Global model for Analyzing Environmental and Economical impacts of Electric Vehicle adoption.

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***Abstract*—The world of transport is rapidly changing towards electric mobility, somewhat in response to climate change and the desire to reduce reliance on fossil fuels. This article examines the environmental and economic impacts of Electric Vehicle (EV) adoption through a globally applicable model that includes vehicle registration, energy production, and lifecycle emissions. Results show that Electric Vehicle (EV) adoption has avoided more than 5 million tons of CO_2 emissions in 2024. Each Electric Vehicle (EV), on average, saves 1.95 tons of CO_2 emissions compared to a typical Internal Combustion Engine (ICE) vehicle per year. Monthly scenario modeling indicates that if a dynamic Electric Vehicle (EV) adoption pathway becomes common practice, Electric Vehicles (EVs) could achieve a reduction of over 30% emissions by 2030, while providing a reduction in long-term transportation costs. Though the upfront costs of Electric Vehicles (EVs) remain significant, their overall financial feasibility remains healthy due to the differential operating and maintenance cost savings compared to Internal Combustion Engine (ICE) vehicles. Across the analyses and models, findings indicate three crucial enabling factors to accelerate the benefits: first, supportive policy; second, clean energy infrastructure; and finally, broad-based charging infrastructure. In conclusion, it can be determined that electrifying transportation (policy supported with renewable energy) could produce significant environmental benefits and strengths in transportation planning. This study provides practical prompts for policymakers, car manufacturers, and energy planners to accelerate the change towards global sustainable mobility.**

Keywords*—*Electric Vehicle (EV), Internal Combustion Engine (ICE), greenhouse gases (GHG)

I. Introduction

The transportation sector is experiencing significant change as countries, industries, and communities all around the world move towards electric transportation. The adoption of Electric Vehicles (EVs) is a main strategy for handling climate change, reducing greenhouse gas emissions, and reducing dependence on fossil fuels [1] , [8] , [16]. This change is not just necessary for the environment; it also shows a big economic change. Countries are competing to lead in Electric Vehicle (EV) manufacturing, battery technology, and the development of charging infrastructure [17], [19]. Governments are implementing regulations, incentives, and investments to speed up the Electric Vehicle (EV) adoption [2], [3], [4], [7], while vehicle manufacturers are setting targeted electrification goals [6], [8]. Therefore, Electric Vehicles (EVs) are quickly becoming a conventional transportation option, transforming global transportation systems and energy markets [18], [20].

While there is a lot of research on Electric Vehicle (EV) adoption, many research focuses only on specific regions, looking at local energy systems, policies, and market behaviors [2], [8], [9]. This means they do not capture how Electric Vehicle (EV) adoption affects the global economy and environment. Many existing models tend to emphasize just one side like emissions reduction [1], [16], vehicle cost analysis [15], or charging infrastructure needs [11], [12], [13], [14] without bringing these elements together into a single model. This limited application makes it hard for decision-makers to get insights that are broad and relevant worldwide. Without a complete, globally applicable model, policymakers, investors, and environmental planners can't fully evaluate the trade-offs between environmental benefits and economic situations, which may result in less effective policies and investments [6], [19].

This research aims to fill these gaps by creating a globally relevant model to analyze the environmental and economic impacts of Electric Vehicle (EV) adoption. Unlike previous research that mainly addresses specific countries or areas [8], [18], this model integrates various factors, such as renewable energy sources, lifecycle emissions, vehicle production costs, government incentives, and total ownership costs [15], [16], [17]. It also considers regional differences in energy infrastructure and economic factors to give a clear picture of Electric Vehicle (EV) adoption results. By providing a more complete model, this study looks to create practical findings that can facilitate the change towards sustainable and cost-effective electric transportation worldwide [19], [20].

Overall, this research adds to the ongoing discussion about decarbonizing transportation and transitioning to clean energy [1], [16]. The model can guide decision-making across different levels, from national governments creating climate strategies to automakers planning investments and energy companies adjusting their portfolios [6], [8], [17]. By presenting a combined analysis of both environmental and economic effects, this study emphasizes that electric vehicles can drive significant changes while identifying the challenges that need to be solved to ensure a fair and effective global transition [7], [19].

II. LITERATURE REVIEW

Adoption to Electric vehicles (EVs), especially that can recover energy through regeneration systems, can have a significant positive impact on Environmental evolution. With the transport sector being responsible for one of the most polluting, which is around 60% carbon pollution, the use of Electric Vehicles (EVs) will reduce a considerable amount of carbon pollution over time [1]. Their adoption could lead to cleaner air, lower greenhouse gas (GHG) levels, and a healthy environment for future generations.

Government support is very important for the successful adoption of Electric Vehicles (EVs) and achieving the reduction of greenhouse gas (GHG) emissions. The Malaysian government has introduced a 100% import duty exemption to encourage the purchase of Electric Vehicle (EVs) and expect to reach a sale of 125,000 MYR by 2030. Electric Vehicle (EV) registrations, which were 9000 in 2017 and 2018 have increased up to 31,000 as of 2024 in Malaysia [2]. By the experience of the European countries the most effective way to promote the purchase of a new Electric Vehicle (EV) includes purchase subsidies, exemption from the registration fee and operating tax, development of charging station infrastructure and free parking [3], [4], [5], [6]. Ministry of Finance in Thailand significantly reduced excise tax on Electric Vehicles (EVs) from 20% to 40% up to 2% to 8%, creating a financial incentive for domestic consumers [7]. The Government of India has implemented several initiatives, including Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, to increase Electric Vehicle (EV) deployment. By implementing policy incentives, tax benefits, and charging infrastructure development, India aims to achieve a substantial decrease in transportation-related emissions by 2030 [8].

Spatial economic model study 50 Chinese cities from 2010 to 2020 and examines the impact of electric vehicles adoption on carbon emission through three main ways, substitution effect, energy consumption effect and technological effect, according to substitution effect, it suggest that replacing traditional petrol or diesel vehicles with Electric Vehicle (EV) can reduce carbon emissions but energy consumption effect indicates that increased electricity demand from Electric Vehicles (EVs) will lead to higher carbon emissions as 50% of electricity comes from burning fossil fuel. This highlights the importance of a cleaner energy mix in realizing the full environmental benefits of Electric Vehicle (EV) [9]. A Bottom-up Model was first proposed by China to evaluate charging demand and electric usage across three climate zones (South China. North China and Lower Reaches of the Yangtze River) during 2020 to 2022 [10]. According to the "Urban Road Engineering Design Code", literature [11] establishes a model of electricity consumption per unit mileage of electric vehicles for cities of roads above grade 3. Literature [12] developed an Electric Vehicle (EV) model using Cruise software, and while calculating the power consumption per unit mileage, three random factors of temperature, vehicle speed and driving behavior were mainly considered. Literature [13] presented a model of Electric Vehicle (EV) power consumption per unit mileage by considering the influence of passenger load. Literature [14] uses the relationship between the average speed and power consumption of Electric Vehicles (EVs) to calculate the power consumption per unit mileage by predicting the average speed of the car. Therefore, there are plenty of models which are related to reduce the impact on environmental and economic factors through Electric Vehicles (EVs).

Although Electric Vehicles (EVs) reduce the emission of greenhouse gases (GHG), they cannot completely omit the emission of those gases, because while manufacturing of the Electric Vehicle (EVs) at the manufacturing stage and the use of electricity to charge the Electric Vehicle (EVs) at the operation stage, emission of CO_2 and other greenhouse gases (GHG) takes place. The factors used for developing the Environmental Impact index include tailpipe emissions (non-EVs) and upstream emissions of Electric Vehicles (EVs). Tailpipe emissions include CO_2, NO_x, SO_2, and other greenhouse gases (GHG) emitted by Internal Combustion Engine (ICE) vehicles while upstream emissions for Electric Vehicles (EVs) refers to the amount of fuel burnt to generate electricity which is necessary to recharge the battery [15]. Therefore, by generating electricity from wind and solar, Electric Vehicles (EVs) charging can be much cleaner than using coal-fired power [16]. Since lithium-ion batteries are expensive studies suggest that using alternatives technologies such as solid-state batteries (which are safer and have higher energy density), sodium-ion batteries (which are cheaper and made from abundant materials), and aluminum or organic batteries (which are more environmentally friendly) can further reduce carbon emission [17].

According to the International Energy Agency (IEA), the number of electric cars on the road surpassed 10 million globally in 2020, and Electric Vehicle (EV) sales have continued to grow year over year. In 2023, Electric Vehicles (EVs) accounted for about 14% of global car sales, and the market share of Electric Vehicles (EVs) is expected to continue increasing, with projections suggesting that Electric Vehicles (EVs) could represent over 30% of global vehicle sales by 2030 and Major automakers are setting ambitious targets to shift toward electrification. Companies like Volkswagen, General Motors, Ford, BMW, Toyota, and Hyundai are investing heavily in Electric Vehicle (EV) production. Several automakers, including Volvo and General Motors, have announced plans to be fully electric by 2035 or 2040. [8]. In 2016 the Norwegian parliament which is now a major force in Electric Vehicle (EV) market committed to the ensure that all new cars sold by 2025 would be zero emission vehicles (fully electric or hydrogen powered)[18].

Chinese government also investing heavily in the development of advance technologies for both Electric Vehicles (EVs) and energy storage applications [19]. Even though government subsidies help Electric Vehicle (EV) adoption, strain toll revenue and reducing public transit use (e.g. Norway) will be a challenge [20].

While multiple existing models assess the environmental and economic implications of Electric Vehicle (EV) adoption, most of the models are region-specific and not widely applied or not accessible to the general public. Many of these models do not consider global differences in electricity generation, market dynamics, or policy support and incentives. Thus, our research is unique because it proposes a model with global applicability that also applies for regional variation, which makes it more applicable and inclusive to be applied globally. Therefore, this research aims at developing a constructive model which evaluates the advantages of emissions reduction and energy efficiency in conjunction with economics (ex. total cost of ownership, incentives by the government and other market dynamics). The study includes findings among the environments and automobile sectors to develop a complete model that could reflect the true sustainability of electric vehicles, thereby helping policymakers and other interested parties to effect valid decisions that drive viable transformation of transport.

III. METHODOLOGY

The approach followed in the study is an integrated method of data analysis, modeling, and simulation of scenarios to determine the environmental and economic impacts of the adoption of Electric Vehicles (EVs) on a global scale. The methodology consists of three significant parts: data gathering and completeness, environmental and economic model, and forecasting of the scenarios.

The analysis involved three datasets: vehicle data, energy mix data and emission data and examined them in a systematic way to determine the environmental impact and the economic impact of Electric Vehicle (EV) adoption. The vehicle information was followed with the use of the vehicle dataset (bilsalg_data.csv) and contains information on sales and registration of Internal Combustion Engine (ICE) vehicles and Electric Vehicles (EVs) in detail. In estimating upstream emissions, the energy dataset (energy_data.xlsx) gave the data about electricity generated by source, which defined it as nuclear, hydro, fossil fuels, and renewable energy. All CO2, NO3, SO3, and other emission factors of Internal Combustion Engine (ICE) tailpipe emissions and Electric Vehicle (EV) related upstream charging emissions were involved in the emission dataset (emission_data.xlsx). These datasets were harmonized through the identification of country and year matches, normalization of measures including grams of CO2 per kilometer (g/km) and US dollar (USD) in costs, and interpolation or deletion of missing measures where suitable. Also, the nations were sorted based on their electricity production mix as renewable-dominant, heavy fossil fuel, or mixed.

The preprocessing was done in a systematic manner. All this was done through the use of exploratory data analysis to evaluate descriptive statistics, column structures, and data dimensions. Interpolation and removal were used to fill in missing values when cleaning the data. This was followed by the combination of vehicle, energy and emission records into one analytical framework. To give comparability to the units and countries, standardization was done, and all the datasets were organized in terms of annual time series of vehicle stock, fuel and electricity consumption and related emissions. This enabled the following modeling of environmental as well as economic impacts.

Early analysis in the form of descriptive analysis gave early insights into the datasets. Trends in vehicles adoption were analyzed to show increasing Electric Vehicles (EVs) adoption, and regional variations in electricity generation looked at in terms of energy share distributions received across the energy dataset. Emissions and energy factor summaries were created to give a background to environmental impact assessment. The data patterns of adoption, energy mixes, and emissions were visualized using visualization tools, such as line charts, bar charts, and pie charts, which were used to clearly show the data patterns.

The impact on the environment was modeled by estimating the emissions per kilometer of the Internal Combustion Engine (ICE) cars and Electric Vehicles (EVs). Calculated tailpipe emissions of Internal Combustion Engine (ICE) vehicles were obtained by multiplying the average fuel consumption per kilometer by fuel-specific emission factors, with a representative emission average of 0.21 kg CO2 per kilometer (g/km). In the case of Electric Vehicles (EVs), the upstream emissions were calculated as the product of electricity consumption per kilometer and the grid carbon intensity of the charging electricity, with a representative emission rate of 0.08 kg CO2 per kilometer (g/km). Net emissions savings due to the replacement of Internal Combustion Engine (ICE) vehicles with Electric Vehicles (EVs) were calculated as the difference between these quantities, multiplied by the assumed annual vehicle mileage of 15,000 km, and scaled to the fleet level by the number of Electric Vehicles (EVs) per year. The emission of CO2, NOx, and SOx were also measured, which allowed comparing them, based on varying degrees of Electric Vehicle (EV) adoption.

The modeling of the economic impact was carried out based on the estimation of the annual operating cost of Internal Combustion Engine (ICE) vehicles and Electric Vehicles (EVs). Per kilometer consumption multiplied by the price of fuel or electricity calculated energy expenditures, and standard values were used to estimate maintenance costs. The difference between Internal Combustion Engine (ICE) vehicles and Electric Vehicles (EVs) in terms of operating costs was summed up in order to calculate possible economic savings in the long term. Sensitivity analysis was conducted to determine the extent to which changes in major parameters, including policy incentives, adoption rates, and electricity prices might affect the overall economic performance. The findings were shown as cost savings and possible economic benefits per year as estimates.

To capture potential uncertainties in Electric Vehicle (EV) adoption patterns and energy transition patterns, scenario modeling was carried out. Three were taken into account: the optimistic scenario, where the rapid EV adoption and a renewable-controlled electricity grid was assumed, the business-as-usual (BAU) scenario where moderate adoption and a mixed electricity grid was assumed, and the pessimistic scenario where slow adoption and fossil-fuel-dominated electricity generation was assumed. All the scenarios were modeled to test the cost implication and also the reduction of emissions under different assumptions.

The Electric Vehicle (EV) adoption was forecasted in a hybrid manner. Yearly Electric Vehicles (EVs) registration data, 2018 to 2024, were represented using the Prophet forecasting algorithm to include short-term growth tendencies, and a logistic growth was implemented to forecast long-term adoption to 2040, taking into consideration the eventual market saturation. Predicted Electric Vehicle (EV) stock prices were subsequently matched with per-vehicle environmental and economic effects, to produce aggregate curves of prevented emissions and money saved in each case. Illustrations were made of the adoption patterns, energy combinations, Total Cost of Ownership (TCO) differences, and emission abatements. A web-based application in the form of Streamlit (app_p1.py) allows policymakers and researchers to make assumptions and see how the numbers vary in both emissions and economy real-time to maintain transparency and flexibility of the modeling framework.

The model was validated through cross-checking of grid emission intensities calculated with published data from International Energy Agency (IEA) and Ember and comparing per kilometer estimates with values of existing lifecycle assessment studies of selected countries. Key parameters, such as annual mileage, emission rates, electricity mix, and discount rates, were subject to sensitivity analysis to determine the strength of the results. It is the methodological design that, through a complete approach, will provide a systematic connection between the raw data, emission model, and cost model and the outlook with the output of a comprehensive evaluation of the capacity of Electric Vehicle (EV) adoption to reinvent environmental and economic dynamics around the world.

IV. MODEL DEVELOPMENT

A hybrid forecasting and impact assessment model was established in order to estimate the environmental and economic effects of Electric Vehicle (EV) adoption. The model is composed of three significant elements: EV adoption forecasting, emissions estimation, and cost savings calculation.

A. EV Adoption Forecasting

The sample of the historical data was a stock of Electric Vehicles (EV) per year 2018-2024 to forecast the future adoption. A logistic growth function was used to include the market saturation in the end:

$$EV_t = \frac{K}{1 + e^{-r(t-t_0)}}$$

Where:

- EV_t = number of EVs projected at year.
- K = Saturation limit of the market (capacity), which is established at 5 times the existing maximum EV stock.
- r = rate of growth based on the past data.
- t_0 = point of inflection of adoption curve.

Prophet algorithm was used to model the short-term trend to explain the annual seasonality and growth trends. The projected EV stock was further projected to 2030 in three types, Business-as-Usual, Aggressive Adoption, and Slow Adoption.

B. Emissions Estimation

The per-vehicle emission factors and annual mileage assumptions were used to estimate the total amount of CO2s emitted by both the ICE and EV fleets:

$$CO2_{ICE} = ICE_t \times D \times EF_{ICE}$$

$$CO2_{EV} = EV_t \times D \times EF_{EV}$$

Where:

- ICE_t= Projected number of ICE vehicles at year t
- EV_t = number of EVs projected at year t
- D = distance vehicle per annum *(15,000km/y)*
- EF_{ICE} = emission factor per km for ICE vehicles (0.21 kg CO_2/km)
- EF_{EV} = emission factor per km of EVs (0.08 kg CO2/km, grid-dependent)

The CO2 saved by the adoption of EVs was then estimated as the difference between the ICE-only emissions at baseline and the actual fleet-emissions at baseline:

$$CO2_{avoided} = CO2_{baseline} - (CO2_{ICE} + CO2_{EV})$$

C. Economic Impact Assessment

The annual operating cost per fleet was determined based on the fuel consumption rates/electricity consumption rates, and average energy prices:

$$Cost_{ICE} = ICE_t \times C_{fuel}$$

$$Cost_{EV} = EV_t \times C_{elec}$$

Where:

- C_{fuel}= annual fuel price per ICE car on average.
- C_{elec} = average annual cost of electricity per EV.

The amount of money saved by the switch to EVs was calculated as:

$$Money\_Saved = Cost_{ICE\_baseline} - (Cost_{ICE} + Cost_{EV})$$

A combination of these equations made it possible to derive time-series projections of EV adoption, CO2 reductions, and economic savings in other situations of adoption. These assumptions were the foundation of the further results and scenario analyses.

V. RESULTS

A. Electric Vehicle (EV) Adoption Trends in Norway

The database of vehicle registration between 1990 and 2025 shows a steep trend of the adoption of Electric Vehicle (EV) particularly after 2015. As illustrated in Fig 1, the Electric Vehicle (EV) registration has soared, and the Internal Combustion Engine (ICE) vehicle registration has continuously decreased. Most of the new vehicles are Electric Vehicles (EVs) with more than 80 percent of the total vehicles registered in 2025, which is a significant change in the Norway automotive market. This trend shows the efficiency of state policies and incentives of Electric Vehicle (EV) use.

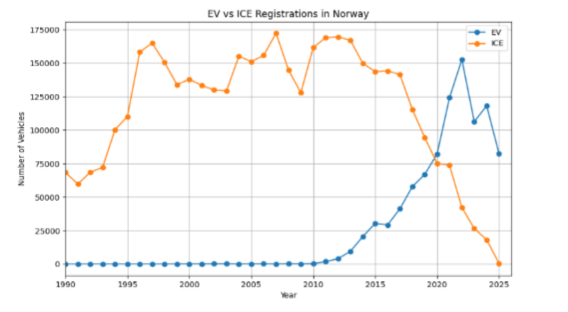

Fig 1 Total Vehicle Registration Over Time in Norway

B. Electric Vehicle (EV) vs Internal Combustion Engine (ICE) Vehicles Energies and Demand

Energy requirements of Electric Vehicles (EVs) and Internal Combustion Engine (ICE) vehicles were compared on average annual mileage and consumption rates. This can be seen in Fig 2, which indicates that Electric Vehicle (EV) energy demand (with kWh as the unit) has risen greatly with Electric Vehicle (EV) adoption, approaching almost 320 million kWh/yr by 2024. However, the opposite is true of the demand of fuel by Internal Combustion Engine (ICE) vehicles (in liters). This has decreased, indicating less usage. This direction indicates the shift of the reliance on fossil fuels towards more electricity.

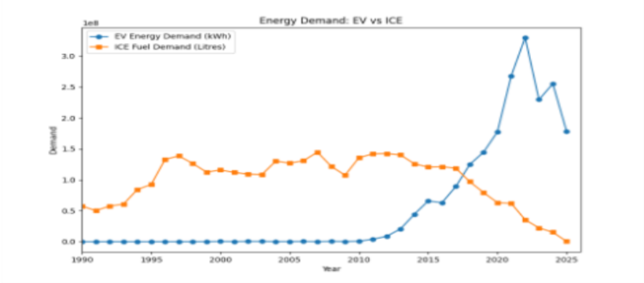

Fig 2 Average Energy Consumption of Electric Vehicles (EVs) and internal Combustion Engine (ICE) Vehicles

C. CO_2 Emissions Reduction

On a lifecycle basis, the emission reductions attributed to the replacement of Internal Combustion Engine (ICE) vehicles with Electric Vehicles (EVs) are significant in terms of CO_2 emission. With a factor of 0.21 kg/km of Internal Combustion Engine (ICE) and 0.08 kg/km of Electric Vehicles (EVs), overall CO_2 emissions of Internal Combustion Engine (ICE) vehicles have decreased considerably since 2015 Fig 3. The total CO_2 savings to Electric Vehicle (EV) adoption have by 2024 already exceeded 5 million tons of CO_2 savings due to Electric Vehicles (EVs)Fig 4, with individual Electric Vehicles (EVs) saving around 1.95 tons of CO_2 per year verimesus an Internal Combustion Engine (ICE) vehicle.

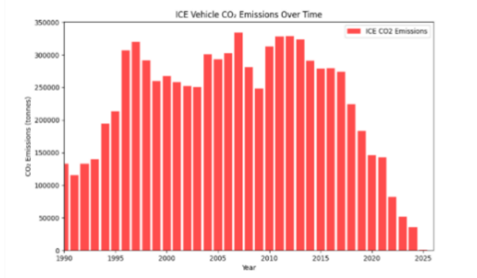

Fig 3 Internal Combustion Engine CO2 Emissions Over Time

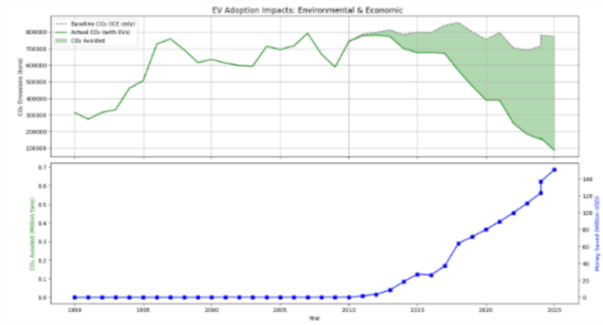

Fig 4 Annual CO2 Savings Per EV

D. Energy Source Composition

Energy supply in Norway is an important factor in environmental advantages of Electric Vehicles (EVs). Fig 5 and Fig 6 above reveal the overall energy mix and indicate that renewable sources, mainly hydro and wind power, produce over 57 percent of energy production. The proportion of non-renewable sources is only about 1.2 with the rest being other sources like imported energy.

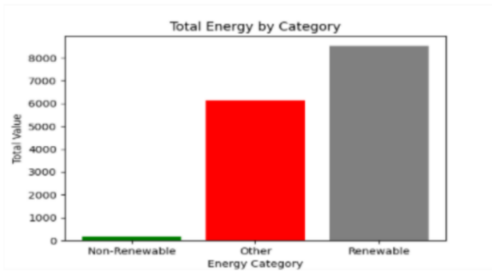

Fig 5 Energy Production Mix Renewable vs Non- Renewable

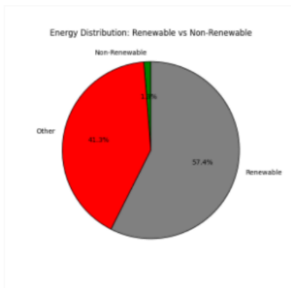

Fig 6 Detailed Renewable Energy Contributions

Fig 7 below presents a breakdown of renewable energy sources in detail, with much contribution being made by hydroelectric power and wind energy. On the other hand, non-renewable sources are disaggregated in Fig 8, meaning that coal, fossil gas and oil contribute insignificantly to the energy mix.

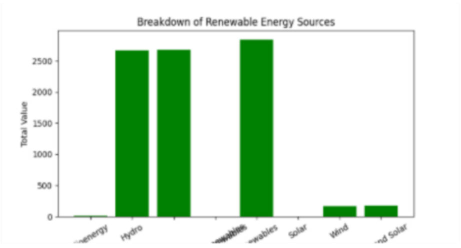

Fig 7 Breakdown of Renewable energy sources, with hydroelectric and wind power as main contributors

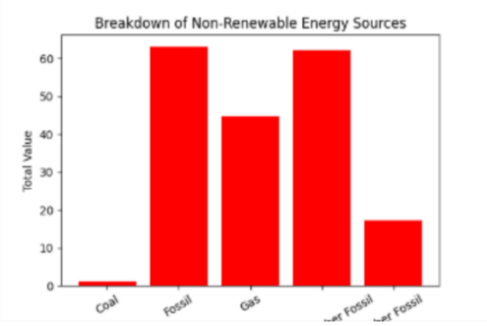

Fig 8 Breakdown of non-renewable energy sources, showing coal, fossilgas and oil contributions

E. *Electric Vehicle (EV) Adoption and Emissions (2025 to 2030): Prediction*

Based on logistic growth and Prophet algorithm forecast models project three scenarios of Electric Vehicle (EV) adoption and reduction of emissions in 2030. These situations can be captured as Business as Usual, Aggressive Adoption and Slow Adoption as in the table below and depicted in a graphical manner in Fig 9, 10 and 11.

Aggressive adoption has the greatest Electric Vehicle (EV) market share (Fig 9). Reductions in CO2 emissions and fuel savings are presented respectively in Fig 10 and 11. This demonstrates that the higher the penetration of Electric Vehicles (EVs), the greater the environmental and economic benefits are realized.

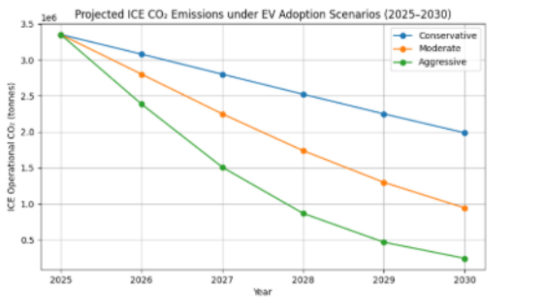

Fig 9 Forecasted EV market share scenarios from 2025 to 2030 under different adoption rates

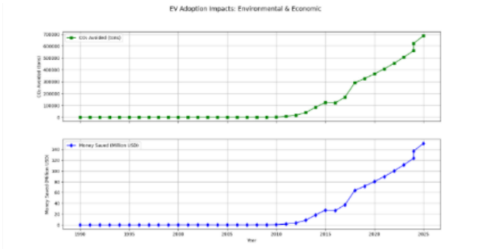

Fig 10 Projected CO2 emissions avoided under the three EV adoption scenarios

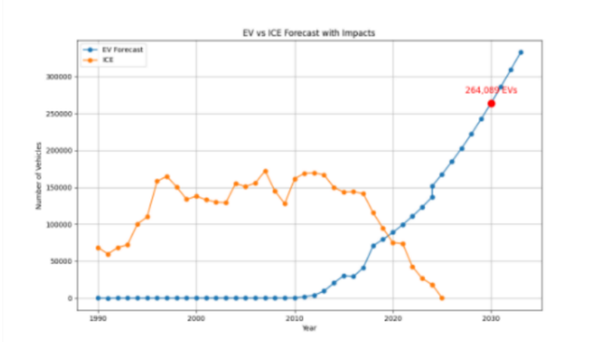

Fig 11 Projected economic savings due to reduced fuel and maintenance costs from EV adoption

VI. DISCUSSION

The vehicle sales statistics and energy consumption patterns analysis reveals that there is an evident trend towards the adoption of Electric Vehicle (EV), especially in the areas where the policies are highly supported. To illustrate, the registration information shows a gradual rise in the Electric Vehicle (EV) penetration, which is consistent with the evidence provided in Norway, where the mature Electric Vehicle (EV) market has been established thanks to the consistent incentives and the infrastructure development [18], [20]. Comparatively, other countries in the ASEAN like Malaysia are still at the initial stages of adoption simply because of the financial constraints and support policies are unavailable [2]. This affirms the key position of policy frameworks, subsidies and infrastructure in speeding up Electric Vehicle (EV) adoption, which is in line with research on the significance of government action in Europe and Germany [3], [4], [6].

With regards to environmental considerations, the model outcomes show that carbon emissions will be greatly reduced as Electric Vehicle (EV) adoption improves. It agrees with other reports on India, China, and lifecycle reviews in general, which indicate that Electric Vehicles (EVs) are able to lower CO2 emissions throughout the lifecycle of its operation, particularly when used with low-carbon electricity grids [8], [9], [10], [16]. Nevertheless, we also find that the degree to which the emission is reduced is extremely contingent on the energy generation mix. The environmental gains are less in situations when fossil fuels still dominate in the generation of electricity [1], [16].

Energy demand analysis also highlights how difficult it is to make the shift towards large-scale Electric Vehicle (EV) adoption. We find that with our simulations Electric Vehicle (EV) penetration would raise electricity demand and at the same time reduce fossil fuel demand in Internal Combustion Engine (ICE) vehicles. This two-fold tendency is evidenced by the previous literature modeling charging loads and anticipating grid effects [11], [12], [13], [14]. The results emphasize the need to combine renewable energy sources to make sure that the positive effect of Electric Vehicle (EV) adoption on the environment is not neutralized by an increase in electricity consumption based on fossil fuels.

In the socio-economic aspect, the findings indicate that though Electric Vehicles (EVs) initial cost is still a barrier, the economic benefits in the long run are significant because of low costs of operation and maintenance. This is in line with research which analyzed the environmental and economic trade-offs between ownership of Electric Vehicles (EVs) and gasoline or hybrid cars [15], [17]. Further, the user perception studies [5] point out that other factors including social acceptance and trust in the infrastructure reliability also determine the adoption rates. Such attributes of behavior should thus be incorporated in the adoption models in the future.

On the whole, the findings of the given study prove that Electric Vehicle (EV) adoption may provide significant environmental and economic advantages. Nevertheless, these benefits depend on the policy frameworks, grid decarbonization and investing in charging infrastructure, which are like the trends in the international Electric Vehicle (EV) research [7] , [19].

VII. CONCLUSION

This paper has analyzed the environmental and economic effects of the adoption of Electric Vehicle (EV) by bringing together the vehicle registration data, emission factors and energy generation trends. The analysis shows that the penetration of Electric Vehicles (EVs) can contribute greatly to carbon emission reduction and fossil reliance when the integration of renewable energy is a priority. Moreover, even though Electric Vehicles (EVs) have increased initial costs, economic advantages related to their use in the long-term are also available, such as a decrease in energy costs and maintenance expenses, which also indicate the potential of enhancing the overall economic performance. As an example, we have estimated that, when rolled out to nationwide totals of vehicles, per-vehicle emissions cuts and fleet-wide CO_2 savings could be significant, and lifetime cost reductions justify Electric Vehicles (EVs) uptake.

The results highlight three essential enablers to the maximization of benefits of Electric Vehicles (EVs) effective policy frameworks that include financial incentives, an electricity generation mix that is clean and based on renewable energy, and the establishment of efficient charging infrastructure. Although such measures have worked in developed economies such as Norway, developing economies have continued to experience challenges in terms of affordability, poor infrastructure, and slow policies. To make sure that Electric Vehicle (EV) adoption provides both environmental and economic benefits to the world, it is necessary to address these barriers.

Nevertheless, this paper has several drawbacks. The precision of the estimates might be affected by the use of secondary data, assumptions on the consumption of energy in vehicles and exclusion of certain lifecycle stages, like battery production and recycling. Evidence-based studies in the future would include in-depth lifecycle studies, future Electric Vehicle (EV) adoption predictions to 2030s and 2050s and model the impact of different renewable energy inputs to be more reflective of long-term environmental and economic performance. Also, consideration of technological innovations, including better battery performance, vehicle-to-grid, and smart charging solutions would help hone the estimates and policy directions.

To summarize, Electric Vehicle (EV) adoption is not just a change in technology but a systemic change that requires a joint approach in the field of policy, industry, and society. The use of Electric Vehicle (EV) can offer significant carbon emission cuts, boost economic performance, and give co-benefits like cleaner air quality and energy security by tackling the intertwined challenges of cost, infrastructure, and energy sources. These results support the idea of the holistic approach to the process of making the transport sector more electric, bearing in mind that strategic planning, supportive policies, and technological innovation are the most important factors to unlock the full potential of Electric Vehicles (EVs) and make it a global part of re-modelling sustainable mobility.

VIII. LIMITATIONS AND FUTURE WORK

There are a number of limitations in this study. First, the analysis fails to include the entire lifecycle of the Electric Vehicle (EV) batteries, such as emissions during the extraction of raw materials, manufacturing, recycling, and second life. This omission is a huge limitation considering batteries will be a significant contributor to the total environmental footprint of Electric Vehicles (EVs). Second, although the model is based on the global approach, some findings are generalized and do not reflect country-specific differences in the rates of adoption, infrastructure preparedness, and policy measures. Third, the assumptions on the energy mix are simplified with little being said on the variations that exist regionally in terms of renewable and fossil fuel dependence. There is also a chance that the economic forecasts are calculated on the estimates of costs, subsidies and fuel prices which are not confirmed and might change with time. Lastly, such behavioral and social issues like consumer preferences, charging patterns, and cultural acceptability were not modelled in details.

These constraints present a number of opportunities on how to work in the future. Future research must incorporate a more thorough battery lifecycle analysis, that is, including production, recycling, and supply chain impacts, to be able to more effectively analyze the environmental trade-offs of Electric Vehicle (EV) adoption. It would be useful to expand the model to country-level analyses, which would offer more insightful and policy-relevant information, especially in developing countries. The integration of dynamic energy transitions pathways would enhance the dependence between Electric Vehicle (EV) development and the adoption of renewable energy. Additional studies could also be aimed at carrying out sensitivity studies of the economic factors like variations in fuel prices, changes in subsidies and the battery price cuts. Also, more consideration of consumer behavior, social adoption processes, and the existence of charging infrastructure would contribute to the strength of adoption models. Lastly, it would be beneficial to combine Electric Vehicle (EV) uptake with grid stability research (impact on peak loads and vehicle-to-grid (V2G) opportunities) to have a more comprehensive picture of the opportunities and challenges in the global shift to the use of electric mobility.

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