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Exploring Strategies to Support Net-Zero Emission Transitions through Battery Swapping Industry Development

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ABSTRACT

The Indonesian government has set a roadmap toward net-zero emissions by 2060, including accelerating the adoption of electric motorcycles. The government has assigned the state electricity company as a locomotive to accelerate adoption by optimizing the potential for internal combustion engine motorcycle and ride-hailing users. The battery swapping scheme is an attractive option for companies to increase profits. However, users still experience uncertainty when exchanging batteries at battery swapping stations, which can hinder the development of the battery swapping industry. Therefore, it is essential to make it easier for battery-swapping electric motorcycle users to exchange batteries. Nevertheless, the development of the battery swapping industry is complex and involves many interrelated elements. Developing a strategy to improve it requires a holistic view to understand the process and define relationships between elements. This research uses system dynamics modeling to explore strategies for improving battery swapping industry development. Criteria for improvement focus on the number of batteries swapping electric motorcycle users, CO_2e emissions reduction, and profits. Three company interventions to achieve objectives are electricity tariffs, battery reservation fees, and battery swapping station constructions. The company's intervention was tested in three different scenarios. The results of the strategy exploration show that implementing battery reservations results in the highest number of electric motorcycle users, resulting in more significant emission reductions than others. However, in a different scenario, adding more battery-swapping stations each year results in better profits. Therefore, rather than focusing on one strategy, companies can integrate battery reservation strategies and the construction of battery exchange stations to eliminate the pain points electric motorcycle users feel, profit from battery reservations, and ultimately support the net-zero emission transitions.

Keywords: Battery Swapping, Electric Motorcycle, Systems Dynamics, Net Zero Emission Transitions, Indonesia
JEL Classifications: C61, L51, O21, O25, Q48

1. INTRODUCTION

The 21st Conference of the Parties (COP) in Paris resulted in the Paris Agreement maintaining temperature increases of no more than 2°C, including Indonesia (UNFCCC, 2015). Around 60% of greenhouse gas (GHG) emissions come from only 10 countries: China, the United States, India, Russia, Indonesia, Brazil, Japan, Iran, Canada, and Saudi Arabia. The 100 countries with the lowest emissions contribute <3%. Energy accounts for about 75% of global emissions, followed by agriculture. The energy field's most significant emission-producing sectors are power and thermal plants, transportation, and manufacturing. Indonesia is the fifth largest producer of GHG emissions in 2020, namely 1,475.83 Mt CO_2e caused by humans as a driver of climate change (Climatewatch, 2020). Where the transportation sector contributes more than a quarter of Indonesia's energy needs, emissions from this sector in 2020 amounted to 27% or 398.47 Mt CO_2e of the total GHG in Indonesia. The three most significant contributors to GHG emissions are the power generation, industry, and transportation sectors. The decarbonization of the transportation sector is crucial for Indonesia's goal of achieving net-zero emissions (NZE) goals. GHG emissions from the transportation sector must be reduced by three million tons of CO_2e every year until 2030 and seven million tons of CO_2e every year from 2030 to 2050, and they will reach zero emissions by 2050 (IESR, 2022; Syaifudin et al., 2015).

The Government of Indonesia (GoI) has issued various fiscal and non-fiscal policies to boost the adoption of electric vehicles (EV) (IESR, 2022) namely the growth target of 2 million electric cars and 13 million electric motorcycles by 2030 through a roadmap towards net zero emissions by 2060 (ESDM, 2021b), with a projection of 105,000 battery-swapping electric vehicles and 9,000 battery-swapping stations by 2030 (Gaikindo, 2021). However, the conditions are different from the existing realization. There are only 40,312 battery-swapping electric motor units and 1,401 battery-swapping stations (PLN, 2023a). The availability of charging infrastructure is essential for the adoption of electric vehicles. GoI assigned the PLN as the locomotive for developing battery-based electric vehicles (ESDM, 2021a). PLN must provide facilities that make battery swapping easier for users and benefit the company by optimizing the adoption of internal combustion engine (ICE) motorcycles and ride-hailing.

However, mileage is still a barrier to increasing the adoption of battery-based electric motorcycles (Adu-Gyamfi et al., 2022). User discomfort about the possibility of getting stuck mid-ride significantly influences users' intention to use battery-swapping technology (Adu-Gyamfi et al., 2022) and the limited number of battery swapping stations are also pain points for electric motorcycle users (Lai and Li, 2022). Therefore, battery reservations are necessary to ensure the availability of the required batteries when needed. By making battery reservations, the system can manage battery use efficiently, avoid conflicts between vehicles that need batteries, and minimize vehicle waiting time at battery exchange stations (Adler and Mirchandani, 2014). However, none of these studies have addressed the pain points experienced by electric vehicles and motorcycles using battery swapping, especially regarding battery reservation. Addressing such an issue provides opportunities for better strategies to improve the development of the battery swapping industry.

Regarding the above, this research extends previous research to explore ways to eliminate the pain points experienced by electric motorcycle users when exchanging batteries at battery swapping stations (Riskiyadi and Setiawan, 2024). More specifically, it aims to explore strategies to improve battery swapping industry development, thus supporting the government's effort to the NZE transition in 2060. This research uses the system dynamics modelling approach to systematically explore strategies for improving the battery swapping industry development and supporting the NZE transition. The battery swapping industry is a complex system. So, it is necessary to identify, map, and communicate a business model concept that can be applied to more comprehensively describe the dynamics of battery exchange. The development of a conceptual model uses a dynamic systems approach to gain insight into exploring battery swapping industry strategies and as a first step to identify company interventions to produce company objectives, namely the number of battery swapping electric motorcycle users, emission reduction, and profits to support the net-zero emissions transition. The model is verified and validated to check whether it corresponds to the real world with consistent units and appropriate behavior. Next, create a scenario, explore the company's intervention strategy, and analyze the scenario effects of the results of the intervention. This research provides policy recommendations to implement the government's roadmap targets and increase company profits, which companies can apply to accelerate the battery-swapping electric motorcycle ecosystem to support the NZE transition in 2060.

2. LITERATURE REVIEW

The Indonesian government is aggressively implementing an electric motorcycle adoption program to form an electric vehicle ecosystem in Indonesia by providing incentives or discounts on the purchase price of electric motorcycles and various policies. According to Jones et al. (2013) sales tax incentives and technological advances can increase people's interest in swapping electric motorcycles. Meanwhile, according to Truong (2023) The right incentive policy to increase the acceptance of electric motorcycles is incentives related to cost and time, such as tax discounts and free parking, rather than incentives about product quality, such as quality assurance and guarantees. The government can also provide incentives and subsidies to encourage the use of electric motorcycles and increase the availability of charging infrastructure (Setiawan et al., 2020; Su et al., 2023). In addition, the availability of adequate electric charging infrastructure is also an essential factor in ride-hailing service drivers' decisions to adopt electric motorcycles. (Waluyo et al., 2022). Governments worldwide are encouraging the switch from ICE motorcycles to electric motorcycles to increase energy savings and reduce GHG emissions. Despite this, several technical challenges – price, range, and charging time have hampered the adoption of electric motorcycles. So, battery swapping is an alternative to overcome these challenges, allowing two-wheeled EV users to easily replace a depleted battery with a fully charged one at the desired charging station (Setiawan et al., 2023). In addition, the battery swapping scheme is an attractive option for companies to increase their profits (Riskiyadi and Setiawan, 2024).

This research focuses on the exploration strategy of battery swapping in Indonesia. Several previous studies have shown that factors such as lower operating costs, environmental awareness, and government policies play an essential role in driving the adoption of EV (Farzin, 2022; Infante et al., 2018; Uribe et al., 2023; Wang et al., 2023; Wu et al., 2017; Wu et al., 2022; Zhan et al., 2022; Zhang et al., 2022; Zhang et al., 2023). Factors of adoption of battery swapping technology for electric vehicles at battery swapping stations were also investigated (Adu-Gyamfi et al., 2022; Adu-Gyamfi et al., 2022; Setiawan et al., 2023). Other research discusses models or frameworks for developing business processes and increasing operational cost efficiency (Adler and Mirchandani, 2014; Li et al., 2022; Shao et al., 2017; Yang et al., 2023). While those studies explore development strategies for the battery swapping industry, none quantitatively discusses its business development.

Previous studies have found that the implementation of policies such as subsidies, regulations, and infrastructure development can significantly increase the adoption of battery and electric motorcycle swapping services and also show that the profitability of battery swapping providers is highly dependent on the number of electric motorcycle users and battery swapping users using a dynamic system method approach (Setiawan et al., 2023). The results of other studies using survey methods and PLS-SEM provide valuable insights for policymakers and electric vehicle manufacturers in designing strategies to promote the adoption of battery swapping technology for electric vehicles and reduce pollution (Adu-Gyamfi et al., 2022) Other studies provide a comprehensive literature review on determining the location, size, and operation of the Battery Swapping Station (BSS) mechanism using Mathematical methods (Weight method, Mixed integer linear programming), and Meta Heuristic methods (Cuckoo search algorithm) (Zhan et al., 2022). To build an environmentally friendly and sustainable transportation system, battery swapping technology is a superior solution in all criteria measured using mathematical modeling methods and semi-qualitative analysis (Vallera et al., 2021). This research quantitatively tests the conceptual model developed to verify and analyze the impact of company intervention in developing the battery swapping industry in more depth (Riskiyadi and Setiawan, 2024).

3. RESEARCH METHODOLOGY

This research uses the system dynamics modelling approach. System dynamics is used as a method for improving learning in correlation with the battery swapping industry and the relationship between variables selected based on expert judgment complex systems (Sterman, 2002). First, a literature study was carried out, which aimed to determine mental model variables and related theories. Then, actor analysis is needed to analyze who is actively involved in the battery swapping industry; each actor is analyzed for their perception of the problem, the roots of the problem, goals, interests, owned resources, and stance that can be taken of the actors (Setiawan et al., 2023). After the system process is determined, the system diagram defines all processes and strategies for exploring battery swapping industry strategies. The system diagram shows the problem owner and the goals desired by the problem owner, all stakeholders involved in industrial development, how the system works, and company intervention to influence system output. The battery swapping industry study (Setiawan et al., 2023) was developed with the willingness of ride-hailing drivers to adopt electric motorcycles (Waluyo et al., 2022) into a Causal Loop Diagram (CLD).

CLD is a visual aid in systems thinking that visualizes the interdependence of various important variables in decision-making. CLD is essential in modelling system dynamics to be carried out as an initial sketch of a causal relationship hypothesis, especially in building complex models which, sometimes later in the application of dynamic systems, are not easy to find. CLD can also simplify complex models, making it easier for modelers to reflect the structural construction of their models. The relationship between variables can be seen in the arrows with positive or negative polarity symbols, which indicate a causal impact or vice versa. Next, the feedback relationship between variables in CLD is analyzed further through systems thinking patterns to understand the problem better (Hidayatno, 2013; Setiawan et al., 2018). Next, dynamic system modelling was carried out to simulate various company intervention scenarios and see their impact on the primary research variables. Analysis uses stock and flow diagrams (SFD) to understand system dynamics comprehensively. It represents a system using two main components: stock and flows that influence that stock. SFD is described globally with the condition that the flow flows from left to right (Hidayatno, 2013).

3.1. Actor Analysis

Table 1 shows players' personalities in exploring the battery swapping industry in Indonesia, obtained through literature studies from various journals and press releases from ministries and companies. Actors are classified into three parties: parties affected by the problem and the solution implemented, parties formally involved in the company's intervention, and parties involved in implementing the solution.

GoI is the first actor. By building optimal battery swapping station facilities, the government wants to build an adequate battery swapping industry to elevate user adoption of electric motorcycles (IESR, 2023). The government has prepared a roadmap to achieve NZE by 2060 by targeting the number of electric motorcycle users at 13 million units (ESDM, 2021b).

PLN is the second actor. The government has tasked PLN to be the locomotive for developing battery-based electric vehicles and providing electric vehicle facilities and infrastructure. PLN is looking for investors to collaborate in efforts to accelerate the construction of profitable battery swapping stations (PLN, 2023e). Therefore, PLN is expected to intervene in the battery swapping process to eliminate the pain points felt by electric motorcycle users (IESR, 2023).

The third actor is an ICE motorcycle user. ICE motorcycle users have a perceived pain point, namely limited travel distance and a lack of battery swapping station infrastructure, which is an obstacle to the growth of the electric vehicle market (IESR, 2022).

The fourth actor is the user of an existing electric motorcycle. Electric motorcycle users have the right to decide whether to use battery swapping services or not (Setiawan et al., 2023). This actor needs certainty about obtaining batteries at battery exchange stations using battery reservation services (Adler and Mirchandani, 2014).

Ride-hailing services are the fifth actor. Ride-hailing service providers prioritize low operational costs and a reliable and profitable network of battery swapping stations (Waluyo et al., 2022). Increasing the usage of ride-hailing services can increase the number of electric motorcycle users, increasing the profits of battery swapping station infrastructure providers.

3.2. System Diagram

Figure 1 shows a system diagram for exploring Indonesia's battery swapping industry development. The system diagram includes input, output, goals, company intervention, stakeholders, problem owners, and CLD as the system base model. External elements that the problem owner cannot control are among the inputs into

Table 1: Actors' personalities of exploration strategy battery swapping industry development, adapted from (Riskiyadi and Setiawan, 2024)

Actors'	Problem perception	Cause of problem	Objective	Interest	Resource	Position
Government of Indonesia (GoI)	Limited battery swap facilities hamper electric vehicle market growth (IESR, 2022)	The battery swapping industry is low or not profitable (Setiawan et al., 2023)	Develop a battery infrastructure swapping station to elevate the number of electric motorcycle users (Setiawan et al., 2023)	Adequate battery swapping facilities (IESR, 2022)	Authority to enact regulations to develop the battery swapping sector (Setiawan et al., 2023)	Establish a roadmap towards NZE 2060 for implementation (ESDM, 2021b)
State Electricity Company (PLN)	Government assignment to be the locomotive for the development of Battery Electric Motor Vehicle implementation (ESDM, 2021a)	Efforts to Reduce Carbon Emissions (PLN, 2023b)	Strengthen electric vehicle infrastructure (PLN, 2023a)	Profitable battery swapping business (PLN, 2021)	Policies to influence Electricity tariffs (Setiawan et al., 2023) and intervention in the battery swapping process.	Encourage and promote the use of electric vehicles (PLN, 2023c)
ICE Motorcycle Users	Running out of battery at the station because another vehicle has taken it away (Adler and Mirchandani, 2014)	Not implementing online battery reservations (Adler and Mirchandani, 2014)	To eliminate range anxiety and difficulty finding charging infrastructure (IESR, 2023)	Obtain certainty of battery availability at battery swapping stations (Adler and Mirchandani, 2014)	The decision not to switch to electric vehicles (Setiawan et al., 2023)	Waiting to adopt an electric motorcycle (Setiawan et al., 2023)
Electric Motorcycle Users	Uncertainty about obtaining batteries at battery swapping stations (Adler and Mirchandani, 2014)	Not considering battery reservation (Adler and Mirchandani, 2014)	Unlimited driving range (Adu-Gyamfi et al., 2022) and minimize the battery swapping lead time (Adler and Mirchandani, 2014)	Easy-to-use technology and affordable access (Adu-Gyamfi et al., 2022)	The decision not to use battery swapping (Setiawan et al., 2023)	Waiting to use battery swapping (Setiawan et al., 2023)
Electric motorcycle ride-hailing services	Limited range leads to anxiety about running out of power on the go and lack of charging infrastructure (Waluyo et al., 2022)	Access to a reliable and convenient network of battery swapping stations (Waluyo et al., 2022)	Lower operating costs and environmental benefits (Waluyo et al., 2022)	Benefits of hailing service providers (Waluyo et al., 2022)	The power of not adopting electric vehicles (Waluyo et al., 2022)	Waiting to embrace an electric motorcycle

the system. The variables used for intervention are the same as those used by the problem owner. CLD, which was created by Setiawan et al. (2023), defines a pattern structure and illustrates the cause-and-effect link between variables or components in the industrial service of battery swapping. Output is measured as an objective criterion used as an indicator to assess the effectiveness of company interventions, particularly the amount of battery swapping electric motorcycle users, the profits of companies providing battery swapping services, and the total reduction in CO_2e emissions. These output indicators follow the interests and objectives of the actors in Table 1. Company interventions will be implemented to evaluate model behavior and the effectiveness of each policy in achieving objectives.

Figure 2 shows that the CLD in the system diagram has five loops that explain the EV adoption process (Setiawan et al., 2023). The impact of word of mouth (WoM) on the application of electric motors is defined by Loop R1. Through WoM, more users have more influence, affecting electric motorcycles' expansion. Loop R2 explains how WoM affects users' adoption of battery swapping. Furthermore, through WoM, the elevated rate of battery-swapping users may contribute to the development in the number of battery-swapping electric motorbike users. Because battery swapping stations have developed, loops R3 and R4 involve using electric motors and battery swapping. Increasing the quantity of electric motors may increase earnings for the companies that provide battery swapping stations. Loop R5 indicates that infrastructure investment for electric motorcycles is expected to increase with earnings. Revenue is also influenced by battery reservation strategies to improve service and convenience for battery-swapping electric motorcycle users. Loop R6 describes the increasing adoption of ride-hailing services obtained by purchasing or renting electric motorcycles (Waluyo et al., 2022). The number of people who switch out their electric motorcycle batteries will rise if the number of people using electric ride-hailing services increases. Loop B1 balances revenue and costs to generate profits; the cost component is influenced by battery swapping costs and lab or training (Setiawan et al., 2023) as well as taking into account taxes, labor, and land rent (Zhan et al., 2022).

Figure 1: System diagram of the exploration battery swapping industry development in Indonesia (note: the bigger version of the CLD is available in figure 2)

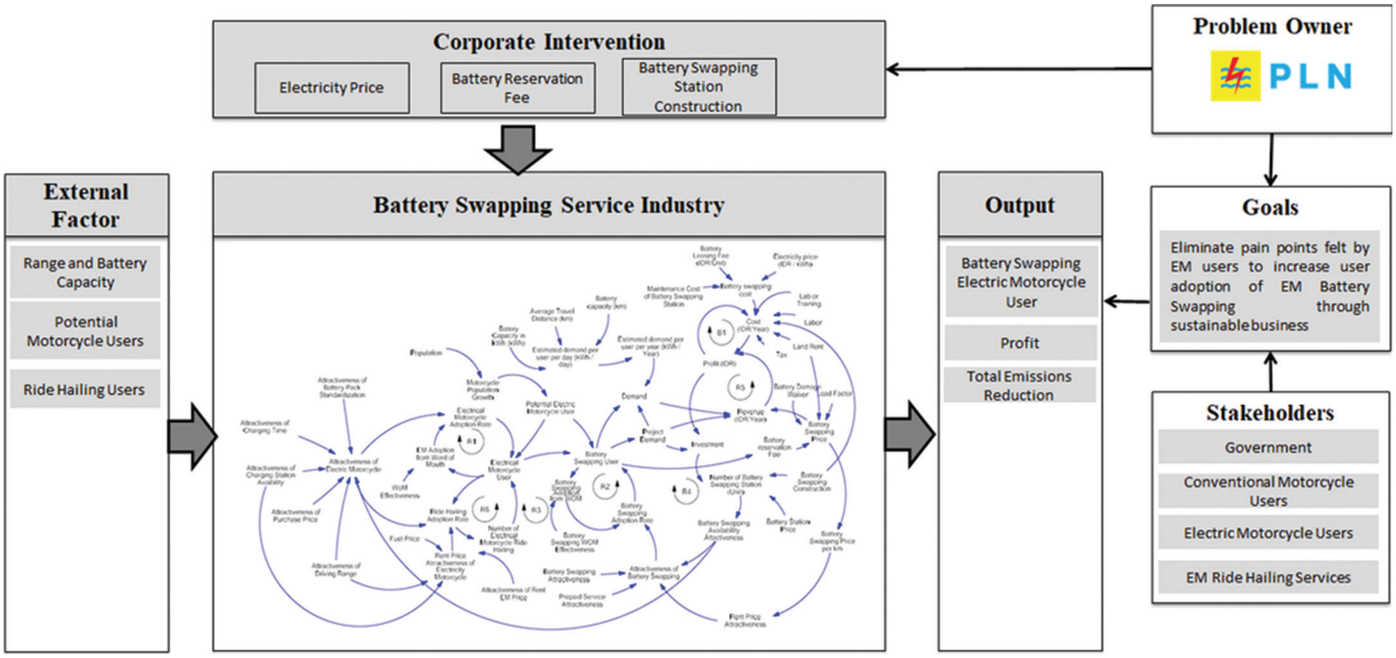
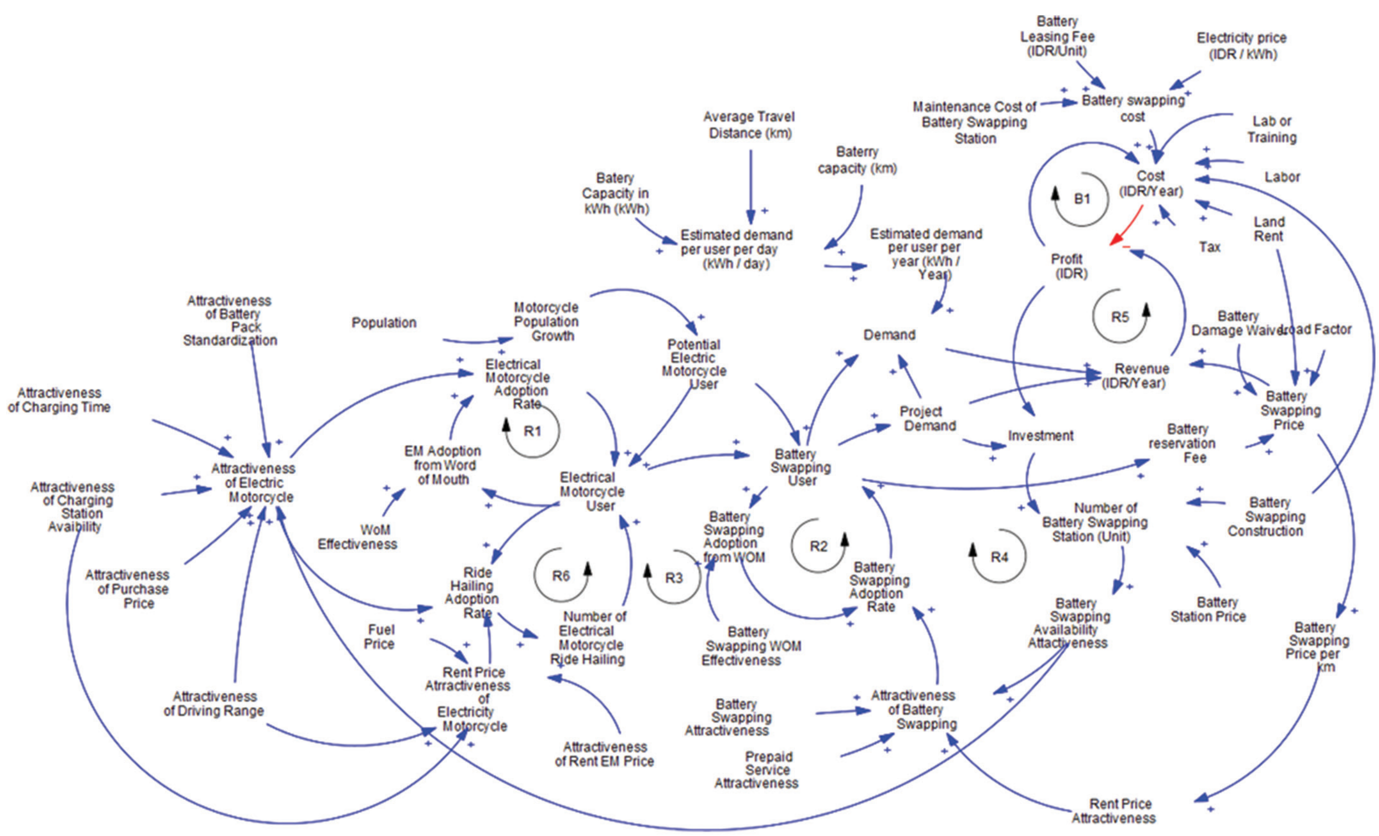


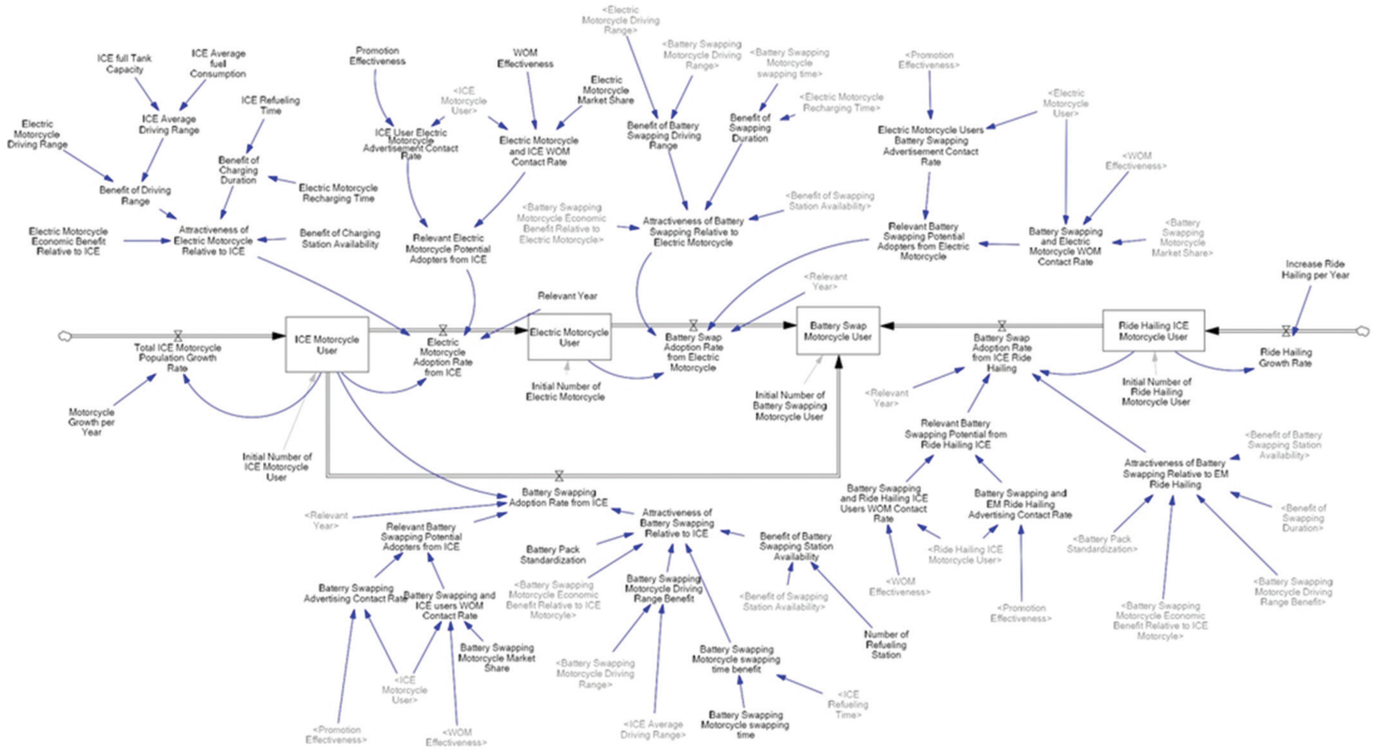
Figure 2: CLD development of the exploration strategy battery swap industry in Indonesia, adapted from (Riskiyadi and Setiawan, 2024)



3.3. Stock Flow Diagram

Model development converts the CLD conceptual model into a quantitative Stock Flow Diagram (SFD) model, and quantitative validation of the model is carried out through several standard tests in a dynamic system approach. The CLD shown in Figure 2 be modified into two SFD Modules: strategy development of the battery swapping services industry (Figure 3), the profitability of the battery swapping provider industry, and reduction of CO_2e emissions (Figure 4). In the process of developing and simulating the quantitative model in this research, Vensim PLE was used.

Figure 3: SFD module for exploring the development battery swapping industry strategies



3.3.1. Quantitative model development

Since this research focuses on the exploration strategy for developing the battery swapping sector, the first step is identifying the company's resources that may be utilized to inform policy or company involvement. Transitioning between four different technologies: ICE motorcycle, plug-in electric motorcycles, battery-swap motorcycles, and ride-hailing services, was another issue the business faced. Through alternative technology users or advertising media, or simply through marketing and WoM, consumers of one technology can see users of other technologies. Users of one technology may be interested in adopting another once use of that technology is deemed acceptable, taking into account several influential factors. The advantages of driving distance, refueling/recharging time, and the availability of refueling infrastructure/recharging battery swapping stations are among the aspects considered in this research, along with the relative economic benefits of original purchase costs and operating expenditures. In addition, the growth in the number of ICE motorcycles each year is also a factor in increasing the addition of vehicles by the average purchasing power of the community over the past 6 years in Indonesia (2015-2020) (BPS, 2024). The availability of battery swapping stations for battery swap motorcycles will significantly depend on the appeal for adoption. Figure 3 shows the module for exploring the development of battery swapping industry strategies (Appendix A and B for the module and formula details).

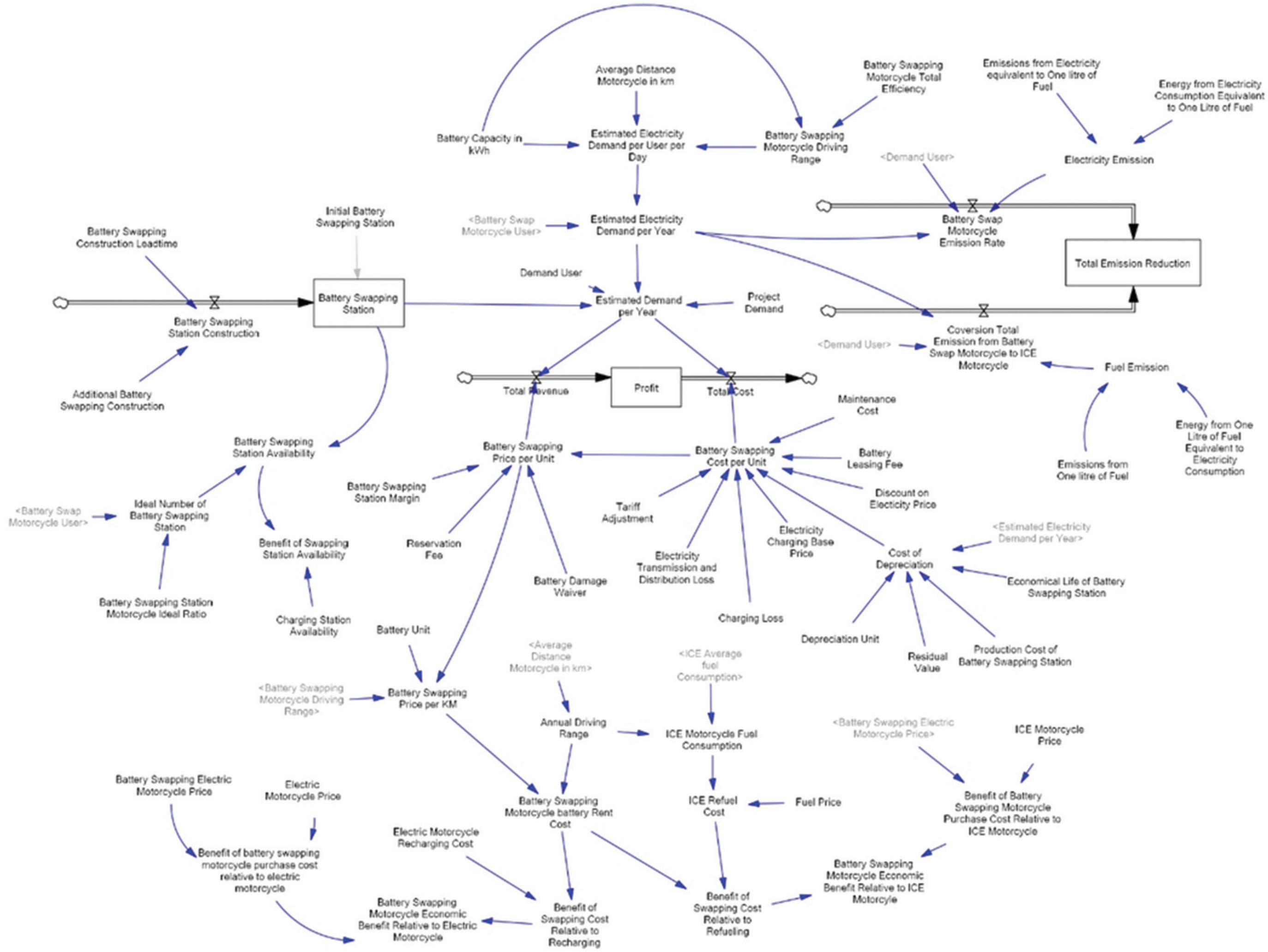
Figure 4 presents the SFD module profitability and CO_2e emissions reduction in the battery swapping industry (Appendix A and B for details of the module and formula), which shows the profit a battery swap station provider company can obtain and the reduction in CO_2e emissions. The estimated demand is derived from the projected number of battery swap users, which is the input for the revenue and cost structure (Setiawan et al., 2023). Revenue is derived from the projected demand multiplied by the battery swapping and reservation costs. Since these costs are the main cost components of the business, this study uses the resulting profit to estimate the business profit. The reduction in CO_2e emissions is a projection of the use of the number of electric motors compared to ICE motors. Every liter of fuel oil is equivalent to the use of electricity of 1.2 kWh, the carbon emissions of one liter of fuel oil are equivalent to 2.4 kg of CO_2e, while 1.2 kWh of electricity emissions are equivalent to 1.02 kg CO_2e (PLN, 2023b). Each battery swap motor is calculated from the reduction in Conversion Total Emission from Battery Swap Motorcycle to ICE Motorcycle and Battery Swap Motorcycle Emission Rate.

3.3.2. Verification and validation

Before using a quantitative model to analyze company intervention exploration, the SFD developed in this research was tested for validity by four basic examines in the dynamic systems approach: dimension analysis for unit consistency check, Numerical Errors Test (Integration Errors Test), structural assessment with Extreme Condition Test, and Qualitative Behavior Analysis.

This model is simulated with the business as usual (BaU) scenario from the base model of Setiawan et al. (2023). The simulation interval was set to 2023-2038 to support the Ministry of Energy and Mineral Resources Roadmap (ESDM, 2021b). The BAU scenario is built based on current conditions in state-owned companies in Indonesia. First, the basic electricity tariff for special services in Indonesia is IDR 1,644.52 or USD0.10 (PLN, 2023d). By Minister of Energy and Mineral Resources Regulation No. 28 of 2016, special service tariffs are used for electricity users who

Figure 4: SFD module profitability and CO_2e emissions reduction in the battery swapping industry



require special quality services and who for various reasons are not included in the provisions of the social, household, business, industrial, government office and public road lighting, traction tariff categories, and bulk.

Model verification is the initial stage to ensure no errors in the SFD. To carry out this check, we check the dimensions of each equation's right and left sides. If there are inconsistent units, this will cause an error in the SFD model in the Vensim PLE application. As attached in Appendix A, all variable units are consistent with circumstances. The subsequent verification is a numerical errors test (integration errors test) to assess the change between simulation results in different term steps. The model simulation results are not sensitive to the time step at the various time steps. Figure 5 shows the results of the integration error test using Runge Kutta, which shows trivial deviations. Integration Error Testing using Runge Kutta because the system has oscillatory behavior and is more precise. System simulations under BaU conditions in the Vensim application are carried out at time steps of 3 months, 6 months, and 12 months. The model simulation produces different period steps (±5%). So, the model is steady and ready for further testing. The final validation test was the Structure-oriented Behavior Test, which consisted of an extreme condition test and qualitative behavior analysis. Extreme condition tests check whether the behavior corresponds to the conditions of extreme input values and whether there is any unexpected behavior and analyze why it occurs. We tested extreme conditions on two system outputs: the number of battery-swapping electric motorcycle users and the total reduction in emissions in kg CO_2e. In Figure 6, profit growth and emissions reduction are at zero when there is no demand. So, the model does not have input values to produce output. This means that when the model simulation is run, the model is run by real-world conditions.

Qualitative behavioral tests are carried out to test behavior according to logic. In Figure 7, it is explained that when the growth of ride-hailing and/or ICE Motorcycle growth decreases or even equals zero, this will affect decreasing profits, emissions, and the number of battery swap motorcycle users, namely below Business as Usual.

Where profit is calculated using the formula:

Total Revenue-Total Cost (1)

Battery Swap Motorcycle User is calculated using the following formula:

Figure 5: Integration error test: (a) battery swapping station providers and (b) battery swap motorcycle (conducted in time steps 3, 6, and 12 months)

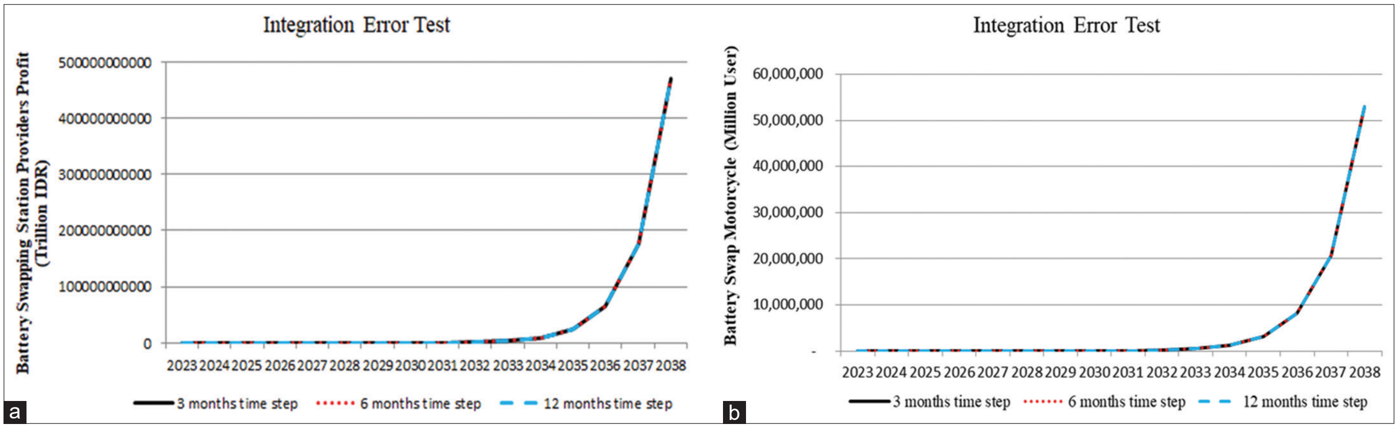


Figure 6: Structure-oriented behavioral test results: (a) extreme condition test results in zero battery swapping station benefit provider and (b) total emission reduction.

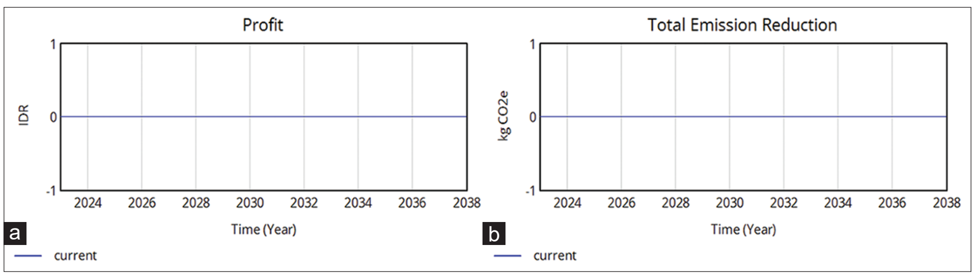
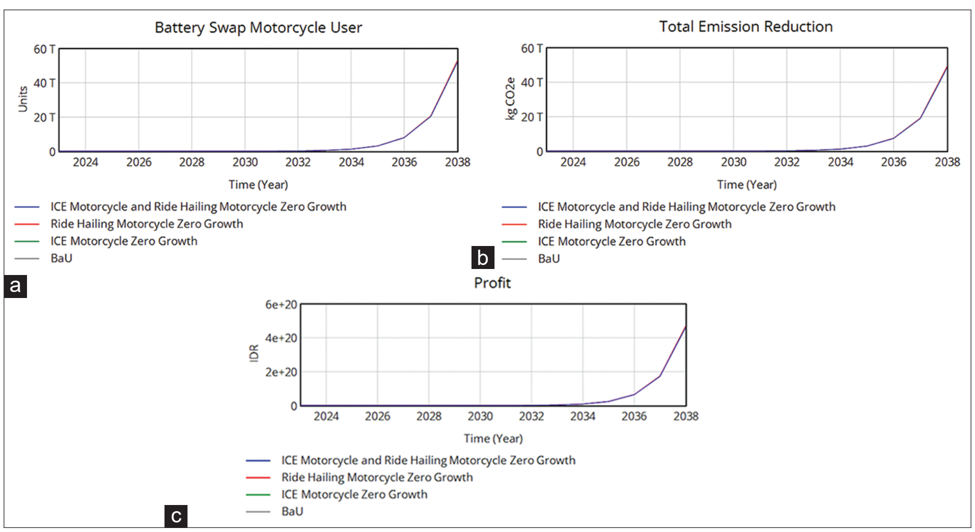


Figure 7: Results from structure-oriented behavior test: (a) qualitative behavior analysis produces values below BaU for battery swap motorcycle users, (b) total emission reduction, and (c) profit of battery swapping station providers



Battery Swap Adoption Rate from Electric Motorcycle+Battery Swap Adoption Rate from ICE Ride Hailing + Battery Swapping Adoption Rate from ICE (2)

Total Emission Reduction is calculated using the formula:

Conversion Total Emission from Battery Swap Motorcycle to ICE Motorcycle- Battery Swap Motorcycle Emission Rate (3)

These formulas are used to test validation up to the model simulation results in Figure 8, which can be seen in Appendix A.

3.3.3. Scenario drivers

Model validation has been completed, and the model has been simulated in various scenarios. In addition to the BaU scenario, three scenarios were developed to explore the effectiveness of company intervention in implementing battery swapping on motorcycles. In this scenario, system output is influenced by external factors.

This research explores the influence of electricity tariffs, reservation costs, and infrastructure construction. The company's resources are behind this choice to eliminate the pain point of battery-swapping electric motorcycle users. Table 2 presents scenarios for exploring battery swapping industry strategies.

Explanation of scenarios 1, 2, and 3 are provided below:

- Tariff Adjustment
  In this scenario, the company discounts battery exchange rates at battery swapping stations to attract people to use electric motorcycles. Determining an attractive and sustainable discount scheme, we assume a 30% discount on electricity rates when exchanging batteries at battery swapping stations (PLN, 2023c). Furthermore, loyalty members/points shape consumers into loyal customers on the mobile app.
- Large-scale Scale Development
  In this scenario, the company meets the government's target for 2030 by building massive battery swapping stations, namely 67,000 units (Antara, 2021) while PLN in the press release targets 68,800 units (PLN, 2022). So if reduced by the current number of SPBKLUs, it will be as much as 1,401 units (PLN, 2023a) which is 67,399 units, so the number of units built from 2024 to 2030 is 11,233 units. With a large amount of development, partnerships with the government and the private sector are also needed in infrastructure development. Apart from that, regional mapping is required by considering the population of battery-based electric motorcycle users so that it is right on target and according to needs.
- Charge On The Go
  This scenario aims to eliminate pain points, namely range anxiety experienced by electric motorcycle users (IESR, 2023) by providing the option of battery exchange services via reservation (Adler and Mirchandani, 2014). By collaborating with ride-hailing services in Indonesia, innovation is needed in developing company-owned applications that provide battery reservation features, battery availability, and battery charge percentage. So, companies need to apply reservation fees/service fees to develop applications and increase their profits.

4. RESULTS

As a basis for evaluating the effectiveness of company intervention in exploring development strategies for the battery exchange

Figure 8: Baseline simulation results of company intervention: (a) number of battery swapping motorcycle users, (b) reduction in CO_2e emissions (c) profit of battery swapping station providers

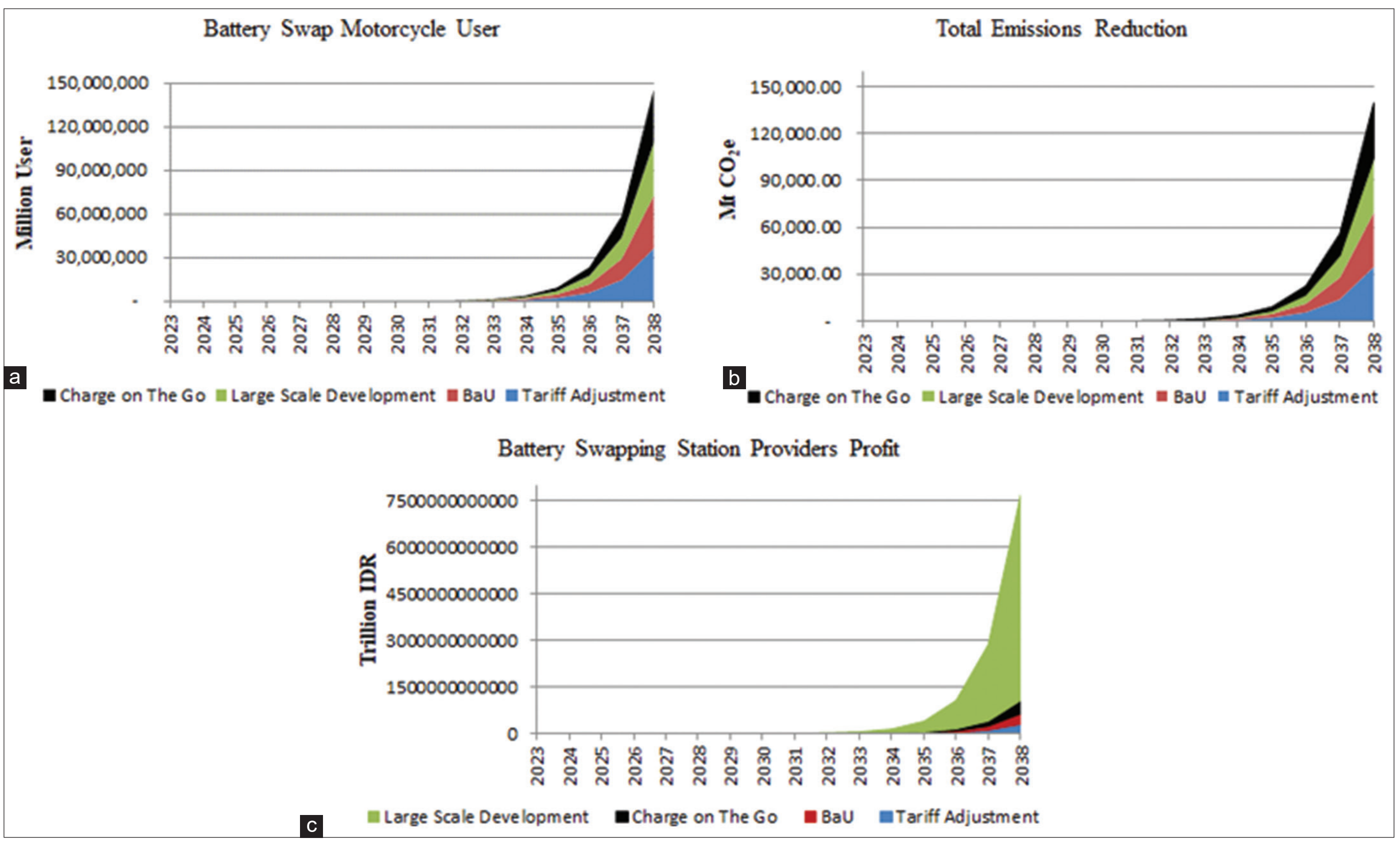


Table 2: Scenarios setting for explore strategy

Scenario	Business as usual (BaU)	Scenario 1 (Tariff adjustment)	Scenario 2 (Large scale development)	Scenario 3 (Charge on the go)
Electricity price	IDR1.644,52/kWh	IDR1.150,94/kWh	IDR1.644,52/kWh	IDR1.644,52/kWh
Battery swapping station construction	373 stations/year	373 stations/year	11.233 stations/year	373 stations/year
Battery reservation fee	IDR0/Reservation	IDR0/Reservation	IDR0/Reservation	IDR1.000/Reservation

industry, the company intervenes in carrying out its business processes to determine the best strategy to improve company performance and profits and carry out government assignments. We observe the number of battery-swapping electric motorcycle users in diverse scenarios developed previously without any policy intervention. Figure 8a shows that the number of battery-swapping electric motorcycle users in the BaU and Tariff Adjustment scenarios is not that different. Interestingly, the model simulation results show that battery swapping electric motorcycle users are not sensitive to price reductions. However, in conditions of a surge in the number of battery swapping station infrastructures in the Large Scale Development scenario, the number of users who swap batteries is increased. In the "In Charge On The Go" scenario, where the pain point of battery swapping electric motorcycle users is eliminated with a battery reservation scheme, the user of battery swapping out their batteries is at its peak. Based on these basic results, the Charge On The Go scenario can answer the needs of battery-swapping electric motorcycle users.

Furthermore, the model simulation results show that the reduction in CO_2e emissions is in line with the number of battery-switching electric motorcycle users. The more electric motorcycle users there are, the more CO_2e emissions will decrease. Figure 8b shows that the most significant reduction in emissions is also in the Charge on the Go scenario, and the lowest result is in the Tariff Adjustment scenario.

In the Large Scale Development scenario, the company optimizes resources to support the battery-based electric vehicle ecosystem, namely the massive construction of battery swapping stations. In Figure 8c, it can be seen that company profits have the highest results in the Large Scale Development scenario, followed by the Charge On The Go scenario and two others in succession, namely BaU and Tariff Adjustment. Interestingly, the discount strategy on electricity tariffs has not been proven to significantly influence the increase in battery-swapping electric motorcycle users and the reduction of emissions. On the other hand, the Tariff Adjustment has an impact on reducing the profits of the battery swapping station provider industry. The increasing number of battery swapping stations in the Large Scale Development scenario causes the estimated demand for battery swapping to increase so that the company's profit simulation results are the highest among the other scenarios.

The simulation results are in accordance with the conceptual model developed, the number of battery swapping electric motorcycle users has naturally formed and increased along with the existing ecosystem and company intervention. This has a positive impact on the total profits of the battery swap station provider. The outcomes validate the model's dynamic theory, namely that the number of electric motors can increase if the availability of battery swapping stations increases and the profits of the battery swapping provider industry increase if companies implement policy interventions that have been made so that the government and companies can achieve objectives.

Companies must tread carefully when providing price reductions to elevate the appeal of electric motorcycles. The simulation results show that the tariff adjustment could be more than IDR 8,600 trillion by the end of 2030, a discount to reduce battery exchange rates at battery swapping stations. Considering that the simulation results show that the user yield for battery swapping is smaller than BaU, companies must consider the benefits of this discount and focus on investment in building battery swapping stations.

5. DISCUSSION

System dynamics and corporate intervention provide an experimental framework that works well together for study. Combining a system dynamics approach and a corporate intervention framework has made a methodical and thorough investigation of the growth of the battery swapping market in Indonesia possible. The system diagram provides a comprehensive visual representation of the industry development strategy for battery swapping. By identifying important components in the variables and structures that underpin the adoption process of battery swapping electric motors, CLD also enables researchers to analyze the intricate dynamics of battery swapping adoption carefully.

Moreover, system dynamics model simulations facilitate the evaluation of the efficacy of various corporate interventions. To do this, the outcomes of the three indicators—profits, overall emission reductions, and users of electric motorcycles with battery swapping—are examined in a variety of appropriate situations.

By using a system dynamics model to investigate business strategies for the battery exchange service industry that complement the government's roadmap and are profitable for the enterprise, this research builds on the work of Setiawan et al. (2023). Additionally, this enriches the literature on EVs and adoption strategies generally (Adu-Gyamfi et al., 2022; Adu-Gyamfi et al., 2022). It also adds to the literature on the dynamics of battery swapping, strategies for swapping batteries using reservations (Adler and Mirchandani, 2014; Wang et al., 2023) and determining the location and size of battery swapping stations (Zhang et al., 2022). However, this research only considers company strategies when exploring appropriate policies. Future research on the complete execution of the model should include battery swapping users' level of acceptance of the company's interventions offered to eliminate user pain points. Such a product innovation development model can produce more benefits for business processes that provide value for the company, including exploring risks and other perceived pain points. When considering buying a battery swap motorcycle, a new consideration may be the availability of fully charged batteries at battery swapping stations that could be tracked via a smartphone app. These details could be included in more complete models. The model created in this study offers helpful insight into the dynamics and complexity of battery-swapping electric motorcycles in Indonesia. Still, it is not comprehensive enough to account for other adoption factors, including social, political, and environmental regulations. However, this study has several limitations in its analysis because the author compares electric and ICE motorcycles to compare current carbon emissions. Electric motorcycle users in Indonesia have not directly determined the level of acceptance of battery reservations. The battery reservation strategy is obtained from literature studies including (Adler and Mirchandani, 2014) and (Wang et al., 2023).

6. CONCLUSIONS

With a vast and expanding motorcyclist population, Indonesia's shift to clean energy offers enormous possibilities for ecologically friendly travel through EVs. The goal of this study was to highlight several firm exploration and intervention efforts toward NZE 2060 and a lucrative battery swapping market:

- The elements in the battery swapping industry are interrelated and produce a complex system. As described in this research, battery swapping electric motorcycle users experience pain points, namely the limited number of battery swapping stations, anxiety when traveling long distances (range anxiety), and long battery charging waiting times. Companies can provide strategies through parallel battery reservations that can increase profits. The research results can be a reference for companies providing battery swapping stations.
- There are three company interventions to encourage the achievement of objectives, namely the construction of battery swapping stations, battery reservation fees, and electricity tariffs.

a. The battery reservation scheme and the construction of battery swapping stations significantly impact the number of battery-swapping electric motorcycle users, while the provision of electricity tariff discounts does not significantly influence their growth.

b. The construction of battery swapping stations increases the estimated demand for battery swapping, resulting in the company's highest profit simulation results among other scenarios. The reduction in electricity tariffs significantly impacts the profits of the battery swapping provider.

  - This research suggests building massive battery swapping stations and making changes to the battery swapping process with prior reservations that will result in higher profits. However, in some situations, putting in place battery reservations may benefit battery swapping station users more than building new ones; in other situations, however, building new battery swapping stations may yield higher profits. Therefore, to balance governmental and corporate aims, the government can apply these regulations in an integrated manner rather than depending just on one intervention.
  - This study has variable limitations in its analysis; the author compares electric and ICE motors in comparing carbon emissions currently produced. Therefore, future research is suggested to address this issue more thoroughly.

This study has discussed and formulated strategies from several alternative scenarios of company intervention in developing the battery swapping industry in Indonesia. This study has limitations, and it is possible to create in further research. In the study, it is necessary to test the solution to determine the level of acceptance of reservations by customers and verify the business model and whether it is appropriate and produces value for the company. They are explicitly examining whether the need for battery reservations can answer the needs of electric motorcycle users for battery replacement through surveys, interviews, and expert panel discussions. So that the model can be further developed. Then, the author also suggests further research that discusses measuring the performance of electric motorcycle battery swaps that support the environment, society, and governance (ESG).

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APPENDICES

Appendix A: Battery swapping industry development module formula

Variable	Formula/Value (variable value "0" indicates an initial value)	Unit
Attractiveness of Battery Swapping Relative to ICE	(Battery Pack Standardization*0.162+Battery Swapping Motorcycle Economic Benefit Relative to ICE*0.211+Battery Swapping Motorcycle Driving Range Benefit*0.222+Battery Swapping Motorcycle swapping time benefit*0.193+Benefit of Battery Swapping Station Availability*0.212)/2+0.5	-
Attractiveness of Battery Swapping Relative to Electric Motorcycle	(Battery Swapping Motorcycle Economic Benefit Relative to Electric Motorcycle*0.211+Benefit of Battery Swapping Driving Range*0.222+Benefit of Swapping Duration*0.193+Benefit of Swapping Station Availability*0.212)/2+0.5	-
Attractiveness of Battery Swapping Relative to EM Ride Hailing	(Battery Pack Standardization*0.162+Battery Swapping Motorcycle Economic Benefit Relative to ICE*0.211+Battery Swapping Motorcycle Driving Range Benefit*0.222+Benefit of Swapping Duration*0.193+Benefit of Battery Swapping Station Availability*0.212)/2+0.5	-
Attractiveness of Electric Motorcycle Relative to ICE	(Benefit of Charging Duration*0.249+Benefit of Charging Station Availability*0.255+Benefit of Driving Range*0.26+Electric Motorcycle Economic Benefit Relative to ICE*0.236)/2+0.5	-
Battery Swapping Advertising Contact Rate	ICE Motorcycle User*Promotion Effectiveness	Units
Battery Swapping and Electric Motorcycle WOM Contact Rate	Electric Motorcycle User*WOM Effectiveness*Battery Swapping Motorcycle Market Share	Units
Battery Swapping and EM Ride Hailing Advertising Contact Rate	Promotion Effectiveness*Ride Hailing ICE Motorcycle User	Units
Battery Swapping and ICE users WOM Contact Rate	ICE Motorcycle User*WOM Effectiveness*Battery Swapping Motorcycle Market Share	Units
Battery Swapping and Ride Hailing ICE Users WOM Contact Rate	Ride Hailing ICE Motorcycle User*WOM Effectiveness	Units
Battery Swapping Motorcycle Driving Range Benefit	(Battery Swapping Motorcycle Driving Range-ICE Average Driving Range)/MAX (Battery Swapping Motorcycle Driving Range, ICE Average Driving Range)	-
Battery Swapping Motorcycle swapping time benefit	-(Battery Swapping Motorcycle Swapping Time-ICE Refueling Time)/MAX (Battery Swapping Motorcycle Swapping Time, ICE Refueling Time)	-
Benefit of Battery Swapping Driving Range	((Battery Swapping Motorcycle Driving Range)-Electric Motorcycle Driving Range)/ MAX (Battery Swapping Motorcycle Driving Range, Electric Motorcycle Driving Range)	-
Benefit of Charging Duration	-(Electric Motorcycle Recharging Time-ICE Refueling Time)/MAX (Electric Motorcycle Recharging Time, ICE Refueling Time)	-
Benefit of Driving Range	-(Electric Motorcycle Driving Range-ICE Average Driving Range)/MAX (Electric Motorcycle Driving Range, ICE Average Driving Range)	-
Benefit of Swapping Duration	-(Battery Swapping Motorcycle swapping time-Electric Motorcycle Recharging Time)/ MAX (Battery Swapping Motorcycle swapping time, Electric Motorcycle Recharging Time)	-
Electric Motorcycle and ICE WOM Contact Rate	ICE Motorcycle User*WOM Effectiveness*Electric Motorcycle Market Share	Units
Electric Motorcycle Users Battery Swapping Advertisement Contact Rate	Electric Motorcycle User*Promotion Effectiveness	
ICE Average Driving Range	ICE Average fuel Consumption*ICE full Tank Capacity	km
ICE User Electric Motorcycle Advertisement Contact Rate	ICE Motorcycle User*Promotion Effectiveness	Units
Relevant Battery Swapping Potential Adopters from Electric Motorcycle	(Battery Swapping and Electric Motorcycle WOM Contact Rate+Electric Motorcycle Users Battery Swapping Advertisement Contact Rate)	-
Relevant Battery Swapping Potential Adopters from ICE	(Battery Swapping Advertising Contact Rate+Battery Swapping and ICE users WOM Contact Rate)	-
Relevant Battery Swapping Potential from Ride Hailing ICE	(Battery Swapping and EM Ride Hailing Advertising Contact Rate+Battery Swapping and Ride Hailing ICE Users WOM Contact Rate)	-
Relevant Electric Motorcycle Potential Adopters from ICE	(Electric Motorcycle and ICE WOM Contact Rate+ICE User Electric Motorcycle Advertisement Contact Rate)	-
Ride Hailing Growth Rate	Ride Hailing ICE Motorcycle User*Increase Ride Hailing per Year	Units/Year
Annual Driving Range	Average Distance Motorcycle in km*365	km/Year
Battery Swap Motorcycle Emission Rate	Estimated Electricity Demand per User per Year*Electricity Emission	kg CO_2e/ Year
Battery Swapping Cost per Unit	(Electricity Charging Base Price*(1-Discount on Electricity Price)/(1-Charging Loss)/ (1-Electricity Transmission and Distribution Loss))+Battery Leasing Fee+Maintenance Cost+Cost of Depreciation - Tariff Adjustment	IDR/kWh
Battery Swapping Motorcycle battery Rent Cost	Annual Driving Range*Battery Swapping Price per KM	IDR/Year

(Contd...)

Appendix A: ***(Continued)***

Variable	Formula/Value (variable value "0" indicates an initial value)	Unit
Battery Swapping Motorcycle Driving Range	Battery Capacity in kWh*Battery Swapping Motorcycle Total Efficiency	km
Battery Swapping Motorcycle Economic Benefit Relative to Electric Motorcycle	(0.499*Benefit of battery swapping motorcycle purchase cost relative to electric motorcycle+0.501*Benefit of Swapping Cost Relative to Recharging)	-
Battery Swapping Motorcycle Economic Benefit Relative to ICE Motorcycle	(0.499*Benefit of Battery Swapping Motorcycle Purchase Cost Relative to ICE Motorcycle+0.501*Benefit of Swapping Cost Relative to Refueling)	-
Battery Swapping Motorcycle Total Efficiency	41.67	km/kWh
Battery Swapping Price per KM	(Battery Swapping Price per Unit/Battery Swapping Motorcycle Driving Range)*Battery Unit	IDR/km
Battery Swapping Price per Unit	(Battery Swapping Cost per Unit*Battery Swapping Station Margin)+Battery Damage Waiver+Reservation Fee	IDR/kWh
Battery Swapping Station Availability	IF THEN ELSE (Ideal Number of Battery Swapping Station=0, 0, Battery Swapping Station/Ideal Number of Battery Swapping Station)	-
Battery Swapping Station Construction	Additional Battery Swapping Construction/Battery Swapping Construction Lead time	Station/Year
Benefit of battery swapping motorcycle purchase cost relative to electric motorcycle	(-(Battery Swapping Electric Motorcycle Price-Electric Motorcycle Price))/MAX (Battery Swapping Electric Motorcycle Price, Electric Motorcycle Price)	-
Benefit of Battery Swapping Motorcycle Purchase Cost Relative to ICE Motorcycle	(-(Battery Swapping Electric Motorcycle Price-ICE Motorcycle Price))/MAX (Battery Swapping Electric Motorcycle Price , ICE Motorcycle Price)	-
Benefit of Swapping Cost Relative to Recharging	(Electric Motorcycle Recharging Cost-Battery Swapping Motorcycle battery Rent Cost)/MAX (Battery Swapping Motorcycle battery Rent Cost, Electric Motorcycle Recharging Cost)	-
Benefit of Swapping Cost Relative to Refueling	(ICE Refuel Cost-Battery Swapping Motorcycle battery Rent Cost)/MAX (Battery Swapping Motorcycle battery Rent Cost, ICE Refuel Cost)	-
Benefit of Swapping Station Availability	(Battery Swapping Station Availability-Charging Station Availability)/MAX (Battery Swapping Station Availability, Charging Station Availability)	-
Cost of Depreciation	(Production Cost of Battery Swapping Station -Residual Value)/Economical Life of Battery Swapping Station/Estimated Electricity Demand per Year*Depreciation Unit	IDR/kWh
Conversion Total Emission from Battery Swap Motorcycle to ICE Motorcycle	Estimated Electricity Demand per User per Year*Fuel Emission	kg CO_2e/Year
Electricity Emission	Emissions from Electricity equivalent to One liter of Fuel/Energy from Electricity Consumption Equivalent to One Liter of Fuel	kg CO_2e/kWh
Estimated Demand per Year	Estimated Electricity Demand per Year*Battery Swapping Station*Project Demand*Demand User	kWh/Year
Estimated Electricity Demand per User per Day	Battery Capacity in kWh/(Battery Swapping Motorcycle Driving Range/Average Distance Motorcycle in km)	kWh/Year
Estimated Electricity Demand per User per Year	Estimated Electricity Demand per User per Day*Battery Swap Motorcycle User*Demand User	kWh/Year
Estimated Electricity Demand per Year	Estimated Electricity Demand per User per Day*Battery Swap Motorcycle User	Units*kWh/Year
Fuel Emission	Emissions from One liter of Fuel/Energy from One Liter of Fuel Equivalent to Electricity Consumption	kg CO_2e/kWh
ICE Motorcycle Fuel Consumption	Annual Driving Range/ICE Average fuel Consumption	liter/Year
ICE Refuel Cost	Fuel Price*ICE Motorcycle Fuel Consumption	IDR/Year
Profit	Total Revenue-Total Cost	IDR
Total Cost	Battery Swapping Cost per Unit*Estimated Demand per Year	IDR/Year
Total Revenue	Battery Swapping Price per Unit*Estimated Demand per Year	IDR/Year

Appendix B: Battery swapping industry development module data

Variable	Value	Unit
Battery Pack Standardization	0	-
Battery Swapping Motorcycle Market Share	0.44	-
Battery Swapping Motorcycle swapping time	1/60	hours
Benefit of Charging Station Availability	0.51	-
Electric Motorcycle Driving Range	100	km
Electric Motorcycle Economic Benefit Relative to ICE	0.21	-
Electric Motorcycle Market Share	0.55	-
Electric Motorcycle Recharging Time	6	hours
ICE Average fuel Consumption	50.7	km/litre
ICE full Tank Capacity	5.5	Litre
ICE Refueling Time	0.0083	hours
Increase Ride Hailing per Year	0.1	1/Year
Initial Number of Battery Swapping Motorcycle User	28267	Units
Initial Number of ICE Motorcycle User	120,042,000	Unit
Initial Number of ICE Motorcycle User	14,000,000	Unit
Initial Number of Ride Hailing Motorcycle User	4,000,000	Units
Motorcycle Growth per Year	0.052	
Number of Refueling Station	6729	Units
Promotion Effectiveness	0.01	-
WOM Effectiveness	0.25	-
Additional Battery Swapping Construction	373	Station
Average Distance Motorcycle in km	23.48	km/Year
Battery Capacity in kWh	3.46	kWh
Battery Damage Waiver	800	IDR/kWh
Battery Leasing Fee	5517	IDR/kWh
Battery Swapping Construction Lead time	2	Year
Battery Swapping Electric Motorcycle Price	17,211,700	IDR/Units
Battery Swapping Motorcycle Total Efficiency	41.67	km/kWh
Battery Swapping Station Margin	1.45	-
Battery Swapping Station Motorcycle Ideal Ratio	1/10	Station/Units
Charging Loss	12.38	
Charging Station Availability	0.86	-
Discount on Electricity Price	0	IDR/kWh
Economical Life of Battery Swapping Station	15	Year/Station
Electric Motorcycle Price	28,270,000	IDR/Units
Electric Motorcycle Recharging Cost	279,189	IDR/Year
Electricity Charging Base Price	1644.52	
Electricity Cost of Battery Swapping	1370.43	IDR/kWh
Electricity Transmission and Distribution Loss	0.1	
Emissions from Electricity equivalent to One liter of Fuel	1.02	kg CO_2e
Emissions from One liter of Fuel	2.4	kg CO_2e/litre
Energy from Electricity Consumption Equivalent to One Liter of Fuel	1.2	kWh
Energy from One Liter of Fuel Equivalent to Electricity Consumption	1	kWh/litre
Fuel Price	10,000	IDR/litre
ICE Motorcycle Price	18,776,400	IDR/Units
Initial Battery Swapping Station	1401	Station
Maintenance Cost	1070	IDR/kWh
Production Cost of Battery Swapping Station	90,347,800	IDR/Station
Reservation Fee	1000	IDR/kWh
Residual Value	15,000,000	IDR/Station
Tariff Adjustment	493.58	IDR/kWh