Reflexive Evidence-Based Multimodal Learning for Clean Energy Transitions

Causal Insights on Cooking Fuel Access, Urbanization, and Carbon Emission

Shan Shan

Zhejiang University, shanshanfy@gmail.com

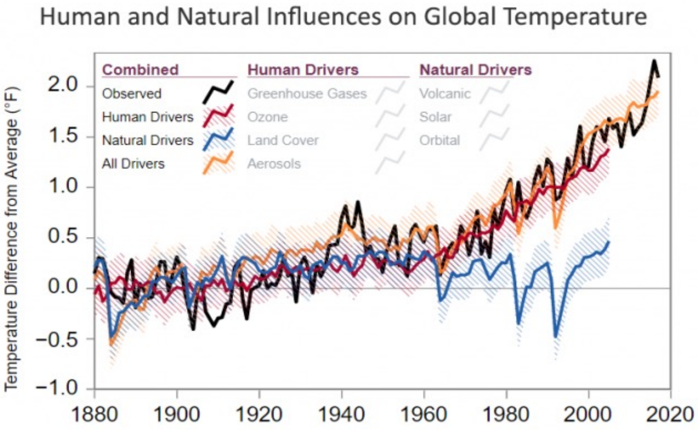
Reflexive Evidenced-Based Multimodal Learning for Clean Energy Transitions

- Rationale: Social Dimensions of Climate Change
- Multimodal Learning with ClimateAgents
- Evidence-Informed Policy Reasoning
- Causal Insights: Cooking Fuel, Urbanization & Emissions
- Conclusion & Future Directions

Disentangling Human Influence on Emissions Patterns

- Long-term global warming is also likely driven by anthropogenic factors.

History (Cornwall, England, 1887)



Science (NOAA,2018)

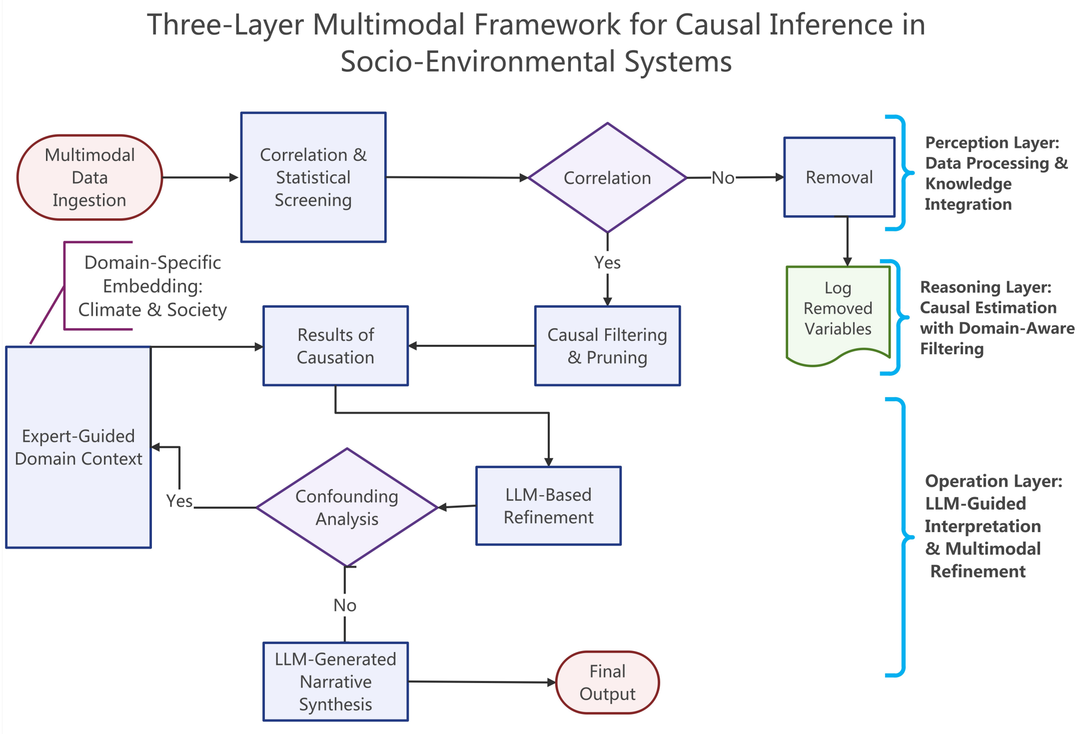
Society (UN,2030)

Advancing Evidence-Based AI Policy for Climate Change

- Need for Actionable Evidence
  - AI policy would benefit from evidence that is **credible and actionable.**
- Ensure Credibility
  - Use validated data sources (e.g., World Bank database)
  - Multi-modals
- Align Evidence with Policy Needs
  - Causal
  - Integrate **reflexive machine learning**
  - Use LLMs for Interpretation

Reflexive Multimodal Learning

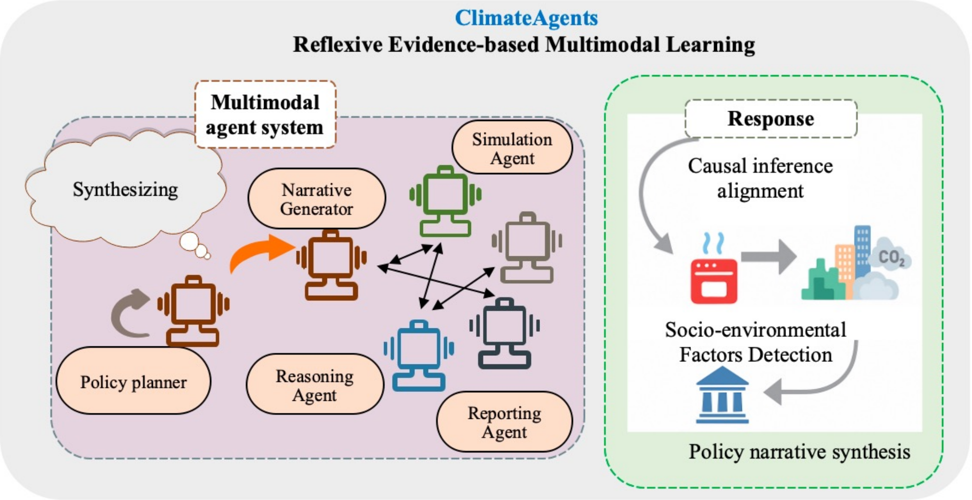
- Multi-agent systems
  - Layer separation (perception, reasoning, operation)
  - Interaction between LLMs (language/text) and structured data (correlation, filtering)
  - Causal reasoning



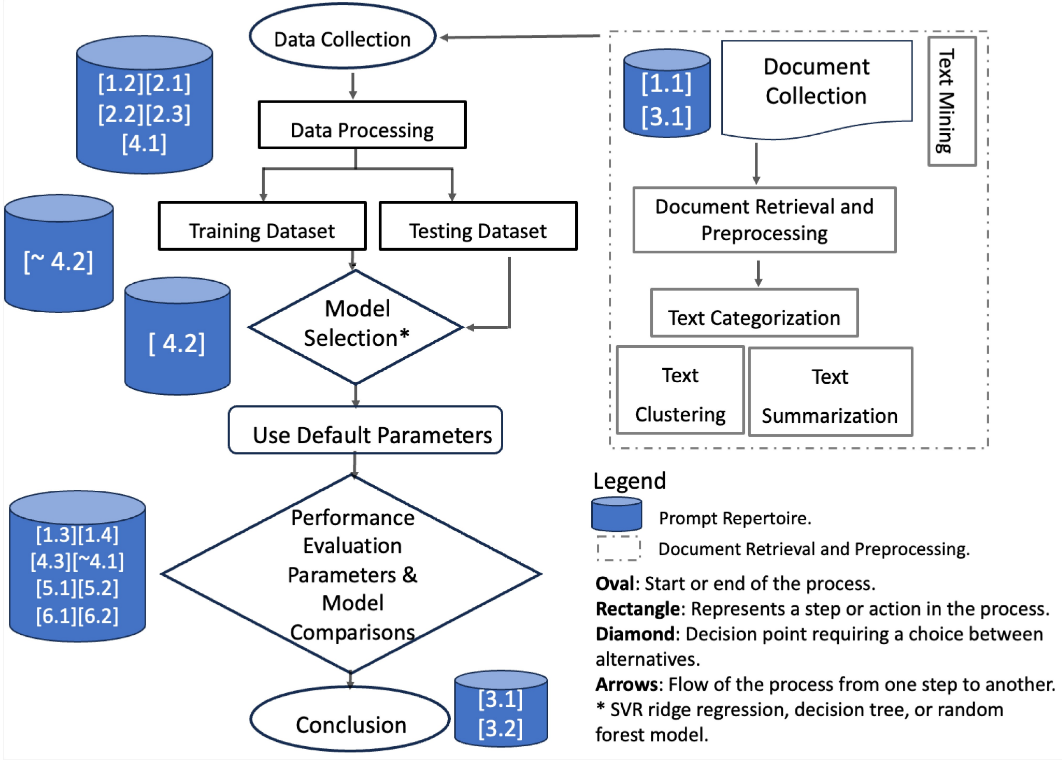
Hybrid AI-Based Framework: ClimateAgents

- AI-driven policy design

🧠 Policy Planner: Parses prompts, selects features
📚 Reasoning Agent: Injects causal logic
🔁 Simulation Agent: Runs scenarios
✍️ Narrative Generator: Summarizes outcomes
📤 Reporting Agent: Formats and stores outputs



Perception Layer: Retrieval-Augmented Evidence



Prompts Categories	Input	Output	LLM's reflexive scale
[1] Zero-shot Evaluation Instruction	[1.1] [1.2] [1.3] [1.4]	[#1.1] [#1.2] [#1.3] [#1.4]	Flexibility and adaptability
[2] Few-shot Evaluation Instruction	[2.1] [2.2] [2.3]	[#2.1] [#2.2] [#2.3]	Generalization
[3]Forward Generation	[3.1] [3.2]	[#3.1] [#3.2]	Autonomous creative capability
[4]Reverse Generation 1	[4.1] [4.2] [4.3]	[#4.1] [#4.2] [#4.3] [#4.4]	Explore potential causal relationships or complete missing parts of a dataset or narrative.
[~ 4] [Reverse Generation 2]	[~4.1] [~4.2]	[~ #4.1] [~#4.2]	Simulations or prediction
[5]Resample Instruction	[5.1] [5.2]	[#5.1] [#5.2]	Optimize tasks handling; improve model performance; increase iteration efficiency; enhance robustness to input variations; strengthen feedback loop effectiveness.
[6] Zero-shot-CoT Instruction	[6.1] [6.2]	[#6.1] [#6.2]	Accuracy of final output; quality of reasoning steps; generalization across tasks; explainability and transparency.

Reasoning : Societal Factors in Climate Attribution

Key Societal Drivers

🔥 Clean Fuel Access (Rural): Reduces emissions in less urbanized areas

🏙️ Urban Fuel Access: Key for emissions reduction in dense cities

🌆 Urbanization: Drives energy demand; sustainable growth is essential

Reasoning Layer: Causal Effects

1. **Dataset:** Selected variables $\{X_1, \ldots, X_{16}\} = \{V^{2000}, Y^{2005}\}$ modeled as:

$$X_i = f_i(\mathrm{pa}_i(X)) + \epsilon_i, \quad p(x) = \prod_i p(x_i \mid \mathrm{pa}_i(x))$$

   where $\mathrm{pa}_i(X)$ are parents, and ϵ_i is additive noise.

2. **Score Function:** Defined as $s(x) = \nabla \log p(x)$. A variable X_j is a leaf node if:

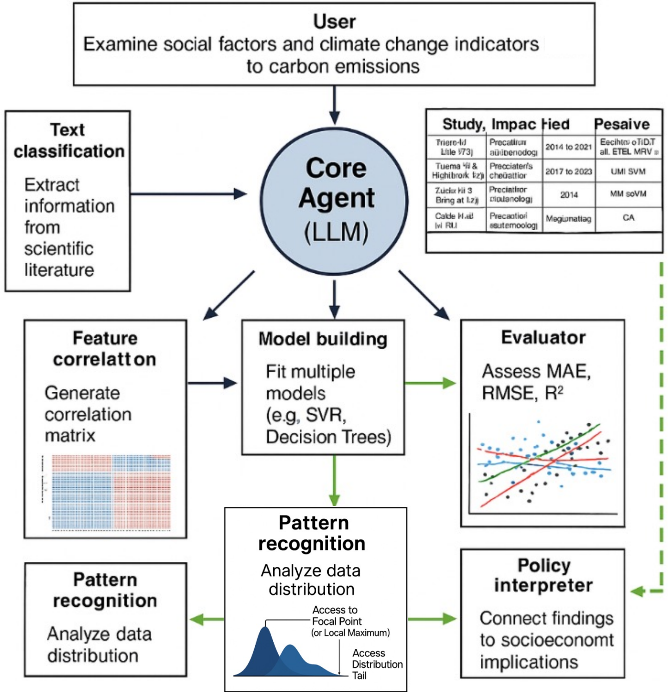
$$\mathrm{Var}_X\left(\frac{\partial s_j}{\partial x_j}\right) = 0, \quad \mathrm{Var}_X\left(\frac{\partial s_j}{\partial x_i}\right) \neq 0 \text{ for parent } X_i$$

   Leaf nodes are removed iteratively using Stein gradient estimator with RBF kernel to estimate Jacobian (Rolland et al., 2022).

3. **CAM Pruning:** Refines causal structure by eliminating spurious links:
   - *Structural*: SID, SHD
   - *Predictive*: Precision, Recall, F1 score
   - *Deviation*: L2 distance

Operation Orchestrate : From Representation to Action

- Translate learned representations into actionable insights
- Task-specific modules
- LLM agent orchestrates the pipeline
- Operationalize reasoning
- Bridging statical learning and domain-aware interpretation



Socio-Environmental Narrative Synthesis

- Agent-generated insights emphasize how regional disparities in clean fuel access and urbanization dynamics affect emission outcomes and policy design.

User:
Rural areas (`EG.CFT.ACCS.RU.ZS`) have lower access to clean fuels than urban ones (`EG.CFT.ACCS.UR.ZS`), and urbanization (`SP.URB.TOTL.IN.ZS`) is increasing.
Could variability in clean fuel access affect the effectiveness of environmental policies at reducing emissions?

AI Social-Scientist (GPT-4-turbo):

- **Policy Effectiveness:** Greater variability (standard deviation) in access weakens uniform policy outcomes by reflecting infrastructure inequity.
- **Emission Impact:** Urban-focused policies may yield quick results, but lasting success requires rural inclusion.
- **Urbanization Factor:** Urbanization shifts where and how policies work; less urbanized regions need tailored approaches.
- **Policy Design:** Reducing variability in access could lead to more equitable and impactful environmental strategies.

Implications:

- Targeted investments in rural infrastructure could improve long-term emission reductions.
- Adaptive policy frameworks should consider regional disparities in energy access.
- Integration of socio-environmental data with LLM reasoning may improve decision-making in complex systems.

Conclusion & Future Directions

- **Key Capabilities**
  - Models complex socio-environmental dynamics
  - Analyzes clean energy, urbanization, and carbon emissions
  - Synthesizes heterogeneous data into narratives and visualizations
  - Enhances policy relevance with interpretable, evidence-based outputs
- **Current Limitations**
  - Causal inference relies on data quality
  - Emission models “simplify” reality (not represent)
  - Automated simulation is a work-in-progress
  - LLMs are not good at causal reasoning (social/linguistic biases)
- **Future Directions**
  - Integrate advanced foundation models and generative tools
  - Improve scalability, reduce computational costs
  - Expand predictive depth and policy simulation capabilities

Reflexive AI for Climate Change Roadmap

- **Reflexive AI for Climate Change Roadmap**: compile development and implementation, empirical validation and societal implications, integration with existing AI technology.

- Project location: https://github.com/shanshanfy/TowardsReflexiveAI

Thank You