An Impact Assessment of the Motorcycle Electronification Policy in Taiwan: From the Economy-Energy-Environment (3E) Perspective

Sheng-Ming Hsu[1], Hsing-Chun Lin[2], Wen-Hung Huang[3], Min-Long Chen[4], Ching-Cheng Chang[5]

Abstract

As the problem of global warming becomes increasingly serious, countries regard electric vehicles as a key measure to reduce carbon emissions. Asia countries are highly dependent on motorcycles, with Taiwan ranking at the top in terms of motorcycle density (followed by Vietnam, India, Malaysia and Thailand). As of October 2023, there are 620 motorcycles per thousand people, and the number continues to increase. Taiwan government plans to completely ban the sale of fuel-powered motorcycles by 2040 and achieve a 100% market share of electric motorcycles. It places special emphasis on the localization of the industry chain and fosters the local electric motorcycle industry through subsidies, research and development, etc. As technology gradually improves, with maturity and improved price competitiveness, electric locomotives have become a breakthrough in carbon reduction. Similar policies have been successful in countries such as Norway, showing rapid growth in the electric vehicle market and reductions in carbon emissions (Figenbaum, *et al*., 2020). China's new energy vehicle subsidy policy has also driven a significant increase in electric vehicle sales (Zhang, *et al*., 2020). In addition, the improvement of charging infrastructure and renewable energy are crucial to the popularization of electric motorcycles, especially in Sweden and the Netherlands (Bakker & Vassilakopoulou, 2017; IEA, 2021). Therefore, Taiwan's electric locomotive policy will help reduce domestic greenhouse gas emissions, green the energy structure, and promote economic development.

This study applies the dynamic computable general equilibrium model (CGE) and the 2021 Taiwan Input-Output Table to explore the development of Taiwan's electric motorcycle industry. The cost structure and distribution flow of electric motorcycles in the original motorcycles sector will be separated into an independent sector to facilitate the subsequent assessment of its impact on industrial development, energy use, and

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greenhouse gas (GHG) emission. We first determine the total output value of Taiwan's electric motorcycles which based on the number of electric motorcycles registered by the Ministry of Transportation and Communications (MOTC) and the production and sales statistics of the Taiwan Vehicle Industry Association. Second, the total output value of Taiwan's electric motorcycles is determined based on the survey data of Taiwan manufacturers. After the input cost structure of electric motorcycles production is determined based on the data, it is scaled by gross domestic product. Finally, the distribution of electric motorcycles is estimated based on household income and expenditure surveys and industrial survey data.

This paper analyzes the multiple impacts of Taiwan's motorcycle electronification policy from three perspectives: economy, energy, and environment. We also designed several policy scenarios, such as using subsidy incentives to increase electric motorcycle sales and banning the sale of fuel motorcycles, to explore the impact of different scenarios on the electric motorcycle industry chain. However, these policies will also bring structural shocks to the traditional fuel locomotive market. Therefore, we explore the impact of electric locomotive development policies on the overall economy, industrial development, and changes in employment demand from an economic perspective. In addition, the promotion of electric motorcycles will significantly reduce dependence on petroleum gasoline, help Taiwan's energy structure adjustment, and promote the transition to green energy. As the proportion of renewable energy increases, Taiwan's electricity carbon emission coefficient will be significantly reduced, further reducing carbon emissions over the entire life cycle of electric motorcycles and laying the foundation for achieving the net zero emissions target by 2050. This process will not only have a positive impact on the environment, but will also promote the joint development of the economy and energy, and promote Taiwan's steady progress in the global green transformation wave. Therefore, motorcycle electronification policy is not only an effective means to address climate change, but also a key strategy to achieve sustainable economic growth in Taiwan.

Keywords: Electric motorcycle, Greenhouse gas emissions, Computable general equilibrium model

1. Introduction

Amid the increasingly severe trends of global climate change and warming, the low-carbon transition of the transportation sector is regarded as a key strategy for achieving carbon neutrality and sustainable development goals (Figenbaum et al., 2020; International Energy Agency [IEA], 2021). Among various options, electric vehicles—particularly electric two-wheelers (E2Ws)—have emerged as a vital tool for urban carbon reduction due to their high energy efficiency and low emissions. In Asia, there is a high dependence on motorcycles for daily transportation, with Taiwan standing out in particular. As of October 2023, Taiwan had 620 motorcycles per 1,000 people, the highest in the world (Ministry of Transportation and Communications, 2023), underscoring the indispensable role motorcycles play in daily mobility. Taiwan has pledged to ban the sale of fuel motorcycles starting in 2040 and is actively promoting electric motorcycle alternatives through subsidies, R&D investments, and localizing supply chains to build a comprehensive electric motorcycle ecosystem. These efforts aim to simultaneously achieve industrial transformation and environmental sustainability (IEA, 2021).

On the consumer behavior front, previous studies have shown that environmental awareness and green image positively influence the willingness to purchase electric motorcycles (Liang & Yu, 2005; Liu & Lu, 2018). In Asian countries like Vietnam, fluctuations in oil prices and the commercialization of electric two-wheeler technologies have also been confirmed as major drivers of market penetration (Jones et al., 2013). Furthermore, Weiss et al. (2015) compared price trends between the Chinese and European markets and found that prices for electric two-wheelers in China dropped by 30% from 1999 to 2005, while prices in Europe remained relatively stable, suggesting that policy intervention and market structures play significant roles in price formation.

In terms of technological and energy transitions, electric two-wheelers also demonstrate considerable carbon reduction potential. In Norway, for instance, Figenbaum et al. (2020) found that comprehensive tax incentives and infrastructure development significantly increased electric vehicle penetration and effectively reduced transportation sector emissions. China also rapidly expanded its electric vehicle market following the implementation of new energy vehicle subsidies (Zhang et al., 2020). The development of charging infrastructure and the increase in renewable energy share are also seen as essential conditions for successful electrification (Bakker & Vassilakopoulou, 2017; IEA, 2021). From an environmental perspective, Tsai (1996) noted that Taiwan began research and development of electric two-wheelers as early as 1995, with per-unit carbon emissions significantly lower than those of fuel motorcycles. Lee and Pan (2003), using life cycle assessment (LCA), found that while emissions during the use phase are lower for electric two-wheelers, more solid waste is generated during the end-of-life phase, indicating the need for a full life cycle evaluation. Lin et al. (2008) also emphasized that pollution may shift across different stages, and piecemeal comparisons should be avoided.

However, LCA—as a static analysis tool—cannot capture the economic and behavioral structural changes induced by policy shifts and struggles to handle markets with highly heterogeneous product types (Neves et al., 2024). In recent years, computable general equilibrium (CGE) models have been increasingly applied to analyze electric vehicle policies. These models can simulate resource reallocation among sectors, changes in energy demand, and emission pathways under different policy scenarios (Guo et al., 2021). CGE-based studies from China, Laos, and Taiwan have shown that while strong electrification policies can lead to significant emission reductions, they may also result in GDP decline and contraction of traditional industries, thus presenting an "environment–economy trade-off" (Jiang et al., 2020; Lin et al., 2023; Khamphilavanh & Masui, 2020).

In summary, while electric two-wheelers hold considerable potential for carbon reduction and policy implementation, their overall environmental and economic impacts require integrated assessments using tools such as LCA and CGE. This is especially true in markets like Taiwan, where motorcycle dependence is particularly high. This study aims to address this research gap by employing a dynamic CGE model to simulate policy effects under multiple scenarios, with the goal of providing more evidence-based recommendations for sustainable and net-zero transportation policies.

2. Electric Two-Wheeler Development and Future Policy Goals in Taiwan

Taiwan is known for having the highest density of motorcycles in the world, with both the total number and usage rate of motorcycles steadily increasing over the past decade. According to statistics from the Ministry of Transportation and

Communications (2023), as of October 2023, the total number of registered motorcycles nationwide had reached 14.53 million, rising further to approximately 14.57 million by March 2024. This underscores the central role of motorcycles in Taiwan's transportation system. With one of the highest per capita motorcycle ownership rates globally, motorcycles have become an indispensable mode of daily commuting for Taiwanese citizens (Lin et al., 2006). However, the sheer number of motorcycles also imposes multiple environmental and energy-related challenges.

First, in terms of air pollution, fuel motorcycles have been identified as one of the main contributors to urban air quality deterioration. According to Taiwan's Environmental Protection Administration (EPA) emission inventory and empirical studies, motorcycles contribute between 19.6% and 38% of carbon monoxide (CO) emissions and 10.6% to 64% of hydrocarbon (HC) emissions in specific areas (Lin et al., 2006; Wu et al., 2016). In addition, fine particulate matter (PM2.5) emissions from two-stroke and four-stroke motorcycles are recognized as a critical factor affecting urban air quality and public health (Research Highlights Editorial Team, 2021; Chinese Institute of Engineers, 2018). As a result, both environmental authorities and academia generally advocate phasing out old motorcycles—especially two-stroke motorcycles—as a key strategy to reduce PM2.5 concentrations (Chinese Institute of Engineers, 2018).

Second, motorcycles are also a major source of urban noise pollution, affecting the quality of life for residents over the long term. Although each individual motorcycle consumes a relatively small amount of gasoline, the large overall fleet size leads to significant total gasoline consumption, thereby exacerbating Taiwan's dependence on imported fossil fuels and posing potential risks to energy security (Ministry of Transportation and Communications, 2023). This fossil fuel–dependent transportation model also stands in sharp contrast to Taiwan's "2050 Net-Zero Transition" policy, which outlines electrification of the transportation sector as a key objective (National Development Council, 2022).

Against this backdrop, the government began promoting electric two-wheelers policies as early as 1998. The Environmental Protection Administration (now the Ministry of Environment) initially focused on replacement subsidies (Taiwan Today, 2014), while the Ministry of Economic Affairs has gradually developed a comprehensive policy system through purchase subsidies, commodity tax reductions, and technical R&D support. Since 2009, central and local governments have jointly launched a new wave of promotion programs, incorporating not only economic incentives but also industrial chain development, charging infrastructure expansion, and regulatory standard-setting. The overall policy framework has since evolved toward a more integrated system (Sustainable Transport Strategy). According to Industrial Production, Shipment and Inventory Statistics Survey Industrial Statistics from the Department of Statistics, Ministry of Economic Affairs, the output value of Taiwan's electric two-wheeler industry reached NT$830 million in 2015 and grew to NT$5.52 billion by 2024. Furthermore, data from the Highway Bureau of MOTC show that domestic electric motorcycle sales have demonstrated an annual doubling trend. By dividing total output value by the number of units sold (see Table 1), it can be observed that the average unit price has been declining year by year.

Starting in 2015, Taiwan's electric motorcycle market experienced rapid growth under strong government subsidy policies. From 2015 to 2019, the average annual growth rate in output value exceeded 80%, and sales volumes nearly doubled each year, reflecting strong policy incentives and market confidence. In particular, the government's 2017 announcement of a long-term ban on the sale of fuel motorcycles by 2035 further boosted public expectations for electrified transport. Combined with that year's maximum subsidy of up to NT$13,000, electric motorcycles gained a significant price advantage, driving a surge in sales.

Literature suggests that purchase subsidies and tax incentives play a critical role in lowering the initial cost barrier and stimulating demand for electric two-wheelers (Huang et al., 2018; Factors Influencing…, 2025). Even during the COVID-19 pandemic, the market demonstrated a certain level of resilience, indicating that policy interventions can stabilize market operations under high uncertainty.

However, since 2020, significant changes have been made to electric two-wheeler subsidies. The Ministry of Economic Affairs reduced subsidies for heavy and light electric motorcycles from NT$10,000 to NT$7,000, and for small light motorcycles from NT$7,200 to NT$5,100. More critically, the Environmental Protection Administration eliminated the purchase subsidies (previously NT$3,000 for heavy/light motorcycles and NT$1,000 for small light motorcycles), retaining only incentives for replacing old vehicles. The inclusion of phase 7 emissions standard fuel motorcycles in the subsidy scheme further eroded the relative advantage of electric motorcycles.

This abrupt policy shift led to a historic drop in sales in 2020, with only 105,753 units sold—a year-on-year decrease of 41.76%. Output value also fell by 45.33%. This drastic decline not only reflects the direct effect of reduced subsidies but also highlights a sharp loss of consumer confidence. From 2021 to 2022, the market entered a period of stagnation and adjustment. Despite relatively stable subsidy policies, consumer confidence had not fully recovered, and electric motorcycle sales continued to decline. The simultaneous drop in average unit price suggests increasing pressure from price competition across the industry. Since 2023, increasing public awareness of energy efficiency and the strengthening of brand recognition have contributed to a modest market recovery. Both sales volume and average unit price have shown upward trends, suggesting a gradual revitalization of the electric two-wheeler sector. According to manufacturers interviewed, the decline in sales can be directly attributed to the 2020 subsidy reduction.

Table1 Output value of electric motorcycle sector

Year	Output value		Sales volume		Average unit price	
	Output value (NT$1,000)	Growth Rate	Sales Volume (units)	Growth rate	NT$/unit	Growth rate
2015	835,850	-	12,150	-	68,794	-
2016	1,674,749	100.36%	21,394	76.08%	78,281	-13.79%
2017	3,483,897	107.86%	50,144	134.38%	69,424	-11.32%
2018	6,352,381	82.19%	91,103	81.68%	69,619	0.28%
2019	12,188,496	91.72%	181,587	99.32%	66,965	-3.81%
2020	6,647,311	-45.33%	105,753	-41.76%	62,857	-6.13%
2021	5,191,719	-21.90%	88,761	-16.07%	58,491	-6.95%
2022	4,980,474	-4.07%	83,251	-6.21%	59,825	2.28%
2023	5,360,881	7.64%	84,331	1.30%	63,570	6.26%
2024	5,527,729	3.11%	90,234	7.00%	61,260	-3.63%

Sources：Department of Statistics, Ministry of Economic Affairs（2025）

In response to global climate change and the trend toward carbon neutrality, electric two-wheelers have been incorporated as a core component of Taiwan’s “Electric & Carbon-Free Vehicles” and are part of the national goal to achieve 100% electric motorcycle sales by 2040 (Ministry of Transportation and Communications, 2023).

This plan not only integrates inter-ministerial resources but also emphasizes the simultaneous transformation of industry and infrastructure. Key measures include expanding subsidy programs, establishing charging and battery-swapping networks in rural areas, enhancing battery recycling and energy efficiency standards, strengthening grid resilience, and addressing the issue of just transition for the traditional internal combustion engine industry. This strategy reflects the Taiwanese government's strong commitment and forward-looking approach toward achieving net-zero carbon emissions by 2050 (National Development Council, 2022).

3. Model and database

General Equilibrium Model for Taiwanese Economy and Environment (GEMTEE) is a dynamic recursive computable general equilibrium (CGE) model. What sets it apart from other CGE models in Taiwan is its consideration of dynamic systems involving investment and population. The model accounts for age and gender population distributions and long-term demographic trends. The investment mechanism allows for capital stock transfer across periods, which industries can utilize for production in subsequent periods. GEMTEE has also been regionalized and developed with submodules that connect to human resources, energy security, and water security. The completed related economic and sustainable development indicators include economic growth, carbon emissions, food security, population baseline forecasts, low birth rates, long-term care systems, global value chains, and the fiscal impacts of major public investments (Chen et al., 2015; Liu et al., 2018).

3.1 Basic Structure of the GEMTEE Model

The basic theory behind the GEMTEE model is derived from the MONASH dynamic CGE model, which is designed for policy simulation, historical analysis, and forecasting (Dixon and Rimmer 2002, Dixon et al. 1982). Within the general equilibrium analytical framework, GEMTEE uses inter-sectoral transaction data to capture the linkages between industries, enabling it to reflect the structural adjustments and other macroeconomic impacts in response to external shocks.

The system of equations in the GEMTEE model, which describes economic behaviors and their relationships, generally includes the following components: industry demand for intermediate inputs and primary factors, investment and demand for investment goods, household final demand, export, supply of goods and production inputs, government expenditures, transport margin and indirect taxes, macroeconomic indices and so on (Lin et al. 2015, Liu et al. 2018, Hsu et al. 2020).

The GEMTEE database includes modules for population, fiscal policy, economy, and the environment, as shown in Fig. 1. In the population module, per capita income influences life expectancy and fertility rates, which in turn affect natural population changes. Additionally, the composition of the population is influenced by net migration. Within the economy module, the model primarily consists of input-output tables. The model's impacts are driven by natural population changes calculated by the population module, as well as feedback from education and workforce training, which influence labor endowments. These factors lead to changes in industrial production techniques and industry structure through the endogenous dynamic mechanism of investment returns. Furthermore, changes in population composition, such as aging and declining birth rates, also affect private consumption and the pattern of consumer demand.

In the fiscal module, government revenue mainly comes from environmental taxes calculated by the environmental module, as well as corporate income taxes, individual (personal) income taxes, social security and health insurance fees, and commodity taxes computed from the economy module. The expenditures under the fiscal module consist of social welfare spending, recurring government expenditures, and government investments.

The social module primarily examines the long-term care system for the elderly under social insurance and social assistance policies, as well as childcare and maternal care policies for younger populations. It also explores the effects of immigration policies on net labor migration.

Finally, the environmental module uses the environmental quality accounts. It analyzes factors such as water, energy (including electricity), and land use. In addition to being considered as production inputs, these factors are also analyzed from the perspective of external costs to evaluate related taxes and fees.

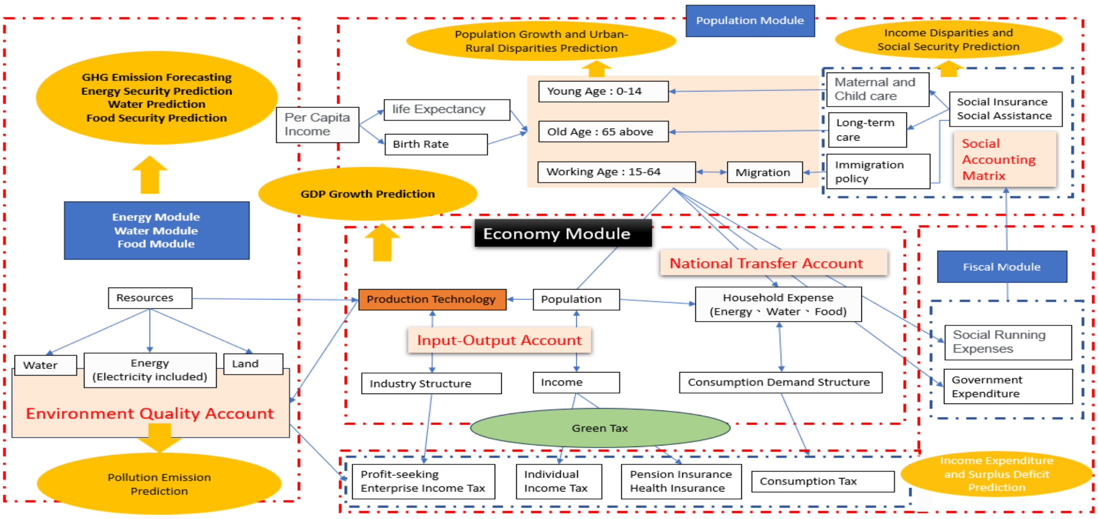


Figure 1. GEMTEE framework

In the GEMTEE model, the production inputs of the industry in the model are constructed as a six-level nested structure as in Fig. 2, which describes the economic behavior of production, consumption, import and export. The nested structure allows the decision-making process at different levels to proceed independently, and producers decide on their optimal combination of inputs, subject to cost minimization and production function constraints.

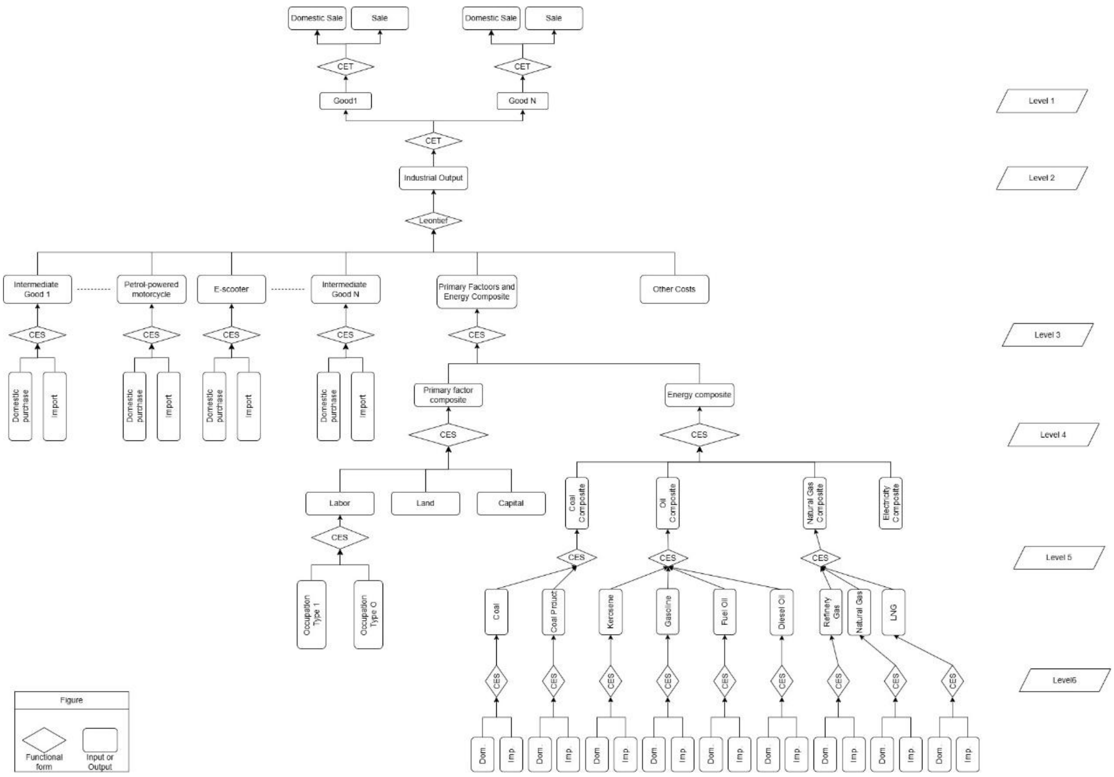


Figure 2. GEMTEE's nested production structure

The top level is the product market structure, where the CET function determines whether the product will be sold to the local market or exported. The second level covers industrial output which is produced using intermediate inputs, a composite of energy and primary factors, and other input costs. These input factors are aggregated using the Leontief function, i.e., an increase in production requires an equal increase in the proportions of the various types of inputs.

The third level shows how intermediate goods 1 through N, and the combination of energy composite and primary factor composite are aggregated. Each intermediate input product is either domestically purchased or imported, the composition of which is determined by the elasticity of substitution in the CES function for each intermediate good. Likewise, the combination of energy and primary factor composites are aggregated using a CES function with its own elasticity of substitution.

The fourth level describes how the energy and primary factor composites are aggregated using their own CES functions. Primary factors consist of land, labor, and capital. Energy is composed of different energy goods including coal products, oil products, natural gas products and electricity.

In the fifth level, labor is aggregated across several occupation types with its own CES function. Each energy good is also further composed of sub-products. Except for electricity, each energy good is aggregated using CES; and in the sixth level, each energy sub-product is either domestically purchased or imported, the combination of which is also described using CES. For the electricity sector, its sub-products are aggregated using a Technology Bundle Approach (TBA) as in Li et al.(2000).

3.2 Decomposition of EV from motorcycle sector

This study utilizes a Computable General Equilibrium (CGE) model to evaluate the environmental and economic impacts of the electric two-wheeler (E2W) industry. The primary database is based on the 2021 Input-Output Table with 163 sectors published by the Directorate-General of Budget, Accounting and Statistics (DGBAS), Executive Yuan. According to the 2021 sector classification report, sector No. 99, labeled as "Motorcycles and Parts," includes both fuel and electric motorcycles.

However, their input structures and input compositions differ significantly. Therefore, to accurately assess the impact of electric motorcycles on the broader industrial structure, this study separates the electric two-wheeler industry into an independent sector.

Since the latest published Input-Output Table does not provide a standalone classification for electric two-wheelers, nor does it include updated input-output data specific to the current state of the E2W industry, this study incorporates fieldwork to better align the model with real-world conditions. Information on production inputs and distribution channels was collected through interviews with major domestic electric two-wheeler manufacturers and industry associations.

Production inputs are used to construct the input structure of the industry sector and include intermediate inputs—such as vehicle structure and business-related costs—as well as primary inputs, categorized by the type of production income recipients. Sales and distribution channel information is employed to build the demand structure of the sector, providing detailed data on the flow of E2W products.

Based on the information obtained through these interviews, as well as references to domestic and international literature, the following sections present a summary of the E2W industry's output value, input structure, and demand structure.

As shown in Table 2, we begin by presenting the input-output relationships among three sectors (Sector 1, Motorcycle Sector, and Sector *n*) using an input-output table that includes intermediate demand, final demand, and total output for each sector. In the table, x_i^j represents the amount of intermediate input from Sector *j* used by Sector *i*; C_i and I_i denote the final consumption and investment demand for Sector *i*, respectively; and X_i represents the total output of that sector. For original inputs, labor and capital are denoted by L_j and K_j, respectively, representing the amounts of labor and capital required by Sector *j*.

Table 2. Taiwan Input-output Table (Three-Sector Example)

I-O Table		Intermediate Demand			Final Demand		Output
		Sector 1	Motorcycle	Sector n	Consumption	Investment	
Intermediate Input	Sector 1	x_1^1	x_1^m	x_1^n	C_1	I_1	X_1
	Motorcycle	x_m^1	x_m^m	x_m^n	C_m	I_m	X_m
	Sector n	x_n^1	x_n^m	x_n^n	C_n	I_n	X_n
Original Input	Labor	L_1	L_m	L_n			
	Capital	K_1	K_m	K_n			
Input		X_1	X_m	X_n			

Since the original motorcycle sector includes both fuel and electric motorcycles, which differ significantly in terms of production inputs and cost structure, this study disaggregates the original motorcycle sector into two separate sectors: Electric Motorcycle and fuel Motorcycle, denoted by the subscripts *em* and *fm*, respectively, as shown in Table 3.

Table 3. Modified I-O Table: Fuel vs. Electric Motorcycles

I-O Table		Intermediate Demand				Final Demand		Output
		Sector 1	Electric Motorcycle	Fuel Motorcycle	Sector n	Consumption	Investment	
Intermediate Input	Sector 1	x_1^1	x_1^{em}	x_1^{fm}	x_1^n	C_1	I_1	X_1
	Electric Motorcycle	x_{em}^1	x_{em}^{em}	x_{em}^{fm}	x_{em}^n	C_{em}	I_{em}	X_{em}
	Fuel Motorcycle	x_{fm}^1	x_{fm}^{em}	x_{fm}^{fn}	x_{fm}^n	C_{fm}	I_{fm}	X_{fm}
	Sector n	x_n^1	x_n^{em}	x_n^{fm}	x_n^n	C_n	I_n	X_n
Original Input	Labor	L_1	L_{em}	L_{fm}	L_n			
	Capital	K_1	K_{em}	K_{fm}	K_n			
Input		X_1	X_{em}	X_{fm}	X_n			

(1) Input structure of the electric two-wheeler industry

According to research conducted by the Industrial Technology Research Institute (ITRI) and the Automotive Research & Testing Center (ARTC), the cost structure of electric two-wheelers can be categorized into six major systems: power battery system, electric drive system, electrical system, transmission system, suspension system, and body structure (see Figure 2). The costs associated with these systems, along with vehicle assembly, sales, maintenance, and other operational expenses, constitute the intermediate inputs of the electric two-wheeler industry—i.e., the essential components required to produce an electric motorcycle.

In addition to intermediate inputs, primary inputs are categorized based on the recipients of production income. These include compensation of employees, operating surplus, consumption of fixed capital, and net taxes on production and imports. The sum of intermediate and primary inputs constitutes the total input of the industry, which is equivalent to the total output value generated by the electric two-wheeler sector. The following section provides a detailed explanation of how the input structure for the electric two-wheeler sector was constructed.

Based on the survey conducted by Ho (2020), this study categorizes the intermediate input structure of electric motorcycles into five major systems and business-related costs which is shown in Fig 3. Among these, the power battery system accounts for the largest share, approximately 33.89%. This system includes the battery pack and Battery Management System (BMS), which serve as the core power source for electric motorcycle propulsion. Notably, the battery cell is the most expensive component in the entire vehicle. Since there are currently no domestic manufacturers capable of mass-producing battery cells, they must be imported.

The electric powertrain which consists of the motor and motor controller, is the second-largest cost component, accounting for 18.09% of intermediate inputs. Functionally equivalent to the engine in a conventional fuel-powered motorcycle, this system can now be independently produced by domestic manufacturers and is widely used across various brands.

For the components shared with fuel motorcycles:

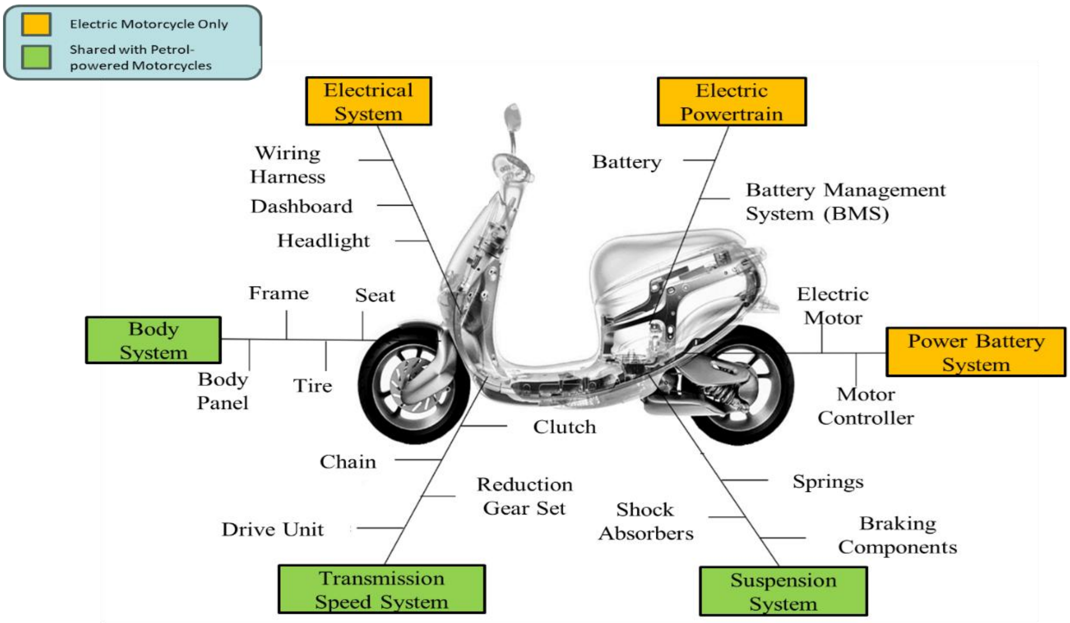
- The transmission system accounts for 11.93% (including drive units, reduction gear sets, chains, etc.),

- The body system accounts for 6.29% (including the frame, body panel, seat, tires, etc.),
- The suspension system accounts for 6.37% (including shock absorbers, springs, braking components, etc.).

These three systems are highly similar to those found in fuel-powered motorcycles in terms of component design and manufacturing processes and are directly integrated into existing supply chains.

Regarding primary factor inputs, labor accounts for 9.91% and capital for 13.52%, totaling 23.43%. These proportions reflect the factor income structure of the electric motorcycle sector, as shown in Table 4.

Overall, the intermediate inputs (76.57%) and primary inputs (23.43%) together form the foundation for the CGE model simulations used to assess the economic and environmental impacts of the electric motorcycle industry. This structure provides the analytical basis for evaluating sectoral impacts within the CGE framework.



Source: ARTC(2018)

Figure 3. Structure of electric motorcycle

Table 4. Input Structure of E2W sector

Input item	Cost item	Percentage (%)
Intermediate input	Power battery system	33.89%
	Electric powertrain	18.09%
	Suspension system	6.37%
	Transmission system	11.93%
	Body system	6.29%
Original input	Labor	9.91%
	Capital	13.52%
Total		100%

Source: Ho (2020)

Given that the demand structure for electric motorcycles can be categorized into intermediate demand and final demand, the former primarily reflects purchases made by industries or other economic agents for use as inputs in their production or service processes, while the latter represents electric motorcycles sold as final consumption goods or export commodities. This study also draws on the survey conducted by Ho (2020), which indicates that corporate or institutional purchases account for approximately 9.73% of total demand (intermediate demand), whereas the remaining 90.27% is attributed to household and individual consumers, making final consumption the dominant source of demand for this sector.

Based on the above information, the sales channels and their corresponding proportions for the electric motorcycle industry have been compiled, and the resulting demand structure for the newly defined electric motorcycle sector is presented in Table 5.

Table 5. Demand Structure of Newly Defined Electric Motorcycle Sector

Item	Intermediate Demand	Final Demand	Total
Electric Motorcycle	9.73%	90.27%	100%

(2) Discussion on power and sensitivity of dispersion

In I-O analysis, the power of dispersion and sensitivity of dispersion indices of the motorcycle industry help assess its role within the economic system. As shown in Fig 4, the overall motorcycle industry is located in the second quadrant, indicating that it exerts a relatively high influence on other sectors (index of the power of dispersion ≈ 1.25), while also displaying a moderate-to-high sensitivity to external shocks (index of the sensitivity of dispersion ≈ 0.62). This suggests that the motorcycle sector is not only tightly linked to upstream supply chains such as metalworking, component manufacturing, plastics, and electronic systems, but is also highly responsive to shifts in consumer demand.

Therefore, when formulating industrial policy or designing pathways for net-zero transition, treating the "motorcycle industry" as a single aggregated sector may overlook its internal structural heterogeneity and transformation potential.

When the motorcycle industry is further disaggregated into fuel motorcycles and electric motorcycles, Fig 5 illustrates differences in their power and sensitivity of dispersion. The fuel-powered motorcycle sector remains in a relatively high-influence zone (power ≈ 1.28) and moderate-to-high sensitivity zone (≈ 0.63), indicating that it continues to dominate both production and consumption, with strong inter-industry linkages and responsiveness to external changes.

By contrast, the electric motorcycle sector is situated in a lower dispersion quadrant, with power of dispersion ≈ 0.58 and sensitivity of dispersion ≈ 0.38, suggesting that despite growth potential and policy support, it remains peripheral within the current industrial structure, with limited influence and exposure to other sectors.

This disaggregation not only reveals the transitional dynamics within the motorcycle industry, but also underscores the importance of sectoral differentiation in policy design and carbon transition strategies. Conducting analysis based solely on the aggregate motorcycle industry may fail to distinguish between high-emission fuel motorcycles and low-emission electric motorcycles, potentially resulting in inefficient resource allocation and suboptimal policy performance. A more granular approach is therefore essential for crafting targeted support mechanisms and monitoring systems for each sub-sector.

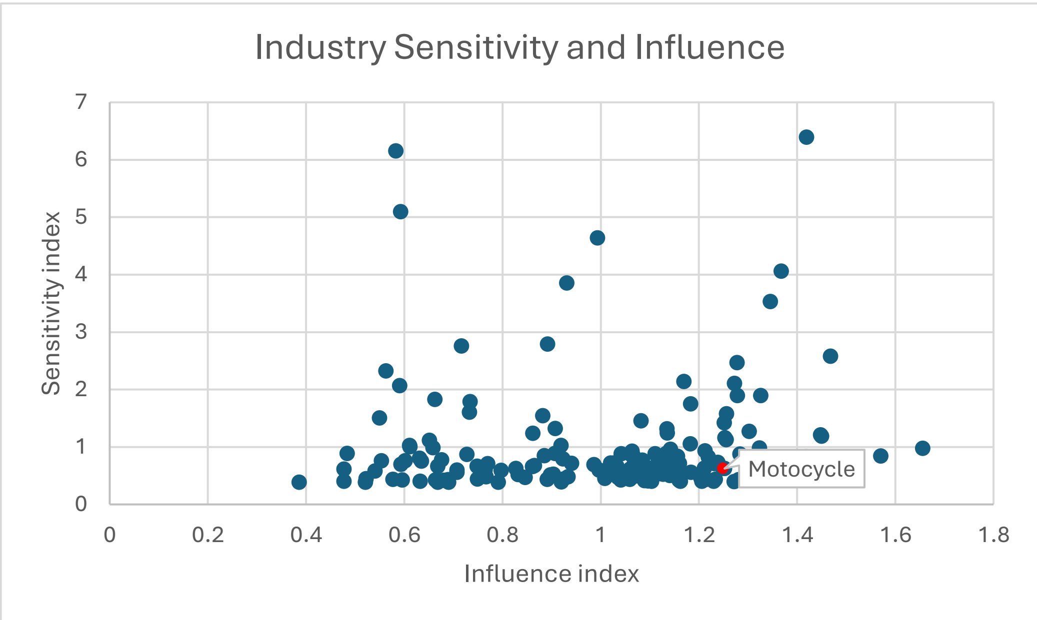


Figure 4. Indices of the power and sensitivity of dispersion of motorcycle sector

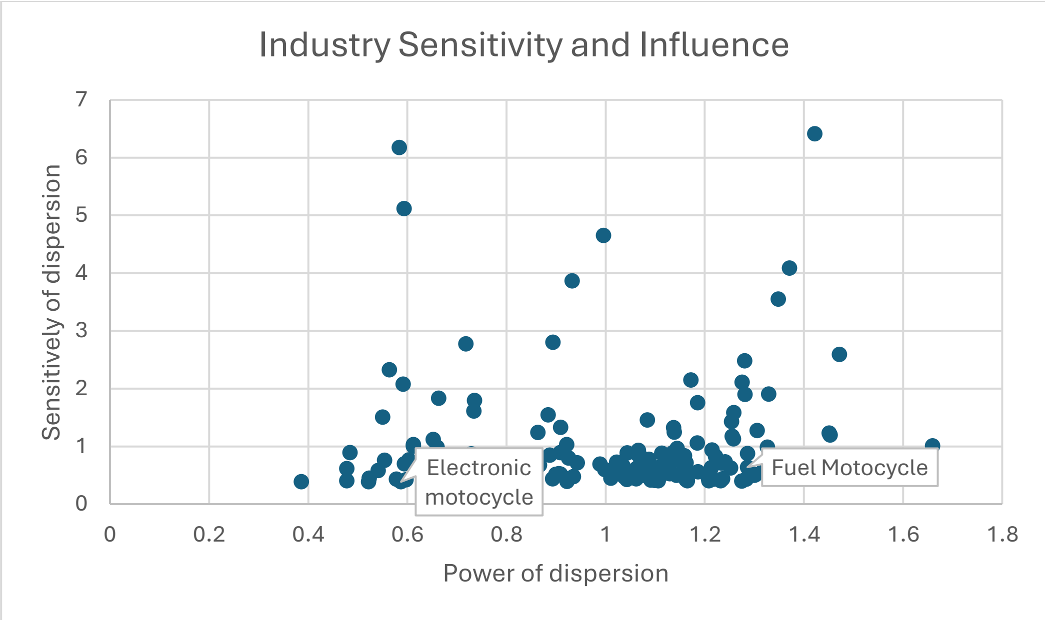


Figure 5. Indices of power and sensitivity of dispersion of electric and fuel motorcycle sector

3.3 Emission intensity of six major sectors and emission of electric motorcycle

The construction of the greenhouse gas (GHG) emission matrix is primarily based on the emission sources and emission data provided in the National Greenhouse Gas Inventory Report. Each emission source is mapped to its corresponding sector in the Input-Output (I-O) Table. Using information on the use of energy or materials and the production processes within each industrial sector, the emissions are allocated or attributed accordingly.

Emission sources in the inventory are broadly categorized into fuel combustion sources and non-fuel combustion sources. Fuel combustion sources refer to emissions generated during the combustion of fossil fuels in the industrial production process. These account for approximately 90% of Taiwan’s total GHG emissions, making them the country’s dominant emission source. Non-fuel combustion sources include all other emission sources not related to fuel combustion.

By dividing the total GHG emissions of each sector by its total output value for the year 2021, emission factors can be calculated. These indicate the amount of emissions generated per NT$1 million of output. The transportation sector ranks highest in emissions per unit of output, followed by the environmental services sector, then energy, agriculture, manufacturing, and finally the residential and commercial sector.

The total output vector x for all sectors in an economy can be expressed by eq.(1):

$$x = (\frac{z_{ij}}{x_j})x + y = Ax + y \quad (1)$$

where x is the vector of total sectoral outputs, $A= (\frac{z_{ij}}{x_j})$ is the technical coefficient matrix, z_{ij} represents the intermediate input provided by sector i to sector j and x_j is the total output of sector j, y is the final demand sector, then eq.(1) can be expressed as:

$$x = (I - A)^{-1}y \quad (2)$$

Where I is the identity matrix, $(I - A)^{-1}$ is the Leontief inverse matrix, representing the total output (including both direct and indirect effects) required to satisfy a given change in final demand.

The previously constructed GHG emission matrix reveals emissions resulting from different types of fossil fuel use in production activities—either from combustion or from non-combustion processes. By dividing the total emissions of each sector by its total output, the emission intensity per unit output can be determined. Combining this emission intensity with the total output formulation in equation (2), the total GHG emissions across sectors in response to final demand can be estimated using:

$$E = \varepsilon x = \varepsilon(I - A)^{-1}\hat{y} \quad (3)$$

where E is the emission matrix, representing the sectoral emission changes induced by changes in final demand, ε is the vector of emission intensities, representing GHG emissions per unit of output, and $\hat{y}$ is the final demand vector.

Table 6. Sectoral GHG Emissions and Intensities in Taiwan (2021)

Sector	Fuel combustion ($MtCO_2e$)	Non-fuel combustion ($MtCO_2e$)	Electricity-Related Emissions ($MtCO_2e$)	Total Emissions ($MtCO_2e$)	Output Value (NT$ million)	Emission Intensity (tCO_2e / NT$ million)
Energy	19.13	0.33	18.06	37.51	2,949,453	12.72
Manufacturing	35.68	22.14	99.50	157.31	31,150,725	5.05
Transportation	34.64	0.00	0.79	35.43	1,146,851	30.89
Residential & Commercial	7.94	0.00	49.88	57.82	19,597,754	2.95
Agriculture	1.33	3.28	1.68	6.29	796,688	7.90
Environment	0.00	2.84	0.00	2.84	211,987	13.40

3.4 Emissions from Fuel-Powered and Electric Motorcycles

The emissions from fuel and electric motorcycles are estimated using Equation (4). According to the report published by the Ministry of Transportation and Communications in 2018 and 2022, the average daily mileage for fuel-powered motorcycles in Taiwan is approximately 13.3 kilometers, while that for electric motorcycles is around 19.1 kilometers.

In terms of energy efficiency, news from the Bureau of Energy, Ministry of Economic Affairs, indicate that as of the end of November 2021, the average fuel efficiency of fuel motorcycles in Taiwan was approximately 49.05 km/l. For electric motorcycles, energy efficiency is estimated based on the average performance of electric motorcycles sold in 2021 by Gogoro, the brand with the largest market share in Taiwan. According to the auto energy website database, 39 Gogoro models are registered, with an average energy efficiency of approximately 23.92 km/kWh.

The carbon emission factor for gasoline combustion is based on the 2006 IPCC guidelines, which report approximately 2.4 $kgCO_2e$/l of gasoline. For electricity, the emission factor published by the Bureau of Energy in 2021 is 0.509 $kgCO_2e$/kWh. As a result, the monthly average emissions per unit for fuel-powered motorcycles and electric motorcycles are 19.52 $kgCO_2e$ and 12.2 $kgCO_2e$, respectively, as shown in Table 7.

$$\text{Monthly Emissions } (kgCO_2e) = \frac{\text{Daily Mileage}}{\text{Energy Efficientcy}} \times \text{Emission Factor} \times 30 \qquad (4)$$

Table 7. Monthly Emissions Calculation for Fuel and Electric Motorcycles

Vehicle Type	Daily Mileage(km)	Energy Efficiency	Emission Factor	Monthly Emissions ($kgCO_2e$)
Fuel Motorcycle	13.3	49.05 (km/l)	2.4 ($kgCO_2e$/l)	19.52
Electric Motorcycle	19.1	23.92 (km/kWh)	0.509 ($kgCO_2e$/ kWh)	12.20

4. Scenario design and simulation result

4.1 Scenario design

To assess the future impacts of electric motorcycle development on Taiwan's economy, environment, and energy system, this study employs Input-Output (IO) analysis and a dynamic Computable General Equilibrium (CGE) model. Three scenarios are constructed: a baseline projection, a policy target scenario, and an electric motorcycle development scenario under high oil price. The details of each scenario are as follows:

(1) Baseline Scenario:

The model is calibrated using historical simulation to adjust industrial production technologies. This calibrated framework is then used to simulate future growth in the number of electric and fuel-powered motorcycles, in order to evaluate the associated impacts on the economy, environment, and energy consumption.

(2) Policy Target Scenario(S1):

This scenario reflects Taiwan’s 2050 target for transport electrification, with projections for electric and fuel motorcycle fleets as shown in Fig 6. The number of vehicles is exogenously specified in the model to simulate their impacts on economic performance, greenhouse gas emissions, and energy usage.

(3) High Oil Price Scenario(S2):

This scenario simulates a sharp increase in international oil price, assuming an annual growth rate of 5%. Based on this assumption, projections are made for the number of new electric motorcycles and fuel motorcycles The scenario then examines the resulting impacts on Taiwan's economy, environment, and energy consumption.

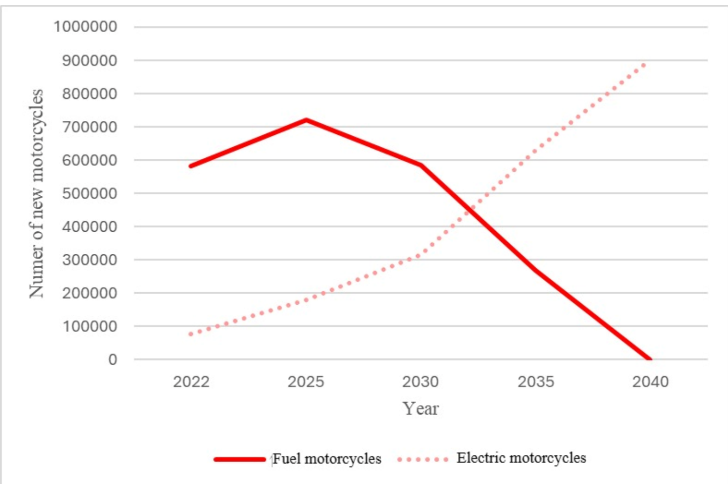


Figure 6. Number of new electric and fuel motorcycles

4.2 Result of IO analysis

Based on Equation (2), this study estimates the output effects and GDP contributions of each unit of final demand for fuel-powered motorcycles and electric motorcycles, as shown in Table 8. The results indicate that for each additional unit of final demand, fuel-powered motorcycles generate approximately NTD 203,300 in total output and create around NTD 62,600 in value-added. In comparison, electric motorcycles yield about NTD 197,400 in total output and contribute NTD 58,500 to GDP. The slightly higher output and value-added multipliers of fuel-powered motorcycles can be attributed to their stronger linkages with traditional metal and mechanical component industries. Although electric motorcycles maintain comparable output effects through battery and electronic component demand, their value-added remains lower, resulting in a slightly smaller overall contribution to the economy.

Table 8. Output Effects and GDP Contributions of Electric and Fuel Motorcycles

	Output Effects	GDP Contributions
Electric Motorcycles	197,400	58,500
Fuel Motorcycles	203,300	62,600

Based on Equation (3), this study estimates the greenhouse gas (GHG) emissions associated with the material acquisition and manufacturing stages for each unit of electric and fuel-powered motorcycles. Assuming a ten-year usage lifespan, the use-phase emissions were further calculated using the data presented in Table 7. As shown in the table, the electric motorcycle emits approximately 1.317 tons of CO_2e during the production stage and 1.464 tons of CO_2e during the use phase, totaling 2.781 tons of CO_2e over its lifecycle. In contrast, the fuel-powered motorcycle emits 1.646 tons of CO_2e during production and 2.342 tons of CO_2e during the use phase, totaling 3.988 tons of CO_2e.

These results indicate that, over its entire lifecycle, a fuel-powered motorcycle emits approximately 1.207 tons more CO_2e than an electric motorcycle, with the most significant difference arising from the use phase (2.342 vs. 1.464 tons of CO_2e). This highlights that, under Taiwan's current energy mix and fuel efficiency conditions, fuel-powered motorcycles exert a much greater climate impact during the operational phase compared to electric motorcycles.

Table 9. GHG Emissions of Electric and Fuel-Powered Motorcycles

	LCA	GHG Emissions(ton CO2e)	Total Emissions(ton CO_2e)
Electric Motorcycles	Material Acquisition & Manufacturing	1.317	2.781
	Use Phase	1.464	
Fuel Motorcycles	Material Acquisition & Manufacturing	1.646	3.988
	Use Phase	2.342	

4.3 Result of CGE simulation

This study uses the 2021 Input-Output Table compiled by Taiwan's Directorate-General of Budget, Accounting and Statistics (DGBAS) in 2024 as the primary empirical dataset. To better align the data with current economic conditions, the 2021 database was updated to reflect the state of the economy in 2024. This update was carried out by collecting the annual growth rates of key macroeconomic indicators—such as private consumption, government consumption, investment, exports, and imports—from the DGBAS website for the years 2021 to 2024. These known historical indicators were treated as exogenous variables, and calibration was performed accordingly. The ultimate goal of the calibration process was to ensure that the model-generated (endogenous) annual GDP growth rates closely matched the official statistics released by DGBAS. Details of the calibration data are presented in Table 8.

Table 8. Official growth rate data on macroeconomic variables (in percentage)

Year	GDP	Consumption	Government Spending	Investment	Export	Import
2021	6.72	-0.06	3.72	14.44	15.09	16.14
2022	2.68	4.02	5.15	7.93	2.77	5.18
2023	1.12	7.90	0.42	-7.76	-4.08	-5.49
2024	4.59	2.81	2.46	5.30	8.71	11.41

Source: Directorate General of Budget, Accounting and Statistics, Executive Yuan

Finally, the technology growth rates obtained through historical calibration for the period 2021 to 2024 were used as the assumed annual growth rates of production technology for the forecasting period from 2024 to 2040. The baseline simulation settings for each stage of the 2024–2040 projection are illustrated in Fig 7.

The simulation results indicate distinct macroeconomic trajectories under the three scenarios. Under the baseline scenario, Taiwan maintains steady economic growth, with real GDP increasing by 3.71% during 2025–2030, followed by moderate growth of 1.93% and 1.23% in the subsequent two periods (2031–2035 and 2036–2040, respectively). This reflects a continuation of existing economic trends without major structural shifts or external shocks.

In contrast, the policy scenario (S1), which simulates the large-scale adoption of electric motorcycles in alignment with Taiwan's 2050 net-zero roadmap, reveals a short-term decline in economic performance. Real GDP grows by only 0.49% in 2025–2030, and contracts by –1.50% in 2031–2035. This temporary contraction may be attributed to industrial adjustment costs and the displacement of traditional supply chains, especially in internal combustion engine-related sectors. Nevertheless, the economy shows signs of recovery in 2036–2040, with GDP returning to a positive growth of 0.19%, indicating that the electrification strategy—while initially disruptive—has the potential to restore growth momentum over the long term.

The high oil price scenario (S2) presents the most adverse outcomes. While the economy initially grows at 1.25% (2025–2030), sustained oil price shocks result in continuous decline, with GDP shrinking by –0.85% (2031–2035) and further deteriorating to –1.47% (2036–2040). This suggests that Taiwan's current reliance on imported fossil fuels significantly exposes it to external energy volatility. Without structural reforms, high oil prices could severely undermine macroeconomic stability.

Overall, the results suggest that although the electrification policy introduces short-term economic adjustment costs, its long-run economic impact is considerably more favorable than that of an unmanaged fossil fuel dependency under high oil price volatility.

In terms of trade, the baseline scenario exhibits stable export performance, with average growth rates of 5.06% in 2025–2030, gradually slowing to 0.55% by 2036–

2040. Import growth also accelerates over time, reaching 8.34% in the final period, likely due to increasing demand for intermediate and capital goods. Under the policy scenario (S1), export growth deteriorates significantly in the long term, turning negative after 2030 (–3.56% in 2031–2035 and –8.48% in 2036–2040), suggesting that the industrial transition toward electric motorcycles may impose adjustment pressure on Taiwan's export-oriented sectors. Nevertheless, import growth in S1 mirrors that of the baseline, indicating continued demand for foreign components such as electric motors and batteries. On the other hand, the high oil price scenario (S2) leads to a consistent decline in both exports and imports, reflecting weakened external competitiveness and domestic production contraction in the face of rising energy costs.

Investment outcomes also vary significantly across scenarios. In the baseline, real investment contracts initially (–4.05% in 2025–2030), but gradually returns to positive territory (0.62% by 2036–2040). The policy scenario (S1) experiences a similar trend but with a more pronounced rebound in the final period (3.72%), suggesting that the adoption of electric motorcycles may stimulate long-term investment in associated industries such as battery manufacturing, smart infrastructure, and R&D. Conversely, under the high oil price scenario (S2), investment remains negative throughout the entire period, with –8.24%, –4.25%, and –2.97% in each respective interval, highlighting long-term investor pessimism and energy-related capital crowding-out effects.

As for real household consumption, the baseline scenario indicates stable growth across all periods, averaging 4.14%, 2.51%, and 1.85%. The policy scenario (S1) exhibits a weaker start (1.68%) but ends with a stronger rebound in 2036–2040 (3.79%), reflecting increased consumer confidence and lower operating costs associated with electric vehicles. In contrast, the S2 scenario shows sustained weakness, with household consumption dropping to –1.73% and –2.36% in the final two periods, indicating that high oil prices erode disposable income and reduce consumption capacity.

Table 9. Average Five-Year Growth in Macroeconomic Variables

Macro Indices	Scenario	2025-2030	2031-2035	2036-2040
	Baseline	3.71	0.49	1.25
GDP	S1	0.49	-1.50	0.19
	S2	1.25	-0.85	-1.47
	Baseline	5.06	1.54	0.55
Export	S1	1.12	-3.56	-8.48
	S2	1.23	-2.23	-2.49
	Baseline	0.34	0.79	8.34
Import	S1	0.34	0.79	8.34
	S2	-4.85	-4.90	-4.43
	Baseline	-4.05	-0.50	0.62
Investment	S1	-4.89	-0.76	3.72
	S2	-8.24	-4.25	-2.97
	Baseline	4.14	2.51	1.85
Consumption	S1	1.68	0.34	3.79
	S2	0.32	-1.73	-2.36

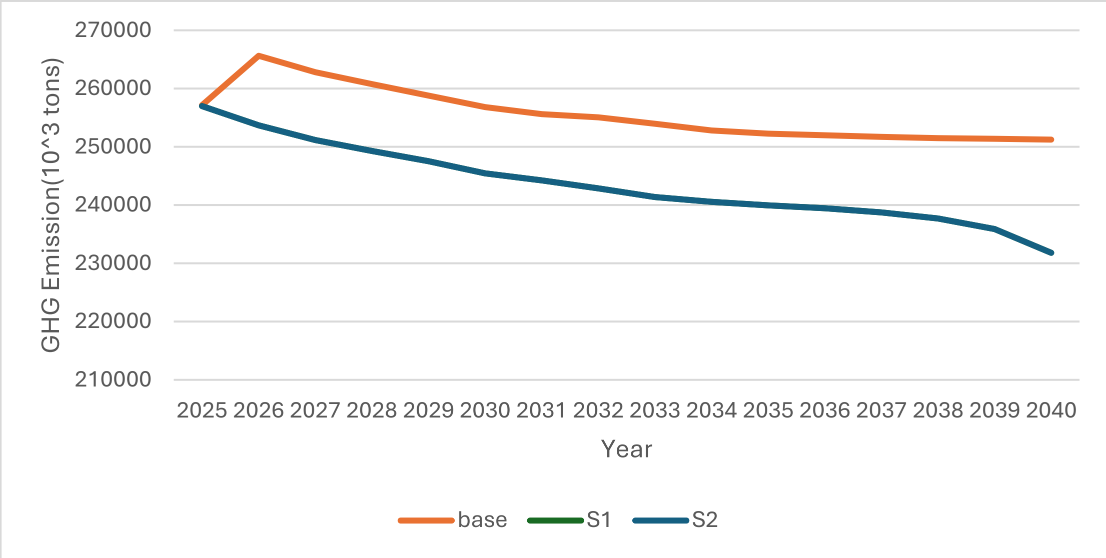
Fig 7 illustrates the projected greenhouse gas (GHG) emissions under three scenarios from 2025 to 2040. The y-axis represents total GHG emissions measured in thousands of tons (10^3 tons).

Under the baseline scenario, emissions increase slightly in 2026, reaching a peak of over 265,000 thousand tons, and then gradually decline over time. However, the reduction is relatively modest, with emissions remaining above 252,000 thousand tons by 2040.

In contrast, both Scenario 1 (S1) and Scenario 2 (S2) demonstrate more substantial and consistent emission reductions. S1, which reflects the electric motorcycle policy intervention, shows a steady decline across the years, achieving lower emissions than the baseline after 2026. Scenario 2, which simulates sustained high oil prices, leads to the most significant decline. By 2040, emissions under S2 fall to approximately 232,000 thousand tons, representing the most aggressive mitigation trajectory among the three.

These results highlight that without policy or price-driven behavioral change, baseline GHG emissions will remain relatively high. In contrast, electrification policies and market signals such as high fuel prices can drive significant and sustained emission reductions.

Figure 7 GHG emissions of each scenario



According to the simulation results, a clear substitution effect is observed in energy consumption patterns. As shown in the Fig 8, fuel usage is significantly lower under both the policy scenario (S1) and the high oil price scenario (S2) compared to the baseline, with the most pronounced reduction occurring in S2. In contrast, electricity usage increases steadily over time in both S1 and S2, surpassing the baseline levels due to the rising share of electric motorcycles. This reflects the energy structure shift induced by transport electrification.

Figure 8. Fuel usage of Each Scenario

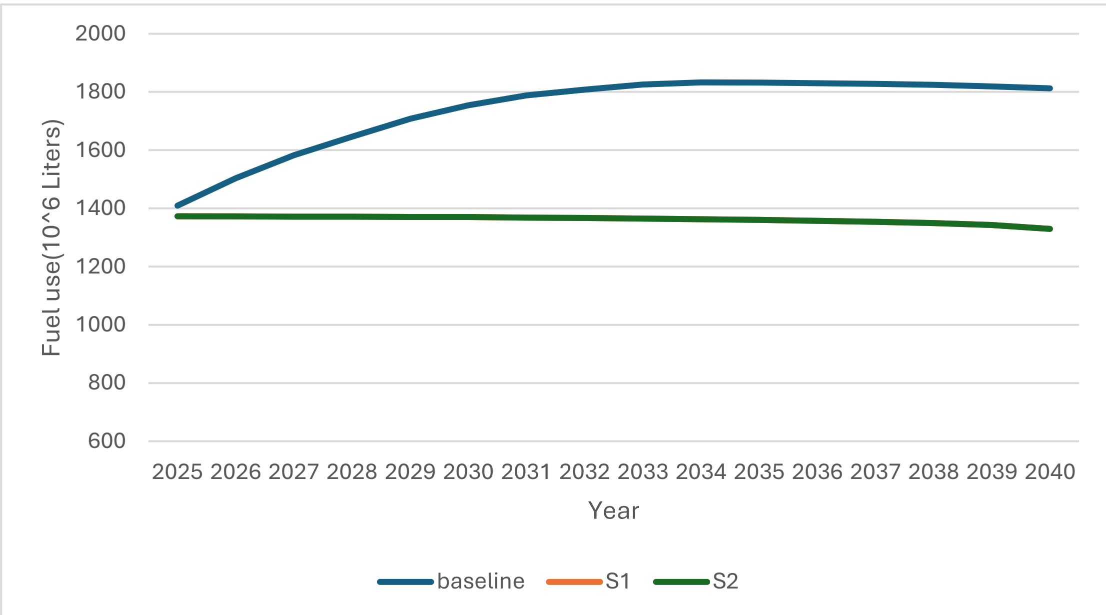
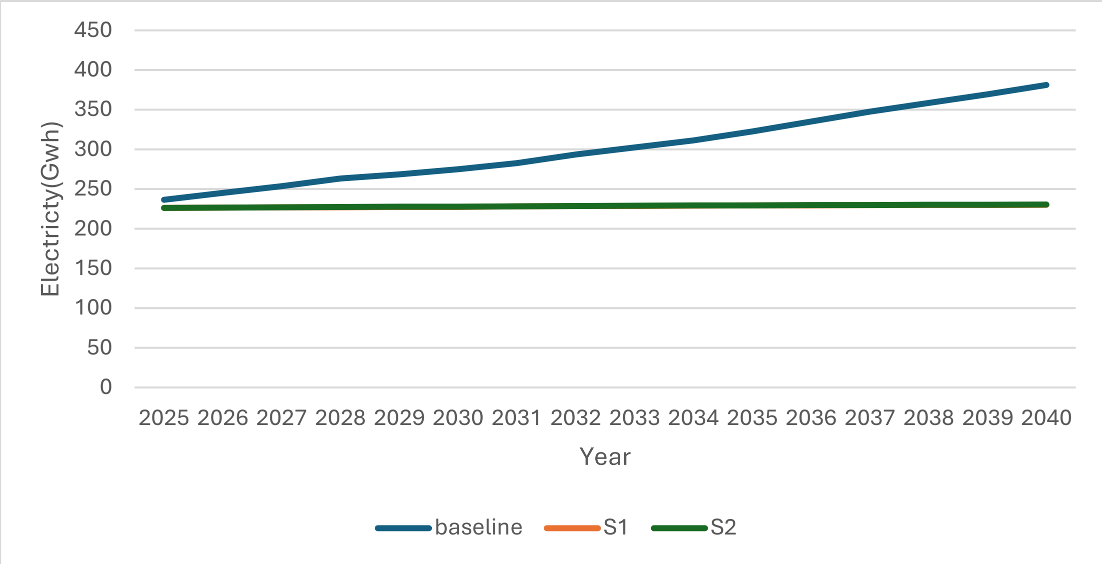


Figure 9. Electricity usage of Each Scenario



5. Conclusions

This study adopts Taiwan as a case to evaluate the long-term economic, energy, and environmental impacts of electric motorcycle (E2W) development using an integrated Input-Output analysis, lifecycle analysis(LCA) and a dynamic Computable General Equilibrium (CGE) model. Three scenarios were constructed—baseline, policy target, and high oil price—to simulate the evolution of vehicle fleet structure and associated system-wide effects. The results suggest that both policy interventions and market-based signals can effectively drive the substitution of electric motorcycles for conventional fuel-powered ones, thereby reducing carbon emissions and fuel consumption.

In environmental terms, the High Oil Price Scenario (S2) delivers the greatest reduction in CO_2 emissions by 2040, while the Policy Scenario (S1) demonstrates steady and sustained mitigation benefits. On the energy side, S1 and S2 both show significantly lower fuel usage than the baseline, while electricity consumption increases, indicating a structural shift in Taiwan's future energy demand. From an economic perspective, fuel-powered motorcycles still generate slightly higher output and value-added due to stronger linkages with traditional industries, yet the gap is narrowing as the electric motorcycle sector matures. LCA results further confirm that the life-cycle GHG emissions of electric motorcycles are considerably lower, especially during the use phase.

Policy implications include the need to sustain purchase subsidies and expand charging infrastructure to accelerate the electrification transition. Tailored support should also be provided to user groups still reliant on fuel-powered motorcycles. On the energy front, early planning of electricity distribution and integration with renewable energy is critical to prevent indirect emissions. Finally, the CGE simulation suggests that incorporating pricing mechanisms, such as fuel taxes or carbon fees, could further amplify decarbonization impacts, providing a crucial policy direction for Taiwan's transport transition strategy.

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