Forecasting CO_2 Emissions from Libya's Transport Sector

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Received August 15, 2024; Accepted September 17, 2024; Published October 9, 2024

This paper presents an innovative approach to forecast carbon dioxide (CO_2) emissions from the transport sector in Libya. The method combines machine learning algorithms with historical data and future estimates. The research built a model that took into account factors such as population growth, rates of car ownership, patterns of fuel consumption and government regulations in order to provide an accurate forecast of carbon dioxide (CO_2) emissions over the next decade based on the Global Change Assessment Model (GCAM). The authors used a variety of statistical time series models to forecast future CO_2 emissions from Libya's transportation sector. These models included the exponential smoothing model (ESM) and the autoregressive integrated moving average (ARIMA). The ARIMA model outperformed the ESM model, achieving an R^2 of 0.931 and a root mean square error (RMSE) of 1.040 Mt CO_2. The results of the study found that CO_2 emissions from Libya's transport sector could increase by 27.98% and 57.99% in 2030 and 2050, respectively. The study proposed six transportation theories to reduce CO_2 emissions from Africa's and Libya's transport sectors. The identified factors encompass price systems, land use planning, eco-driving, electric automobiles, bicycle infrastructure, and telecommuting. The authors also examined the needs to reduce CO_2 emissions from Libya's transport sector in order to meet the International Energy Agency's ambitious targets for reducing CO_2 emissions from the global transport sector. These needs arise due to increasing urbanization, population growth, underinvestment in public transportation infrastructure, and the increasing incidence and severity of heat waves. Additionally, hypothetical scenarios are presented to demonstrate the importance of further reducing CO_2 emissions from these sectors to match the projections of global change assessment models.

Keywords: *Paris Agreement; CO_2 emission reduction; Greenhouse gas emissions; Libya's emission reduction; Climate change; ARIMA*

1. Introduction

To effectively tackle climate change and accomplish sustainable development goals in Libya, it is imperative to implement decisive measures aimed at decreasing carbon dioxide emissions in transportation systems across urban areas [1], developing towns [2], and distant villages [3]. By analyzing different policies and situations related to compliance with the Paris Agreement [4, 5], we can determine effective methods for reducing carbon emissions [6, 7] and improving sustainable transportation systems in Libya [8, 9]. This analysis can help us develop a comprehensive strategy that includes

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renewable energy sources [10], promotes public transportation [11], and encourages the adoption of electric vehicles [12]. The target of this research is to provide valuable insights into the challenges and opportunities for reducing carbon dioxide emissions in transportation networks [13] in Libya. By examining the outcomes of various policies and scenarios, we can provide evidence-based suggestions to policymakers [14, 15] and stakeholders to advance sustainable development in the nation. This study is intended to contribute to the global conversation on efforts to mitigate climate change [16] and highlight the importance of sustainable transportation in achieving emission reduction targets [17]. The target is to promote the use of cleaner and more efficient transportation options [18] in Libya, which can lead to significant environmental [19] and economic benefits for the country [20]. By analyzing data and studying different policy implementations, we can provide valuable insights into the most effective methods for reducing carbon emissions [21, 22] and promoting sustainable practices [23, 24]. This research will also facilitate the identification of potential issues and obstacles to the execution of these recommendations [25], empowering key decision-makers in the country to make more knowledgeable decisions [26]. This research serves as a strategic blueprint for future initiatives and financial investments in the transportation sector [27], guiding stakeholders towards the adoption of greener practices [28]. The target is to develop a transportation system that is environmentally friendly and extremely efficient, leading to benefits for both the economy and the environment [29]. By taking a proactive approach to reducing the impact of climate change in the transportation industry, we can work towards a more environmentally friendly future for future generations [30, 31].

The authors also discussed various transportation theories that support the reduction of CO_2 emissions from Libya's transportation sector, with the goal of achieving sustainable development objectives and reducing the continent's carbon footprint. Furthermore, authorities were recommended to prioritize expenditures in the infrastructure of public transportation [32] and promote the adoption of environmentally friendly technology in the area. The theories cover pricing mechanisms, land use planning, eco-driving, electric automobiles, bicycle infrastructure, and telecommuting. The target of these strategies is to reduce reliance on fossil fuels and promote the use of more environmentally friendly modes of transportation [33, 34]. Libya should endeavor to achieve a more ecologically sustainable future and make a significant contribution to global efforts aimed at reducing the impact of climate change by embracing these suggestions.

The transportation industry in Libya is a significant source of greenhouse gas emissions in Africa, making it a crucial obstacle to overcome in order to achieve sustainable development [35] and effectively address climate change [36]. Accurately predicting the amount of CO_2 emissions from this industry is crucial for policymakers and stakeholders to develop and implement successful plans [37] to decrease carbon footprints and encourage the use of cleaner [38] and more efficient transportation systems [39]. Accurate prediction of carbon dioxide (CO_2) emissions from Libya's transportation sector is essential for comprehending the environmental consequences of the country's fast urbanization [40], economic expansion [41,42], and the subsequent rise in vehicle ownership and usage [42, 43]. Through the application of sophisticated modeling approaches and data analysis [44], academics can offer valuable insights into prospective measures and policy interventions [45] to effectively address this urgent issue [46]. The intricate interaction of various elements that impact the release of CO_2 from Libya's transportation industry, such as the way fuel is consumed [47], developments in vehicle technology [48], and the development of infrastructure[49], highlights the significance of reliable forecasting techniques [50-52]. Through the integration of interdisciplinary methodologies and the utilization of state-of-the-art research instruments [53], scholars can produce practical insights to aid in the development of sustainable transportation strategies [54] and the achievement of carbon reduction goals in accordance with global climate agreements [55-57].

The ClimateWatch database's global change assessment model did not include carbon dioxide (CO_2) emissions from the transportation sector in Libya from 2023 to 2050. Therefore, the authors utilized a time series methodology to forecast the historical carbon dioxide (CO_2) emissions in Libya's transportation sector, covering the period from 1990 to 2022. Later on, these predictions were extended to cover the time frame from 2023 to 2050. By employing time series approaches, the authors achieved a more precise prediction of the trends and patterns in carbon dioxide (CO_2) emissions in Libya's transportation sector during the chosen timeframe. This approach was devised to address the deficiencies in prior research that overlooked the influence of transportation emissions on the total levels of carbon dioxide in Libya. In addition, the utilization of time series techniques facilitated a thorough examination of past data and predictions for the future, resulting in a stronger comprehension of the nation's carbon emissions in the transportation sector [58, 59]. The authors found that the anticipated result greatly exceeded the International Energy Agency's estimate of global CO_2 emissions in transportation by mode in the sustainable development scenario from 2022 to 2070 [60]. This study highlights the urgent need to adopt greener transportation practices in Libya to tackle the rising levels of carbon emissions. In order to attain a future that is more environmentally friendly, it is imperative to incorporate transportation emissions into future policy planning. The authors discussed several transportation theories and their practical implementations in order to address the necessary needs and strategies for reaching this purpose. A framework has been developed that advocates for the implementation of more efficient public transportation networks in order to reduce reliance on private vehicles. Furthermore, the research suggests dedicating resources to enhance the infrastructure for alternative modes of transportation [61, 62], such as cycling and walking [63], with the aim of substantially mitigating carbon emissions in Libya. In addition, the authors emphasized the importance of integrating sustainable urban design techniques to promote the growth of cities that are more favorable for walking and biking [64, 65]. By encouraging the use of active transportation and reducing dependence on cars, Libya has the capacity to significantly reduce its carbon emissions and improve air quality for its citizens [66-70]. The adoption of sustainable transportation alternatives can lead to various health benefits [71-74], such as increased physical activity [31, 75-77] and a reduced incidence of obesity and related diseases [73, 74, 78]. Investing in these projects can result in a favorable outcome for both the environment and public health in Libya.

2. Transportation Theories that Support the Mitigation of CO_2 Emissions from Libya's Transport Sector

2.1 The Theory of Pricing Mechanisms

The idea of pricing mechanisms proposes the adoption of policies (such as congestion pricing and carbon taxes) to encourage actions that result in reduced CO_2

emissions in Libya's transportation industry. Pricing mechanisms in transportation theory have a significant impact on consumer behavior and encourage the adoption of more environmentally friendly transportation options. Libya can efficiently decrease CO_2 emissions from its transportation sector and promote the adoption of environmentally friendly alternatives by introducing techniques like congestion pricing or carbon taxes. Implementing these pricing systems can internalize the external costs linked to carbon emissions, resulting in a more effective allocation of resources in the transportation sector. Moreover, they have the ability to encourage investment in cleaner technologies and infrastructure, ultimately leading to a more sustainable and environmentally conscious transportation system in Libya. Moreover, these pricing mechanisms have the possibility of creating income that may be redirected towards other sustainability projects within the transportation industry.

The adoption of congestion pricing or carbon taxes can have a significant impact on assisting Libya in attaining its environmental objectives and diminishing its carbon emissions. Through the implementation of these pricing mechanisms, Libya has the potential to mitigate traffic congestion and enhance air quality in metropolitan areas. This can result in improved public health and a more streamlined transportation system as a whole. Furthermore, the income derived from congestion pricing or carbon taxes might be used towards enhancing public transit infrastructure and encouraging the adoption of electric vehicles. This can additionally contribute to the reduction of greenhouse gas emissions and the promotion of a more environmentally friendly atmosphere in Libya. In general, introducing these pricing mechanisms can have positive effects on both the environment and the well-being of Libyan residents. This is a progressive measure aimed at fostering a sustainable and environmentally conscious future for the nation.

2.2 The Theory of Land Use Planning

The notion of land use planning prioritizes the design of cities and communities to minimize the necessity for extensive travel, thereby reducing carbon emissions resulting from transportation. Land use planning is essential in determining the transportation infrastructure of a nation, which has a direct influence on the levels of CO_2 emissions. Urban planners can effectively mitigate CO_2 emissions in Libya's transport sector by carefully positioning residential neighborhoods, commercial centers, and public transportation hubs. This approach reduces the necessity for long journeys and encourages the use of sustainable means of transportation. Incorporating green spaces and pedestrian-friendly features into urban planning can promote walking and cycling as alternate forms of transportation, thereby reducing dependence on carbon-intensive vehicles. Moreover, allocating funds towards sustainable energy sources for public transportation and enacting laws that encourage the adoption of electric vehicles can have a substantial impact on mitigating CO_2 emissions in Libya's transportation industry. In order to effectively tackle the carbon emissions caused by transportation systems in the country, it is essential to adopt a comprehensive approach to urban design that places a high value on sustainability and environmental conservation. By incorporating green spaces and pedestrian-friendly infrastructure into urban design, communities may establish more sustainable and healthier environments for their inhabitants. Advocating for mixed land use development can decrease the necessity for lengthy commutes and enhance the overall efficiency of the transportation system. This can result in a reduction in dependence on private automobiles and, thus, a decrease in emissions. Enforcing laws that provide incentives for using public transportation and non-motorized modes of travel can also have a substantial impact on reaching carbon neutrality in Libya's transportation industry.

2.3 The Theory of Eco-Driving

The theory of eco-driving posits that advocating for fuel-efficient driving practices, such as maintaining consistent speeds and refraining from excessive idling, can contribute to the mitigation of CO_2 emissions from vehicles in Libya. The concept of eco-driving focuses on employing driving strategies that minimize fuel consumption and emissions, including gradual acceleration and maintaining a consistent speed. By integrating eco-driving principles into transportation regulations in Libya, the nation can substantially reduce its carbon emissions and make a meaningful contribution to global initiatives aimed at mitigating climate change. This idea is in accordance with the overarching objective of sustainability in transportation, advocating for a more effective and eco-friendly approach to driving. Adopting eco-driving techniques can result in financial benefits for both individuals and organizations through the reduction of fuel usage, thereby leading to cost savings. Moreover, implementing eco-driving techniques can also prolong the durability of cars and diminish maintenance expenses, leading to supplementary financial advantages for drivers and fleet operators. Incorporating eco-driving concepts into transportation laws in Libya can have extensive beneficial effects on both the environment and the economy. Libya may further diminish its carbon footprint and decrease its reliance on fossil fuels by promoting the utilization of public transit, carpooling, and electric automobiles. Allocating resources towards the development of infrastructure for alternative modes of transportation, such as dedicated lanes for bicycles and designated pathways for pedestrians, can additionally enhance the sustainability of the transportation system within the country.

2.4 The Theory of Electric Vehicles

The theory of electric vehicles, which advocates for the utilization of low-emission cars propelled by electricity, plays a vital role in mitigating the carbon footprint of Libya's transportation industry. Electric vehicles offer a possible approach for mitigating carbon emissions in Libya's transportation sector, as they are devoid of any exhaust emissions. By integrating electric vehicles into Libya's transportation infrastructure, the country can make progress towards its environmental objectives and decrease its carbon emissions. Moreover, allocating funds towards renewable energy sources to fuel these cars can additionally bolster the sustainability of the transportation industry in the nation. The adoption of electric vehicles can also aid in mitigating air pollution and enhancing public health in Libya. It is imperative for the government to provide incentives for the adoption of electric vehicles and allocate resources to develop the required infrastructure to facilitate their broad usage. By advocating for the adoption of electric vehicles, Libya may both diminish its reliance on imported fossil fuels and enhance its energy security. Enacting regulations that promote the shift to electric transportation will have dual advantages: it will not only have a positive impact on the environment but also stimulate economic growth by generating employment opportunities and fostering technological advancements. Moreover, the act of investing in electric vehicles can assist Libya in broadening its economic base and diminishing its susceptibility to variations in worldwide oil prices. Through the adoption of sustainable mobility solutions, Libya has the potential to establish itself as a frontrunner in the area and entice investments in clean energy technologies.

2.5 The Theory of Cycling Infrastructure

The theory of cycling infrastructure proposes the construction of more bike lanes and trails to promote cycling as a means of transportation. The theory of cycling infrastructure highlights the need to establish secure and easily reachable routes for bicycles. This can lead to a reduction in the dependence on motor vehicles and, thus, a drop in carbon emissions. By integrating cycling infrastructure into transportation planning in Libya, the country may strive towards attaining its environmental objectives while simultaneously advocating for a healthier and more sustainable means of transportation for its population. The adoption of bike infrastructure can enhance public health by promoting physical activity and mitigating air pollution in metropolitan regions. Moreover, allocating resources to develop bicycle infrastructure might result in economic advantages by attracting more tourists and generating employment opportunities within the cycling sector. Integrating cycling infrastructure into transportation planning in Libya can have numerous positive effects on the environment and public health. By giving priority to sustainable modes of transportation, the country can lay the foundation for a future that is both cleaner and healthier for its population. In addition, advocating for cycling as a feasible means of transportation can effectively alleviate traffic congestion and diminish the dependence on fossil fuels, thereby fostering a more sustainable and eco-conscious society. Highlighting the significance of bicycle infrastructure can help promote a sense of community and connectivity among locals, ultimately improving the overall quality of life in Libya.

2.6 The Theory of Telecommuting

The theory of telecommuting, which advocates for working from home or remote areas to reduce the number of individuals commuting to work on a daily basis, has the potential to greatly diminish the carbon footprint of Libya's transport sector by reducing dependence on conventional transportation systems. Telecommuting is a transportation concept that provides a sustainable alternative for reducing Libya's transport sector's carbon footprint by reducing the requirement for daily travel. Enabling employees to work remotely reduces the number of vehicles on the road, leading to decreased CO_2 emissions and alleviating traffic congestion. This strategy is in line with international endeavors to address climate change and advance eco-friendly practices in the workplace. Furthermore, telecommuting can result in cost savings for both employees and businesses by minimizing gasoline usage and car maintenance expenses. Incorporating telecommuting into transportation strategies in Libya can yield favorable environmental outcomes and contribute to a more sustainable future. Additionally, remote work can enhance the equilibrium between work and personal life for employees, as it grants them greater autonomy in time management and alleviates the strain of commuting. Moreover, telecommuting has the potential to enhance productivity and boost employee happiness, resulting in a more effective and committed team.

Telecommuting can enhance firms' ability to attract and retain highly skilled individuals by providing them with flexible work arrangements. This can lead to a staff that is more diversified and skilled, ultimately benefiting the firm as a whole. Furthermore, telecommuting can mitigate the environmental impact of firms by diminishing the necessity for employees to travel to a brick-and-mortar office. This can facilitate the creation of a more environmentally friendly ecosystem and aid in the mitigation of climate change. Moreover, telecommuting can result in cost savings for both individuals and businesses by reducing expenses associated with commutes, office space, and utilities. Telecommuting provides a range of advantages for both workers and companies, including enhanced efficiency, better equilibrium between work and personal life, and a decreased environmental footprint. It is a mutually beneficial scenario that can result in a more effective and environmentally friendly approach to work in the contemporary world.

3. Forecasting CO_2 Emissions from Libya's Transport Sector

3.1 Data

The ClimateWatch database employed the Global Change Assessment Model (GCAM) to examine past patterns and forecast future emissions under different scenarios. The model considers variables such as population growth, economic progress, and energy usage to generate a thorough prediction of carbon dioxide emissions in Libya's transportation industry. The GCAM model incorporates governmental interventions and technical breakthroughs that have the potential to influence future emissions. This comprehensive approach aids in generating a more precise and intricate forecast of Libya's transportation carbon dioxide emissions. By utilizing a data-driven methodology, it becomes possible to produce more precise forecasts regarding future emissions. This, in turn, enables policymakers to make well-informed choices in order to reduce the impact of transportation on climate change. The GCAM model provides a comprehensive perspective on the various elements that impact CO_2 emissions in Libya's transportation sector by taking into account different variables. The utilization of the GCAM model allows for a thorough examination of possible approaches to decrease emissions and enhance sustainability in the transportation industry. Adopting a data-driven approach is crucial in formulating strategies that effectively tackle the difficulties posed by climate change in Libya.

3.2 Method of Forecast

To forecast Libya's transportation CO_2 emissions from 2022 to 2050, we will utilize an autoregressive integrated moving average (ARIMA) model and an exponential smoothing model (ESM). These models will examine historical data and detect patterns in order to make accurate forecasts. These models will utilize historical patterns and changes in the data to forecast future emissions. By utilizing these two models, researchers can enhance their comprehension of the elements that impact CO_2 emissions in Libya's transportation sector and make well-informed choices regarding prospective mitigation strategies. The utilization of data in this way will offer significant and meaningful information for policymakers and stakeholders that aim to tackle environmental issues in the area. The exponential smoothing model (ESM) is a widely used technique in time series analysis that predicts future values by assigning decreasing weights to prior observations in an exponential manner. The ESM is highly effective in capturing transient trends and seasonal patterns in the data, rendering it a promising instrument for forecasting transport CO_2 emissions in Libya in the forthcoming decades. By employing the ESM, policymakers and academics can make well-informed judgments about the implementation of initiatives aimed at reducing carbon emissions and mitigating environmental impacts. This forecasting methodology enables a more precise estimation of future patterns in carbon dioxide emissions connected to transportation, thus assisting in the formulation of sustainable policies for Libya's transportation industry. The autoregressive integrated moving average (ARIMA) model will also be used to find the linear relationship between past and present data points in order to make forecasts more accurate. Both models are extensively utilized in forecasting and have demonstrated their efficacy in capturing intricate patterns in time series data. To enhance the model's robustness, the authors integrates the advantages of ARIMA and ESM, leading to a more reliable and precise forecast of future emissions levels. This hybrid technique utilizes the advantages of both models to offer a more thorough examination of the data and enhance the precision of forecasts. The authors' objective is to enhance the reliability of future emissions level forecasts by integrating these two methodologies. The literature provides comprehensive information on the ARIMA model and its hybridization approach [9, 35, 38-40, 51, 52, 79, 80]. To fully understand how well this method works at predicting emissions levels, you need to know a lot about the specifics of the hybridization process, like how to choose parameters and evaluate models. Researchers wishing to use this hybrid model should consult these studies for a thorough manual on its implementation.

3.3 Performance of the Forecast

The carbon dioxide emissions from transportation in Libya exhibit a consistent and direct correlation over the period from 1990 to 2020, as illustrated in Figure 1. Based on Figure 1, the coefficient of determination (R^2) was 0.886%. This suggests that 88.6% of the variability in carbon dioxide emissions from transportation in Libya can be accounted for by the linear correlation found between 1990 and 2020. The high R^2 value indicates a robust link between the years and CO_2 emissions in the transportation sector. This association has the potential to be valuable in forecasting future patterns of carbon dioxide (CO_2) emissions from transportation in Libya. In addition, a more in-depth investigation could investigate the underlying reasons influencing this correlation and propose measures to mitigate emissions. Overall, this illustrates a persistent pattern in carbon dioxide emissions from transportation during the previous thirty years. Policymakers must take into account this correlation when developing initiatives to mitigate carbon emissions in the transportation sector. Comprehending the historical trend of carbon dioxide (CO_2) emissions in transportation can provide valuable insights for making informed decisions regarding sustainable development strategies. Policymakers in Libya can establish focused actions to reduce the environmental impact of transportation activities by acknowledging the influence of previous trends.

The graph in Figure 2 illustrates the expected results of annual transportation CO_2 emissions in Libya, using the exponential smoothing model (ESM) and ARIMA time series models. Figure 2 clearly demonstrates that the ESM model exhibited a steady and linear rise in transportation CO_2 emissions between 2022 and 2050. Conversely, the ARIMA model exhibited a more intricate and non-linear trend of transportation CO_2 emissions during the identical time frame. The ESM model is better suited for forecasting slow and consistent changes in CO_2 emissions, whereas the ARIMA model is more adept at capturing fluctuations and anomalies in the data. Both models offer useful insights into potential patterns in transportation CO_2 emissions in Libya. The selection between the ESM and ARIMA models may depend on the distinct attributes of the data and the intended level of precision in predicting emissions. In precision analysis, error parameters are the only established measures for evaluating the accuracy of the models.

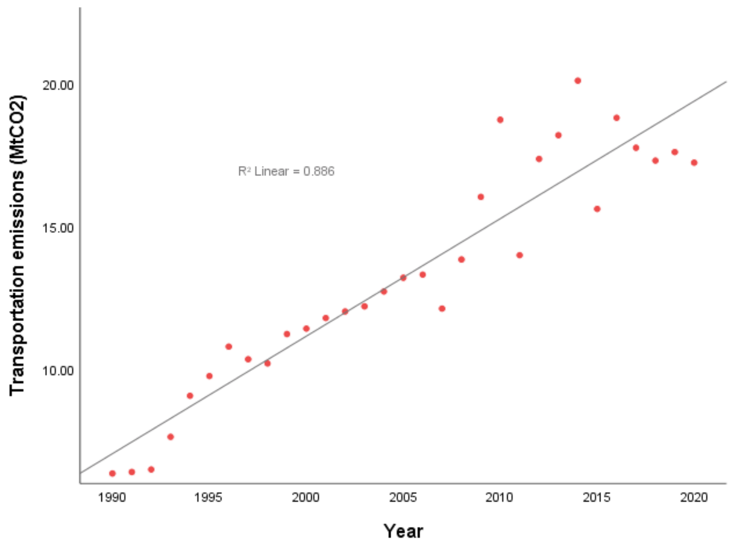

Fig. 1. Correlation between transportation emissions and year in Libya

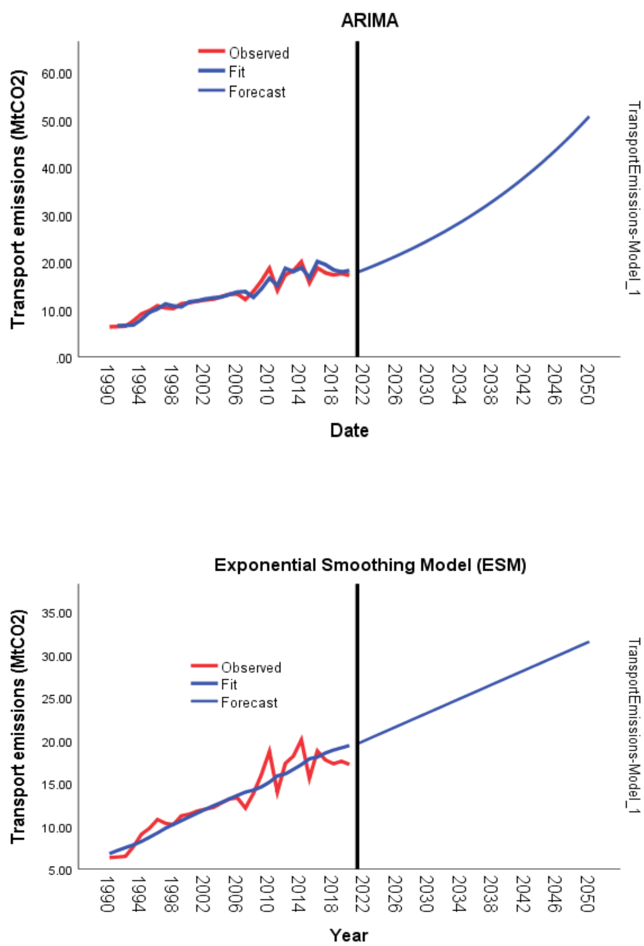

Fig. 2. Efficiency of Libya's time series models for predicting CO_2 emissions from transportation

The ARIMA model outperformed the ESM model according to the error metrics shown in Table 1, as it produced a higher R^2 value of 0.931 than the ESM model's R^2 value of 0.878, which was necessary for choosing the best fit models as shown in Table 2. The ESM model had an R^2 value of 0.878%, an RMSE value of 1.410 $MtCO_2e/yr$, a MAPE value of 7.627%, and a normalized BIC value of 0.909. The ARIMA model had a lower RMSE value of 1.040 $MtCO_2e/yr$, a MAPE value of 5.805%, and a normalized BIC value of 0.419, as shown in Table 2. In general, the ARIMA model exhibited better performance than the ESM model across several error metrics. This suggests that the ARIMA model would be better suited for accurately forecasting CO_2 emissions. In addition, the ARIMA model had a higher R^2 value of 0.931%, suggesting a superior fit to the data in comparison to the ESM model. The ARIMA model's reduced RMSE and MAPE values provide more evidence of its superior prediction ability in this particular situation.

Table 1. Details of the statistical indicators

S/N	Abbreviation	Statistical test	Expression	Ideal value
1	R^2	Coefficient of determination	$R^2 = 1 - \left[\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - O_{ave})^2}\right]$	One
2	RMSE	Root mean square error	$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2}$	Zero
3	BIC	Normalized Bayesian Information Criterion	$BIC = -2log(\hat{\theta}) + KlogN$	Zero
4	MAPE	Mean absolute percentage error	$MAPE = \frac{1}{n}\sum_{i=1}^{n}\lvert O_i - P_i\rvert$	Zero

Table 2. Comparison of the performance of the ARIMA and ESM models in forecasting transport CO_2 emissions

Country	Model #	Training Model Fit statistics			
		R^2	MAPE	RMSE	BIC
Libya	ARIMA	0.931	5.805	1.040	0.419
Libya	ESM	0.878	7.627	1.410	0.909

Autoregressive integrated moving average (ARIMA) model and an exponential smoothing model (ESM)

Due to its superior performance compared to the ESM model, the ARIMA model was selected to forecast Libya's transportation CO_2 emissions. The accuracy of the ARIMA model's best fit was then compared to the documented transport CO_2 emissions in the literature. In their study, Qiao *et al.* [81] utilized a variety of machine learning models to predict carbon dioxide (CO_2) emissions specifically for the transportation industry in the United Kingdom. The machine learning models consist of Gaussin process regression (GPR), long short-term memory (LSTM) networks, gradient tree boosting with least squares (LSBoost), and random forest (RF). In this study, the ARIMA approach performed better than [81] machine learning approaches. The ARIMA model reported a lower RMSE value of 1.040 $MtCO_2e/yr$, while the LSBoost model recorded a higher value of 1.189 $MtCO_2e/yr$, the random forest (RF) model recorded 1.311 $MtCO_2e/yr$, the GPR model recorded 1.197 $MtCO_2e/yr$, and the LSTM model recorded 1.920 $MtCO_2e/yr$. The findings of this study are also found to be superior when compared to other forecast outcomes regarding transport COe emissions, which were obtained using time series and machine learning models. This comparison is evident in the publications [7, 42, 43, 82-84].

4. The Need to Reduce Libya's Transport Sector CO_2 Emissions to Meet the International Energy Agency's Drastic Projections for Global Transport Sector CO_2 Emissions Reduction

4.1 Increasing Urbanization

The urbanization trend in Libya is causing a rise in the population residing in cities, which in turn is creating a greater need for personal vehicles as people look for easy and adaptable transportation choices. The current situation is worsening the carbon dioxide emissions in Libya's transportation sector, highlighting the urgent need for the country to adopt sustainable transportation solutions in order to achieve the International Energy Agency's ambitious goals of reducing global emissions in the transport sector. According to a World Bank study, over the past ten years, urbanization in Libya has led to a 15% increase in the ownership of personal vehicles. Projections indicate that if existing regulations remain intact, there will be a 25% rise in personal automobile ownership by 2030, and this trend is anticipated to persist. It is imperative to implement sustainable transportation solutions in order to meet the increasing demand and decrease carbon dioxide emissions from the transportation industry. Addressing this issue would necessitate a thorough strategy encompassing the allocation of resources towards enhancing public transportation infrastructure, advocating for the use of electric vehicles, and fostering the use of alternate means of transportation such as cycling and walking. By promptly taking measures, Libya can strive towards attaining the objectives set by the International Energy Agency [60] and establishing a more environmentally viable future for its populace.

4.2 Growth in Population

The population growth necessitates an increased need for transportation services, which consequently leads to a greater number of automobiles on the road. As per the World Bank [85], Libya's population is expected to grow at a rate of 2.5% per year, resulting in an increased need for transportation. The anticipated population growth is expected to lead to a proportional rise in the number of vehicles on the road, hence exacerbating the emission of CO_2 from the transportation industry. In order to achieve the International Energy Agency's forecasted targets for lowering CO_2 emissions in the global transportation industry, Libya must adopt policies and strategies that specifically target the reduction of emissions from its expanding fleet of automobiles. To alleviate the environmental impact of the transportation industry in Libya, it is advisable to implement measures such as encouraging public transportation, investing in electric vehicles, and enhancing fuel economy standards. Moreover, fostering a greater understanding among the general public about the significance of adopting sustainable transportation methods can significantly contribute to the mitigation of carbon dioxide emissions originating from automobiles.

4.3 Lack of Investment in Public Transportation Infrastructure

Inadequate investment in public transit infrastructure worsens dependence on private vehicles. Based on research conducted by the World Bank [85], Libya presently has one of the lowest levels of investment in public transportation infrastructure in the area, with a mere 0.5% of its gross domestic product (GDP) committed to this sector. The absence of financial allocation has resulted in a notable increase in both the number of cars owned and their usage, which has had a substantial impact on the amount of carbon dioxide emissions produced by the transportation sector in the country. Libya must prioritize investment in public transportation infrastructure to reduce dependency on private vehicles in order to reach the International Energy Agency's target of lowering global transport sector CO_2 emissions by 60% by 2050 [60]. This would not only reduce CO_2 emissions but also enhance the accessibility and affordability of transportation for all individuals. Moreover, allocating resources to public transportation can foster economic expansion and generate employment prospects within the nation. Enhancing the public transportation system in Libya can effectively alleviate traffic congestion and enhance air quality in urban regions. This will result in a more robust and enduring ecosystem for both present and future generations.

4.4 Growth in Commercial Transportation

According to research conducted by the International Energy Agency, the transportation industry accounts for 23% of worldwide carbon dioxide (CO_2) emissions, with commercial transportation playing a substantial role in this contribution [60]. If no action is taken, the expected increase in commercial transportation will result in a 60% rise in CO_2 emissions by 2050. This emphasizes the urgent necessity for Libya to undertake policies aimed at reducing emissions in this sector. According to a World Bank [85] study, commercial transportation in Libya has increased its level of greenhouse gas emissions by 15% over the past ten years. Projections indicate that there will be an additional 25% increase in emissions by the year 2030. The economy is experiencing growth, and there is an increasing demand for products and services. This highlights the pressing requirement for specific policies and investments to decrease CO_2 emissions in the transportation industry. Enacting measures such as advocating for the use of electric vehicles, enhancing the infrastructure for public transportation, and providing incentives for fuel-efficient behaviors can effectively reduce the consequences of increasing emissions. Moreover, allocating funds towards renewable energy sources for transportation can additionally aid in diminishing carbon footprints in Libya.

4.5 The Increased Frequency and Intensity of Heatwaves

The strong association between the increasing levels of carbon dioxide (CO_2) and the more frequent heatwaves in the region highlights the pressing necessity for Libya to tackle the emissions from its transportation industry. Adopting sustainable transportation practices, such as advocating for electric vehicles and allocating resources to enhance public transportation infrastructure, is essential for achieving global emissions reduction goals and minimizing the consequences of climate change. Implementing stricter fuel economy regulations for automobiles and providing incentives for the use of alternative fuels can also play a significant role in decreasing carbon dioxide emissions in the transportation industry. Engaging in international cooperation with other nations and organizations to exchange knowledge and advanced technologies can provide additional assistance to Libya in attaining its objectives of reducing emissions. Introducing measures that give priority to the development of walking and cycling infrastructure can effectively decrease emissions and enhance air quality in metropolitan regions. The incorporation of renewable energy sources into transportation networks might additionally reduce greenhouse gas emissions and advance environmental cleanliness.

5. Scenarios that Support the Mitigation of CO_2 Emissions from Libya's Transport Sector

5.1 Implementing Fuel Efficiency Standards for Vehicles to Reduce Carbon Emissions

Enforcing fuel efficiency regulations for automobiles is an essential measure for mitigating carbon emissions from Libya's transportation industry. This program will not only aid in reducing CO_2 emissions but also make a significant contribution to the country's broader sustainability objectives and efforts to protect the environment. Libya can ensure reduced CO_2 emissions per kilometer traveled by establishing precise fuel efficiency regulations for vehicles. This will not only have a positive impact on the environment, but it will also enhance air quality and promote public health in the country.

5.2 Promoting the Use of Electric Vehicles and Expanding Charging Infrastructure across the Country

Advocating for the use of electric vehicles not only mitigates the release of greenhouse gas emissions but also diminishes reliance on fossil fuels. Increasing the availability of charging infrastructure is vital to ensuring that electric car owners have easy access to charging stations, hence promoting the adoption of greener transportation alternatives. Allocating resources towards the development of charging infrastructure might generate novel employment prospects and foster economic expansion within the renewable energy industry. By adopting electric vehicles, Libya can make substantial strides towards attaining its emissions reduction objectives and actively participating in global endeavors to battle climate change. Moreover, diminishing the dependence on fossil fuels will additionally enhance air quality and public health in Libya. Investing in electric vehicle infrastructure is consistent with the nation's dedication to sustainable growth and environmental preservation.

5.3 Encouraging the adoption of alternative fuels such as biofuels or hydrogen in the transport sector

Biofuels and hydrogen, which are alternative fuels, have the capacity to greatly diminish greenhouse gas emissions in the transportation industry, thereby aiding in the creation of a more sustainable future for Libya. By advocating for the widespread use of these more environmentally friendly energy sources, Libya can effectively decrease its carbon dioxide emissions and decrease its reliance on non-renewable energy sources, ultimately resulting in enhanced air quality and long-term energy stability. The adoption of alternative fuels can contribute to the diversification of Libya's energy sources and generate fresh economic prospects in the renewable energy industry. Furthermore, by investing in alternative fuels, Libya can effectively fulfill its international obligations to decrease carbon emissions and address the issue of climate change. By adopting these more environmentally friendly energy sources, Libya can establish itself as a prominent participant in sustainable transportation practices and serve as a model for other nations to emulate.

5.4 Implementing Policies to Incentivize Carpooling and Ride-Sharing Services

Enforcing measures to encourage carpooling and ride-sharing services can effectively diminish the number of individual vehicles on the road, resulting in a decline in carbon emissions. By advocating for these sustainable modes of transportation, Libya can strive towards attaining its environmental objectives and establishing a transportation sector that is more effective and environmentally conscious. In addition, allocating resources to provide infrastructure that facilitates carpooling and ride-sharing, such as dedicated lanes or parking areas, might further incentivize individuals to opt for these alternatives instead of driving alone. This can also mitigate traffic congestion and decrease the overall carbon footprint of the transportation sector in Libya. The government can encourage a transition to more environmentally friendly forms of transportation by providing incentives and enhancing infrastructure.

5.5 Introducing Congestion Pricing to Reduce Traffic Congestion and Emissions in Urban Areas

Congestion pricing is imposing a charge on motorists for utilizing particular roadways or accessing specified areas during periods of high demand. This approach can effectively alleviate traffic congestion by incentivizing the use of alternate transportation modes and encouraging travelers to adjust their travel schedules. By applying this strategy in metropolitan areas of Libya, it is possible to not only reduce CO_2 emissions from the transport sector but also enhance air quality, resulting in a healthier and more sustainable environment for residents. Furthermore, congestion pricing can also yield income that can be reinvested in enhancing public transportation infrastructure, providing further motivation for the use of environmentally friendly modes of transportation. Implementing this comprehensive strategy can lead to a substantial decrease in greenhouse gas emissions and provide a more streamlined and eco-friendly transportation system in Libya.

5.6 Implementing Stricter Vehicle Emission Standards and Regular Inspections to Ensure Compliance

Enforcing more stringent vehicle emission regulations and conducting frequent inspections are essential measures for decreasing the carbon footprint of Libya's transportation industry. By implementing these steps, the nation can effectively reduce detrimental emissions, enhance air quality, and make a valuable contribution to global endeavors in addressing climate change. Moreover, the adoption of these standards might also result in technological and infrastructural progress within Libya's transportation sector. This will not only have a positive impact on the environment but also generate prospects for economic expansion and advancement in the nation.

5.7 Encouraging Telecommuting and Flexible Work Arrangements to Reduce the Need for Daily Commuting

Promoting telecommuting and flexible work arrangements can substantially diminish the number of vehicles on the road, resulting in a decline in greenhouse gas emissions from transportation. This strategy not only aids in reducing CO_2 emissions but also fosters a more balanced work-life equilibrium for employees, thereby enhancing productivity and job contentment. By minimizing the necessity for daily travel to work, employees can save on time and expenses related to transportation while also making a positive impact on the environment by lowering pollution. Moreover, the implementation of telecommuting and flexible work arrangements can effectively mitigate traffic congestion and enhance the overall air quality in urban regions. In general, advocating for telecommuting and flexible work arrangements can provide favourable outcomes for both the environment and the well-being of employees. It is an enduring solution that has advantageous effects for both humans and the planet over an extended period of time.

6. Study's Insights and Concluding Remarks

The global change assessment model of the ClimateWatch database did not incorporate CO_2 emissions from the transportation sector in Libya. Hence, the authors employed a time series methodology to forecast the past Libyan carbon dioxide (CO_2) emissions in the transportation industry, spanning from 1990 to 2022. Subsequently, these forecasts were extrapolated to encompass the period from 2023 to 2050. Using the time series approach, the authors were able to obtain a more accurate estimation of the trends and patterns in CO_2 emissions in Libya's transportation sector throughout the specified time period. The authors effectively rectified the shortcomings of the global change assessment model and conducted a comprehensive analysis of Libya's carbon emissions in the transportation sector through the utilization of this method. The achieved results include a comprehensive comprehension of the historical patterns in CO_2 emissions in Libya's transportation sector, precise forecasts for future emissions until 2050, and valuable insights into potential strategies for mitigating carbon emissions in the country.

The carbon dioxide emissions from transportation in Libya have a consistent and direct correlation between 1990 and 2020, with a coefficient of determination (R2) of 0.886%. This indicates a robust link between the years and CO_2 emissions in the transportation sector, which could be valuable in forecasting future patterns of CO_2 emissions in Libya. Policymakers must consider this correlation when developing initiatives to mitigate carbon emissions in the transportation sector. Understanding the historical trend of carbon dioxide emissions in transportation can provide valuable insights for making informed decisions regarding sustainable development strategies.

The exponential smoothing model (ESM) and ARIMA time series models were used to predict annual transportation CO_2 emissions in Libya. The ESM model showed a steady and linear rise in transportation CO_2 emissions between 2022 and 2050, while the ARIMA model exhibited a more intricate and non-linear trend. Both models offer useful insights into potential patterns in transportation CO_2 emissions in Libya. The selection between the ESM and ARIMA models may depend on the distinct attributes of the data and the intended level of precision in predicting emissions.

The ARIMA model outperformed the ESM model according to error metrics, producing a higher R^2 value of 0.931 than the ESM model's R^2 value of 0.878. This suggests that the ARIMA model would be better suited for accurately forecasting CO_2 emissions. In general, the ARIMA model exhibited better performance than the ESM model across several error metrics, suggesting that it would be better suited for accurately forecasting CO_2 emissions. The ARIMA model was selected to forecast Libya's transportation CO_2 emissions due to its superior performance compared to the ESM model. In their study, Qiao *et al*. [81] utilized various machine learning models to predict carbon dioxide emissions specifically for the transportation industry in the United Kingdom. The ARIMA approach performed better than Qiao *et al*.'s [81] machine learning approaches, with the ARIMA model reporting a lower RMSE value of 1.040 $MtCO_2e/yr$, while the LSBoost model recorded a higher value of 1.189 $MtCO_2e/yr$, the random forest model recorded 1.311 $MtCO_2e/yr$, the GPR model recorded 1.197

$MtCO_2e$/yr, and the LSTM model recorded 1.920 $MtCO_2e$/yr. This comparison is evident in publications [7, 42, 43, 82-84].

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

REFERENCES

[1] Beitelmal, W. H., Nwokolo, S. C., Meyer, E. L., & Ahia, C. C. (2024). Exploring Adaptation Strategies to Mitigate Climate Threats to Transportation Infrastructure in Nigeria: Lagos City, as a Case Study. *Climate*, *12*(8), 117. doi:https://doi.org/10.3390/cli12080117

[2] Benatallah, M., Bailek, N., Bouchouicha, K., Sharifi, A., Abdel-Hadi, Y., Nwokolo, S. C., ... & M. El-kenawy, E. S. (2024). Solar Radiation Prediction in Adrar, Algeria: A Case Study of Hybrid Extreme Machine-Based Techniques. *International Journal of Engineering Research in Africa*, *68*, 151-164. doi:https://doi.org/10.4028/p-VH0u4y

[3] Nwokolo, S. C., Singh, R., Khan, S., Kumar, A., & Luthra, S. (2023). Introduction: Africa's Net Zero Transition. In *Africa's Path to Net-Zero: Exploring Scenarios for a Sustainable Energy Transition* (pp. 1-13). Cham: Springer Nature Switzerland. doi:https://doi.org/10.1007/978-3-031-44514-9_1

[4] Kwilinski, A., Lyulyov, O., & Pimonenko, T. (2024). Reducing transport sector CO2 emissions patterns: Environmental technologies and renewable energy. *Journal of Open Innovation: Technology, Market, and Complexity, 10*(1), 100217. doi:https://doi.org/10.1016/j.joitmc.2024.100217

[5] Solaymani, S. (2022). CO2 emissions and the transport sector in Malaysia. *Frontiers in Environmental Science*, *9*, 774164. doi:https://doi.org/10.3389/fenvs.2021.774164

[6] Ahmed, S., Ahmed, K., & Ismail, M. (2020). Predictive analysis of CO 2 emissions and the role of environmental technology, energy use and economic output: evidence from emerging economies. *Air Quality, Atmosphere & Health*, *13*, 1035-1044. doi:https://doi.org/10.1007/s11869-020-00855-1.

[7] Wang, L., Xue, X., Zhao, Z., Wang, Y., & Zeng, Z. (2020). Finding the de-carbonization potentials in the transport sector: application of scenario analysis with a hybrid prediction model. *Environmental Science and Pollution Research*, *27*, 21762-21776. doi:https://doi.org/10.1007/s11356-020-08627-1.

[8] Nwokolo, S., Eyime, E., Obiwulu, A., & Ogbulezie, J. (2023). Africa's Path to Sustainability: Harnessing Technology, Policy, and Collaboration. *Trends in Renewable Energy, 10*(1), 98-131. doi:http://dx.doi.org/10.17737/tre.2024.10.1.00166

[9] Nwokolo, S. C., Eyime, E. E., Obiwulu, A. U., Meyer, E. L., Ahia, C. C., Ogbulezie, J. C., & Proutsos, N. (2024). A multi-model approach based on CARIMA-SARIMA-GPM for assessing the impacts of climate change on

concentrated photovoltaic (CPV) potential. *Physics and Chemistry of the Earth, Parts A/B/C, 134*, 103560. doi:https://doi.org/10.1016/j.pce.2024.103560
[10] Nwokolo, S. C., Singh, R., Khan, S., Kumar, A., & Luthra, S. (2023). Global Investment and Development in Africa. In *Africa's Path to Net-Zero: Exploring Scenarios for a Sustainable Energy Transition* (pp. 15-58). Cham: Springer Nature Switzerland. doi:https://doi.org/10.1007/978-3-031-44514-9_2
[11] Nwokolo, S. C., Singh, R., Khan, S., Kumar, A., & Luthra, S. (2023). Remedies to the Challenges of Renewable Energy Deployment in Africa. In *Africa's Path to Net-Zero: Exploring Scenarios for a Sustainable Energy Transition* (pp. 59-74). Cham: Springer Nature Switzerland. doi:https://doi.org/10.1007/978-3-031-44514-9_3
[12] Nwokolo, S. C., Singh, R., Khan, S., Kumar, A., & Luthra, S. (2023). Influencing the Scale of Africa's Energy Transition. In *Africa's Path to Net-Zero: Exploring Scenarios for a Sustainable Energy Transition* (pp. 75-91). Cham: Springer Nature Switzerland. doi:https://doi.org/10.1007/978-3-031-44514-9_4
[13] Nwokolo, S. C., Singh, R., Khan, S., Kumar, A., & Luthra, S. (2023). Technological Pathways to Net-Zero Goals in Africa. In Africa's Path to Net-Zero: Exploring Scenarios for a Sustainable Energy Transition (pp. 93-210). Cham: Springer Nature Switzerland. doi:https://doi.org/10.1007/978-3-031-44514-9_5
[14] Nwokolo, S. C., Singh, R., Khan, S., Kumar, A., & Luthra, S. (2023). Decarbonizing Hard-to-Abate Sectors in Africa. In *Africa's Path to Net-Zero: Exploring Scenarios for a Sustainable Energy Transition* (pp. 211-236). Cham: Springer Nature Switzerland. doi:https://doi.org/10.1007/978-3-031-44514-9_6
[15] Alataş, S. (2022). Do environmental technologies help to reduce transport sector CO2 emissions? Evidence from the EU15 countries. *Research in Transportation Economics, 91*, 101047. doi:https://doi.org/10.1016/j.retrec.2021.101047
[16] Amin, A., Altinoz, B., & Dogan, E. (2020). Analyzing the determinants of carbon emissions from transportation in European countries: the role of renewable energy and urbanization. *Clean Technologies and Environmental Policy*, *22*, 1725-1734. doi:https://doi.org/10.1007/s10098-020-01910-2
[17] Awan, A., Alnour, M., Jahanger, A., & Onwe, J. C. (2022). Do technological innovation and urbanization mitigate carbon dioxide emissions from the transport sector? *Technology in Society, 71*, 102128. doi:https://doi.org/10.1016/j.techsoc.2022.102128
[18] Nwokolo, S. C., Singh, R., Khan, S., Kumar, A., & Luthra, S. (2023). Impacts of Climate Change in Africa. In *Africa's Path to Net-Zero: Exploring Scenarios for a Sustainable Energy Transition* (pp. 237-262). Cham: Springer Nature Switzerland. doi:https://doi.org/10.1007/978-3-031-44514-9_7.
[19] Wang, C., Wood, J., Wang, Y., Geng, X., & Long, X. (2020). CO2 emission in transportation sector across 51 countries along the Belt and Road from 2000 to 2014. *Journal of Cleaner Production, 266*, 122000. doi:https://doi.org/10.1016/j.jclepro.2020.122000
[20] Nwokolo, S. C., Singh, R., Khan, S., Kumar, A., & Luthra, S. (2023). Scenarios that Could Give Rise to an African Net-Zero Energy Transition. In *Africa's Path to Net-Zero: Exploring Scenarios for a Sustainable Energy Transition* (pp. 263-298). Cham: Springer Nature Switzerland. doi: https://doi.org/10.1007/978-3-031-44514-9_8

[21] Nwokolo, S. C., & Ogbulezie, J. C. (2018). A quantitative review and classification of empirical models for predicting global solar radiation in West Africa. *Beni-Suef University Journal of Basic and Applied Sciences, 7*(4), 367-396. doi:https://doi.org/10.1016/j.bjbas.2017.05.001
[22] Nwokolo, S. C., & Ogbulezie, J. C. (2018). A qualitative review of empirical models for estimating diffuse solar radiation from experimental data in Africa. *Renewable and Sustainable Energy Reviews, 92*, 353-393. doi:https://doi.org/10.1016/j.rser.2018.04.118
[23] Samuel Chukwujindu, N. (2017). A comprehensive review of empirical models for estimating global solar radiation in Africa. *Renewable and Sustainable Energy Reviews, 78*, 955-995. doi:https://doi.org/10.1016/j.rser.2017.04.101
[24] Barman, P., Dutta, L., Bordoloi, S., Kalita, A., Buragohain, P., Bharali, S., & Azzopardi, B. (2023). Renewable energy integration with electric vehicle technology: A review of the existing smart charging approaches. *Renewable and Sustainable Energy Reviews, 183*, 113518. doi:https://doi.org/10.1016/j.rser.2023.113518
[25] Nwokolo, S. C., Singh, R., Khan, S., Kumar, A., & Luthra, S. (2023). *Africa's Path to Net-Zero*. Cham: Springer Nature Switzerland; 2023. doi:https://doi.org/10.1007/978-3-031-44514-9
[26] Nwokolo, S. C., Singh, R., Khan, S., Kumar, A., & Luthra, S. (2023). Africa’s Awakening to Climate Action. In *Africa's Path to Net-Zero: Exploring Scenarios for a Sustainable Energy Transition* (pp. 299-310). Cham: Springer Nature Switzerland. doi:https://doi.org/10.1007/978-3-031-44514-9_9
[27] Nwokolo, S., Eyime, E., Obiwulu, A., & Ogbulezie, J. (2023). Exploring Cutting-Edge Approaches to Reduce Africa's Carbon Footprint through Innovative Technology Dissemination. *Trends in Renewable Energy, 10*(1), 1-29. doi:http://dx.doi.org/10.17737/tre.2024.10.1.00163
[28] Borysova, T., Monastyrskyi, G., Zielinska, A., & Barczak, M. (2019). Innovation activity development of urban public transport service providers: multifactor economic and mathematical model. *Marketing and Management of Innovations*, *4*, 98-109. doi:https://doi.org/10.21272/mmi.2019.4-08
[29] Fontanot, T., Kishore, R., Van den Kerkhof, S., Blommaert, M., Peremans, B., Dupon, O., Kaaya, I., Tuomiranta, A., Duerinckx, F., & Meuret, Y. (2024). Multi-physics based energy yield modelling of a hybrid concentrated solar power/photovoltaic system with spectral beam splitting. *Solar Energy, 278*, 112753. doi:https://doi.org/10.1016/j.solener.2024.112753
[30] Godil, D. I., Yu, Z., Sharif, A., Usman, R., & Khan, S. A. R. (2021). Investigate the role of technology innovation and renewable energy in reducing transport sector CO2 emission in China: a path toward sustainable development. *Sustainable Development*, *29*(4), 694-707. doi:https://doi.org/10.1002/sd.2167
[31] Gulagi, A., Alcanzare, M., Bogdanov, D., Esparcia, E., Ocon, J., & Breyer, C. (2021). Transition pathway towards 100% renewable energy across the sectors of power, heat, transport, and desalination for the Philippines. *Renewable and Sustainable Energy Reviews, 144*, 110934. doi:https://doi.org/10.1016/j.rser.2021.110934
[32] Hens, L., Melnyk, L. H., Matsenko, O. M., Chygryn, O. Y., & Gonzales, C. C. (2019). Transport economics and sustainable development in Ukraine. *Marketing*

and Management of Innovations, 3, 272-284. doi:https://doi.org/10.21272/mmi.2019.3-21

[33] Hickman, R., Ashiru, O., & Banister, D. (2009). Achieving carbon-efficient transportation: backcasting from London. *Transportation Research Record*, *2139*(1), 172-182. doi:https://doi.org/10.3141/2139-20

[34] Nwokolo, S. C., Meyer, E. L., & Ahia, C. C. (2024). Exploring the Interactive Influences of Climate Change and Urban Development on the Fraction of Absorbed Photosynthetically Active Radiation. *Atmosphere*, *15*(3), 253. doi:https://doi.org/10.3390/atmos15030253

[35] Proutsos, N., Liakatas, A., Alexandris, S., Nwokolo, S. C., Solomou, A. D., & Amadi, S. O. (2024). Assessing the impact of atmospheric attributes on the effectiveness of solar irradiance for photosynthesis of urban vegetation in Attica, Greece. *Theoretical and Applied Climatology*, *155*(2), 1415-1427. doi:https://doi.org/10.1007/s00704-023-04700-0

[36] Nwokolo, S., Obiwulu, A., Amadi, S., & Ogbulezie, J. (2023). Assessing the Impact of Soiling, Tilt Angle, and Solar Radiation on the Performance of Solar PV Systems. *Trends in Renewable Energy, 9*(2), 120-136. doi:http://dx.doi.org/10.17737/tre.2023.9.2.00156

[37] Nwokolo, S. C., Proutsos, N., Meyer, E. L., & Ahia, C. C. (2023). Machine learning and physics-based hybridization models for evaluation of the effects of climate change and urban expansion on photosynthetically active radiation. *Atmosphere*, *14*(4), 687. doi:https://doi.org/10.3390/atmos14040687

[38] Agbor, M., Udo, S., Ewona, I., Nwokolo, S., Ogbulezie, J., Amadi, S., & Billy, U. (2023). Effects of Angstrom-Prescott and Hargreaves-Samani Coefficients on Climate Forcing and Solar PV Technology Selection in West Africa. *Trends in Renewable Energy, 9*(1), 78-106. doi:http://dx.doi.org/10.17737/tre.2023.9.1.00150

[39] Agbor, M. E., Udo, S. O., Ewona, I. O., Nwokolo, S. C., Ogbulezie, J. C., & Amadi, S. O. (2023). Potential impacts of climate change on global solar radiation and PV output using the CMIP6 model in West Africa. *Cleaner Engineering and Technology, 13*, 100630. doi:https://doi.org/10.1016/j.clet.2023.100630

[40] Chusi, T. N., Bouraima, M. B., Qian, S., Badi, I., Oloketuyi, E. A., & Qiu, Y. (2024). Evaluating the barriers to the transition to net-zero emissions in developing countries: a multi-criteria decision-making approach. *Computer and decision making: an international journal, 1*, 51-64.

[41] Li, X., Ren, A., & Li, Q. (2022). Exploring patterns of transportation-related CO2 emissions using machine learning methods. *Sustainability*, *14*(8), 4588. doi:https://doi.org/10.3390/su14084588

[42] Ağbulut, Ü. (2022). Forecasting of transportation-related energy demand and CO2 emissions in Turkey with different machine learning algorithms. *Sustainable Production and Consumption, 29*, 141-157. doi:https://doi.org/10.1016/j.spc.2021.10.001

[43] Klemm, C., & Vennemann, P. (2021). Modeling and optimization of multi-energy systems in mixed-use districts: A review of existing methods and approaches. *Renewable and Sustainable Energy Reviews, 135*, 110206. doi:https://doi.org/10.1016/j.rser.2020.110206

[44] IPCC. (2021).Summary for Policymakers. In *Climate Change 2021: The Physical Science Basis*, https://www.ipcc.ch/report/ar6/wg1/chapter/summary-for-policymakers/ (Accessed on 9/22.2024).

[45] Proutsos, N., Tigkas, D., Tsevreni, I., Alexandris, S. G., Solomou, A. D., Bourletsikas, A., ... & Nwokolo, S. C. (2023). A thorough evaluation of 127 potential evapotranspiration models in two mediterranean urban green sites. *Remote Sensing*, *15*(14), 3680. doi:https://doi.org/10.3390/rs15143680

[46] Schmidt Rivera, X. C., Topriska, E., Kolokotroni, M., & Azapagic, A. (2018). Environmental sustainability of renewable hydrogen in comparison with conventional cooking fuels. *Journal of Cleaner Production, 196*, 863-879. doi:https://doi.org/10.1016/j.jclepro.2018.06.033.

[47] Agyekum, E. B., Nutakor, C., Khan, T., Adegboye, O. R., Odoi-Yorke, F., & Okonkwo, P. C. (2024). Analyzing the research trends in the direction of hydrogen storage – A look into the past, present and future for the various technologies. *International Journal of Hydrogen Energy, 74*, 259-275. doi:https://doi.org/10.1016/j.ijhydene.2024.05.399

[48] Okonkwo, P. C., Islam, M. S., Taura, U. H., Barhoumi, E. M., Mansir, I. B., Das, B. K., Ali Sulaiman, M. M. B., Agyekum, E. B., & Bahadur, I. (2024). A techno-economic analysis of renewable hybrid energy systems for hydrogen production at refueling stations. *International Journal of Hydrogen Energy, 78*, 68-82. doi:https://doi.org/10.1016/j.ijhydene.2024.06.294

[49] Chukwujindu Nwokolo, S., Ogbulezie, J. C., & Umunnakwe Obiwulu, A. (2022). Impacts of climate change and meteo-solar parameters on photosynthetically active radiation prediction using hybrid machine learning with Physics-based models. *Advances in Space Research, 70*(11), 3614-3637. doi:https://doi.org/10.1016/j.asr.2022.08.010

[50] Nwokolo, S. C., Obiwulu, A. U., Ogbulezie, J. C., & Amadi, S. O. (2022). Hybridization of statistical machine learning and numerical models for improving beam, diffuse and global solar radiation prediction. *Cleaner Engineering and Technology, 9*, 100529. doi:https://doi.org/10.1016/j.clet.2022.100529

[51] Nwokolo, S. C., Amadi, S. O., Obiwulu, A. U., Ogbulezie, J. C., & Eyibio, E. E. (2022). Prediction of global solar radiation potential for sustainable and cleaner energy generation using improved Angstrom-Prescott and Gumbel probabilistic models. *Cleaner Engineering and Technology, 6*, 100416. doi:https://doi.org/10.1016/j.clet.2022.100416

[52] Yang, B., Xie, R., Duan, J., & Wang, J. (2023). State-of-the-art review of MPPT techniques for hybrid PV-TEG systems: Modeling, methodologies, and perspectives. *Global Energy Interconnection, 6*(5), 567-591. doi:https://doi.org/10.1016/j.gloei.2023.10.005

[53] Shah, K. J., Pan, S.-Y., Lee, I., Kim, H., You, Z., Zheng, J.-M., & Chiang, P.-C. (2021). Green transportation for sustainability: Review of current barriers, strategies, and innovative technologies. *Journal of Cleaner Production, 326*, 129392. doi:https://doi.org/10.1016/j.jclepro.2021.129392

[54] Georgopoulou, E., Mirasgedis, S., Sarafidis, Y., Giannakopoulos, C., Varotsos, K. V., & Gakis, N. (2024). Climate Change Impacts on the Energy System of a Climate-Vulnerable Mediterranean Country (Greece). *Atmosphere*, *15*(3), 286. doi:https://doi.org/10.3390/atmos15030286.

[55] Gaetani, M., Huld, T., Vignati, E., Monforti-Ferrario, F., Dosio, A., & Raes, F. (2014). The near future availability of photovoltaic energy in Europe and Africa in climate-aerosol modeling experiments. *Renewable and Sustainable Energy Reviews, 38*, 706-716. doi:https://doi.org/10.1016/j.rser.2014.07.041

[56] Mango, M., Casey, J. A., & Hernández, D. (2021). Resilient Power: A home-based electricity generation and storage solution for the medically vulnerable during climate-induced power outages. *Futures, 128*, 102707. doi:https://doi.org/10.1016/j.futures.2021.102707

[57] Kany, M. S., Mathiesen, B. V., Skov, I. R., Korberg, A. D., Thellufsen, J. Z., Lund, H., Sorknæs, P., & Chang, M. (2022). Energy efficient decarbonisation strategy for the Danish transport sector by 2045. *Smart Energy, 5*, 100063. doi:https://doi.org/10.1016/j.segy.2022.100063

[58] Abbas, S., Saqib, N., & Shahzad, U. (2024). Global export flow of Chilean copper: The role of environmental innovation and renewable energy transition. *Geoscience Frontiers, 15*(3), 101697. doi:https://doi.org/10.1016/j.gsf.2023.101697

[59] International Energy Agency. (2022). *World Energy Outlook 2022*. https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf (Accessed on 9/22/2024)

[60] Khurshid, A., Khan, K., & Cifuentes-Faura, J. (2023). 2030 Agenda of sustainable transport: Can current progress lead towards carbon neutrality? *Transportation Research Part D: Transport and Environment, 122*, 103869. doi:https://doi.org/10.1016/j.trd.2023.103869

[61] Xia, X., Li, P., Xia, Z., Wu, R., & Cheng, Y. (2022). Life cycle carbon footprint of electric vehicles in different countries: A review. *Separation and Purification Technology, 301*, 122063. doi:https://doi.org/10.1016/j.seppur.2022.122063

[62] Khurshid, A., Khan, K., Chen, Y., & Cifuentes-Faura, J. (2023). Do green transport and mitigation technologies drive OECD countries to sustainable path? *Transportation Research Part D: Transport and Environment, 118*, 103669. doi:https://doi.org/10.1016/j.trd.2023.103669

[63] Khurshid, A., Rauf, A., Qayyum, S., Calin, A. C., & Duan, W. (2023). Green innovation and carbon emissions: the role of carbon pricing and environmental policies in attaining sustainable development targets of carbon mitigation—evidence from Central-Eastern Europe. *Environment, Development and Sustainability*, *25*(8), 8777-8798. doi:https://doi.org/10.1007/s10668-022-02422-3

[64] Liu, M., Chen, Z., Sowah, J. K., Ahmed, Z., & Kirikkaleli, D. (2023). The dynamic impact of energy productivity and economic growth on environmental sustainability in South European countries. *Gondwana Research, 115*, 116-127. doi:https://doi.org/10.1016/j.gr.2022.11.012

[65] Hassan, M. A., Bailek, N., Bouchouicha, K., & Nwokolo, S. C. (2021). Ultra-short-term exogenous forecasting of photovoltaic power production using genetically optimized non-linear auto-regressive recurrent neural networks. *Renewable Energy, 171*, 191-209. doi:https://doi.org/10.1016/j.renene.2021.02.103

[66] Obiwulu, A. U., Erusiafe, N., Olopade, M. A., & Nwokolo, S. C. (2020). Modeling and optimization of back temperature models of mono-crystalline silicon modules with special focus on the effect of meteorological and

geographical parameters on PV performance. *Renewable Energy, 154*, 404-431. doi:https://doi.org/10.1016/j.renene.2020.02.103
[67] Obiwulu, A. U., Chendo, M. A. C., Erusiafe, N., & Nwokolo, S. C. (2020). Implicit meteorological parameter-based empirical models for estimating back temperature solar modules under varying tilt-angles in Lagos, Nigeria. *Renewable Energy, 145*, 442-457. doi:https://doi.org/10.1016/j.renene.2019.05.136
[68] Hassan, M. A., Bailek, N., Bouchouicha, K., Ibrahim, A., Jamil, B., Kuriqi, A., ... & El-kenawy, E. S. M. (2022). Evaluation of energy extraction of PV systems affected by environmental factors under real outdoor conditions. *Theoretical and Applied Climatology*, *150*(1), 715-729. doi:https://doi.org/10.1007/s00704-022-04166-6
[69] Obiwulu, A. U., Erusiafe, N., Olopade, M. A., & Nwokolo, S. C. (2022). Modeling and estimation of the optimal tilt angle, maximum incident solar radiation, and global radiation index of the photovoltaic system. *Heliyon, 8*(6). doi:https://doi.org/10.1016/j.heliyon.2022.e09598
[70] Nwokolo, S. C., Meyer, E. L., & Ahia, C. C. (2023). Credible pathways to catching up with climate goals in Nigeria. *Climate*, *11*(9), 196. doi:https://doi.org/10.3390/cli11090196
[71] Sylvia John-Jaja, A., Abdullah, A. R., & Samuel Nwokolo, C. (2017). Genetic Analysis of Egg Quality Traits in Bovan Nera Black Laying Hen under Sparse Egg Production Periods. *Iranian Journal of Applied Animal Science*, *7*(1), 155-162.
[72] John-Jaja, S. A., Abdullah, A.-R., & Nwokolo, S. C. (2016). Effects of age variance on repeatability estimates of egg dimensions of Bovan Nera Black laying chickens. *Journal of Genetic Engineering and Biotechnology, 14*(1), 219-226. doi:https://doi.org/10.1016/j.jgeb.2016.06.003
[73] John-Jaja, S. A., Udoh, U. H., & Nwokolo, S. C. (2016). Repeatability estimates of egg weight and egg-shell weight under various production periods for Bovan Nera Black laying chicken. *Beni-Suef University Journal of Basic and Applied Sciences, 5*(4), 389-394. doi:https://doi.org/10.1016/j.bjbas.2016.11.001
[74] Ituen, E. E., Esen, N. U., Nwokolo, S. C., & Udo, E. G. (2012). Prediction of global solar radiation using relative humidity, maximum temperature and sunshine hours in Uyo, in the Niger Delta Region, Nigeria. *Advances in Applied Science Research*, *3*(4), 1923-1937.
[75] Sunday, E., Agbasi, O., & Samuel, N. (2016). Modelling and estimating photosynthetically active radiation from measured global solar radiation at Calabar, Nigeria. *Physical Science International Journal*, *12*, 1-12. doi:https://doi.org/10.9734/PSIJ/2016/28446
[76] Etuk, S. E., Nwokolo, S. C., Okechukwu, E. A., & John-Jaja, S. A. (2016). Analysis of photosynthetically active radiation over six tropical ecological zones in Nigeria. *Journal of Geography, Environment and Earth Science International*, *7*(4), 1-15. doi:https://doi.org/10.9734/JGEESI/2016/27945
[77] Nwokolo, S., & Otse, C. (2019). Impact of Sunshine Duration and Clearness Index on Diffuse Solar Radiation Estimation in Mountainous Climate. *Trends in Renewable Energy, 5*(3), 307-332. doi:http://dx.doi.org/10.17737/tre.2019.5.3.00107
[78] Amadi, S., Dike, T., & Nwokolo, S. (2020). Global Solar Radiation Characteristics at Calabar and Port Harcourt Cities in Nigeria. *Trends in*

Renewable Energy, 6(2), 111-130. doi:http://dx.doi.org/10.17737/tre.2020.6.2.00114
[79] Nwokolo, S. C., Obiwulu, A. U., & Ogbulezie, J. C. (2023). Machine learning and analytical model hybridization to assess the impact of climate change on solar PV energy production. *Physics and Chemistry of the Earth, Parts A/B/C, 130*, 103389. doi:https://doi.org/10.1016/j.pce.2023.103389
[80] Nwokolo, S. C., Ogbulezie, J. C., & Ushie, O. J. (2023). A multi-model ensemble-based CMIP6 assessment of future solar radiation and PV potential under various climate warming scenarios. *Optik, 285*, 170956. doi:https://doi.org/10.1016/j.ijleo.2023.170956
[81] Qiao, Q., Eskandari, H., Saadatmand, H., & Sahraei, M. A. (2024). An interpretable multi-stage forecasting framework for energy consumption and CO2 emissions for the transportation sector. *Energy, 286*, 129499. doi:https://doi.org/10.1016/j.energy.2023.129499
[82] Emami Javanmard, M., Tang, Y., Wang, Z., & Tontiwachwuthikul, P. (2023). Forecast energy demand, CO2 emissions and energy resource impacts for the transportation sector. *Applied Energy, 338*, 120830. doi:https://doi.org/10.1016/j.apenergy.2023.120830
[83] Giannakis, E., Serghides, D., Dimitriou, S., & Zittis, G. (2020). Land transport CO2 emissions and climate change: evidence from Cyprus. *International Journal of Sustainable Energy*, *39*(7), 634-647. doi:https://doi.org/10.1080/14786451.2020.1743704
[84] Yasin Çodur, M., & Ünal, A. (2019). An estimation of transport energy demand in Turkey via artificial neural networks. *Promet-Traffic&Transportation*, *31*(2), 151-161. doi:https://doi.org/10.7307/ptt.v31i2.3041
[85] Galeazzi, C., Steinbuks, J., & Cust, J. (2020). Africa's Resource Export Opportunities and the Global Energy Transition (English). Live wire knowledge note series,no. 2020/111 Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/431621608028194772/Africa-s-Resource-Export-Opportunities-and-the-Global-Energy-Transition (Accessed on 9/22/2024)