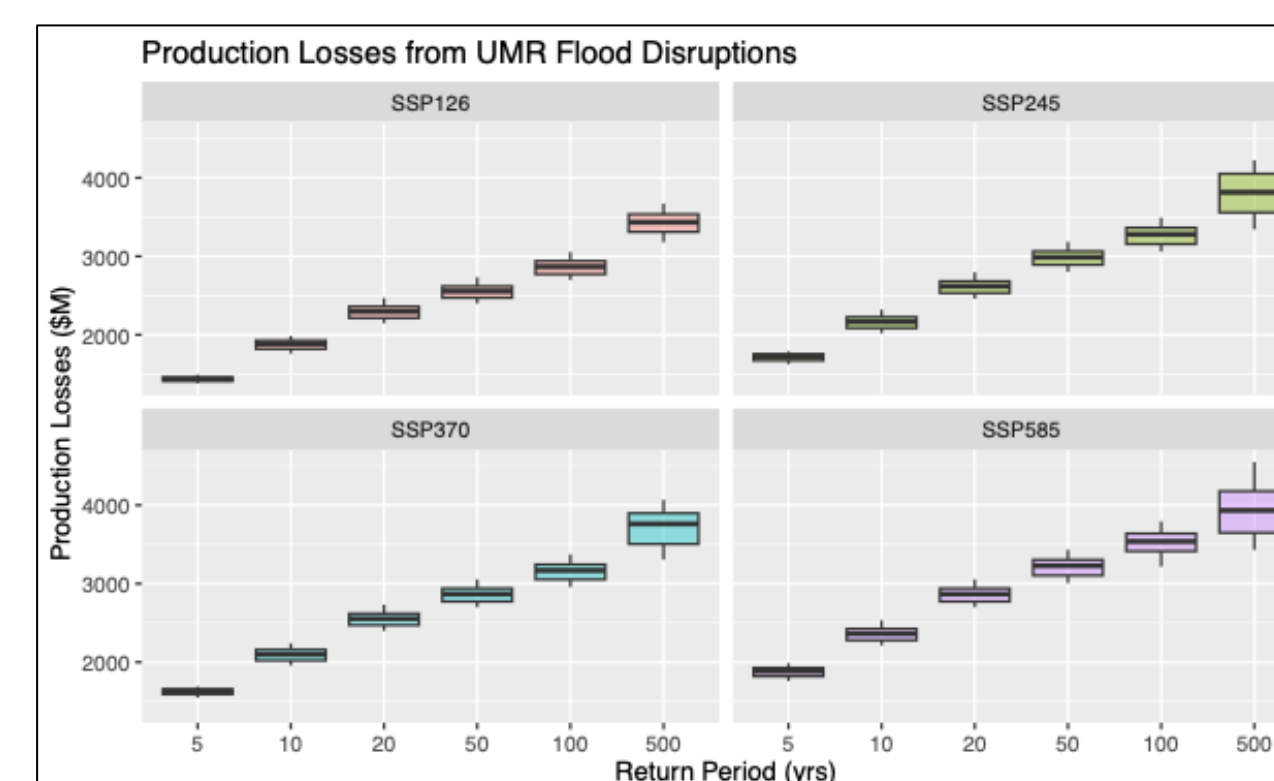


Figure 6: Production losses from UMR flood scenarios

RESULTS

- Down-scaled climate projections reveal that impacts from floods are expected to increase under future climate scenarios
- A flood-resilient port (e.g., the Port of Cates Landing) mitigates disruptions due to floods along the Upper Mississippi River in all but most optimistic carbon emission scenarios
- These savings are not realized equally between states or industries

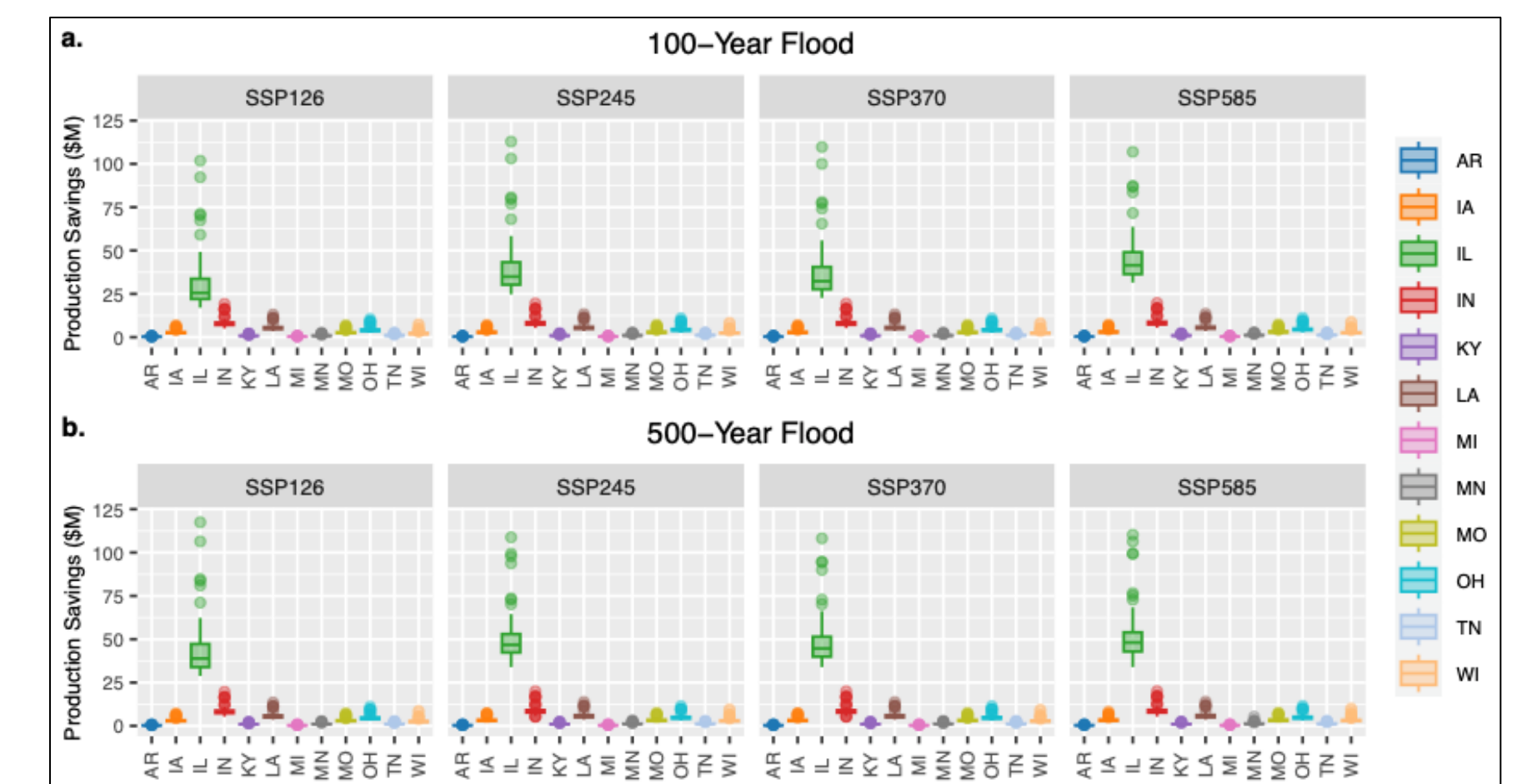


Figure 7: Savings in the form of mitigated losses by state for (a) 100-year and (b) 500-year floods under various climate scenarios

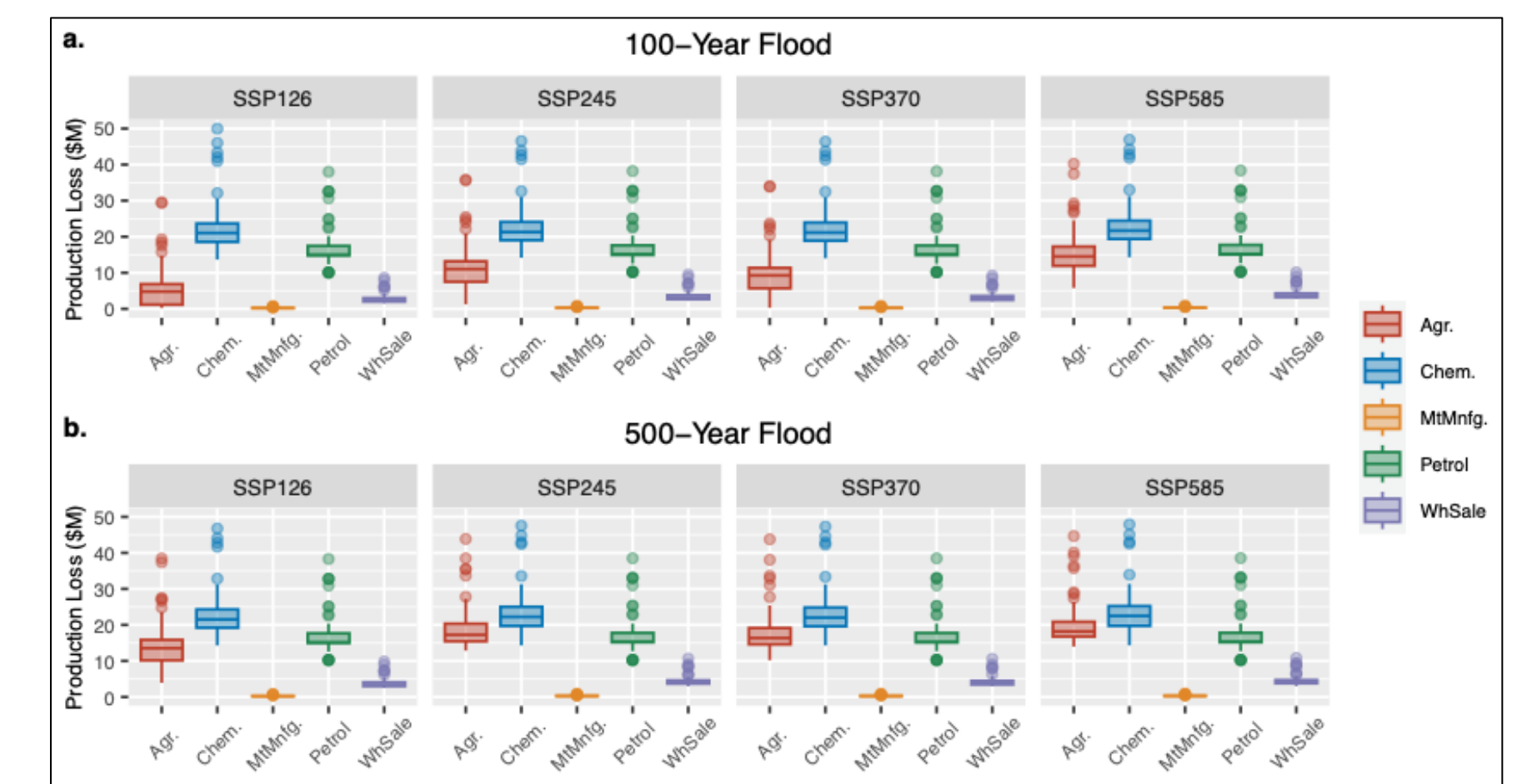


Figure 8: Savings in the form of mitigated losses by industry sector for (a) 100-year and (b) 500-year floods under various climate scenarios

DISCUSSION

- There is a general call for technological solutions to improve efficiency among stakeholders of the U.S. multi-modal freight network
- Tools to facilitate evaluation of such investments need to be developed
- Funding investments can be difficult, as cooperative dilemmas often arise between stakeholders along supply chains

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ACKNOWLEDGEMENTS

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Incorporating an Investment Multiplier into DICE Supports Rapid Decarbonization

Anders Fremstad, Mark Paul, Gregor Semieniuk

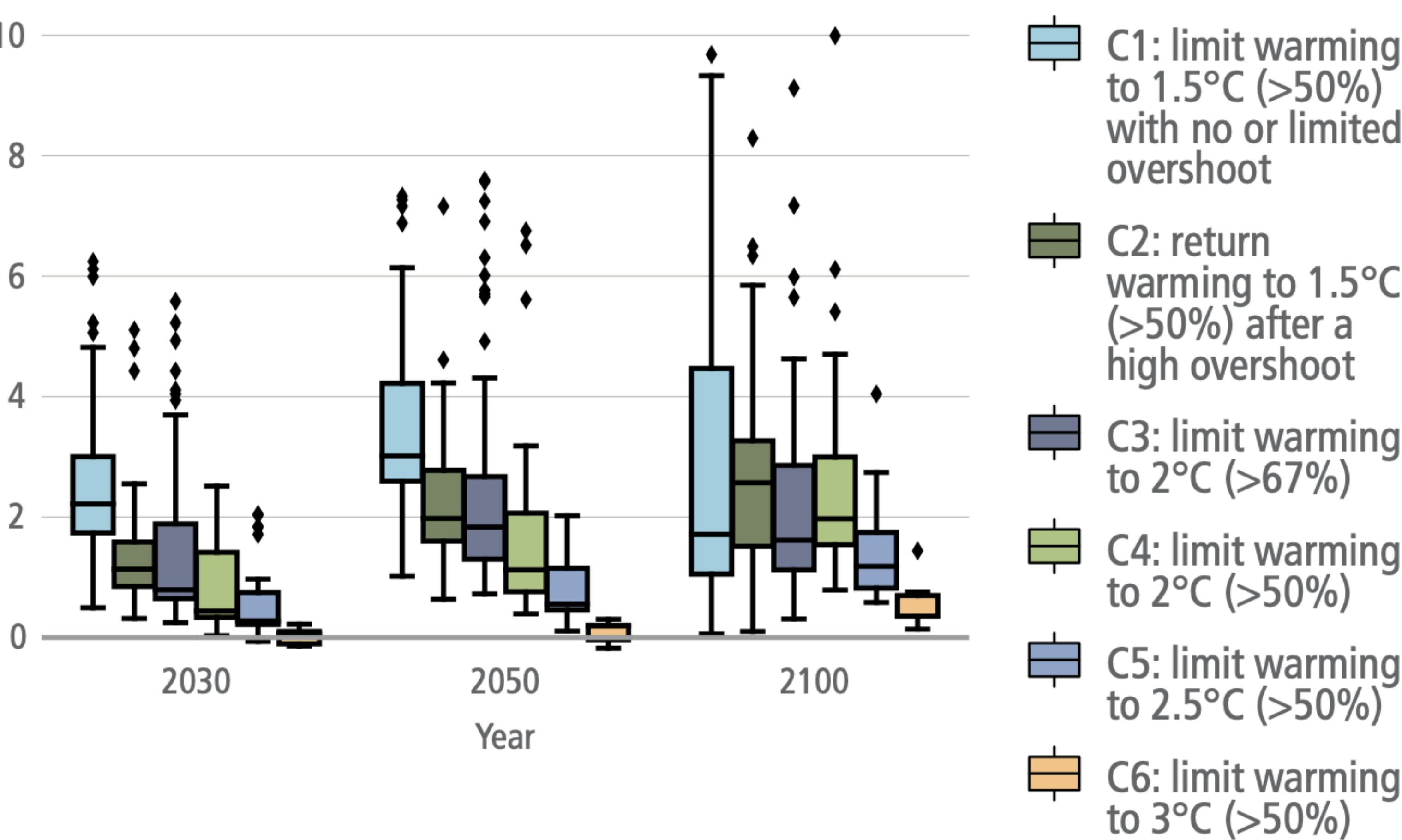
Introduction

DICE & other IAMs assume economies always operate on the efficiency frontier, resulting in hard tradeoffs between decarbonization, consumption, & non-climate investments.

Since climate action is always costly, protecting future generations requires austerity today. This results in discrepancies between DICE’s optimal pathways & scientific community’s recommendations. Our work re-evaluates this perspective. We review the (neo)classical economic assumptions underpinning IAMs and incorporate Keynesian investment multipliers into DICE that reflect economists’ understanding about how the economy operates.

By incorporating modest investment multipliers into DICE, we find that it is better to engage in rapid decarbonization to limit warming to 1.5-2°C, & that rapid decarbonization increases output in the short- & long-run.

Fig. 1 | Global GDP Loss Compared to Baseline (in %)



Note: IPCC AR6, pp. 361. Figure does not include any climate damages.

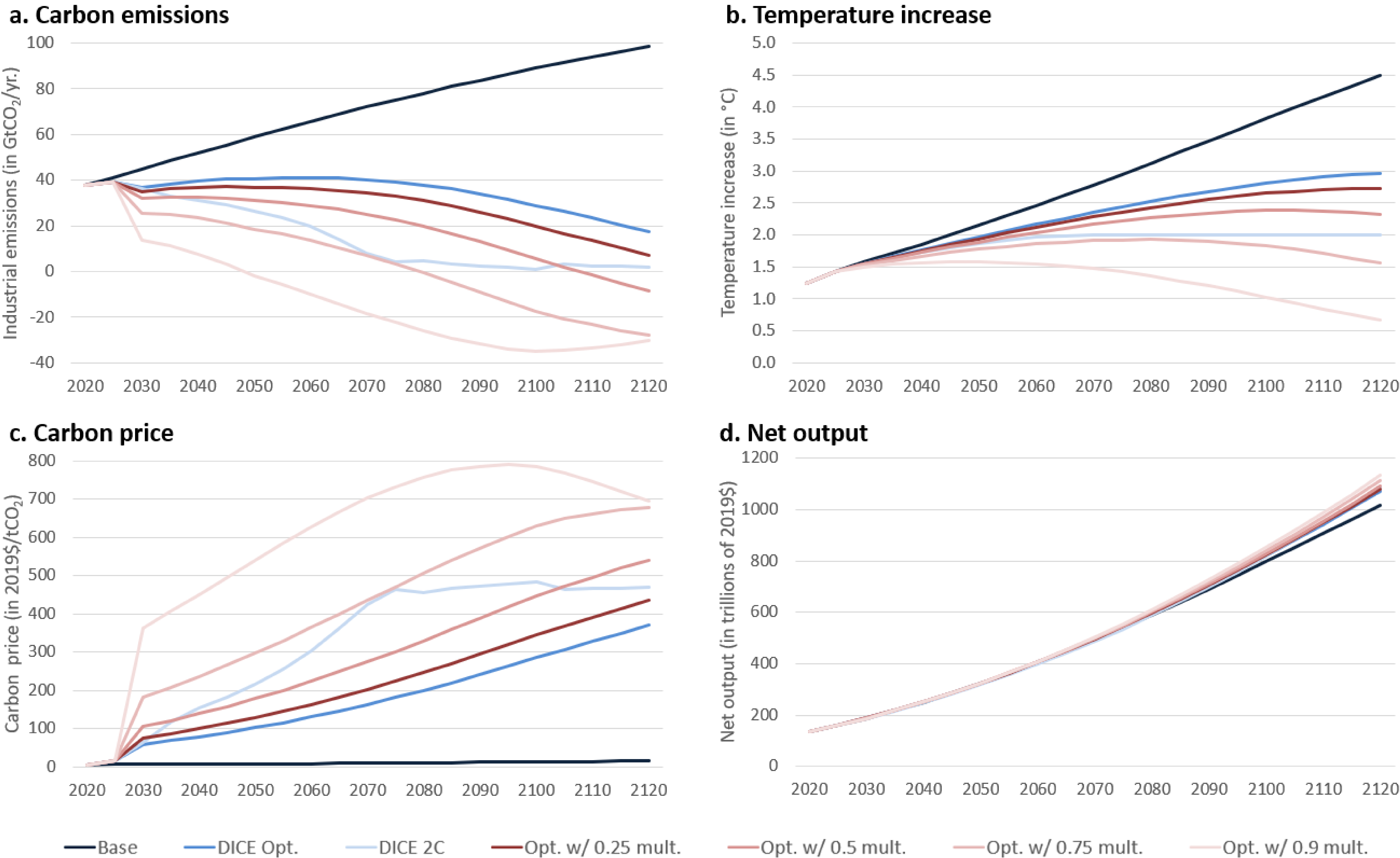
The (Neo)Classical Economics of DICE

DICE seeks to maximize the utility of a representative agent. To do this, it calculates emissions, temperature, & carbon price paths by balancing the cost of decarbonization & the benefits of climate change mitigation. We sidestep many of the historic debates around discount rate, damage function, treatment of extreme risk, dynamics of the carbon cycle, and & of technological change & instead focus on the relationship between spending on mitigation and economic output.

Key economic assumptions we focus on:

- Economy always on efficiency frontier
- Single market failure: climate change
- No unemployment or underemployment
- Complete crowding-out of investment
- Climate mitigation requires a decrease in consumption or investment

Fig. 2 | Climate policy pathways in DICE without and with an investment multiplier



Note: DICE’s baseline scenario, its optimal policy, and its cost-minimizing policy to limit warming to 2°C (in blue) are from Nordhaus and Barrage (2023). The optimal policy pathways with an investment multiplier of 0.25, 0.5, 0.75, and 0.9 (in red) are calculated by the authors.

Keynesian Economics in DICE

IPCC’s 6th assessment reports on mitigation & impacts both note potential for climate spending to boost GDP if a Keynesian outlook is adopted & the economy is not on the efficiency frontier. Based on a growing body of economic literature, both empirical & theoretical, indicating economies tend to operate below the efficiency frontier we incorporate an investment multiplier into DICE.

DICE models the level of output through a Cobb-Douglas production function, so we mimic an investment multiplier, m , by re-interpreting DICE’s abatement cost function as investment in decarbonization. In our specification, as the investment multiplier approaches 1, there is no cost to decarbonization. This is because every dollar investment in decarbonization increases current output by one dollar, so that decarbonization pays for itself.

$$Q(t) = \frac{[1-\Lambda(t)][A(t)K(t)^{0.3}L(t)^{0.7}+m\Lambda(t)]}{[1+\Omega(t)]}$$

Climate Policy Pathways with an Investment Multiplier

Accounting for modest investment multipliers substantially changes the optimal climate policy pathways. A multiplier of 0.25 suggests that emissions should peak in 2045; multipliers of 0.5, 0.75, and 0.9 all suggest that emissions should peak in 2025, with differences only in how quickly net-zero & negative emissions are obtained. Empirical evidence suggests multipliers in renewables are currently 1.1-1.5.

The addition of an investment multiplier also suggests that rapid decarbonization can lead to economic expansion. Assuming the investment multiplier is 0.75, our optimal climate policy path increases output by 0.7% in 2030 and by 1.5% in 2050, relative to what it would be following DICE’s optimal emissions path. These results suggest that small changes to the key assumptions in IAMs regarding how the economy operates can lead to significantly different conclusions regarding optimal climate action & its economic implications.

Beyond Offsetting: Leveraging the Voluntary Carbon Market as a Catalyst for Sustainable Development in Africa

(Theme: Economic Risks and Opportunities)

Idowu Kunlere, Kalim Shah



Abstract

Africa, despite contributing a relatively small share (4%) of global greenhouse gas emissions, bears a disproportionate burden of climate change's impacts. In addition, the continent has huge funding gaps, millions lack access to reliable energy, hindering sustainable development and exacerbating existing vulnerabilities.

The voluntary carbon offset market (VCM) has been touted as an emission reduction solution that also offers climate finance to address other challenges. However, the VCM's effectiveness in delivering tangible benefits remains a subject of debate.

While arguing that the VCM has a dual nature and can be harnessed to drive sustainable development, the paper links the VCM's weaknesses to its structure and suggest how these could be improved.

Introduction

Within the climate arena, innovative private climate financing or self-regulating systems such as the VCM have emerged due to perceived failures existing frameworks, such as the Kyoto Protocol's CDM's.

While entities such as the VCM offer promising avenues for addressing climate challenges, their success is far from guaranteed. Indeed, the VCM, like the preceding CDM, is considered ineffective in Africa thus far, leaving growing concerns about climate mitigation, climate finance, institutional capacity, and the worsening energy poverty situation amidst a rapidly growing population.

The study thus investigates how the VCM can be strengthened and harnessed to drive emissions reductions and investment in clean energy to address pervasive energy poverty on the continent.

Purpose & Research Question

This study investigates the challenges of the VCM in driving emissions reductions and fostering investment in clean energy, particularly within the context of improving energy access in Africa. Given the increasing public skepticism surrounding the VCM's efficacy as a climate finance and emissions reduction tool, the study highlights the underlying challenges hindering its effectiveness. The study frames these challenges as design-related defects and proposes a reformative framework to enhance the VCM's ability to improve energy access in critical regions across the continent.

Theoretical Framework

- The success of “innovations” like the VCM often depends on several factors, including the institutional capacity of their founders.
- We argue that the VCM's limitations of the are deeply rooted in its underlying design and structure. This structural framework, however well-intentioned, inadvertently hinders its ability to drive meaningful carbon emissions reductions.
- Thus, our theoretical approach (institutional theory) hinges on how collective pressure from private and public institutions (institutional pressure) can force or encourage steps that help private entities (such as the VCM) drive reforms (changes) that produce specific amplifiable impacts (compliance or beyond-compliance) across economic and social sectors.

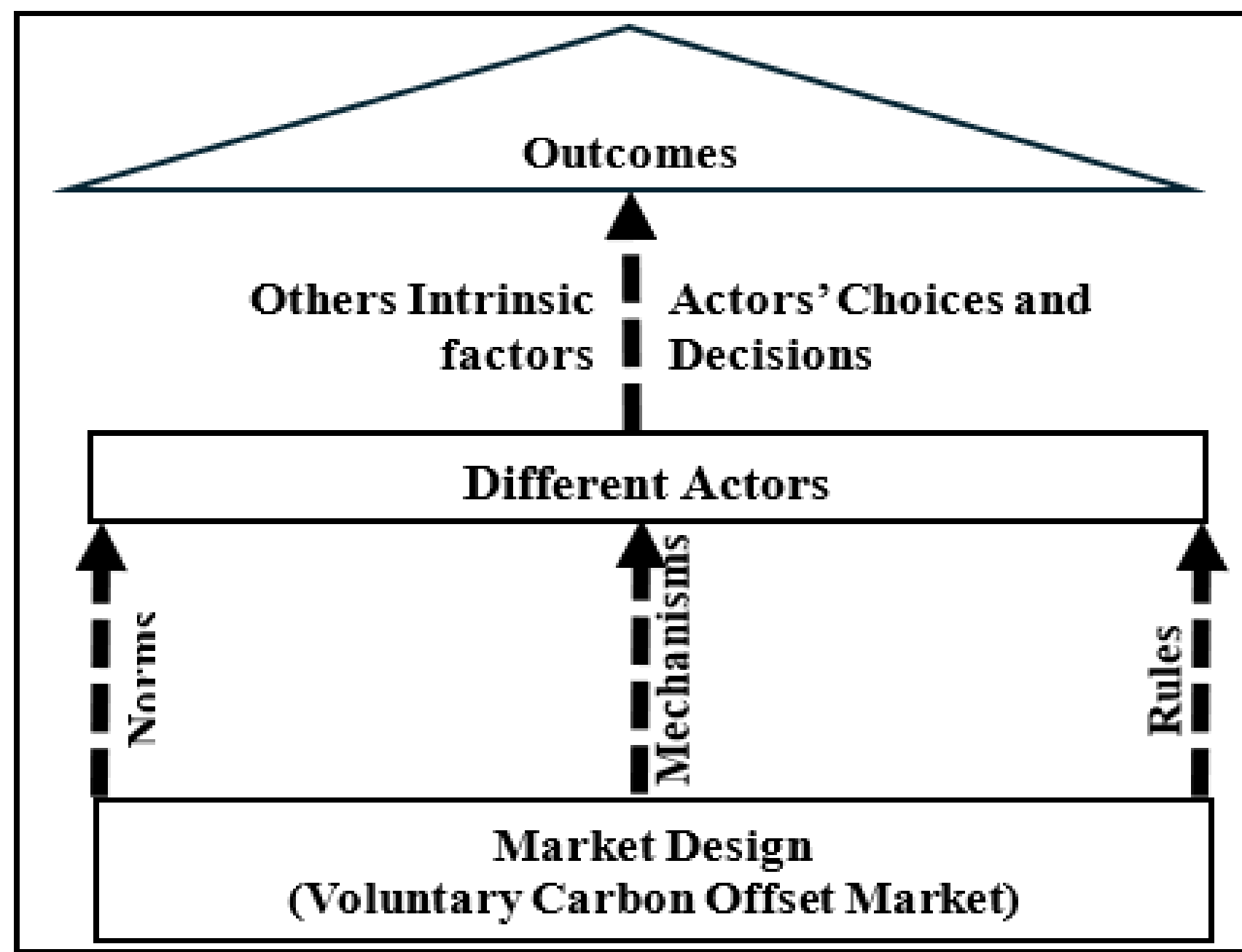


Figure 1: The VCM Design-Outcome Loop

Methods & Analysis

This paper employs a multi-method approach to examine the VCM's structural limitations and explore potential reforms to enhance its efficacy in reducing emissions and improving energy access in Africa. The methods include:

- Critical analysis
- Case studies
- Theoretical framing

Two case studies are utilized to provide empirical insights. The first examines the Clean Cooking Project in Ghana, and the second focuses on the Kuyasa CDM Solar Water Heater Project in South Africa. These case studies highlight the strengths and weaknesses of the VCM as both an emission reduction tool and a mechanism for enhancing energy access.

Results

The Landscape of Climate Finance in Africa



Figure 2: Africa needs at least nine times more climate finance (CPI, 2022)

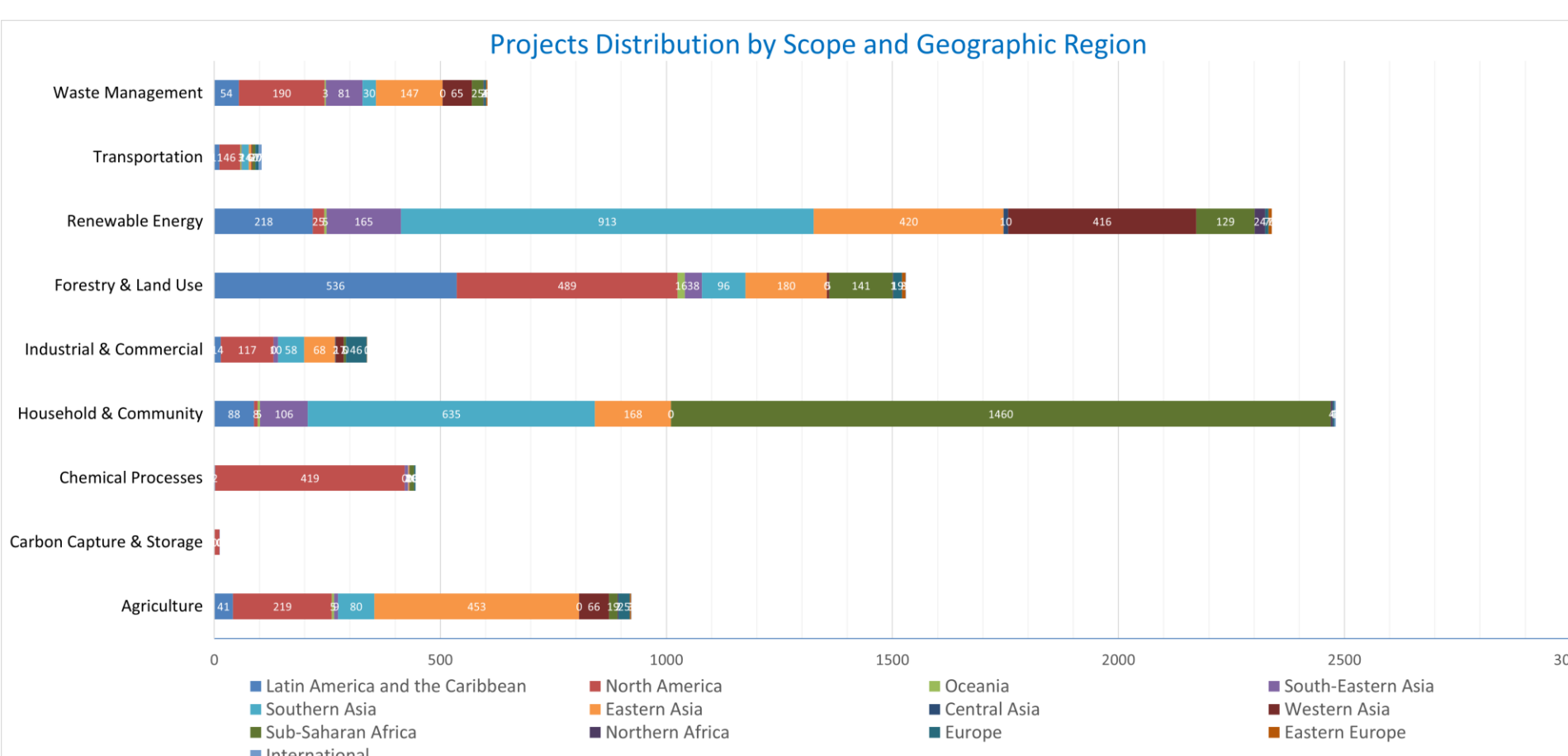


Figure 3: Clean energy projects are a small portion of the VCM projects in Africa (Haya et al., 2023)

Table 1: Case Study Framework Analysis

S/N	Case Study	Type	Strengths	Weaknesses
1.	Cookstove Project, Ghana	VCM	High emission reduction potential Significant health co-benefits	Scaling distribution can be challenging Monitoring and verification complexities
2.	Kuyasa CDM Project, South Africa	CDM	First CDM-linked project with solar thermal technology in Africa Social impact Extensive energy efficiency upgrades (energy savings)	Limited to a specific urban area (Small scale) Market dependency High upfront costs for implementation

The VCM's Limitations for Emissions Reduction and Sustainable Clean Energy Investments in Africa

The nature and circumstances of the VCM's inception and formative years have shaped its current landscape. These early characteristics, including its founding principles, governance structures, and initial market dynamics, confer advantages or limitations that define the VCM's overall effectiveness and impact and will likely influence its ability to achieve its long-term goals.

We identify two broad types of limitations within the VCM:

- Operational limitations: For example, inconsistent measurement, reporting, and verification (VCM) processes.
- Structural limitations: For example, the absence of robust regulatory frameworks, market fragmentation, and inherent power imbalances.

Thus, these design-linked attributes may partly explain some of the VCM's challenges and ineffectiveness.

Results

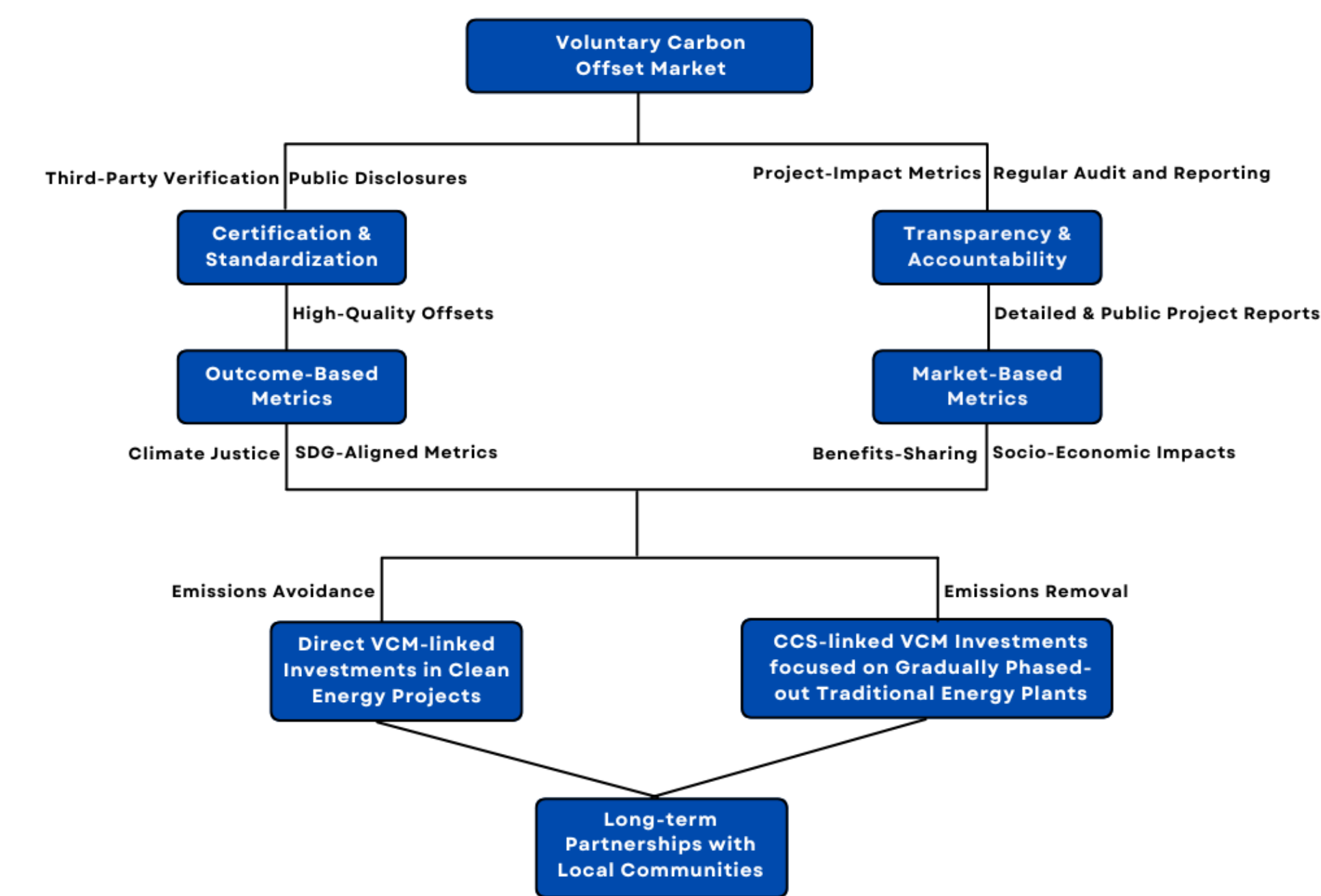


Figure 4: VCM projects targeted at driving emissions reduction and clean energy production

Conclusion and Future Directions

- Strengthening the VCM could help harness it to drive emissions reduction and clean energy investments simultaneously. This could strengthen climate mitigation and improve energy access on the continent.
- However, the continent requires the requisite institutional mechanisms, such as relevant policies, to harness the emerging VCM appropriately.
- More studies are required on the role of local institutions and system strengthening in effectively harnessing the VCM's dual purpose of driving sustainable development.

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Energy Transitions in Sovereign Native Nations of the American West

Tabitha Benney, PhD, Brett Clark, PhD, Jordan Giese, Jenna Murray, and Scott Collingwood, PhD, *University of Utah*

I. Introduction

Energy transition in the US de-prioritizes rural and tribal communities, but they are critical to securing the national grid

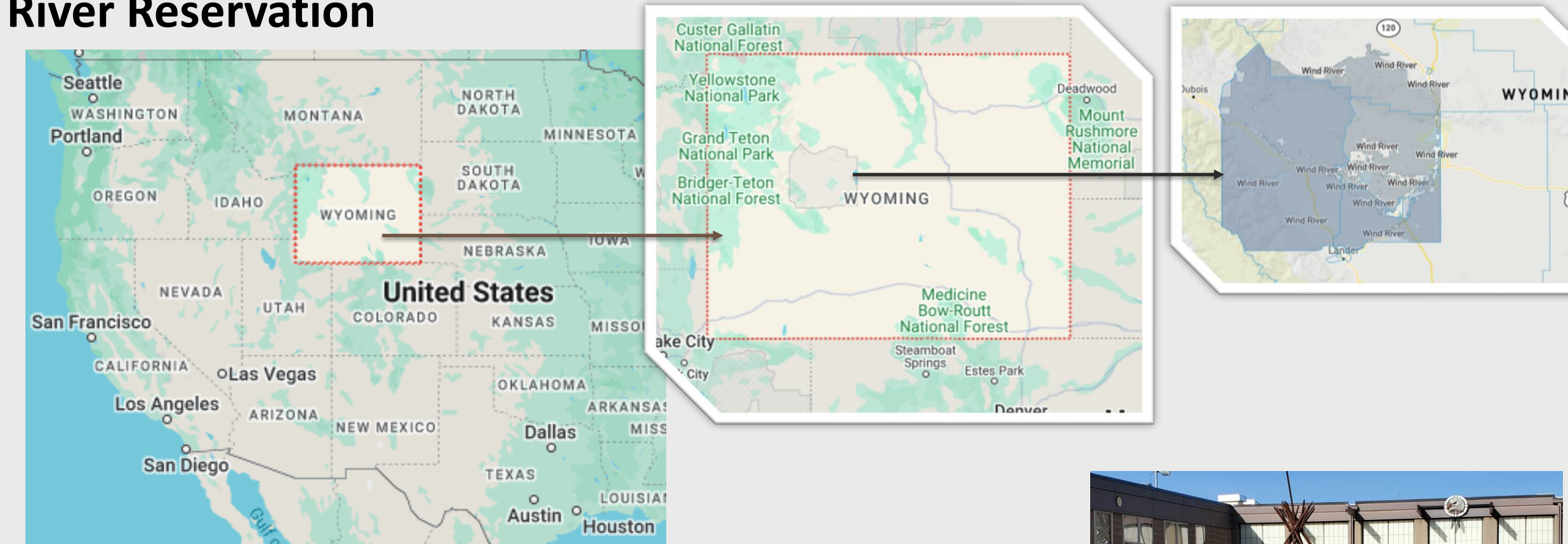
- Areas of grid insecurity make us all more vulnerable
- Rural and Tribal areas lead the critical mineral industry (which is needed for EVs and net zero energy transition)
- These groups provide a large portion of US energy resources

Native American communities have long-standing environmental practices and a tradition of taking care of nature

- 12th World Wilderness Congress (WILD12) – (Conservationists and Indigenous leaders from 36 nations) calls for greater support and autonomy for Indigenous bands, tribes, and nations leading in land and water protection
- The US, bipartisan infrastructure bill and Inflation Reduction Act (IRA), included \$14 billion in subsidies and incentives for wind and solar projects on tribal lands (Volcovici, 2023)

If Native Americans have historically been environmentalists and tribal lands are prime territory for profitable renewable energy generation - why are the tribes of the American West reluctant to participate?

Figure 1 – Map of the American West, the state of Wyoming, and the Wind River Reservation



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II. Theory

Colonial Settlement History

- Rural and tribal communities often had conflictual histories with the USG, which led to the dispossession of land and a legacy of mistrust
- The USG has produced social, political and economic structures that undermine development and lead to a legacy of weak or impaired self-determination on sovereign native nations (Yazzie, 2018)

Path Dependency

- Varying capacity and governance structures create gaps in governance
- Mining and energy extraction are often located in rural/tribal areas
- These industries contribute to uneven development, explain the lack of capital formation, and limit economic opportunities
- Weaker educational outcomes push local industries towards the incumbent technology, locking in fossil fuels and reducing the motivation to transition (Minx et al., 2024)

Fragmented Governance

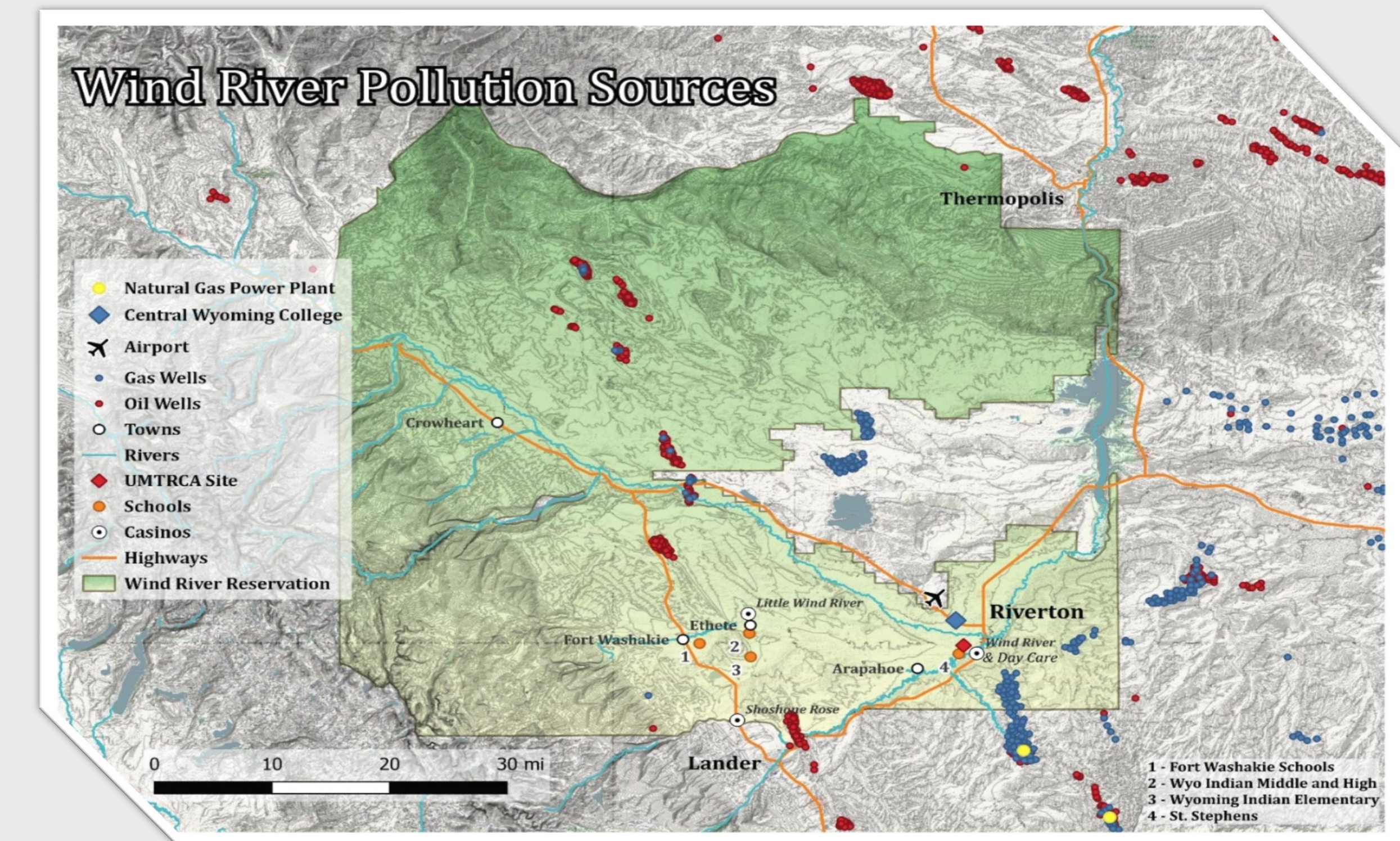
- US policy often fractures attempts at tribal governance by forcing tribes to be weak to be “legitimate” (Cattellino, 2010)
- Sovereign tribes are often ignored in US energy policy, but the unique rights, obstacles, and incentives of these actors are consequential

Identity

- Imbalances in power, development, and the rural landscape shape local identities, which in turn shape local industry and workforce
- Attempts to assimilate have led to large and wasteful bureaucracies (i.e., Bureau of Indian Affairs) and staggering poverty (Hipp, 2019)

Together, these factors further distract from clear energy goals and counter intuitive action or inaction often results in these communities

Figure 2 – Current Oil and Natural Gas Sites on the Wind River Reservation



III. Energy Transition Case Studies

Coal King and the Navajo Nation Case

- The Navajo nation had a long-standing tradition around coal-driven energy because they were disconnected from the larger US electricity grid and only had coal as an available energy solution

The Northern Arapaho of Wind River Case (Figure 1)

- **Settlement Impacts:** Colonial and modern history has been conflictual
- **Path Dependency:** (Figure 2) Oil and gas on the reservation has been a central source of revenue for tribal members for more than a century
- **Fragmented Governance:** With a conservative state government, strong gas interests and infrastructure combined with widespread energy insecurity and a lack of support for the Tribe in this area
- **Identity:** After the oil scandal, tribe began buying back the oil leases from outsiders and continued to develop the oil themselves

IV. Recommendations & Conclusions

1) Address a range of contexts and diversify (technology and scale)

Recognizing context and creating adaptive policies may produce more comprehensive and equivalent change

2) Energy Transition policy is focused on carbon pricing and subsidies, but this is not ideal for most Indigenous nations (e.g. skeptical of US policies and laws that favor other large capacity corporate actors)

- **Solutions** must involve dynamic sociotechnical policies that include fair and inclusive policies that prioritize all

3) Energy transition approaches must evolve beyond technical solutions to include grassroots social movements

- Social transformation must begin in civil society. The government can then support this change through coordinated policy intervention

4) Renewed Respect for Sovereignty, Self-Determination

- Co-creation of policy, community dialog, incorporating EDI, renewed respect for self-determination & sovereignty

Conclusion

- Factors related to colonialism, path dependency, fragmented governance and evolving identities, constrain rural and Tribal clean energy transitions
- U.S. Federal policy must address the predisposed features of Native energy issues if future clean energy is to be successful

This work was conducted in cooperation with the Northern Arapaho Tribe and funded by the College of Social and Behavioral Sciences, University of Utah



Unique Data on Decarbonization Strategies in the 2023 Annual Business Survey

Audrey E. Kindlon and Timothy R. Wojan

U.S. NSF, NATIONAL CENTER FOR SCIENCE AND ENGINEERING STATISTICS

The Annual Business Survey: Measuring Business Innovation and R&D in the United States

Innovation and research and development (R&D) are valuable to businesses in the United States that advance knowledge and help grow a competitive workforce.

The Annual Business Survey (ABS) collects data on the characteristics of U.S. businesses and owners from a sample of nonfarm, for-profit businesses. It is developed and is cosponsored by the National Center for Science and Engineering Statistics (NCSES) in partnership with the Census Bureau.

The ABS is the primary source of information about R&D expenditures and the R&D workforce for companies in the United States with one to nine employees, and it is the only survey to collect innovation information from employer businesses.

Businesses report information such as

- Characteristics of business owners
- Indicators of innovation, including environmental innovation
- Climate and sustainability
- Patenting and intellectual property, technology use, finance, and management practices

Data from the 2023 ABS can answer questions such as

- Are businesses introducing innovations with environmental benefits affecting consumers (Scope 3) or production (Scope 1)?
- What types of businesses develop plans for reducing carbon emissions? How ambitious are those plans? On what timescale?
- What strategies for reducing emissions are most common?
- Are more firms regarding energy as a make vs. buy decision owing to declining costs of wind and solar renewable energy and of battery storage?

Annual Business Survey—Environmental Innovation Questions (ABS 2023, reference year 2022)

E.3 Innovation and Environmental Benefits During Use of Goods or Services
During the three years 2020 to 2022, did this business introduce innovations with any of the following environmental benefits **obtained during the consumption or use of a good or service by the end user?** If "Yes," was the extent of that contribution a great deal or not? **Select one for each row.**

Yes, a great extent

Yes, but not a great extent

No

a. Reduced energy use or CO2 "footprint".....

☐

☐

☐

b. Reduced air, water, soil or noise pollution

☐

☐

☐

c. Facilitated recycling of product after use.....

☐

☐

☐

d. Extended product life through longer-lasting, more durable, or easier-to-repair products

☐

☐

☐

E.10 Innovation and Environmental Benefits Within This Business
During the three years 2020 to 2022, did this business introduce innovations with any of the following environmental benefits **obtained within this business?** If "Yes," was the extent of that contribution a great deal or not? **Select one for each row.**

Yes, a great extent

Yes, but not a great extent

No

a. Reduced material or water use per unit of output.....

☐

☐

☐

b. Reduced energy use or CO2 "footprint" (i.e., reduced total CO2 emission).....

☐

☐

☐

c. Reduced soil, noise, water or air pollution

☐

☐

☐

d. Replaced a share of materials with less polluting or hazardous substitutes

☐

☐

☐

e. Replaced a share of fossil energy with renewable energy.....

☐

☐

☐

f. Recycled waste, water, or materials for own use or sale.....

☐

☐

☐

Annual Business Survey—Climate and Sustainability Module (ABS 2023, reference year 2022)

H.1 Energy or Carbon Emissions Tracking
Does this business track energy use or carbon emissions from the following sources? **Select all that apply for each row.**

No, does not track either

Yes, tracks energy expenditures

Yes, tracks carbon emissions

Source is not applicable to this business or is inaccessible

a. Heating of buildings.....

☐

☐

☐

☐

b. Cooling of buildings.....

☐

☐

☐

☐

c. Fleet transportation

☐

☐

☐

☐

d. Electricity (used for lighting, computing, HVAC, production, etc.).....

☐

☐

☐

☐

e. Thermal energy in production (e.g., from natural gas, petroleum, coal, biomass, etc.).....

☐

☐

☐

☐

H.2 Carbon Emissions Reduction Plan
Has this business developed plans for reducing carbon emissions?
☐ Yes - Skip to "H.4 Carbon Emissions Strategies"
☐ No

H.3 Future Plans for Carbon Emissions
Is this business considering developing plans in the future for reducing carbon emissions?
☐ Yes
☐ No - Skip to "H.7 Sustainability Alternatives" on page 64

H.4 Carbon Emissions Strategies
Will this business implement any of the following strategies to reduce carbon emissions? **Select one for each row.**

Yes

No

a. Eliminating products or activities reliant on fossil fuel use by changing the company's product or service mix.....

☐

☐

b. Replacing fossil fuel using activities with zero or low emissions alternatives (e.g., adding electric vehicles to the company's fleet).....

☐

☐

c. Reducing carbon emissions by increasing the efficiency of activities using fossil fuels.....

☐

☐

d. Offsetting carbon emissions that cannot be abated by supporting projects that reduce carbon emissions elsewhere (e.g., providing funds for reforestation or capping abandoned oil wells).....

☐

☐

H.5 Carbon Emissions Reduction Goal Date
What is the target date for achieving this business's carbon emissions reduction goals?
☐ No target date set
☐ No later than 2030
☐ No later than 2040
☐ No later than 2050
☐ After 2050

H.7 Sustainability Alternatives
If this business is not successful at improving sustainability, does the business foresee any of the following effects? **Select one for each row.**

Yes

No

a. Fines for lack of compliance with regulations.....

☐

☐

b. Inability to raise capital or secure credit.....

☐

☐

c. A loss of customer trust.....

☐

☐

d. A loss of brand reputation.....

☐

☐

e. Hiring difficulties or lower employee retention.....

☐

☐

f. Financial risks associated with future policy changes such as a carbon tax.....

☐

☐

g. Lost sales due to inability to provide emissions or other environmental information to potential customers.....

☐

☐

H.8 Sustainability Investments
Is this business making any of the following investments to improve sustainability? **Select one for each row.**

Yes

No

Not applicable

a. Purchase power agreements for renewable energy.....

☐

☐

☐

b. Renewable energy generation on-site (e.g., solar, wind, geothermal) ...

☐

☐

☐

c. Battery storage or other means of saving renewable energy generation for later use.....

☐

☐

☐

d. Improved energy efficiency and management.....

☐

☐

☐

e. Engineering innovation to improve sustainability of our materials (e.g., innovating to produce goods with lower CO2 content).....

☐

☐

☐

f. Redesigning processes to make similar products with less environmental impacts

☐

☐

☐

g. Elimination of waste through circular economy or design for re-use strategies

☐

☐

☐

h. Recycling initiative going beyond municipal mandates

☐

☐

☐

Accessing ABS data through the Standard Application Process



Standardized process across statistical agencies



Common application form



Standard review criteria for access determination



Time frames for prompt determinations



Standards for transparency



An appeals process for adverse decisions

Accessing 2023 ABS Data for Research

Data for the ABS are collected under Titles 13 and 26, meaning that data access is limited to approved researchers at the Federal Statistical Research Data Centers (FSRDCs)

Researchers with an approved project through the Standard Application Process (SAP) must obtain Special Sworn Status. U.S. citizenship is not required, but the researcher must have resided in the United States for 3 years prior to applying.

To learn more about the SAP, visit researchdata.gov.

Linking the ABS to Other Relevant Data

The 2023 ABS, 2022 Manufacturing Energy Consumption Survey (MECS), and 2022 Economic Census, share the same reference year (2022). All will be available in the FSRDC.

2022 Manufacturing Energy Consumption Survey
Highly detailed energy use data for the manufacturing sector that accounts for the majority of commercial green house gas (GHG) emissions

- Application of the Environmental Protection Agency GHG emissions factor allows estimating establishment-level carbon ton equivalent emissions in the reference year
- Expenditures and quantities used of electricity, natural gas, diesel, butane, propane, coal, coke, gasoline, agricultural or paper waste, among others
- Information on fuel switching capabilities, energy management activities, and energy technologies

2022 Economic Census

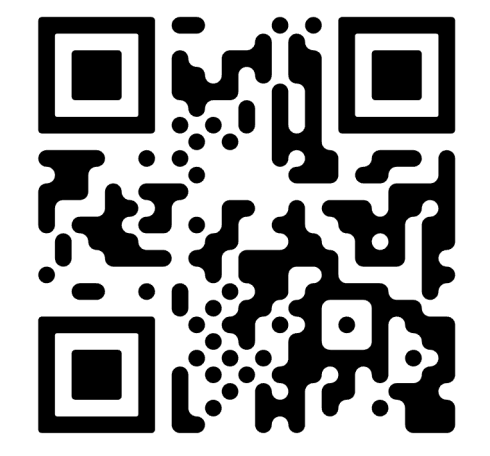
- Information on energy expenditures for many industries beyond manufacturing, as well as sales and employment of manufacturers, that is missing from MECS



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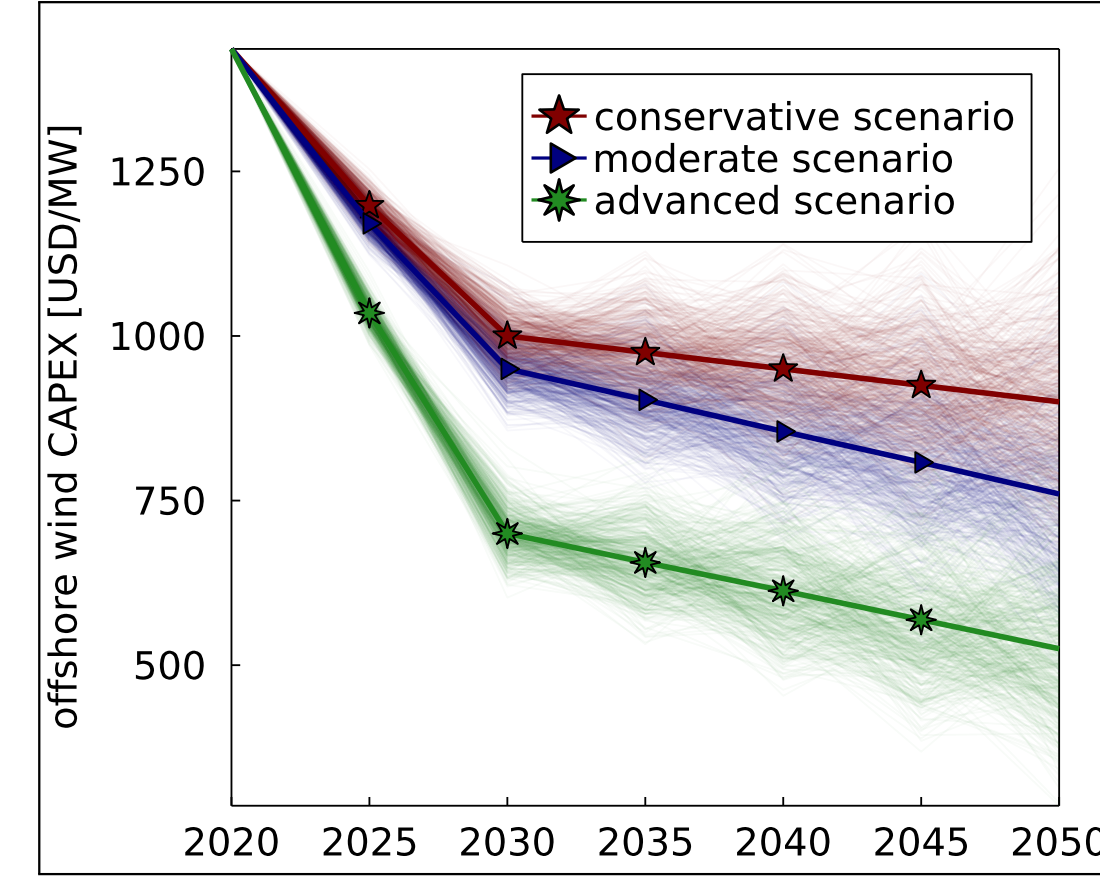
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Tim Wojan is a fellow in the Oak Ridge Institute for Science and Education Research Ambassadors Program through the National Center for Science and Engineering Statistics.



Key aspects of the long-term power system planning

- Large, spatially distributed energy infrastructures
- Long investment horizons (e.g., decades ahead, 2050 targets)
- Lack of expert consensus on the future of energy systems
- Hence, the investments are subject to long-term uncertainties



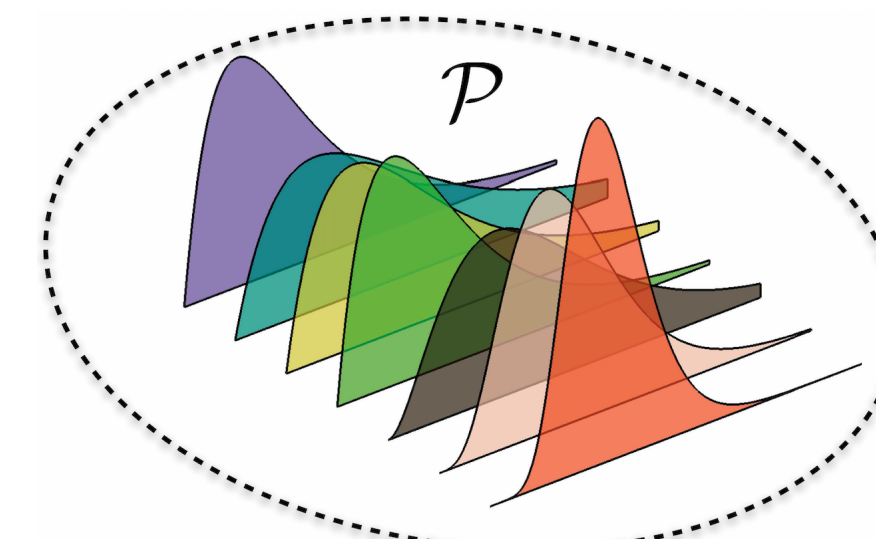
Uncertainty in the NREL cost scenarios

Incorporating long-term uncertainty using linear investment decision rules

Stochastic optimization program:

$$\begin{aligned} \min \quad & \mathbb{E} \left[\sum_{t=1}^T (\text{CAPEX}(t) + \text{OPEX}(t)) \right] \\ \text{s.t.} \quad & \text{Stochastic power balance} \quad \forall t = 1, \dots, T \\ & \text{Stochastic generation limits} \quad \forall t = 1, \dots, T \\ & \text{Stochastic investment limits} \quad \forall t = 1, \dots, T \end{aligned}$$

- Constrained cost minimization problem
- T -stage horizon (e.g., several stages up to 2050)
- Uncertain parameters (CAPEX, OPEX, demand, etc.) render investment decisions also uncertain

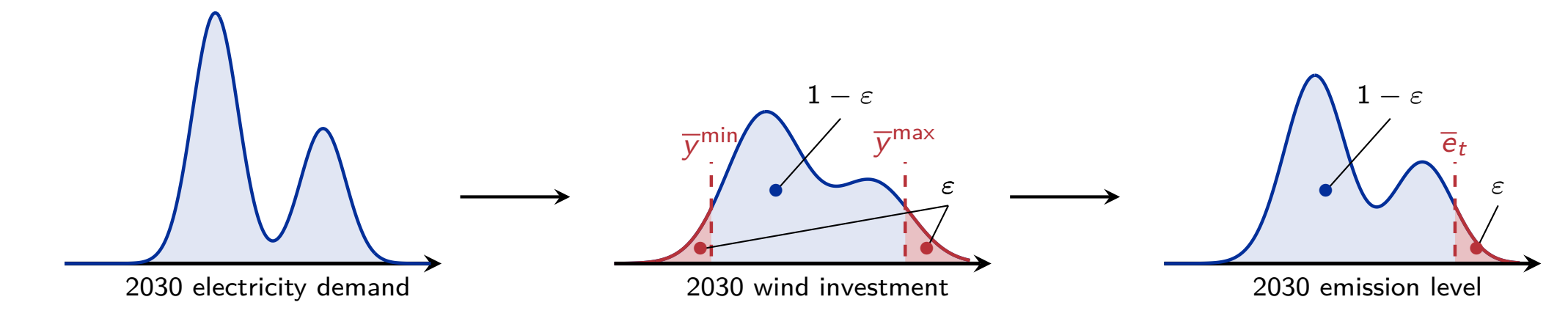


distributional ambiguity set

- We can discretize uncertainty using scenarios (can be intractable)
- Or use **linear decision rule (LDR)** for scenario-free approximation
- We can include all possible expert scenarios using **ambiguity set**

Performance guarantees for investment LDRs

- Uncertainty of planning parameters (costs, demand, etc.) translates into optimal decision uncertainty
- LDR are optimized to guarantee investment adequacy and policy constraint satisfaction with a high probability



- Chance constraints** ensure feasibility
- ε is a small parameter (e.g., 5%)

Investment feasibility

$$\mathbb{P}_{\xi^t} [\bar{y}^{\min} \leq \bar{Y}_t \xi^t \leq \bar{y}^{\max}] \geq 1 - \varepsilon$$

Policy feasibility

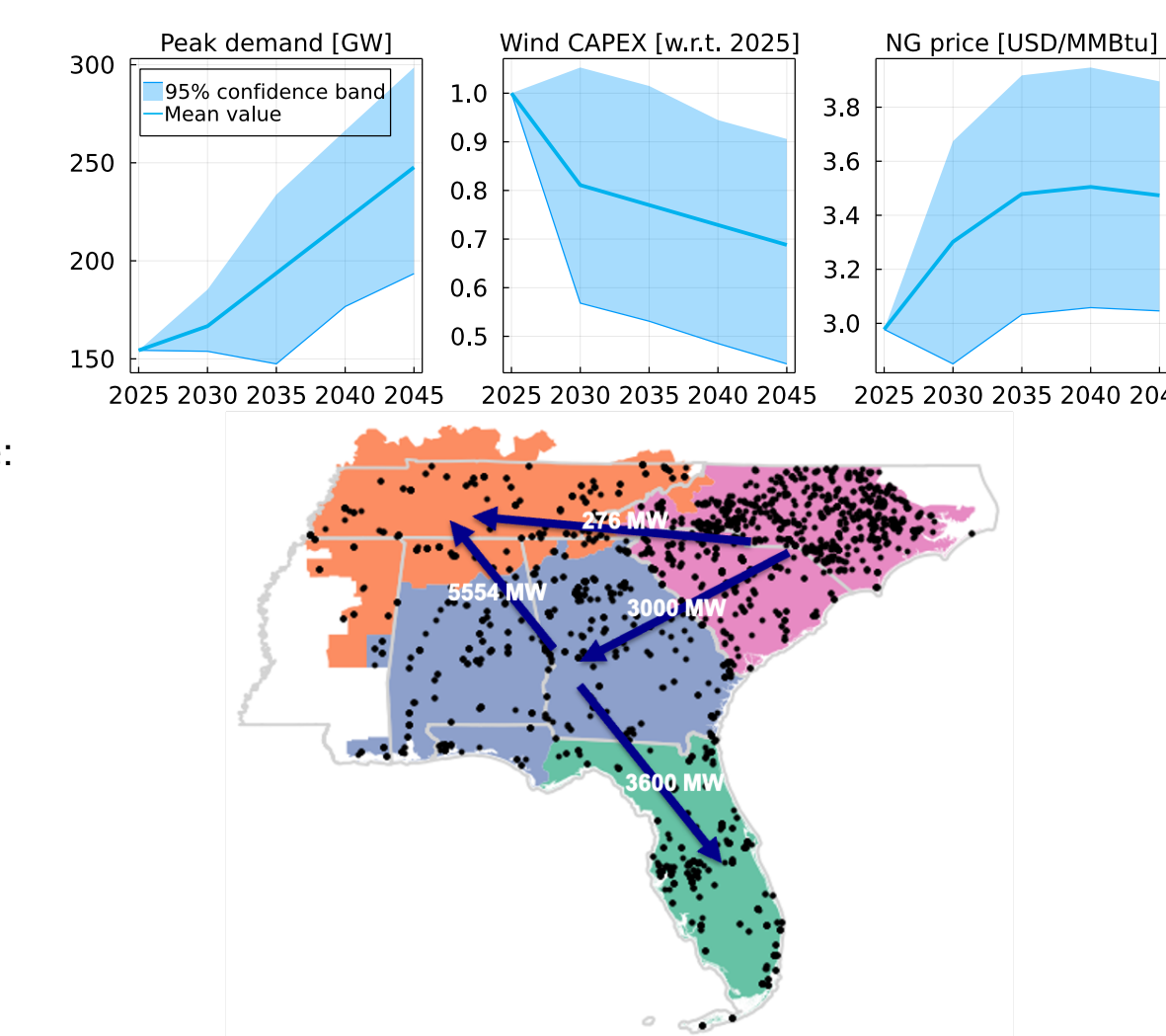
$$\mathbb{P}_{\xi^t} [e^T Y_t \xi^t \leq \bar{e}_t] \geq 1 - \varepsilon$$

- We also provide guarantees for the **optimality** and **minimal variance** of the LDR-guided investment plans

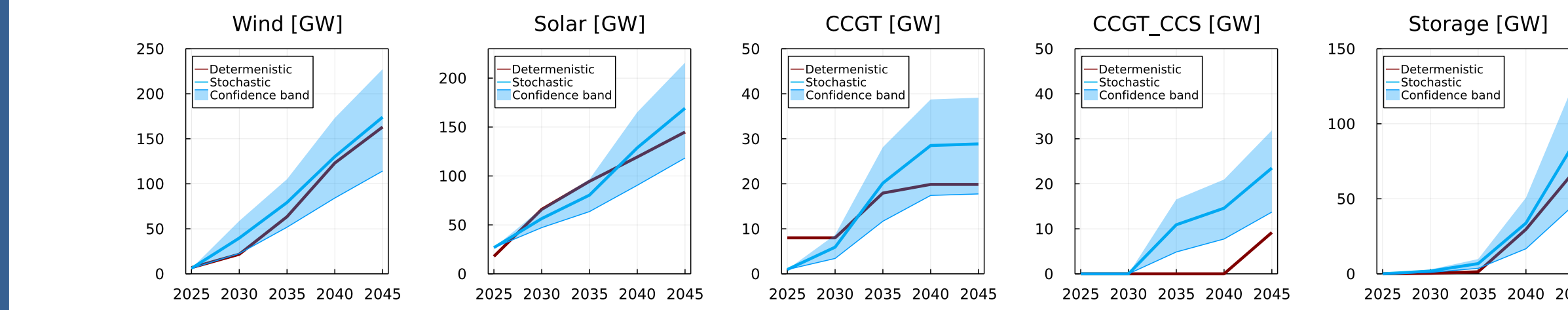
Case study: Southeast United States

- Investment stages: 2025, 2030, 2035, 2040, 2045
- 14 representative periods, 24 hours each
- Demand data from 2020 NREL electrification study
- Investment data from 2021 NREL Annual Technology Baseline:
 - Onshore Wind, PV, Li-ion Storage, CCGT, Nuclear
- Energy prices from the EIA Annual Energy Outlook 2021
- Annual emission cap baseline [Mt]:

	2025	2030	2035	2040	2045
	150	125	100	75	50



Deterministic vs. Stochastic Investment Planning



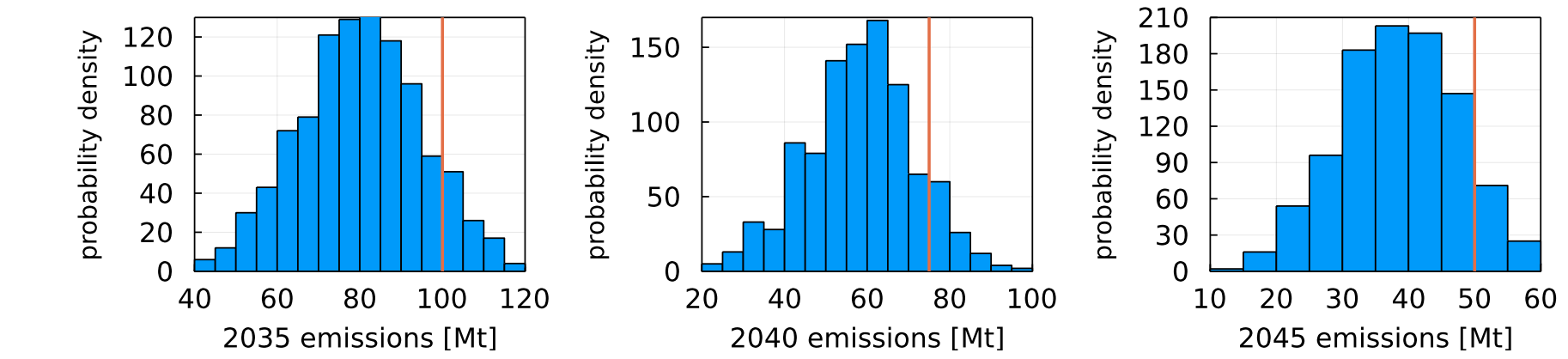
- Deterministic plan is insensitive to uncertainty
- Stochastic plan adapts to uncertainty
- First-stage decisions differ by ≈ 15 GW:
- To accommodate uncertainty, we need to act **now!**
- Cost of uncertainty** (in terms of planning costs):
 - Deterministic plan: **\$ 524.4 bil.**
 - Stochastic plan: **\$ 582.3 bil. (+11.0%)**
- Stress test** (on various uncertainty realizations):
 - Cost of load shedding is set to \$9000/MWh
 - Deterministic plan: **\$ 6,607.3 bil. ($\times 11.7$)**
 - Stochastic plan: **\$ 584.1 bil.**
- Key observations:**
 - Deterministic plan is less expensive but fails to meet demands in all uncertainty realization scenarios
 - Stochastic plan is more expensive but accommodates uncertainty successfully

Trade-offs between policy feasibility in investment planning costs

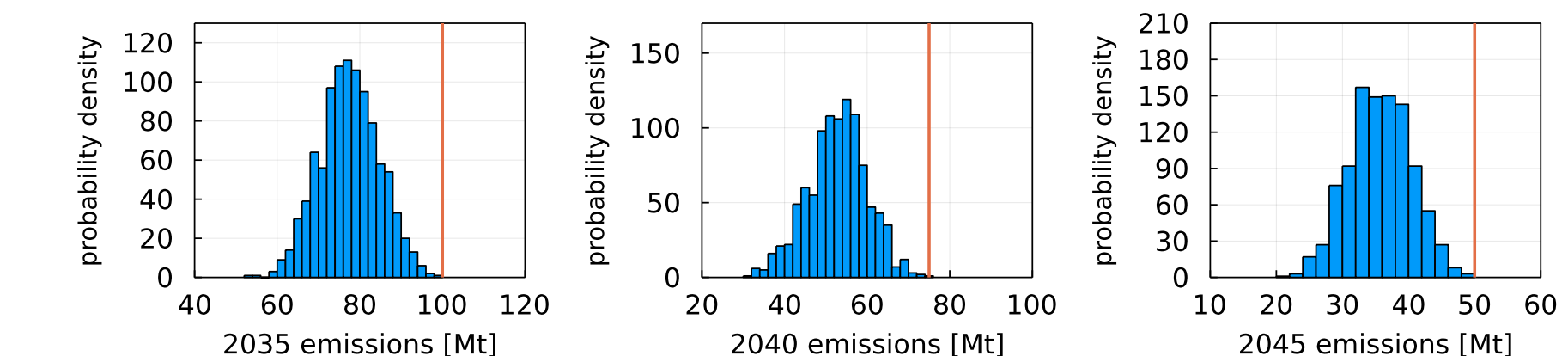
- We compare two stochastic investment plans
- With different risk tolerances towards emission cap violation

$$\mathbb{P}_{\xi^t} \left[e^T Y_t \xi^t \leq \bar{e}_t \right] \geq 1 - \frac{\varepsilon}{\text{tolerance}}$$

- Plan I: Risk tolerance $\varepsilon \rightarrow 10\%$. Cost of investment plan **\$567.6 bil.**

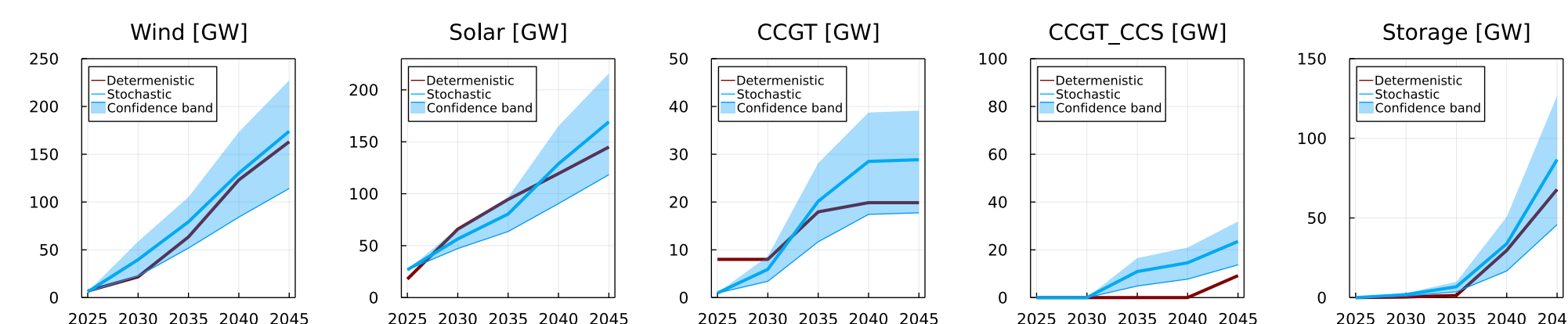


- Plan II: Risk tolerance $\varepsilon \rightarrow 0.1\%$. Cost of investment plan **\$582.3 bil. (+2.6%)**

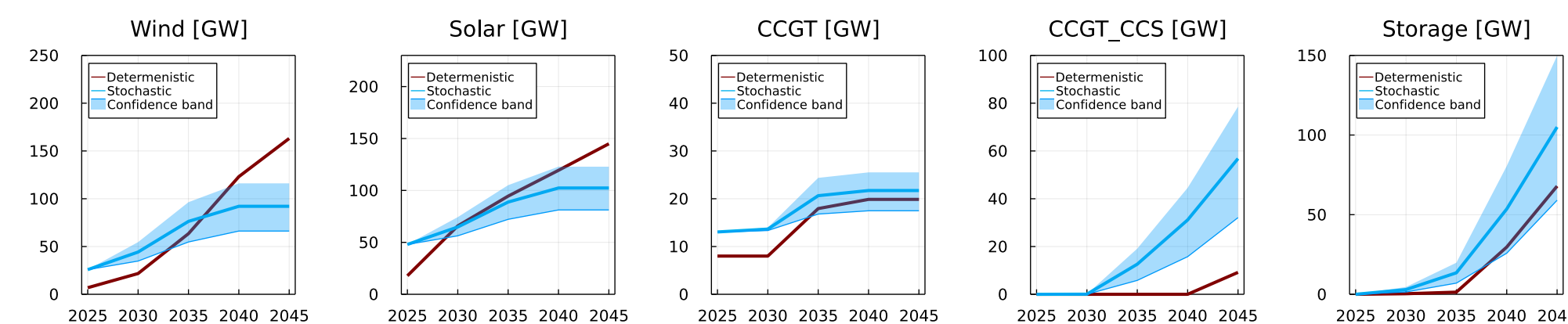


LDRs help exploring different pathways to decarbonization

- Uncertainty-sensitive plan.** Investment standard deviation: **379 GW**, cost: **\$582.3 bil.**



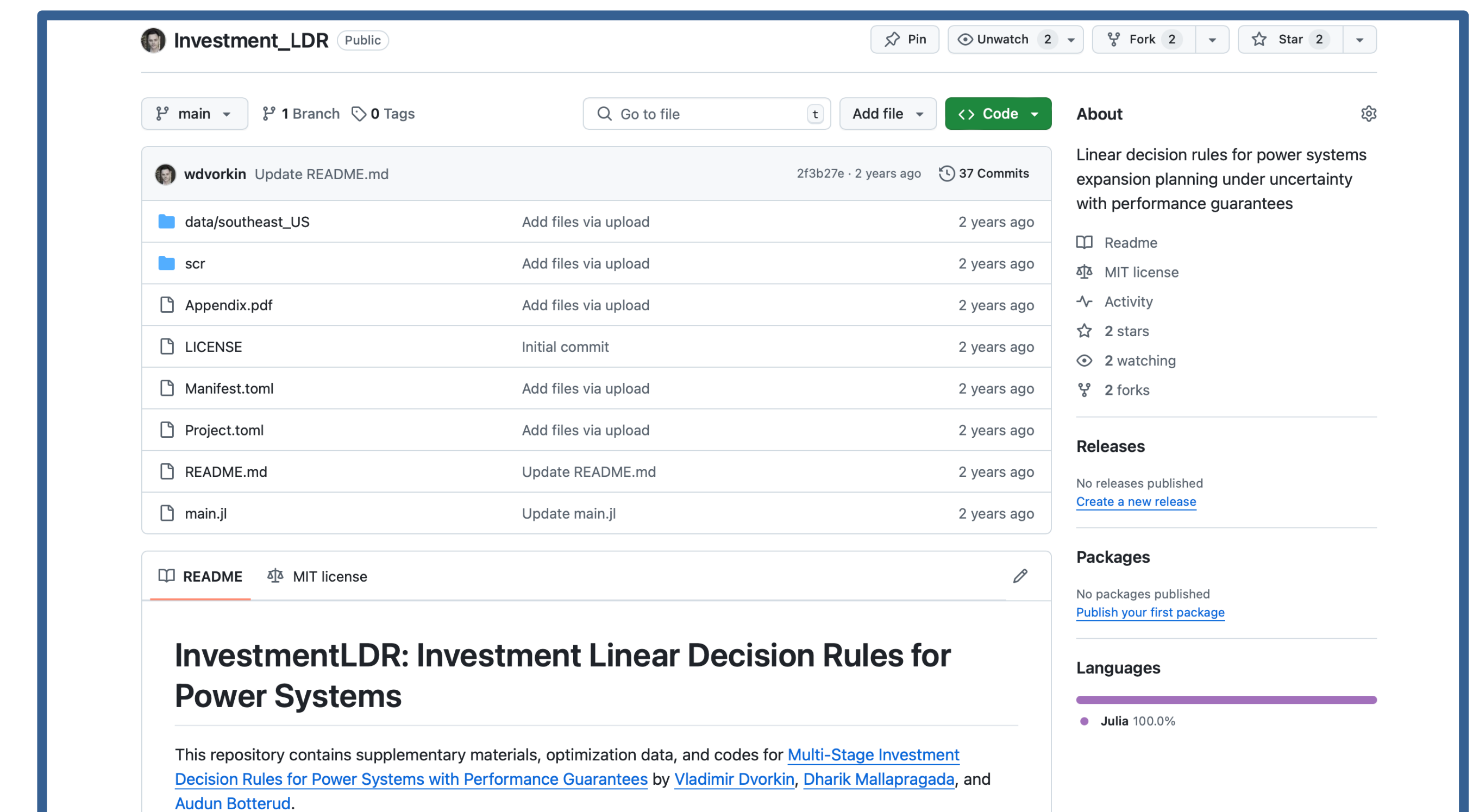
- Less sensitive plan.** Investment standard deviation: **196 GW (-51.7%)**, cost: **\$722.3 bil. (+24.0%)**



- LDR helps accommodating different tolerances to the **"stochasticity"** of the investment plan

Investment planning for Southeast US: Conclusions

- LDRs accommodate long-term uncertainty and its ambiguity in generation and storage investment planning
- Deterministic investments feature small planning cost but fail to meet uncertainty realizations in a feasible and cost efficient manner (e.g., frequent load shedding, ignorance to capex reducing scenarios)
- Linear decision rules enable a computationally tractable (≈ 30 min.) stochastic investment planning
- Chance constraints provide trade-offs between expansion costs and carbon policy satisfaction under uncertainty
- By optimizing investment sensitivity to uncertainty, the decarbonization targets can be met via different pathways:
 - Stochastic wind and solar investment plan and certain CCGT-CCS investments ... or
 - Certain wind and solar investment plan and stochastic CCGT-CCS investments
- Software** and **preprint** are out by the end of the month



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References

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Acknowledgements

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Modeling the effects of policy sequencing on energy decarbonization

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**These two authors contribute equally to this paper

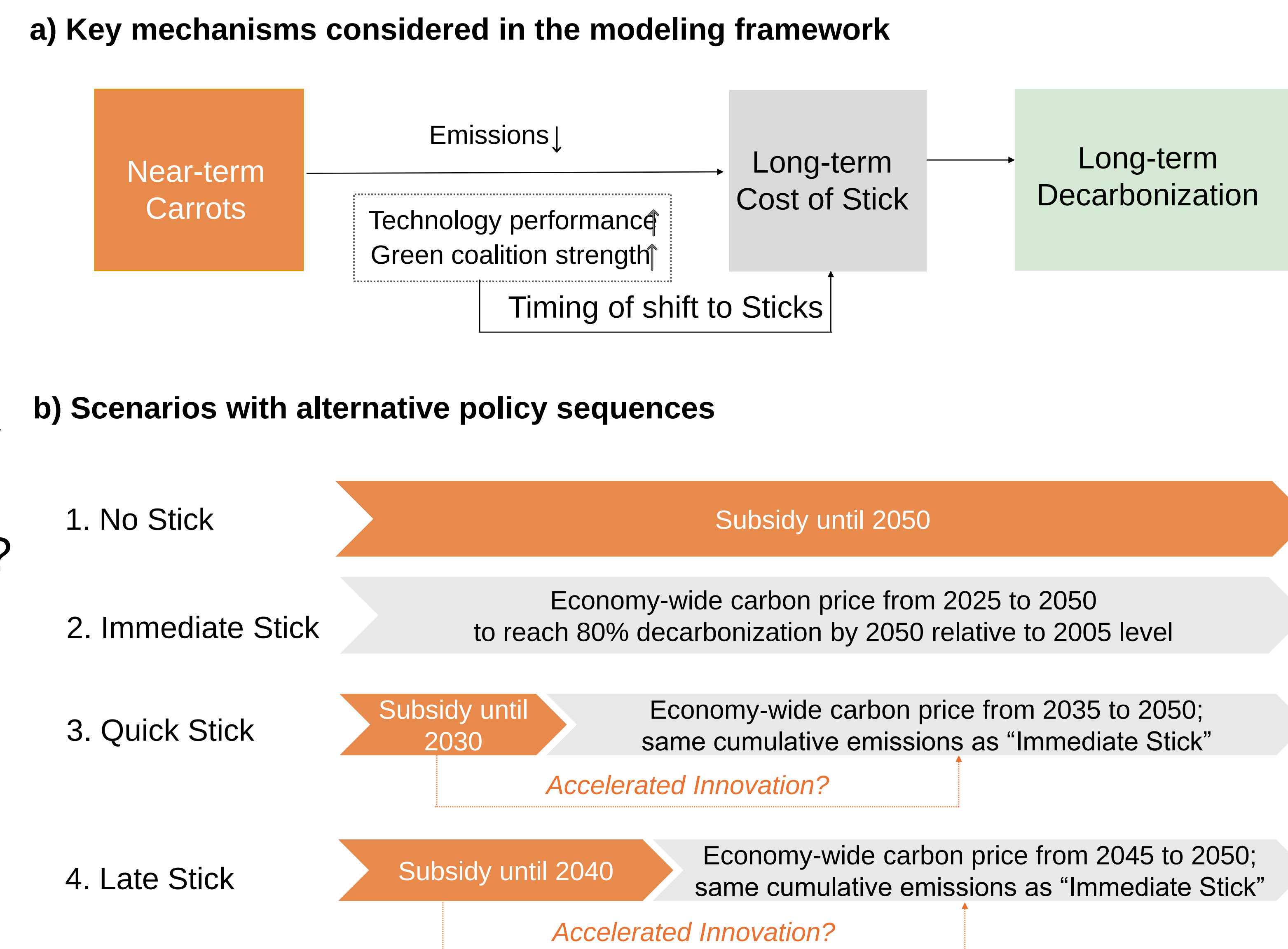
Introduction

- Policy experts favor carbon taxes (“sticks”), but most governments respond to political incentives that cause policy to rely heavily on clean technology subsidies (“carrots”).
- Research question - Impacts of a policy sequence of carrots to sticks:** How does the politically realistic policy approach to control emissions that relies initially on heavy subsidies compare with the idealized approach that relies on sticks from the onset?

Methodology

- Core model: A state-level integrated assessment model, GCAM-USA.
- “Carrots”: Subsidies included in the Inflation Reduction Act and other current policies.
- “Stick”: Economy-wide carbon price

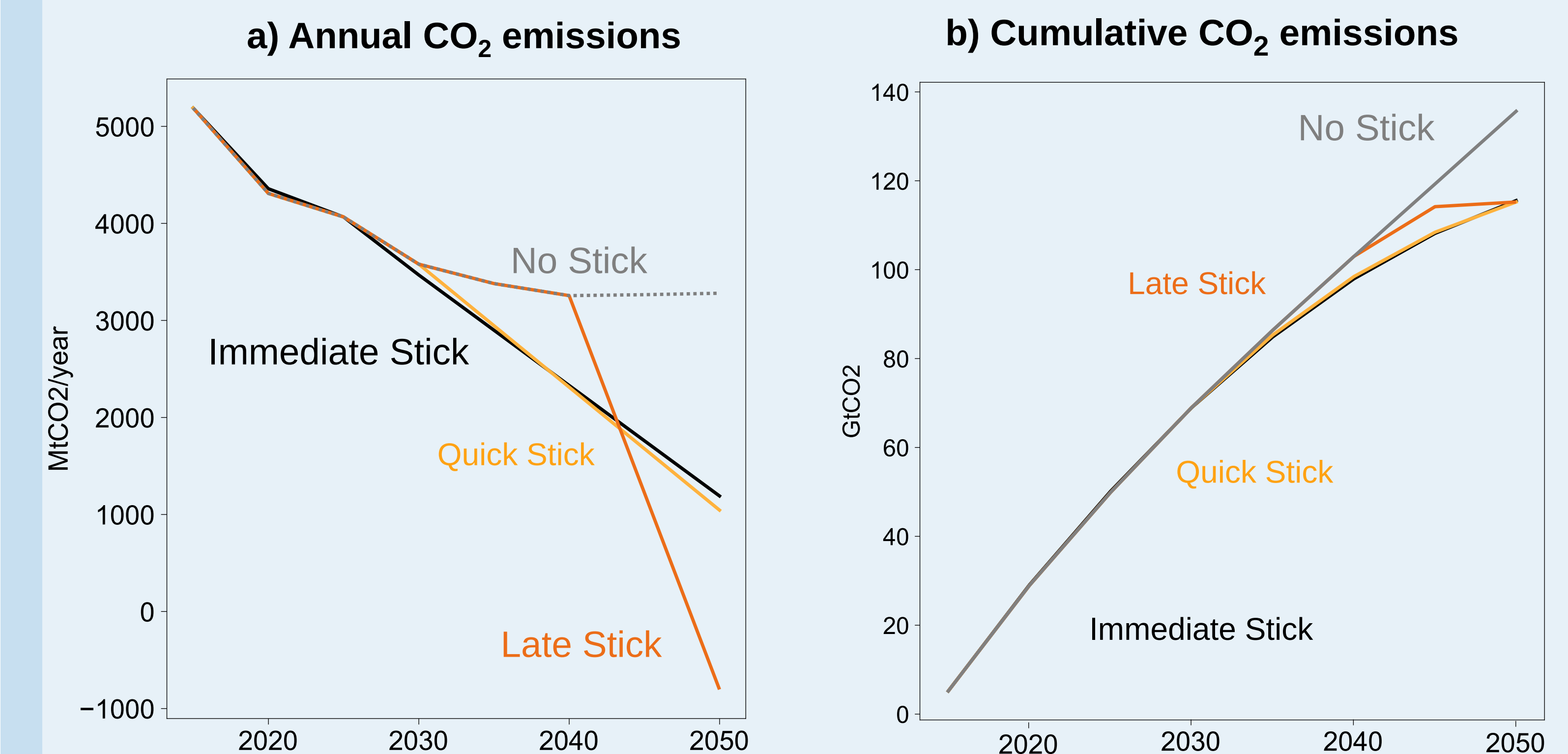
Figure 1. Overview of our modeling approach.



Sticks are essential for deep decarbonization.

- Carrots alone are unlikely to achieve deep decarbonization by mid-century.
- Extending the carrots to 2040 and introducing sticks late pushes for a much deeper cut in emissions in the last decade.

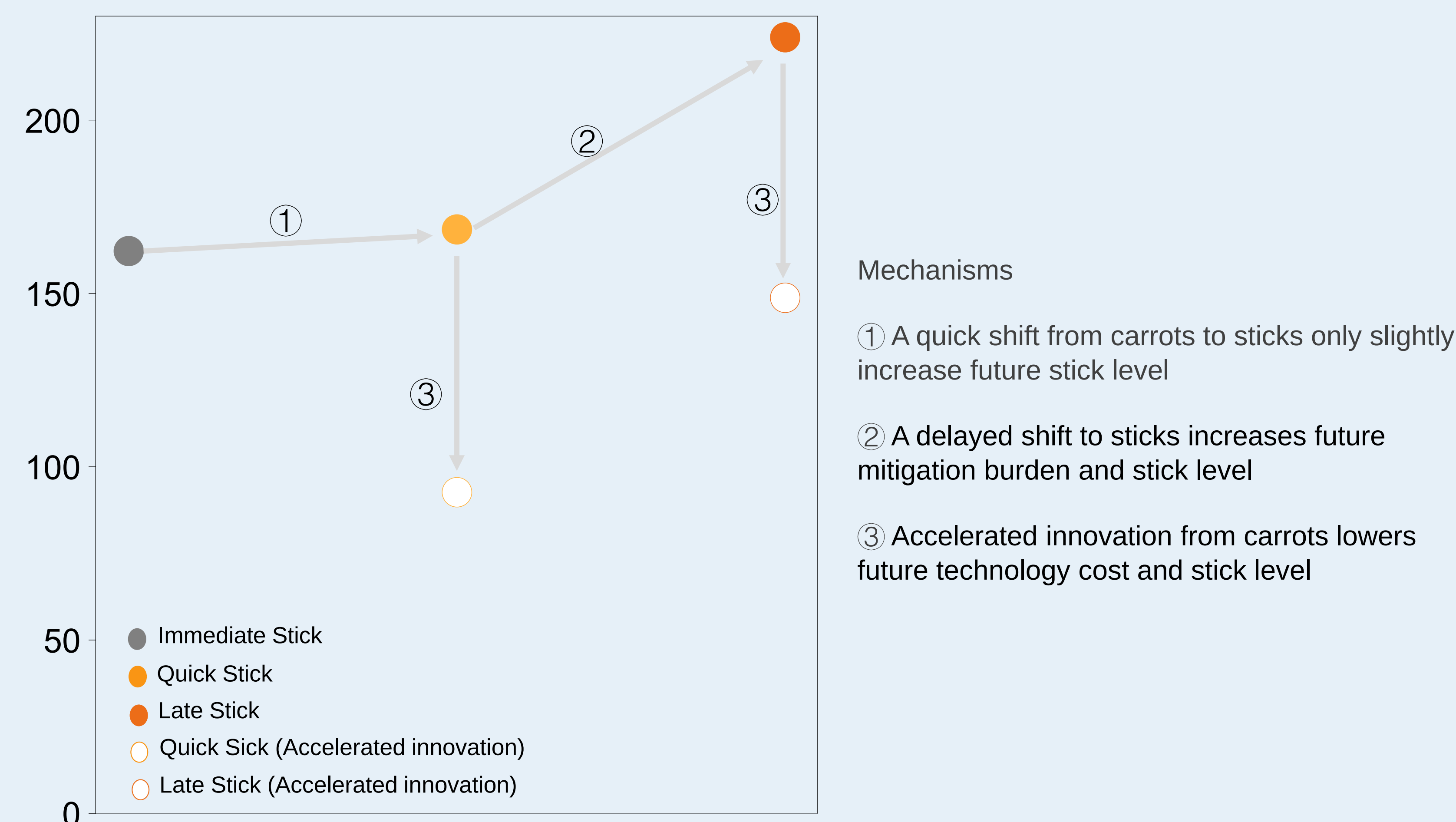
Figure 2. Energy system CO₂ emissions



Carrots are effective if (1) the shift to sticks is faster and (2) consequent reductions in technology costs are accelerated.

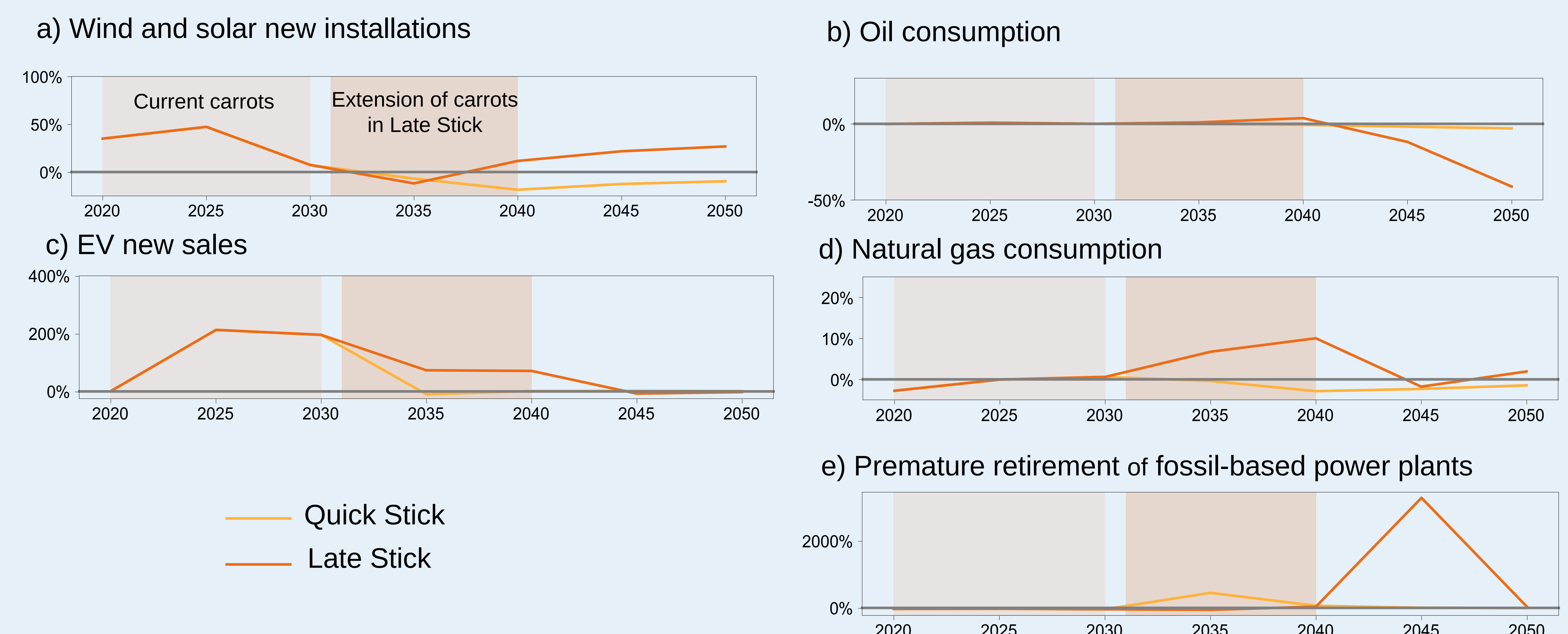
Faster transition to sticks if carrots could accelerate technology innovation and strengthen green coalition.

Figure 3. Impacts of alternative policy sequences on emission reduction required for the stick stage and the associated stick level in 2050



Carrots support the growth of green industry, but do not harm fossil industry - potentially strengthen the green coalition but unlikely to weaken the fossil interest groups.

Figure 4. Uneven impacts on green (left column) and fossil technologies (right column) in “Quick Stick” and “Late Stick” scenarios compared to “Immediate Stick”.



Introduction

By neglecting to incorporate life cycle assessment (LCA) during decarbonization planning, the predicted outcomes of such plans may overestimate their actual climate change mitigation benefits. We quantified the overlooked life cycle greenhouse gas (GHG) emissions of the projected changes in the electricity sector described in California's deep decarbonization plan (the 2022 Scoping Plan) using detailed geospatial LCA in order to determine the importance of their inclusion for effective decarbonization strategy.

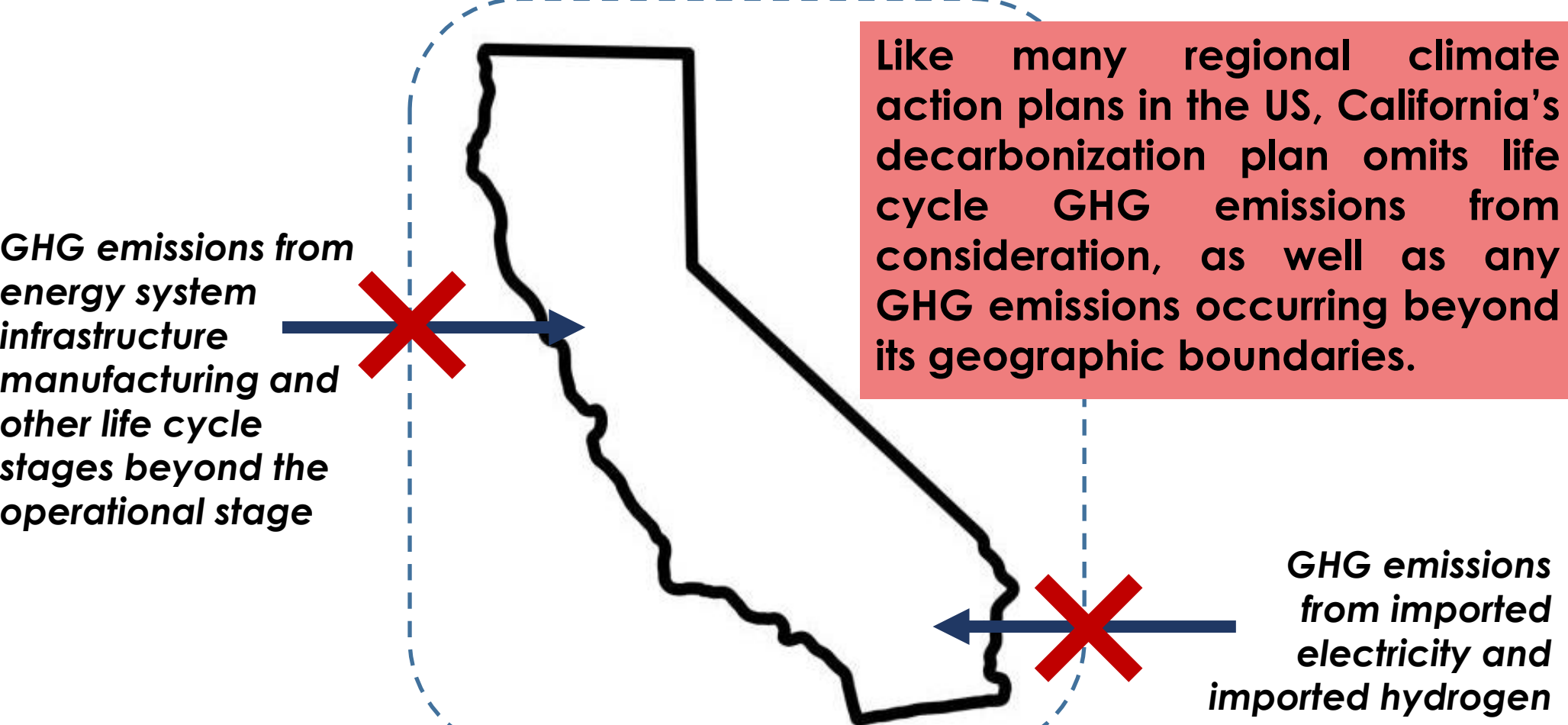


Figure 1: The life cycle GHG emissions currently omitted from California's decarbonization plan for the electricity sector by 2045.

Why does this matter?

For renewable energy systems such as wind farms or solar power plants, the majority of GHG emissions tend to occur early along their life cycles, creating a large "pulse" of emissions. **This sudden increase in GHG emissions and its climate change impacts at the scale of the global energy transition are being overlooked by decarbonization plans.**



Figure 2: Conceptual graph of the timing of GHG emissions along the life cycle of a renewable electricity generation system.

These life cycle GHG emissions are:

- not evenly spread out throughout the life cycle,
- not "zero emission" even during the operational phase due to maintenance needs, and
- variable by installation site due to differences in natural resource availability that affects the performance and productivity of renewable energy systems.

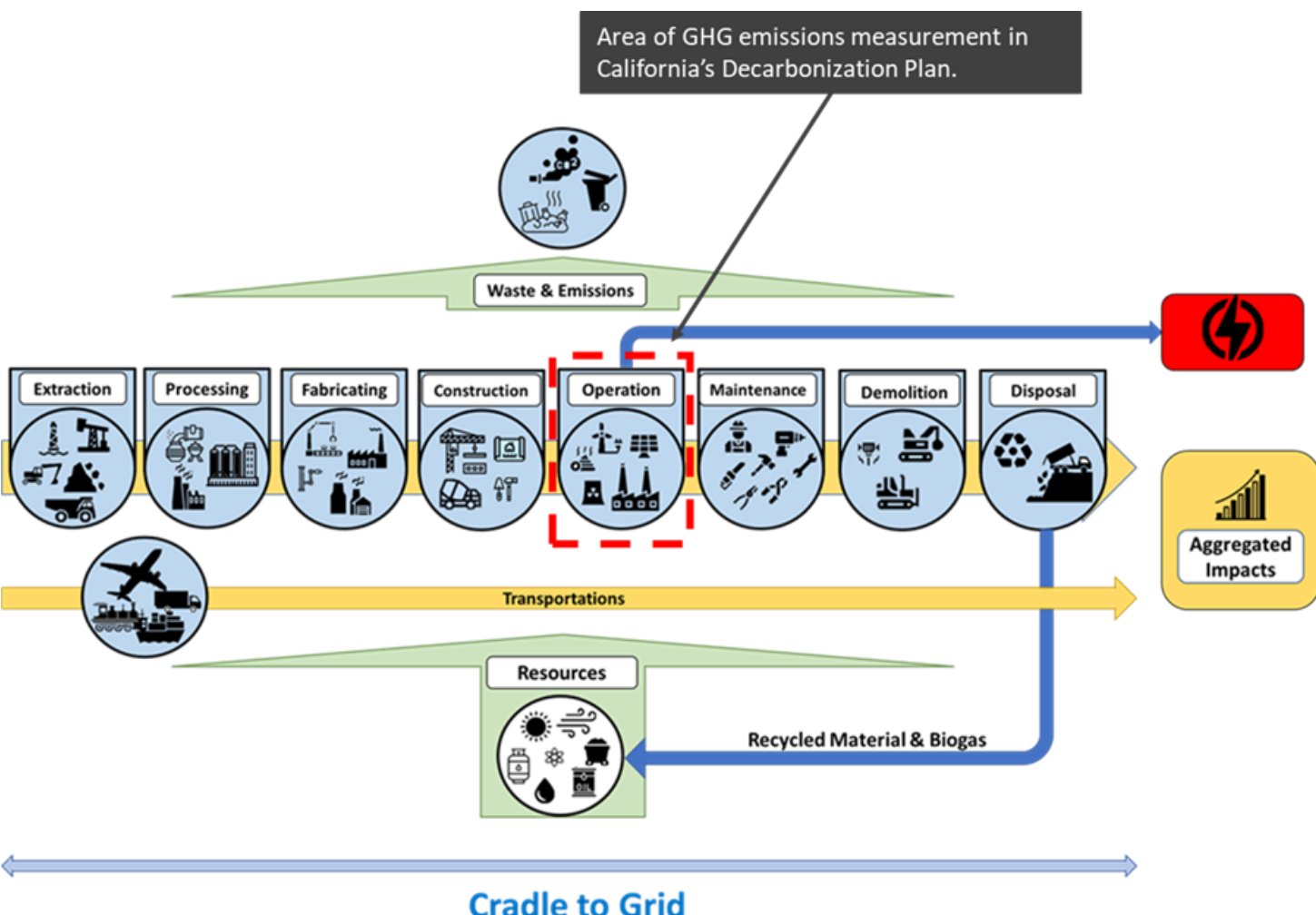


Figure 3: Processes along the life cycle of energy systems, which can contribute GHG emissions beyond the operational stage.

Methods

California served as a case study due to its ambitious decarbonization plan that explicitly omitted life cycle GHG emissions and GHG emissions from imported electricity, and because of its geographically diverse resources across its 163,696 mi² area and 840-mile coastline.

Thus, to identify the best-predicted performance and the lowest GHG emission power system locations in California while meeting the capacities projected by the Scoping Plan, a Python pipeline algorithm was developed. Future climate conditions were incorporated into this analysis.

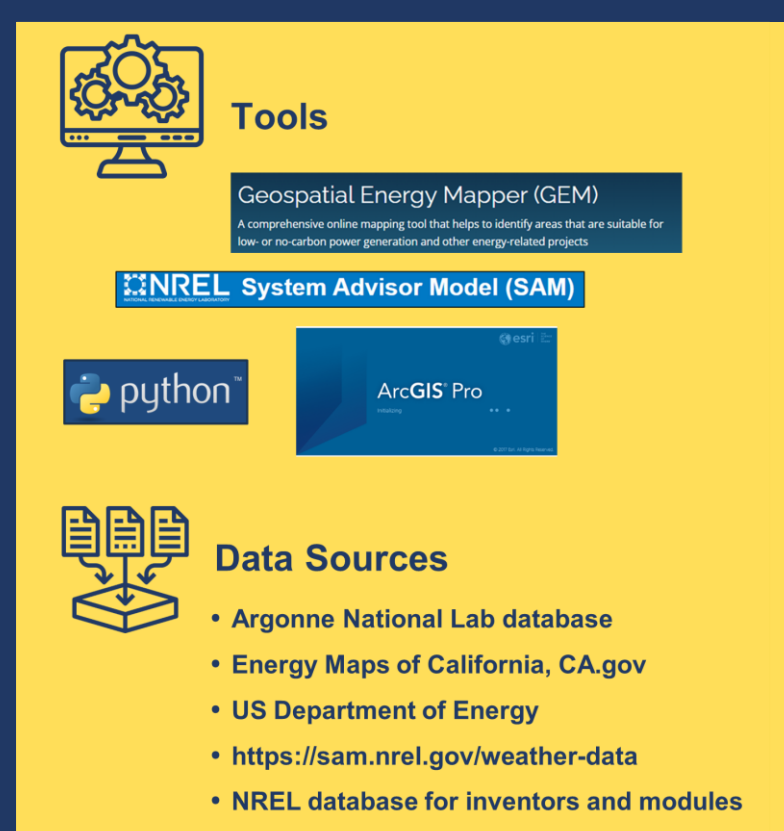


Figure 4: Data sources and tools used in this study

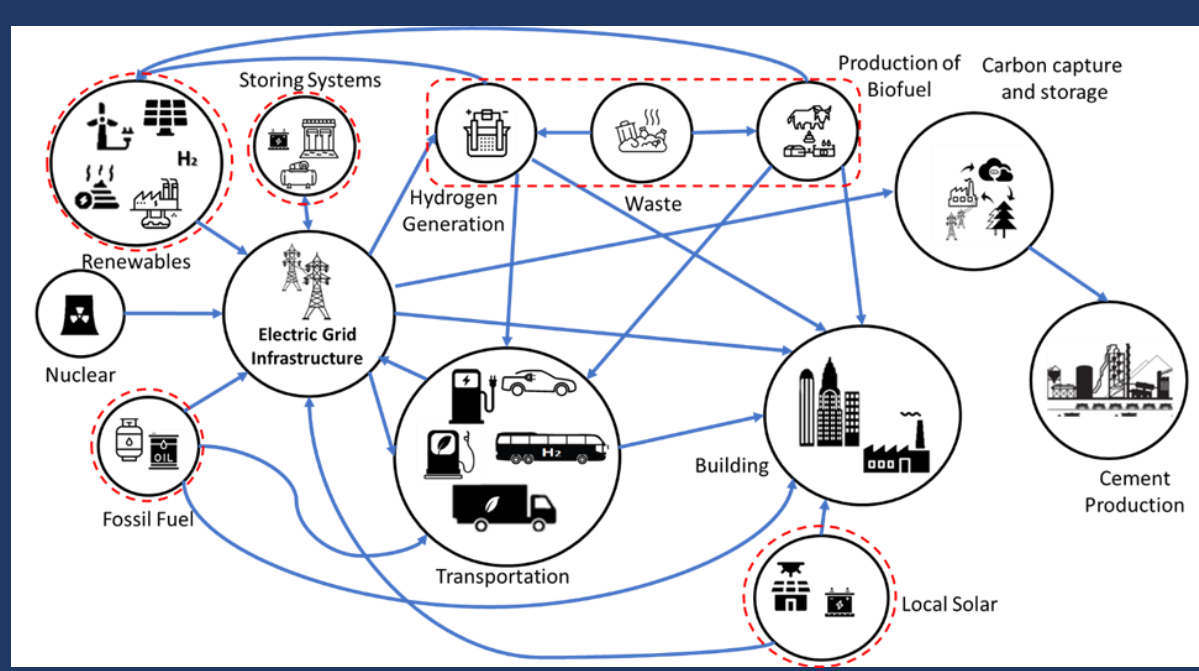


Figure 5: Sectors included in the analysis of California's Scoping Plan

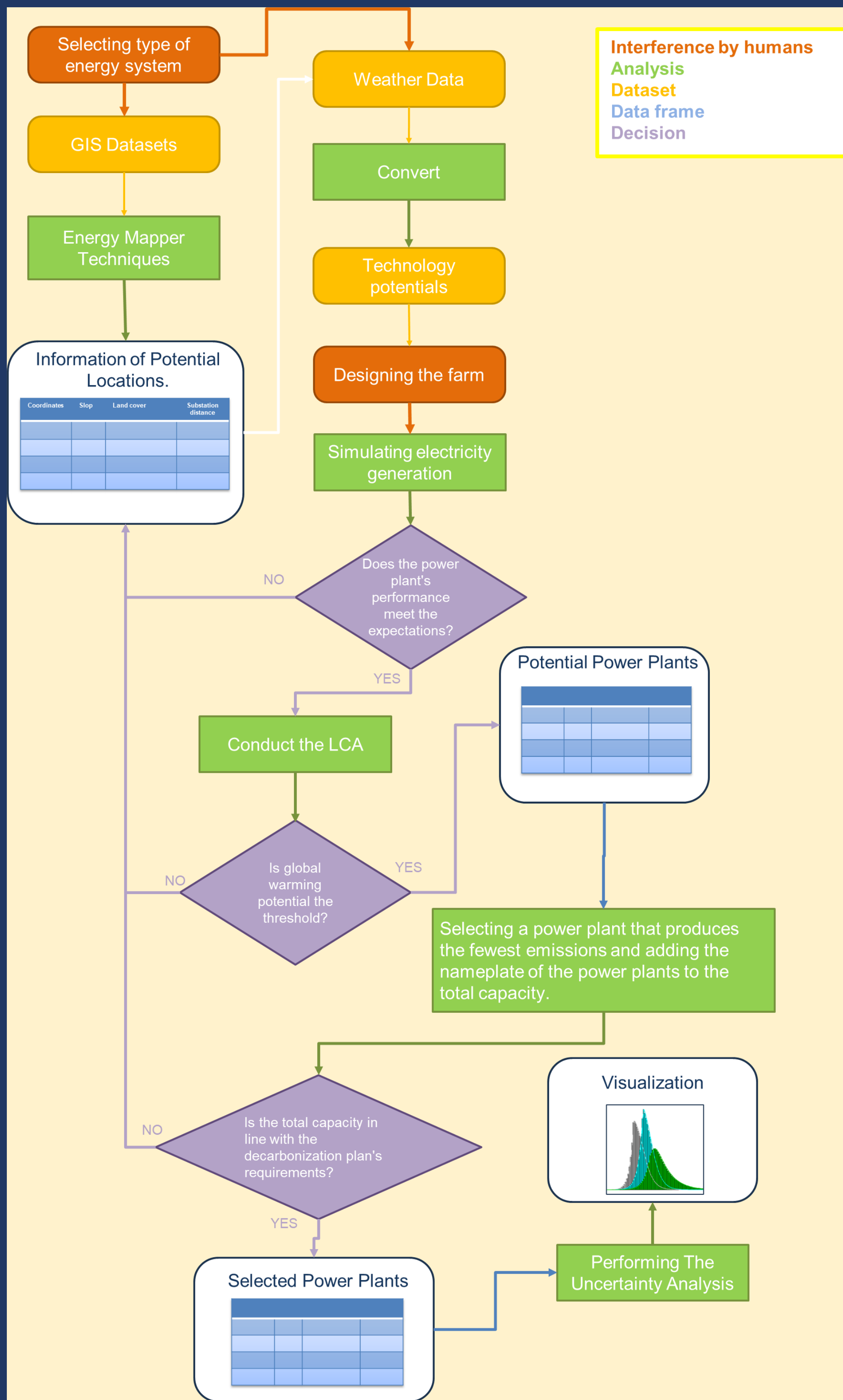


Figure 6: Pipeline algorithm for siting and designing renewable energy power plants for the California decarbonization plan

Results and Discussion

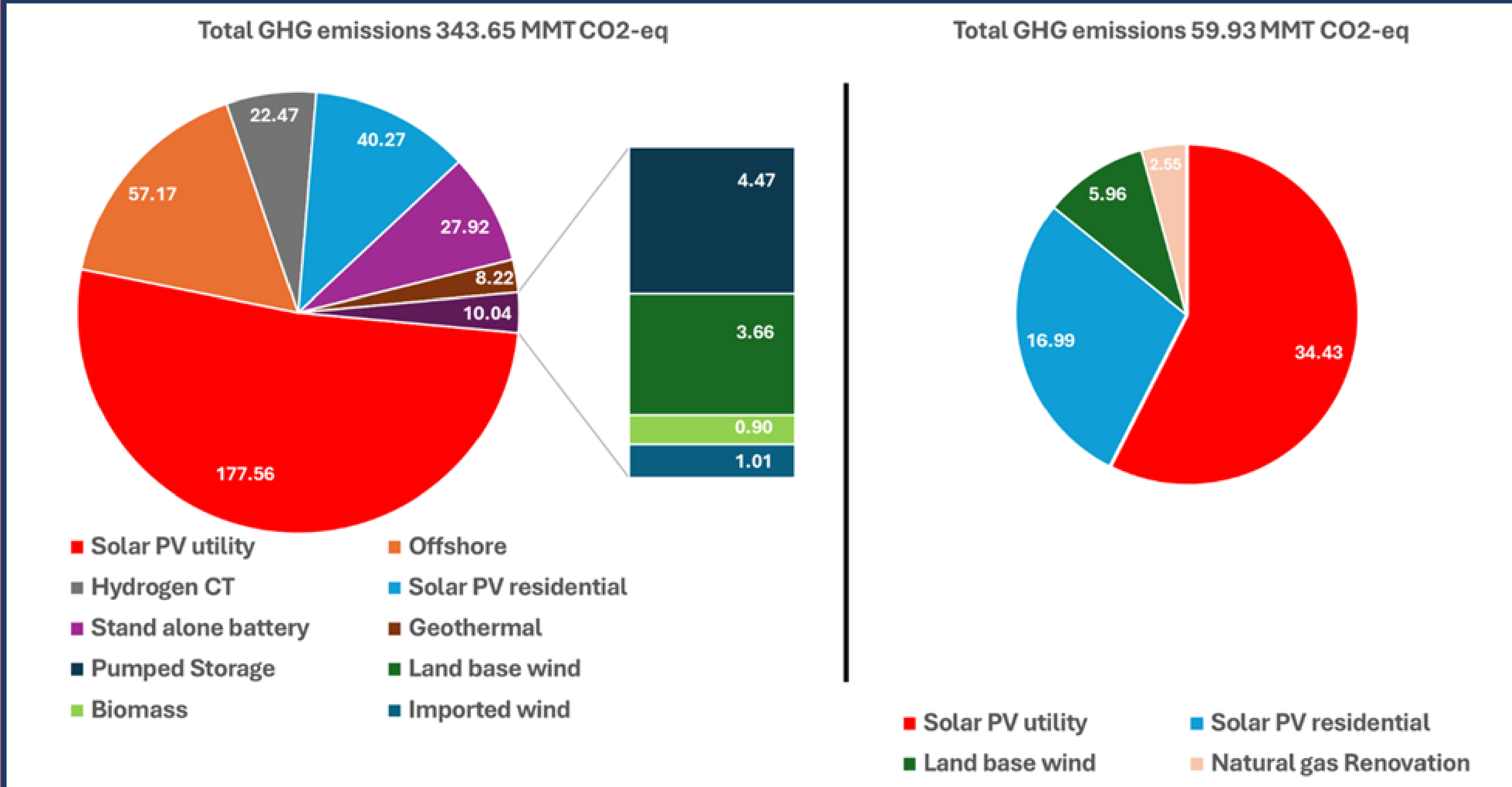


Figure 7: Unaccounted-for life cycle GHG emissions from the power sector of California's decarbonization plan through 2045 (left) and life cycle GHG emissions from renovations of current electricity generation infrastructure to meet demands through 2045 (right).

Figure 10: Siting of electricity generation systems across the state of California while minimizing life cycle GHG emissions

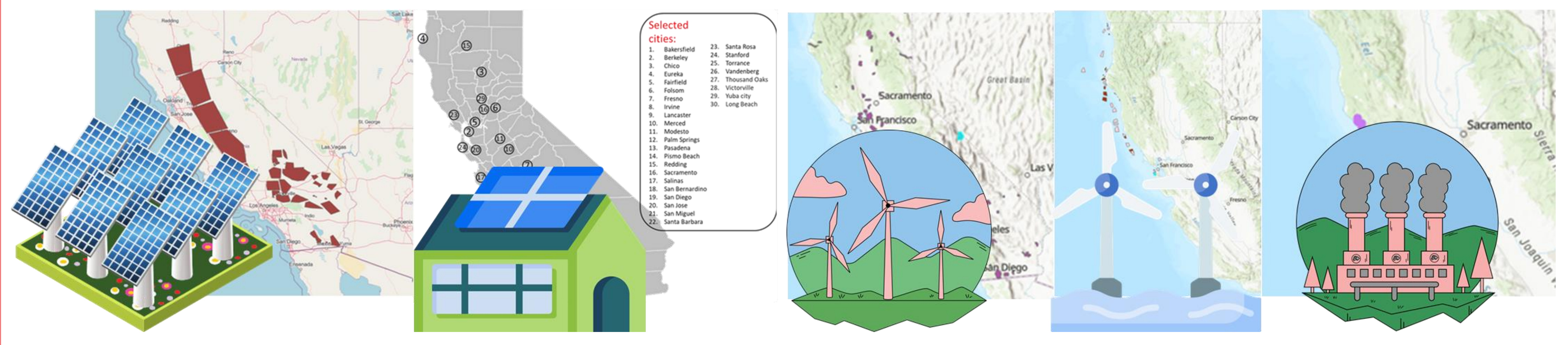


Table 1: Carbon footprints of the electricity grid mix by year in California following the capacities of the Scoping Plan and optimized siting of energy systems within the state.

Years	2022	2023	2025	2028	2030	2035	2045
Average climate change impact of grid mix of available electricity (g CO ₂ eq/kWh)	259	233	206	183	145	117	84.9
Total in-state generation of electricity per year (TWh)	203.2	282.7	302.1	326.5	345.2	389.6	516.3
Total imported electricity into the state per year (TWh)	83.96	53.27	49.15	36.94	36.83	22.38	0.00

- "Zero emission" renewables contribute 85.8% of the ~404 million metric tons (MMT) of life cycle GHG emissions in CO₂eq that were previously omitted from decarbonization accounting for California.
- Energy storage systems (pumped hydro, hydrogen combustion turbines, batteries) comprise 13.6%.
- Maintaining natural gas power generation capacity equal to today's will require retrofits of existing plants or new power plants to be constructed by 2045, a process that will emit 2.55 MMT CO₂eq.

Conclusions

- California's 2022 Scoping Plan is **missing nearly 404 million metric tons (MMT) CO₂eq of GHG emissions** by excluding the impacts of processes that are required to ultimately produce electricity.
- The state's total GHG emissions associated with its electricity sector transition through 2045 are instead **at least 54% higher than reported**.
- This study optimized the electricity systems proposed by the 2022 Scoping Plan for 2045 towards minimized carbon footprints (and not towards minimizing the economic impact of the transition), and so **these overlooked GHG emissions are most likely underestimated as well**.

Comprehensive LCA should be integrated with other methods during decarbonization planning to more accurately determine the GHG emissions reductions that the plan may achieve, before substantial economic resources are invested in implementing an energy transition.

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- [3] Pfadt-Trilling, A.R. and M.-O.P. Fortier, Greenwashed energy transitions: Are US cities accounting for the life cycle greenhouse gas emissions of energy resources in climate action plans? Energy and Climate Change, 2021. 2: p. 100020.

Acknowledgments

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- (1) The University of California Office of the President (UCOP) for funding this analysis through award #L22CR4556: "California's Deep Decarbonization Pathways: A Holistic Multi-Layer Assessment;"
 - (2) The National Science Foundation (NSF) for enabling the development of geospatial life cycle assessment methodology through award #2316124: "CAREER: Geospatial life cycle climate change impacts of solar and ocean renewable energy systems;"

A Global and Inclusive Just Labor Transition

Challenges and Opportunities in Developing and Developed Countries

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Abstract

This research examines challenges and opportunities for achieving an inclusive just labor transition (JLT) to a low-carbon economy. We compare JLT policies in developed and developing countries, focusing on common challenges such as ensuring quality jobs, compensating displaced workers, and the role of government intervention. In developing countries, we consider their diversity, analyzing labor markets in key sectors. We highlight challenges and opportunities for job creation, retraining, and community integration within the JLT. Additionally, we explore emerging partnerships for just energy transitions. Finally, we present a Just Labor Transition Progress Scale to assess countries’ progress, offering insights for researchers and policymakers.

Introduction

There is a growing global focus on justice in climate action, particularly at events like COP28, where the Just Transition concept is central to policymaking. A Just Transition involves ensuring equitable outcomes in various areas, including financing from the Global North to the Global South, energy poverty, and the fair distribution of benefits and risks from the clean energy transition. This paper focuses specifically on the labor market aspect of the Just Transition, referred to as the Just Labor Transition (JLT). It compares labor policies in 14 countries—seven developed and seven developing—offering new insights into an under-researched aspect of the energy transition.

The research introduces the Just Labor Transition Progress Scale (JLTPS), a qualitative tool designed to assess and compare countries’ progress in achieving a JLT. By analyzing labor market responses to environmental regulations and transitions from “dirty” to “green” jobs, the paper aims to identify effective strategies for managing the socio-economic impacts of moving away from fossil fuel industries. The introduction emphasizes the importance of learning from developed and developing nations’ experiences to develop targeted and effective policies aligning economic growth with social justice and environmental sustainability. The JLTPS will provide a foundation for future research to explore JLT progress further using quantitative methods.

Main Objectives

1. Examine the role of the labor market in the Just Transition (JLT).
2. Conduct a comparative analysis of JLT policies in 14 countries:
 - (a) Developing: Argentina, Colombia, India, Indonesia, Nigeria, South Africa, and Vietnam.
 - (b) Developed: Australia, Germany, Netherlands, New Zealand, Poland, United Kingdom, and the United States.
3. Introduce and apply the Just Labor Transition Progress Scale (JLTPS).
4. Identify successful and unsuccessful JLT policies.
5. Provide policy recommendations and set the agenda for future research.

Lessons and Challenges in 7 Developed Countries and 7 Developing Countries

From the partial energy transition experiences in developed countries — given their continued reliance on fossil fuels— and the initial stages of developing countries, we draw several key lessons about the JLT:

1. JLT policies are expected to be effective within a comprehensive framework characterized by a robust, explicit, and cohesive top-down leadership approach, coordinated efforts, and substantial central (federal) government funding.
2. The success of JLT initiatives also hinges on fostering extensive and inclusive local consultations, primarily through local networks capable of accessing top-down funding and coordination.
3. Realizing successful JLT efforts may require emphasizing “economic diversification,” aimed at revitalizing energy communities (through regional development plans) by fostering alternative labor market opportunities.

These lessons highlight the importance of strong and committed government support for diversifying the local economy, comprehensive ‘just’ policy frameworks that provide clear guidelines and funding, developing new renewable energy projects, and creating worker retraining and education programs.

Tools, Policies, and Strategies to Advance a Just Labor Transition

- Worker Support:
 - Retraining, Reskilling, and Upskilling Programs
 - Other Active Labor Market Policies (Job Search Assistance, Wage Subsidies, ...)
 - Social protection (Unemployment insurance, Early retirements, Pension plans, Income Support...)
 - Mobility/Migration/Relocation Assistance
- Job Creation and Development:
 - Regional development strategies/Place-based policies
 - Community Engagement
- Strategic Planning and Evaluation:
 - Monitoring and Evaluation
 - Identifying Optimal Timing – how is this different for Developed and Developing

Evaluating the Just Labor Transition Journey: the Just Labor Transition Progress Scale

The JLT Progress Scale (JLTPS) is a clear and structured approach to analyzing the progress of selected countries in their JLT efforts. The aim is to provide a systematic and comparative assessment, aiding policymakers and stakeholders in understanding the development of JLT policies and practices.

Our method for analyzing countries’ progress toward a Just Labor Transition (JLT) is articulated through the Just Labor Transition Progress Scale (JLTPS). Similar scales have been effectively used in policymaking due to their clarity and focus on medium- to long-term progress. The JLTPS methodology enables us to track countries’ efforts over time, ensuring that their actions align with the principles of procedural justice—promoting participation and inclusion—and recognition of justice, which addresses social and cultural inequalities. We base our analysis on a thorough review of national policies, Nationally Determined Contributions (NDCs), and laws pertinent to the just transition. The regular and detailed evaluation of these factors provides a deeper understanding of each country’s successes and challenges.

Countries are classified into five stages based on their adherence to key criteria:

Rank	Color Code	JT Journey Progression	JT Experience
5		Beginner	The country is at the early stages of the JT journey. Some initial 'steps' have been taken.
4		Moderate	The country is beginning to implement some JT policies and there is moderate progression visible.
3		Intermediate	The country is at a more developed stage of the JT journey where there is a mix of progression, regression and neutrality.
2		Advanced	The country is at an advanced stage of the JT journey where there is a high rate of implementation and some early examples of successful JT policy actions and/or results.
1		Peak	This is the highest score and demonstrates that country is on track to achieve a just transition; it can be where the country is where it should be given its JT journey and experiences.

Figure 1: The Just Labor Transition Progress Scale

Our evaluation of countries on the JLT Progress Scale highlights each nation’s varied progress and challenges in their just labor transition journeys. Among developing countries, India and Nigeria are identified as beginners, just starting their efforts. Argentina, Colombia, Indonesia, and South Africa are in a moderate stage, showing more developed policies and strategies. Vietnam stands out as the most advanced among these nations. In developed countries, Germany and the United Kingdom lead with an advanced approach, prioritizing social inclusion and managing coal industry decline effectively. The Netherlands is positioned between intermediate and advanced stages, with strong regional programs. In contrast, Australia remains at the beginner stage, lacking comprehensive plans for coal closures. This assessment offers a clear view of each country’s preparedness and effectiveness in managing the socio-economic impacts of the transition away from fossil fuels, providing deeper insights into their varying degrees of success and challenges.

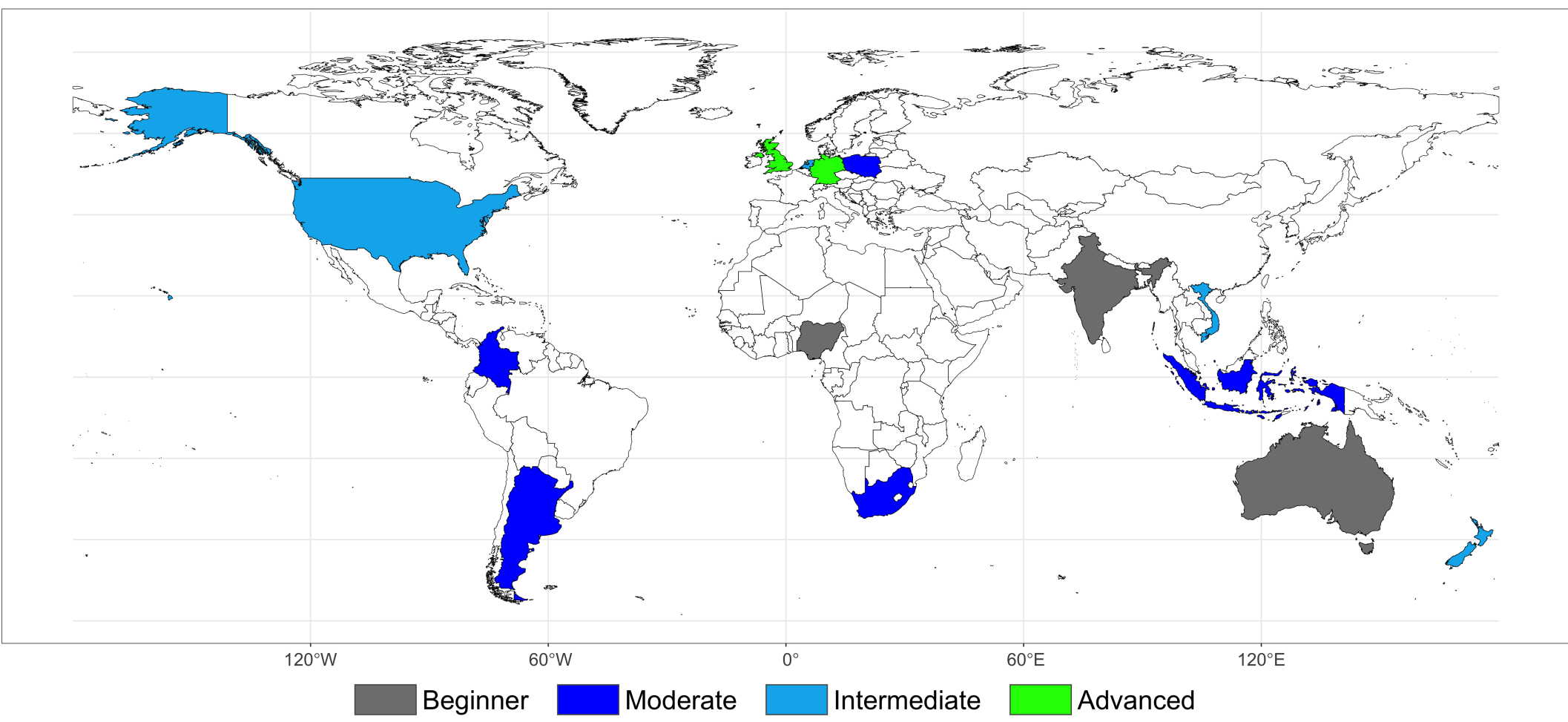


Figure 2: Just Labor Transition Progress Across Countries

Conclusions

- The escalating climate crisis calls for immediate policy action on a Just Labor Transition (JLT) globally, emphasizing the labor market’s potential to generate green jobs and foster positive societal impacts.
- This paper offers three key contributions: a comparative analysis of 14 countries’ JLT progress, key lessons for policy success and failure, and the introduction of the JLT Progress Scale (JLTPS) to systematically assess different nations’ advancement.
- Ensuring that justice principles (procedural, distributive) are integrated into JLT policy frameworks is crucial for accelerating a just transition and addressing inequalities.
- Policymakers can leverage the JLTPS to develop tailored, effective strategies. Future research should focus on quantitative analyses of JLT progress for global applicability.

Acknowledgements

We thank Suzi Kerr, Jonathan Camuzeaux, and Pablo Sanguinetti for their suggestions. We want to thank seminar participants at the AERE Summer Conference, SETI Annual Workshop, EDF Economic Seminar for insightful comments and discussions.

Decarbonising Transport: Opportunities for Africa - US Collaboration



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Theme 4; 5

*Based on the report “Decarbonisation of Transport in Africa: Opportunities, Challenges and Policy Options (2024)” published by the Network of African Science Academies (NASAC) and InterAcademy Partnership (IAP).

I. Background

- Global shift towards electric vehicles (EVs) is critical for decarbonising the transport sector, which accounts for 25% of global emissions. Transition is especially significant for regions like Africa, where it presents an opportunity to leapfrog to low-emission technologies.
- Africa is a small contributor (4%) to global transport emissions - average emissions per person per year in Africa is 0.8 tonnes compared to global average of 4.8 tonnes. But emissions are projected to increase due to rapid urbanisation, economic growth, and rising motorisation rates in Africa.
- Africa holds the largest reserves of several critical minerals essential for EV production, including cobalt and manganese.

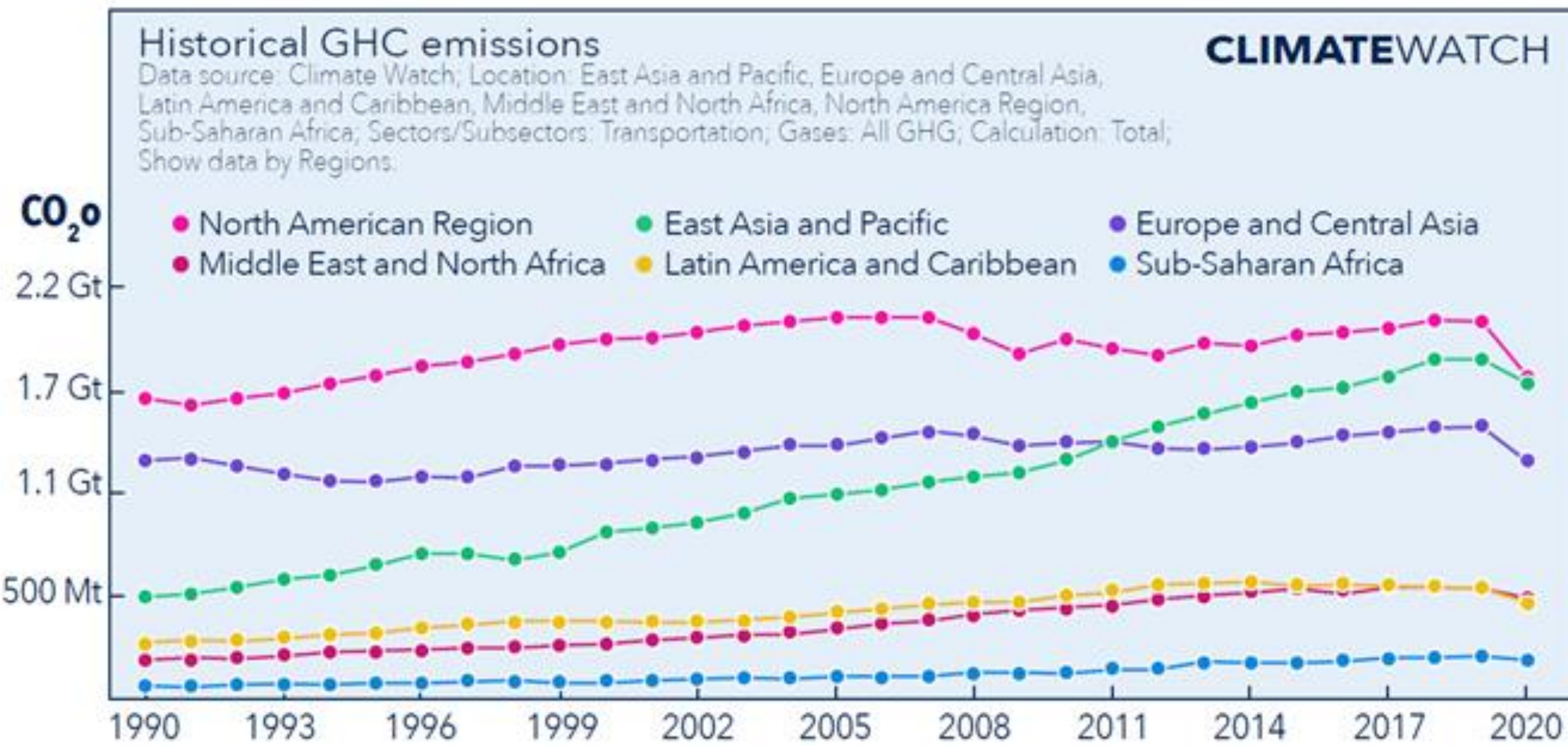
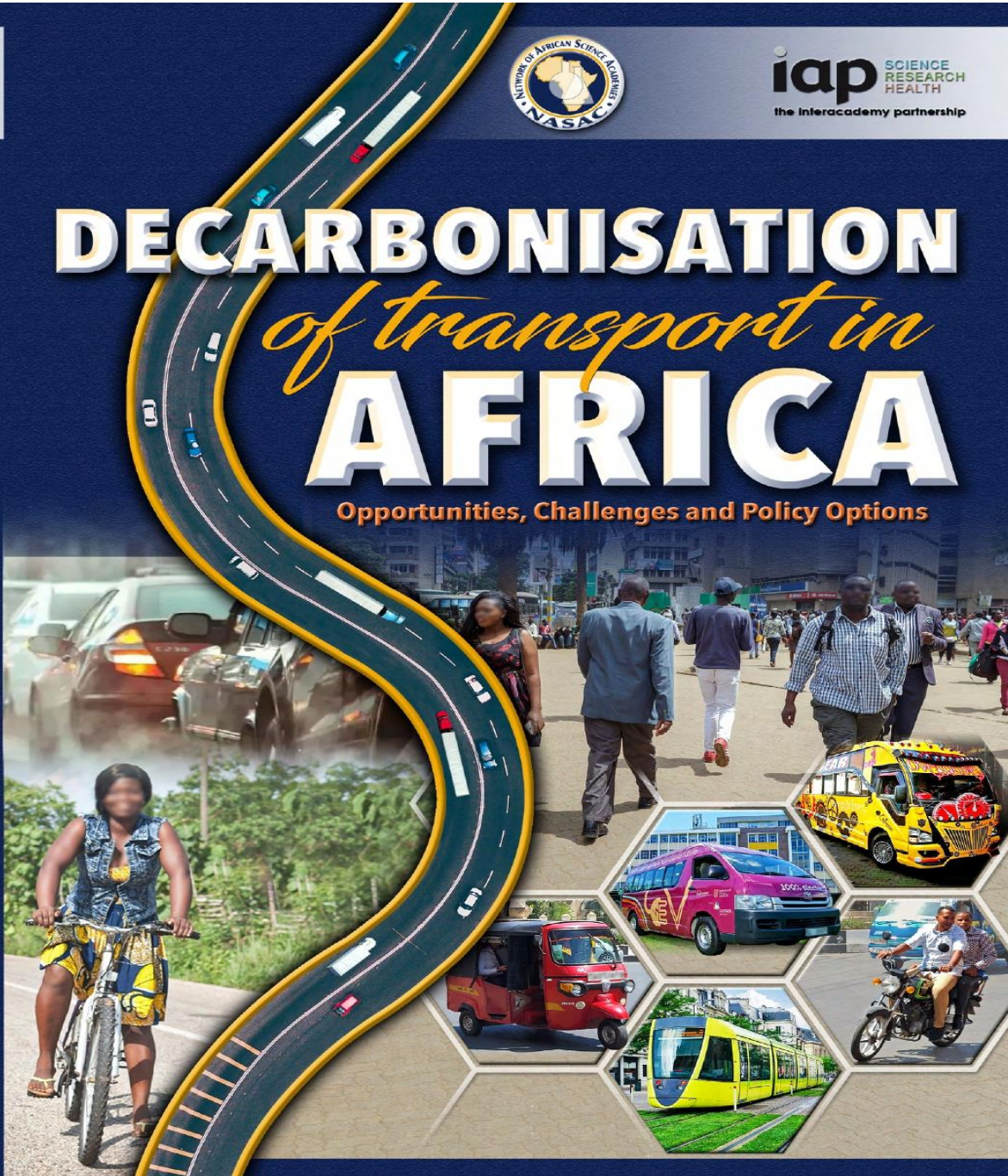


Figure 1. Global Transport emissions by region

- Decarbonisation faces challenges like inadequate financial and technical capacity, competition from existing transport and oil industry regimes, concerns around impact on the grid, and equity of the transition.

II. Report on Decarbonisation of Transport in Africa



- Assessed:** Status, Policies; Strategies; Regulations; Technologies; Cross-cutting issues; Institutional capacity; Financing



[Download Report](#)

III. Key Lessons

- Current Status:** Decarbonisation efforts are underway across Africa.
- Strategy:** The Enable-Avoid-Shift-Improve-Resilience (EASIR) approach.
- Policy and regulatory instruments** are crucial: mix of (1) market-based instruments; (2) regulatory instruments; (3) direct provisions; and (4) information provisions.
- Growth Opportunities:** industrial growth & green jobs – in addition to environmental & social benefits.



Figure 2. Electric vehicle manufacturing in Kenya



Figure 3. Retrofitting internal combustion engine vehicles to electric propulsion in South Africa

- Increased electricity demand strains the fragile grid; charging infrastructure – leading to **range anxiety**.
- EV prioritization:** Target high-mileage, extensively used vehicle segments (buses, two and three-wheelers) for EV adoption.



- An integrated sustainable transport strategy:** Integrating mass rapid transport (e.g., Bus Rapid Transit, Metro) and non-motorised transport crucial – also focus on enhancing capacity existing transport systems and infrastructure.
- Financial Limitations:** Inadequate funding frameworks restrict decarbonisation potential.
- Industry Resistance:** Competition from entrenched system e.g., fossil fuel vehicle industries.

IV. Implications

Equity and Sustainability: Decarbonisation efforts must be grounded in equitable practices within the supply chain to avoid future costs related to equity and distributional effects (e.g., social risks or compensations).

Competing Interests: Decarbonisation of transport efforts must navigate resistance from entrenched fossil fuel industries. Strategic collaborations can provide the economic and political leverage needed to overcome these interests and support a transition to cleaner technologies.

Economic Growth: Partnerships can support global climate goals, drive economic development in Africa, create jobs while aiding the US's transition to a low-carbon economy.

Comprehensive Frameworks: The Enable-Avoid-Shift-Improve-Resilience (EASIR) approach provides a holistic strategy that integrates social, economic, and environmental considerations into transport decarbonisation



Enable: Establish foundational governance, laws, institutions & financial arrangements.



Avoid: reduce the need for & distances of travel.



Shift: Moving travel demand from individual motorized modes of transport to more sustainable modes



Improve: Enhancing efficiency & environmental performance of transport system.



Resilience: Enhancing resilience & adaptive capacity of transport infrastructure.

Strategic partnerships between Africa and the US: Can address financial and technical challenges and enhance the overall effectiveness of decarbonisation efforts in Africa, the US, and beyond.

V. Conclusion

- Decarbonisation efforts in the transport sector depend significantly on global cooperation. The success of the transition is contingent upon strategic partnerships that address financial, technical and equity and sustainability challenges.
- Strategic collaborations can ensure that African nations benefit from the industrial growth and job creation potential of the EV market, while also supporting the US's transition to a low-carbon economy through sustainable supply chain of critical minerals.

EQUITY IN TRANSITION: DISTRIBUTIONAL EFFECTS OF CLEAN TECHNOLOGY SUBSIDIES (5)

Yagmur Menzilcioglu

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Motivation

- During the 2006-2021 period the top income quintile received 70% of subsidies for residential solar panel installations and 90% of subsidies for electric vehicles.

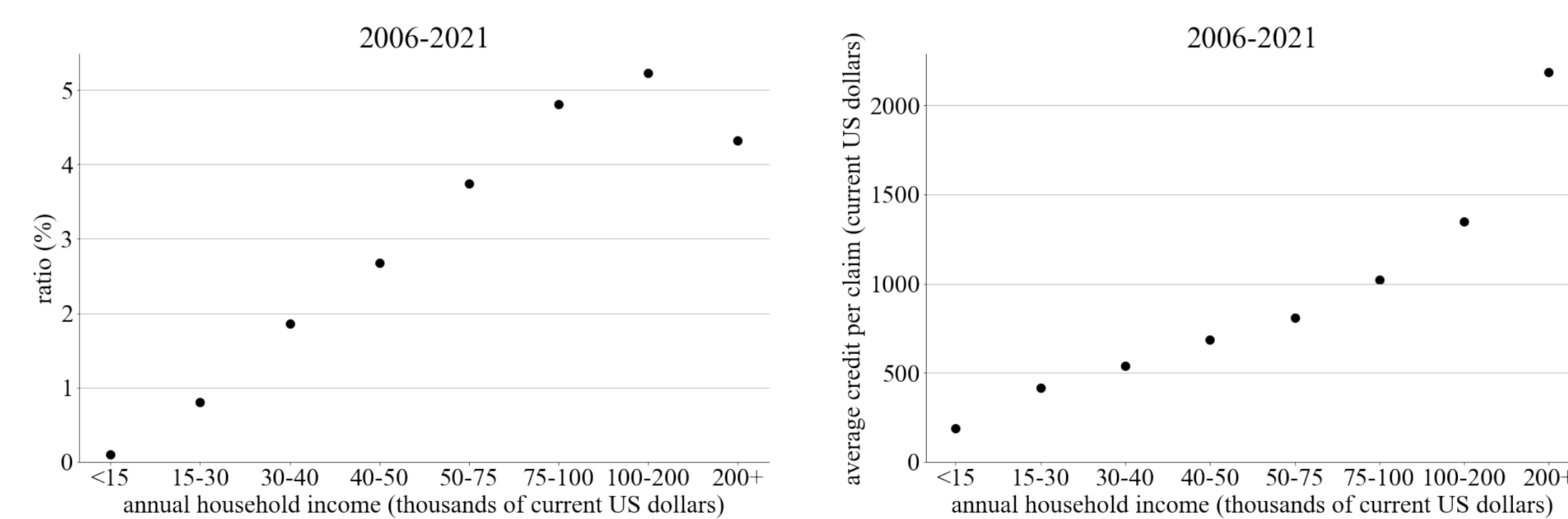


Fig. 1: Statements of income (SOI) data on residential energy credits, 2006-2021. Source: [2].

- Depending on the financing structure of these subsidies, they can be regressive, affecting income inequality.

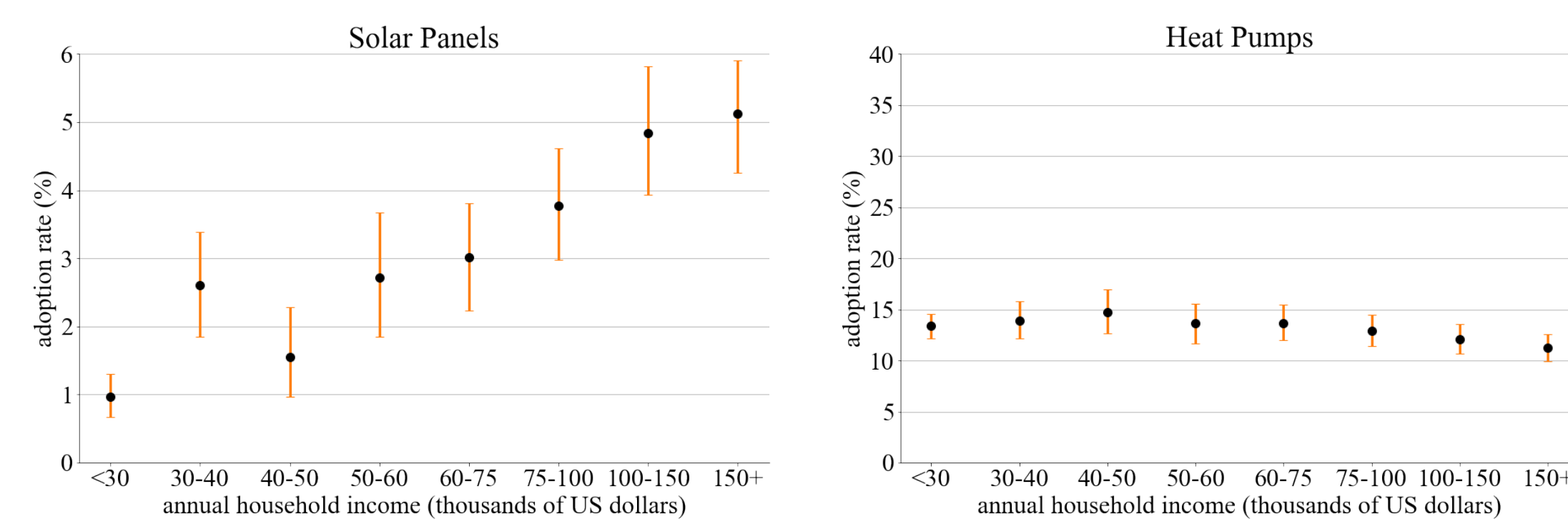


Fig. 2: Low-carbon technology adoption rates by income group, 2020. Source: [5].

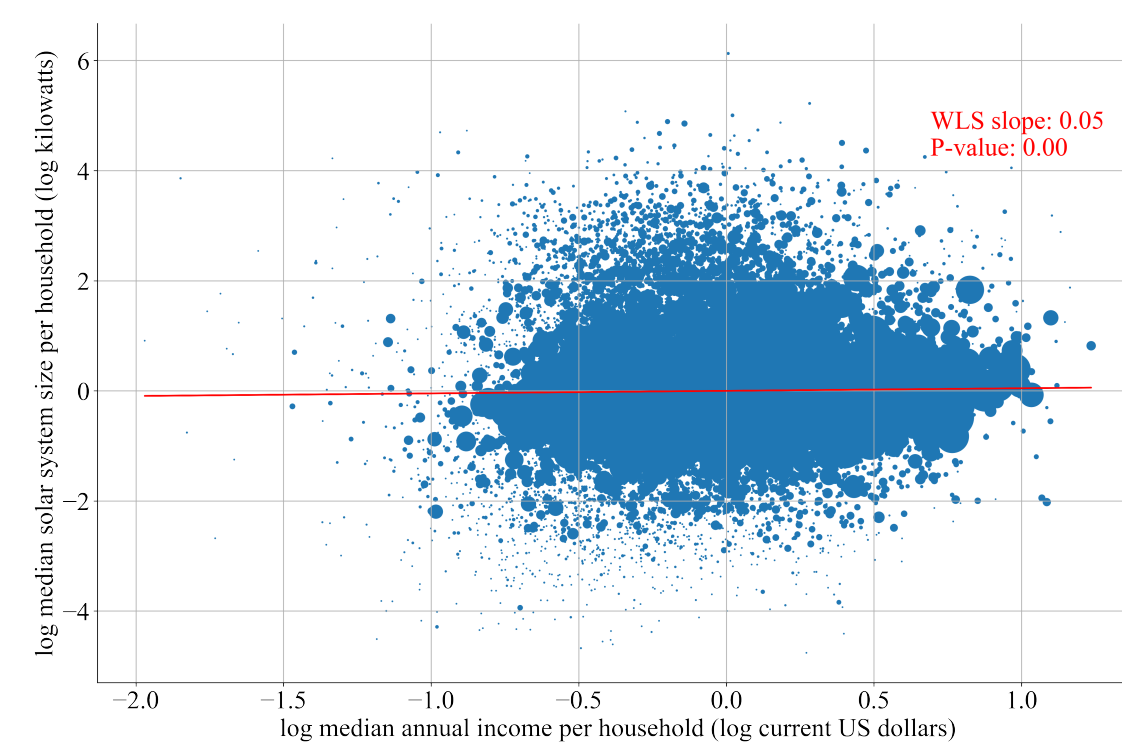


Fig. 3: Median ZIP code-level solar panel installation size vs household income. Sources: [1], [4], and [3].

Research Questions

- How is low-carbon technology adoption related to household income?
- If related, how heterogeneous are the welfare costs of low-carbon technology adoption subsidies across income groups during the transition to full adoption?
 - How do these costs vary by the financing structure of the subsidies?
 - How do these costs vary by technology?
 - What if climate damages vary across income groups?

Model

Consumers:

- Continuum of households $i \in [0, 1]$ with idiosyncratic labor endowments ℓ^i :
- Preferences: $\mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t U(c_t^i) \right]$.
- Budget constraint:

$$c_t^i + a_{t+1}^i + \bar{q}e(c_t^i)(1 - s_t^i) + \underline{q}e(c_t^i)s_t^i + p_t(1 - \tau_t)S_t^i = w_t\ell_t^i + (1 + r_t)a_t^i - T_t^i,$$
 - s_t^i is the adoption state of the household,
 - $s_t^i = 1$ when the household has already adopted the technology and is utilizing it (absorbing state),
 - $s_t^i = 0$ when the household has not adopted the technology yet,
 - $\underline{q} < \bar{q}$ and $e(\cdot)$ is an affine function with nonzero intercept,
 - $S_t^i \in \{0, 1\}$ is the household's adoption decision.
- Borrowing constraint: $a_{t+1}^i \geq \underline{a}$ for all t , where $\underline{a} < 0$.
- The dynamic programming problem of the household that has not adopted the technology yet ($s = 0$) is:

$$V_t(a, \ell, 0; \tau) = \max_c \begin{cases} U(c) + \beta \mathbb{E}_t[V_{t+1}(w\ell + (1+r)a - T - c - \bar{q}e(c), \ell', 0; \tau)|\ell], \\ U(c) + \beta \mathbb{E}_t[V_{t+1}(w\ell + (1+r)a - T - c - \bar{q}e(c) - p(1 - \tau), \ell', 1; \tau)|\ell]. \end{cases}$$
- The DP problem of the household that already possesses the technology ($s = 1$) is:

$$V_t(a, \ell, 1; \tau) = \max_c U(c) + \beta \mathbb{E}_t[V_{t+1}(w\ell + (1+r)a - T - c - \underline{q}e(c), \ell', 1; \tau)|\ell].$$

Producers:

- Final good production: $Y_t = [1 - D(X_t)]K_t^\alpha L_t^{1-\alpha}$,
 - X_t is the atmospheric carbon concentration,
 - $D(\cdot)$ is the damage function mapping carbon concentration to the fraction of output lost due to climate damages.

Government:

- Balanced budget: $p_t\tau_t \int_0^1 S_t^i di = \int_0^1 T_t^i di$.

Carbon Cycle:

- Carbon stock law of motion: $X_{t+1} = \eta X_t + F \left(\int_0^1 e(c_t^i)(1 - s_t^i) di \right)$,
 - η is the depreciation rate of the carbon stock,
 - $F(\cdot)$ maps the carbon-based energy consumption to the flow of carbon emissions entering the atmospheric carbon stock.

Market Clearing Conditions:

- Capital: $K_t = \int_0^1 a_t^i di$,
- Labor: $L_t = \int_0^1 \ell_t^i di$.

Quantitative Analysis

- Solve the model and calibrate it to the U.S. data.
- Analyze the transition dynamics to full adoption of the low-carbon technology.
- Evaluate the welfare costs of low-carbon technology adoption subsidies across income groups and the aggregate economy.
- Compare these welfare costs for different technologies and financing strategies.
- Analyze the implications of climate damages varying across income groups and alternative policies.

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Energy Consumption and Inequality in the U.S.: Who are the Energy Burdened?

Octavio M. Aguilar¹; Cristina Fuentes-Albero²
^{1,2}Federal Reserve Board of Governors*

Abstract

In this paper, we propose the use of a broader definition of energy consumption that includes gas for transport in assessing whether a household is energy burdened. We document that **17% of households in the PSID are energy burdened (EB)** and that they are not merely hand-to-mouth (HTM) households. We put forward a characterization of EB households using logit regression analysis, a set of empirical regularities for energy consumption and EB status, and a study of the evolution of inequality in energy consumption and income in the PSID. These results provide reference moments to calibrate models with a focus on energy consumption and household heterogeneity.

Definitions

- Definition of energy consumption:**
 - In the literature on energy poverty, energy consumption is defined as within-home energy expenditures.
 - Our proposal:** energy consumption is defined as the **sum of within-home energy expenditures and expenditures in gas for transport**.
- Indicator for energy poverty:**
 - Traditionally, a household is classified as energy poor if the ratio of within-home energy consumption to disposable income exceeds 10%.
 - Our indicator:** a household is classified as energy burdened if the **ratio of total energy consumption to disposable income exceeds twice the median ratio**.

Energy-Burdened Households in the PSID

- We use data from **1999 to 2021** (biennial waves) from the Panel Study of Income Dynamics (**PSID**) for the U.S.
- 17% of households** are classified as energy-burdened using our indicator:
 - Concentrated in the lowest two quintiles of the income distribution, mostly non-White, unmarried with dependents, and receive housing or energy subsidies.
- Are EB households just hand-to-mouth consumers?
 - 30% of EB households are not-HTM**, 38% are poor HTM, and 32% are wealthy HTM.
 - 48% of non-EB households are not-HTM, 27% are poor HTM, and 25% are wealthy HTM.

Determinants of Being Energy Burdened

- Logit analysis:**
$$\log(\text{odds of being EB}) = x_i' \beta + \varepsilon_i$$
- Results:**
 - HHs in **mobile homes** are 1.3 to 1.8 times more likely to experience energy burden.
 - Being a **race other than White** is associated with higher probability of being energy burdened.
 - Receiving **Gov't-subsidized housing and heating subsidies** increases the probability of energy burden.
 - Higher levels of **education** and being **employed** reduce the probability of being energy burdened.

TABLE 1: Logit Analysis	
Variables	Logit
Socioeconomic	
Bottom two income quintiles	0.082***
P-HTM	0.015***
W-HTM	0.073***
Home characteristics	
Homeowner	0.010**
One family house	0.075***
Two family house	0.055***
Mobile home	0.112***
Heating	
Oil	0.046***
Other (propane, wood, kerosene)	0.049***
Household characteristics	
Race	
Black	0.055***
Asian	0.032**
Other	0.033***
Hispanic	0.029***
Married	-0.049***
Kids	0.012***
Head 65+	-0.032***
Other socioeconomic	
Employed	-0.063***
Postsecondary education	-0.056***
Subsidized housing	0.032***
Heating subsidy	0.104***
Behind on mortgage	0.097***
Year dummies?	✓
N	57,248
Pseudo R ²	0.177

NOTE: Asterisks indicate the level of significance of the parameters, * $p < .10$; ** $p < .05$; and *** $p < .01$.

Empirical Regularities

- FACT 1: EB/non-EB status is persistent.** If a household is EB (non-EB), the probability of remaining EB (non-EB) is 47% (90%).
- FACT 2: EB households have significantly larger MPC and MPCEs** than non-EB households.

TABLE 2: MARGINAL PROPENSITIES.

	Energy-Burdened Households	Non-Burdened Households
MPC	0.26	0.08
MPCE total	0.09	0.01
MPCE within-home	0.04	0.01
MPCE transport	0.09	0.02

- FACT 3: EB households have lower energy consumption growth** than non-EB households despite having **higher income growth**.
- FACT 4: EB households have more volatile energy consumption and income** than non-EB households.

TABLE 3: Energy Consumption and Income: Growth and Volatility

Regressor	Dependent Variable:	
	Income	Energy Consumption
A. Growth		
Energy-Burdened	0.239*** (0.011)	-0.195*** (0.01)
Controls?	✓	✓
Fixed Effects?	✓	✓
R ²	0.26	0.25
B. Volatility		
Energy-Burdened	0.025*** (0.006)	0.013*** (0.005)
Controls?	✓	✓
Fixed Effects?	✓	✓
R ²	0.45	0.43

NOTE: Standard errors are clustered at the household level and are reported in parentheses. * $p < .10$; ** $p < .05$; and *** $p < .01$.

Energy Consumption and Inequality

- The **increase in income inequality is substantially larger** than the increase in overall **consumption** and total **energy consumption inequality** for EB and non-EB households.
 - The increase in **income inequality for EB households is twice** as large as that for non-EB households.
- The **increase in energy consumption inequality is similar** for EB and non-EB households.
- The **increase in energy for transport consumption inequality** is almost **double the increase in income inequality** for EB and non-EB households.
- Inequality in within-home energy consumption declined for EB households** but increased for non-EB households over the entire sample.

TABLE 4: CHANGES IN INEQUALITY (90/10 RATIO): 1999-2021 (%)

	PERCENTAGE CHANGES			
	Initial Level	1999-2009	2009-2021	1999-2021
All households				
Income	8.29	-0.56	24.38	23.68
Consumption	4.69	8.18	4.94	13.53
Energy	4.53	29.04	-10.81	15.09
Within-home	4.00	26.92	-15.96	6.67
Transport	5.83	2.86	45.83	50.00
EB households				
Income	6.12	7.34	42.32	52.77
Consumption	4.57	4.27	-1.55	2.65
Energy	3.87	4.16	9.28	13.83
Within-home	4.29	2.67	-9.09	-6.67
Transport	8.33	20.00	60.00	92.00
Non-EB households				
Income	6.48	0.72	24.87	25.77
Consumption	4.58	9.57	5.71	15.83
Energy	4.51	20.74	-3.25	16.81
Within-home	4.00	25.00	-15.07	6.16
Transport	5.00	20.00	25.00	50.00

Conclusions

- We argue it is crucial to **use a holistic definition for energy consumption** that encompasses expenditures in transport to assess the degree of energy vulnerability of a household.
- We document the characteristics of EB households and highlight that they are **not merely HTM households**.
- We put forward empirical regularities of energy consumption and EB status facilitating reference **moments to calibrate theoretical models**.

Contact

*The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of anyone else associated with the Federal Reserve System.

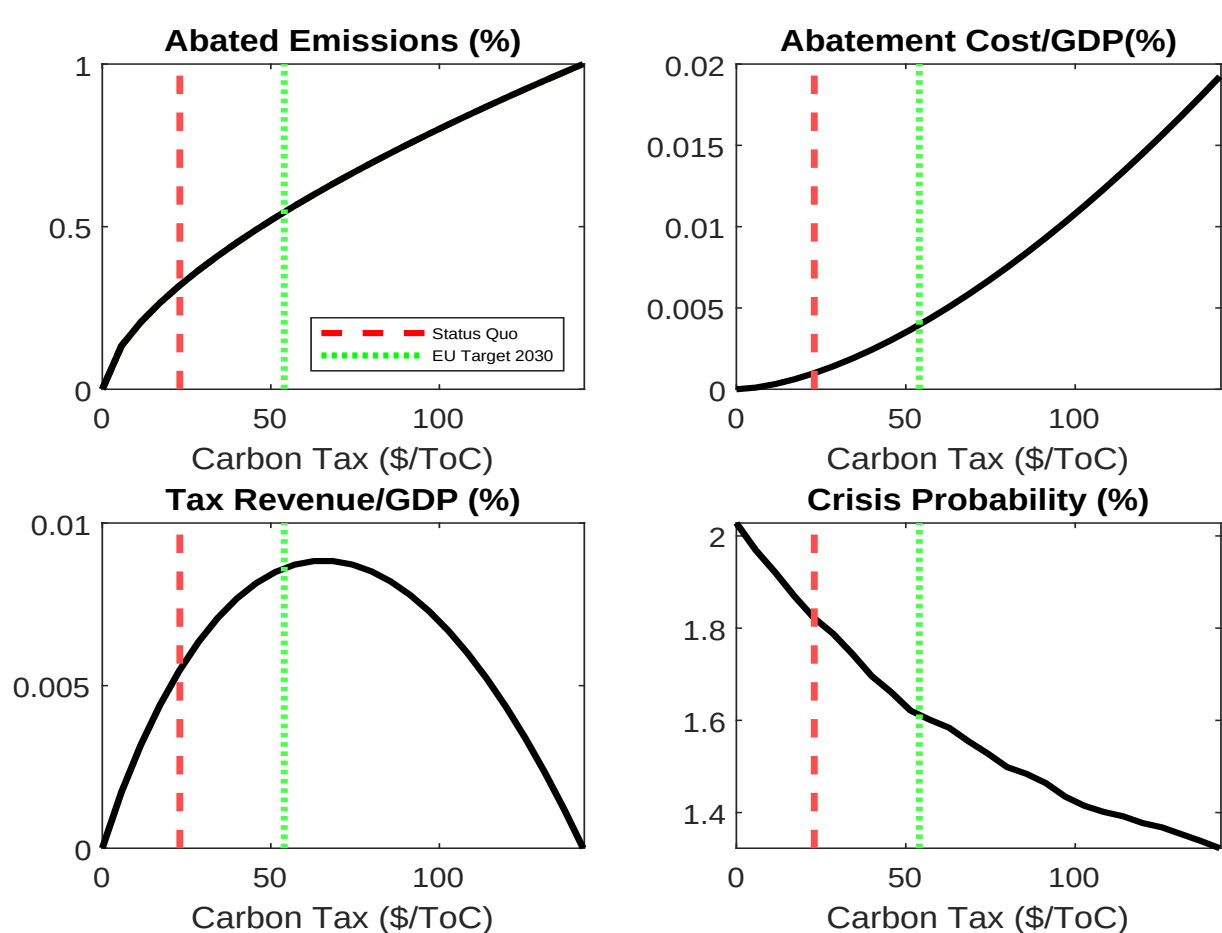
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Climate Minsky Moments and Endogenous Financial Crises

A Macroeconomic Model with Endogenous Financial Crises

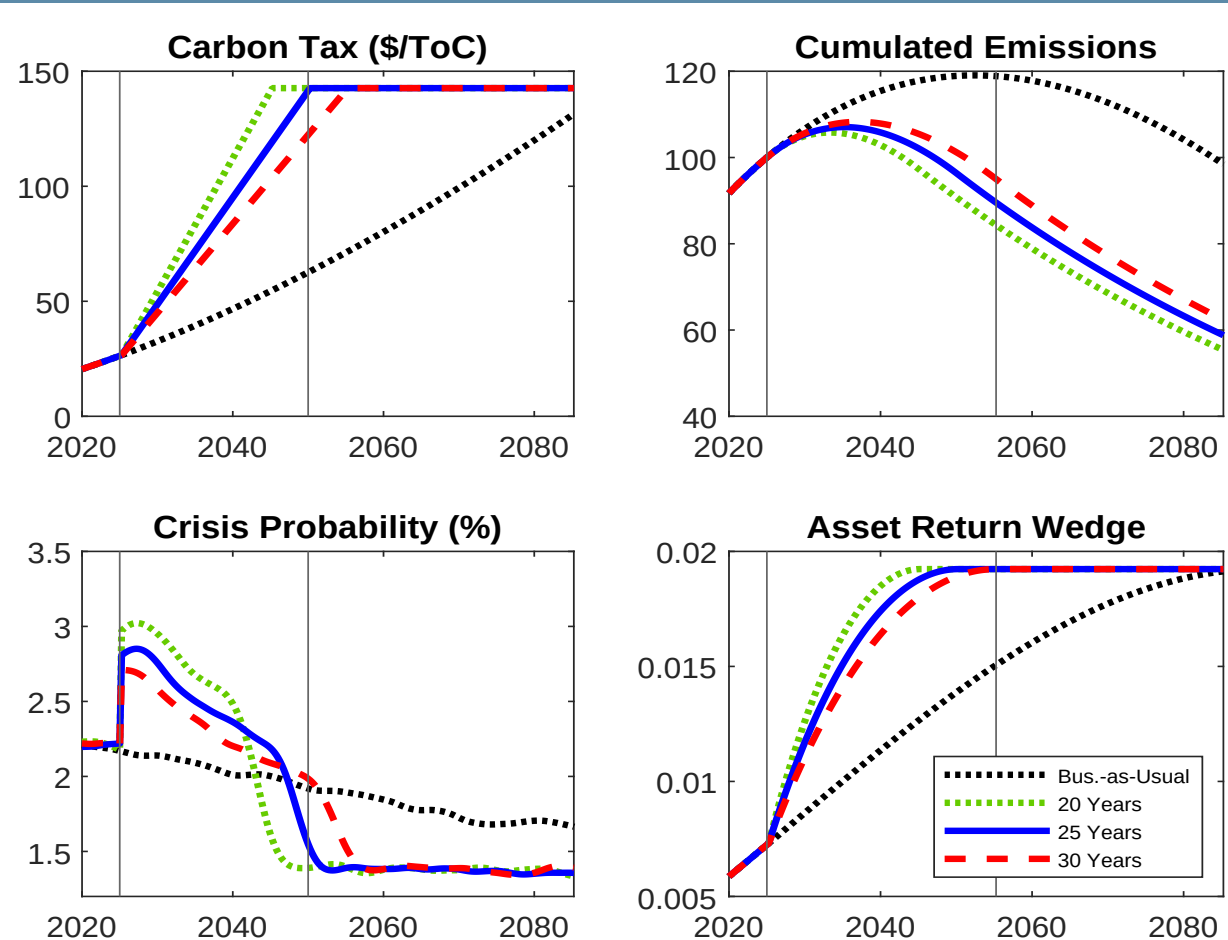
- Nonlinear DSGE model: production economy with levered, run-prone financial intermediaries. Key features:
 - Carbon taxes induce firms to switch to clean but *less productive* technology: return on capital declines.
 - Intermediaries are *more efficient* at managing capital than households but have to *de-leverage in downturns*. Implications:
 - runs are socially costly, **b)** households demand capital at fire-sale price. **c)** intermediaries sell capital in downturns.
 ⇒ Downturn evolves into crisis if value of intermediaries' assets is lower than deposits ("*Minsky moment*").
- Model solved with global techniques due to non-linearities associated with financial crises.

Climate Policy and Financial Stability in the Long Run



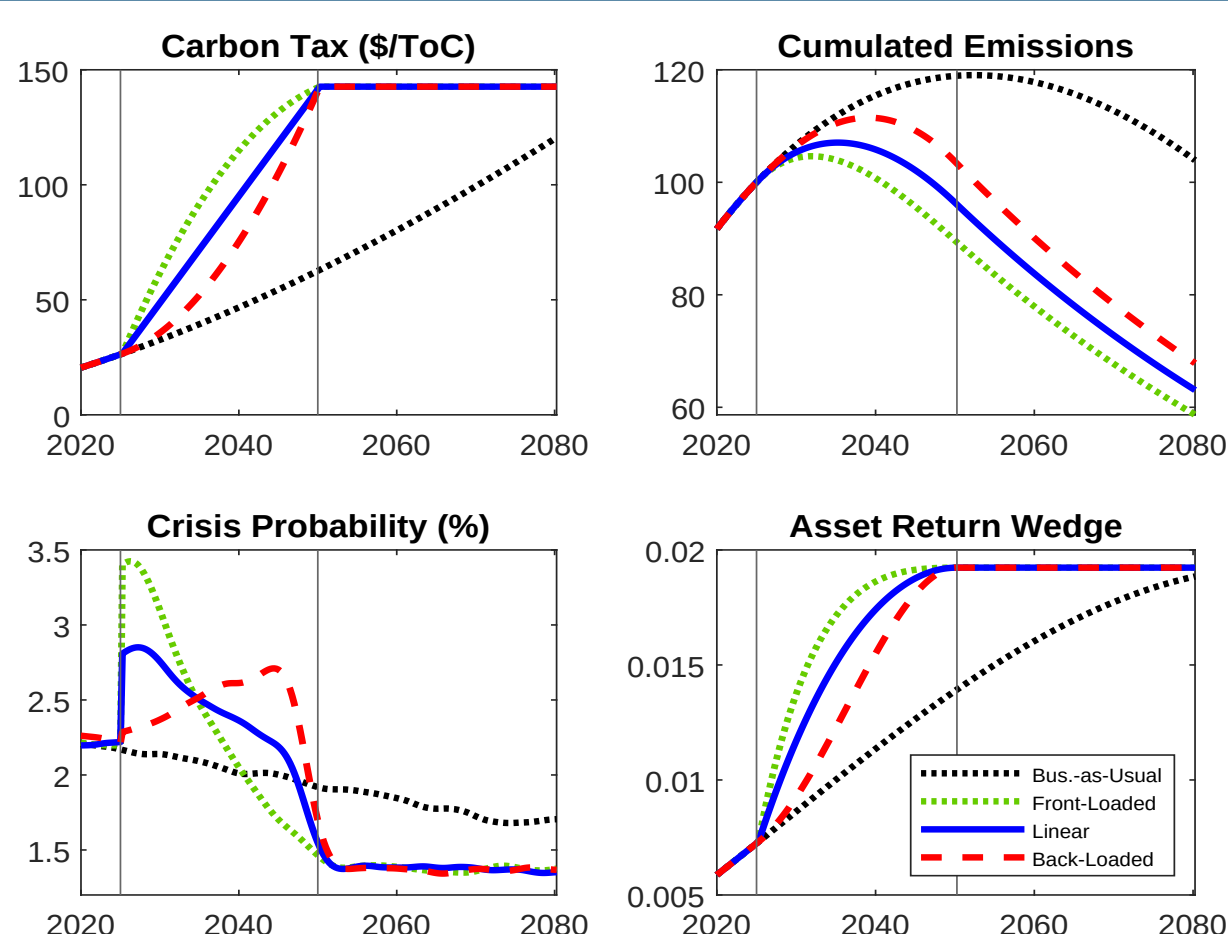
- Emission reduction is associated with higher abatement costs and depresses (aggregate) return on capital.
- ⇒ This reduces the incentive to accumulate capital.
- ⇒ **Decline** in the crisis probability from 2% to 1.4% p.a. Why?
 - Households can absorb more assets in a downturn, financial sector can de-leverage during a downturn with smaller run risk.
 - What happens along the transition to the new long run level?

Financial Stability Along the Net Zero Transition



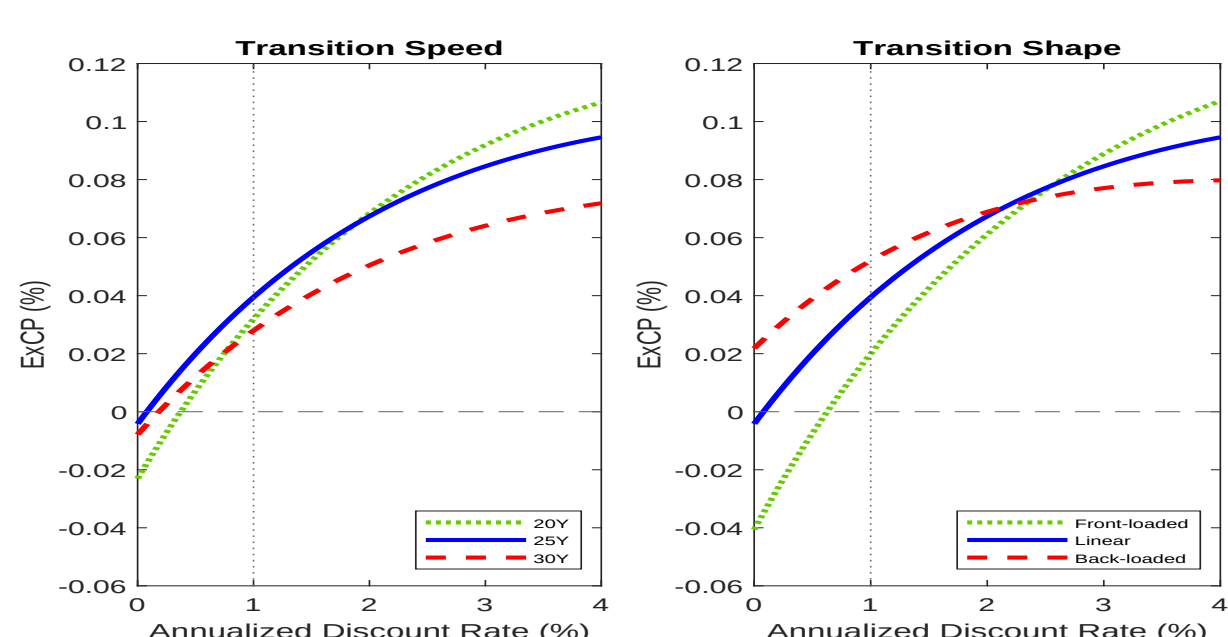
- Business-as-usual*: extrapolating historical emission reduction implies slow transition to net zero in 2090.
- ⇒ Crisis probability slowly declines to new long run level.
- Fast, baseline* and *slow* transition: linear increase to full abatement in **2045**, **2050**, and **2055**, respectively.
- ⇒ Emission reduction and asset return wedge larger for faster transition paths.
- ⇒ Intermediaries have to deleverage fast, which (temporarily) increases the crisis probability above its long run level ("*Climate Minsky moment*").

Back- and front-loading Climate Policy



- Back-loading climate policy **does not generally improve** financial stability, front-loading does. Why?
- Softer (harder) impact effect but smaller (larger) de-leveraging incentives going forward for **back-loaded** (**front-loaded**) policy.
- ⇒ The **net effect** depends on the social discount rate.
- Raises doubt on trade-off between achieving climate policy objectives and maintaining financial stability.
- ⇒ **Key** to our results: endogeneity of **intermediary leverage**.

Evaluating the Net Financial Stability Effect



- Define the *Excess Crisis Probability* as the discounted sum of crisis probabilities, relative to business-as-usual:

$$ExCP = \frac{1}{T_{post} - T_0} \sum_{t=T_0}^{T_{post}} \tilde{\beta}^t \left(\pi_t(\text{policy}) - \pi_t(\text{business-as-usual}) \right).$$

- For low social discount rates $\tilde{\beta}$, steeper and front-loaded climate policy **reduces** the Excess Crisis Probability.

Climate Change, Firms, and Aggregate Productivity

By Andrea Caggese, Andrea Chiavari, **Sampreet S. Goraya (presenter)**, Carolina Villegas–Sanchez

Email: sampreetgrg@gmail.com, [Website](#)

Key Findings:

- Extreme temperatures negatively affect firm–level productivity.
- Increase misallocation of resources across firms.

Macroeconomic Projections:

- Aggregate productivity losses are higher than previously estimated.
- Losses range from **0.60% to 6.82%** depending on scenarios and adaptation levels.
- Adaptation is important, lowers losses by 30 percent.

Implications for Inequality:

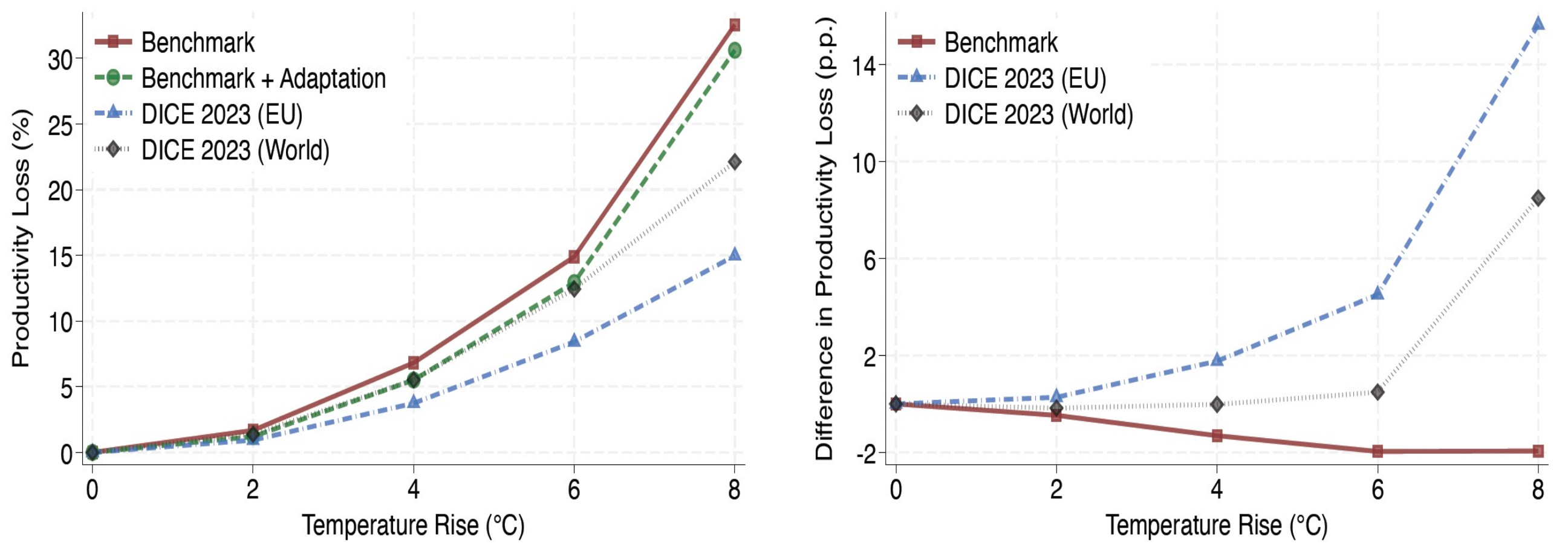
- Climate change is likely to exacerbate regional inequality within Italy.

Question

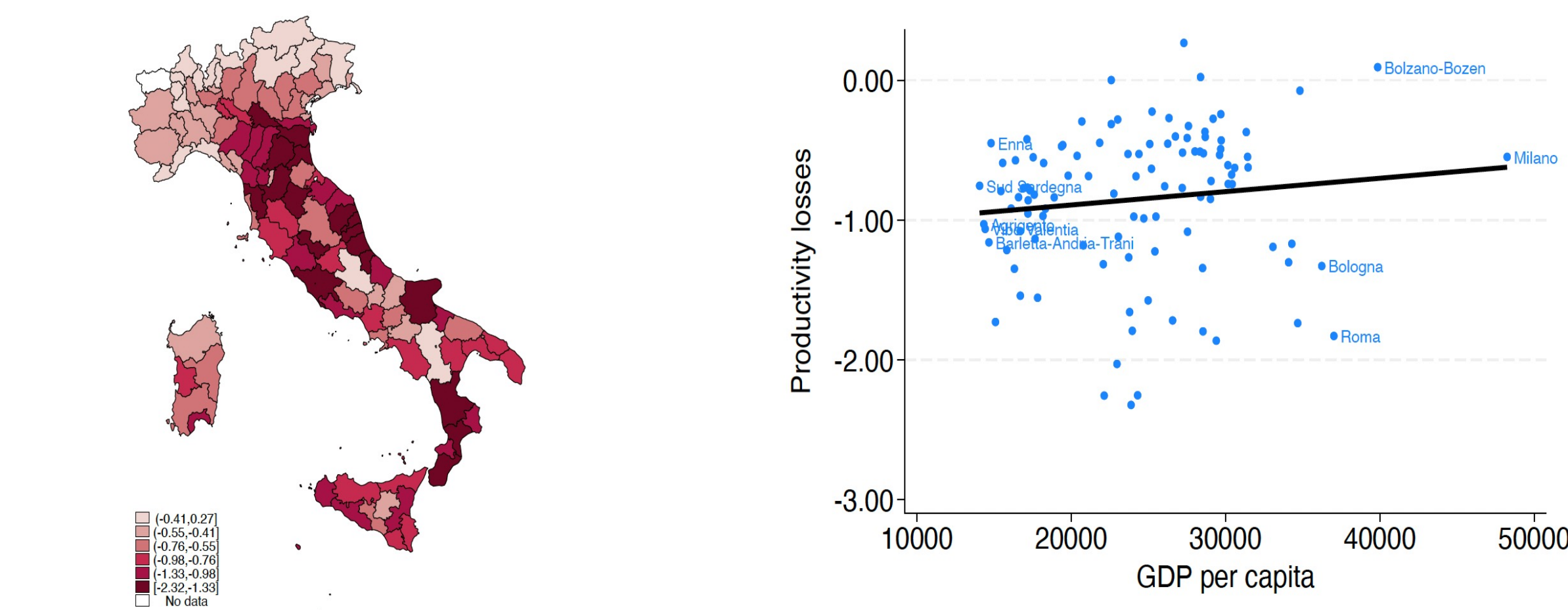
Econmic costs of climate shocks depends on aggregate productivity damage function. What are the driving factors?

Aim:

1. Quantify the relative importance of three different channels determining the impact of climate change on firm outcomes:
 - I. the *demand channel*,
 - II. the *productivity channel*, and
 - III. the *reallocation channel*.
2. Develop a structural framework that allows us to *estimate aggregate productivity losses from these firm–level effects*.
3. Estimate the *aggregate effect of adaptation* across different regions.



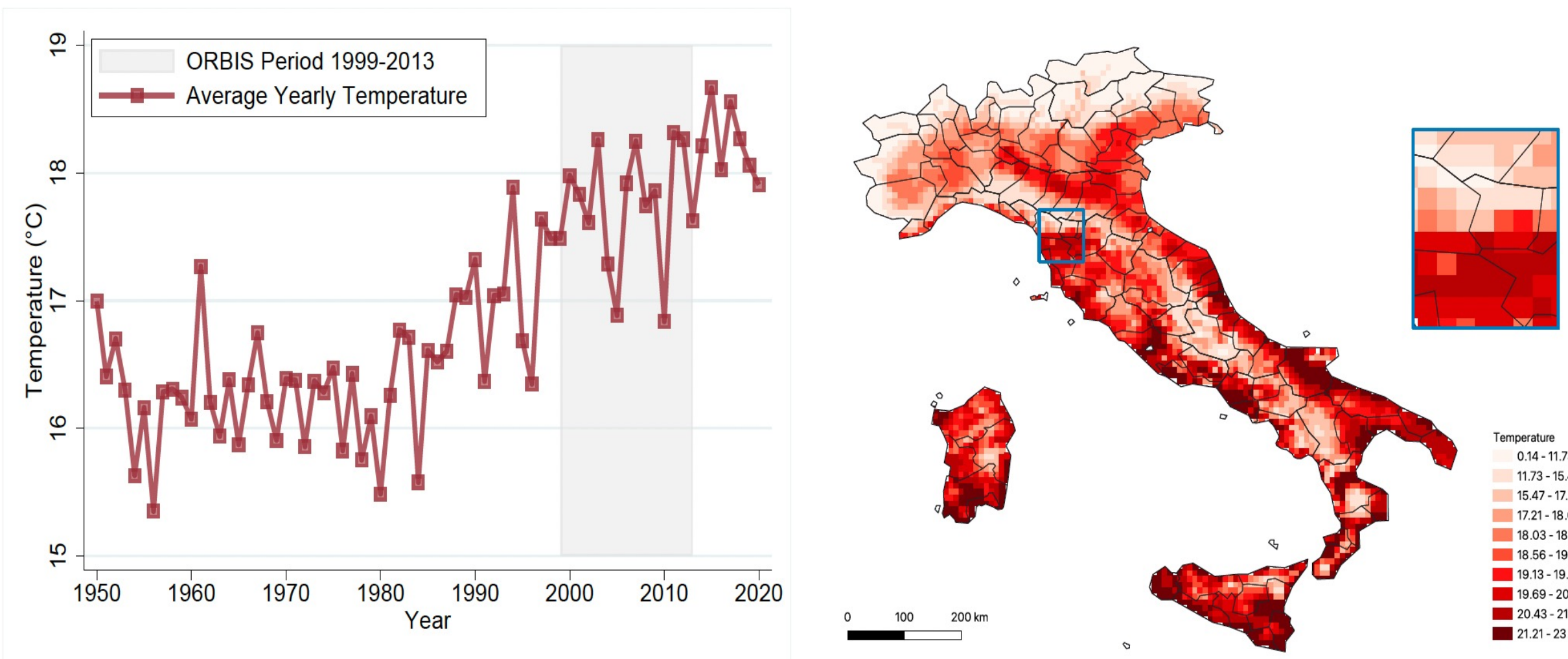
Differences Across Productivity Loss Functions



Regional Productivity Losses for 2°C Warming Scenario



I work on topics related to Growth & Development, focusing on firm dynamics, resource allocation and productivity.



Average Yearly Temperature In Italy

		Aggregate Productivity Loss		
		$\Delta Total$	$\Delta Technology$	$\Delta Allocative Efficiency$
Baseline	2°C	1.68%	0.81%	0.87%
	1°C	0.77%	0.31%	0.46%
Robustness	2°C, Adaptation	1.21%	0.53%	0.68%
	4°C	6.82%	3.33%	3.49%
	RCP4.5	1.64%	0.85%	0.79%
	RCP8.5	5.35%	2.75%	2.60%

Effect of Climate Change on Aggregate Productivity

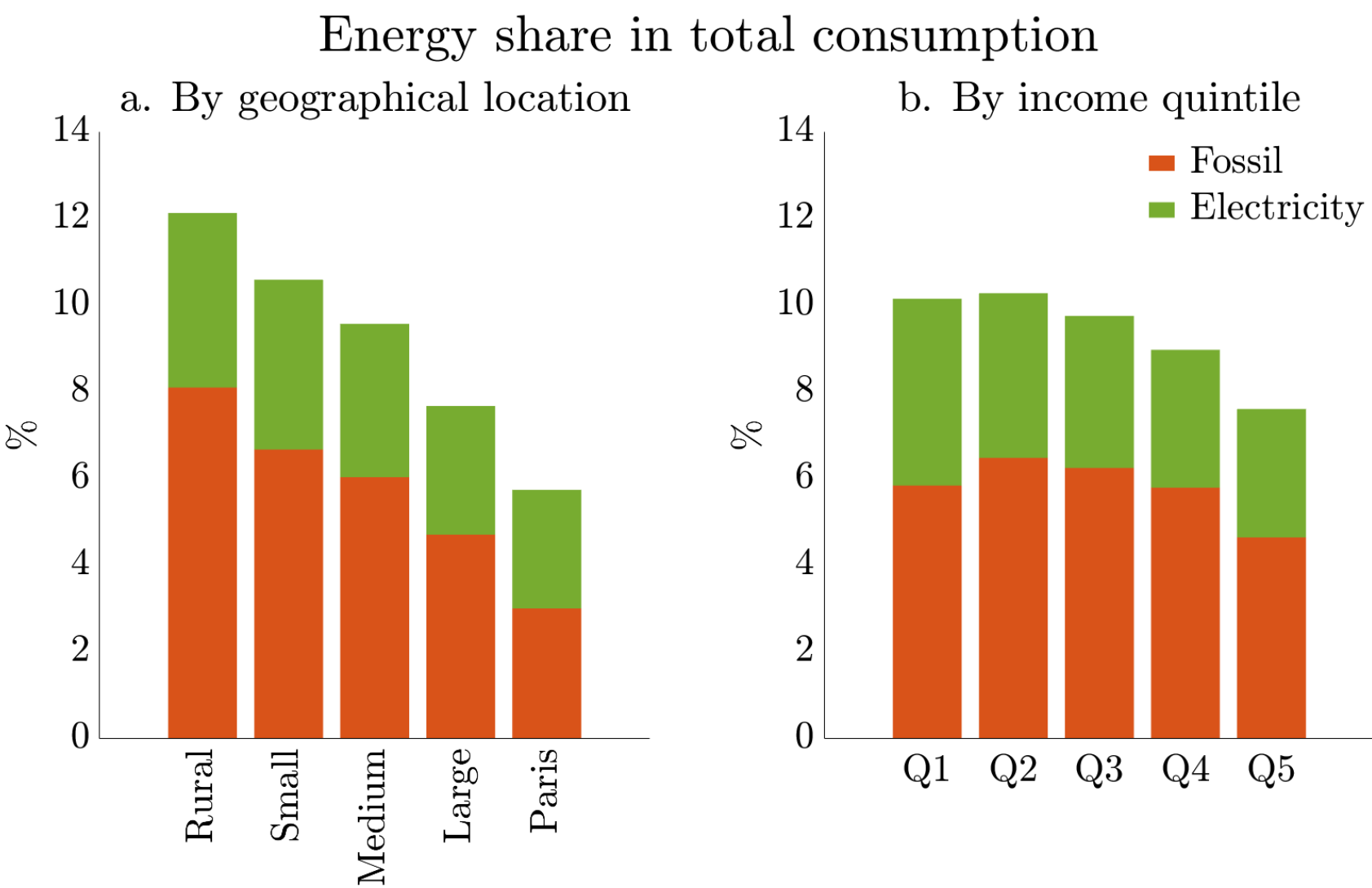
Geography versus Income: The Heterogeneous Effects of Carbon Taxation

Charles Labrousse (Insee - PSE) & Yann Perdereau (ENS - PSE)

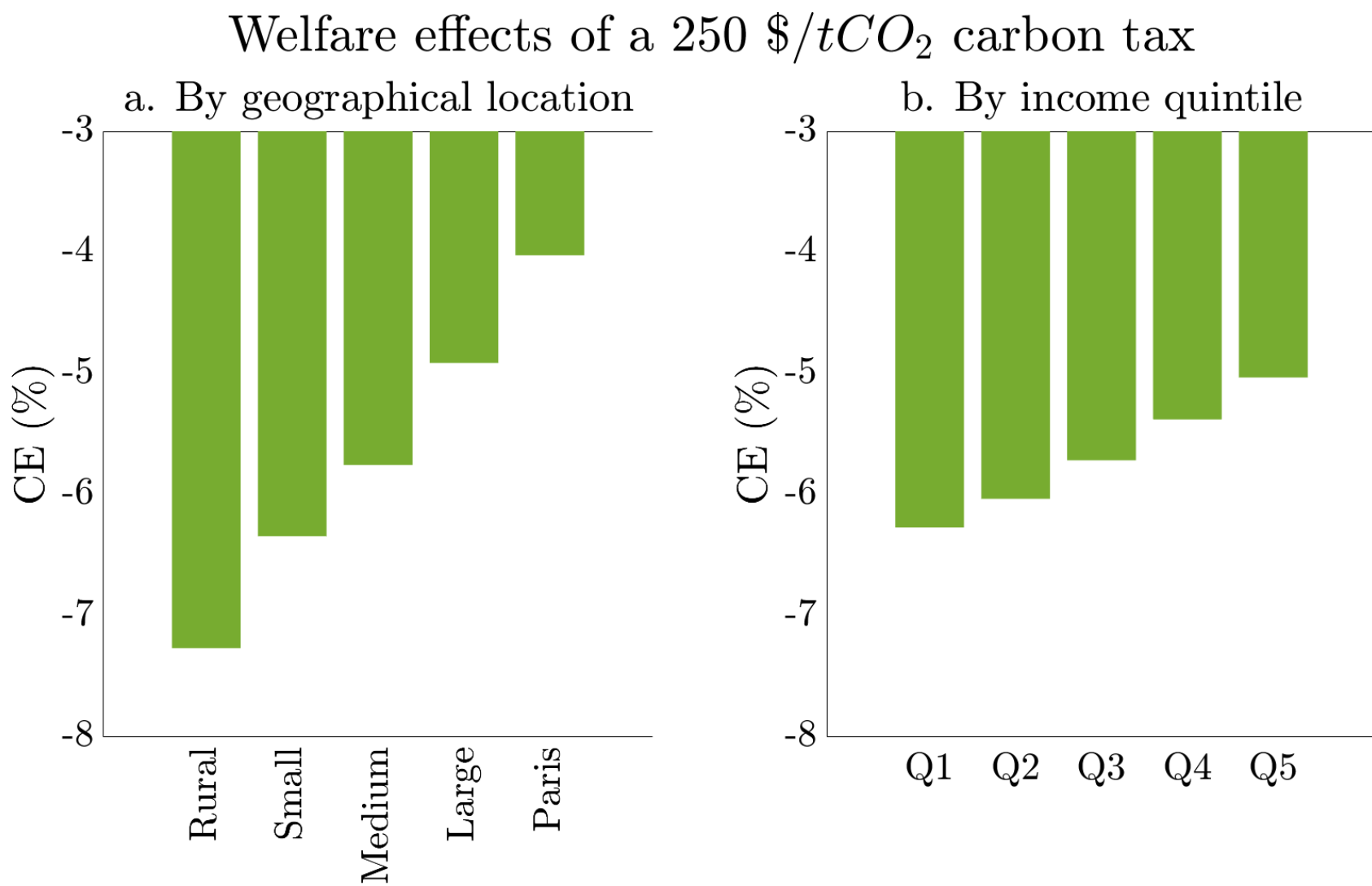
We introduce geography in a general equilibrium heterogeneous-agent model, calibrated on French micro data. We assess the aggregate and distributive effects of carbon taxation and obtain three key results.

I – Geography trumps income in determining distributive effects

Rural households consume more energy, and a larger share coming from fossil fuels. Consequently, low-income rural residents incur the largest losses.



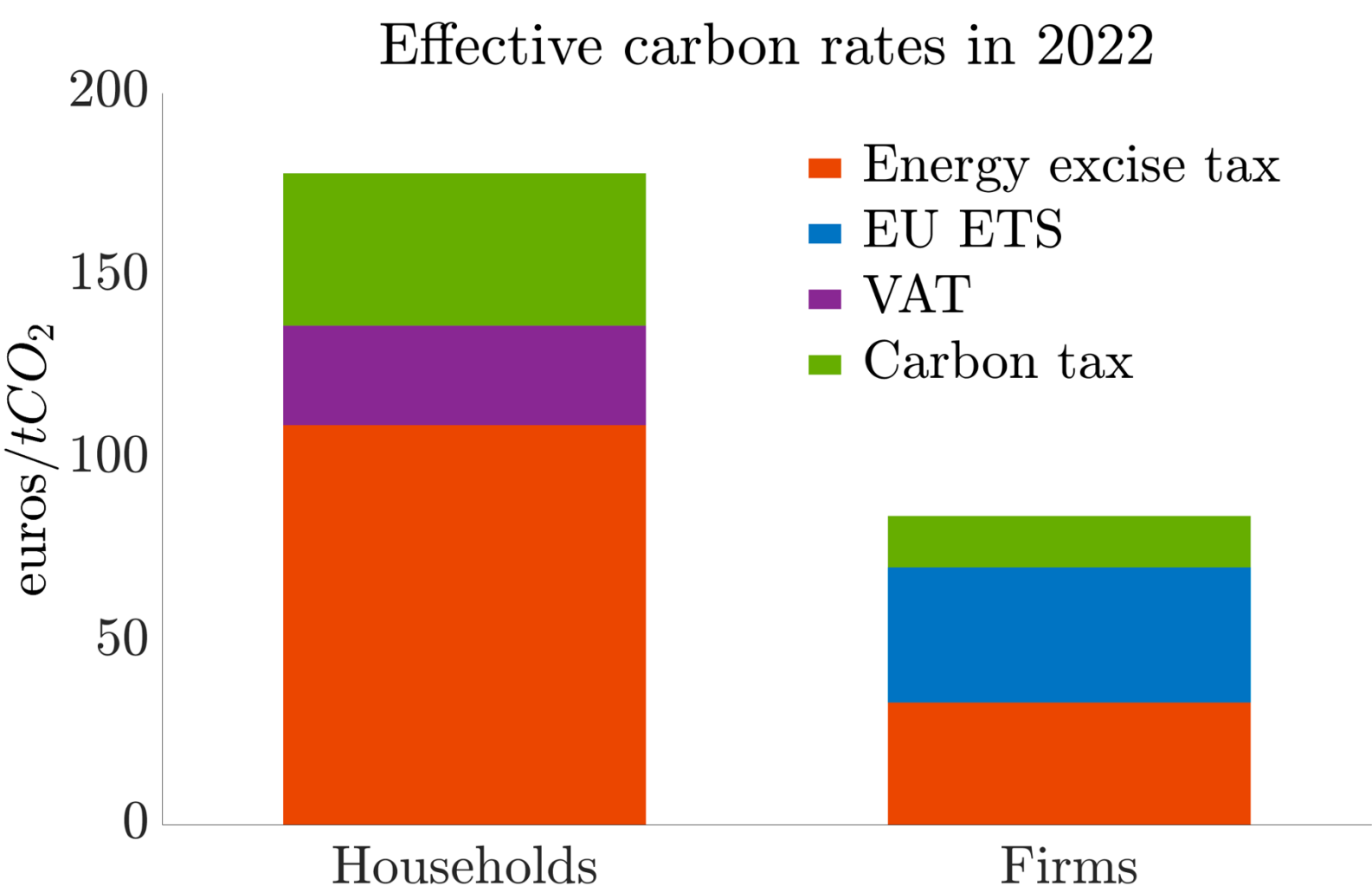
Source: Insee – 2017 “Budget des Familles” survey



Source: Authors’ results

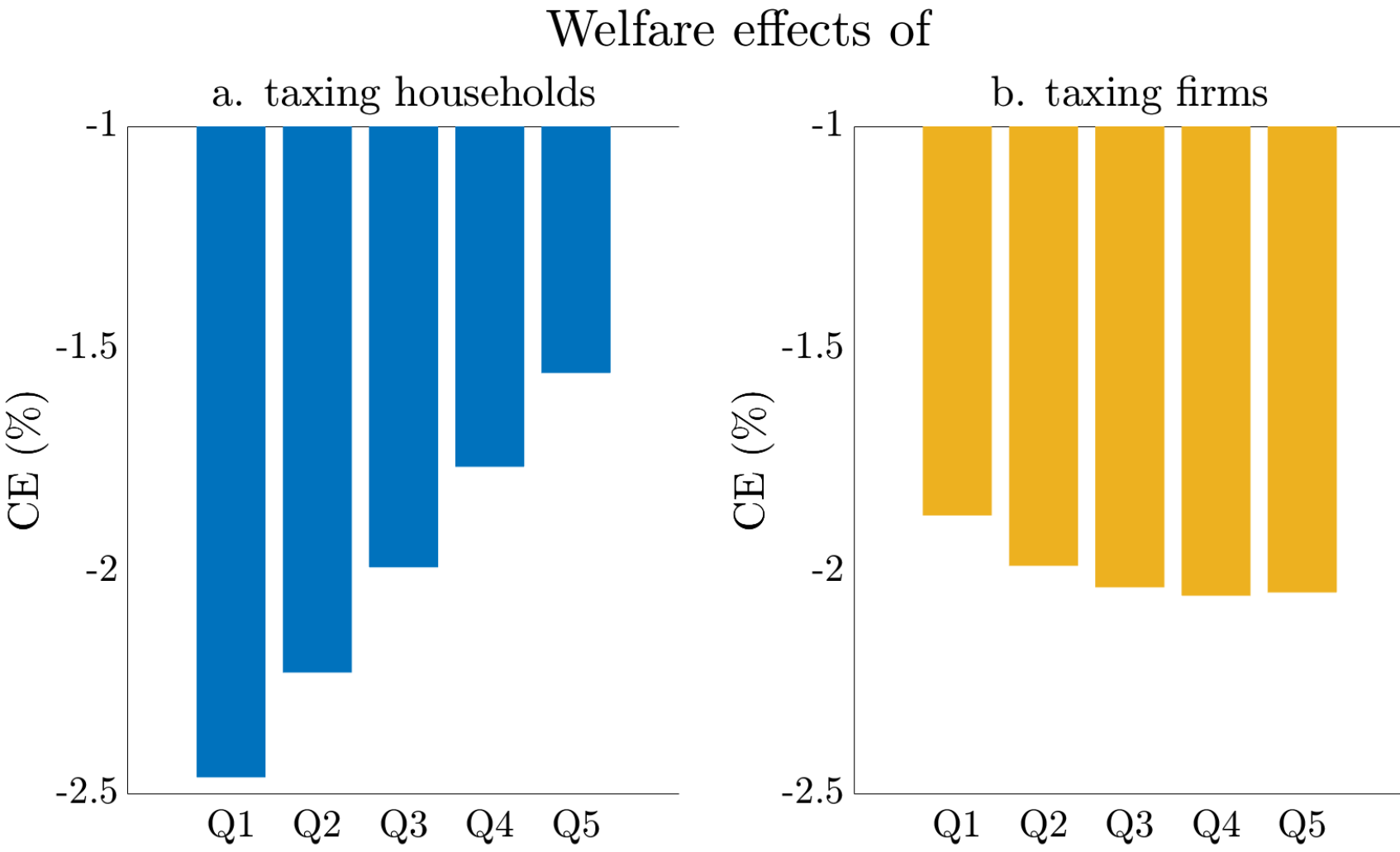
II – Taxing households increases inequalities, taxing firms decreases them

Due to various exemptions, firms’ direct emissions are less taxed than households’ ones.



Source: Green Budget, 2024 French Budget Bill

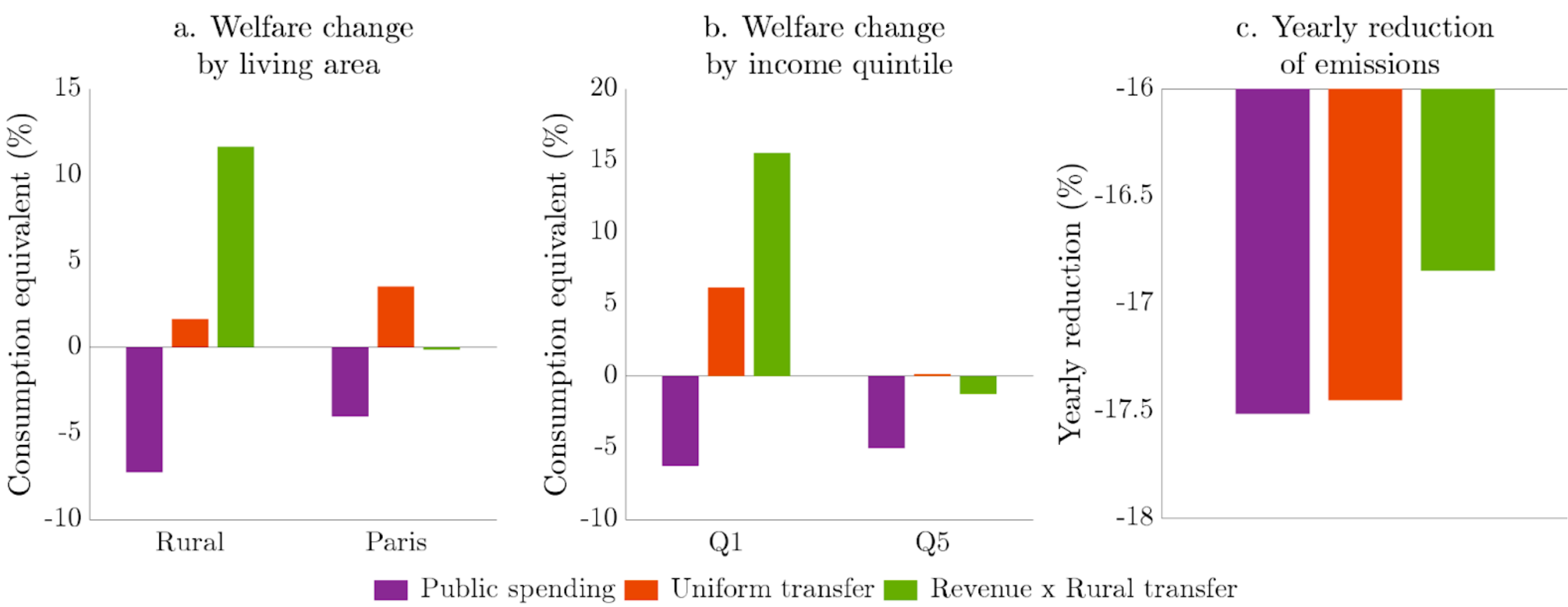
Taxing households’ direct emissions is regressive, while taxing firms’ ones is progressive.



Source: Authors’ results

III – We can enhance political acceptability while reducing emissions

Redistributing the carbon tax revenue through targeted transfers towards low-income households and rural areas enhances overall well-being at a low environmental cost.



Using the carbon tax revenue to increase public spending reduces emissions by 17.5% yearly. Introducing targeted transfers reduces them by 16.8%. Source: Authors’ results



Carbon Emissions and the Transmission of Monetary Policy

José Nicolás Rosas (Universitat Pompeu Fabra)

Economic Risks and Opportunities of Decarbonization | josenicolas.rosas@upf.edu | <https://sites.google.com/view/jnrosas>

I. Motivation

- Climate change, driven by CO2 emissions from fossil fuels, is one of the most pressing environmental issues ever faced.
- Addressing it has become a top public policy priority, raising questions about the role of central banks.
- Research Question:** How does *conventional monetary policy* impact carbon emissions, emission intensity, and energy consumption?

II. This paper

- Structural VAR of the U.S. economy, including CO2 emissions, energy consumption, commodity prices, and emission intensity.
- Identification of monetary policy shocks using external instruments (Stock and Watson, 2012; Mertens and Ravn, 2013).
- Quantify dynamic effects of these shocks using impulse response analysis, focusing on the U.S. energy mix.

III. Econometric approach

$$y_t = b + B_1 y_{t-1} + \dots + B_p y_{t-p} + S \varepsilon_t \quad \varepsilon_t \sim N(0, \Omega)$$

- External instrument z_t *correlated* with **shock of interest** (ε_{1t}) but not with the other shocks

$$\begin{aligned} \mathbb{E}[z_t \varepsilon_{1t}] &= \alpha \neq 0, & (\text{Relevance}) \\ \mathbb{E}[z_t \varepsilon_{\{2:n\}t}] &= 0, & (\text{Exogeneity}) \\ u_t &= S \varepsilon_t & (\text{Invertibility}) \end{aligned}$$

Data:

- Monthly U.S. data (1973M1 - 2019M12)
- z_t : Jarociński and Karadi (2020)

IV. Aggregate effects of MP

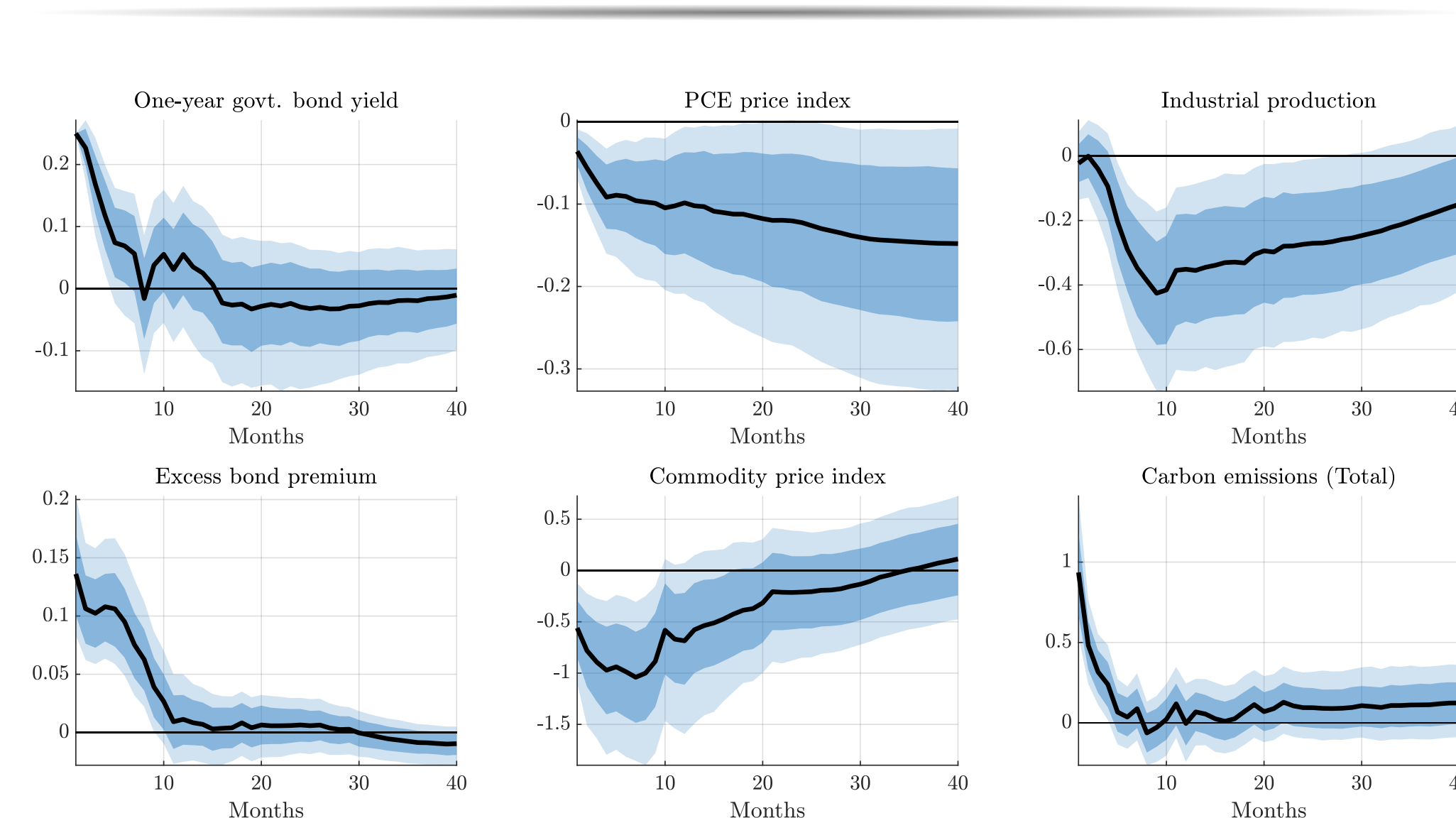
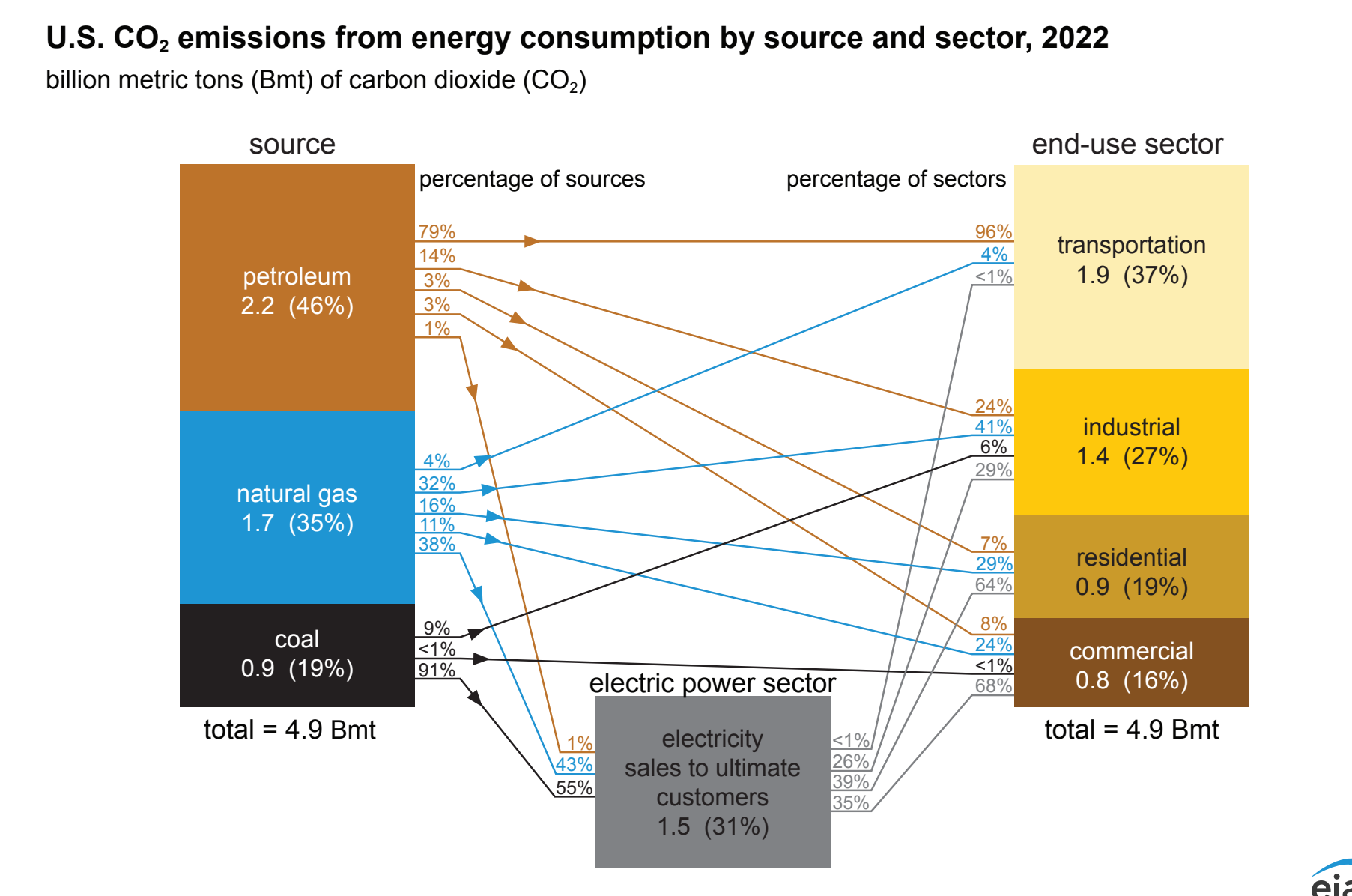


Figure 1: IRFs to a 25bps monetary policy tightening

V. Who produces emissions?



VI. Sectorial effects of MP

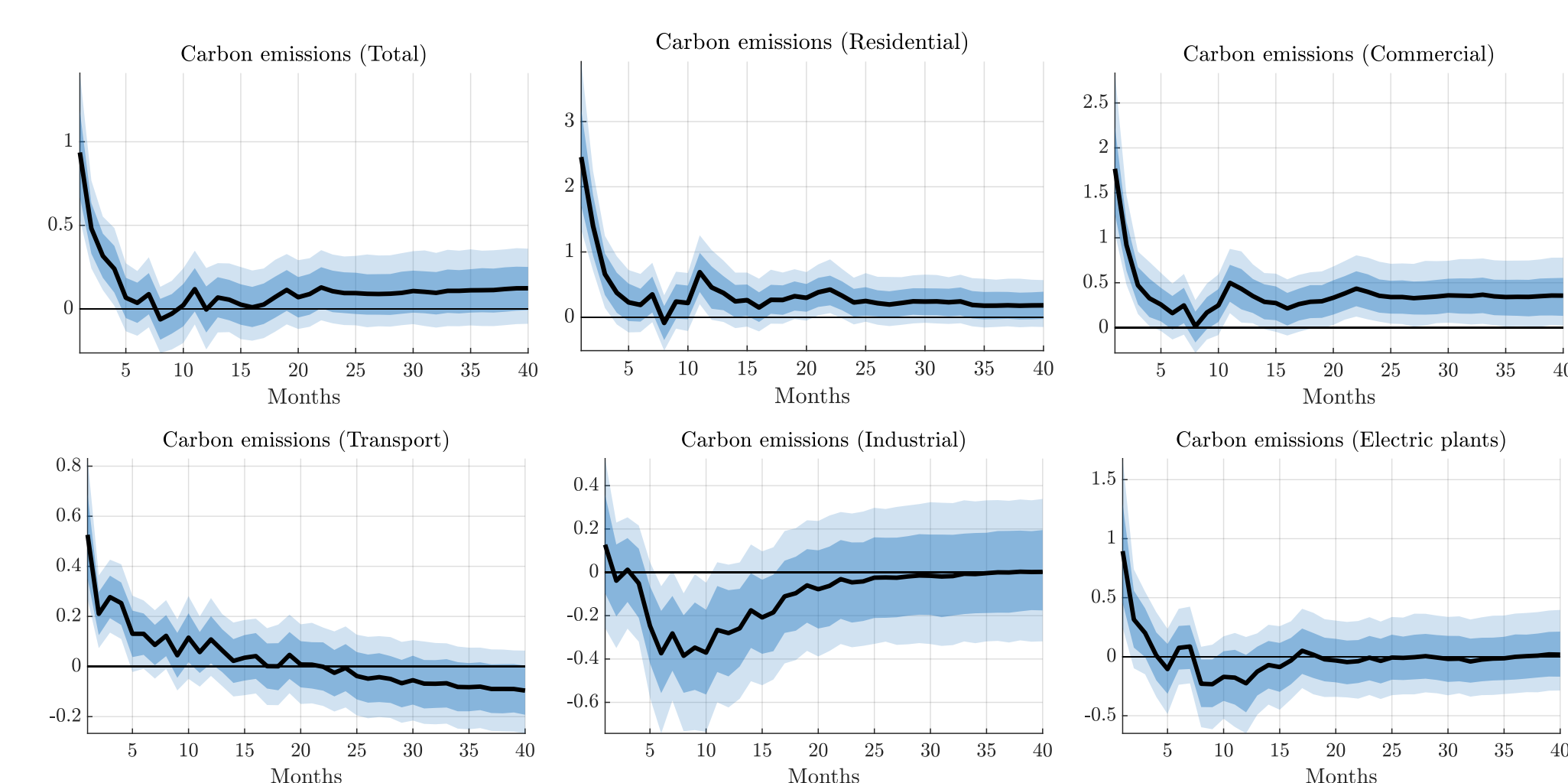


Figure 2: IRFs to a 25bps monetary policy tightening

VII. The role of the electric power sector

- Relative use of coal and natural gas is the key driver of the sector's overall carbon emission levels.
- Monetary policy by major central banks is a key driver of global commodity prices (Frankel, 1986; Miranda-Pinto et al., 2023; Degasperri et al., 2023), influencing electricity production costs.
- U.S. power generation has high fuel flexibility and substitutability, with coal often replacing gas under monetary-induced price shifts.

VIII. Commodity prices

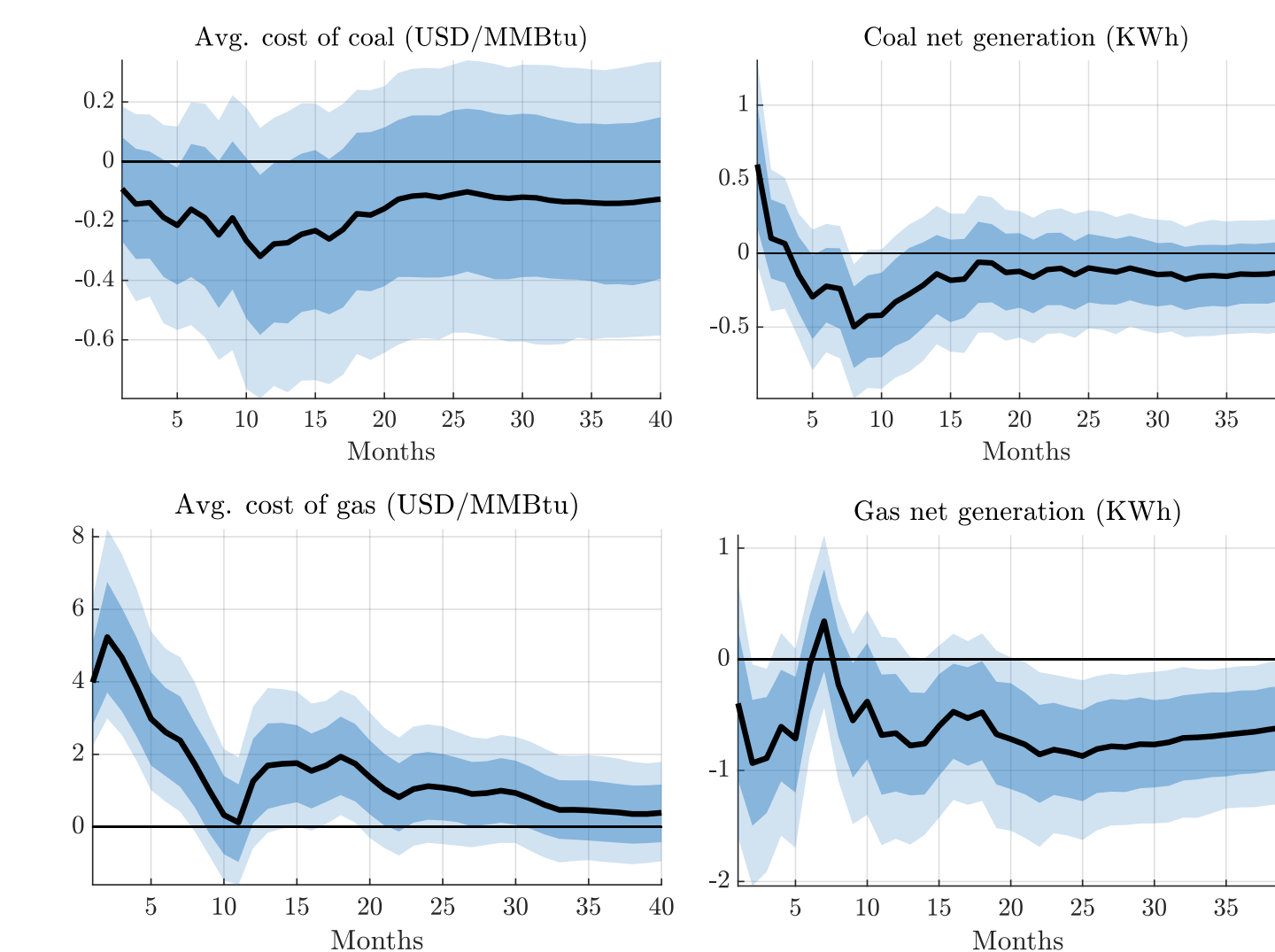


Figure 3: IRFs to a 25bps monetary policy tightening

- ↓ relative price of coal wrt. gas.
- ↑ electricity demand in recessions: leisure, involuntary stock building and storing.

IX. Transmission channels

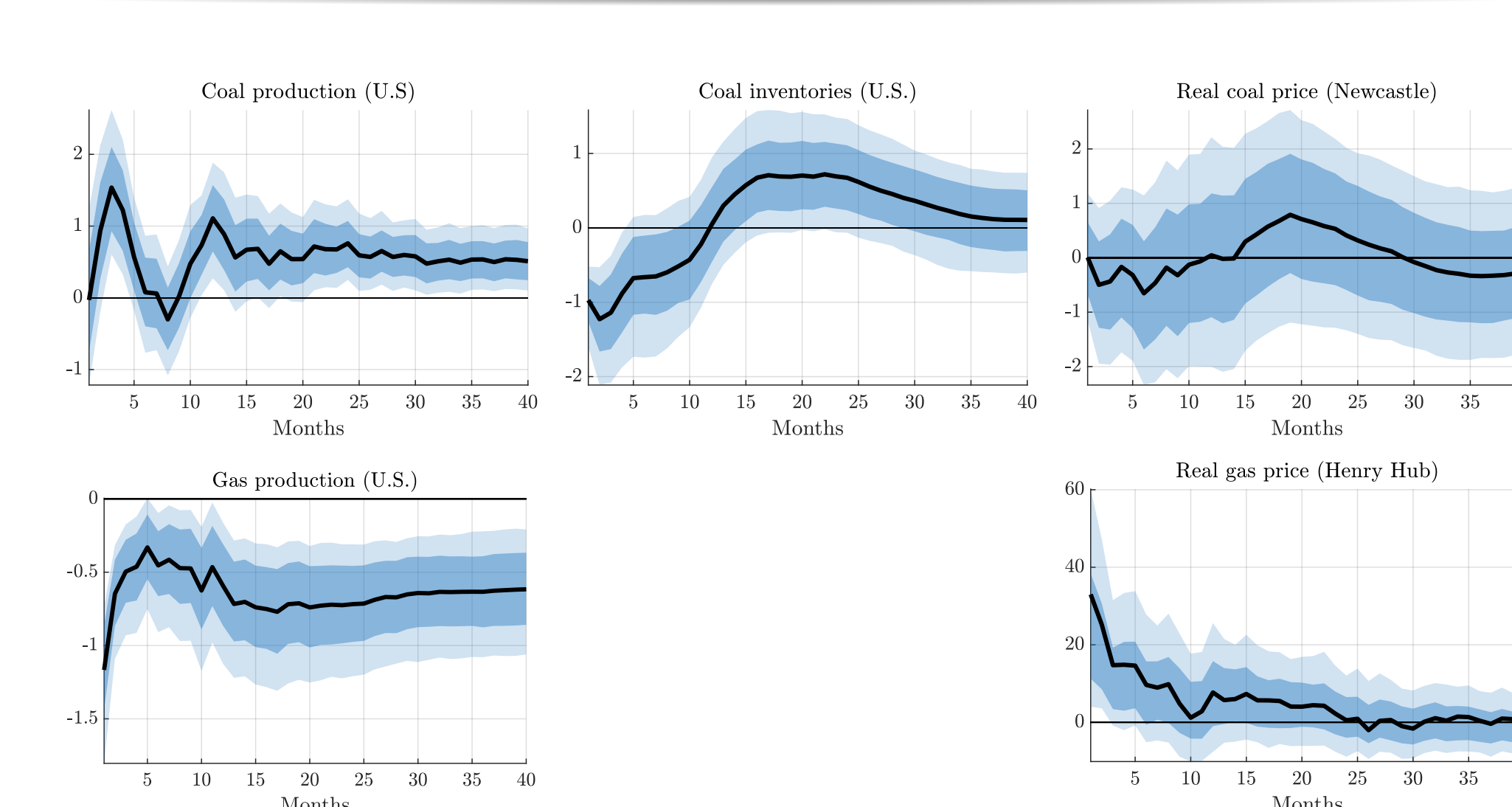


Figure 4: IRFs to a 25bps monetary policy tightening

X. Sectorial energy shares

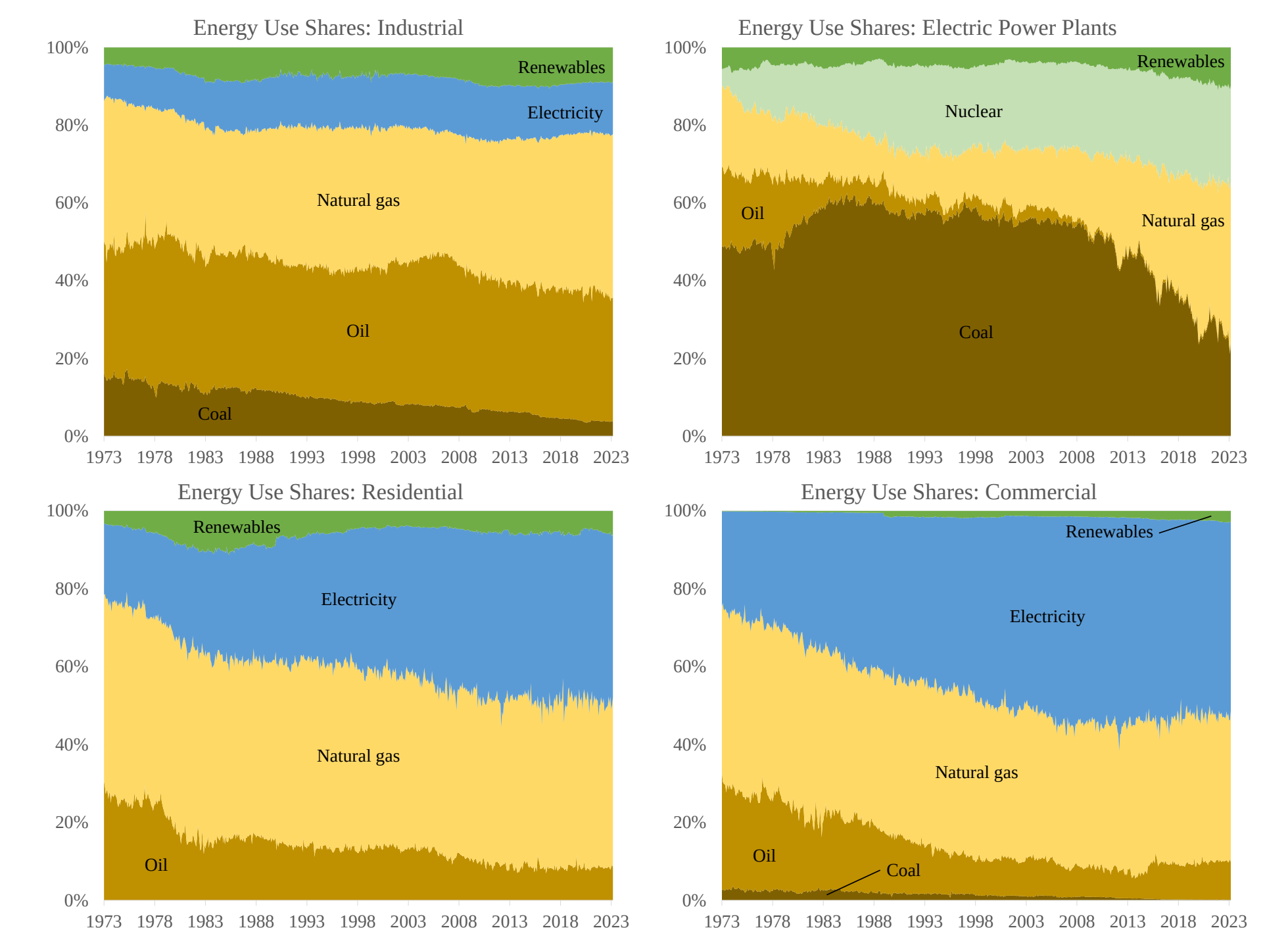


Figure 5: Energy consumption by sector

XI. Conclusion

- Conventional monetary policy has unintended effects on carbon emissions and energy consumption.
- Sectoral responses vary significantly, with industrial emissions decreasing and non-industrial emissions increasing.
- Monetary policy indirectly influences environmental outcomes through changes in demand, energy use and commodity prices.

Information about Climate Transition Risk and Bank Lending (Theme # 2)

Bhavyaa Sharma¹

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¹University of California, Santa Cruz

Background

- Exposure of firms to regulatory and technological aspects of climate transition risk has been increasing over the years.

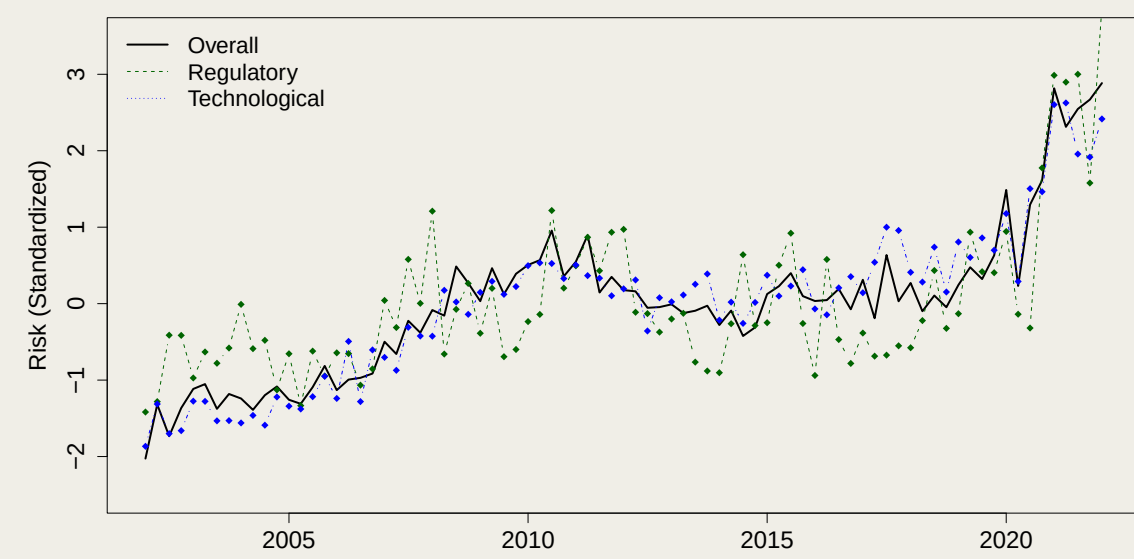


Figure 1. Average firm-level transition risk exposure

- Disorderly transition - a jump in carbon prices - can affect banks through credit risk and market risk channels (Jung et al., 2023)
- Lenders face **significant information gaps** to identify their exposures (lack of standardization (EBA, 2021), obligor emissions and transition risk management (FRB, 2024))

Question:

- Do banks charge higher lending rates to firms more exposed to transition risks?
- Can **costly information acquisition** about borrowers' industry exposure and **under-reaction to public signals** about transition risk explain the interest rate differentials between more and less exposed firms?

Summary of results

"Specialized" banks charge higher rates to negatively exposed firms

- Bank specialization** in borrower's industry $\Rightarrow$ Lower information costs in lending (Paravisini et al., 2023; Blickle et al., 2023)
- Oil supply news shock** (Känzig, 2021) - higher energy price expectations
- Forward-looking **climate regulatory exposure** (Sautner et al., 2023) priced **higher** by banks **specializing** in the borrower's industry for **EU firms**
- Specialized banks price **technological** transition risk **less** for **EU firms** after a news shock - **higher** for **US firms** exposed to both regulatory and technological risk

Role of information acquisition costs and under-reaction in response to public information for the pricing of transition risk

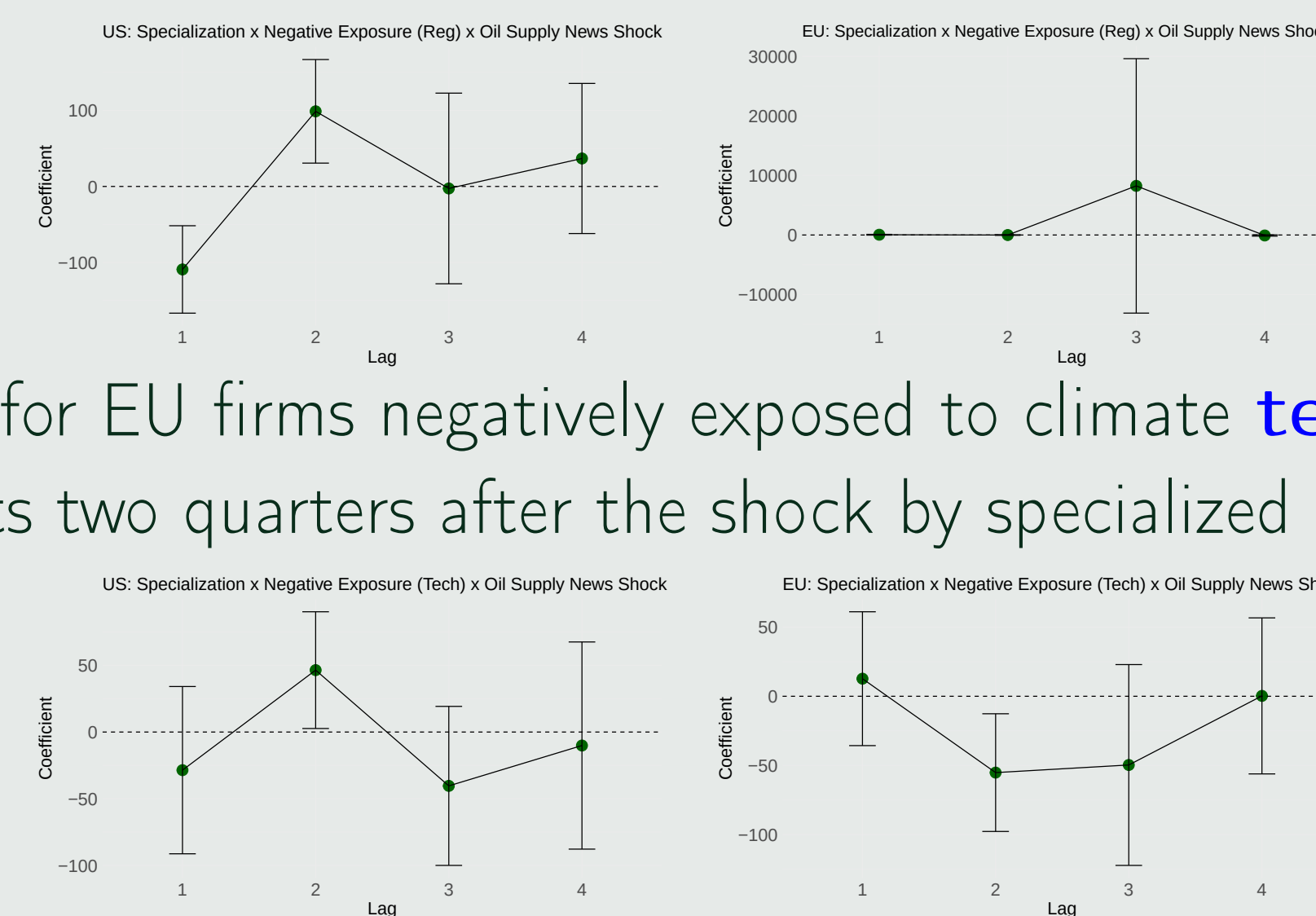
- Interest rate differentials **decline** in favor of the more exposed borrowers if lenders **under-react** to public signals
- Greater dependence on private information during **high credit risk** $\Rightarrow$ small levels of under-reaction can result in **sharply** $\downarrow$ **interest rate differentials** in favor of more exposed borrowers

Negative climate regulatory exposure associated with higher rates if lending by bank specializing in the borrower's industry for EU firms

	All-in-spread-drawn (bps)		
	All	US	EU
Scope 1 and 2 emission intensity ($t - 1$)	0.00	0.00	0.01
Reg. Sentiment _{Neg}	3.33	11.70*	-37.24*
Tech. Sentiment _{Neg}	-2.28	-1.29	29.69
Emissions $\times$ Specialization _{t-1}	0.05	-0.01	-0.01
Reg. Sentiment _{Neg} $\times$ Specialization _{t-1}	-16.10	-29.25	27.24**
Tech. Sentiment _{Neg} $\times$ Specialization _{t-1}	14.28	7.33	6.14
Firm and Loan-level controls	✓	✓	✓
Firm, Bank-Year and Industry-Year F.E.	✓	✓	✓
R ²	0.73	0.69	0.88
N	65,633	48,113	9,023

- Negative exposure to regulatory developments associated with higher rates on average for US firms

Does pricing by specialized banks change after an oil supply news shock?



- Lower rates for EU firms negatively exposed to climate **technological** developments two quarters after the shock by specialized banks

- Regulatory** and **technological** exposure priced **higher** for US firms two quarters after the shock

Model of costly information acquisition with under-reaction to informative public signals

- Two entrepreneurs $\in H, L$
- Transition risk: $P(\text{successful project}) = p_j; j \in \{h, l\}$ with terminal return $= R$ (0 if unsuccessful)
- Two banks
 - Specialized** (Informed) - Better equipped to acquire information
 - Non-Specialized** (Uninformed) - Less equipped to acquire information
- Information structure:
 - Informed bank: imperfect and costly **private** signal $\eta \in \{l, h\}$

$$Pr(\eta = h|H) = Pr(\eta = l|L) = \phi \geq \frac{1}{2} \text{ and } C(\phi) = \frac{(\phi - 0.5)^2}{2}$$

ϕ = Quality of private information

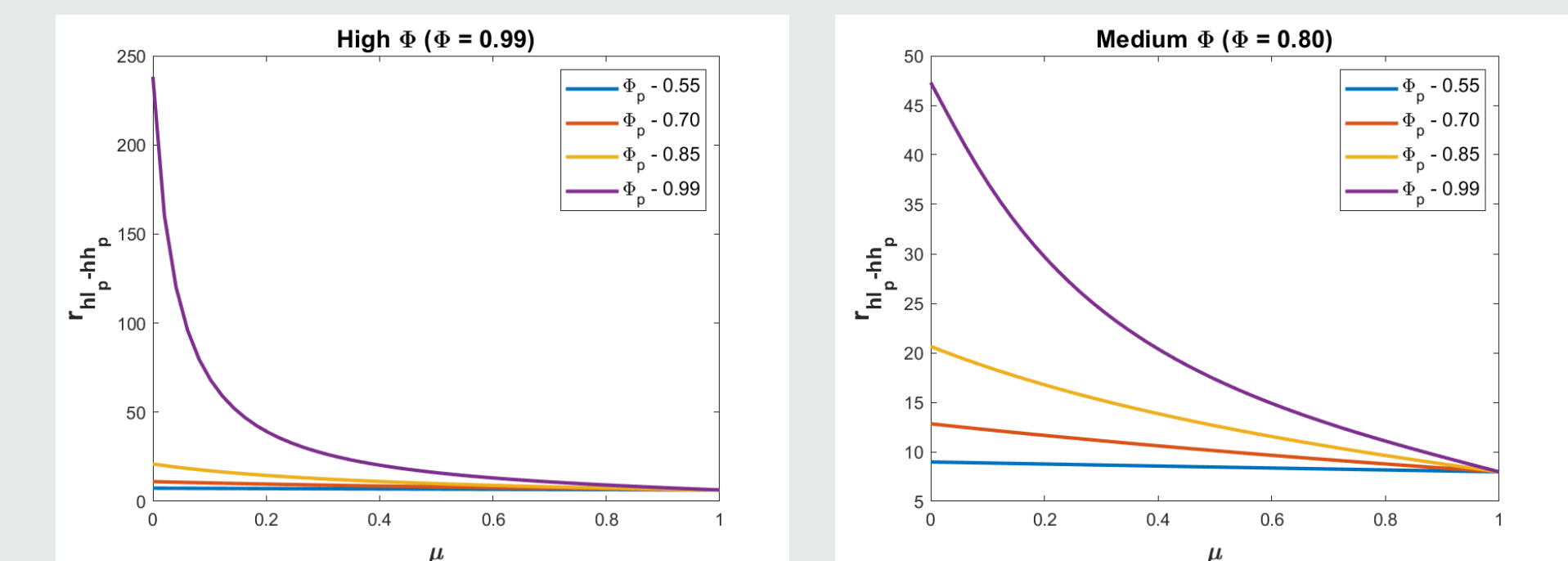
- Informative but imperfect, exogenous **public** signal η_p - costlessly observed by both banks

$$Pr(\eta = h_p|H) = Pr(\eta = l_p|L) = \phi_p \geq \frac{1}{2}$$

Difference in subjective probabilities of borrower success for by specialized and non-specialized banks in response to public signals

- $0 < \mu \leq 1$ - (exogenous) under-reaction to public signals about climate risks
- The success probabilities used by the Specialized bank:
$$p(i, j) = \mu p(i) + (1 - \mu) [P(H|\eta = i, \eta_p = j) p_h + P(L|\eta = i, \eta_p = j) p_l] \forall i, j \in \{h, l\}$$
$$p(i) = \text{Probability of success of the borrower based on private signal}$$
- Success probabilities used by the Non-specialized bank are:
$$p(j) = \mu [\lambda p_h + (1 - \lambda) p_l] + (1 - \mu) [P(H|\eta_p = j) p_h + P(L|\eta_p = j) p_l] \forall j \in \{h_p, l_p\}$$

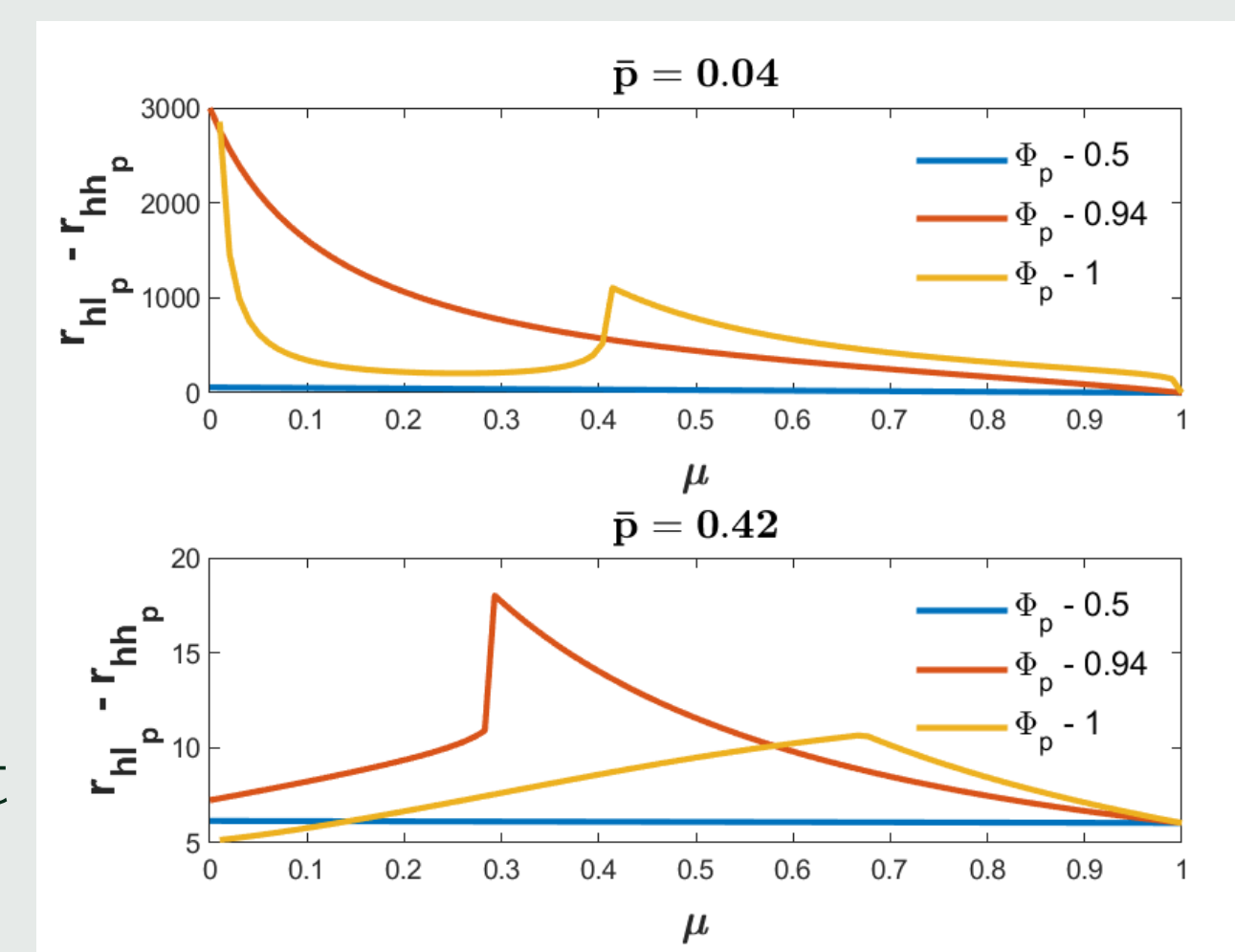
The interest rate differentials (at a given level of informativeness of screening and the public signal) decrease as the under-reaction (i.e. μ) increases.



Transition risk priced less during periods of poor borrower quality

As average borrower quality $\bar{p} = \lambda p_h + (1 - \lambda) p_l$ increases

- Optimal private information for $\phi_p > 0.5$ for $\mu < \bar{\mu}$ decreases $\Rightarrow$ **greater dependence on private information during periods of poorer average borrower quality (low $\bar{p}$)**
- For low $\bar{p}$, even small levels of μ can result in a $\downarrow$ interest rate differential between more and less exposed borrowers



Empirical tests:

- Regulatory and technological exposure priced **lower** in favor of more exposed EU firms by specialized banks after an oil supply news shock during periods of high financial stress

Policy Implication

Lowering the cost of acquiring information about firms' climate change exposure (**standardized firm-level disclosures; stress-testing guidelines**) important for lowering financing costs for **green** projects, even if the quality of public information increases.

MATE-AR: MODEL FOR THE ANALYSIS OF ENERGY TRANSFORMATIONS IN THE ARGENTINEAN RESIDENTIAL SECTOR: A KEY TOOL FOR ENERGY POLICY DESIGN

PhD Pedro Chévez

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1.- Background and objectives of the project

Due to the conditions of inequality among Argentine households, in recent years energy policies have been implemented that include segmented tariff structures and targeted subsidy systems, taking into account the different realities of the population. Within this framework, the development of diagnostic methodologies is crucial to identify the specific energy characteristics of different sectors of the population and to provide data and arguments to support decision-making.

However, in Argentina, as well as in many other countries, there is no database that synthesizes disaggregated residential energy information to support decision making in this area. On the other hand, in several countries around the world there is a long tradition of governmental energy surveys and databases that are updated periodically and allow the design and evaluation of the effectiveness of the policies implemented. Based on the identification of these aspects, the construction of the MATE-AR model was planned and built. Below it is described the objective of the MATE-AR project, which was funded by CONICET:

Objective: The aim of the project is to state an open methodology for the construction of the *Model for the analysis of energy transformations in the Argentinean residential sector* (MATE-AR) and its validation, departing from the “equipment dataset” of the *National Household Expenditure Survey 2017/2018*. This will allow its subsequent future replication and/or improvement by the energy planning offices and researchers.

This is the first comprehensive bottom-up residential energy demand model at the national level for Argentina and it allows to organize the national energy demand disaggregated by province, by user income segments, by energy sources (electricity, natural gas and bulk fuels) and by end uses (cooking, domestic hot water, heating, cooling, refrigerators and freezers, lighting, laundry, and home appliances).

2.- Methods

The dataset of the National Household Expenditure Survey 2017/2018 of Argentina (ENGHo for its acronym in Spanish) was used for the construction of the model and it is publicly accessible at the website of the National Institute of Statistics and Census of Argentina.

There were used two files of the database:

- the “household dataset” (engho2018_hogares.txt) which has 21,547 rows (surveyed households) and 134 columns (variables); each households have an expansion weight factor that totalizes 12,642,525 households in the country
- the “equipment dataset” (engho2018 equipamiento.txt) which has 1,067,019 rows (equipment surveyed) and 17 columns (variables). There are 46 different equipment.

Below is an example for the calculation of the energy consumption of an air conditioning equipment, where it can be seen that the equation includes variables that have been surveyed (green), variables that require external calculation (red), and the output (yellow). Every equation for each equipment needs particular external calculations.

indec Instituto Nacional de Estadística y Censos República Argentina



3.1.- Results – METHODOLOGICAL VALIDATION

The validation is made for two sub models: electricity and natural gas. We use the R^2 and relative error (see the Table 1) to evaluate them. Also, below are concatenated the annual energy consumption curves of the 24 provinces, the modeled and the empirical, which behave similarly.

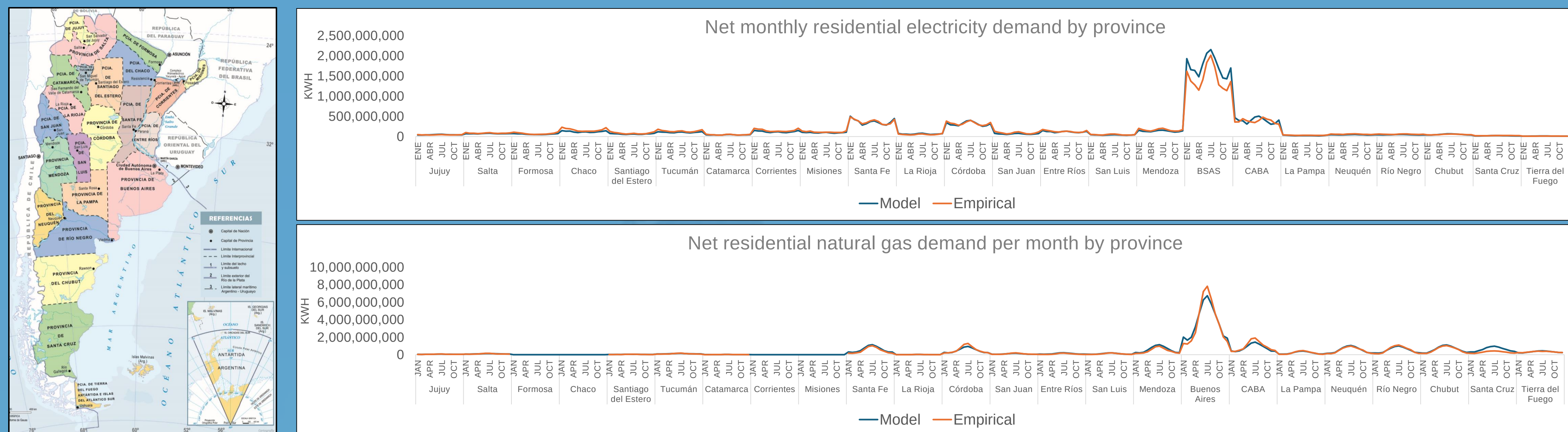


Table 1. Validation of the models		
Sub model	R ²	Rel.error
Net electricity cons.	0.986	16.96%
Net natural gas cons.	0.972	26.4%

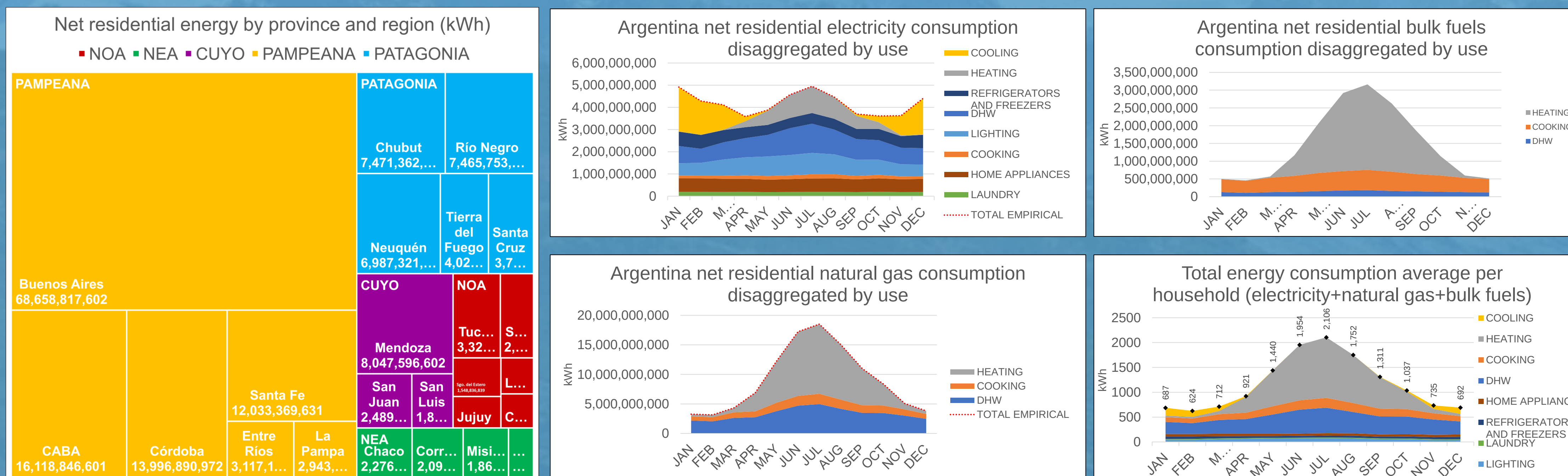
3.2.- Results – OPEN DATASETS

Once the methodology is validated and published, the processed databases will be published. That is, the monthly consumption of the 21,547 households of electricity, natural gas and bulk fuels. And the monthly consumption of each of the 1,067,019 appliances surveyed.

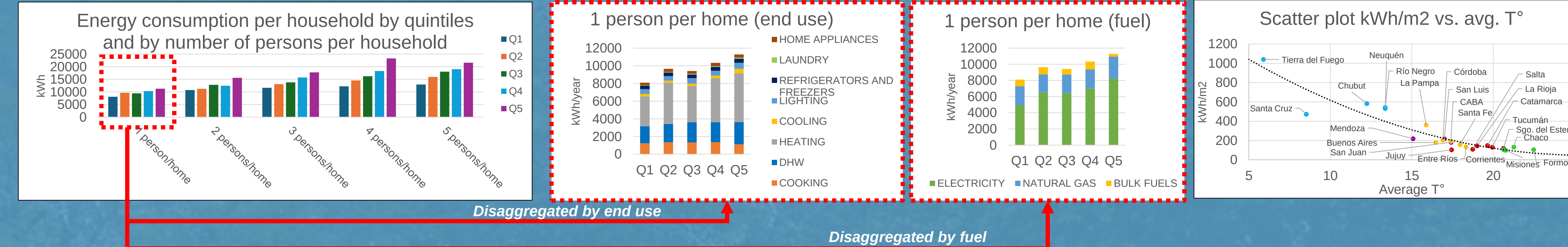
3.3.- Results – DATA ANALYSIS.

Below are a few examples of the possible output results from the model.

3.3.1.- General analysis



3.3.2.- Quintil analysis



4.-Conclusions

-It was possible to construct a national bottom-up model of energy consumption with high accuracy, even though the dataset did not collect all the variables needed for the calculations for each appliance.

-The methods used to estimate non-collected variables and energy calculations can be applied in other countries with similar data sets.

-Bottom-up national energy models linked to socioeconomic information allow an analysis of users by income segments and by provinces/regions. This is key for the design of energy policies and the targeting of specific resources to each segment.

-This contributes to the reduction of inequality and makes public spending more efficient, which has an impact on the macroeconomy.

3.56 USO DE ENERGÍA - CALEFACCIÓN Y REFRIGERACIÓN				USO HABITUAL			
Código	¿Habitualmente utiliza...?	¿Con qué frecuencia lo usa?	¿Cuántas horas al día en promedio lo usa?	Código	¿Cuál es la antigüedad del equipo según la etiqueta?	Código	¿Cuál es la eficiencia del equipo según la etiqueta?
1. Utiliza	1. Menos de 1 vez por semana	1. Menos de 5 días	1. Menos de 1 a 24 según corresponda	1. A	1. Menos de 5 años	1. A	1. Menos de 5 años
2. No utiliza	2. Entre 1 y 3 veces por semana	2. Entre 5 y 10 días	2. Entre 11 y 20 años	2. B	2. Entre 5 y 10 años	2. B	2. Entre 5 y 10 años
3. No tiene	3. Entre 4 y 6 veces por semana	3. Entre 11 y 20 años	3. Más de 20 años	3. C	3. Más de 10 años	3. C	3. Más de 10 años
4. No tiene	4. Todos los días de la semana	4. Más de 20 años	4. Más de 20 años	4. D	4. Más de 20 años	4. D	4. Más de 20 años
5. No tiene	5. Cuando hay más de un equipo utiliza los rangos al final de la página	5. Cuando hay más de un equipo utiliza los rangos al final de la página	5. Cuando hay más de un equipo utiliza los rangos al final de la página	5. E	5. Cuando hay más de un equipo utiliza los rangos al final de la página	5. E	5. Cuando hay más de un equipo utiliza los rangos al final de la página
6. No tiene	6. Cuando hay más de un equipo utiliza los rangos al final de la página	6. Cuando hay más de un equipo utiliza los rangos al final de la página	6. Cuando hay más de un equipo utiliza los rangos al final de la página	6. F	6. Cuando hay más de un equipo utiliza los rangos al final de la página	6. F	6. Cuando hay más de un equipo utiliza los rangos al final de la página
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8. No tiene	8. Cuando hay más de un equipo utiliza los rangos al final de la página	8. Cuando hay más de un equipo utiliza los rangos al final de la página	8. Cuando hay más de un equipo utiliza los rangos al final de la página	8. H	8. Cuando hay más de un equipo utiliza los rangos al final de la página	8. H	8. Cuando hay más de un equipo utiliza los rangos al final de la página
9. No tiene	9. Cuando hay más de un equipo utiliza los rangos al final de la página	9. Cuando hay más de un equipo utiliza los rangos al final de la página	9. Cuando hay más de un equipo utiliza los rangos al final de la página	9. I	9. Cuando hay más de un equipo utiliza los rangos al final de la página	9. I	9. Cuando hay más de un equipo utiliza los rangos al final de la página

$$E_{HEAT_IND\,i,j,k} = Power_k * days_{week\,k} * hs_{day\,k} * HeatSeason_j * pondera_k * WeightHDD_{i,j}$$

Energy consumption for one AC (heating mode) in each month

Electric Power of the equipment: to be defined by COP/EER

Months of heating use: to be calculated for each province

Expansion weight factor of the equipment. From “household dataset”

Heating consumption sensibilization factor. To be calculated for each province and month

NATIONAL ACADEMIES Sciences Engineering Medicine

IIPAC Instituto de Investigaciones y Políticas del Ambiente Construido



Strategic Interventions for Urban Carbon Reduction: EcoSphere, A Bottom-Up Simulation Software for Sustainable Cities

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Topical Theme: 03



Introduction

- The **Built Environment** is responsible for **40% of greenhouse gas emissions**.
- Not enough **comprehensive data and frameworks** are available to capture the current and future state of the urban areas.
- Different urban areas** require **different measurements**. A single recipe is not necessarily good for all cities.
- There are many different aspects to urban areas' embodied carbon reduction. **Decision makers** need a **simple tool** to interpret the results in **simple terms** for them.

Building Stock Data

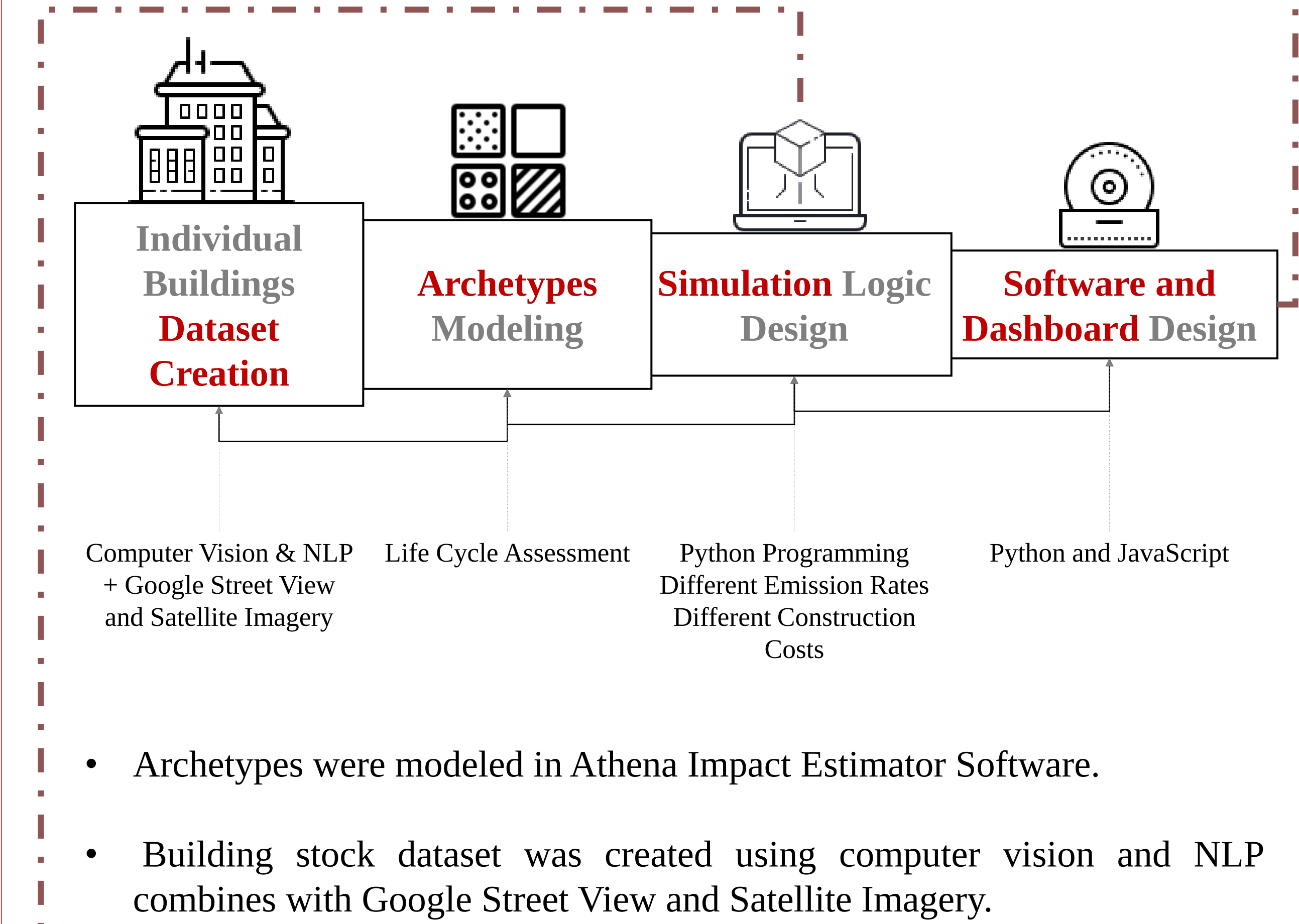
- The building stock dataset contains the **different types environmental impact** for each building, including Global Warming Potential (GWP).
- This is for the **first time in the U.S.** that a building stock model was made with such a **scale**. The image shows **Chicago as a prototype**.



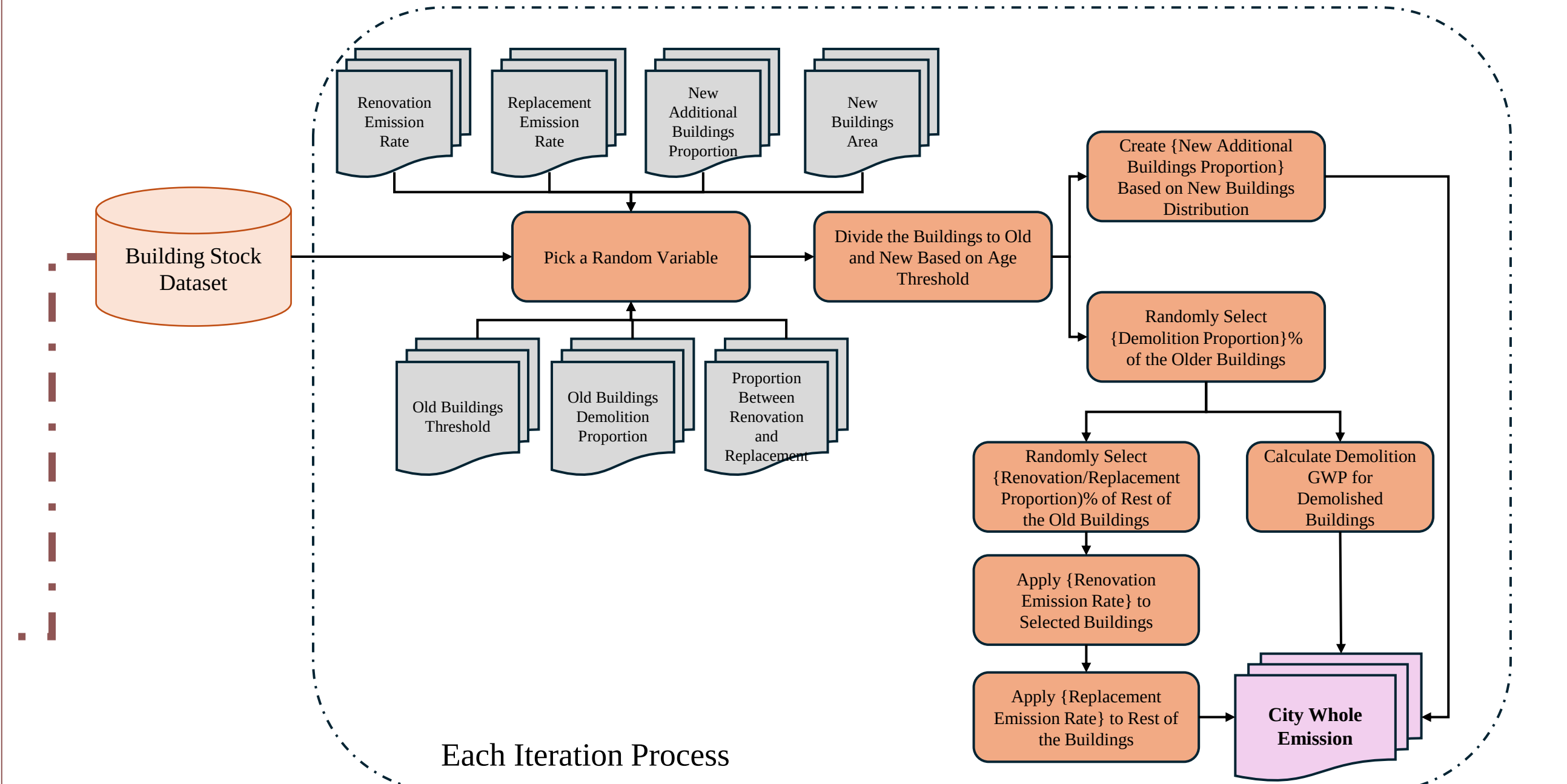
Future Path

- Refining the building selection algorithms** for replacement and renovation scenarios.
- The next step for us is to **increase the automation in LCA calculations** for each of buildings instead of using Athena models.
- The ultimate goal of this study is to **expand it to the national scale**.

Methodology



Simulation Logic



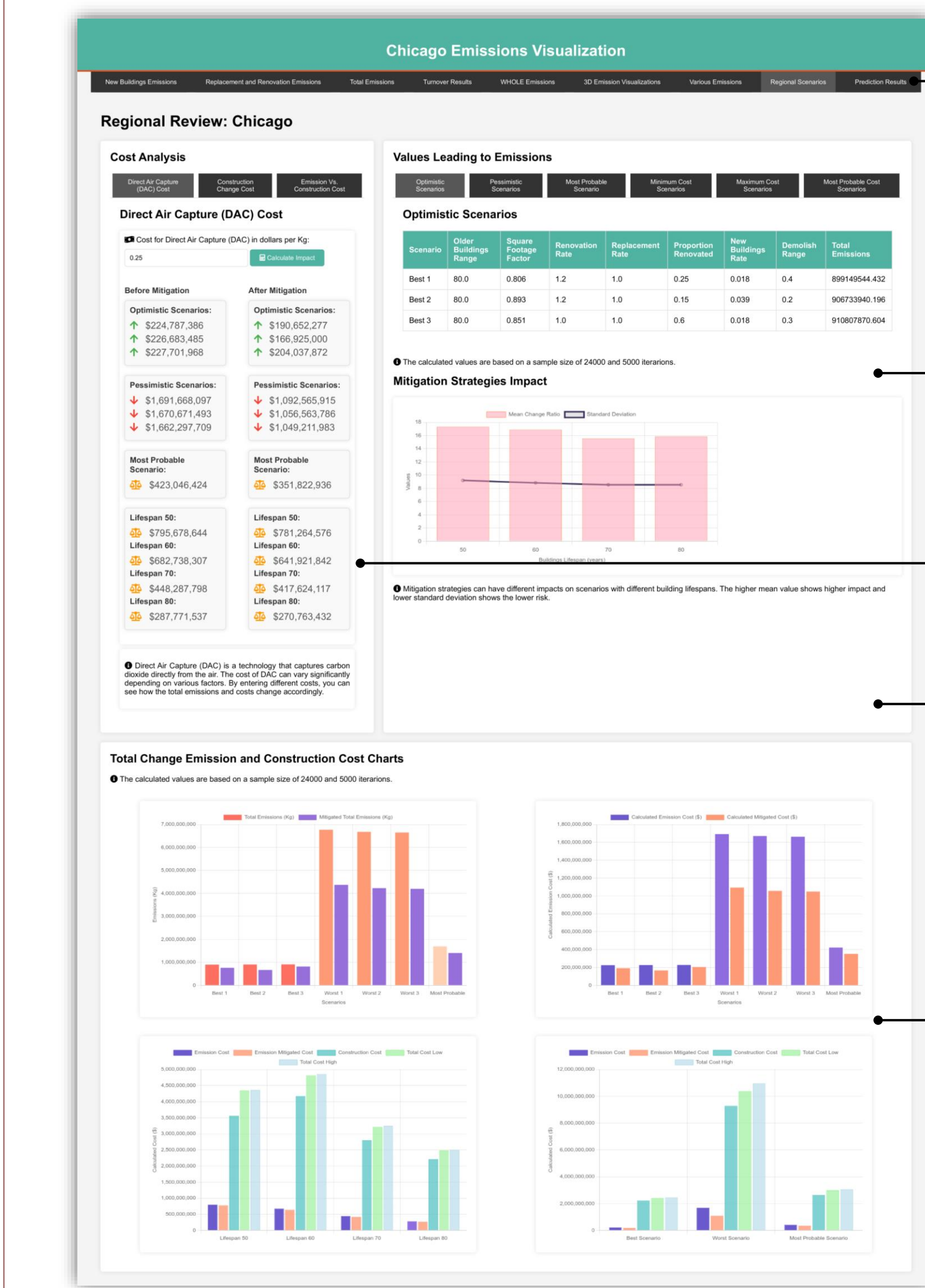
Conclusion

The results of this study provided a tool for studying the embodied carbon emission of the United States cities **for all type of users**. The prototype model was implemented on **over one million buildings in Chicago** and the results showed that **extending buildings' lifespan is over 65% effective in GWP reduction**. It also showed that the **renovation scenarios** are much **more efficient** comparing to replacing the buildings. The outcomes of this research combined with 3D visualizations **demonstrates the most influential buildings in the cities environmental impact**. The outcome of this research provides a blueprint for **sustainable feature of the United States**.

Results

- The outcome of research resulted into a **standalone software** for simulation different scenarios.
- The scenarios were examined from **three different perspectives**:
 - The embodied carbon amount**
 - Decarbonization cost**
 - Construction costs** associated with each scenario
- Findings showed:
 - lower lifespans lead to 3 times more emission** in the cities.
 - 20% increase in average buildings area** leads to negating carbon mitigation strategies.
 - Constructing **new buildings** emits **7,500 times more** embodied carbon compared to renovating buildings.

EcoSphere Dashboard: Information Summary Page



- Results Tabs;
 - Emission Measurement Charts
 - Results Interpretations
 - Point Estimation
- Values Leading to Best & Worst Scenarios;
- Cost and Impact Analysis;
- Mitigation Strategies Impact on Each Lifespan Range;
- Scenarios Comparison Charts;

Result Tabs Samples



Acknowledgments

This project was funded by National Science Foundation (NSF) and National Institutes of Health (NIH). We thank Zachary Dooner and Carter Powers for their contributions to data collection. We also thank all faculty, staff, and students in the School of Architecture and Department of Civil and Environmental Engineering and Earth Science at the University of Notre Dame for their support of this project.



Carbon Capture and the Power Sector: Health and Environmental Outcomes of US Policies

Paola P. Furlanetto (ppimentelfur@umass.edu) and Erin Baker, Industrial Engineering and Operations Research, UMass Amherst

I. Motivation



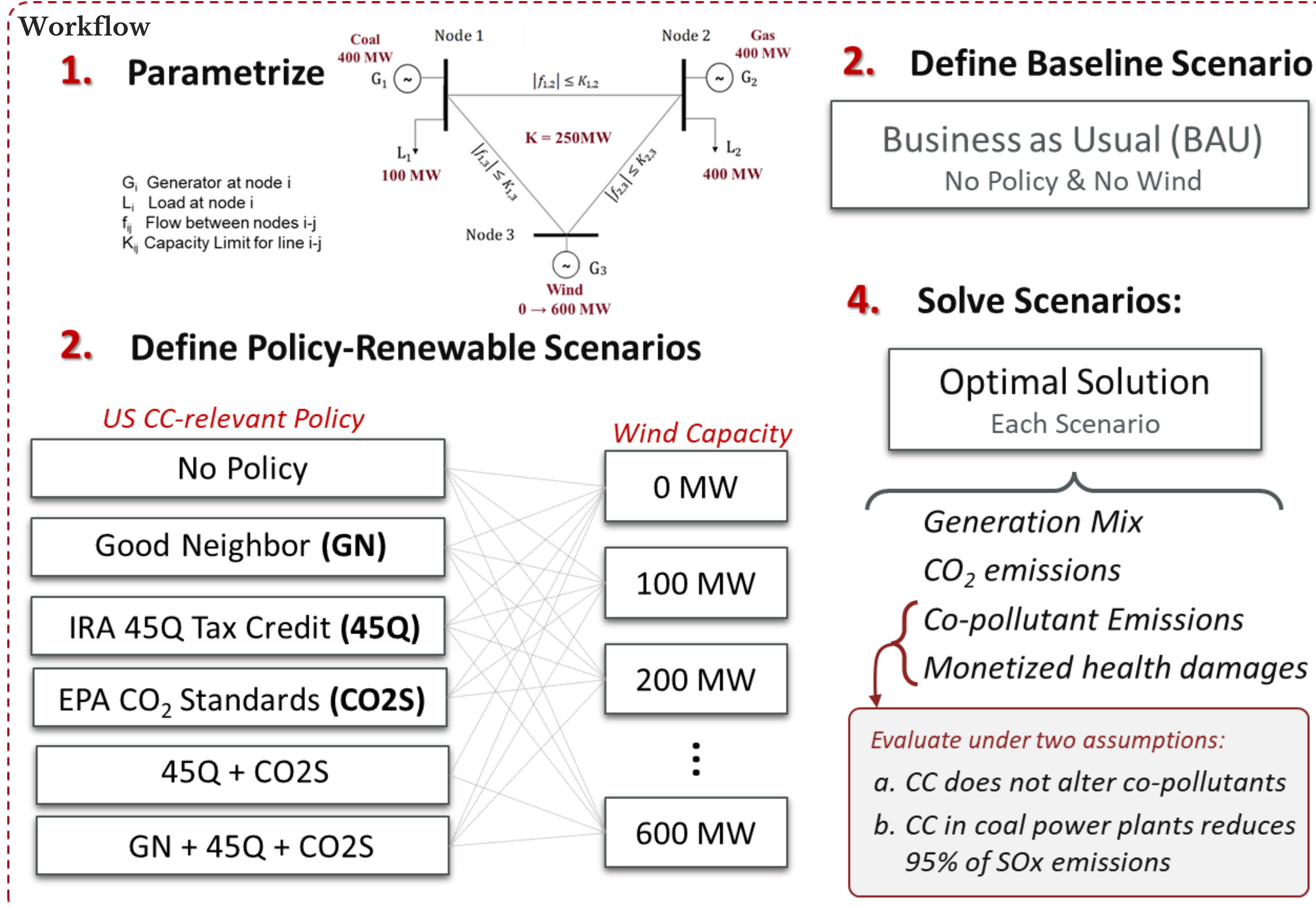
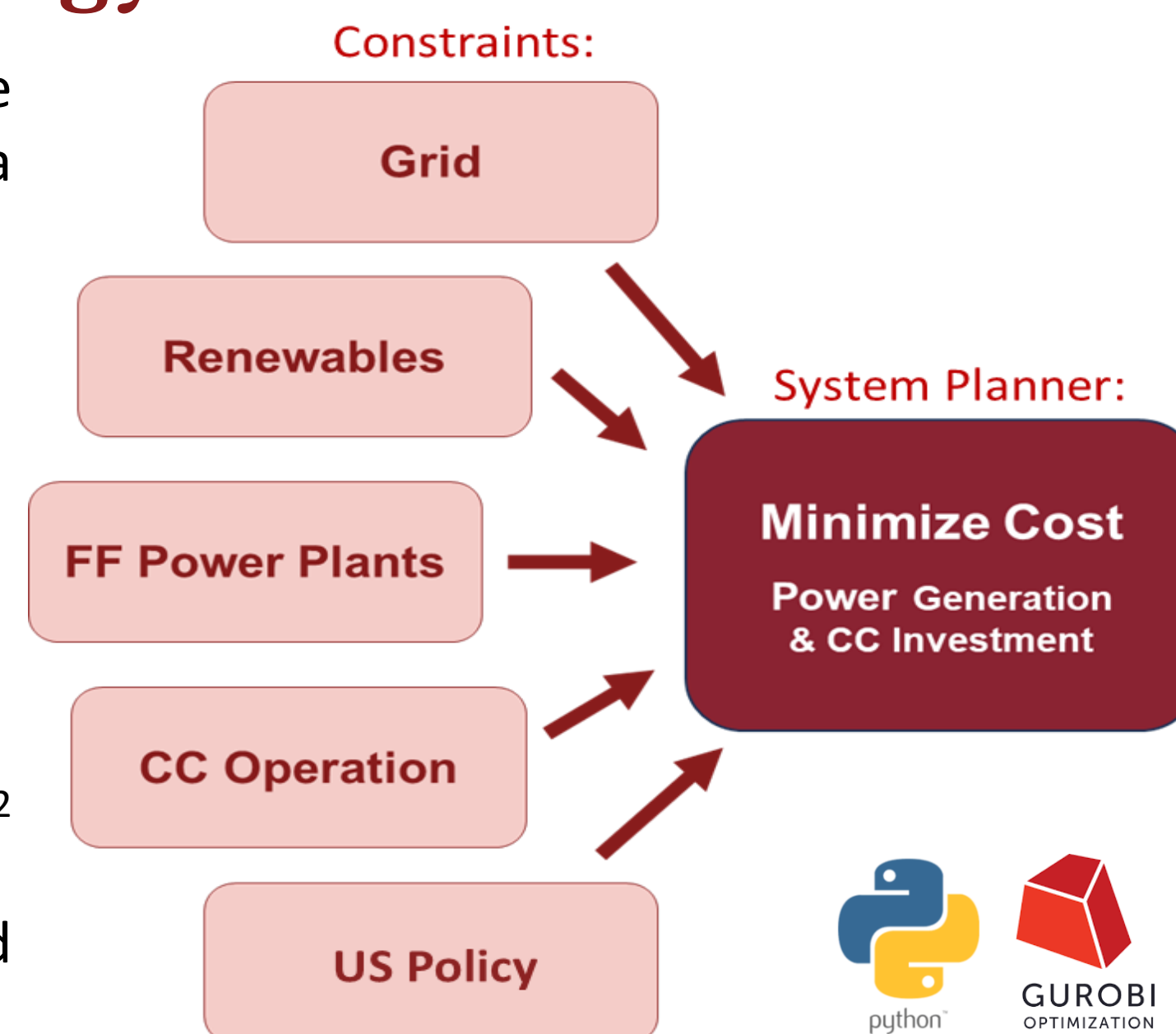
- Carbon Capture (CC)** captures CO_2 at the source (such as coal and gas power plants) preventing it to reach the atmosphere and contribute to global warming.
- CC has received much attention, especially in the Inflation Reduction Act and EPA power plant regulations. It is **promising but has proven controversial** in many dimensions (cost, environment, public health, etc.)
- We focus on the airborne pollution controversy:** while CO_2 emissions affect the entire planet, co-pollutants (other emissions from fossil fuel generators, like NO_x and SO_x) are harmful for those directly exposed.
- CC guarantees removal of most CO_2 but the data is uncertain when it comes to co-pollutants.** This rises concerns for public health. Particularly for people of color and low-income, as their disproportionate exposure and residential proximity to power plants is well documented in the US

II. Objective

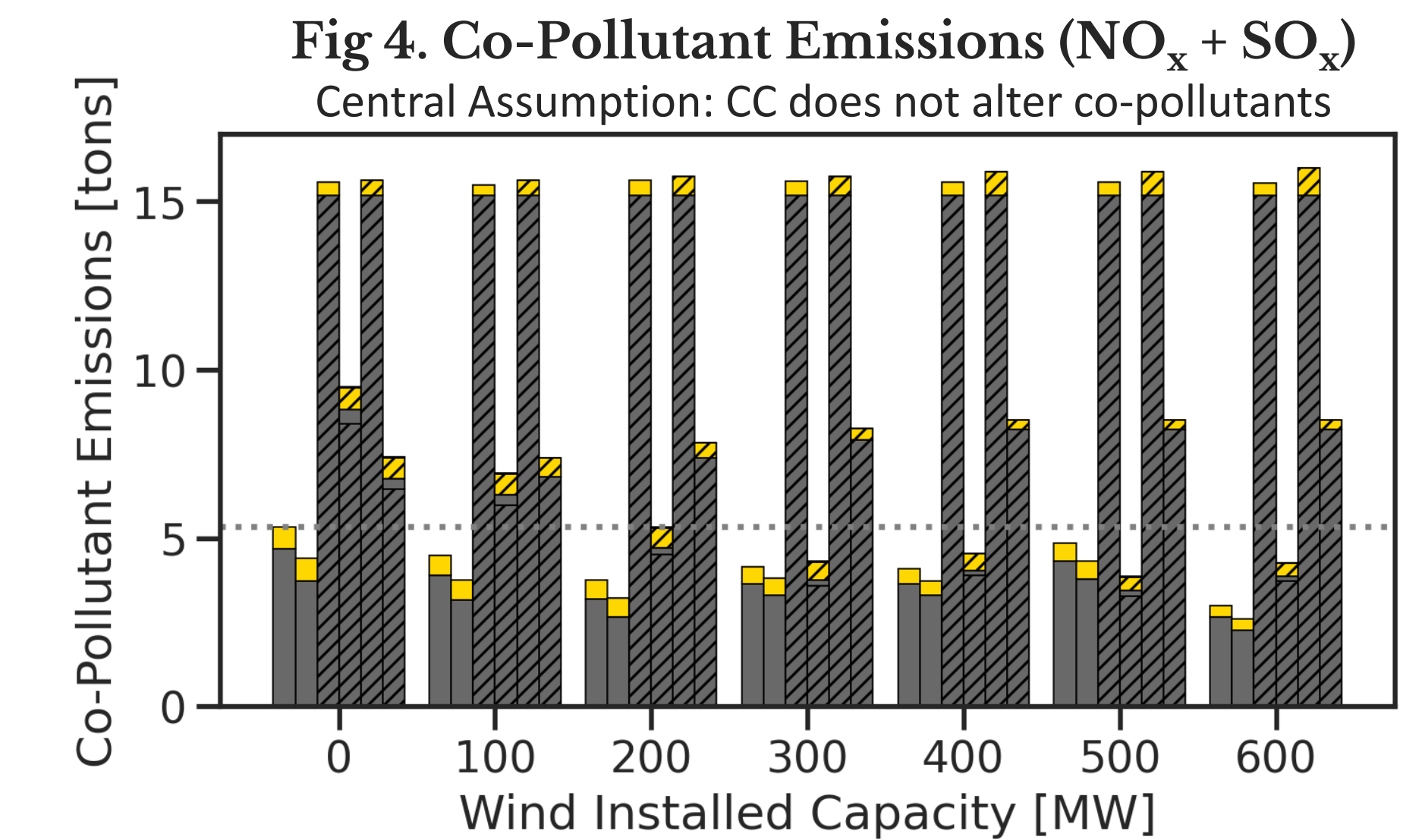
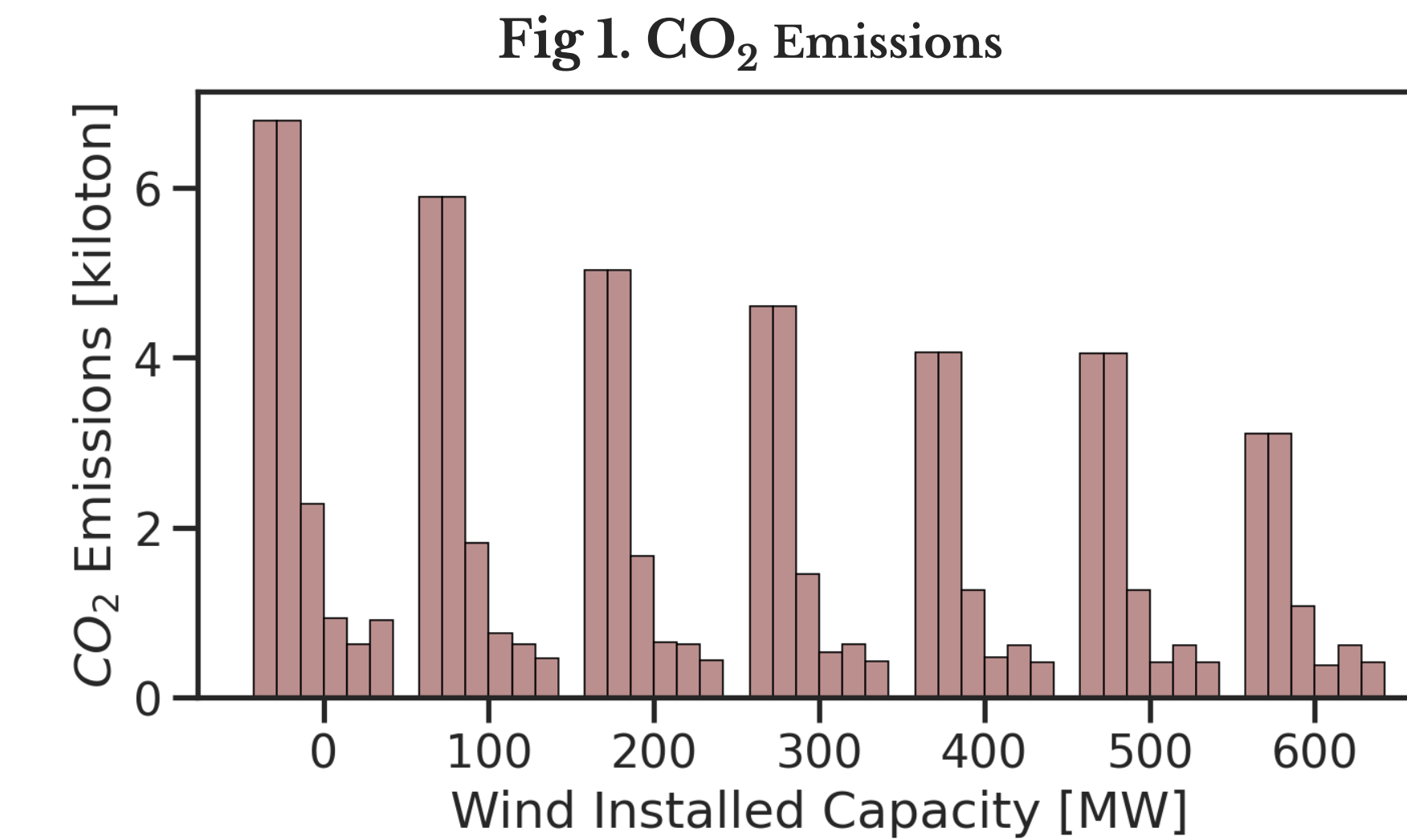
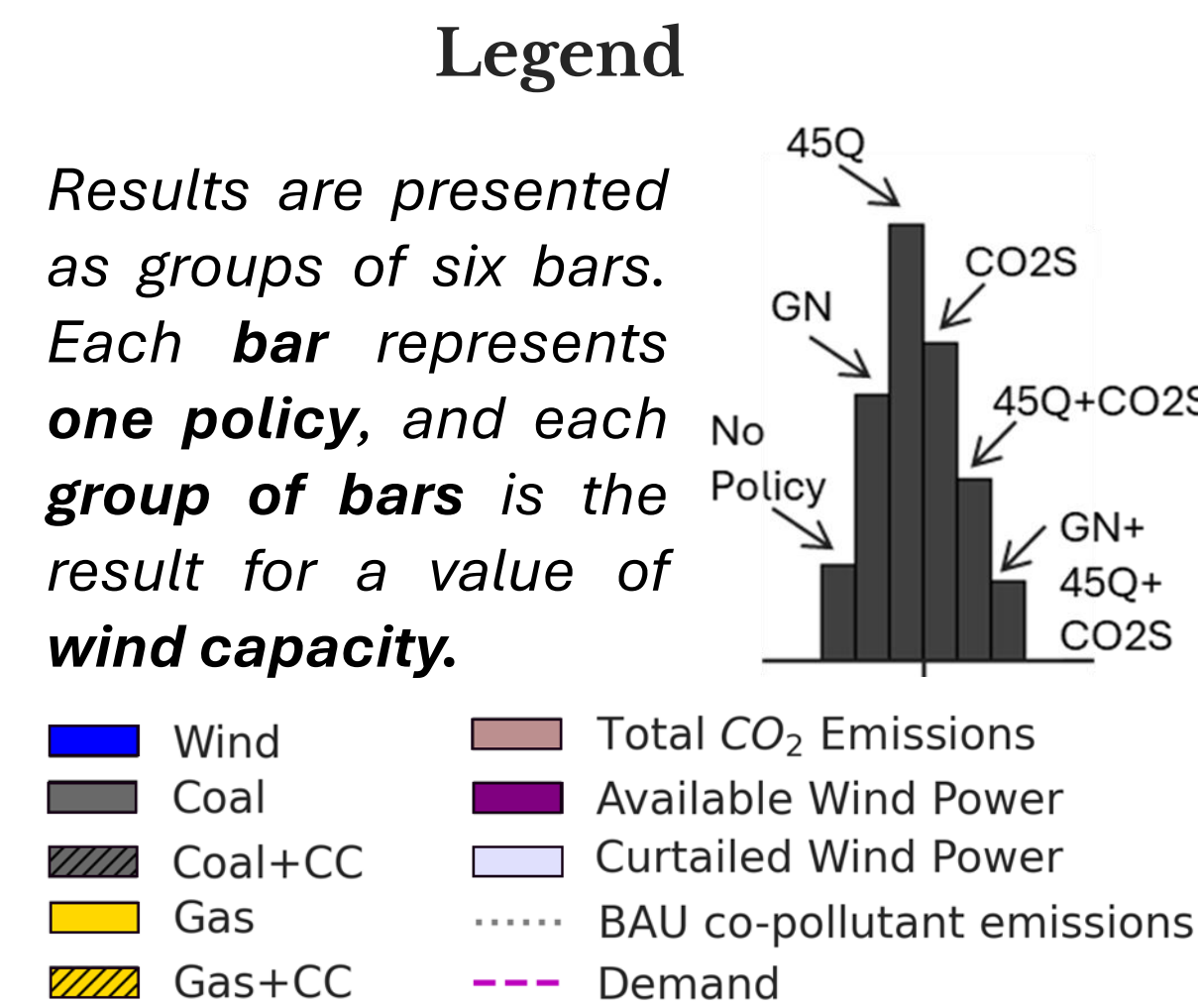
- Focus on powers sector policies that directly mention CC or that deal with co-pollutants.
- Investigate how such policies, when alone or combined, impact the deployment of CC, the generation mix and, consequently, the emission dynamics and the co-pollutant damages.

III. Methodology

- We employ a Power Flow model of a three-node, mixed-source network where fossil fuel power plants may invest in CC via retrofit while renewable capacity is exogenous.
- Classification:
 - Mixed Integer Problem (MIP)
 - Cost minimization from central planner perspective
- Model three **US policies** and their combinations:
 - IRA 45Q Tax Credit** as a subsidy for CO_2 captured.
 - EPA New CO_2 Standards** as a requirement to reduce CO_2 emissions by 90% for both coal and gas power plants.
 - EPA Good Neighbor** as a system-wide NO_x limit and addition of NO_x controls in coal power plants (at no cost).



IV. Results



Key Findings

CC Underlying mechanisms:

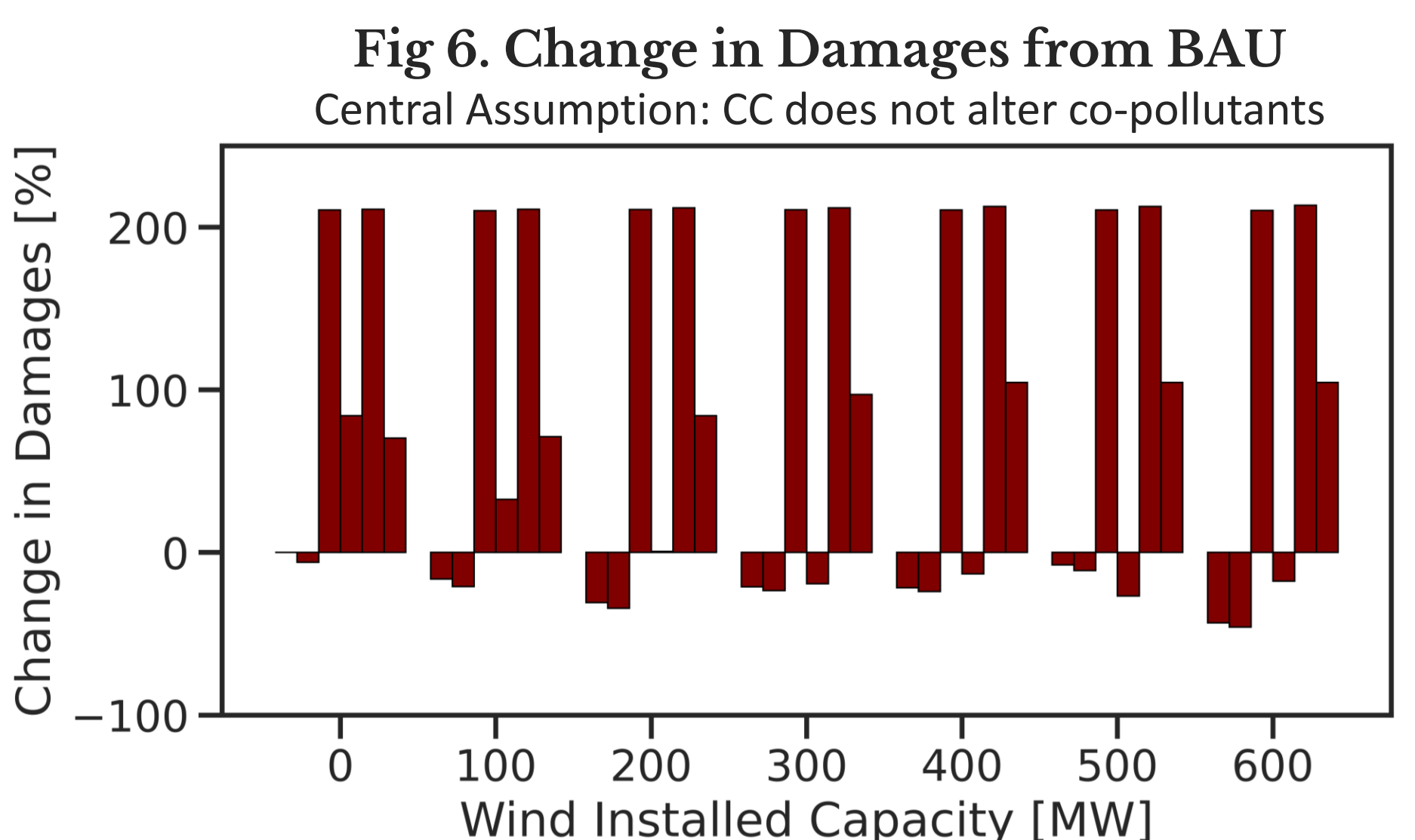
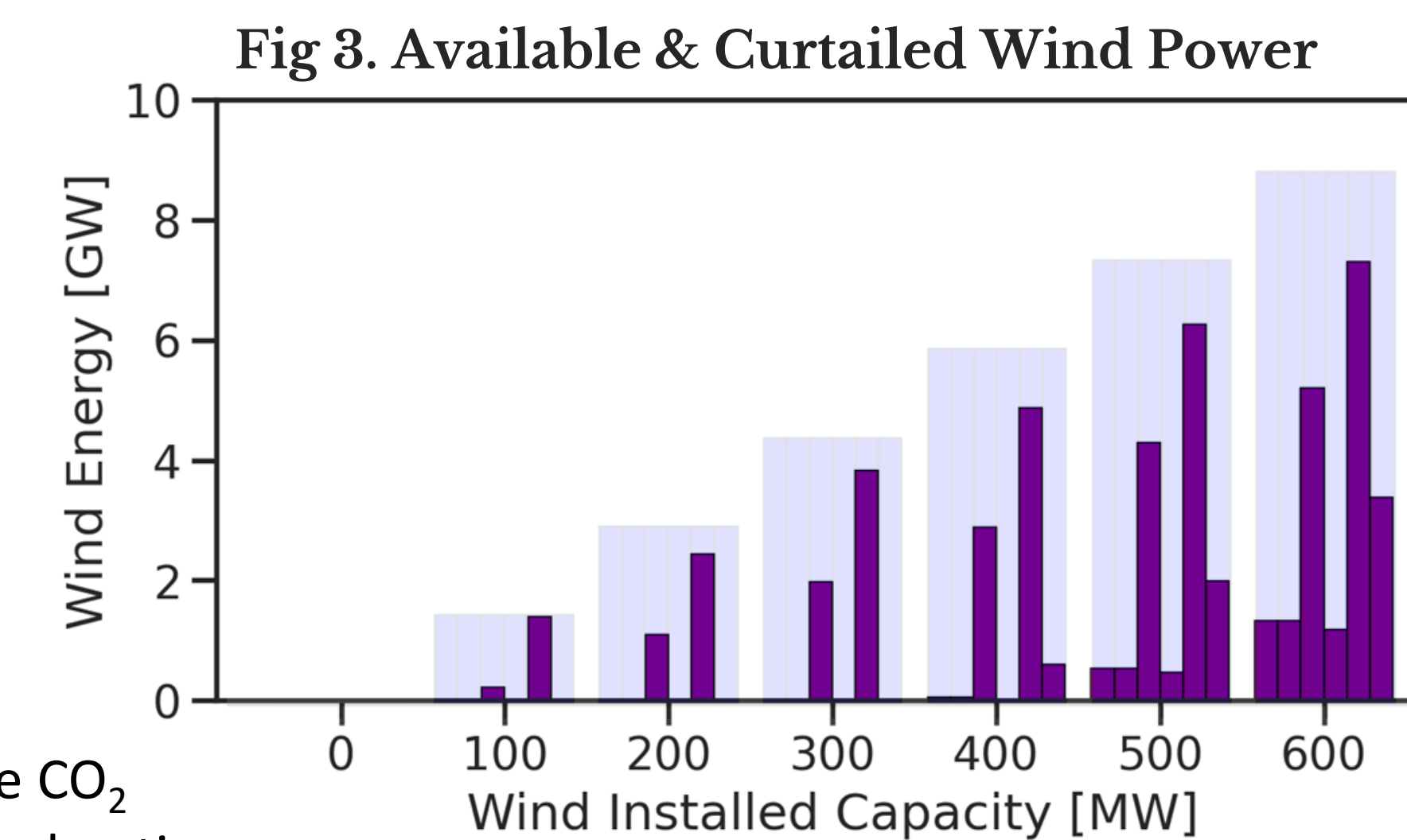
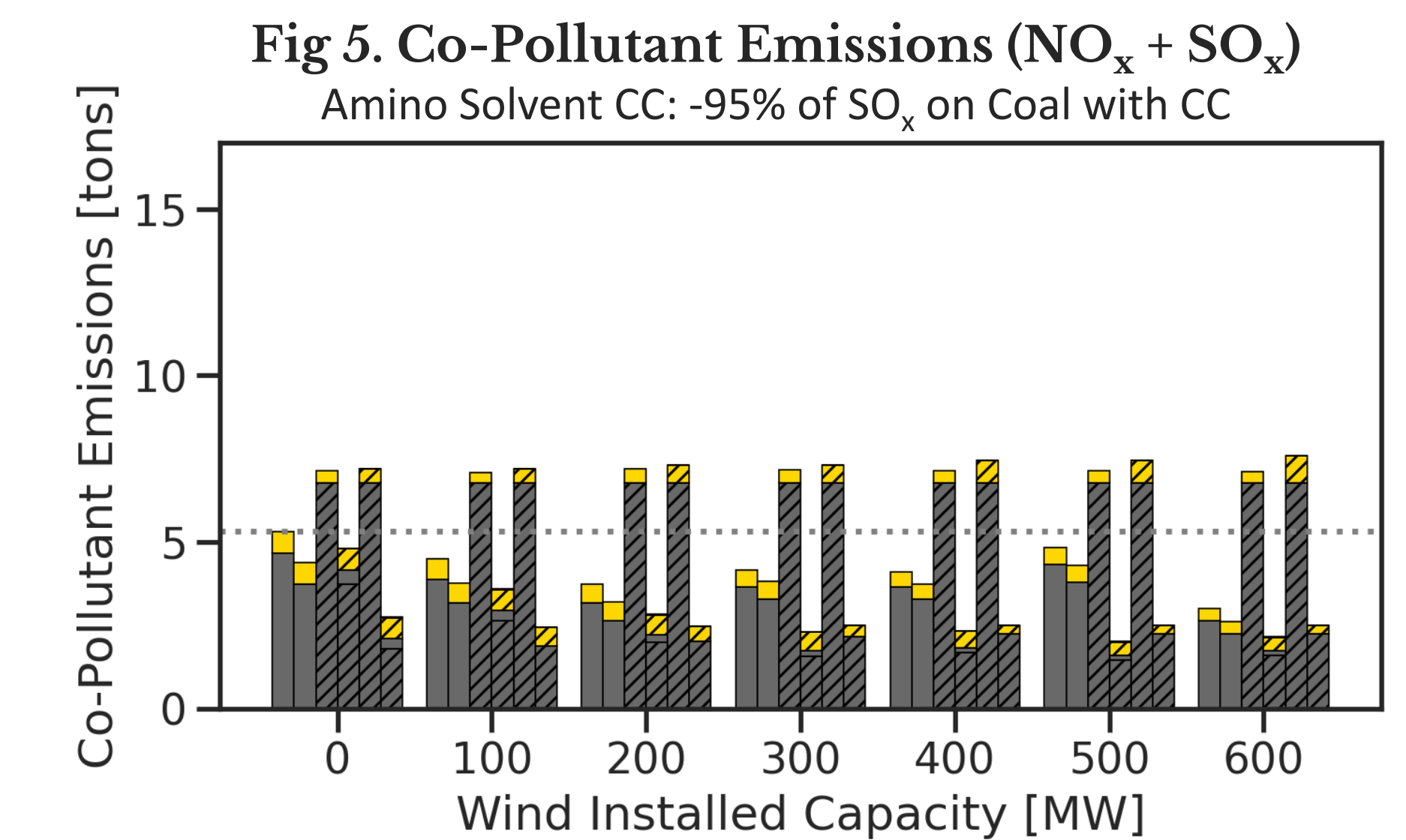
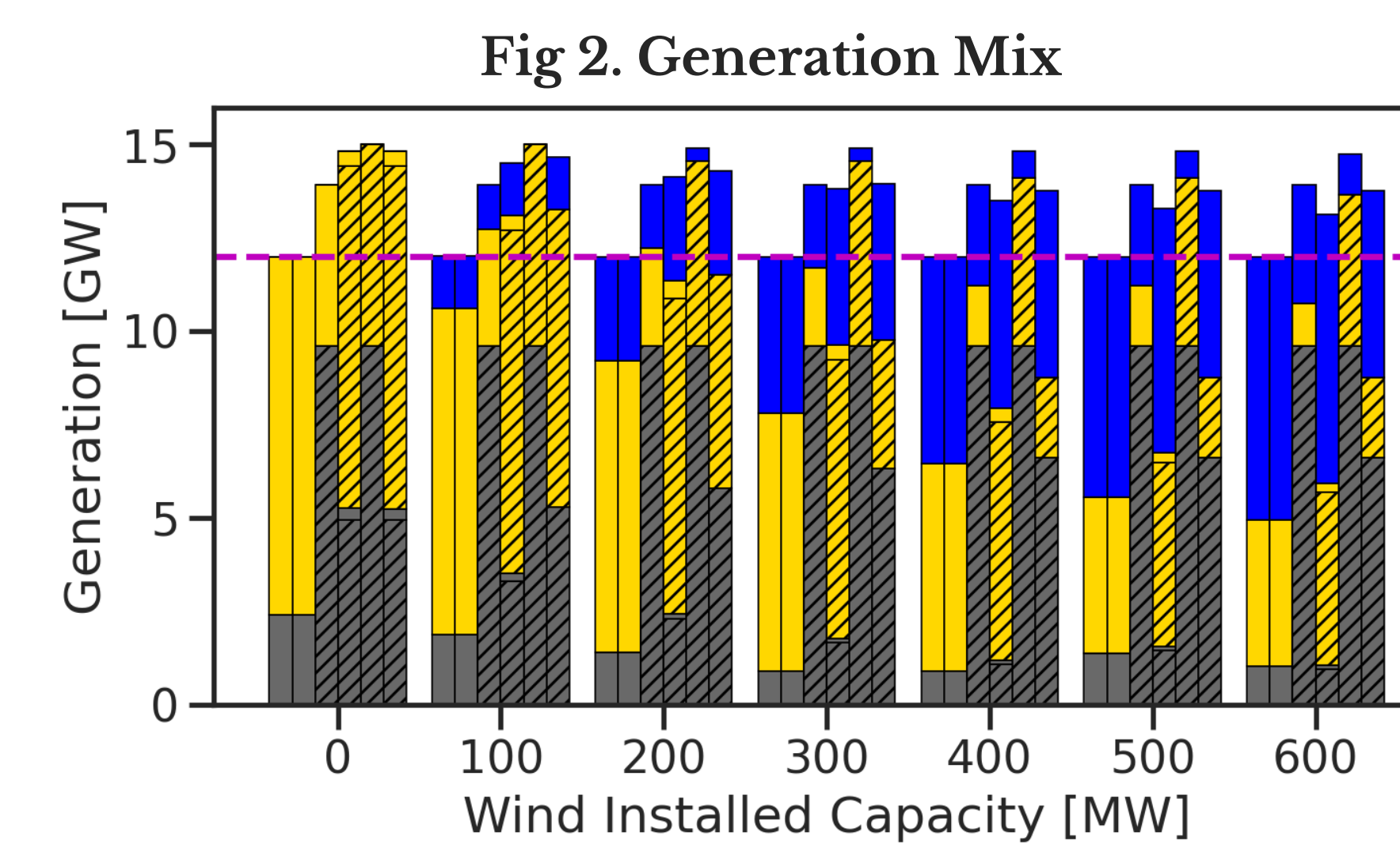
- CC as an abatement technology is more cost effective on Coal** because it is more CO_2 intensive
- Energy Penalty** is the energy to operate the CC facility, it increases in gross generation beyond the system's demand

CO_2 reductions

- In all but GN policy
- Smallest reduction $\rightarrow$ IRA 45Q

Co-pollutants mixed impacts

- GN always reduces due to NO_x controls being used
- CO_2S reduces for moderate to high wind (when renewable supports the energy penalty)
- 45Q always increases (alone or combined with other rules)



Negative effect of IRA 45Q

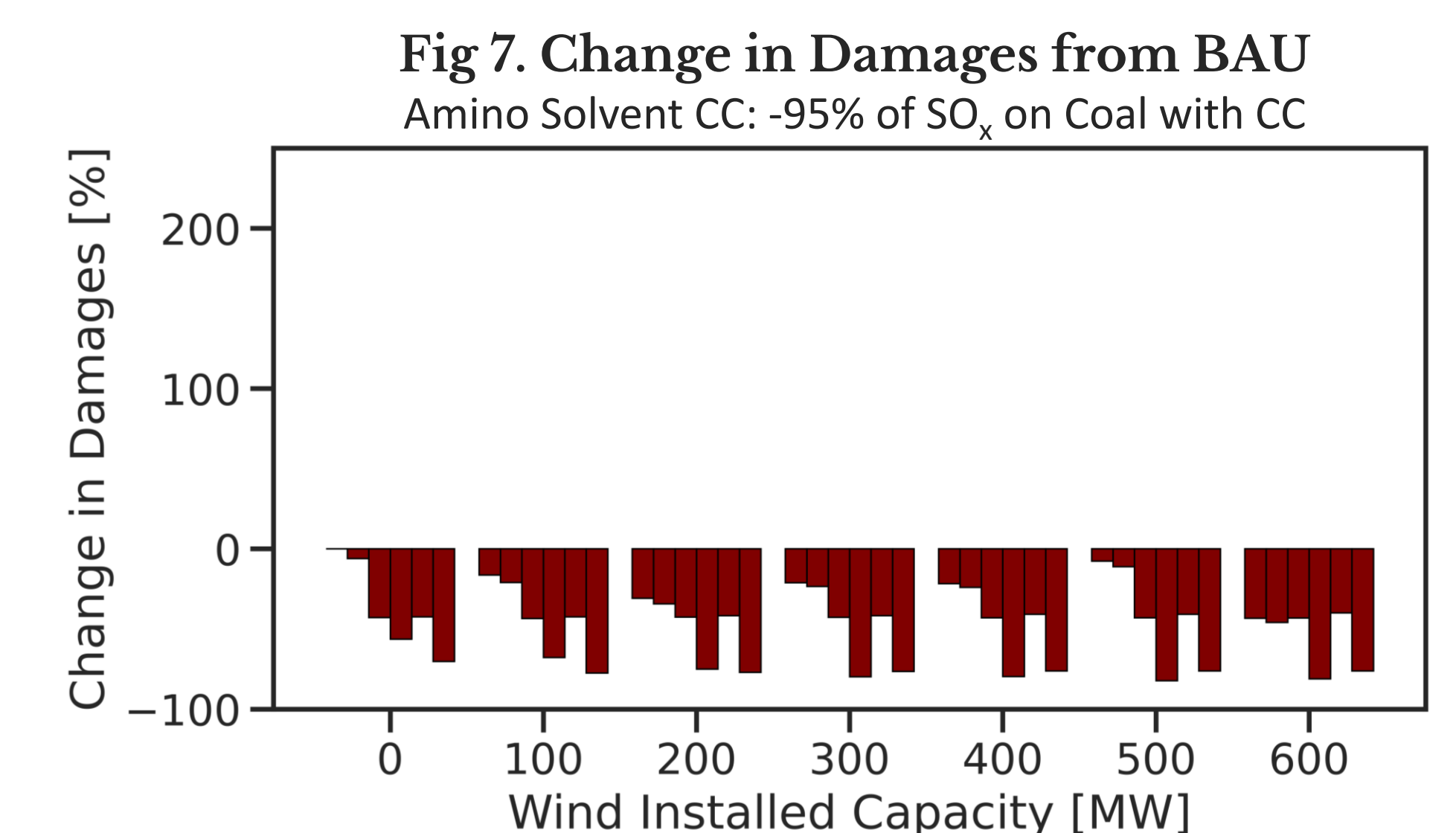
- CC subsidy $\rightarrow$ incentive to produce CO_2
- Coal with CC is the most economical option
- Builds CC only on coal and maximizes its generation to maximize CO_2 capture
- Steep increase in wind curtailment
- Worse results when combined to CO_2S because CC is available in both coal and gas

Importance of Co-Pollutant Policy

- GN ameliorates results when all US policies are combined
- The limit on NO_x ultimately curbs coal increase

Uncertainty & Damages

- If CC does not impact co-emissions the damages increase in almost all policies. The exceptions are GN and CO_2S when wind capacity is at least 200 MW.
- The amino-solvent assumption leads to lower damages as it reduces SO_x from coal generation. Coal is the largest emitter and SO_x has the highest damage factor.
- A focus on total co-pollutants may be misleading $\rightarrow$ need for damage estimation



V. Final Remarks

- Policies that provide incentives for CC should be paired with policies directly attacking local air pollution.
 - If co-pollutant reductions are free, the air quality policies will be redundant. But if not, the air quality policies will bar CC from exacerbating health damages.
- Policies that provide incentives for CC may have perverse outcomes that perpetuate and/or increase fossil fuel generation.
 - If the energy transition is understood as a movement away from fossil fuels, additional controls may be needed to guarantee an efficient use of CC.
- Future work will explore how damages are distributed among population groups.
 - Literature indicates that damages are not shared equally by socioeconomic groups.

The Distributional Effects of Carbon Pricing and the Implications for Vulnerable Households in Taiwan

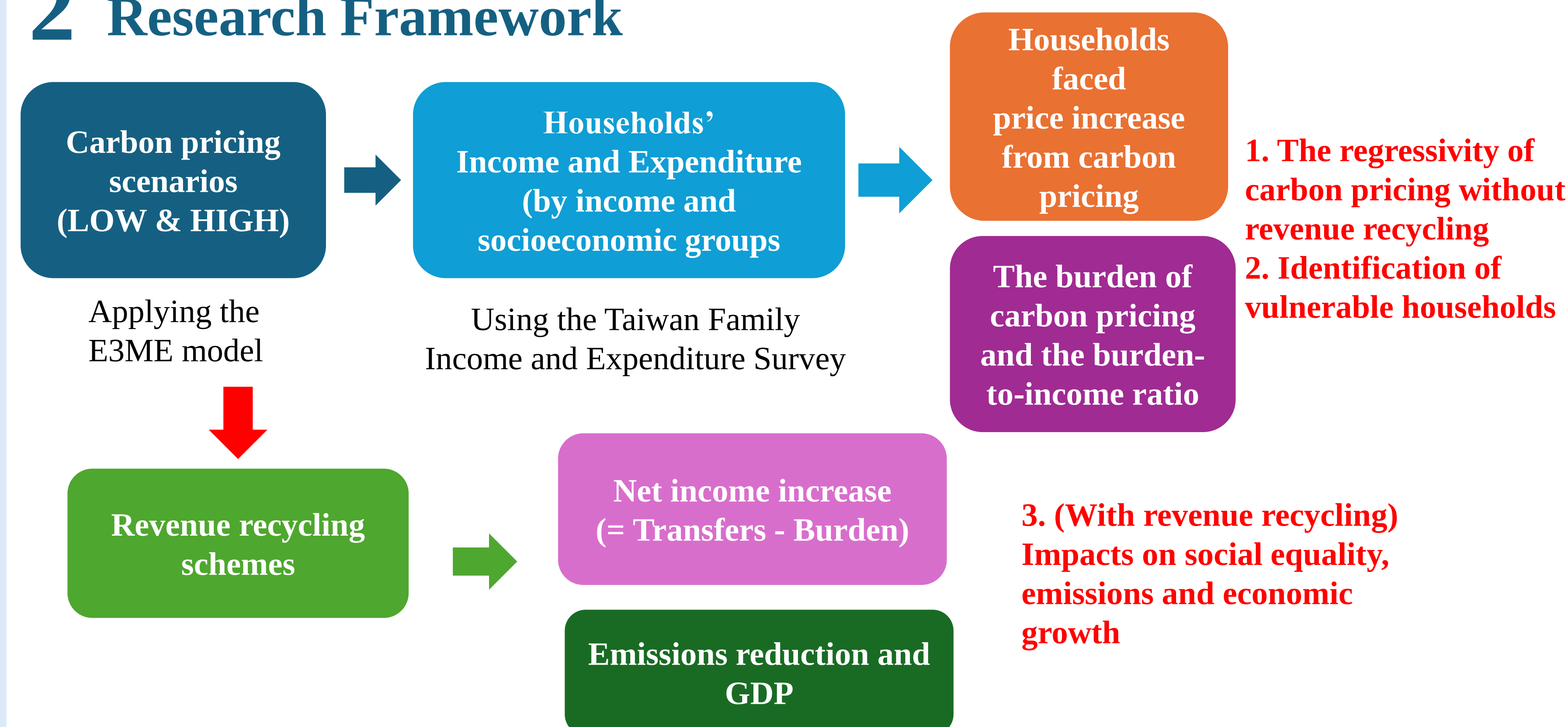
The Topical Theme 5: Other Cross-cutting Themes (Role of Policy, Equity and Distributional Effects, or Temporal Dimensions)

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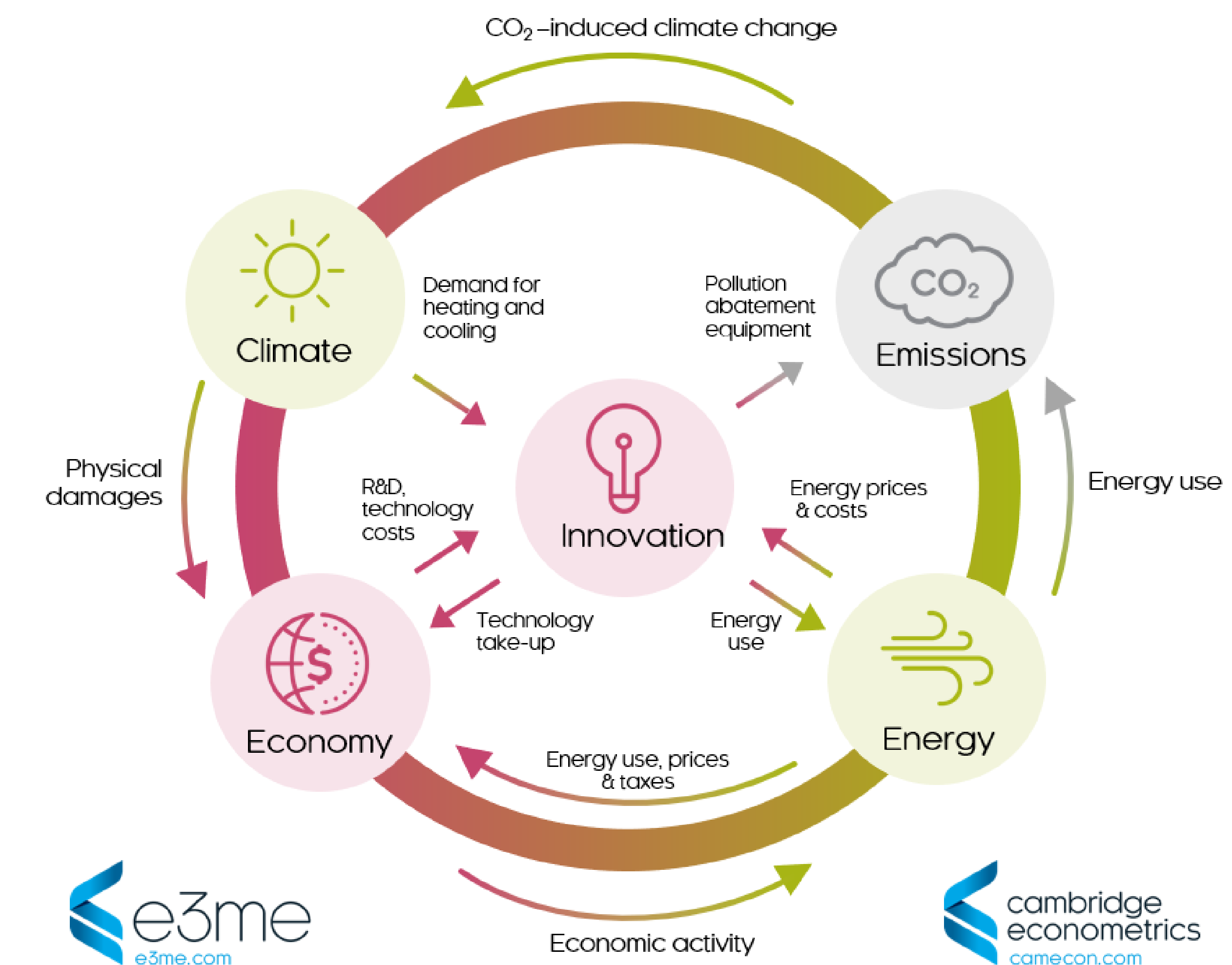
1 Introduction

- Research has revealed that **carbon pricing without revenue recycling** appears **regressive**, which may harm the lower-income group more than the higher-income group mainly
- This is because of the **different consumption structures** across income groups
- Many studies have analyzed how **price inflation faced** varies across **income groups** and specific **household characteristics**
- Unfortunately, most assessments of the distributional effects of carbon pricing were limited to regressivity without considering other essential household characteristics
- Although **vertical redistribution** between high- and low-income groups can be well addressed by several available revenue recycling schemes, less is known about how to deal with **horizontal redistribution**, that is, redistribution among socioeconomic groups

2 Research Framework

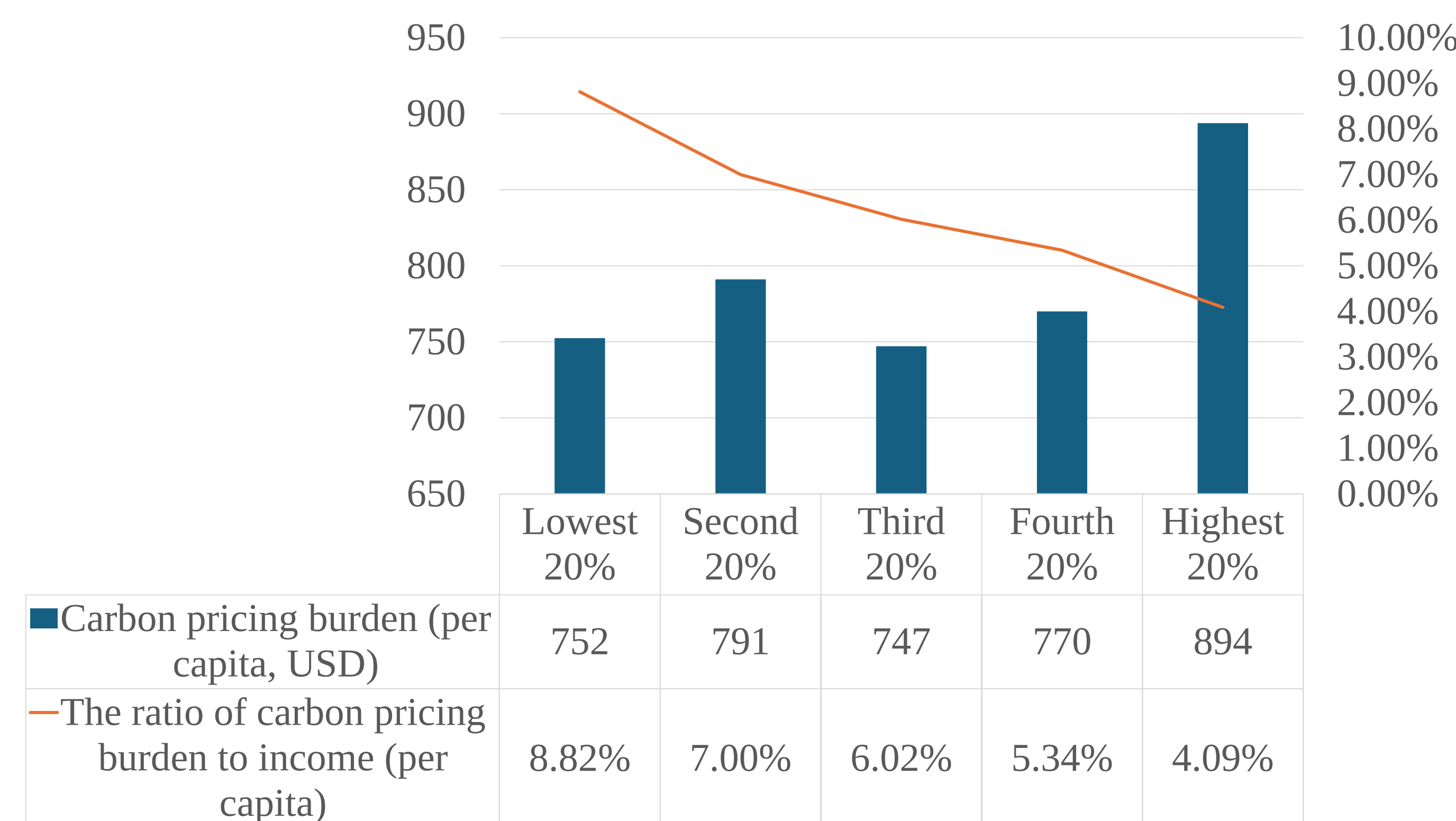


3 Methodology

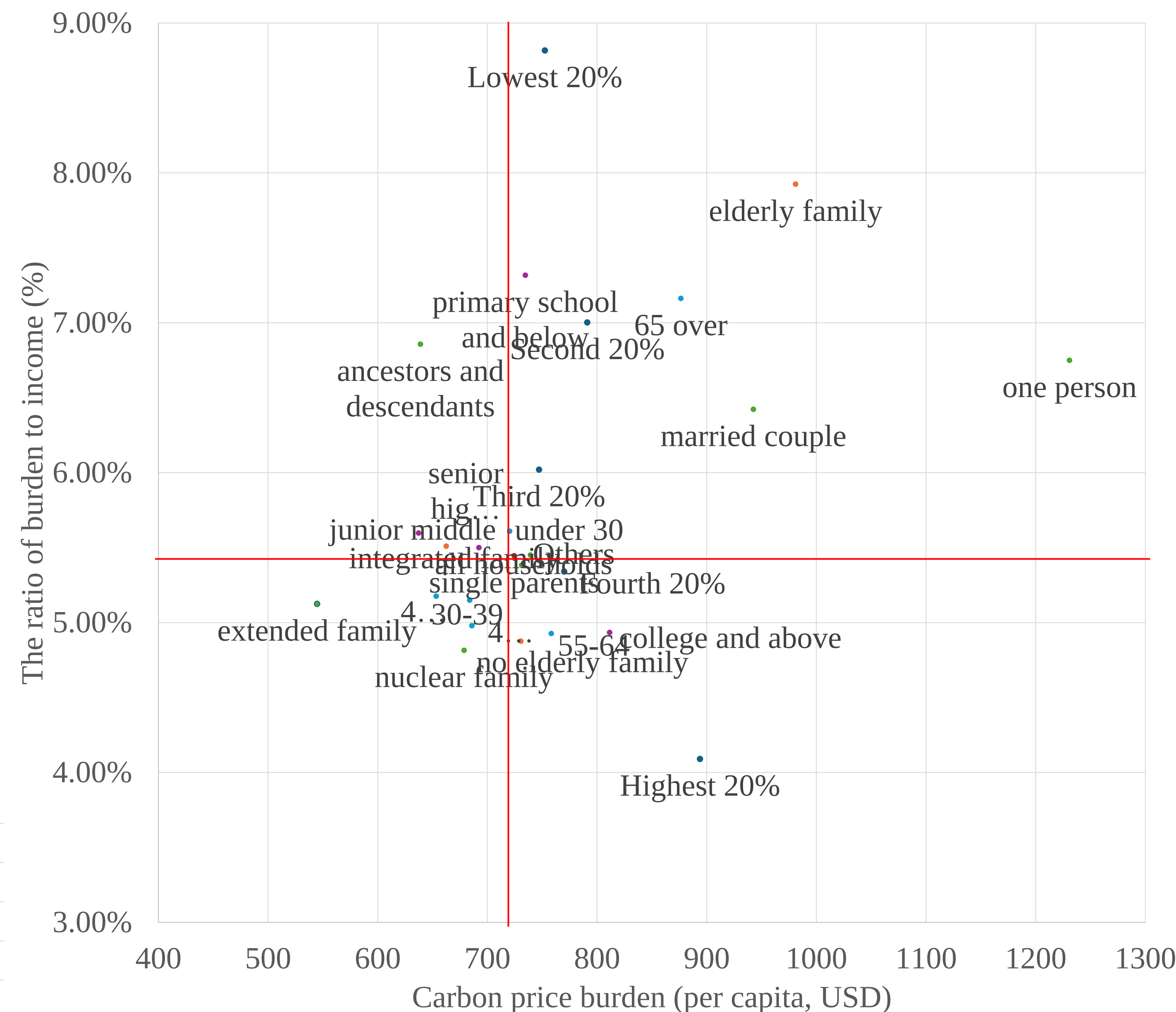


4 Results & Conclusion Under the HIGH scenario, carbon price in 2025 = 94 USD/tCO₂

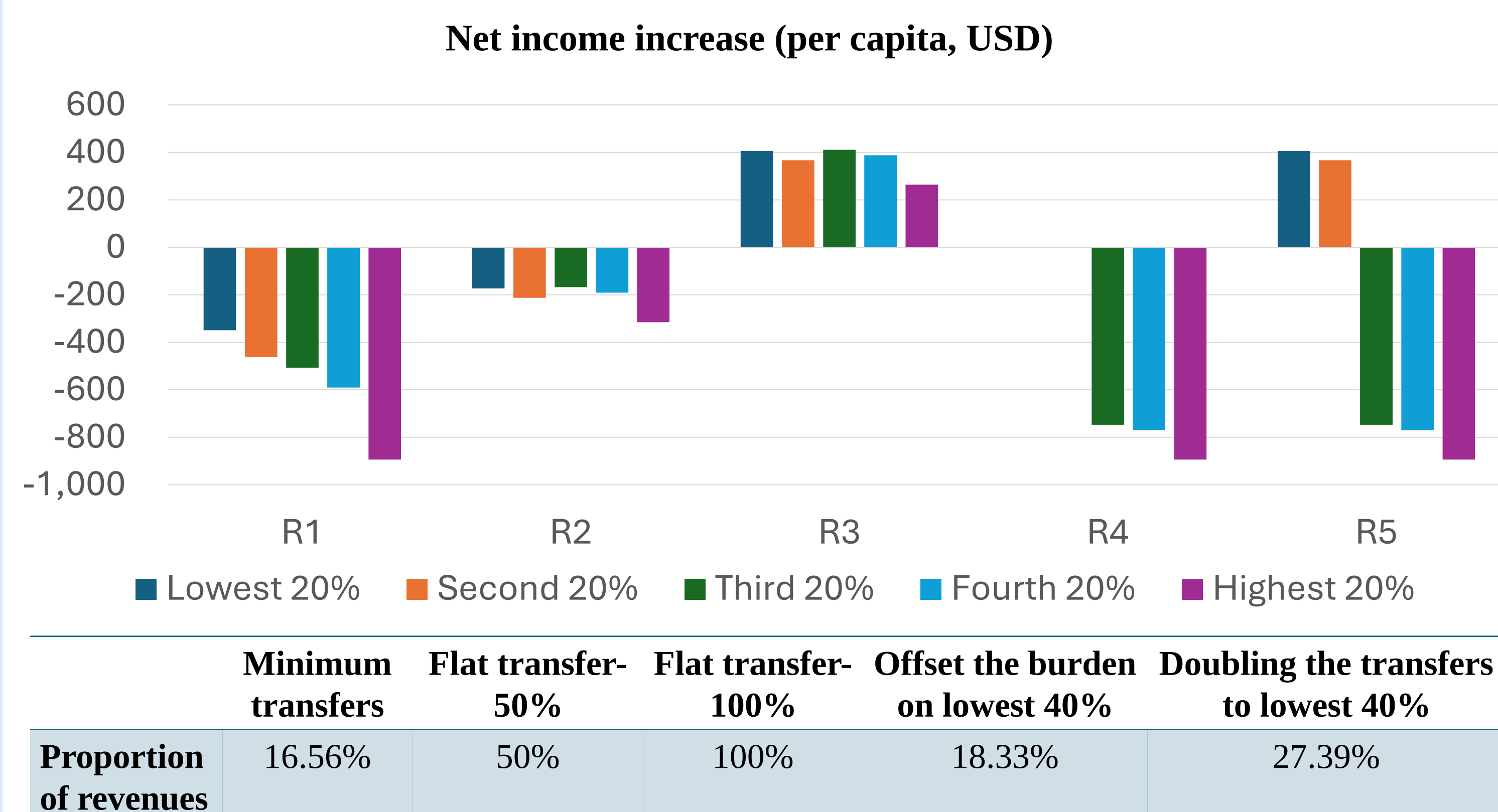
4.1 The regressivity of carbon pricing without revenue recycling



4.3 Vulnerable household characteristics



4.2 Revenue Recycling Schemes



4.4 Conclusion

- The results confirm the **regressivity** of carbon pricing without revenue recycling and suggest that **transfers targeting low-income households** can increase their net income, hence improving income distribution
- Regarding **household characteristics**, we find that households **with elderly, children, and low education attainment** may struggle more financially without appropriate support if carbon pricing is implemented. This implies that the policymaker should consider these specific **vulnerable groups** to achieve a **just transition**

3.1 The Laspeyres Price Index

$$CPI_t^i = \sum_k w_{k,2022}^i \cdot \left(\frac{p_{kt}^{POL}}{p_{kt}^{REF}} \right) \times 100$$

where $w_{k,2022}^i$ is **fixed weights**; p_{kt}^{POL} is the price level of goods or services k in year t under **the policy scenarios**; p_{kt}^{REF} is the price level of goods or services k in year t under **the reference scenario**

$$w_{k,2022}^i = \frac{p_{k,2022}^i Q_{k,2022}^i}{\sum_k p_{k,2022}^i Q_{k,2022}^i}$$

where $w_{k,2022}^i$ is the ratio of the expenditure of goods k to the total expenditure for household i in year 2022

3.2 The price increase from carbon pricing

$$\pi_t^{POLi} = \frac{CPI_t^{POLi} - CPI_t^{REFi}}{CPI_t^{REFi}} = \sum_k w_{k,2022}^i \times \left(\frac{p_{kt}^{POL} - p_{kt}^{REF}}{p_{kt}^{REF}} \right)$$

where $\frac{p_{kt}^{POL} - p_{kt}^{REF}}{p_{kt}^{REF}}$ can be projected by the E3ME model

3.3 The burden of carbon pricing

$$B_t^i = \sum_k w_{k,2022}^i \times \left(\frac{p_{kt}^{POL} Q_{kt}^{POL} - p_{kt}^{REF} Q_{kt}^{REF}}{p_{kt}^{REF} Q_{kt}^{REF}} \right)$$

where $\frac{p_{kt}^{POL} Q_{kt}^{POL} - p_{kt}^{REF} Q_{kt}^{REF}}{p_{kt}^{REF} Q_{kt}^{REF}}$ can be projected by the E3ME model

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Call for Abstracts

The interplay between decarbonization strategies and the macroeconomy plays a crucial role in informing equitable and effective public policy to ensure a just transition and requires innovative multifaceted approaches. To foster interdisciplinary dialogue, the National Academies of Sciences, Engineering, and Medicine will hold a public workshop on September 12-13, 2024 to distill key insights from scientific and economic research efforts to inform effective decarbonization policies and actions within the broader macroeconomic landscape and to explore and address their macroeconomic and socioeconomic implications.

To inform workshop discussions, the workshop committee would like to invite a series of invited poster presentations highlighting innovative approaches to addressing key challenges and themes of the workshop scope (detailed below).

Early-career researchers are highly encouraged to apply. Selected abstracts will have the opportunity to participate in the full workshop in person in Washington, DC, or virtually.

This project is funded by the National Oceanic and Atmospheric Administration, National Science Foundation, Bezos Earth Fund, Wallace Global Fund, and William and Flora Hewlett Fund. More information about the project is available on [our website](#).

Invited to apply: Researchers, scholars, practitioners, community group leaders, and experts from industry and government from all disciplines are all welcome to submit abstracts. **Early career applicants are highly encouraged.** (*Submission deadline was July 7, 2024*)

Submission Focus: We welcome abstract submissions with varied focuses. These include but are not limited to, presentations on research, practice, and policy/education:

1. **Research** - for example, a presentation of original research findings, how they offer a new perspective, inform, or link to existing research and understanding
2. **Practice** - for example, a presentation of how a practitioner approaches addressing challenges in their role
3. **Policy/education** - for example, describing a new policy, initiative, or law

Topical Themes:

We welcome contributions covering innovative research and/or practices/applications using a range of approaches, including but not limited to, theory, data/modeling tools, and frameworks, on the following themes:

1. **Economic Risks and Opportunities:** Risks are potential adverse outcomes that could emerge as we progress. The process of decarbonization carries inherent economic risks, while concurrently presenting opportunities for future economic growth. Potential economic risks and opportunities associated with decarbonization span areas such as finance, labor, supply chains, and the political economy. Explore these potential economic risks and how public policy can either exacerbate or mitigate these risks and help harness potential opportunities.
2. **Barriers to Decarbonization and Solutions:** Barriers are obstacles that hinder or obstruct progress. Potential barriers to achieving decarbonization goals include technical, social, legal, and political obstacles. Explore their implications, potential interconnections, and possible solutions to eliminate or overcome these barriers.
3. **Incorporating Modeling Insights into Policy Design:** Current and emerging innovative methods for incorporating insights from various modeling disciplines, e.g., energy systems modeling, into macroeconomic models with a focus on applications to actionable decarbonization policy design.
4. **Global Interactions:** The interplay among the U.S. economy and supply chains, other nation's energy transitions, and the global economy in the context of the global energy transition.
5. **Other Cross-cutting Themes:** Including but not limited to:
 - **Role of policy** (e.g., to kick-start transitions, complementary approaches to mitigate risk and equity challenges, etc.)
 - **Equity and Distributional Effects** in the Transition (e.g., local/regional distributional and structural change effects and their implications on certain geographic, underserved, and vulnerable populations)
 - **Temporal Dimensions** (e.g., ex post versus ex ante)