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Research Statement

I have always been drawn to the fundamental tension between economic development and environmental sustainability. My research began with a deceptively simple task: how to reconstruct city-level carbon emission trajectories from sparse and inconsistent datasets. But as machine learning—based data alignment techniques gradually revealed a more complete national map, a deeper structural reality emerged. Why do carbon peaks occur at vastly different times across cities with seemingly similar economic or industrial profiles? Is this variation simply a function of development stage, or does it reflect deeper institutional asymmetries, policy attention, or resource endowments? If local trajectories are so fragmented, then how can a national climate target—uniform in its ambition—be disaggregated and fairly shared? And if coordination is possible, what principles should guide it: cost-efficiency, historical responsibility, marginal abatement potential, or future welfare optimization? Confronting these multi-dimensional trade-offs — between fairness, efficiency, and feasibility — pushed me to explore artificial intelligence not merely as a modeling tool, but as a generative framework capable of simulating inter-city cooperation, learning adaptive strategies, and stress-testing climate policies across hundreds of heterogeneous agents. Yet this shift raised further questions: can algorithmically derived solutions be translated into politically feasible and socially acceptable action? Do models of optimality conceal tensions between equity and efficiency, or can they help resolve them by revealing new institutional designs? Increasingly, I find myself turning toward this broader inquiry: not only how carbon emissions can be measured or predicted, but how technological and policy interventions reshape systemic outcomes across environmental, economic, and social dimensions. What would it mean—materially, institutionally, and symbolically—to turn national highways into solar energy infrastructure? In seeking to answer these questions, my research aims to bridge empirical reconstruction, intelligent modeling, and normative evaluation—toward a science of climate action that is analytically rigorous, practically grounded, and ethically attentive.

Recent & Current Research

My current research builds on a comprehensive dataset of annual carbon emissions for over 300 Chinese cities from 1992 to 2023, which I reconstructed using machine learning — based data alignment methods. The first line of inquiry explores the fragmented and asynchronous nature of urban carbon peaking across China. Despite national ambitions for a unified carbon peak timeline, my findings reveal striking heterogeneity: some cities peaked as early as the mid-2000s, while others are projected to peak only after 2030. This divergence cannot be explained by GDP per capita or industrial share alone. Instead, it reflects a complex interplay between development stage, industrial lock-in, policy exposure, and regional governance structures. Through spatial clustering and classification models, I identify distinct city archetypes — early peakers with shrinking industrial bases, late peakers undergoing industrial upgrading, and structurally locked-in emitters — each calling for differentiated policy instruments and timelines. This research contributes to a more granular understanding of national peaking dynamics and questions the viability of one-size-fits-all decarbonization mandates.

In my second line of work, I examine how cities can collectively achieve national emission reduction targets in a way that balances fairness, economic efficiency, and aggregate welfare. To this end, I develop a cooperative optimization framework that simulates burden-sharing scenarios among heterogeneous cities. The model integrates carbon emission projections, marginal abatement costs, and welfare weights to allocate differentiated targets under national constraints. My results show that under certain coordination schemes, national goals can be achieved at significantly lower system-wide costs, while also reducing the distributional inequities of uncoordinated emission cuts. Moreover, cities that are economically weaker or structurally constrained stand to benefit most from collaborative arrangements. This framework provides a formal basis for policy instruments such as carbon compensation mechanisms or differentiated mitigation responsibilities.

Together, these two studies form the foundation of a broader research agenda aimed at rethinking how large, regionally diverse economies manage the transition to carbon neutrality. By beginning with data reconstruction and moving toward cooperative simulation, my work seeks to bridge technical, institutional, and ethical dimensions of climate governance. The fragmented nature of urban carbon peaks is not merely an empirical pattern — it is a manifestation of deeper asymmetries in development pathways, administrative capacity, and political attention. Similarly, the possibility of coordinated decarbonization is not only a modeling question, but a test of what justice, feasibility, and efficiency mean in practice when distributed across hundreds of unequal actors. In this sense, I view my research as an effort to develop analytical frameworks that do not only describe carbon dynamics, but help design more adaptive, differentiated, and socially responsive forms of climate action.

In summary, my current research centers on reconstructing city-level carbon emissions data for over 300 Chinese cities (1992-2023), using machine learning—based data alignment techniques to correct inconsistencies and fill gaps. I use this reconstructed dataset to investigate two core problems:

- ➢ The fragmented and asynchronous peaking of carbon emissions across cities—revealing structural asymmetries in development, governance, and industrial trajectories.
- ➢ The design of cooperative, burden-sharing frameworks for emission reduction, balancing national carbon targets with local fairness, economic feasibility, and welfare optimization.
- ✧ These studies combine empirical modeling, optimization, and normative reasoning to inform differentiated climate policy and subnational coordination.
- ✧ My work contributes to emerging conversations on data-driven climate governance, city-level transitions, and the institutional design of equitable decarbonization in large, diverse economies.

Future Research

Recent advances in climate and sustainability research have significantly expanded the understanding of how climate interventions operate not just as technical fixes, but as systemically embedded actions. A growing body of work highlights how climate shocks such as extreme heat can propagate through supply chains and macroeconomic networks, amplifying indirect costs across regions and sectors [1]. This literature underscores the need to assess climate policies not solely by their local carbon abatement, but by their spatial and structural repercussions—including productivity loss, trade disruptions, and institutional fragility. Complementary research reveals that cities follow diverse emission trajectories and warming pathways, influenced by their developmental stage, land use dynamics, and urbanization patterns [2, 3]. The effects of photovoltaic deployment, too, are found to be spatially differentiated and sometimes counterintuitive—producing localized thermal shifts that interact with microclimates and building forms [4, 5]. These insights point toward the insufficiency of one-dimensional evaluations and encourage a broader systems perspective that captures environment-technology-society interactions.

Equally important are findings on distributional justice and institutional complexity. Evidence shows that high-income populations contribute disproportionately to emissions while enjoying relative insulation from climate risks [6], and that spatial inequality — between and within cities — can distort the effects and acceptance of climate measures [7]. Some studies show that economic activities' environmental consequences often transcend national boundaries, demanding policy instruments that internalize cross-border externalities [8, 9]. Others document how health, welfare, and inclusive wealth can be co-benefits of low-carbon transitions, particularly in post-crisis recovery settings [10, 11]. Yet even well-designed policies may fail under fragmented governance, as seen in the difficulties of aligning national and subnational action [12]. A small subset of empirical studies has begun to isolate the conditions under which past policies have succeeded in driving major emissions reductions [13, 14]. These insights collectively demand new modeling strategies that can incorporate not only effectiveness, but equity, feasibility, and governance structures.

Together, these works call for a new generation of climate research that moves beyond isolated optimization toward integrated evaluation frameworks—frameworks that can capture carbon effectiveness, equity implications, and institutional feasibility simultaneously. It is within this emerging scholarly space that I locate the next phase of my research.

Building on this foundation, my future research will shift from modeling emission pathways to evaluating the broader systemic impacts of specific climate technologies and policy interventions. My central interest lies in understanding how targeted actions—such as equipping national highways with solar panels or redesigning urban infrastructure around zero-carbon goals — reshape outcomes not only in terms of carbon reduction, but across economic productivity, spatial equity, and institutional capacity. What are the distributional consequences of such projects across regions and social groups? How do they affect land use, public budgets, and perceptions of fairness? To answer these questions, I aim to develop integrated frameworks that combine machine learning, structural modeling, and causal inference to simulate and quantify policy spillovers and co-benefits. In parallel, I hope to explore how reinforcement learning and multi-agent simulations can help test the feasibility and resilience of these interventions under real-world constraints — budget limits, local governance frictions, and competing priorities. Ultimately, I seek to build a research program that bridges climate engineering, economic policy, and social science, enabling a deeper understanding of how ambitious technologies and policies can be aligned with just and sustainable transitions.

Short-term (During Master's studies)

- Extend my current work to simulate real-world policy interventions — such as carbon budgeting schemes or differentiated responsibility allocation — under complex regional and institutional constraints.
- Evaluate systemic impacts of specific climate technologies (e.g., solar-powered highways, low-carbon transport networks), focusing not only on carbon outcomes but also on land use, public finance, and distributional effects.
- Develop integrated frameworks combining machine learning, causal inference, and multi-agent simulation to model co-benefits and trade-offs of infrastructure-scale interventions.

Long-term (During PhD's studies)

- Build a research program at the intersection of environmental economics, machine learning, and institutional policy design, focused on translating technical solutions into socially sustainable pathways.
- Establish a "computational social science of climate action" that links predictive modeling with normative evaluation, enabling better policy foresight and more equitable climate transitions.
- Contribute to interdisciplinary collaboration across environmental science, urban studies, and public policy, and train students to tackle climate challenges with rigorous, data-driven, and socially conscious approaches.

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