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System Dynamics Modeling of Indonesia Road Transportation Energy Demand and Scenario Analysis to achieve National Energy Policy Target

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Abstract. The Indonesian transportation sector is currently the nation's largest consumer of petroleum products and a significant source of greenhouse gas (GHG) emissions overall. Many policies have been implemented by central and local governments, from the introduction of alternative fuels until demand management like odd-even policy; results, however, are in most cases disappointing. This paper explained a system dynamics model for the road transportation sector in Indonesia. The model considers basic policy options under Activity, Structure, Intensity, and Fuel (ASIF) framework and includes two main objectives, i.e., reduction of energy consumption and CO_2 emission. Policy scenarios were developed to cover business as usual (REF), transport demand management (TDM), the introduction of fuel economy (FE) standard and feebate system (FEE), adoption of electric vehicles (EV) which considers future technological improvement factors and fuel switching strategy. The result indicates that it is mandatory to have a policy mix as the most effective strategy to reduce energy consumption, CO_2 emission and achieve national energy mix target in 2050.

1. Introduction

Among economic sectors, transportation is the largest consumer of oil and is experiencing rapidly increased demand. Globally, transport technologies rely primarily on liquid petroleum fuels, while within the transportation sector, consumption of energy and carbon emission from road transport are the majority contributor, nearly the only one of consequence. In 2016, the transport sector contributed around 23% share in total fuel combustion carbon emissions. Majority of the Carbon emissions within the transport sector are from the road transport sector, which represents about three-quarters of transport carbon emissions, *i.e.*, about 6 GT of direct Carbon emissions in 2017. Since the year 2000, road transport carbon emissions have increased at an annual rate of 2% and becoming one of the fastest growing sub-sectors of fuel combustion emissions over the past half-century. However, since 2015, road transport carbon emissions have grown at a slower annual rate of 1.4% when compared with the historical yearly growth of 2%.

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The forecast for Indonesia transportation energy demand is an area of great concern if there is no significant improvement in terms of vehicle technology and travel demand management. In 2014, Indonesia transportation sector GHG emissions were at 141,246 $GgCO_2e$ (representing about 23% of the total emission from the energy sector). It is also predicted that future emissions will be even more significant because the demand for transportation is growing 4.1% percent per year. Especially for Freight transport, the increased demand has been increasing even faster than passenger traffic, particularly in big cities where transport of goods become more vital as pushing by the digital economy.

In the past few years, Energy policy in Indonesia has become an essential subject for discussion among academician, government and business entity. Policies related to energy must be able to balance the two critical aspects of any energy policy: how to improve economic welfare while also avoiding environmental degradation [1]. As one of a developing country and a net importer of oil, Indonesia urgently need to review its energy policy to improve energy dependency and at the same time to achieve CO_2 reduction target as reported at COP21 in Paris. Energy modeling and simulation can help decision-makers to compare between different policies scenario and also get the insight of policies impact analysis.

This paper is intended to establish System Dynamics (SD) [2] modeling as an effort to understand the past behavior state of Indonesia's road transport energy performance in the way to develop a new foreseeable policy scenario to achieve national energy policy target and CO_2 reduction.

2. The methodology of System Dynamics Modeling

2.1. Methodology for Road Transport Energy Demand Modeling

The main research question of the paper is to forecast energy demand and CO_2 emission based on past relevant data, which also identify and highlight key challenges need to address by providing insights into plausible alternative future transport demand 'realities' [3]. To achieve this, three main steps of work were conducted: 1) the development of reference scenario which represents the business as usual case consist of policies which already put in place by government, 2) the identification of future passenger and transport demand trends and development of policies scenario using ASIF Framework (Figure 1) and 3) analyse plausible future scenarios impacts and made iteration of policy mix in order to achieve target of oil reduction and CO_2 emissions. Figure 2 is a description of modeling methodology which consists of three steps used for this study.

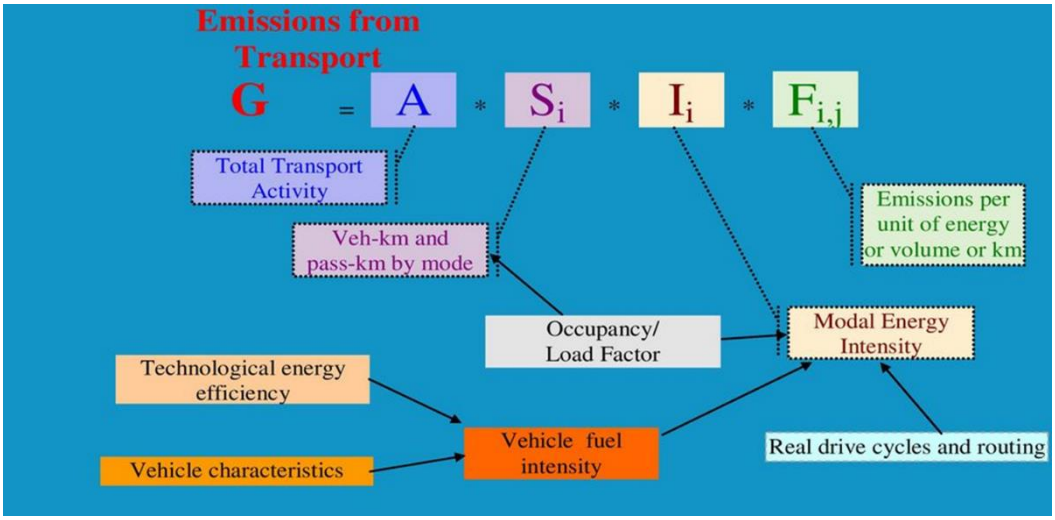


Figure 1. ASIF Framework for Reducing Oil Consumption and Emissions.

Steps (1) and (2) were interlinked and able to provide feedback respectively. A literature review was done to seek the insight of past policies, and it also added with a focus group discussion with experts. With the recent development of CASE (connected, autonomous, sharing and electric vehicle), it is required to identify critical factors affecting future demand of transport sector energy, both for passenger and freight. The plausible scenarios making and the identification of essential factors for transport were done as a result of the extensive literature review and output of focus group discussion. In step (3), the output from the two previous steps was analyzed in the context of critical questions regarding the future of Indonesia road transport trends and challenges.

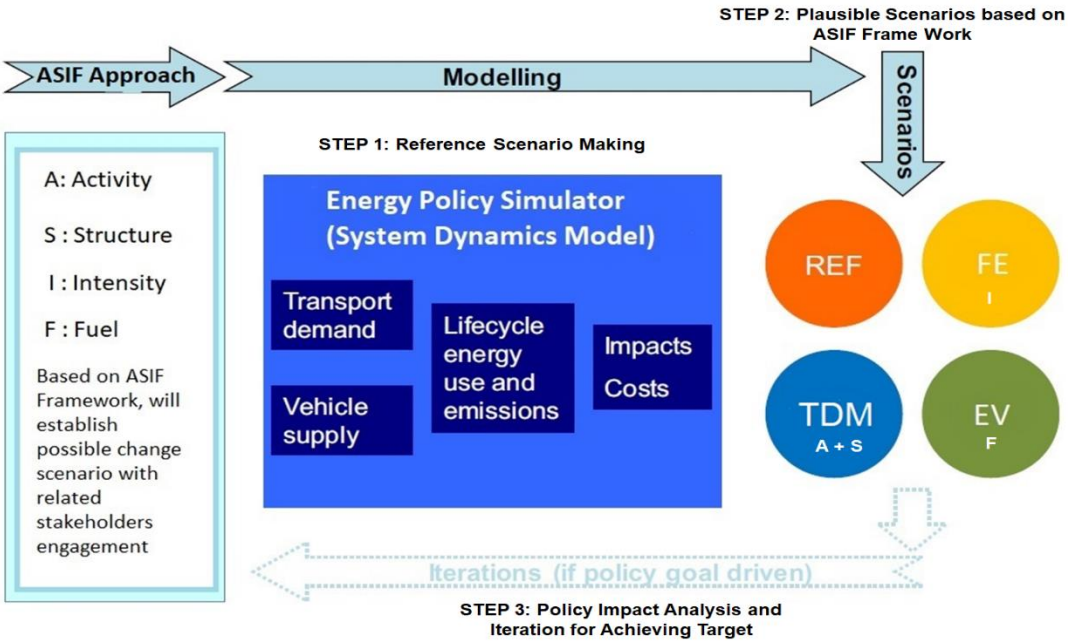


Figure 2. Modeling Methodology using three steps and ASIF Approach.

2.2. System Dynamic Modeling

The utilization of system dynamics modeling concerning energy demand of Indonesian transport sector is one of significant effort which can forecast scenarios and meaningful hypotheses on energy consumptions, as well as on related consequences in terms of emissions up to the year 2050. The modeling step starts with the development of a causal map to understand the relationships among the various main variables as well as among the main dynamic system drivers and leverages. For the transport sector demand, the primary driver of energy consumption represented by transport demand in terms of passenger and freight travel per kilometer in each year [4][5]. GDP growth also had a strong linkage with the growth of transportation demand. Vehicle fuel efficiency, fuel price, and the average distance traveled per vehicle (measured in kilometers per year) must be included as a primary driver for energy consumption [1]. Figure 3 is an overall causal map used for the modeling purposes.

System dynamics models often include “stocks,” or variables whose value is remembered from timestep to timestep, and which are affected by “flows” into and out of these variables [6]. The model uses stocks for two purposes: tracking quantities that grow or shrink over time and tracking differences from the reference (REF) input data that tend to increase over the course of the model run (for instance, the cumulative differences in the potential fuel consumption of the light-duty vehicle fleet caused by enabled policies) [6]. The models consist of two dimensions: a visible structure that comprises of equations which define variable relationships and another back structure which includes of arrays and their elements, which contain data and are instructed by the equations. The visible structure of transport sector modeling consists of input data, policies scenario, and calculated values, such as the quantities of fuels consumed by vehicles.

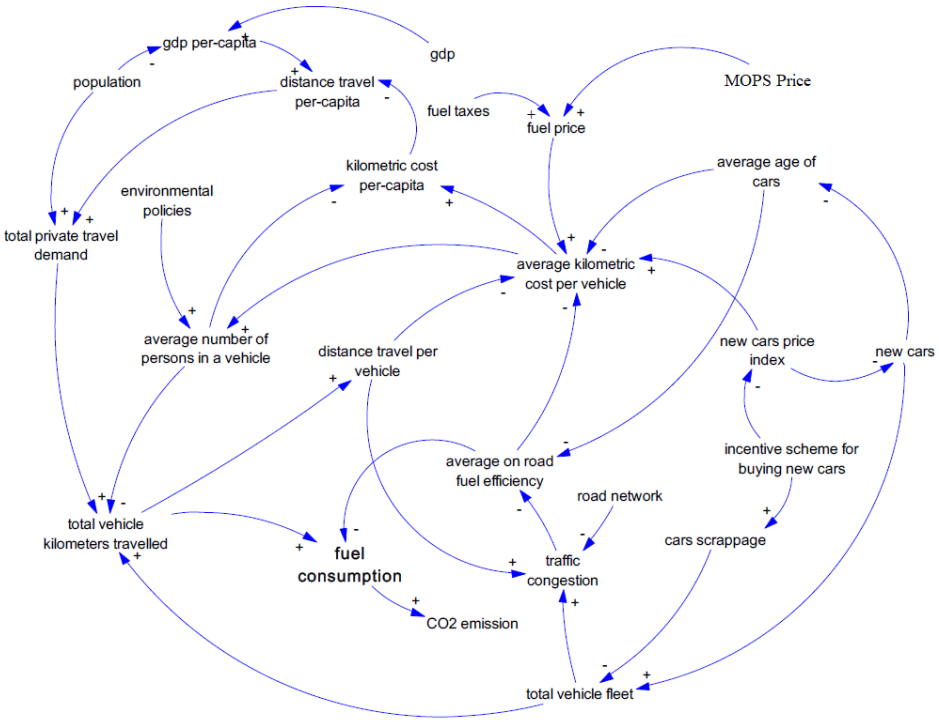


Figure 3. Overall Causal Map.

Figure 4 shows the structure of the model, and the arrows describe the calculation order inside the model, not the flow of energy itself. The calculation logic starts with the Fuels, where basic properties of all related fuels were determined and possible that affect the price of fuels were applied.

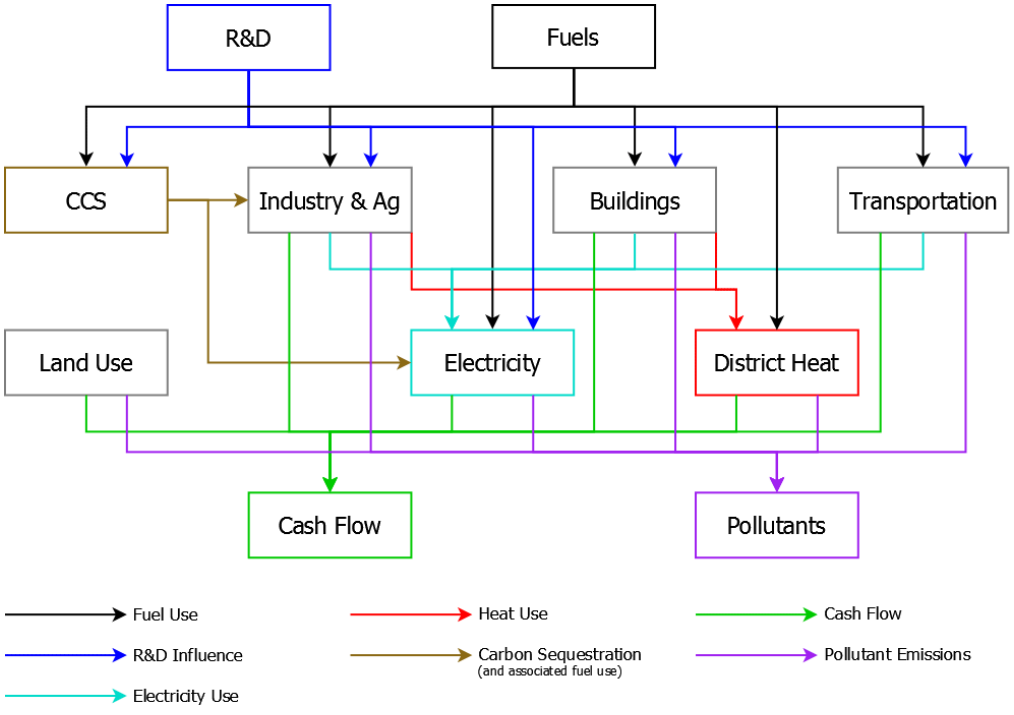


Figure 4. Model Structure and calculation order.

2.3. Scenario of Policies

To develop plausible scenarios, the model used the ASIF framework, and five scenarios were designed to examine the effect of each scenario on energy consumption and CO_2 emissions as listed in Table 1.

Table 1. Developed Scenarios

Scenarios	Contents	Remarks
Reference (REF)	Reference following existing government regulation	• Existing Policies already implemented such as the biofuel mixture schedule according to the 2013 biodiesel mandate up to B20. • No Bio-ethanol mix into gasoline • CNG vehicles very limited • The ratio of new gasoline to diesel vehicle sales is assumed to be 3 to 1.
Fuel Economy (FE)	This policy specifies a tightening of REF fuel economy standards, above and beyond their improvement in the REF case throughout the model run.	Based on Fuel Economy improvement target at Global Level up to 2050 and Ministry of Industry Target, the FE target used as follow: • LDV: 5% Increase per year • HDV: 3% Increase per year • Motorcycle: 5% Increase per year
Transport demand management (TDM)	The Transportation Demand Management policy package reflects the International Energy Agency (IEA)'s "BLUE Shifts" scenario for the year 2050 (source information below). For passengers, this package includes measures such as land-use planning, promoting telework and information-based travel substitutes, parking supply and pricing policies, roadway/congestion pricing, improving bus transit, and encouraging non-motorized transportation such as biking and walking. For freight, this is primarily mode shifting from truck to rail.	For Indonesia, based on other research's and an interview with experts, the value for TDM policy as follows: • Passenger Transport: 30% Shifted • Freight Transport:20% Shifted
Electric Vehicle Adoption (EV)	In this policy, Indonesian fleets are adopting Electric Vehicle.	Based on Indonesian Buying Power, Infrastructure readiness and Battery Technology Improvement, this scenario adopts Electric vehicle percentage up to 2050 as follow: • LDV: 50% of new car sales • HDV: 30% of new car sales • Motorcycle: 100% of new motorcycle sales
Policy Mix	This policy is a combination of all plausible policies based on the ASIF framework	This mix policies scenario is intended to have a quantitative impact of three scenarios developed related to oil reduction and CO_2 emissions up to 2050

3. Results and Discussions

The results of Simulation using system dynamics model are presented as table 3 dan table 4. Also, figure 5 and figure 6 are the output of simulation from each particular scenario developed in this study. The reduction of oil consumption is much more significant than CO_2 emissions due to Indonesian Power Generation still majority generated using coal. Even with higher penetration of Electric vehicle in the transport sector, Indonesia needs to improve emissions factor of Electricity to achieve 29% CO_2 reduction.

Table 2. Simulation Result of Oil Consumption and reduction Percentage.

Petroleum Fuel Consumption (Million Barrels)	Time (Year)						
	2020	2025	2030	2035	2040	2045	2050
REF	915	1073	1254	1627	2081	2579	3139
TDM	914	1067	1244	1607	2044	2521	3056
FE	907	1036	1169	1477	1840	2217	2633
EV	885	995	1119	1382	1677	1986	2335
Policy Mix	848	900	966	1155	1358	1576	1843
TDM Reduction	0%	0%	-1%	-1%	-2%	-2%	-3%
FE Reduction	-1%	-3%	-7%	-9%	-12%	-14%	-16%
EV Reduction	-3%	-7%	-11%	-15%	-19%	-23%	-26%
Policy Mix Reduction	-7%	-16%	-23%	-29%	-35%	-39%	-41%

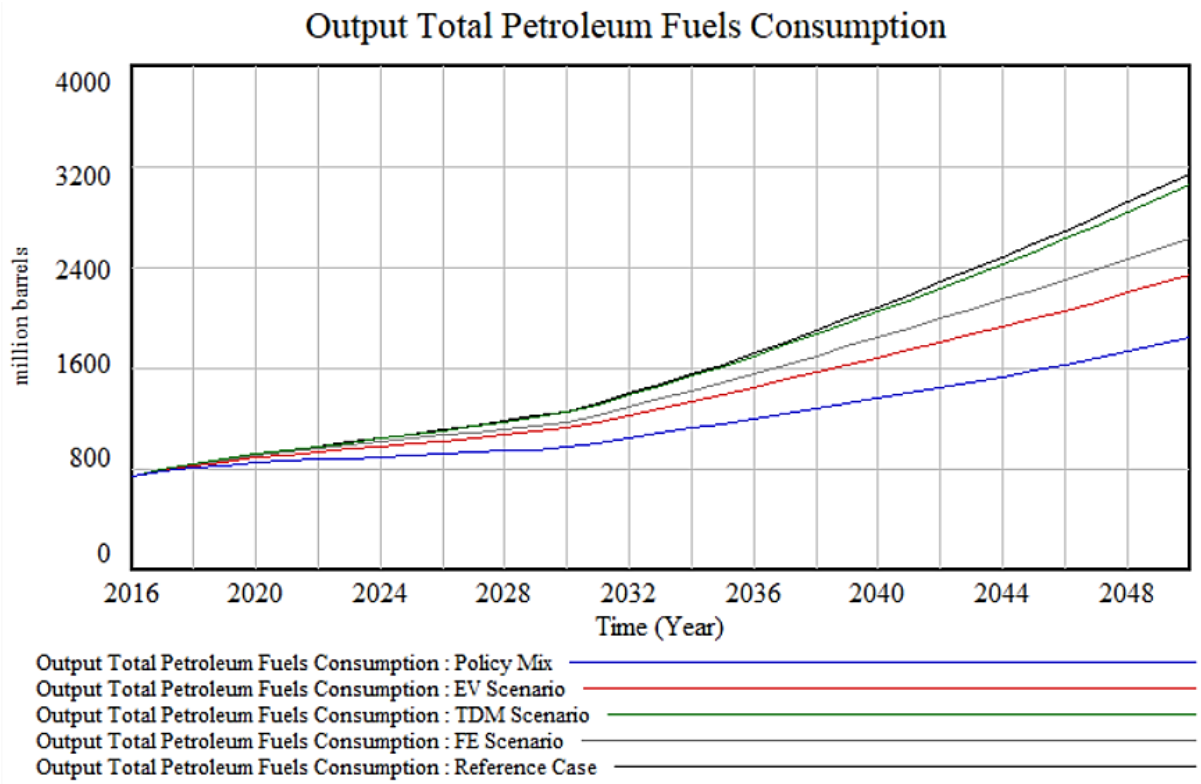


Figure 5. Simulated oil consumption up to 2050.

Table 3. Simulation Result of CO_2 emissions and reduction Percentage.

CO2 Emission (Million Metric Tons)	Time (Year)						
	2020	2025	2030	2035	2040	2045	2050
REF	2445	2696	2994	3470	4159	5062	6245
TDM	2443	2692	2988	3454	4130	5019	6184
FE	2438	2667	2928	3357	3977	4791	5868
EV	2425	2659	2934	3371	3976	4753	5827
Policy Mix	2406	2606	2841	3231	3774	4487	5494
TDM Reduction	0%	0%	0%	0%	-1%	-1%	-1%
FE Reduction	0%	-1%	-2%	-3%	-4%	-5%	-6%
EV Reduction	-1%	-1%	-2%	-3%	-4%	-6%	-7%
Policy Mix Reduction	-2%	-3%	-5%	-7%	-9%	-11%	-12%

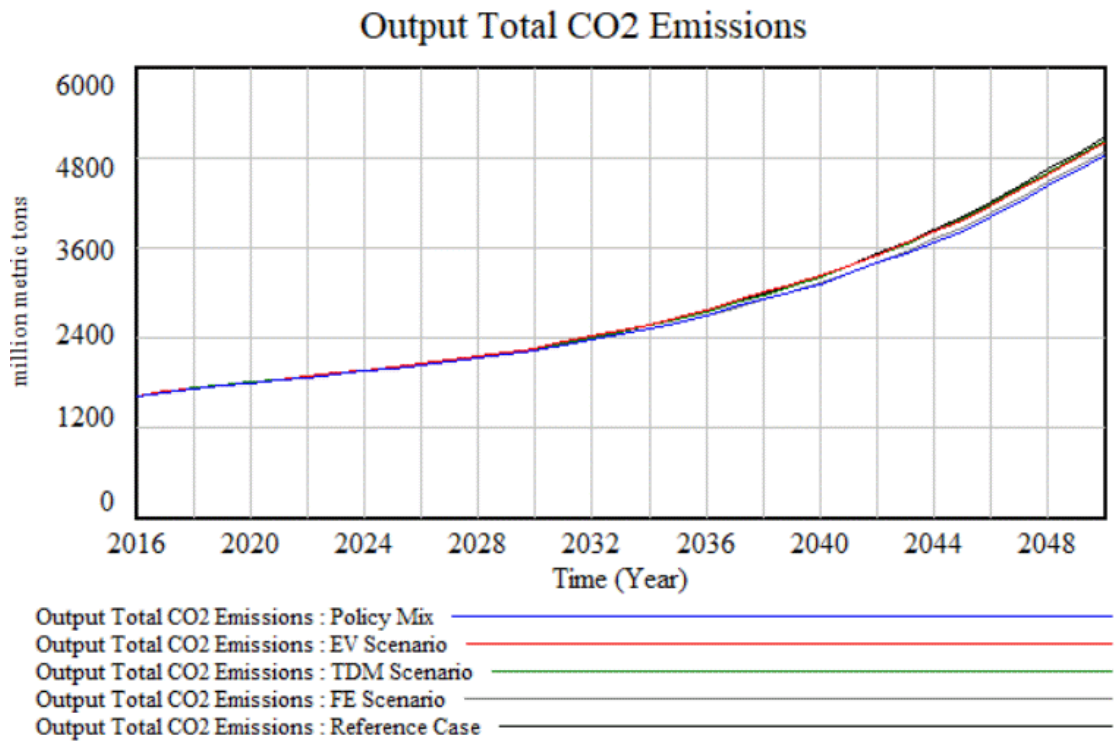


Figure 6. Simulated CO_2 Emissions up to 2050.

4. Conclusions

In conclusion, if using single scenario of Policy, then maximum reduction of Oil Consumption and CO_2 emissions were achieved through EV Policy Scenario which can reduce 26% and 7% respectively. With Policy Mix Scenario, it can achieve 41% reduction of oil consumption and 12% of CO_2 emission for Road Transportation Sector by 2050. If using a single scenario of Policy, the maximum reduction of Oil Consumption and CO_2 emissions were achieved through EV Policy Scenario which can reduce 26% and 7% respectively. With the Policy Mix Scenario, it can achieve a 41% reduction of oil consumption and 12% of CO_2 emission for Road Transportation Sector by 2050.

Acknowledgment
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