Create a data-oriented emission simulation for the transport sector in Vietnam

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***Abstract*—*The primary objective of this study is to develop a data-driven emission simulation framework tailored to the transport sector in Vietnam, with the intention of providing valuable support to policymakers in formulating a roadmap towards achieving net-zero emissions. This objective is realized through a two-stage process. The initial stage involves the comprehensive quantification of the current transport system's impact on emissions by leveraging extensive data obtained from large-scale transport surveys. This information assumes a pivotal role in the development of effective transport strategies and measures aimed at mitigating greenhouse gas (GHG) emissions. In the subsequent stage, policy measures are meticulously modeled to explore feasible pathways for attaining emission reduction targets. The analysis takes into account the contributions of both 'shift' interventions, which involve transitioning towards lower carbon dioxide (CO2) modes of transportation, and 'improve' interventions, which encompass enhancements in fuel CO2 characteristics, within decarbonization scenarios. To facilitate a thorough assessment of the effect of transport strategies and measures on GHG emission mitigation, a case study focusing on Da Nang is presented, wherein quantitative modeling techniques are employed.*

Keywords—emission simulation, transport sector, large-scale data

I. Introduction

The transportation system in Vietnam is distinguished by the prominent utilization of motorcycles (MCs), which have gradually supplanted bicycles and other modes of transportation since their introduction in the 1990s. As a result, motorcycles have emerged as the prevailing mode of transportation, leading to the categorization of Vietnamese urban areas as motorcycle-dependent cities [1].

Vietnam is recognized as one of the countries most impacted by climate change, prompting a strong commitment from the Government of Vietnam (GoV) to address climate-related issues. The updated Nationally Determined Contribution (NDC) of Vietnam sets an unconditional target of reducing greenhouse gas (GHG) emissions by 15.8% by 2030 compared to the Business as Usual (BAU) scenario [2]. Additionally, Vietnam has established a net-zero target as outlined in the National Climate Change Strategy, to be achieved by 2050 [3].

The transport sector in Vietnam plays a significant role in the country's total GHG emissions, contributing approximately 18% of energy-related CO_2 emissions in 2014 [4]. Under BAU) projection, it is anticipated that emissions from the transport sector will surge from 33 $MtCO_2$ in 2014 to 89 $MtCO_2$ by 2030, with road transport accounting for 80% of all transport-related emissions [4]. Furthermore, the transportation sector is a primary contributor to the escalating air pollution problem in Vietnam, particularly in urban areas. The World Health Organization (WHO) [5] has reported that the mean annual concentration of $PM_{2.5}$ in Hanoi and Ho Chi Minh City in 2016 was 48 $\mu g/m^3$ and 42 $\mu g/m^3$, respectively. These levels significantly exceed the WHO's recommended healthy air quality level of 10 $\mu g/m^3$ on an annual mean basis, rendering these cities among the locations with the most hazardous air quality worldwide.

To address these challenges, Vietnam has implemented the Action Program on Green Energy Transition and Reduction of Carbon and Methane Emissions in the transport sector [6]. This program includes specific targets for green-energy vehicles to be achieved by 2025, 2030, and 2050.

The aim of this paper is to develop a data-oriented emission simulation for the transport sector in Vietnam that can support policymakers in a roadmap toward net-zero emission. The paper is structured as follows: Section 2 describes the methodology; Section 3sets ou t the main results; and Section 4 concludes the study.

II. METHODOLOGY

A. Research framework

The study strives to create a data-oriented emission simulation for the transport sector in Vietnam. This goal can be achieved via a two-stage process, presented in Figure 1.

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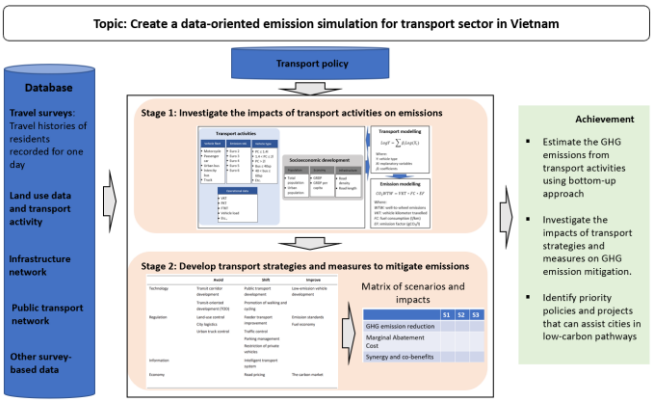


Fig. 1. Distribution steps of activities in the emission model

The first stage involves an investigation of the impacts of the current transport activities on GHG emissions. A large-scale survey data, such as household survey, traffic counting survey, speed and network data are employed to identify the extent to which the current transport activities emit to environment. A number of techniques – including statistic and simulation tools are applied to draw emission dynamics and map changes in transport activities over a long-term period.

The second stage, a central part of this study, is to develop transport strategies and measures to mitigate GHG emissions using data-oriented transport activities. This phase was start by developing several scenarios and explore the impacts of each scenario on the environment in terms of GHG emissions, costs and co-benefits. Four-step model was applied to explore different segments of policies. The spatial analysis approach will subsequently be repeat to evaluate these impacts.

B. *Transport modelling*

This study incorporates a partial dataset as part of its methodology and endeavors to construct a more extensive and up-to-date origin-destination (OD) dataset. This dataset is subsequently utilized in the development of both the Trip Generation/Attraction Model and the Trip Distribution Model. Additionally, the Traffic Assignment model is calibrated based on a comprehensive traffic counting survey. To facilitate demand forecasting, the model utilizes VISUM software. The sequential steps of this procedure are visually represented in Figure 2.

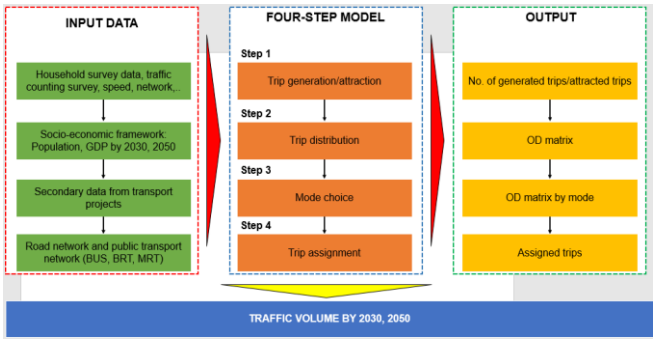


Fig. 2. Transport modelling based on four-step approach.

C. *Emission modelling*

In this study, four distinct scenarios are examined, spanning a time period from 2014 to 2050. These scenarios include the following: the Business-As-Usual (BAU) scenario, a mitigation scenario without international support (scenario 1), a mitigation scenario with international support (scenario 2), and a mitigation scenario aimed at achieving 'net-zero' emissions in the transport sector (scenario 3).

The BAU scenario assumes that future travel patterns and developments in vehicles and fuels will align with macro assumptions. This scenario is characterized by a continuation of trends observed in the base year of 2014, particularly the ongoing increase in car and motorcycle ownership and usage per capita, accompanied by minimal growth in the utilization of alternative modes of transportation such as public transit.

The mitigation scenario without international support (scenario 1) incorporates some of the policies and measures outlined in the existing transport plan. However, these initiatives are implemented solely using domestic resources and do not involve external support.

In contrast, the mitigation scenario with international support (scenario 2) operates within the framework of the existing transport plan but requires a higher level of ambition. Implementation of this scenario necessitates additional resources from international sources and private sector involvement.

Finally, the mitigation scenario towards 'net-zero' transport (scenario 3) encompasses a set of ambitious measures aimed at achieving net-zero greenhouse gas (GHG) emissions in the transport sector by 2050. This scenario focuses on a comprehensive and transformative approach to decarbonize the transportation system.

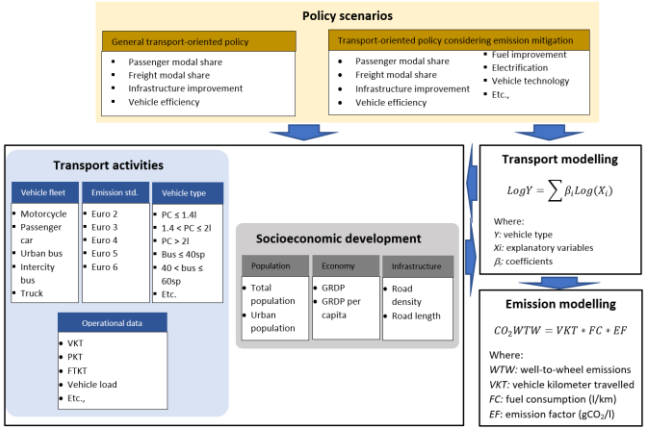


Fig. 3. Bottom-up approach to estimate GHG emissions

D. *Case study*

Vietnam currently has an urbanization rate of approximately 32%, which translates to around 36.6 million individuals residing in 868 urban areas [7]. Cities play a crucial role in the country's economy, contributing to 70-75% of the GDP. With a rapidly growing urban population at a rate of 3.4% per year, the demand for transportation is also increasing. As the economy continues to expand, cities will inevitably face transportation challenges. Addressing these challenges in urban areas through early interventions is crucial in guiding cities towards low-carbon pathways in a cost-effective manner, while simultaneously tackling existing problems. Such interventions can help reduce the overall carbon intensity of the transport sector.

Da Nang city, being one of the five 1st tier center-cities in Vietnam, shares similarities with other center-cities. The city is characterized by a significantly high ownership rate of motorcycles and relatively low ownership of cars per capita. However, there has been a notable increase in private car

ownership, with an average annual growth rate of 18%. In contrast, the annual growth rate of motorcycle ownership has remained at 7% between 2010 and 2021. Interestingly, public transport caters to less than 1% of the total travel demand in the city, despite the trends of economic and population growth. In terms of e-mobility, Da Nang is not considered an emerging adopter of electric mobility. This suggests the need to encourage both electrification and sustainable modal shifts in order to achieve transport decarbonization in the city.

Basic information about large-scale survey data in Da Nang is shown in Table 1.

Table 1. Available data in Da Nang city

Year	Area	Survey type	Sample
2012	Whole city	- Household survey	1,200
		- Traffic counting survey	20 routes
		- Travel speed	20 routes
		- Public transport survey	500 people
2018	Whole city	- Traffic counting survey	10 intersections
2021	Whole city	- Traffic counting survey	10 intersections
		- Parking survey	500 people
		- Public transport survey	800 people
		- Electric mobility survey	500 people

According to the survey conducted, the total passenger travel demand in Da Nang city was estimated to be 3.42 million trips in 2019. This value aligns with the findings of the General Master Plan (GMP) project [8]. When compared to the travel demand in 2012 [9], there was a 1.55-fold increase in the total travel demand, while the population during the same period grew by a factor of 1.18. The growth in travel demand can be attributed to an increase in the trip rate, which refers to the number of trips per person per day. Excluding walking trips, the trip rates in 2012 and 2019 exhibited significant differences, with 2.29 person trips per day in 2012 and 2.98 person trips per day in 2019. This indicates a growth rate of 3.9% in the trip rate.

E. Scenario development

To capture the causality mechanisms relating to environmental problems in Da Nang urban transport and to establish a framework measure to tackle them, it is necessary to integrate traffic management measures to design a low-carbon transport system for Da Nang city. Table 2 compare transport policies in Da Nang and low-carbon transport options within the comparative matrix.

Table 2. Comparative matrix between transport policies and low-carbon transport option

Category	Low carbon option → Pillars of transport policy in Da nang city		Status in Da Nang
Avoid	Transit corridor development	▪ Promotion of public transport	▪ Planned
	Transit-oriented development (TOD)	▪ Promotion of public transport	▪ Planned
	Land-use control	▪ Integrated land use and transport planning	▪ Planned
	City logistics	▪ Establishment of Lien Chieu port	▪ Planned
Shift	Mass transit development	▪ Promotion of public transport	▪ Partly implemented (bus system is in operation)
	Promotion of walking and cycling	▪ Other policy	▪ Partly implemented (pedestrian zone)
	Feeder transport improvement	▪ Promotion of public transport	▪ Partly implemented (bus system is in operation)
	Traffic control	▪ Discouraging private motorized mobility	▪ Implemented
	Parking management	▪ Discouraging private motorized mobility	▪ Implemented
	Restriction of private vehicles	▪ Discouraging private motorized mobility	▪ Planed
	Intelligent transport system	▪ Other policy	▪ Partly implemented
	Road pricing	▪ Discouraging private motorized mobility	▪ Planned
	Freight modal shift	▪ Converting Kim Lien railway station from passenger functional service to freight functional service	▪ Planned
Improve	Low-emission vehicle development	▪ Other policy	▪ Planned
	Emission standard	▪ National policy	▪ Implemented
	Fuel economy	▪ National policy	▪ Planned
	Energy labeling	▪ National policy	▪ Implemented
	Carbon market	▪ N/A	▪ Not in discussion

III. RESULTS

A. Transport demand model

The future traffic demand for the baseline was estimated using travel demand forecast models, considering no additional deployment of GHG emissions mitigating policies and measures after the base year of 2014. Based on available data, the total travel demand in Da Nang is expected to increase to 4.66 million trips by 2030 and 7.61 million trips by 2050.

The BAU forecast shows how transport activity and emissions can be expected to change under an agreed set of macro assumptions. Assumes that no additional mitigation policy measures are adopted after the base year of 2014. Under BAU, Motorized transportation modes include motorcycles, passenger cars and buses. Private vehicles continue to dominate travel demand.

Table 3. Mode share in BAU

Motorized transport modes		2030	2050	Change
Private	Motorcycles	75.67%	64.11%	-11.56%
	Passenger cars	21.03%	29.05%	8.02%
Public	Urban buses	0.5%	3.85%	3.35%
	Other buses	2.8%	3.0%	0.20%
NMT	Bicycles	2.71%	3.8%	1.09%

Under BAU, almost all the Da Nang road network will be at or beyond capacity by 2050. The performance of the Da Nang road sections is illustrated in Figure 4.

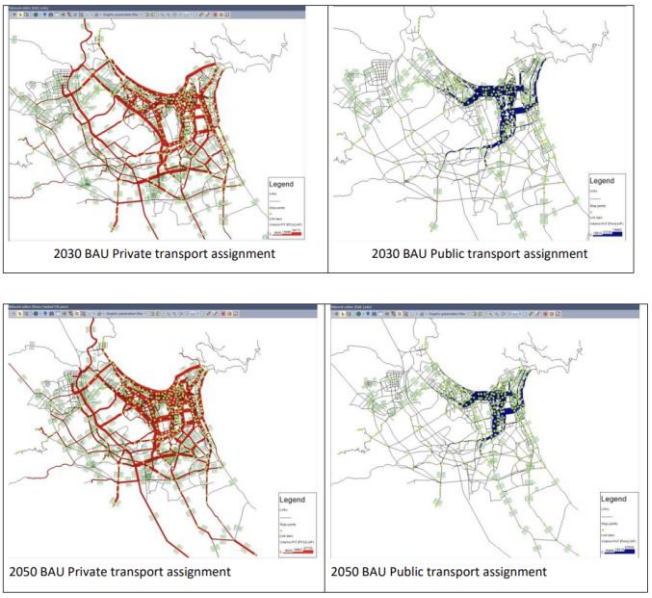


Fig. 4. Distribution of traffic volume on the road network by 2030 and 2050

- Impact of public transport development measures

In order to estimate the potential impact of introducing public transport on modal shift, the researchers utilized the results of a Stated Preference (SP) survey conducted in Da Nang in 2021. This survey involved the use of questionnaires to assess how Da Nang residents might respond to various policy scenarios.

During the survey, respondents were asked to indicate which mode of transportation they would choose for a specific trip. They were also presented with alternative modes and asked to provide information on travel time, travel cost, parking cost, and toll cost (if applicable) for each mode. The mode that the respondent actually chose was considered the base mode.

Subsequently, respondents were presented with hypothetical changes in travel cost and travel time for both the existing modes and the hypothetical modes (MRT and LRT). This allowed the researchers to examine the potential impact of public transport development measures on mode choice.

The findings of the survey, including the impact of public transport development measures on mode choice, are presented in Figure 5 of the study.

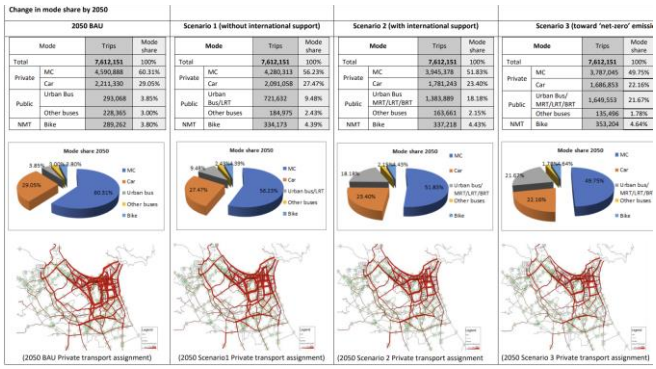


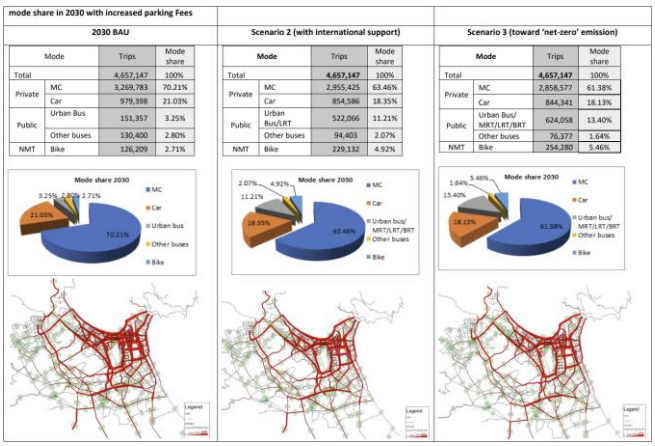
Fig. 5. Change in mode share by 2030 and 2050 under the public transport measures.

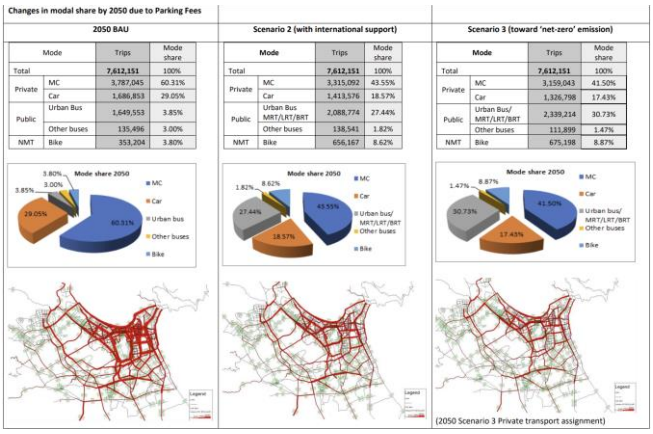
- Impact of parking measures

The proposed strategy to address parking issues involves implementing increased parking fees specifically in the central business district (CBD). The underlying assumption of the model is that an increase in parking fees will influence the behavior of vehicle users, leading to changes in modal share (the proportion of trips made by different modes of transport) and the overall traffic volume on the road network.

In Scenario 2 and Scenario 3, the study considers the implementation of increased parking fees. Under this plan, it is projected that by 2030, the parking fees will double in conjunction with the expansion of the bus and bus rapid transit (BRT) network. Furthermore, by 2035, when the city is fully covered by BRTs, light rail transit (LRTs), and metro rail transit (MRTs), the parking fees will be tripled.

The objective of this strategy is to incentivize a shift towards alternative modes of transportation and reduce reliance on private vehicles, especially in the CBD. By increasing parking fees and simultaneously improving public transportation options, the aim is to encourage modal shift and alleviate traffic congestion in the city.





Changes in modal share by 2050 due to Parking Fees

2050 BAU

Mode		Trips	Mode share
Total		7,612,151	100%
Private	MC	3,787,045	60.31%
	Car	1,686,853	29.05%
Public	Urban Bus	1,649,553	3.85%
	Other buses	135,496	3.00%
NMT	Bike	353,204	3.80%

Scenario 2 (with international support)

Mode		Trips	Mode share
Total		7,612,151	100%
Private	MC	3,315,092	43.55%
	Car	1,413,576	18.57%
Public	Urban Bus MRT/LRT/BRT	2,088,774	27.44%
	Other buses	138,541	1.82%
NMT	Bike	656,167	8.62%

Scenario 3 (toward 'net-zero' emission)

Mode		Trips	Mode share
Total		7,612,151	100%
Private	MC	3,159,043	41.50%
	Car	1,326,798	17.43%
Public	Urban Bus/ MRT/LRT/BRT	2,339,214	30.73%
	Other buses	111,899	1.47%
NMT	Bike	675,198	8.87%

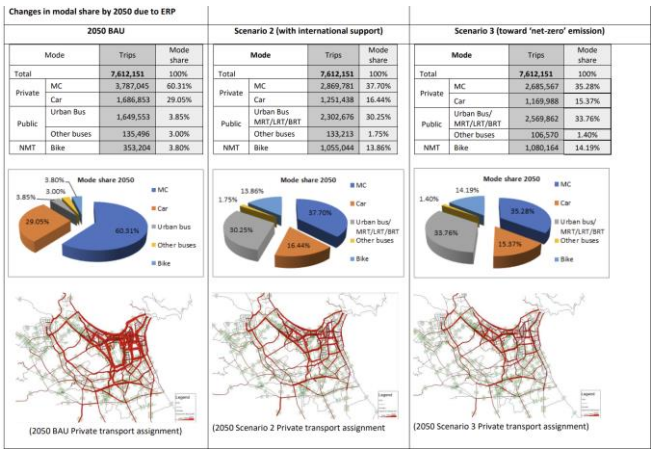
Fig. 6. Change in mode share by 2030 and 2050 under parking measures

- Impact of electric road pricing measures

The study also considers the implementation of Electronic Road Pricing (ERP) in the same areas where the parking fee measures are applied. Specifically, ERP is applied in Hai Chau district and a portion of Thanh Khe district. The objective of ERP is to induce behavioral changes in vehicle use, leading to shifts in modal share and resulting in an impact on traffic volume within the road network.

Both motorcycles and cars are subject to ERP charges. Motorcycle riders entering the central business district (CBD) are required to pay VND 10,000, while car drivers have to pay VND 60,000 for entering the CBD.

The analysis explores two ERP options: ERP-only and a combination of ERP and parking measures. These options are evaluated in terms of their impact on modal share and traffic volume within the designated areas. By implementing ERP and potentially integrating it with parking measures, the aim is to influence travel behavior and encourage a shift towards more sustainable modes of transportation, thereby reducing congestion and improving overall traffic conditions in the CBD.



Changes in modal share by 2050 due to ERP

2050 BAU

Mode		Trips	Mode share
Total		7,612,151	100%
Private	MC	3,787,045	60.31%
	Car	1,686,853	29.05%
Public	Urban Bus	1,649,553	3.85%
	Other buses	135,496	3.00%
NMT	Bike	353,204	3.80%

Scenario 2 (with international support)

Mode		Trips	Mode share
Total		7,612,151	100%
Private	MC	2,869,781	37.70%
	Car	1,251,438	16.44%
Public	Urban Bus MRT/LRT/BRT	2,302,676	30.25%
	Other buses	133,213	1.75%
NMT	Bike	1,055,044	13.86%

Scenario 3 (toward 'net-zero' emission)

Mode		Trips	Mode share
Total		7,612,151	100%
Private	MC	2,685,567	35.28%
	Car	1,169,988	15.37%
Public	Urban Bus/ MRT/LRT/BRT	2,569,862	33.76%
	Other buses	106,570	1.40%
NMT	Bike	1,080,164	14.19%

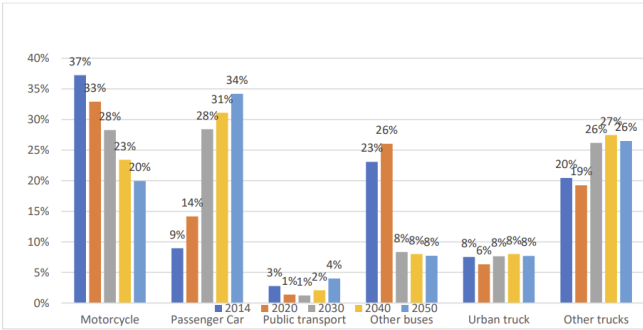
Fig. 7. Change in mode share by 2030 and 2050 under electric road pricing measures

B. Modeling the impact of mitigation scenarios

In the Business-as-Usual (BAU) scenario, passenger transport is responsible for approximately 75% of total emissions in 2030, which decreases to around 65% in 2050. On the other hand, emissions from freight transport are comparatively lower than those from passenger transport. This is primarily due to the prevalence of private vehicles and tourist vehicles in Da Nang's traffic composition. Intracity freight transport mainly consists of small urban trucks, while the fleet of large trucks running from ports to other cities remains limited, accounting for only 32% of the total number of trucks.

Motorcycles contribute approximately 37% of passenger-related greenhouse gas (GHG) emissions in 2014. However, this contribution is projected to decline to 33% by 2030, 28% by 2040, and 20% by 2050. In contrast, GHG emissions from private cars show a significant increase over the period from 2014 to 2050, with emissions growing to over 21 times the 2014 level by 2050.

The emissions from public transport are expected to be the lowest among the different modes, accounting for only 4% of total emissions in 2050. The share of CO2 emissions from urban trucks and other buses within Da Nang's boundaries is similar, comprising 8% of total emissions in 2050.



A summary of the energy consumption and GHG emissions impacts under different policy scenarios is provided in Figure 8 and Figure 9:

(1) Under the Business-as-Usual (BAU) scenario, the energy consumption resulting from transport activities in Da Nang is projected to increase from 5,520 terajoules (TJ) in 2014 to 30,829 TJ in 2050. In line with the increase in energy consumption, CO_2 emissions are expected to rise from 0.38 million metric tons (Mt) of CO_{2e} in 2014 to 2.16 Mt CO_{2e} in 2050 under the BAU scenario. This represents a 5.6-fold increase compared to the base year of 2014.

(2) The total energy consumption in Da Nang is projected to decrease under the different policy scenarios. In Scenario 1, energy consumption is estimated to be 23,331 TJ in 2050, representing a 24% reduction compared to the BAU scenario. In Scenario 2, energy consumption is projected to be 18,371 TJ in 2050, indicating a 53% reduction. Finally, in Scenario 3, the energy consumption is anticipated to be 16,401 TJ in 2050, resulting in a significant 79% reduction compared to the BAU scenario. These reductions in energy consumption correspond to the implementation of various policy measures aimed at promoting sustainable transportation and reducing GHG emissions in Da Nang.

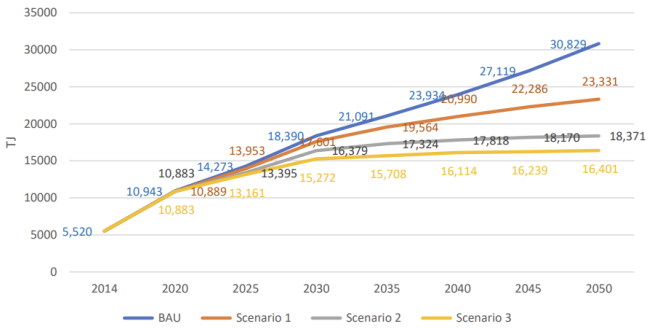


Fig. 8. Total energy consumption of transport sector under different scenarios

Mitigation Scenario 1, which does not rely on international support, incorporates several measures to reduce greenhouse gas (GHG) emissions in Da Nang's transport sector: Expansion of the urban bus network: This scenario involves the expansion of the urban bus network, with 19 routes in 2025 and 21 routes in 2030; Introduction of Light Rail Transit (LRT) lines: LRT Line 1 is introduced in 2035, followed by Line 2 in 2040 and Line 3 in 2045; Adoption of electric vehicles (EVs): The measures includes the introduction of EVs, with specific targets for their market penetration. By 2030, 30% of new motorcycle sales and 10% of new car sales are expected to be electric. These numbers increase to 80% of new motorcycle sales and 45% of new car sales by 2040. Finally, by 2050, all motorcycle and car sales are projected to be electric. As a result of these measures, GHG emissions in the transport sector are estimated to decrease from 2.16 million tons of CO2e under the BAU scenario to 1.2 million tons of CO2e under Scenario 1.

Mitigation Scenario 2 builds upon the measures of Scenario 1 and further increases the ambition level of policy interventions. It includes the implementation of Mass Rapid Transit (MRT) and LRT lines, along with a higher level of electric mobility. This combination results in a substantial reduction of CO_2 emissions from the transport sector in 2050, estimated at 0.67 million tons or a 57.63% reduction compared to the BAU scenario.

Mitigation Scenario 3 represents the most ambitious option, aiming for net-zero emissions in the transport sector. The policy measures included in this scenario lead to a significant reduction in CO_2 emissions by 2050, estimated at 0.74 million tons or a 65.5% reduction compared to the BAU scenario.

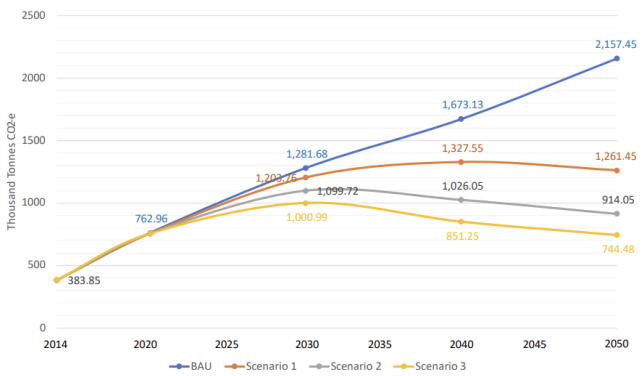


Fig. 9. GHG emissions under scenarios

IV. CONCLUSIONS

This study focuses on GHG emissions simulation for the transport sector and select Da Nang city as a case study. The key findings and methodologies of the study are as follows:

- Identification of strategies and measures: The study identifies potential strategies and measures for Vietnamese cities, including Da Nang, to achieve emission reduction targets.
- "Shift" and "improve" interventions: The analysis considers the contributions of "shift" interventions (encouraging the use of lower CO_2 modes) and "improve" interventions (improving the fuel CO_2 characteristics) to decarbonization scenarios.
- Ground-up models and datasets: The study utilizes datasets from previous surveys and develops two original ground-up models. These models estimate intra-city passenger and freight flows, which are the main drivers of GHG emissions.
- Four-step modeling: A four-step model is developed using VISUM software to gain a quantitative understanding of transport activities. The model integrates analytical models for road passenger demand, road freight demand, and Origin-Destination (O-D) passenger and freight flows to estimate GHG emissions.

Characteristics of urban transportation demand in Da Nang:

(1) Total demand: Future traffic demand in all recommended scenarios is projected using travel demand forecast models. The total travel demand in Da Nang is expected to increase from 3.0 million trips in 2014 to 4.7 million by 2030 (1.6 times) and 7.6 million by 2050 (2.5 times).

(2) Trip generation/attraction: Future trip generation and attraction are anticipated to concentrate in two urban core districts, accounting for more than 38% of total generated trips and 40% of total attracted trips.

(3) Trip distribution: The total demand is distributed throughout Da Nang city, with a high concentration in the urban core. Average trip length is expected to increase due to urban sprawl.

(4) Mode share: Future mode share in different scenarios is examined. Under the BAU scenario, the mode share by car is projected to increase from 4.55% in 2014 to 21.03% in 2030 and further to 29.05% in 2050. Motorcycles are expected to decrease from 90.12% in 2014 to 75.67% in 2030 and 64.11% in 2050 under the BAU scenario. Public transportation's share is estimated to grow from 0.3% in 2014 to 0.5% in 2030 and 3.85% in 2050 under BAU. If the proposed MRT/LRT/BRT system is fully developed, the share of public transport in 2050 could reach 21.67%, and with transport demand management (TDM) measures like parking fees and electric road pricing, it could further increase to 33.76%.

(5) Trip assignment: Future traffic demand is assigned to the transportation network, and the analysis is conducted on road sections. Under the BAU scenario, several roads are projected to be over

capacity, with traffic volume exceeding road capacity.

Summary of mitigation scenarios:

(6) In Mitigation Scenario 1 (without international support), the expansion of the urban bus network, introduction of LRT lines, and adoption of electric vehicles result in a reduction of CO2 emissions in 2050 to 1.2 million tons CO2, compared to 2.16 million tons CO2 under BAU.

(7) Mitigation Scenario 2 increases the ambition level of policy measures, including more LRT lines, MRT lines, and ambitious targets for electric mobility. This scenario leads to CO2 emissions of 0.67 million tons in 2050, representing a 57.63% reduction compared to BAU.

(8) Mitigation Scenario 3 aims for net-zero emissions in the transport sector. The policy measures in this scenario result in CO2 emissions of 0.74 million tons in 2050, corresponding to a 65.5% reduction compared to BAU.

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