

AI-Based Estimation of Carbon Emissions Using Satellite Imagery:
A Case Study on Urban and Agricultural Areas in Saudi Arabia

Literature Review Report

Prepared By:

Mohammad Wajeih Bader

ID: 251000462

Program:

Master of Science in Artificial Intelligence

Institution:

College of Informatics

Midocean University, UAE

Supervisor:

Dr. Amjad Qataish

Date: July 2025

Contents

Abstract	3
Introduction.....	3
Literature Review.....	3
Connections between the Papers.....	10
Conflicts between Findings.....	11
References.....	13
Appendix A: Summary Table of Studies.....	15

Abstract

The global imperative to combat climate change necessitates accurate estimation of carbon dioxide (CO₂) emissions, particularly in rapidly developing nations like Saudi Arabia. The proposed research, "AI-Based Estimation of Carbon Emissions Using Satellite Imagery: A Case Study on Urban and Agricultural Areas in Saudi Arabia," seeks to integrate machine learning (ML) and satellite imagery (e.g., Sentinel-2, Sentinel-5P) to estimate CO₂ emissions in urban and agricultural contexts. This report reviews **sixteen peer-reviewed studies published between 2016 and 2025**, focusing on their use of AI, satellite imagery, and relevance to carbon emissions estimation in Saudi Arabia or similar regions. These studies provide methodological insights, regional context, and performance benchmarks, while highlighting a research gap in combining satellite imagery with CO₂ emissions estimation in Saudi Arabia. The findings are summarized in a comprehensive table, with a critical analysis of each study's strengths and weaknesses, reinforcing the proposed research's novelty and feasibility.

Introduction

Rising CO₂ emissions contribute significantly to global warming, making accurate monitoring critical for sustainable development. Saudi Arabia, with its urban expansion and agricultural initiatives, presents a unique case for studying emissions in arid environments. The proposed research aims to develop an AI-based model using satellite imagery (e.g., Sentinel-2, Sentinel-5P) to estimate CO₂ emissions in urban and agricultural areas. This report reviews **sixteen relevant studies from 2016 to 2025**, assessing their methodologies, datasets, and contributions. Each study is presented with a critical analysis of its strengths and weaknesses, followed by a summary table, a discussion of their support for the proposed project, a dedicated research gap section, and a references section.

Literature Review

Paper1: Application of Artificial Intelligence to Predict CO₂ Emissions (2023)

Nassef et al. (2023) investigated AI-driven prediction of CO₂ emissions in Saudi Arabia, aligning closely with the proposed research's objectives. Using historical emissions data from "Our World in Data" (1954–2020), the study applied Feed-Forward Neural Networks (FFNN), Adaptive Network-Based Fuzzy Inference System (ANFIS), and Long Short-Term Memory (LSTM) models. An ensemble approach achieved an R² of 93.13%, with low RMSE, indicating high predictive accuracy. The study's focus on Saudi Arabia and use of AI models provide a robust benchmark for the proposed research's ML framework, though it lacks satellite imagery

integration. Its performance metrics (R^2 , RMSE) and regional context support the proposed evaluation criteria and highlight the potential for AI in emissions forecasting.

Critical Analysis: A strength of this study is its high predictive accuracy and focus on Saudi Arabia, offering a regional benchmark for AI-based emissions forecasting. However, its reliance on historical data without spatial analysis or satellite imagery limits its applicability to the proposed research's goal of integrating geospatial data for urban and agricultural emissions estimation.

Paper2: Decision Tree-Based Ensemble Model for Predicting GHG Emissions in Saudi Arabia (2023)

Rahman et al. (2023) developed a decision tree-based ensemble model to predict greenhouse gas (GHG) emissions in Saudi Arabia, using socioeconomic and historical data from PRIMAP-hist (1750–2019) and the World Bank (1970–2021). The study compared bagged, boosted, and gradient-boosted decision trees, with the bagged model achieving an R^2 of 0.90 and low MAPE. Shapley analysis identified key predictors, enhancing model interpretability. Although satellite imagery was not used, the study's focus on Saudi Arabia and ML methodologies aligns with the proposed research's objectives. The performance metrics and regional insights provide a foundation for developing robust AI models in the proposed study.

Critical Analysis: The study's strength lies in its robust ensemble models and regional focus, providing a reliable framework for emissions prediction. Its weakness is the absence of satellite imagery, which restricts its relevance to the proposed research's geospatial approach, though its performance metrics are valuable for model evaluation.

Paper 3: AI-Based Modelling for CO2 Emission Prediction in Saudi Arabia (2023)

Alamri and Khan (2023) employed advanced AI models, including Exponential Smoothing, Transformers, Temporal Convolutional Networks (TCN), and N-BEATS, to predict CO2 emissions in Saudi Arabia. Using synthesized data from the World Bank, BP, and Our World in Data, the study achieved an R^2 of 0.7 for N-BEATS, with low MAE and RMSE. The focus on time-series forecasting and Saudi Arabia makes it highly relevant, though it does not incorporate satellite imagery. The study's advanced AI models and performance metrics offer valuable insights for the proposed research's ML framework and evaluation approach.

Critical Analysis: The use of cutting-edge AI models like Transformers is a key strength, providing a modern approach to emissions forecasting. However, the lack of satellite imagery and moderate R^2 (0.7) suggest limitations in spatial analysis and predictive accuracy compared to the proposed research's integrated approach.

Paper 4: Greenhouse Gas Emission Dynamics of Saudi Arabia: Potential of Hydrogen Fuel for Emission Footprint Reduction (2023)

Akinpelu et al. (2023) conducted a comprehensive review of greenhouse gas emission dynamics in Saudi Arabia, exploring the role of hydrogen fuel in reducing the country's emission footprint. The study analyzed current emission patterns, identified key sectors contributing to GHG emissions, and discussed the prospects of green hydrogen as part of Saudi Arabia's strategy to achieve net zero emissions by 2060. Using data from multiple sources including the International Energy Agency and Saudi government reports, the study provides a thorough assessment of emission reduction strategies. The research directly supports the proposed study by providing a comprehensive understanding of Saudi Arabia's emission landscape and highlighting the importance of accurate monitoring systems for policy implementation.

Critical Analysis: The study's strength lies in its comprehensive analysis of national emission dynamics and direct relevance to Saudi Arabia's Vision 2060 goals. It provides crucial context for understanding the policy landscape and emission reduction targets. However, its focus on policy and hydrogen solutions rather than monitoring technologies limits its methodological contribution to the proposed research, though it strongly supports the research's relevance and urgency.

Paper 5: Estimating CO2 Emissions from Power Plants Using Satellite Imagery and ML (2024)

Couture et al. (2024) developed a methodology to estimate CO2 emissions from power plants using satellite imagery (Landsat-8, Sentinel-2, PlanetScope) and ML models, including XGBoost and Convolutional Neural Networks (CNNs). The study used datasets like US EPA CAMPD and Global Energy Monitor, achieving an RMSE of 2.18 Mt CO2 for emissions estimation. This study is directly relevant due to its integration of Sentinel-2 imagery and ML, mirroring the proposed research's methodology. Its global scope, including arid regions, and robust performance metrics provide a strong foundation for the proposed study's approach to emissions estimation.

Critical Analysis: The study's strength is its direct use of Sentinel-2 imagery for CO2 emissions estimation, closely aligning with the proposed research's methodology. Its focus on power plants, however, limits its applicability to the proposed research's broader scope of urban and agricultural areas, necessitating adaptations for diverse land-use contexts.

Paper 6: Air Pollution Trends and Predictive Modeling Using Sentinel-5P and Deep Learning in Saudi Cities (2025)

Alkayal et al. (2025) developed an advanced forecasting model using Sentinel-5P satellite data and deep learning techniques to predict air pollution concentrations in three Saudi Arabian cities

with different characteristics. The study focused on NO₂ monitoring and demonstrated superior accuracy compared to traditional models, achieving significant improvements in prediction reliability. Using convolutional neural networks and LSTM models, the research processed atmospheric data to identify pollution patterns and trends. This study directly supports the proposed research by showcasing the effectiveness of Sentinel-5P data integration with advanced AI models in the Saudi context, providing a methodological framework for atmospheric monitoring that complements traditional land surface analysis.

Critical Analysis: The study's strength lies in its use of cutting-edge Sentinel-5P atmospheric data combined with deep learning, representing the latest technological advancement in satellite-based environmental monitoring in Saudi Arabia. Its application to three different Saudi cities provides valuable regional context and scalability insights. However, its focus on NO₂ rather than CO₂ emissions limits direct applicability, though the methodological framework for integrating atmospheric satellite data with AI models is highly relevant for the proposed research's comprehensive monitoring approach.

Paper 7: PlanetScope Nanosatellites Image Classification Using ML (2022)

Haq (2022) utilized PlanetScope satellite imagery to classify vegetation in Saudi Arabia's Al-Qassim region, a key agricultural area, using Random Forest and Multinomial Logistic Regression. The study achieved a classification accuracy of 98%, leveraging datasets like GRACE/GRACE-FO and MERRA-2 for NDVI analysis. While it does not directly address CO₂ emissions, its focus on satellite imagery and ML in a Saudi agricultural context supports the proposed research's agricultural component. The study's methodology provides insights into processing high-resolution imagery for environmental analysis.

Critical Analysis: The high classification accuracy and use of PlanetScope imagery are strengths, supporting the proposed research's agricultural focus. Its weakness is the lack of direct CO₂ emissions analysis, limiting its thematic alignment, though its methodology is relevant for satellite-based agricultural studies.

Paper 8: Estimating Carbon Stocks and Sequestration in Abha City, Saudi Arabia (2022)

Mallick et al. (2022) estimated carbon storage and sequestration capabilities in Abha, Saudi Arabia, using the InVEST model to evaluate four carbon pools (aboveground biomass, belowground biomass, soil organic carbon, and dead organic matter). The study employed multi-temporal satellite data and land use change analysis to forecast future carbon dynamics under different management scenarios. Using Landsat imagery and field measurements, the research quantified carbon stocks and their monetary valuation, providing actionable insights for developing Abha as a low-carbon city. The study achieved accurate carbon stock estimates with

validation against field data, demonstrating the effectiveness of combining satellite imagery with ecosystem service modeling for carbon assessment in Saudi urban environments.

Critical Analysis: The study's strength lies in its comprehensive carbon cycle analysis using proven InVEST methodology specifically applied to a Saudi city, providing a direct template for urban carbon assessment. Its integration of satellite imagery with ground-truth data offers robust validation approaches. However, its focus on carbon stocks and sequestration rather than active CO₂ emissions limits direct methodological applicability, though it provides valuable insights for validating emissions estimates against carbon pool changes.

Paper 9: Urban Health-Related Air Quality Indicators in MENA Countries (2019)

Elnadry et al. (2019) analyzed air quality indicators in the MENA region, including Saudi Arabia, using multiple satellite sources and ML techniques. The study focused on aerosol optical depth, providing a framework for satellite-based environmental monitoring. Although it does not directly target CO₂ emissions, its use of satellite imagery in a regional context offers methodological insights for the proposed research. The study's ML-based approach to processing satellite data supports the proposed methodology for urban areas.

Critical Analysis: The study's strength lies in its regional focus on MENA countries, including Saudi Arabia, and satellite-based methodology for environmental monitoring. Its use of multiple satellite sources and ML techniques provides valuable insights for urban environmental analysis. However, its focus on air quality indicators rather than CO₂ emissions limits its direct relevance to the proposed research, though its satellite-based ML methodology is applicable to atmospheric monitoring applications.

Paper 10: Estimation of Soil Organic Carbon in Agricultural Fields (2022)

Madugundu et al. (2022) estimated soil organic carbon in Saudi Arabian agricultural fields using Landsat-8 and Sentinel-2 imagery. The study's focus on carbon-related metrics in agricultural settings aligns with the proposed research's agricultural component. By leveraging Sentinel-2, it provides a methodological framework for processing satellite imagery, though it does not directly estimate CO₂ emissions. The study's results support the proposed research's aim to analyze carbon dynamics in arid agricultural environments.

Critical Analysis: The study's strength is its focus on soil organic carbon in Saudi agricultural contexts, directly supporting the proposed research's agricultural component. Its limitation is the lack of direct CO₂ emissions estimation, though its satellite-based methodology is highly relevant.

Paper 11: Improving Spatial Prediction of Soil Organic Carbon in Arid Regions (2020)

Taghizadeh-Mehrjardi et al. (2020) used stacking ML models to predict soil organic carbon in arid regions, including Iran, using satellite-derived covariates. The study's focus on arid environments and advanced ML techniques provides methodological insights for the proposed research's agricultural component. Although it does not address CO₂ emissions directly, its approach to satellite data and ML supports the proposed methodology for carbon analysis in similar climates.

Critical Analysis: The study's strength lies in its advanced ML methodology and relevance to arid regions, offering a framework for agricultural carbon analysis. Its lack of focus on CO₂ emissions and Saudi-specific data limits its direct applicability, though its techniques are transferable.

Paper 12: Deep Learning and Earth Observation for Sustainable Development Goals (2022)

Persello et al. (2022) reviewed the application of deep learning and Earth observation data for sustainable development goals, including climate action. The study highlights the potential of deep learning with satellite imagery, offering methodological guidance for the proposed research. While not specific to Saudi Arabia or CO₂ emissions, its insights into advanced AI techniques support the proposed research's aim to leverage cutting-edge ML models.

Critical Analysis: The study's comprehensive review of deep learning is a strength, providing methodological inspiration for the proposed research. Its broad scope and lack of regional or CO₂-specific focus are weaknesses, limiting its direct relevance but supporting advanced AI applications.

Paper 13: Predicting CO₂ Emission Footprint Using AI through Machine Learning (2022)

Meng and Noman (2022) developed and compared four SARIMA models to predict global CO₂ emissions, with particular focus on the impact of the COVID-19 pandemic on emission patterns. Using global annual CO₂ emission data from 1751 to 2018, the study implemented ARIMA-based models for different pandemic periods (pre-COVID-19, start-COVID-19, trans-COVID-19, post-COVID-19). The post-COVID-19 model achieved the highest accuracy with low MAPE, MSE, and RMSE values, providing predictions from 2022 to 2027 and beyond. While the study's global scope differs from the proposed research's Saudi focus, its advanced time-series modeling approach and consideration of external factors (pandemic impacts) offer valuable methodological insights for developing robust emissions prediction models that can account for external disruptions.

Critical Analysis: The study's strength lies in its sophisticated SARIMA modeling approach and consideration of external factors affecting emission patterns, providing a robust framework for time-series emissions prediction. Its global scope and focus on historical data rather than real-time satellite monitoring limits direct applicability to the proposed research's spatially explicit approach, though its methodological rigor is valuable for temporal modeling components.

Paper 14: Employment of GIS Techniques for Soil Organic Carbon Assessment in Hyper-Arid Conditions (2019)

Tola et al. (2019) employed GIS techniques to assess the long-term impact of tillage practices on soil organic carbon in agricultural fields under hyper-arid conditions, similar to Saudi Arabia's climate. The study utilized spatial analysis and remote sensing data to quantify carbon changes over time, demonstrating the effectiveness of GIS-based approaches for carbon monitoring in arid agricultural systems. The research provides methodological insights for integrating spatial technologies with carbon assessment, particularly relevant for understanding baseline carbon conditions in agricultural areas. The study's focus on hyper-arid environments directly supports the proposed research's agricultural component by providing proven methodologies for carbon analysis in similar climatic conditions.

Critical Analysis: The study's strength is its specific focus on hyper-arid agricultural conditions, providing directly applicable methodologies for the proposed research's agricultural component. Its emphasis on soil organic carbon rather than atmospheric CO₂ emissions is a limitation, though the GIS-based spatial analysis techniques are transferable to atmospheric emissions monitoring applications.

Paper 15: Detection of Land Use/Land Cover Changes and Urban Sprawl in Al-Khobar, Saudi Arabia (2016)

Rahman (2016) analyzed land use/land cover changes and urban sprawl in Al-Khobar, Saudi Arabia, using multi-temporal remote sensing data. The study employed satellite imagery to quantify urban expansion patterns and land cover transitions over time, achieving high accuracy in change detection. Using Landsat imagery and advanced classification techniques, the research documented rapid urban growth and its environmental implications. This study directly supports the proposed research by demonstrating the effectiveness of satellite-based monitoring in Saudi urban environments and providing a proven framework for analyzing land use changes that drive emission patterns. The Al-Khobar case study offers valuable insights for understanding urban development impacts on emissions in Saudi cities.

Critical Analysis: The study's strength lies in its direct application to a Saudi urban environment (Al-Khobar) and proven methodology for satellite-based land use change detection, providing a solid foundation for urban emission monitoring. Its focus on land cover changes rather than

emissions is a limitation, though the methodological framework is highly applicable to the proposed research's urban monitoring component.

Paper 16: ML Techniques to Map Urban Heat Islands in Jeddah (2023)

Addas (2023) used ML and satellite data to map urban heat islands in Jeddah, Saudi Arabia. The study's focus on urban environmental analysis using satellite imagery aligns with the proposed research's urban component. Although it does not target CO₂ emissions, its ML-based approach to satellite data processing provides methodological insights for urban emissions estimation in the proposed study.

Critical Analysis: The study's strength is its urban focus in Saudi Arabia and use of satellite imagery, supporting the proposed research's urban component. Its focus on heat islands rather than CO₂ emissions is a weakness, though its ML methodology is relevant for urban analysis.

Connections between the Papers

The reviewed studies collectively form a robust foundation for the proposed research by addressing various aspects of CO₂ emissions and environmental monitoring in Saudi Arabia and similar arid environments. Several key connections emerge:

1. **Regional Focus on Saudi Arabia:** Studies by Nassef et al. (2023), Rahman et al. (2023), Alamri and Khan (2023), Akinpelu et al. (2023), Alkayal et al. (2025), Haq (2022), Mallick et al. (2022), Madugundu et al. (2022), Rahman (2016), and Addas (2023) all focus on Saudi Arabia, providing a strong regional context. This alignment supports the proposed research's emphasis on Saudi-specific emissions and environmental dynamics, particularly in urban and agricultural settings.
2. **Use of Machine Learning and AI:** A common thread across most studies is the application of advanced ML and AI techniques. For instance, Nassef et al. (2023) and Rahman et al. (2023) use ensemble models, Alamri and Khan (2023) employ Transformers and N-BEATS, Couture et al. (2024) and Alkayal et al. (2025) leverage CNNs and LSTMs, and Haq (2022) applies Random Forest. This convergence on ML/AI underscores their effectiveness in environmental modeling and supports the proposed research's ML-driven approach.
3. **Satellite Imagery Integration:** Studies like Couture et al. (2024), Alkayal et al. (2025), Haq (2022), Mallick et al. (2022), Madugundu et al. (2022), Rahman (2016), and Addas (2023) incorporate satellite imagery (e.g., Sentinel-2, Sentinel-5P, Landsat, PlanetScope), aligning with the proposed research's goal of using geospatial data for emissions estimation. These studies demonstrate the versatility of satellite data in monitoring emissions, air quality, land use, and carbon stocks.

4. **Focus on Carbon Dynamics:** Several studies address carbon-related metrics, such as CO₂ emissions (Nassef et al., 2023; Rahman et al., 2023; Alamri and Khan, 2023; Couture et al., 2024), soil organic carbon (Madugundu et al., 2022; Taghizadeh-Mehrjardi et al., 2020; Tola et al., 2019), and carbon sequestration (Mallick et al., 2022). These studies collectively provide a comprehensive view of carbon cycles in arid environments, supporting the proposed research's dual focus on emissions and carbon storage.
5. **Urban and Agricultural Contexts:** The studies cover both urban (Mallick et al., 2022; Rahman, 2016; Addas, 2023; Alkayal et al., 2025) and agricultural (Haq, 2022; Madugundu et al., 2022; Tola et al., 2019; Taghizadeh-Mehrjardi et al., 2020) environments, mirroring the proposed research's scope. This dual focus enables a holistic approach to emissions monitoring across diverse land-use types in Saudi Arabia.
6. **Policy Relevance:** Akinpelu et al. (2023) and Mallick et al. (2022) emphasize policy implications, linking emissions monitoring to Saudi Arabia's Vision 2060 and low-carbon city development. These studies provide a policy context that enhances the proposed research's relevance to national sustainability goals.

Conflicts between Findings

While the studies share common themes, several conflicts or discrepancies arise, reflecting methodological differences, data sources, or focus areas:

1. **Predictive Accuracy Variations:** Nassef et al. (2023) report a high R^2 of 93.13% for CO₂ emissions prediction, while Alamri and Khan (2023) achieve a lower R^2 of 0.7 using N-BEATS. This discrepancy may stem from differences in model complexity (ensemble vs. single models), data quality, or preprocessing techniques, highlighting the need for standardized evaluation metrics in the proposed research.
2. **Satellite Imagery vs. Historical Data:** Studies like Couture et al. (2024) and Alkayal et al. (2025) integrate satellite imagery for real-time monitoring, achieving robust results, whereas Nassef et al. (2023), Rahman et al. (2023), and Alamri and Khan (2023) rely solely on historical datasets. This creates a methodological conflict, as satellite-based approaches offer spatial granularity but require complex processing, while historical data models are simpler but lack spatial context.
3. **Focus on CO₂ vs. Other Pollutants:** Alkayal et al. (2025) focus on NO₂, while Nassef et al. (2023), Rahman et al. (2023), and Couture et al. (2024) target CO₂ emissions. This divergence limits direct comparability, as NO₂ and CO₂ have different atmospheric behaviors and sources, posing challenges for integrating findings into a unified emissions monitoring framework.

4. **Scope of Application:** Couture et al. (2024) focus narrowly on power plant emissions, while Mallick et al. (2022) and Rahman (2016) address broader urban contexts. This creates a conflict in applicability, as power plant-specific models may not generalize to urban or agricultural settings, necessitating tailored adaptations in the proposed research.
5. **Data Sources and Temporal Coverage:** Studies use varied datasets with different temporal ranges, e.g., Our World in Data (1954–2020) in Nassef et al. (2023), PRIMAP-hist (1750–2019) in Rahman et al. (2023), and Sentinel-5P real-time data in Alkayal et al. (2025). These differences can lead to inconsistencies in baseline emissions estimates, affecting model reliability and comparability.
6. **Methodological Rigor:** Meng and Noman (2022) use SARIMA models with a global scope, achieving high accuracy but lacking spatial resolution, while Couture et al. (2024) and Alkayal et al. (2025) emphasize spatially explicit ML models. This conflict underscores a trade-off between temporal forecasting accuracy and spatial detail, which the proposed research must address by integrating both approaches.

References

- Addas, A. (2023). Machine learning techniques to map the impact of urban heat island: Investigating the city of Jeddah. *Land*, 12(6), 1159. <https://doi.org/10.3390/land12061159>
- Akinpelu, A., Alam, Md. S., Shafiullah, M., Rahman, S., & Alismail, F. (2023). Greenhouse gas emission dynamics of Saudi Arabia: Potential of hydrogen fuel for emission footprint reduction. *Sustainability*, 15(10), 8222. <https://doi.org/10.3390/su15108222>
- Alamri, Y., & Khan, M. R. (2023). Artificial intelligence based modelling for predicting CO2 emission for climate change mitigation in Saudi Arabia. *International Journal of Advanced Computer Science and Applications*, 14(4). <https://doi.org/10.14569/IJACSA.2023.0140448>
- Alkayal, S., Almisbahi, H., Baowidan, S., & Alkayal, E. S. (2025). Air pollution trends and predictive modeling for three cities with different characteristics using Sentinel-5 satellite data and deep learning. *Atmosphere*, 16(1), 45. <https://doi.org/10.3390/atmos16010045>
- Couture, J. J., et al. (2024). Estimating carbon dioxide emissions from power plant water vapor plumes using satellite imagery and machine learning. *Remote Sensing*, 16(7), 1290. <https://doi.org/10.3390/rs16071290>
- Elnadry, A., et al. (2019). Urban health related air quality indicators over the Middle East and North Africa countries using multiple satellites and AERONET data. *Remote Sensing*, 11(18), 2096. <https://doi.org/10.3390/rs11182096>
- Haq, M. A. (2022). Planetscope nanosatellites image classification using machine learning. *Computer Systems Science and Engineering*, 43(1). <https://doi.org/10.32604/csse.2022.021227>
- Madugundu, R., et al. (2022). Estimation of soil organic carbon in agricultural fields: A remote sensing approach. *Journal of Environmental Biology*, 43(1). <https://doi.org/10.22438/jeb/43/1/MRN-1854>
- Mallick, J., Almesfer, M. K., Alsubih, M., Ahmed, M., & Ben Kahla, N. (2022). Estimating carbon stocks and sequestration with their valuation under a changing land use scenario: A multi-temporal research in Abha city, Saudi Arabia. *Frontiers in Ecology and Evolution*, 10, 905799. <https://doi.org/10.3389/fevo.2022.905799>
- Meng, Y., & Noman, H. (2022). Predicting CO2 emission footprint using AI through machine learning. *Atmosphere*, 13(11), 1871. <https://doi.org/10.3390/atmos13111871>
- Nassef, A. M., et al. (2023). Application of artificial intelligence to predict CO2 emissions: Critical step towards sustainable environment. *Sustainability*, 15(9), 7648. <https://doi.org/10.3390/su15097648>

Persello, C., et al. (2022). Deep learning and earth observation to support the sustainable development goals. *IEEE Geoscience and Remote Sensing Magazine*, 10(1). <https://doi.org/10.1109/MGRS.2021.3136100>

Rahman, M. M., et al. (2023). Decision tree-based ensemble model for predicting national greenhouse gas emissions in Saudi Arabia. *Applied Sciences*, 13(6), 3832. <https://doi.org/10.3390/app13063832>

Rahman, M. T. (2016). Detection of land use/land cover changes and urban sprawl in Al-Khobar, Saudi Arabia: An analysis of multi-temporal remote sensing data. *ISPRS International Journal of Geo-Information*, 5(2), 15. <https://doi.org/10.3390/ijgi5020015>

Taghizadeh-Mehrjardi, R., et al. (2020). Improving the spatial prediction of soil organic carbon content in two contrasting climatic regions by stacking machine learning models and rescanning covariate space. *Remote Sensing*, 12(7), 1095. <https://doi.org/10.3390/rs12071095>

Tola, E., Al-Gaadi, K., & Madugundu, R. (2019). Employment of GIS techniques to assess the long-term impact of tillage on the soil organic carbon of agricultural fields under hyper-arid conditions. *PLoS ONE*, 14(2), e0212521. <https://doi.org/10.1371/journal.pone.0212521>

Appendix A: Summary Table of Studies

Authors (Year)	Description	Dataset	Algorithms Used	Methodology	Study Questions	Objectives	Results	Contribution
Nassef et al. (2023)	AI-based prediction of CO2 emissions in Saudi Arabia using historical data.	Our World in Data (1954–2020)	FFNN, ANFIS, LSTM	Ensemble modeling; 70:30 train-test split	How can AI predict CO2 emissions accurately?	Develop accurate AI models for CO2 forecasting	$R^2 = 93.13\%$, low RMSE	Demonstrates AI's potential for emissions forecasting in Saudi Arabia
Rahman et al. (2023)	Prediction of GHG emissions in Saudi Arabia using decision tree-based models.	PRIMAP-hist (1750–2019), World Bank (1970–2021)	Bagged Decision Tree, Boosted Decision Tree, Gradient Boosted Decision Tree	Bagged, boosted, gradient-boosted decision trees; Shapley analysis	Can ensemble models improve GHG prediction accuracy?	Predict GHG emissions using socioeconomic data	$R^2 = 0.90$, low MAPE	Provides robust ML models for GHG prediction in Saudi Arabia
Alamri & Khan (2023)	AI-based CO2 emission prediction in Saudi Arabia using time-series models.	World Bank, BP, Our World in Data	Exponential Smoothing, Transformers, TCN, N-BEATS	Time-series forecasting	How effective are advanced AI models for CO2 prediction?	Forecast CO2 emissions using public datasets	$R^2 = 0.7$ for N-BEATS, low MAE	Introduces advanced AI models for emissions prediction
Akinpelu et al. (2023)	Comprehensive analysis of GHG emission dynamics and hydrogen potential in Saudi Arabia.	IEA, Saudi government reports, multiple energy databases	Literature review and data analysis	Systematic review of emission sources and reduction strategies	What are Saudi Arabia's emission dynamics and hydrogen potential?	Analyze current emissions and assess hydrogen solutions for Vision 2060	Comprehensive emission assessment, hydrogen roadmap	Provides policy context and national emission landscape for Saudi Arabia
Couture et al. (2024)	CO2 emissions estimation from power plants using satellite imagery and ML.	US EPA CAMPD, ENTSO-E, Global Energy Monitor	XGBoost, CNNs	Cross-validation; hyperparameter tuning	Can satellite imagery estimate power plant emissions?	Develop ML models for emissions estimation using satellite data	RMSE = 2.18 Mt CO2	Validates satellite imagery for CO2 emissions estimation
Alkayal et al. (2025)	Air pollution prediction using Sentinel-5P and deep learning in Saudi cities.	Sentinel-5P, meteorological data	CNN, LSTM, Deep Neural Networks	Deep learning with atmospheric satellite data	How effective is Sentinel-5P for air quality prediction in Saudi cities?	Develop advanced models for atmospheric pollution monitoring	Superior accuracy vs traditional models, reliable NO2 predictions	Demonstrates latest atmospheric monitoring technology in Saudi context
Haq (2022)	Vegetation classification in Al-Qassim using PlanetScope imagery and	PlanetScope, GRACE/GRACE-FO, MERRA-2	Random Forest, Multinomial Logistic Regression	Random Forest classification; NDVI analysis	How can satellite imagery classify vegetation in arid regions?	Analyze agricultural land use in Saudi Arabia	Classification accuracy = 98%	Supports satellite-based agricultural analysis in Saudi Arabia

	ML.							
Mallick et al. (2022)	Carbon stocks and sequestration estimation in Abha city using InVEST model.	Landsat imagery, field measurements, land use data	InVEST model, spatial analysis	Multi-temporal analysis, ecosystem service modeling	How can carbon stocks be quantified in Saudi urban environments?	Estimate carbon storage and sequestration capabilities for low-carbon city development	Accurate carbon stock estimates with monetary valuation	Provides urban carbon assessment methodology for Saudi cities
Elnadry et al. (2019)	Air quality analysis in MENA using satellite data and ML.	Multiple satellite sources, AERONET	ML-based classifiers	ML-based analysis of air quality indicators	How can satellite data monitor air quality in MENA?	Assess air quality using satellite imagery	Accurate air quality mapping	Provides methodological insights for satellite-based environmental analysis
Madugundu et al. (2022)	Estimation of soil organic carbon in Saudi agricultural fields using satellite imagery.	Landsat-8, Sentinel-2	Remote sensing algorithms	Remote sensing with Landsat-8, Sentinel-2	Can satellite imagery estimate soil organic carbon?	Quantify soil carbon in agricultural areas	Accurate soil carbon estimates	Supports carbon cycle analysis in agricultural settings
Taghizadeh-Mehrjardi et al. (2020)	Prediction of soil organic carbon in arid regions using ML and satellite data.	Satellite-derived covariates	Stacking ML models	Stacking ML models; covariate rescanning	How can ML improve soil carbon prediction in arid regions?	Enhance spatial prediction of soil carbon	Improved prediction accuracy	Offers ML methodologies for arid region carbon analysis
Persello et al. (2022)	Review of deep learning and Earth observation for sustainable development.	Earth observation data	Deep learning models	Literature review of deep learning applications	How can deep learning support sustainable development?	Explore deep learning with Earth observation data	Insights into deep learning applications	Provides methodological guidance for deep learning in environmental studies
Meng & Noman (2022)	Global CO2 emissions prediction using SARIMA models with pandemic impact analysis.	Global CO2 emissions (1751-2018)	SARIMA, ARIMA	Time-series forecasting with pandemic period analysis	How can we predict global CO2 emissions considering COVID-19 impacts?	Develop robust time-series models for emissions prediction	Post-COVID model: lowest MAPE, MSE, RMSE	Provides sophisticated time-series modeling for emissions with external factor consideration
Tola et al. (2019)	GIS-based assessment of tillage impact on soil organic carbon in hyper-arid conditions.	Spatial agricultural data, soil samples	GIS spatial analysis	Long-term spatial analysis of agricultural practices	How does tillage affect soil carbon in hyper-arid environments?	Assess long-term carbon impacts of agricultural practices	Quantified carbon changes over time	Provides GIS methodology for agricultural carbon monitoring in arid regions

Rahman (2016)	Land use change and urban sprawl analysis in Al-Khobar using remote sensing.	Multi-temporal Landsat imagery	Classification algorithms, change detection	Multi-temporal satellite image analysis	How can remote sensing detect urban sprawl in Saudi cities?	Monitor urban expansion and land cover changes	High accuracy change detection, urban growth quantification	Demonstrates satellite-based urban monitoring methodology in Saudi context
Addas (2023)	Mapping urban heat islands in Jeddah using ML and satellite data.	Satellite data for land use/cover	ML-based classifiers	ML-based mapping of urban heat islands	How can satellite data map urban heat islands?	Analyze urban heat in Jeddah	Accurate heat island mapping	Supports satellite-based urban environmental analysis