Indian Journal of Agricultural Economics 79: 3 (2024) 610-620
DOI:10.63040/25827510.2024.03.020

Mitigating Climate Impact: A Machine Learning Approach to Forecast Methane Emissions from Indian Livestock

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ABSTRACT

Livestock farming plays a pivotal role in the rural economy but poses significant challenges due to methane emissions, primarily from ruminants like cattle and buffalo. Approximately 44 per cent of methane emissions from livestock are attributed to enteric fermentation by ruminants. This study aims to assess the current status of methane emissions from livestock and forecast future emissions using machine learning techniques. The current study utilizes time-series data of methane emissions from 1961 to 2021. Advanced models such as ARIMA, SVM, Prophet, and LSTM were employed to forecast methane emissions. The analysis reveals a consistent rise in methane emissions over six decades, punctuated by periods of acceleration and stabilization, driven by expanding livestock numbers and intensified farming practices. The findings underscore the critical role of dairy and non-dairy cattle, alongside buffaloes, which collectively contribute over 92 per cent of livestock methane emissions in India. The rise in emissions correlates with intensified livestock farming practices and increasing demand for livestock products, particularly from the 1980s onward. Although emissions plateaued temporarily from 2000 to 2010, recent data indicates a renewed upward trend post-2010, highlighting the need for enhanced mitigation strategies. The study emphasizes the urgency of targeted measures, such as improved feed efficiency and manure management, to effectively reduce methane emissions. These insights provide policymakers and stakeholders with valuable guidance for making informed decisions towards sustainable livestock management practices in India, which are essential for mitigating climate change impacts.

Keywords: Livestock emissions, Methane, Sustainability, Climate impact

JEL codes : Q12, Q16, Q54, Q57

I

INTRODUCTION

Livestock farming in India is a significant source of livelihood and a major contributor to greenhouse gas (GHG) emissions, mainly methane (CH4). According to the Climate Watch's Climate Analysis Indicators Tool (CAIT, 2020), India is the third largest producer of GHGs globally, after the USA and China. Recent data from the EDGAR emission inventory ranks India second in methane emissions from various anthropogenic and natural sources. The primary sectors emitting methane in South Asia include livestock, paddy fields, and solid waste (Jha *et al.*, 2011; Garg *et al.*, 2011). Gerber *et al.* (2013) emphasize that livestock contributes nearly 14.5 per cent of global methane emissions from anthropogenic activities, with Asian countries playing a significant role. India's livestock sector has undergone a demand-driven revolution, recording an unprecedented annual growth rate of 7.6 per cent between 2010-11 and 2019-20 (Bitthal, 2019). This sector is vital to the rural economy. India is notable

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among Asian countries in livestock populations, ranking first in cattle, buffalo, goat, and fish in sheep populations. Consequently, bovines and ruminants majorly contribute to global methane emissions (Swamy and Bhattacharya, 2006). Approximately 44 per cent of methane emissions from livestock are attributed to enteric fermentation by ruminants, which possess four-compartment digestive systems as part of their normal digestive processes (GLEAM 2.0; FAO, 2018).

India is renowned for its vast agricultural landscapes and substantial livestock population. It is essential to comprehend the trends and forecast future methane emissions from this sector to formulate effective climate mitigation strategies. However, a notable absence of comprehensive studies focusing on forecasting methane emissions, specifically from livestock in India, creates a significant research gap. This study aims to fill this critical research gap by analyzing historical trends in methane emissions from livestock in India and developing a forecast model to predict future emissions. Through this analysis, the study seeks to provide insights into the potential trajectory of methane emissions from the livestock sector under various scenarios and contribute to informed decision-making towards achieving India's climate goals. Given this background, the objectives are to assess the current status of methane emissions from livestock and to forecast future emissions using machine learning techniques.

II

METHODOLOGY

Data Source

For this research, the dataset was sourced from the Food and Agriculture Organization of the United Nations, which provides publicly accessible data for research, statistics, and scientific purposes. The dataset includes data on methane emissions through enteric fermentation by various livestock species (asses, buffaloes, camels, cattle (dairy and non-dairy), goats, horses, llamas, mules, sheep, swine (breeding and market)) spanning from 1961 to 2021, with projections for 2022 and 2031. Data coverage was by country, regions, and special groups globally. Our study focused on Indian data from 1960 to 2021, comprising 855 rows and seven columns (Area, Element, Item, Year, Source, Unit, and Value). These data were processed using specialized software for data cleaning and preparation following our study objectives.

Modelling

The models employed in this research include ARIMA (Auto Regressive Integrated Moving Average), Support Vector Machine (SVM), Prophet, and Long Short-Term Memory (LSTM). It was partitioned into training and testing sets before inputting the cleaned data into these models. The training phase utilized data from 1961 to 2014, while the forecasting phase was validated on the remaining test data from 2015 to 2021. Below are the specific details regarding the models utilized in this study.

ARIMA

Autoregressive Integrated Moving Average (ARIMA) is a commonly used model for time series forecasting. Before applying the ARIMA model, the time series data must be stationary. The model predicts future values based on past time series data, utilizing three main parameters: p, d, and q. Here, p represents the number of lag observations, d denotes the degree of differencing, and q indicates the size of the moving average component.

PROPHET

Prophet is a time-series forecasting algorithm designed for datasets exhibiting non-linear trends. It incorporates yearly, weekly, and daily seasonality and holiday effects. Known for its ability to handle large seasonal and historical datasets, Prophet is widely regarded as one of the most accurate, fast, and effective models for time-series forecasting. It excels in capturing shifts in trends and identifying significant outliers while demonstrating high sensitivity to missing data. Prophet is available as an open-source package in both Python and R languages.

Support Vector Machine

Support Vector Machine (SVM) has gained popularity for classification and regression tasks due to its simplicity and capability to mitigate certain limitations of Artificial Neural Networks (ANN), such as overfitting. (Tang and Zhou; 2015). SVM employs statistical learning theory as a supervised machine learning algorithm to guide its learning process.

Long Short-Term Memory

Long Short-Term Memory (LSTM) neural networks improve upon the recurrent neural network (RNN) approach by addressing issues like vanishing and exploding gradients. As a type of RNN, LSTM comprises repeating modules, each containing unique "cell states" that facilitate long-term dependency maintenance during model training. This design enables LSTM networks to excel in tasks involving long sequences compared to standard RNNs. Each LSTM storage unit consists of one memory cell C_t and three gates, including the forget gate f_t, the input gate i_t, and the output gate. The three gates jointly control the state of the memory cell Ct.

III

RESULT AND DISCUSSION

The data highlights the significant role of buffalo and cattle, both dairy and non-dairy, in effectively reducing methane emissions through targeted mitigation strategies, such as feed additives, in India. Since these three categories contribute over

92 per cent of livestock methane emissions, focused efforts on management and feeding practices within these sectors can lead to substantial reductions.

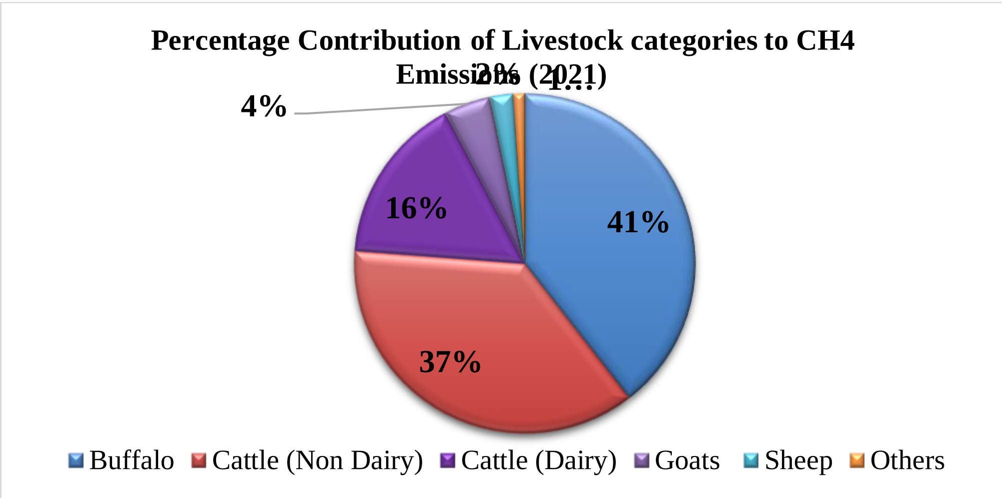

Figure 1: Percentage Contribution of Livestock Categories to Methane Emissions In India.

The pie chart in Figure 1 provides a clear and concise overview of methane emission sources from Indian livestock, emphasizing the key role of buffalo and cattle with 41 per cent and 37 per cent contribution, respectively. This also necessitates targeted mitigation measures. Information can be utilized to enhance methane emission forecasting models, essential for developing effective strategies to control methane emissions from these crucial livestock groups.

Figure 2 depicts the methane (CH4) emissions from livestock in various states of India. It is clear from the figure that Uttar Pradesh (2745 Gg/year), Rajasthan (1529 Gg/year), and Madhya Pradesh (1310 Gg/year) have the highest methane emissions. The significant contribution is due to their large livestock populations, especially cattle and buffalo, which are major methane emitters through enteric fermentation during digestion. Andhra Pradesh (1242 Gg/year), Gujarat (1068 Gg/year), and Maharashtra (996 Gg/year) follow closely, as these states also have substantial livestock populations and intensive dairy farming practices, contributing to methane emissions. Northern states like Punjab (419 Gg/year) and Haryana (442 Gg/year), known for dairy farming and high livestock density, show moderate methane emissions reflecting their agricultural practices focused on milk production. States like Kerala (73 Gg/year), Mizoram (1 Gg/year), Sikkim (7 Gg/year), and Goa (2 Gg/year) have relatively lower emissions because of their smaller livestock populations and different agricultural practices that result in lower methane production.

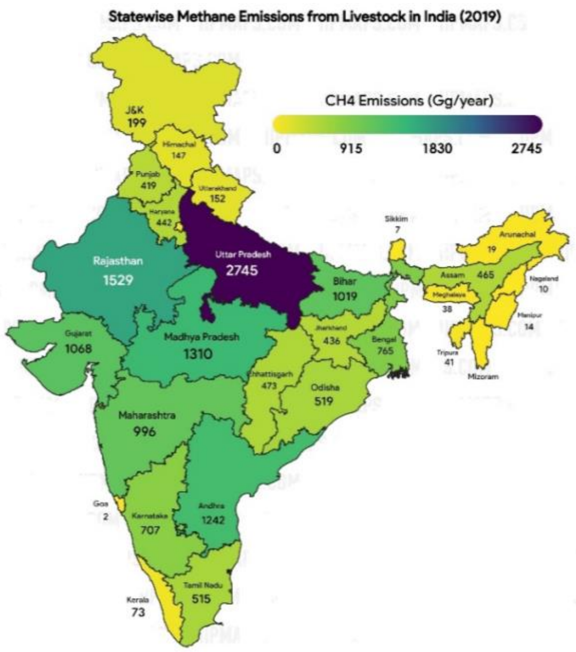

Figure 2: State Wise Methane Emissions From Livestock In India

Figure 3 illustrates a line graph depicting the total CH4 emissions from livestock in India annually from 1961 to 2021. Over these 60 years, there has been a notable increase in emissions from the livestock sector. Between 1961 and 1980, methane emissions experienced a gradual rise, signifying the commencement of livestock expansion. However, as we progress beyond 1980, recent calculations reveal a notable acceleration in emissions attributed to the simultaneous increase in livestock numbers and more intensified farming practices. Notably, there was a stabilization of emissions from 2000 to 2010, indicating a temporary plateau. Nonetheless, despite the apparent emission stagnation during this period, the intensified livestock farming practices from 1990 to the late 2000s, coupled with a surge in demand for livestock products, led to a renewed increase in emissions post-2010 through 2021. The data highlights an upward trajectory, emphasizing the necessity for enhanced mitigation efforts in livestock activities, particularly concerning feed efficiency and manure management. The historical insights provided by the visualization are pivotal for the study's objective of predicting future emissions through machine learning models, which are crucial for aiding policymakers in developing well-informed strategies for emission reduction.

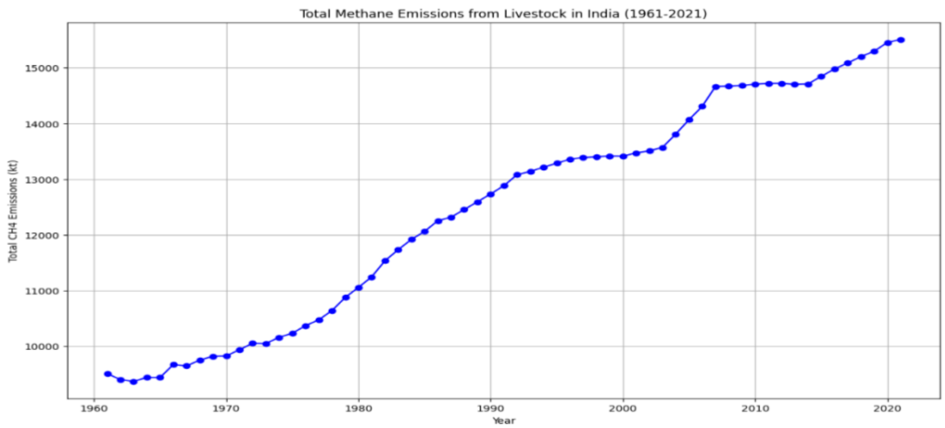

Figure 3: Trend in Methane Emissions from Livestock in India (1961-2021)

Using a bar chart, figure 4 displays the RMSE values obtained from four models: ARIMA, LSTM, SVM, and Prophet. ARIMA performs the best with an RMSE value of 44.54, indicating its accuracy in predicting methane emissions compared to other forecasting models. This low error is impressive for a time series dataset like this. The LSTM model, with an RMSE of 62.98, performs slightly worse than ARIMA but still shows robustness. The gaps widen significantly with the SVM model, which has an RMSE value of 2663.14, making it much less reliable than the ARIMA and LSTM models. Prophet has the highest RMSE of 5199.24, demonstrating the least accuracy among all the models tested. Based on the results, ARIMA and LSTM are robust models for methane emission forecasting in this study.

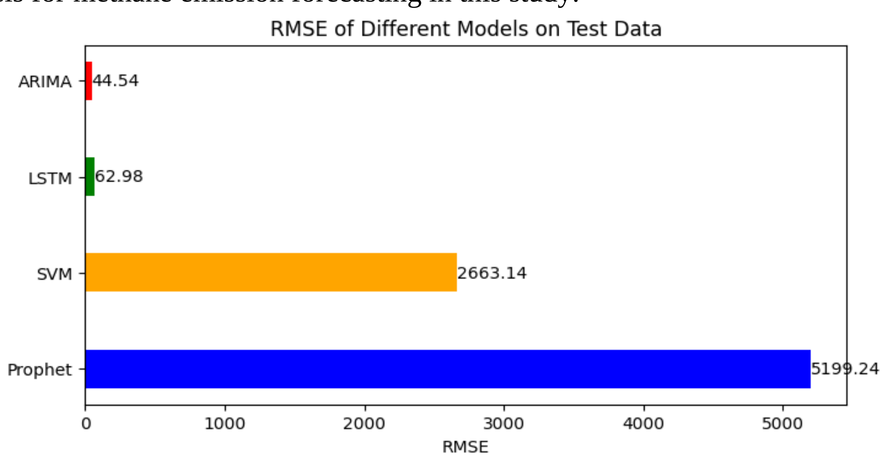

Figure 4: RMSE Values of Different Models

Figure 5 depicts the Mean Absolute Percentage Error (MAPE) and Symmetric Mean Absolute Percentage Error (SMAPE) for four models: Prophet, SVM, ARIMA, and LSTM. Prophet exhibits the highest discrepancies, with a MAPE of 33.95 cent and a SMAPE of 28.32 cent, indicating subpar forecasting accuracy. SVM demonstrates moderate deviations, recording a MAPE of 19.16 cent and a SMAPE of 19.16 per cent. ARIMA delivers notably superior performance, boasting a MAPE of 1.25 cent and a SMAPE of 1.0 cent. Meanwhile, LSTM showcases the strongest performance with minimal errors, achieving a MAPE of 0.35 cent and a SMAPE of 0.35 cent.

These findings underscore LSTM and ARIMA as the most precise models for forecasting methane emissions in this study, with LSTM slightly edging out ARIMA.

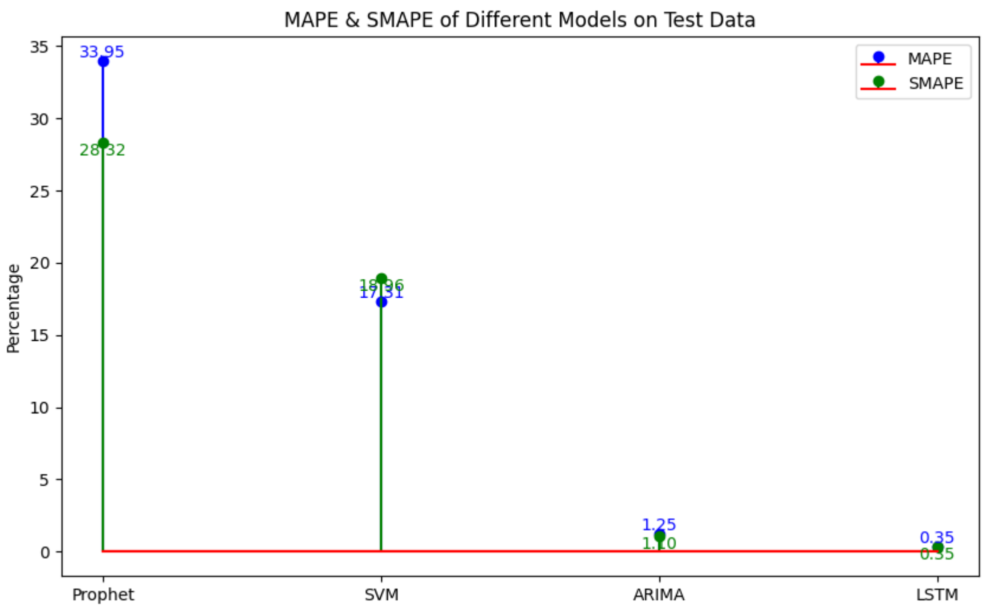

Figure 5: MAPE and SMAPE values of different models

The bar chart in Figure 6 illustrates the Mean Directional Accuracy (MDA) for four models, Prophet, SVM, ARIMA, and LSTM, when applied to the test dataset. LSTM emerges as the top performer with an MDA of 0.95, indicating its exceptional accuracy in predicting changes in the direction of methane emissions. ARIMA follows closely with an MDA of 0.85, showcasing robust predictive capabilities. SVM achieves a moderate MDA of 0.75, demonstrating reasonable accuracy in directional forecasting. Prophet exhibits the lowest MDA at 0.65, suggesting a relatively weaker performance.

These findings underscore LSTM and ARIMA as the most proficient models in accurately capturing directional trends in methane emissions. LSTM stands out as the most dependable among the models tested.

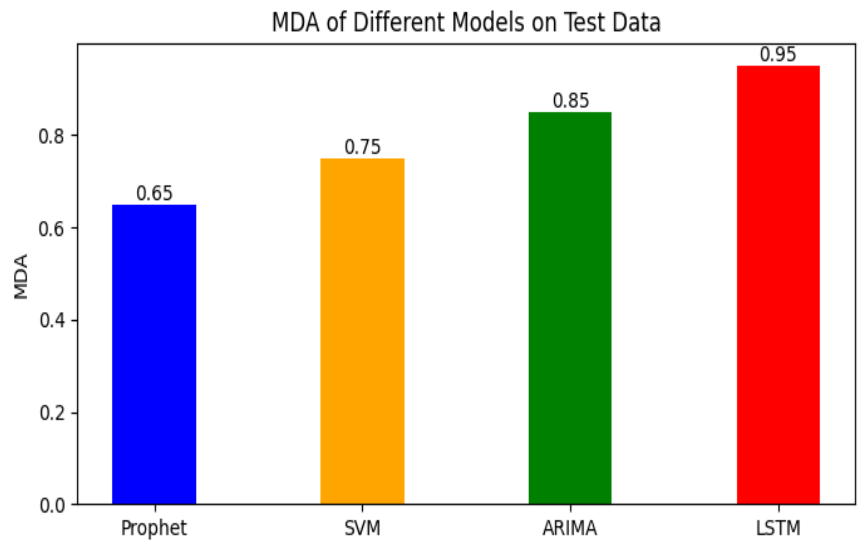

Figure 6: Mean Directional Accuracy (MDA) of Prophet, SVM, ARIMA, and LSTM Models.

Table 1 presents the performance metrics for the four models (ARIMA, Prophet, SVM, and LSTM) tested on the test data. ARIMA and LSTM exhibit better accuracies compared to the others. ARIMA achieved an RMSE of 44.29 and a MAPE of 1.28 cent. It also had a high Mean Directional Accuracy (MDA) of 0.85. LSTM demonstrated slightly better performance with a lower MAPE of 0.35 cent and an MDA of 0.95, making it the most accurate among the models tested. SVM gave a moderate performance, with an RMSE of 2663.14 and a MAPE of 19.16 cent. Prophet exhibited the highest RMSE (5199.24) and MAPE (33.95 cent), indicating poor accuracy.

TABLE 1: PERFORMANCE METRICS OF ARIMA, PROPHET, SVM AND LSTM MODELS.

Model (1)	RMSE (2)	MAPE (3)	SMAPE (4)	MDA (5)
ARIMA	44.29	1.28	1.11	0.82
Prophet	5062.2	33.84	28.92	0.67
SVM	2556.63	18.04	18.17	0.75
LSTM	61.07	0.37	0.34	0.98

Based on these metrics, LSTM and ARIMA are the most reliable models for predicting methane emissions from livestock in India, with LSTM showing slightly better accuracy than ARIMA.

The graph (Figure 7) depicts historical and predicted methane emissions from cattle in India from 1961 to 2031. The blue line represents recorded emissions data from 1961 to 2021, demonstrating a rising trend with rapid increase and stabilization intervals. Notably, there was significant growth from the 1980s to the early 2000s, followed by a plateau and a surge in the last decade.

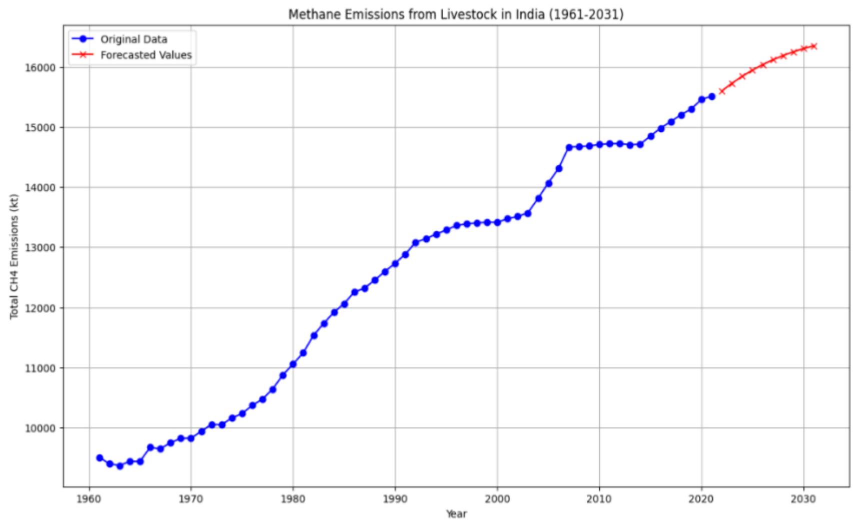

Figure 7: Historical and predicted methane emissions from livestock in India from 1961-2031.

The red line represents anticipated emissions from 2022 to 2031, continuing the rising trend, indicating that methane emissions from cattle are expected to increase. This estimate underscores the need for effective mitigation techniques to address the cattle sector's rising emissions.

The forecast is based on machine learning models that have shown high accuracy in predicting future trends, as evidenced by the historical data's alignment with the forecasted values. This analysis is crucial for policymakers and stakeholders aiming to implement strategies to reduce greenhouse gas emissions and combat climate change.

IV

CONCLUSION

The study underscores the significant impact of livestock farming on methane emissions in India, highlighting its dual role as a crucial economic driver and a notable contributor to greenhouse gas (GHG) emissions. Livestock, particularly ruminants like cattle and buffalo, contribute substantially to methane emissions through enteric fermentation, a natural digestive process accounting for about 44 per cent of total methane from livestock globally. As India experiences rapid growth in its livestock sector, with an unprecedented annual growth rate of 7.6 cent between 2010-11 and 2019-20, mitigating methane emissions becomes increasingly urgent.

The methodology employed in this research leverages comprehensive data sourced from the Food and Agriculture Organization (FAO) of the United Nations, spanning from 1961 to 2021, with projections up to 2031. Through rigorous data preparation and cleaning, focusing specifically on Indian data, this study utilized advanced forecasting models—ARIMA, SVM, Prophet, and LSTM—to predict methane emissions. These models were trained on historical data from 1961 to 2014 and validated on test data from 2015 to 2021, demonstrating their efficacy in capturing emission trends.

Among the models tested, ARIMA and LSTM emerged as the most accurate for forecasting methane emissions, showcasing minimal Mean Absolute Percentage Error (MAPE) and high Mean Directional Accuracy (MDA). ARIMA, known for its ability to predict time series data by considering lag observations and moving averages, exhibited an RMSE of 44.54 and an impressive MAPE of 1.25 cent, indicating robust predictive capabilities. LSTM, a type of recurrent neural network (RNN) designed to handle long-term dependencies, slightly outperformed ARIMA with a lower RMSE of 62.98 and an exceptional MAPE of 0.35per cent, along with the highest MDA of 0.95 among the models tested. In contrast, Prophet and SVM showed higher errors and lower directional accuracy, suggesting their lesser suitability for this forecasting task.

The analysis of methane emissions trends over six decades revealed a persistent increase, punctuated by periods of acceleration and stabilization. This rise in emissions correlates with intensified livestock farming practices and increasing demand for livestock products, which was particularly noticeable from the 1980s onwards. Despite a temporary plateau in emissions from 2000 to 2010, recent data points to a renewed upward trajectory post-2010, emphasizing the need for enhanced mitigation strategies.

Strategically, the data emphasizes the critical role of targeted mitigation measures, such as improved feed efficiency and effective manure management, to effectively curb methane emissions from the livestock sector. These measures are particularly relevant given the dominance of dairy and non-dairy cattle and buffaloes in contributing over 92 per cent of methane emissions from Indian livestock. The insights provided by this research are crucial for policymakers and stakeholders seeking to implement informed strategies to reduce GHG emissions and address climate change impacts.

The forecasted trends depicted in Figure 2 and supported by the models' accuracy underscore the anticipated rise in methane emissions from cattle through 2031. This projection highlights the necessity for proactive measures to mitigate emissions growth, aligning with global climate goals. The predictive capabilities of ARIMA and LSTM models, validated through rigorous testing and performance metrics, provide a reliable basis for developing targeted policies and interventions.

This study not only contributes to the understanding of methane emissions dynamics in Indian livestock but also offers actionable insights for sustainable agricultural practices. By focusing on advanced modelling techniques and comprehensive data analysis, this research paves the way for informed decision-making to achieve environmental sustainability in livestock farming, which is crucial for India's economic development and global climate commitments.

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