ANALYSING THE ADOPTION OF ELECTRIC VEHICLES FOR URBANFREIGHT USING SYSTEM DYNAMIC APPROACH: DENPASAR CASE

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Abstract - In Denpasar, the capital of Bali, the escalating use of motorcycles for both private and commercial purposes hasincreased transportation and logistical issues while contributing to air pollution and noise pollution. This study explores the viability of implementing Motorcycle-Based Electric Logistic Vehicles (MBELV) as a sustainable solution. Employing a combination of qualitative and quantitative methods, including System Dynamics modelling, the research assesses various scenarios, such as government incentives, charging infrastructure policies, and promotional efforts, to promote willingness to adopt MBELVs in 2030 and 2060. Four scenarios are created, considering government incentives, charging infrastructure policies, and a mix of promotional efforts, charging infrastructure improvements, and financial incentives. The result showed that for 2030 the impact of policy 3 (a combination of promotional efforts, infrastructure support, and financial incentives) demonstrates the highest willingness rate, reaching nearly 98%. While in 2060, this same scenario leads to an astonishing 80% willingness to use MBELVs, contributing to a threefold increase in the total number of vehicles within just 40 years from 2023. These findings can serve as a valuable reference for policymakers and stakeholders seeking to promote electric-based logistics vehicles in Denpasar City, Bali.

Keywords - Motorcycle-Based Electric Logistic Vehicles (MBELV), Sustainability, Urban Logistics, System Dynamic, Policy.

I. INTRODUCTION

In recent years, road transport has faced significant challenges mainly related to climate change. High dependence on fossil fuels has led road transport vehicles to account for 74% of emissions worldwide (IEA,2022). The trend is projected to increase in people and goods movements (Pojani, 2020). While supporting commercial activity is essential to maintain living standards, the logistics industry still dominates with internal combustion engine vehicles (ICEs), which means the ecological footprint growth from the logistics industry is inevitable. Compared to developed countries, such as the United Kingdom and the Netherlands, most Asian cities use two and three-wheelers for their last-mile delivery such as in Vietnam, and Indonesia. However, most motorcycles are fossil fuel-based, contributing to environmental concerns like CO2 emissions. Thus, many governments have seen the possibility of eco-friendly freight transport by adopting electric motorcycles or cargo bikes (Mirhedayatian and Yan, 2018).

On the other hand, the inadequate charging infrastructure is believed to impede the widespread adoption of EVs. Another study reveals that oversupplies of charging facilities may result in inefficient operations. This problem might seem like a ‘chicken and egg’ dilemma (Struben and Sterman, 2008). The challenge here is the complexity of the issue, where policy outcomes influence policymaking or affect electric vehicle (EV) utility (Pasaoglu et al., 2016). Exploring the barriers and developing a framework for thinking about the problem ofMBELV implementation in Denpasar would provide insight and recommendations forpolicymakers. Nevertheless, the transition faced multiple barriers, including multi-sectoral and interconnected factors. Therefore, the study combines qualitative andquantitative methods to answer the questions.

This studyapplied System Dynamics as a method to analyze various factors that impact EV adoption (Liu, D. and Xiao, 2018) and assess the repercussions of interventions on the system (Shepherd, S.P., 2014). Additionally, System Dynamics tools, like Vensim, enable us to adjust various variables to achieve realistic objectives. Notably, no prior study currently examines the hurdles to adopting motorcycles for last-mile delivery in Denpasar City, Indonesia.

The limitation of this study lies in its geographical context and several concerns. First,it only focused on exploring motorcycle-based electric vehicles (MBELVs) for last-miledelivery in Denpasar City, capturing logistics patterns in Denpasar, Bali, Indonesia.The literature review, survey and expert interview are the basis for data collection.

II. METHODOLOGY

This study used System Dynamics to represent relations qualitatively and quantitatively to model Electric Vehicle (motorcycle-based) adoption on the logistic transport system in Denpasar, Bali, Indonesia. This approach facilitates the comprehension of the consequences of various actions and decisions while also enabling the analysis of the impacts stemming from endogenous and exogenous factors. The system Dynamic Model also supports calibration,

optimization, and simulation scenarios to aid evidence-based policymaking (Liu, D. and Xiao, 2018). The steps involved in building the model are explained in Figure 1 below.



Fig 1. Steps of the SD Modelling Process

2.1. Data Collection Method

For data collection, this study integrates both secondary and primary data sources. Secondary data, including government policies, reports, papers, and existing literature, provided a basic of the logistics condition in Denpasar. Due to limitations in existing numerical data, the construction of the Causal Loop Diagram (CLD) involved testing variables through expert interviews and questionnaires. Primary data was gathered through online interviews with experts from diverse backgrounds, including academics, government officials, and logistics operators, followed by a survey of 120 respondents from the targeted population in Denpasar.

To enhance the understanding of the Denpasar market for MBELV, expert interviews are conducted in a semi-structured format, which plays a crucial role in validating the Stock Flow Diagram (SFD) model by ensuring alignment with Denpasarscenarios and enhancing the model's reliability. Further, the coefficient and scale of the base level of the choice modelaresummarised in Table 1.

Variable	Units	Value	Evidence/Source
Purchase Price	£ '000	1,485	(ADB, 2022)
Emission	Range 1-10	1	(Shepherd, S. et al., 2012)
Range	miles	62	(ADB, 2022)
Speed	mph	100	Survey
Charging Availability	% Of stations	50	Survey
Charging Point per year policy	Unit	10	(Shepherd, S. et al., 2012)
Maintenance	Pound/mile	0,77	(ADB, 2022)
Electricity per charge	Pound/mile	0,23	(ADB, 2022)
GDP Growth Rate	%	0,05	Bali in the figures 2022
Reference rate social exposure	Dimensionless (dmnl)	0,05	(Oliveira et al., 2019)
Effect C122	Dimensionless (dmnl)	0,25	(Shepherd, S. et al., 2012)
Total Vehicle	Unit'000+Installed base MBELV	12095,383	(Statistics of Bali Province, 2022)
Subsidy duration	Years	10	Own Survey
Purchase Price subsidy	Pound'000/unit	0,358	(ADB, 2022)

Table 1. Values for SFD variables

2.2. Analysis Method

To understand the dynamics of Motorcycle-Based Electric Logistic Vehicles (MBELVs) adoption, the analysis phase used a multifaceted approach. Descriptive analysis was performed to describe the demographic distribution of respondents, while Likert Scale and Garret Rank Analysis were applied to assess the urgency of MBELV adoption, validating causal relationships in the Causal Loop Diagram (CLD). The CLD, which was tailored to Denpasar using existing models, was validated via semi-structured expert interviews and an online survey of 10% of Bali's current electric vehicle users.
Further, the Oliveira et al. (2019) Light Duty Vehicle (LDV) model was used as the basis for the Stock Flow Diagram (SFD), which was validated through expert interviews and surveys. The SFD detailed causalities by employing a social diffusion model based on Oliveira et al. (2019), with modifications based on Batley et al. (2004) with a calibration based on interviews and a survey of original work for the Denpasar situation.

III. RESULTS AND DISCUSSION

This study involved120 people as respondents from different backgrounds. The questionnaire was filed by 97logistic operators, 13 academicians and 10 government officers using an online form. The result shows that most respondents are below 35 years old (86%). Using the Likert-Scale, the preferences of the urgency to adopt MBELV showed positive feedback. On the other hand, the Garret Scale calculation has explained that respondents believe that purchase price and charging station werethe first and second most significant barriers to adopting MBELV in Bali. Subsequently, respondents ranked range, subsidy duration, average vehicle age, speed, and word of mouth as additional barriers. To complement the survey findings and enhance understanding, insights from five experts were incorporated. The causal loop diagram of MBELV was then explained in the model overview and simulated in several scenario test.

3.1.Model Overview

This study used the base model Field Oliveira et al. (2019) shown with blue colour; while,the red colour isthe extended variable of this study. The model has two rebalancing loops and one balancing loop. A

balancing loop is acycle where the influence of an increase or decrease in any variable extends through the loop and returns an offset opposite of the beginning position of the variable (i.e. if a variable increases the cycle will return to decrease the initial variable and vice versa). Whereas a balancing loop will make plateaus condition (stability). Each connection will also have eitherpositive or negative signs to show the impact of the cycle. Further, the model CLD is describedin Fig. 2. and explained in Table 2.

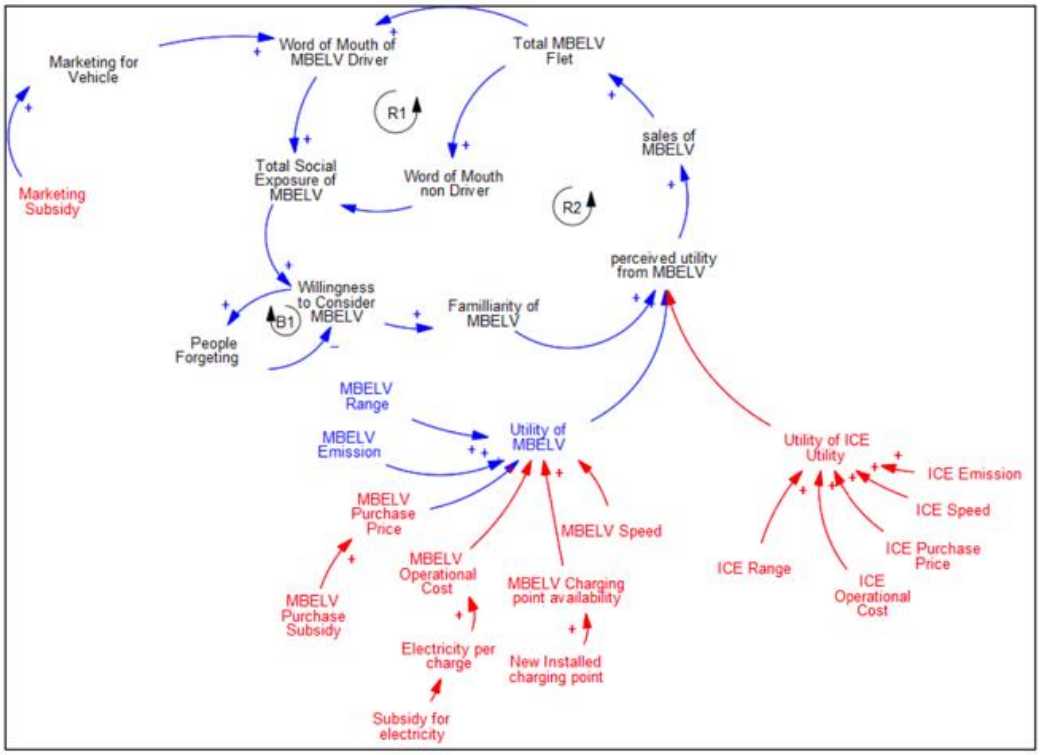


Fig 2. Final CLD of MBELV Adoption

Loop ID	Name Loop ID	Explanation	Evidence
R1	Impact of Driver to MBELV Adoption	**Total MBELV Fleet**→⁺ Word of Mouth of MBELV Driver →⁺ Total Social Exposure of MBELV →⁺ Willingness to Consider MBELV→⁺ Familiarity of MBELV →⁺ Perceived utility from MBELV→⁺ Sales of MBELV →⁺ **Total MELV Fleet**	More people adopting ELV means more ELVs sold and an increase in the amount of ELV in total vehicles, more people talking about ELV through word of mouth means more people get exposure of the ELV and more people Adopting ELV (Shepherd et.al., 2012; Oliveira, 2019)
R2	Impact of Non-Driver to MBELV Adoption	**Total MBELV Fleet**→⁺ Word of Mouth non driver →⁺ Total Social Exposure of MBELV →⁺ Willingness to Consider MBELV→⁺ Familiarity of MBELV →⁺ Perceived utility from→⁺ Sales of MBELV →⁺ **Total MELV Fleet**	More fuel availability means the range for the vehicle can be extended, means the city more attractive for people means, increase investment in the new charging point, means a decrease in the cost for a charging point, means more new charging points that will increase the fuel availability (MS Mastoi et.al., 2022; Ghisolfi 2022)
B1	Forgetting MBELV	**Willingness to Consider MBELV**→⁺WtC Lost→⁻ **Willingness to Consider MBELV**	MBELV market are assumed to consider that people might forget about the MBELV promotion option since the marketing and social exposure are not refreshed.

Table 2. Causal Loop Diagram Description

Loop R1 showcases a reinforcing feedback loop: More MBELVs increase driver adoption, amplifying word-of-mouth and social exposure, ultimately boosting sales. Similarly, loop R2 demonstrates that the total MBELV count influences non-drivers, leading to increased social exposure and, consequently, higher sales. In contrast, loop B1 introduces a balancing feedback loop, indicating that sustained exposure may lead to forgetting information, potentially increasing the willingness to consider MBELVs. These feedback loops have illustrated the complex dynamics of the system.

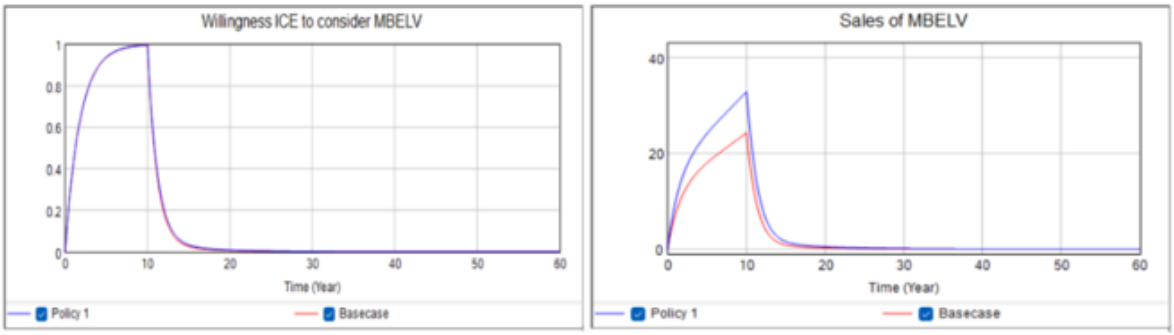
3.2. Scenario Test

In this section, different strategies and assumptions about subsidy, new charging policy and word of mouth (marketing strategy) were simulated using the System Dynamic application Vensim. Changes on attributed to simulate how the market tips from failure to success. The model was set to run for 60 years, and the unit of time specified at years, with atime step 0,25, some indicator recorded includes Willingness to Adopt MBELV and Sales of MBELV.

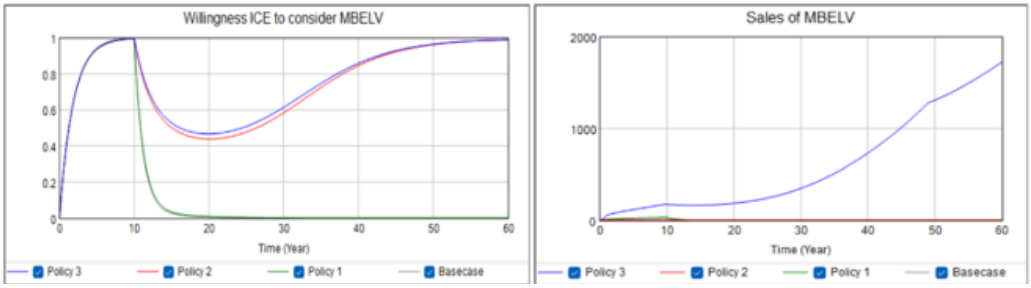
Scenario	Variables and Policy Option				
	Subsidy Purchase Price	New Charging Point/year Policy	Marketing Subsidy	Electricity subsidy	GDP
Baseline	-	-	10 years	-	0.05
Marketing Strategy	-	-	10 years	-	0.05
New Charging point	-	10 unit	-	-	0.05
Mix Policy	Rp. 7 million (10 years) for 10 years	10 unit	10 years	0,13 for 10 years	0.05

Table 3. Simulation Description

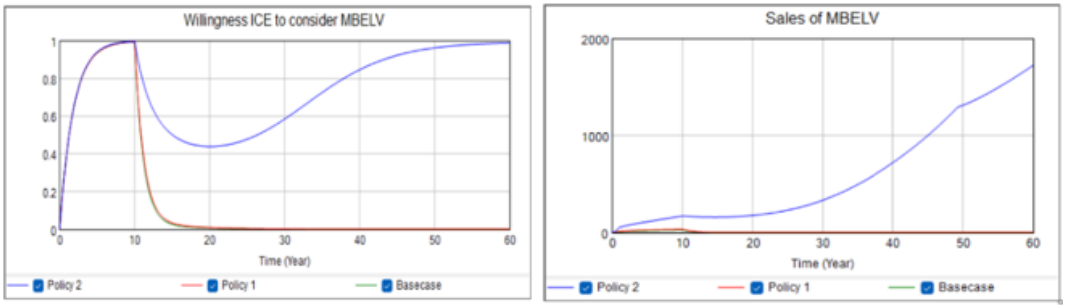
The baseline simulation is depicted in picture (a). the willingness dropped since people were already familiar with the ELV and adoptedthe ELV, so in the following years, fewer people were willing to adopt the ELV. Onthe other hand, since nothing is given to incentivize the adoption, the curve fell afterthe base marketing duration (10 years) ended.The red and blue line in the picture illustrate the marketing strategy scenario. It shows that with a 50% higher marketing effect, there is a slightly increasingadoption of MBELV sales.Picture (b) represented a new charging point simulation. As a result, charging station has increased the willingness to adopt MBELV by morethan 90%, which automatically added to the number of sales of MBELV.While Policy 1 and 2 focus on social and infrastructure, the 3rd policy scenarioimproves the vehicle's purchase and operational cost. The result proved in the picture (c) that this is the best simulation that can boost the willingness toconsider MBELVs up to an astounding percentage of 98,232% in 2030 and79,723% in 2060.



(a)



(b)



(c)

Fig.3. Policy Scenario

IV. CONCLUSIONS

This study aimed to 1)examine the barriers to MBELV adoption in Denpasar and 2) explore policy options to improvethe adoption and has extended a system dynamic model based on the study by Oliveira et al., 2019).

Three key factors (charging station infrastructure, social effect (word of mouth), and subsidy (purchase, operational) were discovered to be the most significant indicators of MBELV adoption intention.
This study used a simplified model that allows for easy experimentation with changes to the BAU case. The goal is to observe the effects of such changes in both favourable and unfavourable market conditions. However, because this model considers a constant number of ranges, speeds, and installed electric vehicles, some limitations are due to vast changes in the logistics and transportation markets. GDP has also become a hugely important factor, followed by marketing decisions.

However, it takes more time to see the changes based on the simulation. According to the mixed policy simulation, significant capital will be required to incentivize those things at the same time. Furthermore, with the current economic climate, operational costs may be difficult to subsidies. As a result, massive improvements to the energy source are critical.

To foster greater engagement, future research should seek increased interaction and involvement from diverse stakeholders in Denpasar or across Indonesia. Key recommendations for further investigation include:

1. Explore the choice model and utility function of MBELV logistic adoption for a broader geographical area.
2. Updating data and notable base unit to be Rupiah for Indonesia context.
3. Analyze side factors that might improve the adoption such as battery recycling and any other energy source.
4. Exploring human behaviours during the market shifts, to find differentfavourableoptions to be more applicable globally.

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