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Estimation of Electric Vehicle Market in Malaysia by using Euler's Method and Runge-Kutta Method

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Abstract

This study investigates the growth of Malaysia's electric vehicle (EV) market using numerical methods to enhance forecasting accuracy, crucial for informed decision-making by stakeholders. Existing methods like Euler's Method often result in significant inaccuracies over long-term predictions due to their simplicity. To address this, the study employs both Euler's Method and the more advanced Runge-Kutta Fourth Order (RK4) Method, utilizing MATLAB simulations to compare their accuracy and in modelling exponential market growth. By analysing Malaysia's EV market dynamics and validating these numerical approaches, the research provides improved predictive tools for manufacturers, policymakers, and investors. The findings aim to support strategic planning and the broader transition toward sustainable transportation solutions. In this study, the EV market growth is modelled using an exponential growth equation, which is solved using numerical methods such as Euler's Method and the Runge-Kutta Fourth Order (RK4) Method. The study confirms that the Runge-Kutta Fourth Order (RK4) method significantly outperforms Euler's Method in forecasting the growth of Malaysia's EV market. RK4 provides higher accuracy and, particularly for long-term predictions.

1. Introduction

The history of electric vehicles (EVs) spans over a century, marked by periods of development, decline, and resurgence. The groundbreaking work of Robert Anderson in the 1830s, when he created the first electric carriage using non-rechargeable batteries, is credited with launching the era of electric vehicles [1]. At this time, electric mobility first emerged, paving the way for future technological advancements. Although EVs went through periods of decline, primarily due to the rise of gasoline-powered vehicles in the 20th century, technological revolutions and growing environmental concerns led to the revival of electric vehicles in the late 20th and early 21st centuries. This resurgence has been characterized by increased production and widespread adoption of electric vehicles worldwide.

The market environment for electric vehicles is constantly evolving due to a variety of factors, including market competition, consumer behaviour, regulations, and technological advancements. These interconnected factors shape how electric vehicles are accepted by society and determine the overall success of the EV market. Academics and industry professionals have conducted in-depth studies on the dynamics of the EV market, offering valuable insights into how these elements interact and influence market trends. These studies emphasize both the positive and negative impacts of each factor on the adoption rate and growth of electric vehicles, providing a deeper understanding of the forces driving the EV revolution [1].

When it comes to modelling complex dynamic systems, Euler's Method plays a crucial role in approximating the behaviour of systems governed by differential equations. Euler's Method offers a straightforward numerical solution to ordinary differential equations (ODEs) by estimating the solution based on the slope of the tangent at each time step. This simplicity makes it a useful tool in various fields of engineering and science for solving direct dynamic problems [2,3]. While this method is simple and easy to implement, it may lack the precision needed for systems that require high accuracy in long-term predictions or for modelling more complex behaviours.

This study aims to estimate the growth of Malaysia's electric vehicle (EV) market using numerical methods to enhance forecasting accuracy and support data-driven decision-making. The first objective is to analyse the EV market landscape. Secondly, the study implements and simulates the Euler Method and the Runge-Kutta Fourth Order (RK4) Method using MATLAB to model the market's growth. Finally, a comparative analysis is conducted to evaluate the accuracy and efficiency of both methods, determining their suitability for long-term market predictions. By achieving these objectives, the research contributes to a deeper understanding of EV market trends and provides valuable insights for policymakers, manufacturers, and investors.

2. Methodology

This section provided a detailed explanation of the methodology used to estimate Malaysia's electric vehicle (EV) market using numerical methods. Historical data on EV adoption was collected to model market growth, and two numerical techniques, Euler's Method and the Runge-Kutta Fourth Order (RK4) Method, were applied to solve the relevant differential equations.

2.1 Exponential Growth Model

The general form of the exponential growth model is given by the differential equation:

$$\frac{dN}{dt} = rN \tag{1}$$

where:

- $N(t)$ is the quantity or population at time t,
- r is the growth rate (a constant),
- N_0 is the initial quantity or population at time $t = 0$,
- t is the time.

The solution to this differential equation is:

$$N(t) = N_0 e^{rt} \tag{2}$$

where:

- N_0 is the initial value of N at $t = 0$,
- e is approximate to 2.718,
- r is the constant growth rate.

2.2 Euler's Method

Euler's approach can be used to forecast the EV population over time given the differential equation $\frac{dN}{dt} = rN$, which indicates the growth of the EV market.

Starting Point:

- Initial value N_0 (the number of EVs at the starting time t_0)
- Initial time t_0
- Growth rate r
- Step size Δt (the interval over which we want to make the predictions)

Iterative Formula:

$$N_{n+1} = N_n + \Delta t \cdot f(t_n, N_n) \tag{3}$$

where $f(t_n, N_n) = rN_n$ based on the differential equation $\frac{dN}{dt} = rN$

Steps to Apply Euler's Method:
Initialize: Set N_0 as the initial number of EVs and t_0 as the initial time.
Compute the Next Value: Use the formula to compute N_{n+1}:

$$N_{n+1} = N_n + \Delta t \cdot rN_n \tag{4}$$

Simplifying, we get:

$$N_{n+1} = N_n(1 + r\Delta t) \tag{5}$$

Repeat: Iterate this process for each time step Δt until you reach the desired forecast time.

2.3 Runge-Kutta Method Fourth Order

The RK4 technique entails choosing an appropriate time step (h) and applying an initial condition ($N(0) = N_0$). The first step of the algorithm is to initialize $t = 0$ and $N = N_0$. Intermediate slopes are computed for each time [5]
RK4 Formula:
Starting Point:

- Initial value N_0 (the number of EVs at the starting time t_0)
- Initial time t_0
- Growth rate r
- Step size Δt (the interval over which we want to make the predictions)

Iterative Formulas:

$$k_1 = \Delta t \cdot f(t_n, N_n) \tag{6}$$

$$k_2 = \Delta t \cdot f\left(t_n + \frac{\Delta t}{2}, N_n + \frac{k_1}{2}\right) \tag{7}$$

$$k_3 = \Delta t \cdot f\left(t_n + \frac{\Delta t}{2}, N_n + \frac{k_2}{2}\right) \tag{8}$$

$$k_4 = \Delta t \cdot f(t_n + \Delta t, N_n + k_3) \tag{9}$$

$$N_{n+1} = N_n + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4) \tag{10}$$

Steps to Apply RK4 Method:

Initialize: Set N_0 as the initial number of EVs and t_0 as the initial time.

Compute the Slopes: Use the RK4 formulas to compute k_1, k_2, k_3 and k_4
Compute the Next Value: Use the RK4 formula to compute N_{n+1}:

$$N_{n+1} = N_n + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4) \tag{11}$$

Repeat: Iterate this process for each time step Δt until reaches the desired forecast time.

2.4 Test Problem

The initial condition for this thesis is based on the exponential growth model, where the initial number of EVs at time $t = 0$ is denoted as $N(0) = N_0$, and the growth rate of EV adoption is r, obtained from historical data. For instance, if the initial EV population (N_0) is 1000 and the growth rate (r) is 10% per year, the condition would be

$N(0) = 1000$ and $r = 0.1$. These values serve as inputs for the Euler's Method and the Runge-Kutta Fourth Order (RK4) Method, enabling accurate simulations and predictions of Malaysia's EV market trends.

3. Results and Discussion

This section focuses on solving the exponential growth model for Malaysia's electric vehicle (EV) market, starting with initial conditions and using two numerical methods: Euler's Method and the Runge-Kutta Fourth Order (RK4) Method, implemented in MATLAB. The study examines how different step sizes, specifically 0.1 and 0.5, influence the accuracy of these methods.

3.1 Analytical Solution using Exponential Growth Model

This study used MATLAB to model the growth of Malaysia's electric vehicle (EV) market based on the exponential growth model. By simulating market expansion patterns, the numerical methods provided valuable insights into how the EV market might develop in the future.

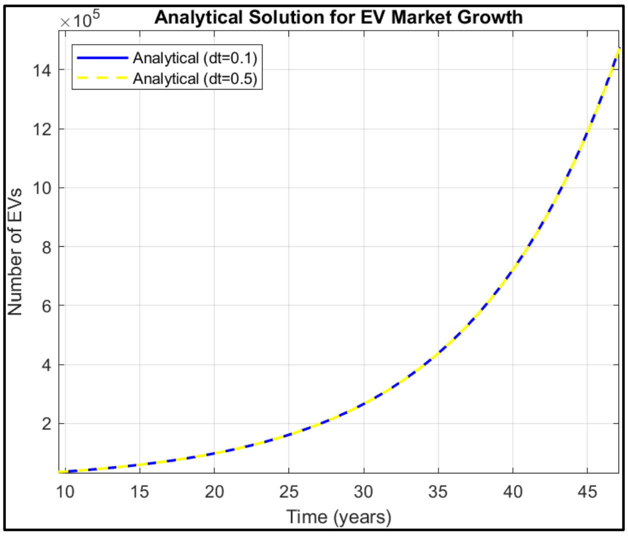

Fig. 1 Simulation of Exponential Growth Model for EV Market

Fig. 1 demonstrates the exponential growth of the EV market over a 50-year period based on the analytical solution of the growth equation [6]. Two different time steps, dt= 0.1(solid blue line) and dt= 0.5 (dashed yellow line), are used to show the consistency of the analytical solution regardless of time resolution. The curves illustrate the unbounded nature of exponential growth, where the number of EVs increases indefinitely under a constant growth rate of r= 0.1 per year.

The x-axis represents time in years, ranging from 0 to 50 years, while the y-axis shows the number of EVs, scaled by 10^6. The initial market size is set at $N_0 = 13226$ EVs [6], which grows exponentially over time. The results highlight that under exponential growth conditions, the EV market expands rapidly, doubling repeatedly as the years progress, with no consideration for resource constraints or saturation.

In the simulation, the analytical solution was computed using the equation:

$$N(t) = N_0 e^{rt}$$

This solution is benchmarked against numerical methods, including Euler's method and the Runge-Kutta 4th Order (RK4) method [4]. Euler's method provides a straightforward approximation of the growth dynamics, while RK4 offers a more precise numerical solution by considering intermediate steps within each time interval.

The choice of time step (dt) significantly impacts numerical accuracy. A smaller time step ($dt = 0.1$) provides finer resolution, producing results closer to the analytical solution. Conversely, a larger time step ($dt = 0.5$) reduces computational effort but may introduce slight deviations over longer time horizons [7]. Nevertheless, the analytical solutions for both time steps align closely, demonstrating the reliability of the exponential growth model for this simulation.

This study emphasizes the implications of unbounded exponential growth. While the model accurately predicts rapid expansion, it does not account for real-world constraints such as market saturation, limited resources, or policy interventions. Therefore, while exponential growth models provide a foundational understanding of market dynamics, future analyses should incorporate logistic constraints to reflect more realistic scenarios.

This section highlights the importance of comparing analytical and numerical methods for modelling growth processes. It underscores the relevance of time-step selection in numerical simulations and serves as a precursor to more complex growth models that consider limiting factors. This analysis is an essential step in forecasting EV market trends and understanding their potential impact.

3.2 Numerical Simulation

This study models the growth of the electric vehicle (EV) market using numerical integration methods to solve the exponential growth equation. Two numerical approaches are implemented: Euler's Method and the Runge-Kutta 4th Order (RK4) Method. These methods are compared to the analytical solution of the equation to evaluate their accuracy and stability over a simulation period of 50 years. The comparison is carried out using two different time step sizes, $\Delta t = 0.1$ and $\Delta t = 0.5$.

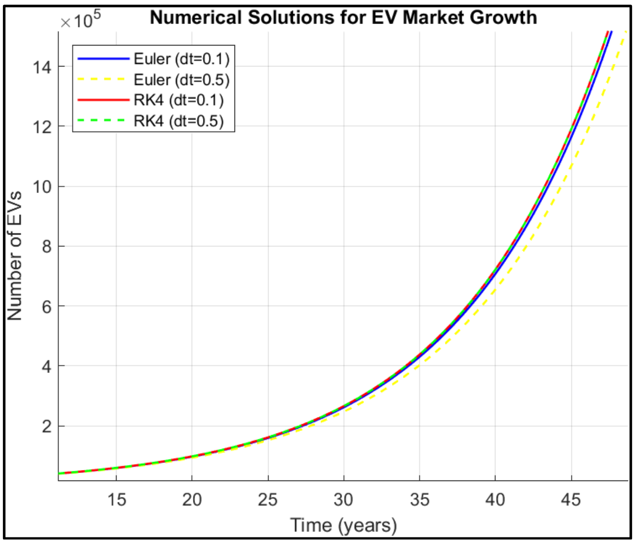

Fig. 2 Simulation of Numerical Solutions for EV Market

Euler's Method uses an iterative formula, $N_{i+1} = N_i + \Delta t \cdot r \cdot N$, to approximate the solution. While this method is simple to implement, its accuracy depends heavily on the time step size [8]. Larger step sizes lead to greater numerical errors and deviation from the true solution over time. In contrast, the RK4 Method improves accuracy by using four intermediate slopes (k_1, k_2, k_3, k_4) to calculate the solution at each step [4]. The updated value is computed using $N_{i+1} = N_i + \frac{k_1+2k_2+2k_3+k_4}{6}$. This approach significantly reduces numerical errors, even with larger step sizes, making it more suitable for long-term simulations [9].

Fig. 2 plots the number of EVs over time, with the x-axis representing time in years (from 0 to 50) and the y-axis representing the number of EVs, scaled in millions. The graph compares the results from Euler's Method and RK4 for both time step sizes.

For smaller time steps ($\Delta t = 0.1$), both Euler's Method and RK4 closely follow the analytical solution, accurately capturing the exponential growth. However, when the larger time step ($\Delta t = 0.5$) is used, Euler's Method shows significant deviations from the true solution due to accumulated numerical errors [4]. In contrast, the RK4 Method remains highly accurate and stable, even with the larger step size, closely matching the analytical solution throughout the simulation [1].

This analysis demonstrates the superiority of the RK4 Method over Euler's Method. While Euler's Method is simpler, its accuracy is heavily dependent on small step sizes, making it less practical for long-term simulations [7]. The RK4 Method, on the other hand, offers greater accuracy and stability across varying step sizes, making it the preferred choice for modelling exponential growth phenomena such as the expansion of the EV market [2].

3.3 Discussion

The findings reveal that RK4 significantly outperforms Euler's Method, especially when larger step sizes are used. RK4's ability to calculate intermediate slopes during each iteration allows it to maintain accuracy and minimize cumulative errors, even with a step size of 0.5. In contrast, Euler's Method shows substantial deviations from the analytical solution when larger step sizes are applied, emphasizing its sensitivity to step size selection.

Smaller step sizes, such as 0.1, improved the precision of both methods, as finer intervals better captured the dynamics of the exponential growth model. However, the computational cost increases with smaller step sizes, highlighting a trade-off between accuracy and efficiency. RK4 demonstrated high accuracy even with larger step sizes, making it a more efficient and reliable choice for long-term forecasting.

The exponential growth model, while effective for early-stage market analysis, does not account for real-world constraints like market saturation or policy changes. Despite this limitation, numerical simulations underscore the importance of using advanced methods like RK4 for accurate market predictions [2]. The absolute error analysis further validates RK4's robustness compared to Euler's Method, ensuring more reliable approximations of EV market trends. These insights highlight the critical role of step size selection and advanced numerical methods in enhancing forecasting accuracy and supporting strategic decisions in the EV industry. Future work could explore incorporating logistic growth models or additional influencing factors to refine the simulations further.

4. Conclusion

The findings demonstrated that RK4 outperforms Euler's Method in terms of accuracy, particularly with larger step sizes, and is more efficient for long-term forecasting. The study also highlighted the impact of step size on simulation accuracy, showing that smaller step sizes improve precision but increase computational cost. While the exponential growth model provided valuable insights, its limitations suggest that future research should incorporate more realistic models, such as logistic growth, to account for factors like market saturation and policy changes. Overall, the study emphasizes the importance of choosing appropriate numerical methods and step sizes for reliable market forecasting, providing valuable insights for stakeholders in Malaysia's EV industry.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Ahmad Danial Mohamad, Mahathir Mohamad;* ***data collection:*** *Ahmad Danial Mohamad;* ***analysis and interpretation of results:*** *Ahmad Danial Mohamad, Mahathir Mohamad;* ***draft manuscript preparation:*** *Ahmad Danial Mohamad, Mahathir Mohamad. All authors reviewed the results and approved the final version of the manuscript.*

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