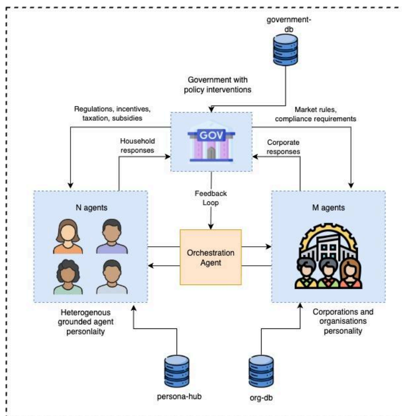
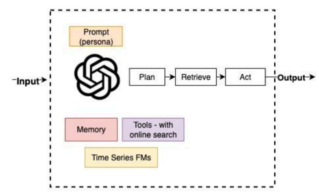
Multi-Agent-based Simulation for Climate Policy Evaluation

Traditional climate policy evaluation approaches, particularly Integrated Assessment Models (IAMs), which commonly aggregate populations into representative, rational agents, often fail to capture the heterogeneity, bounded rationality, and emergent dynamics of real socio-economic systems, resulting in policy recommendations that lack realism and may miss important distributional effects and unintended consequences [1]. We propose a novel framework that leverages Large Language Models (LLMs) instantiated as diverse households and organizational agents, each equipped with theory-informed personas and calibrated through empirical data, enabling richer modeling of actual behavioral diversity and adaptive responses [2]. A central government policymaker agent iteratively generates, tests, and refines policies in response to observed simulation outcomes, while adhering to explicit ethical guardrails that mitigate the risks of bias and ensure the inclusion of equity considerations.

Our proposed method distinguishes itself from traditional Agent-Based Modeling (ABM) by using LLMs, thus introducing human-like reasoning, social learning, and context-sensitive decision-making into the simulation environment [3]. Agents are designed with modules for role-adaptive behavior, scenario-based planning, and environmental context retrieval. This allows the system to represent both individual and organization-level goals and constraints along with causal feedback loops governing their interactions. In the feedback loop, the policy is generated, disseminated through the simulated population, responses and outcomes are collected and analyzed by the policymaker agent which refines the policy with guardrail checking. This iterative process is run for multiple epochs, enabling exploration of dynamic, potentially out-of-equilibrium behaviors like bubbles or tipping points that traditional IAMs cannot capture.



Social Technical System



Agent Architecture

We implemented this approach in a multi-agent simulation using Falcon-7B-Instruct LLM for a short description of the Carbon Border Adjustment Mechanism policy by the EU and 6 personas, 3 each, for households and organizations (firms). Across iterations, the policy refinements shifted from detailed, sector-specific proposals, such as expanding green economy instruments and sectors identified after 3 iterations, to more balanced stakeholder concerns about industry impacts at 5 iterations, progressing to broader, compliance-focused guidelines at 10 iterations. This progression highlights how moderate feedback cycles surface targeted policy adjustments, while excessive iteration can produce generic, less actionable outcomes. For example, the 3-iteration policy proposed revising the Carbon Capture and Taxation Framework (CCTF) to include green bonds, hydrogen, and carbon storage, whereas the 10-iteration version emphasized regulatory compliance and transparency without specific interventions.

Our framework provides a "testbed" in which climate policy scenarios can be evaluated for aggregate impacts, distributional consequences, rebound effects, and social robustness. It thus offers policymakers insight into plausible societal responses, trade-offs, and resilience under deep uncertainty, serving as a complement to IAMs by supplying micro-founded, simulation-driven perspectives. This enables the design of climate interventions that are both cost-effective and socially and politically feasible. The methodology can be extended to incorporate multi-level governance and non-state actors to help guide equitable and adaptive climate transitions in increasingly complex policy landscapes.

[1] Frank Ackerman et al. "Limitations of integrated assessment models of climate change." Climatic Change 95.3 (2009), pp. 297–315. DOI: 10.1007/s10584-009-9570-x.

[2] Tao Ge et al. "Scaling Synthetic Data Creation with 1,000,000,000 Personas." 2025. arXiv: 2406.20094 [cs.CL].

[3] So Kuroki et al. "Reimagining ABM with LLM Agents via Shachi." ICML 2025 Workshop on Computer Use Agents. 2025.