



AI-Enhanced Carbon Emissions Forecasting

AI-Enhanced Carbon Emissions Forecasting for Saudi Arabia

Integrating Multi-Source Data with Advanced Machine Learning

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Presentation Agenda

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Problem & Importance

Saudi Arabia is committed to net-zero emissions by 2060 under the Saudi Green Initiative. Vision 2030 involves massive sustainability investments such as NEOM and renewable energy. The Public Investment Fund (PIF) is projected to reach multi-trillion-dollar assets by 2030 — which underlines the urgent need for accurate carbon emissions forecasting to ensure evidence-based decision making. *[SGI, 2021]*

! Research Gap

Current models lack integration of national and satellite data, don't provide uncertainty estimates, and cannot accurately measure progress toward 2060 net-zero goals.

⚙️ Regional Challenge

Saudi's dust storms and extreme temperatures aren't addressed in current models *[Addas, 2023]*.

🎯 Core Question

How to integrate AI methods with satellite data for robust CO₂ forecasting in Saudi Arabia?

🌐 Global Relevance

Methodology applicable to 41% of Earth's arid and semi-arid regions *[UNCCD, 2022]*, important for GCC countries with similar climate goals.

Research Objectives

Primary Goal: Establish a multi-modal AI framework for uncertainty-quantified CO₂ forecasting in Saudi Arabia.

Specific Objectives

- Integrate ensemble AI (FFNN, LSTM, XGBoost) with satellite data (NO₂, NDVI)
- Enhance Nassef et al. benchmark ($R^2=0.931$) with multi-modal approach [*Nassef et al., 2023*]
- Develop reproducible methodology for future research

Success Criteria

- $R^2 \geq 0.85$ on validation data
 - Integration of 3 AI models with 2-3 satellite indicators
 - Complete documentation and code framework
 - Clear pathway for future PhD research
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Methodology

Data Integration

- **National Data:** CO₂, GDP, energy indicators
- **Satellite Data:** NO₂, NDVI, LST via Google Earth Engine [*Gorelick et al., 2017*]
- **Temporal Coverage:** 1990-2024 (training), 2025-2030 (prediction)

AI Framework

- **Tier 1:** Individual Models (FFNN, LSTM, XGBoost)
- **Tier 2:** Ensemble Methods (Weighted, Stacking)
- **Tier 3:** Multi-Modal Fusion (Early, Late)

Validation Strategy

- Temporal Cross-Validation (k=5 folds)
- Hold-out test on 2020-2024 data (strictly out-of-sample)
- Target: $R^2 \geq 0.93$ (stretch goal)
- Acceptance: $R^2 \geq 0.85$ & $MAPE \leq 10\%$
- Uncertainty: Currently via ensemble spread; BMA deferred [*Le Brazidec et al., 2024*]

Technical Stack

Python, TensorFlow, PyTorch, Google Colab Pro, Google Earth Engine

NO₂ as Carbon Proxy

Key Innovation

Using Nitrogen Dioxide (NO₂) as a proxy for Carbon Dioxide (CO₂) emissions from fossil fuel combustion.

Scientific Foundation

- Both NO₂ and CO₂ are co-emitted during fossil fuel combustion
- NO₂ has a shorter atmospheric lifetime (hours vs. centuries for CO₂)
- Satellites can detect NO₂ with high spatial resolution
- Strong correlation between NO₂ and fossil fuel-derived CO₂ [Cao, 2023]

TROPOMI Instrument

Provides daily global NO₂ measurements at up to 7×3.5 km resolution at nadir, enabling precise monitoring of emission sources [ESA, 2023]

Literature Integration

- Built on established relationship between NO₂ and fossil fuel CO₂ [Dou et al., 2023]
- Improved spatial resolution compared to traditional methods
- Adapted methodology for Saudi Arabia's unique conditions
- Combined with NDVI for comprehensive environmental monitoring

Novel Contribution

First systematic integration of NO₂ satellite data with ensemble AI for Saudi-specific CO₂ forecasting

Risk Management

Proactive identification and mitigation of key risks to ensure 3-month project success.

Risk	Level	Mitigation Strategy
NDVI/NO ₂ data gaps/noise	High×Med	AVHRR pre-2000 + OMI 2004-2017 + dust/cloud filters
Model complexity vs limited data	Med×High	Start simple (XGBoost/small FFNN) + regularization + temporal CV
Bayesian Model Averaging complexity	High×High	Defer full implementation; use ensemble spread for uncertainty now
Dust storms/extreme temperatures	High×Med	Filter high AOD periods + integrate LST + stress testing
Time pressure/infrastructure	Med×High	Critical path + parallel documentation + GEE/Colab backups

Project Timeline

Month 1: Foundation

- **W1-2:** Data collection & preprocessing
- **W3-4:** Baseline model development

Month 2: Core Work

- **W5-6:** Satellite data integration
- **W7-8:** Multi-modal training

Month 3: Validation

- **W9-10:** Comprehensive validation
- **W11-12:** Documentation & final prep

Future Research

- PhD-level uncertainty quantification
 - Saudi-specific adaptations
 - Operational deployment
 - Regional expansion to GCC
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Expected Results & Impact

Immediate Outcomes

- Validated multi-modal framework with $R^2 \geq 0.85$
- 3-8% performance gain over baseline through satellite data
- Complete reproducible methodology
- Analysis of satellite indicator contributions



Academic Value

Foundation for PhD research and publications

Long-Term Impact

- Direct policy relevance for Vision 2030
- Methodology for arid regions (41% of Earth)
- Regional expansion to GCC countries
- Enhanced climate negotiation credibility



Performance Targets

Primary: $R^2 \geq 0.85$ with demonstrated improvement
Innovation: Quantified multi-modal integration benefits

Conclusion & References

This research addresses a critical gap in climate AI for arid regions by proposing a systematic multi-modal approach to CO₂ emissions forecasting with direct policy relevance for Saudi Arabia's Vision 2030.

Selected References

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Thank You

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🕒 Q&A Session

