Using system dynamics approach to build policy scenario for reducing CO2 emission resulted from tourism travel to Karimunjawa

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Using system dynamics approach to build policy scenario for reducing CO2 emission resulted from tourism travel to Karimunjawa

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Abstract

Purpose – This study aims to create the causal relationship between transportation behavior to Karimunjawa, the number of tourists and the amount of CO2 produced; calculate the reduction of CO2 emissions from the transportation to Karimunjawa based on several proposed policy scenarios; and formulate the managerial implication and recommendation to support the implementation of several proposed policy scenarios.

Design/methodology/approach – This study develops a system dynamics-based model by using three sub-systems, i.e. "the number of tourist sub-system," "the switching behavior of tourist travel sub-system" and "the CO2 emission sub-system."

Findings – The simulation results have shown that, under the current situation, tourist travel behavior should be changed to maximum condition to get the minimum CO2 emission. Improvement of the behavior of tourist in selecting the mode of transportation and the departure point of mini-tour bus and ferry are an effective way to reduce the CO2 emission.

Research limitations/implications – This study only considers limited variables as the driver of the level of change of the capacity of Karimunjawa and the road as well as the variables as the driver of tourism growth. This study only focuses on CO2 emission from the direct impacts of tourist travel; this study does not consider the indirect impact of tourism activity on CO2 emissions. International air travel is not included in the present study.

Practical implications – From a managerial perspective, this study demonstrates that change in the tourist travel behavior is generally not effective in triggering CO2 emission reduction, unless it is accompanied by the strict restriction policy related to the tourist route.

Social implications – This study has the potential to raise societal awareness that the causality of tourist growth and CO2 emissions should be seen as the impact of tourist travel behavior. In this case, to modify the travel behavior, tourist needs to change their mode of transportation to more sustainable transportation.

Originality/value – This paper intends to fill the literature gap of the effect of tourism growth from two perspectives, namely, tourist travel behavior and environmental. The modeling of tourist transport and CO2 emission will provide an overview of the selection of the problem-solving mode for tourist transport that can give a significant contribution to the greenhouse gas emissions reduction to the environmental.

Keywords CO2 emission, Policy scenarios, System dynamics, Tourist travel

Paper type Research paper

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1. Introduction

In line with the fast-growing tourism demands, tourism-related sectors have played a significant role in the system of economies of most developed and developing countries (Liu *et al.*, 2018; Ragab and Meis, 2016). The arrival of global tourist has increased at an average annual rate of approximately 4% during the past two decades and will grow at a 3.3% annual rate from 2010 to 2030, reaching 1.8 billion visits in 2030 (World Tourism Organization, 2014). In Indonesia, although the travel and tourism sector gives a smaller share to the national's economy compared to the comparator countries such as Thailand or Malaysia, the total contribution of the travel and tourism sector to Nation's gross domestic product (GDP) is quite significant. It was Rp 770,310.0bn (US$57.9bn) or 6.2% of GDP in 2016. This contribution is forecast to rise by 6.2% pa to Rp 1,464,700.0bn (US $110.1bn) or 6.8% of GDP in 2027. The travel and tourism sector contributed to 1,944,000 jobs (1.6% of total employment) in 2016. This contribution is projected to rise by 2.4% pa to 2,517,000 jobs (1.7% of total employment) in 2027 (World Travel and Tourism Council, 2017). Moreover, foreign tourism is one of the sources for Indonesian foreign currency which reduces dependence on getting foreign currencies from exports of natural resources (e.g. mining and crude palm oil). In 2017, among the top 10 sources of foreign currency, tourism lied on the fifth rank, below coal, palm oil, oil and gas and textile. Over 1995–2007, the number of foreign tourist arrivals remained around 5 million per year. However, since 2007, the number of international arrivals has increased, achieving 14 million in 2017 and this condition has a significant contribution to increasing the market share of Indonesia toward world tourism around 1%. The authorities target to achieve 20 million foreign visitors by 2019. Most of the foreign tourists have originated from Asian countries and Chinese tourists became the largest source market in 2017, surpassing Malaysia, Singapore and Australia (Ollivaud and Haxton, 2019).

Indonesia has many places that can become attractive tourist destinations. Besides Bali, Central Java is one of the tourist destinations in Indonesia. It has a significant contribution to the visitation of tourists, both domestic and overseas. The tourism development in Central Java performs an upward trend from year to year. One of the potential tourist destinations in Central Java is Karimunjawa National Park. It is one of seven national marine parks in Indonesia. The total area of the Karimunjawa National Park is about 152,506 Ha, divided into the land area ± 4,644 Ha (3%) and the water area ± 147,862 Ha (97 %). Karimunjawa National Park is located 120 km north of Semarang. It can be reached by air as well as by sea from Semarang and by sea from Jepara. The attractiveness of Karimunjawa National Park as a tourist destination can be seen from the growth of visitors over 2008–2016. In 2016, the number of visitors to Karimunjawa National Park was only 9,986 people and, in 2016, the number of visitors to Karimunjawa National Park reached 118,301 people or increased by more than 11 times (Purwanti, 2001; Baskara *et al.*, 2017).

The trend of tourism in Karimunjawa National Park not only gave a significant effect to the Central Java Province economy but also raised some negative impacts and practices, such as, e.g. degradation of ecosystem, exploitation of marine resources, decrease in the number of fisheries production, destructive fishing practice and uncontrolled tourism activities (Purwanti, 2001; Taruc, 2011; Baskara *et al.*, 2017; Hafsaridewi *et al.*, 2018). Moreover, according to Robaina-Alves *et al.* (2016), the rapid growth of tourism and travel activity presents an environmental concern, accounting for a massive amount of CO2 emissions. Peeters and Dubois (2010) argued that the tourism sector is accountable for 5% of CO2 emissions in the world. The prior studies have indicated that CO2 emissions of travel and tourism were mainly from three sources, transportation, accommodation and tourist activities (Becken *et al.*, 2003; Wu and Shi, 2011; Gössling, 2013; Becken, 2013). Among three sources, many works have indicated that transportation accounts for a significant proportion of the energy consumption and CO2 emissions by the tourism industry (Lin, 2010; Higham *et al.*, 2016; Gossling 2002; Li *et al.*, 2019). For example, the result of the research conducted by Li *et al.* (2019) indicated that transportation was a leading contributor to environmental pollution (representing 38.75% of tourism-related CO2 emissions). The research conducted by Higham *et al.* (2016) indicated that air travel attributed to 40% of CO2 emission generated by tourism. So, to understand the relationship between the tourist transportation activity to Karimunjawa National Park and the emission of CO2, this study addresses the following issues. First, create the causal relationship between transportation behavior to Karimunjawa, the number of tourists and the amount of CO2 produced. Second, calculate the amount of CO2 emissions reduction from the activity of transportation to Karimunjawa based on several proposed policy scenarios. Third, formulate the managerial implication and recommendation to support the implementation of several proposed policy scenarios.

2. Literature review

2.1 Relationship between tourism and CO2 emission

The study about travel and tourism activity and direct and indirect CO2 emission through several different methods and regions or objects of studies has still been widely carried out and discussed. The direct CO2 emissions refer to the carbon dioxide emissions from direct energy consumption of the tourism system, whereas indirect CO2 emissions refer to the embodied carbon emissions from energy consumption of intermediate products of tourism-related industries (Tao *et al.*, 2014). Research studies have estimated the carbon emissions from the tourism industry in Sweden (Gössling and Michael Hall, 2008), New Zealand (Becken and Patterson, 2006), Australia (Dwyer *et al.*, 2010), Romania (Surugiu *et al.*, 2012), Wales, the UK (Jones, 2013; Munday *et al.*, 2013), China (Liu *et al.*, 2011 for Chengdu; Tang *et al.*, 2017 for Wulingyuan Scenic and Historic Interest Area; Li *et al.*, 2019 for Beijing), Suan Phueng Mountain, Thailand (Jamnongchob *et al.*, 2017) and Pakistan (Sharif *et al.*, 2017). The other scholars have estimated the carbon emission from specific travel and tourism activities, such as packaged tours (Yang *et al.*, 2008) and the international cruise ship journeys (Howitt *et al.*, 2010). Then, some papers have measured and analyzed carbon emissions from tourism using either top-down or bottom-up methodologies (Becken and Patterson, 2006; Howitt *et al.*, 2010; Tang *et al.*, 2017), input-output model (Surugiu *et al.*, 2012; Munday *et al.*, 2013; Li *et al.*, 2019), production approach and expenditure approach (Dwyer *et al.*, 2010), environmental externalities (Jones, 2013) and the other relevant methods. In detail, some studies about travel and tourism activity and CO2 emission from previous research works can be seen in Table 1.

It can be seen that, although there are numerous studies that have explored the CO_2 emission-related impact of tourism activities, the studies about the dynamic relationship between tourist transport behavior, the number of tourists, the amount of CO_2 produced and the proposed policy scenarios (with the case study tourist destination in Indonesia) are still lacking. Therefore, to the best of our knowledge regarding those dynamic relationships, this paper intends to fill the literature gap of the effect of tourism growth in Karimunjawa from two perspectives, namely, tourist travel behavior and environmental. The modeling of tourist transport and CO2 emission will provide an overview of the selection of the problem-solving mode of tourist transport that can give a significant contribution to the greenhouse gas emissions reduction for the environment.

Authors	Domain perspective	Method of research and findings
Becken and Patterson (2006)	Tourist activity in New Zealand	Method: use a bottom-up analysis involving industry and tourist analyses and a top-down analysis using environmental accounting to calculate CO_2 emission from the tourist industry in New Zealand Findings: the two methodologies result in yearly estimates of a similar order for CO_2 emissions (between 1,400 and 1,600 kilotons) by New Zealand tourism sector
Gössling and Michael Hall (2008)	Tourism activity in Sweden	Method: two different methods are used to calculate emissions from aviation and other transport modes. For aviation, total fuel use in Sweden is calculated, i.e. considering bunker fuel used in Sweden for tourism, for which statistics are available. As for other transport modes, an aggregate approach is used, summing up distances traveled for tourism-related purposes and multiplying results with emission factors for different transport modes Findings: the study has shown that Swedish tourism is an important contributor to climate change. Its contribution to Swedish emissions of CO_2 is in the order of 11% (in 2000/2001), i.e. more than twice the share of tourism's contribution to climate change on the global level
Yang *et al.* (2008)	The eight-day packaged tour of Shangri-La, Yunan	Method: use eco-efficiency to study greenhouse gas (GHG) emission on tourism literary products (three different products of the eight-day packaged tour of Shangri-La, Yunan). These three varied in the distance from tourist source regions (Shanghai/ Nanning/ Kunming) to destinations as well as the transport modes Findings: the CO_2 emissions from three different products of an eight-day packaged tour of Shangri-La were 1847.73 kg, 451.88kg and 310.35 kg. This accounted for 68.43%, 33.57% and 14.88% of the average annual emission of CO_2 by Chinese
Howitt *et al.* (2010)	The international cruise ship journeys to and from New Zealand	Method: use "bottom-up" or 'activity-based' model to calculate CO_2 emissions factor in grams of CO_2 per passenger-km (g CO_2 per *p*-km) for cruise ships travelling to and from New Zealand. A bottom-up approach estimates the number of emissions based on individual activities of ships (for example, the distances traveled by ships) Findings: emissions factors for individual journeys by cruise ships to or from New Zealand in 2007 ranged between 250 and 2,200 grams of CO_2 per *p*-km, with a weighted mean of 390 gram CO_2 per *p*-km. The weighted mean energy use per passenger night for the 'hotel' function of these cruise vessels was estimated as 1,600 MJ per visitor night, 12 times larger than the value for a land-based hotel
Dwyer *et al.* (2010)	Tourist industry and related activity in Australia	Method: use a "production-based approach" and an "expenditure-based approach" to estimate the GHG emissions from the tourism industry and related activity in Australia Findings: referring to the "expenditure approach," the total (direct plus indirect) GHG emissions are estimated to be 61.5 million tonnes. As compared to the production-based approach, the expenditure-based measures have higher global GHG emissions because they include more air transport, along with GHG emissions associated with imports provided directly to tourists

(*continued*)

Table 1.
Previous studies about travel, tourism activity and CO2 emission

Authors	Domain perspective	Method of research and findings
Liu *et al.* (2011)	Tourist activity in Chengdu, China	Method: use the method introduced by the IPCC report to calculate the CO_2 emissions of the tourism industry in Chengdu, China Findings: from 1999 to 2004, the CO_2 emission of the tourism industry in Chengdu increased from 1.7 million tonnes to 2.1 million tonnes. The indirect CO_2 emissions dominate the total CO_2 emissions, with an overwhelming percentage of over 90%. Transportation is the major contributor to the carbon emission of the tourism industry
Jones (2013)	Tourist activity in Wales, the UK	Method: propose four different scenarios and use extended tourism environmental satellite account methodology or environmental externalities to estimate the CO_2 emissions associated with trips. Scenario 1 shows the value of low-carbon electricity production in cutting tourism-related emissions. Scenario 2 analyses a possible 50% fall in international arrivals and a 10% increase in the UK domestic arrivals maintaining employment but reducing emissions. Scenario 3 shows the effects of a switch from private to public transport modes for 50% of the UK resident arrivals. Scenario 4 examines the outcomes of reducing ground transport emissions by using electric, biofuel and hybrid technologies Findings: all scenarios cut emissions; none are highly effective and most are dependent on changes in society and governance
Surugiu *et al.* (2012)	Tourist activity in Romania	Method: use input-output analysis to assess the impact of CO_2 emissions generated by economic activities and particularly the tourism sector in Romania Findings: tourism sector ranks 12 and respective 15th position in the analyzed year, in terms of output multiplier 2.45 and CO_2 emission multiplier 0.168 expressing medium inter-linkages with the other sectors of the economy and less pollutant branch. The direct contribution to CO_2 emissions of tourism sectors counts for 4,355 kg per unit of output, whereas if including the indirect effects, the total contribution increases to 1,632 kg of CO_2 per exogenous and unitary inflow received
Munday *et al.* (2013)	Tourist activity in Wales, the UK	Method: use input-output analysis to identify the carbon footprint of tourist activity in Wales, the UK Findings: total tourism activity directly contributes the remaining 3.8% of total Welsh carbon emissions
Tang *et al.* (2017)	The Wulingyuan Scenic and Historic Interest Area (WSHIA) (one of the tourist destinations in China)	Method: use the top-down method, lifecycle assessment method and material flow theory to develop a model on energy consumption and CO_2 emissions for the tourism industry in tourism destinations Findings: the annual geometric mean growth rate of total CO_2 emission for the tourism industry in the WSHIA was 15.87%, for the period from 1979 to 2015, with 1032.09 tonnes in 1979 and 178752.65 tonnes in 2015
Jamnongchob *et al.* (2017)	Tourist transportation to Suan Phueng Mountain, Thailand.	Method: use a bottom-up approach to estimate the amount of CO_2 released from energy used in tourist transportation during the distance between home and Suan Phueng Mountain location Findings: total energy consumption of gasoline and diesel in transportation were 4810.85 and 8640.91 liters. Car was the most popular vehicle for visiting this area; it is about 78%. Total and mean CO_2 emissions in tourist transportation were 32249.66 kg CO_2 equivalent and 21.20 kg CO_2 per person

(*continued*)

Table 1.

Authors	Domain perspective	Method of research and findings
Sharif *et al.* (2017)	Tourist arrival in Pakistan from 1972 to 2013	Method: use autoregressive distributed lag bounds test, Johansen and Juselius and Gregory and Hansen structural break test to estimate the CO_2 emission from tourist arrival from 1972 to 2013 Findings: the results of the CO_2 emission model suggest that in the initial round, the change in CO_2 emission is explained 99% entirely by its own improvements. In the second period, 85.274% describe by own improvement, 5.666% by tourist arrivals, 3.903% by economic growth and 5.157% by foreign direct investment. In period five, the shocks in CO_2 emission describe 39.645% by its own improvement, 19.861% by tourist arrivals, 23.924% by economic growth and 16.571% by foreign direct investment. In the tenth period, the shocks of CO_2 emission describe 20.979% by its own, 41.309% by tourist arrivals, 25.000% by economic growth and 12.712% by foreign direct investment
Li *et al.* (2019)	Tourist activity in Beijing	Method: use the input-output model and tourism satellite accounts to calculate the direct and indirect CO_2 emissions Findings: in all tourism sectors (except for transportation), the indirect CO_2 emissions were over three times greater than the direct CO_2 emissions. Transportation was a leading contributor to both the economic benefit (representing 91.65% of tourism income in 2012) and to environmental pollution (representing 38.75% of tourism-related CO_2 emissions)

Table 1. **Note:** IJPCC = Intergovernmental Panel on Climate Change

2.2 Karimunjawa

Karimunjawa National Park is one of seven marine national parks in Indonesia. It is located in the Karimunjawa Archipelago (5°40' 39"–5°55' 00"S, 110°05' 57"–110°31' 15"E) in the Java Sea between Java and Borneo. Administratively, the park is located within Karimunjawa subdistrict, part of Jepara district, Central Java Province. There are 27 islands in the Karimunjawa Archipelago. Among the 27 islands in the Karimunjawa Archipelago, 22 islands are managed by the Karimunjawa National Park. It covers 7,033 ha of land and 104,592 ha of marine waters including several natural ecosystems, such as sea grass, coral reefs, mangroves, forest beach and lowland forest. The largest island is Karimunjawa, where the principal village of the subdistrict and the ferry dock are located. It is around 4,300 ha. Kemujan is the second-largest island. It is around 1,500 ha. The location of Kemujan Island is adjacent to Karimunjawa and connected by approximately 350 m of mangrove forest and a bridge. This condition makes Karimunjawa and Kemujan to look like one single island. There is Dewandaru Airport in Kemujan Island (Susanto *et al.*, 2014)

There is a human population living in a village on the four islands (Karimunjawa, Kemujan, Parang and Nyamuk Islands). According to the Central Bureau of Statistics (2010), the total number of the population who lives on four islands is 8,733 people (Susanto *et al.*, 2014). There are three dominant ethnics of the people who live in Karimunjawa–Javanese, Buginese and Madurese. The education level of the population in Karimunjawa is classified as low, as most of them only are primary school graduate or not graduate at all (Suliyati *et al.*, 2017).

The Karimunjawa National Park can be accessed by flights and ferry. There is no direct flight to Karimunjawa National Park; both domestic and foreign tourist should fly to Ahmad

Yani International Airport in Semarang before going to the Park. The flight to Semarang is available from Jakarta, Denpasar and also from other cities. Domestic tourists can also use private cars, buses or train to go to Semarang. From Semarang, both domestic and foreign tourist can choose two alternatives to go to Karimunjawa. They can use small flights and land at Dewandaru Airport or they can use ferries from Tanjung Emas Port (Semarang), Kendal Port (Semarang) or Kartini Port (Jepara). Ferries serve the islands three times a week, either from Jepara or also Semarang and speedboats are plenty and available on special request (Setiawan *et al.*, 2018).

2.3 Calculation of CO2 emission

Currently, there is no systematic approach that can be used to calculate the CO2 emissions related to the tourism industry. However, based on various scholars' work, the approach for calculating the CO2 emissions can generally be grouped as two approaches, namely top-down and bottom-up (Becken and Hay, 2007; Gossling *et al.*, 2005; Peeters, 2005). In the top-down approach, the percentage of CO2 emissions for tourism is calculated based on the entire system, i.e. a country or region. In the bottom-up approach, the percentage of CO2 emissions for tourism is calculated based on the data of tourists arriving at the destination (Lin, 2010). This research prefers to use the bottom-up approach for calculating the percentage of CO2 emissions because of the difficulties in getting relevant data and also the complex relationship between tourism activity and other industries.

Different vehicles (such as fossil fuels and electricity) have different energy efficiency rate. Normally, the distance traveled has a positive correlation with the energy consumed. The further the distance, the higher the amount of energy consumed. Moreover, depending on their source, every unit of energy consumed will generate different amounts of CO2 emissions. In the past, the amount of CO2 emission was evaluated based on vehicles volumes. But, it is difficult as most of the tourism data in most countries are calculated based on the number of tourists. Therefore, this work focusses on tourists to calculate CO2 emissions. The formula to calculate the total of CO2 emissions (kg-CO2) by different vehicles can be seen in equation 1 (Lin, 2010):

$$CO_2\ Emission = \sum_{i=1}^{n} P_i \cdot D_i \cdot \beta_i \tag{1}$$

where P_i denotes the total number of tourists using transport mode i, D_i denotes the distance of transportation taken by transport mode i (km) and β_i denotes CO2 emission factor transport mode (CO2 emissions per passenger-kilometre [kg/pkm]). In this case, the β_i value for private cars is from 0.133 to 0.241 kg/pkm and the β_i value for tour bus is from 0.022 to 0.04 kg/pkm (Becken, 2009; Scott *et al.*, 2008). Then, based on analyzed data on CO2 emissions resulting from ferry travels which are obtained from several ferry companies, one of Europe's leading sustainability consultancies recommended that an average emission factor of the ferry is 0.12 kg/pkm (Holthof, 2008). It is important to note that the formula for calculating the CO2 emissions expressed in equation (1) must be multiplied by two to calculate CO2 emission from round-trip consumption as the formula only covers one-way tourist travel (Lin, 2010).

2.4 Volume to capacity ratio, the cost of travel and the change of behavior

According to the Indonesian Highway Capacity Manual (Directorate General of Bina Marga, 1997), the degree of saturation is defined as the ratio between the traffic flow/volume (V) and the designed road capacity (C) of a certain road section. The volume and capacity are both in passenger car units per hour (PCU/hour). A volume to capacity ratio (VCR) value of 1 indicates that traffic volume is equal to road capacity. If this ratio is greater than 1, the traffic flow may be heavy and the traffic speed may decrease to inconvenient levels; conversely, a decrease in the ratio can indicate that traffic is flowing more freely and that travel time may be decreasing (and/or traffic speed may be increasing) to more convenient levels (Wandani and Yoshida, 2013). Then according to the VCR, the engineer defines the levels of service (LoS) to qualitatively describe the operating conditions of a roadway based on factors such as speed, travel time, maneuverability, delay and safety. LoS A has VCR value from 0.00 to 0.60, indicated by free-flow conditions with unimpeded maneuverability and stopped delay at the signalized intersection is minimal. LoS B has VCR 0.61–0.70, indicated by reasonably unimpeded operations with slightly restricted maneuverability and stopped delays are not bothersome. LoS C has VCR from 0.71 to 0.80, indicated by stable operations with somewhat more restrictions in making mid-block lane changes than LoS B and motorists will experience appreciable tension while driving. LoS D has VCR from 0.81 to 0.90, indicated by approaching unstable operations where small increases in volume produce substantial increases in delay and decreases in speed. LoS E has VCR from 0.91 to 1.00, indicated by operations with significant intersection approach delays and low average speeds. Last, LoS F has VCR greater than 1, indicated by extremely low speeds caused by intersection congestion, high delay and adverse signal progression (Wallis and Lupton, 2013).

The high ratio between traffic flow/volume and road capacity also indicates the congestion of the traffic, which is characterized by low average speeds, as well as by increased variations in speed, an increase in potential conflicts and by incentives to seek alternative routes (Albalate and Fageda, 2019). Congestion has a direct impact on fuel consumption as well as the cost of travel. Traffic congestion affects vehicle fuel economy through lower average travel speed and increased vehicle speed variability (accelerations and decelerations). These influence engine/motor operating loads and operating duration, which in turn impacts fuel consumption per km of travel (Bigazzi and Clifton, 2015). According to Treiber *et al.* (2008), the fuel consumption in congested traffic is 14.7 l/100 km and therefore increased by about 80% compared to free traffic conditions resulting in 8.24 l/100 km; inevitably, this condition will increase the cost of travel. The cost of congestion is the difference between the observed cost of travel and the cost of travel when the road is operating at capacity. Observed delays are only part of the true cost of congestion and people change their schedules or mode of transport to avoid delays and make extra time allowances in case of unexpected delays (Wallis and Lupton, 2013). Moreover, the cost of congestion may impact the travel behavior of different socioeconomic groups of travelers. People may change their travel behavior such as changing modes of transportation or time of travel (AbuLibdeh, 2017).

Based on the overview of VCR, cost of travel and change in behavior, it can be said that increasing the value of VCR will increase the traffic congestion and this will have an impact on increasing travel costs as a result of increased the fuel costs. Increased congestion will cause changes in travel behavior, such as making a different option in the mode of transportation used.

2.5 Overview of system dynamics, transportation system and CO2 emissions

System dynamics (SD) was proposed by Forrester in 1961. SD can be defined as a computer-aided approach to understanding the behavior of a system over time. It has been used to solve dynamic problems from different fields of research such as medical, engineering, ecological and social sciences. SD has been used as a tool for modeling the complex systems as well as for understanding the behavior of a system based on the causal effect relationships between the system elements (Egilmez and Tatari, 2012). The research about SD, transportation system and CO2 emission can be seen from several previous authors such as Egilmez and Tatari (2012), Lei *et al.* (2012), Liu *et al.* (2015), Sukarno *et al.* (2016), Setiafindari *et al.* (2017), Setiawan *et al.* (2019).

Eglimez and Tatari (2012) used SD approach to investigate the causal relationship between the number of population, the number of vehicle, the economic condition, the highway system condition, the congestion, the highway system capacity, the construction, the vehicle miles traveled, the fuel use, the fuel efficiency and CO2 emissions. Egilmez and Tatari (2012) simulated 26 different combinations of three policies scenarios. Then, 4 out of 26 options are found to be successful in terms of meeting emission targets set by the Climate Act. Lei *et al.* (2012) used a SD approach to investigate the causal relationship between urban low-carbon transport system and CO2 emissions. The urban low-carbon transport system is a complex dynamic system, which consists of society, economy, motor vehicles, cars, transport infrastructure and other factors. Lei *et al.* (2012) use Shanghai, as a case study and found that the rapid increase of private cars is a significant driver factor of carbon emissions. So, it is essential to strengthen urban transport demand management and enhance the urban transport structure in building urban low-carbon transport. Liu *et al.* (2015) used SD approach to simulate a variety scenario based on management experience in the causal relationship between urban passenger transport energy consumption and CO2 emissions. They used Beijing as a case study. The result of the simulation indicated that priority to the development of public transport could significantly increase the proportion of public transport locally and would help pursue energy savings and emission reductions as well. Sukarno *et al.* (2016) used SD approach to investigate the causal relationship between transportation, fuel consumption and CO2 emissions and the other pollutants. They used Padang, as the object of study. The model of SD consisted of two sub-models, namely, transportation and emission. In the transportation and emissions sub-model, future fuel consumption, CO2 emissions and the other pollutants were affected by the vehicle growth rate, emission standard and split mode between private and public uses. The fuel consumption depended on the total kilometers traveled by the vehicles and vehicle population. Setiafindari *et al.* (2017) used SD approach to investigate the causal relationship between the number of vehicles, the level of environmental awareness, the financial ability, the preference of type vehicle, the transportation need and the level of reduction of CO2 emissions. In this case, the number of vehicles is affected by the number of vehicle purchase and the level of environmental awareness. This level of awareness is affected by the condition of the road; whereas, the number of vehicle purchase is affected by financial ability and preference for the type of vehicle. It depends on their transportation need (the frequency of trips, distance of travel and social network). The purpose of this study is to investigate fuel consumption and road emissions of the transportation sector, thus providing a potential improvement in reducing fuel consumption and emissions. Setiawan *et al.* (2019) used SD approach to investigate the causal relationship between the growth of GDP, growth of transportation demand, vehicle fuel efficiency, fuel price, the average distance traveled per vehicle (kilometers per year) and CO2 emissions. There were six policy scenarios developed, namely, following existing government regulation, fuel economy, transport demand management, electric vehicle adoption and mix of all plausible scenarios. The result of a simulation based on a single scenario indicated that the maximum reduction of oil consumption and CO2 emissions were achieved through electronic vehicle adoption. The result of a simulation based on the policy mix of all plausible scenarios can reduce 41% of oil consumption and 12% of CO_2 emission. So, based on the overview of SD, transportation system and CO_2 emissions, it can be concluded that the CO_2 emission is mainly influenced by the number of vehicles, transport behavior and vehicle fuel efficiency.

3. Method of research

The SD modeling approach is used as a methodology. According to Sternan (1989), the methodology includes following steps, namely, articulating the problem, developing the A (CLD), constructing the simulation model (stock and flow diagram), testing the simulation model and policy or strategy design and analysis (Sterman, 1989; Egilmez and Tatari, 2012). This study refers to Haraldsson and Ólafsdóttir (2018) and Wang *et al.* (2020) in modeling the dynamic relationship between tourist growth, increased infrastructure, changed experience, change behavior and increased environmental pressure. This becomes the basic model, and then it is modified according to the problem that needs to be solved.

The first step, articulating the problem, refers to the work to "recognize the problem" (Goodman, 2006). In this study, recognizing the problem has been done through several activities, such as conducted a short interview, reviewed some relevant literature and collected all relevant data and information. The short interview has been conducted with the representative of the Department of Youth, Sports and Tourism of Central Java Province. The result of the interview indicated that the number of tourist travel to Karimunjawa increases significantly each year. This condition gives a positive impact on economic development as well as the negative impact on the environment as tourist travel has a significant contribution to CO_2 emission. Then, to strengthen the problem identified from the interview, the authors also reviewed some literature on the development of Karimunjawa tourism in past five years, focusing on the tourist travel (domestic and international), problem and related factors and policies. Last, the authors have collected all the relevant data and information that can describe the dominant point of origin of the tourist (domestic and international), the factors contributing to the number of tourists, the mode of transportation, the tourist travel behavior and the factors contributing to tourist switching behavior.

The second step related to describe the causal relationship of all the variables related to the problem has been identified from the first step in the form of CLD. A causal relation means that, the input variable has a causal influence on the output variable. In CLD, if all else being equal, a plus sign (+) over an arrow from X to Y implies that if X increases so does Y or if X decreases Y also decreases. A minus sign (–) indicates an inverse effect. Moreover, the double line on the arrow linking X to Y represents a delay in the system. Delays occur in all systems; it may be of the order of seconds, minutes, hours, months, years, etc. (Armah *et al.*, 2010). In this case, the delay is of the order of years. In detail, the CLDs used in this study can be seen in Figure 1. The third step is related to translating the CLD into a quantitative simulation model. The construction of the simulation model has been facilitated by icon-based programmings, such as stock, flow, auxiliary variables and feedback loops. Stock is the state of an element of the system, which has an impact on the overall or partial pattern of behavior at a time. Flow is the increase or decrease amount on the value of a stock over a period. The auxiliary variables are the rates, which change the stocks by determining the flow values over a period. The feedback loops are represented by causal relationship diagrams (Egilmez and Tatari, 2012). It has been done using Powersim® Studio 10 Professional. The quantitative simulation model (stock and flow diagram) can be seen in Figure 2.

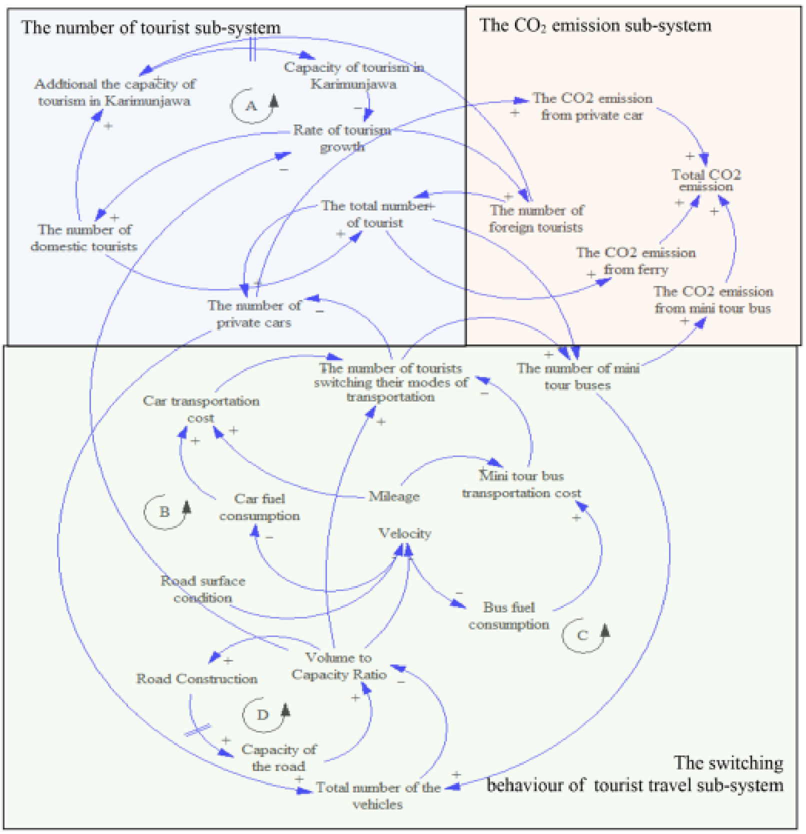

Figure 1.
Three CLD to describe the impact of tourist travel to Karimunjawa on CO_2 emission

Then, the fourth step relates to testing all defined stock, flow, auxiliary variables and causal relationships with certain circumstances or parameter values close enough to a current condition. In this case, all defined stock, flow, auxiliary variables and causal relationships are simulated for a reasonable period concerning initial baseline values of past data. Then, statistical analysis (for example the two-sample *t*-test) was used to check the significance of differences between the results of model simulation and actual past data. Once the difference is not significant, the simulation model is valid and the fifth step can be done. The last step relates to policy or strategy design and analysis. In this step, some question is applied to the simulation model, such as "what if" questions to see the impact of possible scenario policies on simulation system behavior and compare the results with the current condition (baseline). As the example, "what can happen if tourist can change or can't change their behavior in traveling to Karimunjawa?", "What can happen if the government provides more public transport (such as a bus) to go Karimunjawa?", etc.

Related with policy or strategy design, this study proposes nine policy scenarios. This scenario resulted after several discussions with the representative of the Department of Youth, Sports and Tourism of Central Java Province and Central Java Tourism Agency. Each of the scenario is associated with the percentage of tourist changes in their travel behavior to go to Karimunjawa and each scenario is assumed to start from 2019 until 2030. The result of each scenario will be compared with the current condition. Recently, all foreign tourists landed at Ahmad Yani International Airport. Only 40% of the foreign tourists and 20% of the domestic

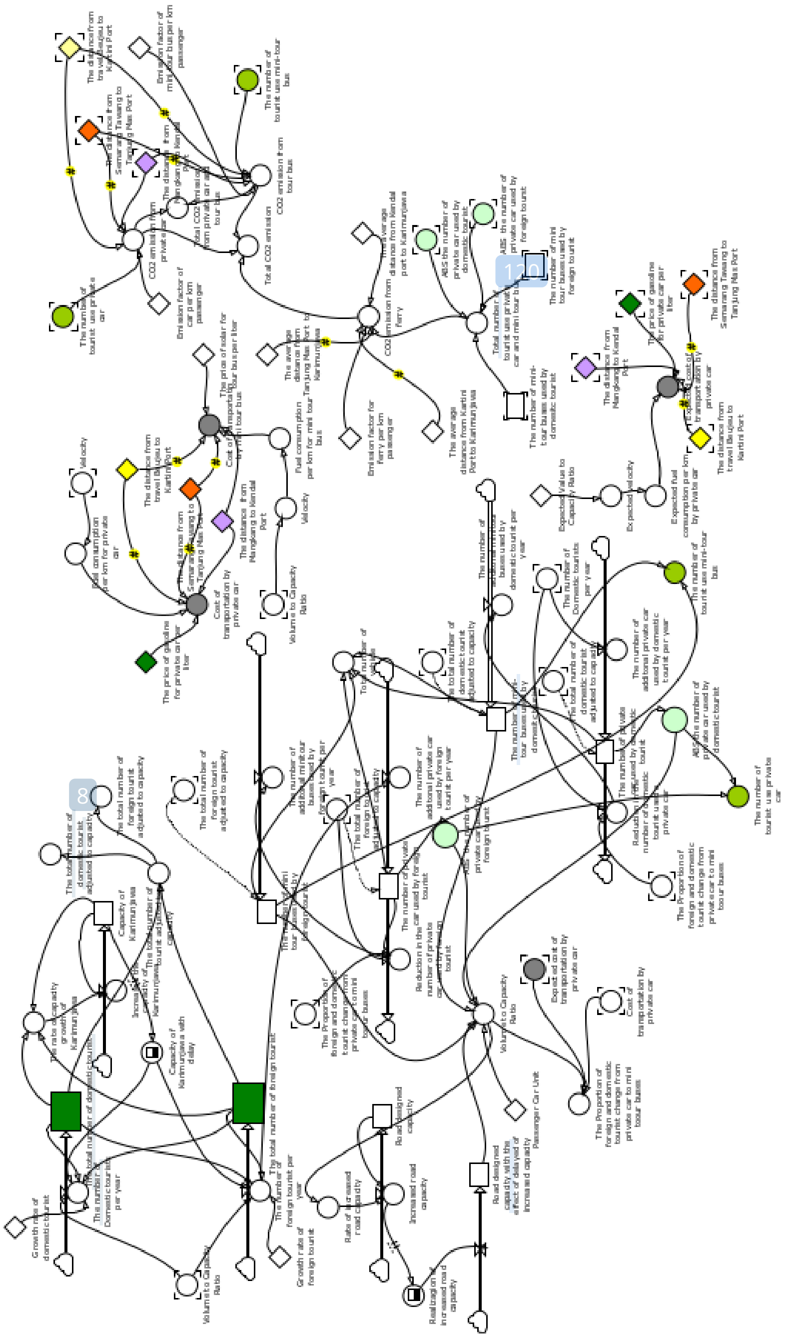

Figure 2.
Stock and flow diagram of the impact of tourist travel to Karimunjawa on CO_2 emission

Increased the capacity of Karimunjawa	=	'Capacity of Karimunjawa'*'The rate of capacity growth of Karimunjawa'
Total CO2 emission from private car and tour bus	=	'CO2 emission from private car'+'CO2 emission from tour bus'
Total CO2 emission	=	'CO2 emission from private car'+'CO2 emission from tour bus'+'CO2 emission from ferry'
Increased road capacity	=	'Rate of increased road capacity'*'Road designed capacity'
The number of additonal private car used by domestic tourist per year	=	'The number of Domestic tourists per year'/2.6
The number of additonal private car used by foreign tourist per year	=	'The number of foreign tourist per year'/2.6
Total number of vehicle	=	'The number of mini tour buses used by foreign tourist'+'The number of minitour buses used by domesitc tourist'+'The number of private car used by domestic tourist'+'The number of private car used by foreign tourist'
The total number of tourist adjusted to capacity	=	'The total number of domestic tourist'+'The total number of foreign tourist'
The total number of foreign tourist adjusted to capacity	=	'The total number of tourist adjusted to capacity'*0.1
The total number of domestic tourist adjusted to capacity	=	'The total number of tourist adjusted to capacity'*0,\.9
The number of tourist use private car	=	('ABS the number of private car used by foreign tourst'+'ABS the number of private car used by domestic tourist')*2.6
The number of additonal minitour buses used by domestic tourist per year	=	('Reduction in the number of domestic tourist used a private car'*2.6)/18
The number of additonal minitour buses used by foreign tourist per year	=	('Reduction in the number of private car used by foreign tourist'*2.6)/18
The number of tourist use mini-tour bus	=	('The number of mini tour buses used by foreign tourist'+'The number of minitour buses used by domesitc tourist')*18
Reduction in the number of domestic tourist used a private car	=	('The Proportion of foreign and domestic tourist change from private car to mini tour buses'*'The number of Domestic tourists per year')/2.6
Total number of tourist use private car and mini tour bus	=	(('ABS the number of private car used by foreign tourst'+'ABS the number of private car used by domestic tourist')*2.6)+(('The number of mini tour buses used by foreign tourist'+'The number of minitour buses used by domesitc tourist')*18)
Volume to Capacity Ratio	=	(('The number of mini tour buses used by foreign tourist'+'The number of minitour buses used by domesitc tourist'+'ABS the number of private car used by foreign tourst'+'ABS the number of private car used by domestic tourist')*'Passenger Car Unit')/'Road designed capacity with the effect of delayed of increased capacity'
CO2 emission from ferry	=	(((1/3)*'Emission factor for ferry per km passenger'*'The average distance from Tanjung Mas Port to Karimunjawa'*'Total number of tourist use private car and mini tour bus')+((1/3)*'Emission factor for ferry per km passenger'*'The average distance from Kartini Port to Karimunjawa'*'Total number of tourist use private car and mini tour bus')+((1/3) *'Emission factor for ferry per km passenger'*'The average distance from Kendal port to Karimunjawa'*'Total number of tourist use private car and mini tour bus'))*2
Cost of transportatin by mini tour bus	=	(((1/3)*'Fuel consumption per km for mini tour bus'*'The distance from Mangkang to Kendal Port'*'The price of solar for tour bus per liter')+((1/3)*'Fuel consumption per km for mini tour bus'*'The distance from Semarang Tawang to Tanjung Mas Port'*'The price of solar for tour bus per liter')+((1/3)*'Fuel consumption per km for mini tour bus'*'The distance from travel Beujeu to Kartini Port'*'The price of solar for tour bus per liter')) *2
Expected cost of transportation by private car	=	(((1/3*'Expected fuel consumption per km by private car'*'The distance from Mangkang to Kendal Port')+(1/3*'Expected fuel consumption per km by private car'*'The distance from Semarang Tawang to Tanjung Mas Port')+(1/3*'Expected fuel consumption per km by private car'*'The distance from travel Beujeu to Kartini Port'))*'The price of gasoline for private car per liter')*2
Cost of transportation by private car	=	(((1/3*'Fuel consumption per km for private car'*'The distance from Mangkang to Kendal Port'*'The price of gasoline for private car per liter'))+((1/3)*'The distance from Semarang Tawang to Tanjung Mas Port'*'Fuel consumption per km for private car'*'The price of gasoline for private car per liter')+((1/3)*'Fuel consumption per km for private car'*'The distance from travel Beujeu to Kartini Port'*'The price of gasoline for private car per liter'))*2
CO2 emission from private car	=	((1/3*'The number of tourist use private car'*'The distance from Mangkang to Kendal Port'*'Emission factor of car per km passenger')+(1/3*'The number of tourist use private car'*'The distance from Semarang Tawang to Tanjung Mas Port'*'Emission factor of car per km passenger')+(1/3*'The number of tourist use private car'*'The distance from travel Beujeu to Kartini Port'*'Emission factor of car per km passenger'))*2
CO2 emission from tour bus	=	((1/3*'The number of tourist use mini-tour bus'*'The distance from Mangkang to Kendal Port'*'Emission factor of mini tour bus per km passenger')+(1/3*'The distance from Semarang Tawang to Tanjung Mas Port'*'The number of tourist use mini-tour bus'*'Emission factor of mini tour bus per km passenger')+(1/3*'The number of tourist use mini-tour bus'*'The distance from travel Beujeu to Kartini Port'*'Emission factor of mini tour bus per km passenger'))*2
Expected velocity	=	(-50.314*'Expected Value to Capacity Ratio') + 143.73
Velocity	=	(-50.314*'Volume to Capacity Ratio') + 143.73
Expected fuel consumption per km by private car	=	(0.05693*('Expected velocity'^2))-(6.42593*'Expected velocity')+269.18576

(*continued*)

Figure 2.

Fuel consumption per km for private car	=	(0.05693*(Velocity^2))-(6.42593*Velocity)+269.18576
Fuel consumption per km for mini tour bus	=	(0.05693*(Velocity^2))-(6.42593*Velocity)+269.18576
The number of mini-tour buses used by domesitc tourist	=	(0.2*'The total number of domestic tourist adjusted to capacity')/18
The number of mini-tour buses used by foreign tourist	=	(0.4*'The total number of foreign tourist adjusted to capacity')/18
The number of private car used by domestic tourist	=	(0.8*'The total number of domestic tourist adjusted to capacity')/2.6
Emission factor of mini tour bus per km passenger	=	0.031
Emission factor for ferry per km passenger	=	0.12
Emission factor of car per km passenger	=	0.187
Growth rate of domestic tourist	=	0.234
Growth rate of foreign tourist	=	0.3668
Capacity of Karimunjawa	=	0.5*608200
Expected Value to Capacity Ratio	=	0.8
The distance from Mangkang to Kendal Port	=	14.6
The distance from Semarang Tawang to Tanjung Mas Port	=	2.6
Road designed capacity	=	2740*4
Road designed capacity with the effect of delayed of increased capacity	=	2740.41*4
The distance from travel Beujeu to Kartini Port	=	73.7
The average distance from Kartini Port to Karimunjawa	=	86.9
ABS the number of private car used by domestic tourist	=	ABS ('The number of private car used by domestic tourist')
ABS the number of private car used by foreign tourst	=	ABS ('The number of private car used by foreign tourist')
The number of private car used by foreign tourist	=	ABS ((0.6*'The total number of foreign tourist adjusted to capacity')/2.6)
Capacity of Karimunjawa with delay	=	DELAYMTR ('Capacity of Karimunjawa';3)
Realizagion of increased road capacity	=	DELAYMTR ('Increased road capacity';5)
Reduction in the number of private car used by foreign tourist	=	IF ('The number of private car used by foreign tourist'>0;('The Proportion of foreign and domestic tourist change from private car to mini toour buses'*'The total number of foreign tourist adjusted to capacity')/2.6;0)
The Proportion of foreign and domestic tourist change from private car to mini toour buses	=	IF ('Volume to Capacity Ratio'>1 OR 'Cost of transportation by private car'>'Expected cost of transportation by private car';0.2;0)
Rate of increased road capacity	=	IF ('Volume to Capacity Ratio'>1;0.1;0)
The number of Domestic tourists per year	=	IF('The total number of domestic tourist'+'The total number of foreign tourist'<'Capacity of Karimunjawa with delay'AND 'Volume to Capacity Ratio'<1;'Growth rate of domestic tourist'*'The total number of domestic tourist';0)
The number of foreign tourist per year	=	IF('The total number of foreign tourist'+'The total number of domestic tourist'<'Capacity of Karimunjawa with delay' AND 'Volume to Capacity Ratio'<1;('Growth rate of foreign tourist'*'The total number of foreign tourist');0)
The rate of capacity growth of Karimunjawa	=	IF(('The total number of domestic tourist'+'The total number of foreign tourist')>'Capacity of Karimunjawa';0.01;0)
Passenger Car Unit	=	1
The average distance from Kendal port to Karimunjawa	=	124
The average distance from Tanjung Mas Port to Karimunjawa	=	124
The total number of foreign tourist	=	1844
The price of solar for tour bus per liter	=	5150
The price of gasoline for private car per liter	=	6550
The total number of domestic tourist	=	15836

Figure 2.

tourists use mini-tour buses to go to a certain port to take a ferry for crossing the sea toward Karimunjawa. In the existing condition, one-third of tourists take a route to Beujeu Travel Semarang–Kartini Port–Karimunjawa, one-third of tourists take a route Semarang Tawang Train Station–Tanjung Mas Port and one-third of tourists take a route Mangkang bus station–Kendal Port–Karimunjawa. In the first, until ninth scenarios, all the foreign tourists landed at Ahmad Yani International Airport and the percentage of foreign tourists who use mini-tour buses to go to Tanjung Mas Port, Kendal Port or Kartini Port from the point of origin Beujeu Travel, Semarang Tawang Train Station or Mangkang Bus Station changed from 40% into 45%, 50% and 55% respectively; whereas, the percentage of domestic tourists who use mini-tour buses changed from 20% to 25%, 30% and 35%, respectively, and they can choose three different the route of travel, i.e. from Beujeu Travel to Kartini Port or Semarang Tawang Station to Tanjung Mas Port or Mangkang Bus Station to Kendal Port. In the first until ninth proposed scenarios, the percentage of foreign and domestic tourist travel behavior is driven by the expected cost of transportation by private car and traffic conditions (VCR value), which in turn, will also affect the cost of traveling by mini-tour bus and private car.

4. Result

4.1 Development of a causal loop diagrams

There are three sections of CLD to describe the impact of tourist travel to Karimunjawa on CO2 emissions, namely, the number of tourists, the switching behavior of tourist travel and the CO2 emission subsystem. All the CLDs can be seen in Figure 1. According to CLD, it can be seen that, in the number of tourist subsystem, the "capacity of Karimunjawa" as well as the condition of the road ("VCR") will reduce the "rate of tourism growth." It is assumed that the "capacity of Karimunjawa" and "VCR" will reduce the level of satisfaction of tourists to go to Karimunjawa. On the other side, "the number of domestic tourists" and "the number of foreign tourists" are a lever for "additional the capacity of Karimunjawa." This study use delay variable to indicate the time needed to add the capacity of Karimunjawa. Then, in the switching behavior of tourist travel subsystem, "VCR," "car transportation cost" and "mini-tour bus transportation cost" are a lever to reduce the "use of private cars." The increasing VCR will be in line with the increasing number of vehicles on the road, if there is no construction to widen the road and the increase of VCR will affect the velocity and the amount of fuel consumption. The more fuel consumed, the more expensive the cost of travel and it will affect the choice of transportation mode in traveling. High transportation costs from the use of private cars will encourage tourists to move to mini-tour buses. Tourist travel switching behavior will affect the number of private cars; although, it can increase the number of the mini-tour bus. However, as the CO2 emission per passenger-kilometer from the mini-tour bus is lower than the private car, the tourist switching behavior from private cars to mini-tour buses will reduce the amount of CO2 emission produced.

4.2 Formulation of a simulation model or stock and flow diagram

The causal loop for the impact of tourist travel to Karimunjawa on CO2 emission has been transformed into stock and flow diagram with the help of the Powersim® Studio 10 Professional software. Level variables, rate variables, decision factors and decision points are interconnected. The SD equations have been created in the model to denote the dynamics of the systems summarizing the degree of changes with complex relations (Sterman, 2000). In detail, the stock and flow diagram for each subsystem can be seen in Figure 2.

In the first subsystem (the number of tourists subsystem), at the level, the number of domestic tourists starts with value 15,836 and the number of foreign tourists starts with value 1,844. This value indicated the number of domestic and foreign tourists in the year 2009 from Central Java Tourism Agency. The number of domestic tourists is assumed to have increased by 39.27% per year and the number of foreign tourists is assumed to have increased by 36.68% per year. The ratio between domestic tourists and foreign tourists is 0.91 and 0.01. All these values are based on the average growth in the number of domestic tourists from 2012 to 2015, the average growth in the number of foreign tourists from 2009 to 2015 and the ratio between domestic and foreign tourists during the period 2009–2015. Furthermore, according to the result of the interview with the representative of the Central Java Tourism Agency, currently, the maximum capacity of Karimunjawa is 608,200 people. In this simulation, the capacity of Karimunjawa will be increased as much as 1% if the number of tourists achieves the current maximum capacity. This assumption is based on the condition that the Indonesian Government is currently focusing on the development of small islands as conservation areas in connection with the tourism industry. According to Central Java Tourism Agency, within a period of five years (from 2011 to 2015), tourism development in Karimunjawa village has undergone a considerable boost, as is evident from the increased numbers of foreign and domestic tourists and there has been a rapid growth in facilities for the tourism business. During the period 2011–2015, the growth of hotels, resorts and homestay accommodation was remarkable, with an increase of 40% for hotels and resorts and 56% for homestay accommodation. The growth of tourism in Karimunjawa is mainly an impact of the dissemination of information about the charm and attractiveness of this region on the social media and the ease of the routine crossing from Jepara by the Siginjai ferryboat and the Bahari Express Ship (Setiawan *et al.*, 2018). In this simulation, there is a time between the need for additional capacity and its realization, as the increased facilities for the tourism business require planning for the budget as well as the approval. The increase in the capacity of Karimunjawa also takes into account the traffic conditions to the location.

In the second subsystem (the switching behavior of tourist travel subsystem), a variable percentage between domestic and foreign tourists using a mini-tour bus starts with value 0.20 and 0.40. This is based on the results of the interview with representatives of the Central Java Tourism Agency. Then, the percentage between domestic and foreign tourists using a mini-tour bus will be determined by two factors. First, the traffic condition, which is indicated by the VCR and, second, the expected cost of transportation by private car. In this case, the expected cost of transportation by private car is determined by the expected fuel consumption per km by private car, the expected velocity and the expected VCR. This simulation uses the expected VCR as much as 0.81, as this value still indicated stable operations with somewhat more restrictions in making mid-block lane changes and motorists will experience appreciable tension while driving (Wallis and Lupton, 2013). The expected value of VCR automatically will define the expected velocity and expected fuel consumption per km by private car.

According to model Pacific Consultant International developed by LAPI-ITB in collaboration with PT. Jasa Marga, the relationship between fuel consumption and the velocity of the vehicle is (0.05693 × Velocity2) (6.42593 × Velocity) + 269.18576. This equation can be applied to a private car and mini-tour bus as both the vehicles belong to the same class (IA class vehicles) (Nardo, 2015). Then, the velocity the vehicle is affected by the VCR or the degree of saturation also called VCR. The VCR is derived by dividing the observed volume in PCU/hour by the design capacity in PCU/ho. VCR is the major indicator in suggesting traffic performance. The higher the degree of saturation value, the lower the service performance of the road (Susilo and Imanuel, 2018) and there are six types of road conditions based on its level of service performance. According to Mathew and Rao (2006), the relationship between VCR and the velocity of vehicle is 0.35, 0.55, 0.77, 0.92, 1.00 and 120 km/hr, 120 km/hr, 114 km/hr, 99 km/hr and 85 km/hr, respectively. So, based on this relationship, the regression equation that can be generated is $y = -50.314x + 143.73$; where y is the velocity of the vehicle and x is the VCR value.

Moreover, as we have mentioned before, the VCR depends on the volume of traffic and the designed road capacity. Referring to data from the Integrated Road Management system 2008, the initial value of the designed road capacity is 2,740.1 PCU. The designed road capacity is assumed to increase as much as 10% if the value of VCR is more than 1.00 and there is time delayed between the need for additional road capacity and its realization. The observed volume of traffic is determined by multiplying the number of each type of vehicle used by tourists by the appropriate weights or grades of various class of vehicles (or the value of PCU of various classes of vehicles). The number of each type of vehicle will be determined by the number of tourists using a certain type of vehicle as well as the load factor. The load factor for the private car (gasoline or diesel) and the minibus is 2.6 and 18, respectively (Dhakal, 2003). The value of PCU is determined from the Indonesian Road Capacity Guidelines (Road and Bridge Research and Development Center, 2014). The PCU value for a private car or mini-tour bus is 1 for the road condition four-lane two directions. Then, the design capacity of the road is derived from the Integrated Road Management System (IRMS). According to IRMS, for national roads, the average width of the road is 7.84 m the design capacity is 2467.2 PCU per line and the value of VCR is 0.50.

Last, in the CO2 emission subsystem, the values of the emission factor of a private car, mini-tour bus and the ferry are 0.187, 0.031, and 0.12, respectively. All these values are based on the average emission factors from private car (0.133 to 0.241 kg/pkm), minibus (0.022 to 0.04 kg/pkm) (Becken, 2009; Scott *et al.*, 2008) and average emission factors from ferry (0.12 kg/pkm) (Holthof, 2008).

4.3 Model validation

Model validation is an important stage in SD modeling hierarchy, which can determine whether a model does replicate the system, it is designed to simulate (Bellocchi *et al.*, 2011). The key to a model's usefulness is leaving out the irrelevant factors and catching the relations between the significant factors. In this study, the model validation is conducted by evaluating whether the output of the SD model (in this case, the number of domestic and foreign tourists) adequately corresponds to available data for the same variable(s). For this purpose, the output results obtained from the model for domestic and foreign tourists (2009 until 2015) were compared statistically by using the Wilcoxon signed-rank test to available historical data from Central Java Tourism Agency. According to Siegal (1956), for small sample sizes, the efficiency of the Wilcoxon signed-rank test to the *t*-test is nearly 95%. There are no differences between the means of the actual historical data and the result of the simulation if the result of the statistic test shows the significance level more than 0.05. It means the model is valid. In detail, the historical data and the result of simulation for domestic and foreign tourists as well as the result of a Wilcoxon signed-rank test can be seen in Table 2.

4.4 Result of simulation

After verifying the validity of the model, we can use this model to simulate the reduction of CO2 emission when different tourist travel behavior is taken. As described in the part of the method of research, this research applies nine different scenarios and each scenario is related with a different route and the change of the proportion of domestic and foreign tourist taking a mini-tour bus to go to a certain port and take a ferry for crossing the sea.

Year	Domestic tourist		Foreign tourist	
	Historical data*	The result of simulation	Historical data*	The result of simulation
2009	15,836	15,912	1,844	1.768
2010	15,070	19,845	1,567	2.206
2011	37,208	24,773	2,016	2.756
2012	53,633	30,956	5,005	3.447
2013	65,568	48,503	5,372	4.316
2014	72,331	60,853	8,904	5.411
2015	84,536	76,382	7,579	6.794
Result of test	*Z*-value	−1.859	*Z*-value	−1.521
	Asymp. sig, (2-tailed)	0.063	Asymp. sig, (2-tailed)	0.128

Notes: *Central Java Tourism Agency, 2018

Table 2. Result of Wilcoxon signed-rank test for domestic and foreign tourist

The CO2 emission can be divided into two types. First, the CO2 emission only from private cars and mini-tour bus and, second, the CO2 emission from private cars, mini-tour bus and ferryboats (total CO2 emission). From Figures 3 and 4, the simulation result indicated, when the comparison ratio of foreign tourist using private car (through rental) and mini-tour bus are 45%, 50% and 55% and the comparison ratios of domestic tourist using private car and mini-tour bus are 25%, 30% and 35%, respectively, the value of VCR decreases as the comparison ratio is increased. This condition indicated the decrease in road congestion or better levels of services as the comparison is increased to 50% for foreign tourists and 30% domestic tourists. In the next simulation test, Figures 5 and 6, when both foreign and domestic tourists departure from Beujeu Travel and go to Karimunjawa through Kartini Port, the amount of CO2 emission from private car and mini-tour bus and the total amount of CO2 emission are worse than the baseline condition (when the one-third of tourist take a

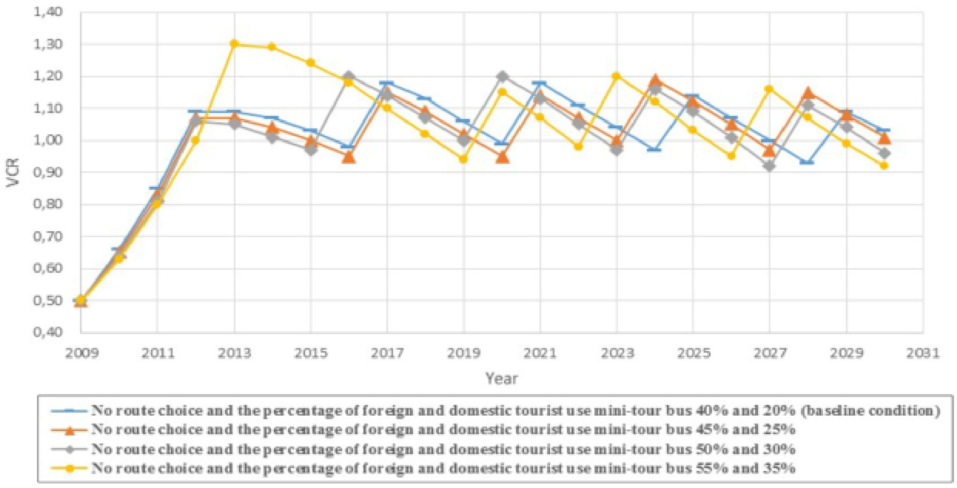

Figure 3.
VCR for no route choice, the percentage of foreign tourists that use mini-tour bus: 40%, 45%, 50% and 55%; and the percentage of domestic tourists that use mini-tour bus: 20%, 25%, 30% and 35%

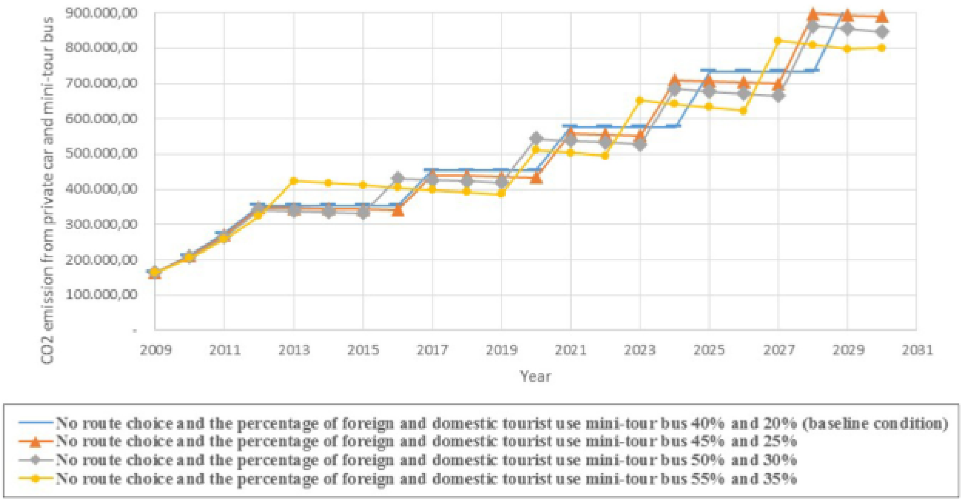

Figure 4.
CO_2 emission from private car and mini-tour bus for the existing condition (no route choice and the percentage of foreign and domestic tourists using mini-tour bus 40% and 20%, respectively)

route Beujeu Travel Semarang–Kartini Port–Karimunjawa, one-third of tourist take a route Semarang Tawang Train Station–Tanjung Mas Port). The amount of CO2 emission from private cars and mini-tour buses, as well as the total amount of CO2 emission, are better than the baseline condition when both foreign and domestic tourists depart from Semarang Tawang Train Station to Tanjung Mas Port or from Mangkang to Kendal Port. In this case, although the distance from Kartini Port to Karimunjawa is the closest compared to the distance from Tanjung Mas Port or Kendal Port to Karimunjawa, the distance from Semarang Tawang Train Station to Tanjung Mas Port and the distance from Mangkang to Kendal Port is much closer compared to the distance from Beujeu Travel to Kartini Port. The distance from Beujeu Travels to Kartini Port is five times further compared to Semarang Tawang Train Station–Tanjung Mas Port and 28 times compared to Mangkang–

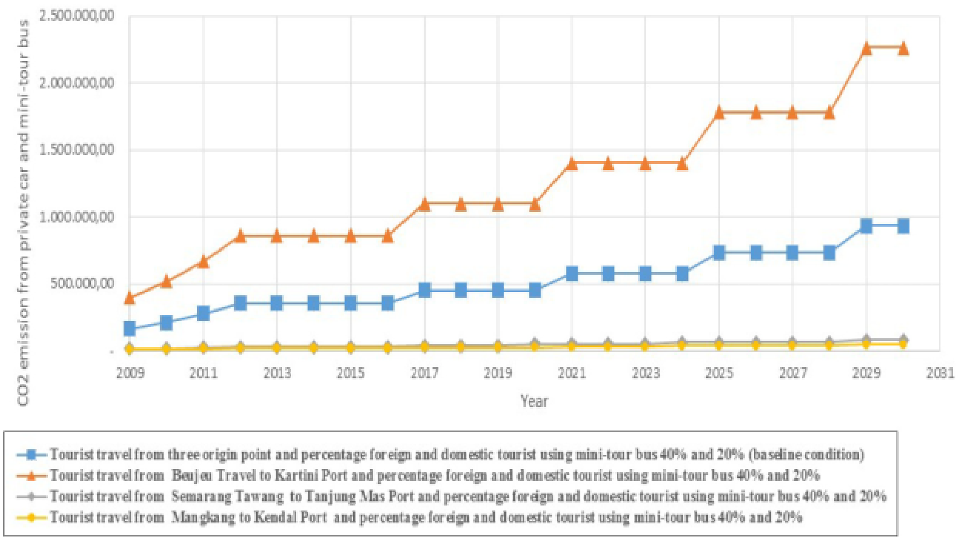

Figure 5.
CO_2 emission by private car and mini-tour bus for no route choice and specific route choice if the percentage of foreign and domestic tourists that use mini-tour bus 40% and 20%, respectively

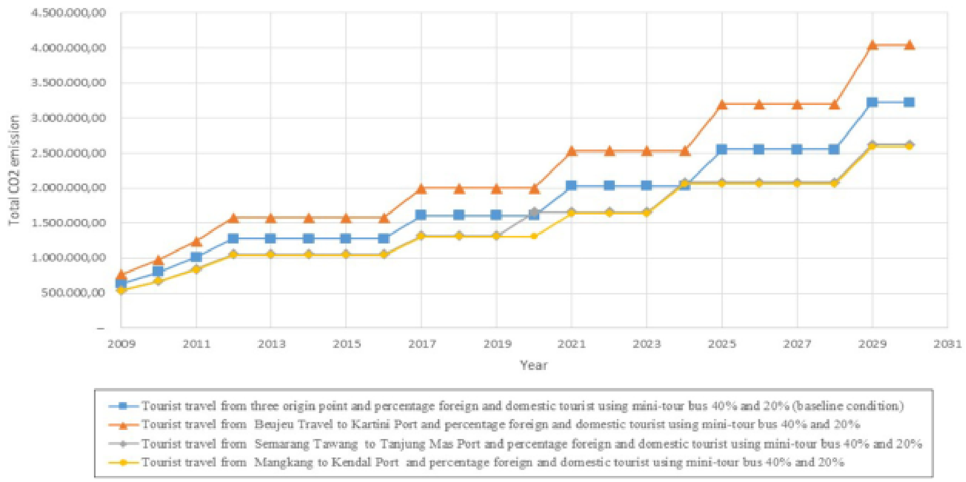

Figure 6.
Total CO_2 emission for no route choice and specific route choice if the percentage of foreign and domestic tourists that use mini-tour bus 40% and 20%, respectively

Kendal Port. Then, in the next simulation test, Figure 7 and 8, the lowest level of CO2 emission from private car and mini-bus tour and the lowest level of total CO2 emission occur when both foreign and domestic tourists departure from Semarang Tawang Train Station and go to Karimunjawa through Tanjung Mas Port or from Mangkang to Karimunjawa through Kendal Port, and the comparison ratio of foreign and domestic tourist using private car and mini-tour bus is 45% and 25% or 50% and 30%, respectively.

Shortly, based on the simulation test, decreased the amount of CO2 emission, not only influenced by the change of travel behavior of the domestic and foreign tourists but also influenced by the departure point choosing by tourists to go Karimunjawa. So, based on the result of the simulation, it is better if the government (in this case the Central Java Tourism Agency) tried to reduce the CO2 emissions from tourist travel to Karimunjawa through arranging

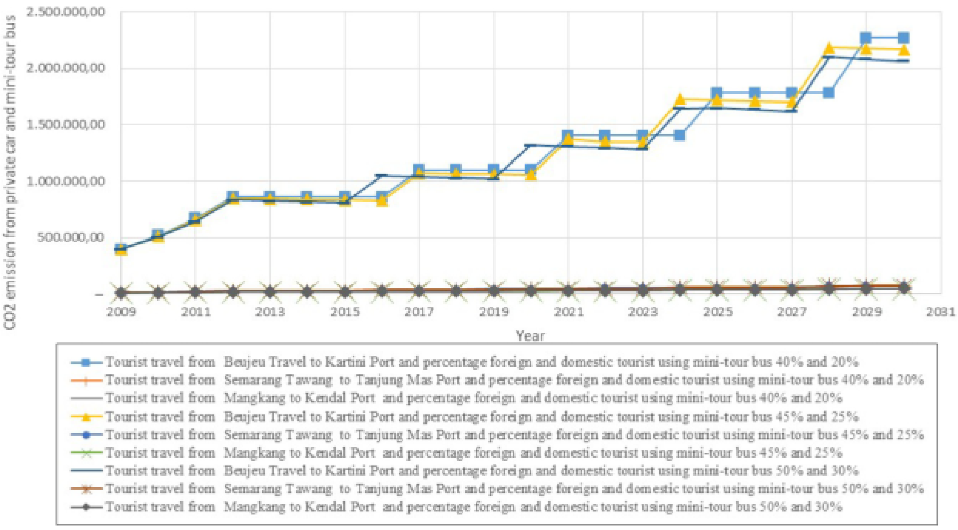

Figure 7.
CO_2 emission from private car and mini-tour bus for three different routes if the percentage of foreign tourists using mini-tour bus is 40%, 45% and 50% and the percentage of domestic tourist using mini-tour bus is 20%, 25% and 30%

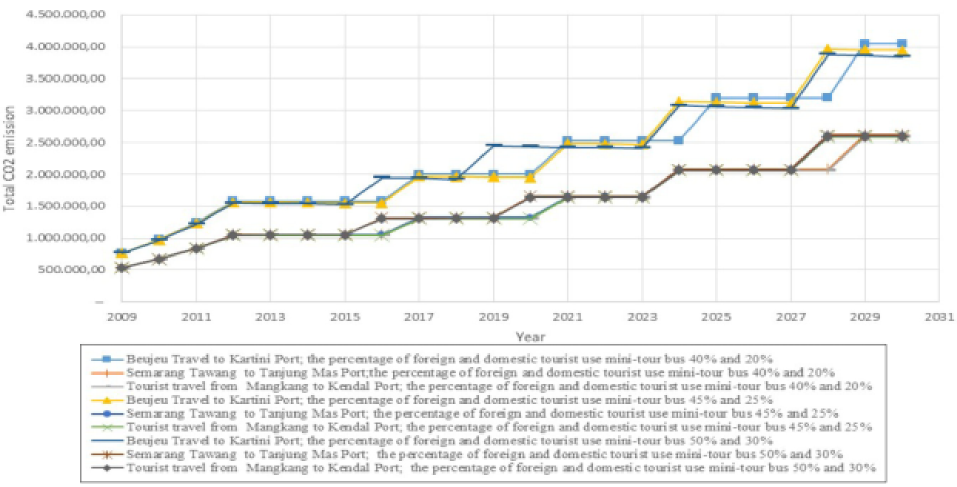

Figure 8.
Total CO2 emission from private car, mini-tour bus, and ferry for three different routes if the percentage of foreign tourists using mini-tour bus is 40%, 45%, 50% and 55% and the percentage of domestic tourist using mini-tour is 20%, 25%% and 30%

and maximizing departure points of a mini-tour bus from the Semarang Tawang Station Train and crossing to Karimunjawa via Tanjung Mas Port or from Mangkang to Karimunjawa through Kendal Port.

5. Conclusion

This paper presents a SD model based on relations between the growth rate of domestic and foreign tourists, the tourist travel change behavior and CO2 emission with the tourist travel to Karimunjawa as the case study. The result of the simulation is in line with most of the studies by prior researchers, such as Eglimez and Tatari (2012), Lei *et al.* (2012), Liu *et al.* (2015), Sukarno *et al.* (2016), Setiafindari *et al.* (2017), Setiawan *et al.* (2019). According to the simulation results for the period of 2015–2030 under different scenarios, the following conclusions can be drawn. Under the current situation that the point of departure of tourists by mini-tour bus is divided into three regions (Beujeu Travel, Semarang Tawang Train Station and Mangkang Bus Station), the tourist travel behavior should be changed to maximum condition to get the minimum CO2 emission. If the comparison ratio of foreign and domestic tourists using the private car (through rental) and a mini-tour bus is too low, the reduction from CO2 emissions does not have a significant amount. Improvement of the departure point of the mini-tour bus and ferry is an effective way to reduce the CO2 emission. The significant effect of departure point intervention on CO2 emission can be seen under the strict restriction policy that the domestic and foreign tourists are expected to departure from Semarang Tawang Train Station and use Tanjung Mas port to cross the sea or expected to departure from Mangkang and use Kendal Port to cross the sea. Semarang Tawang Train Station can be used by a domestic and foreign tourists, who use a train to go to Semarang from the other regions in Indonesia; whereas, Mangkang is a bus terminal and it can be used by the domestic and foreign tourists who use the bus to go to Semarang from the other regions in Indonesia. Because Semarang Tawang Train Station is the best departure point in resulting the minimum CO2 emission, the government can facilitate the shuttle bus from Ahmad Yani International Airport to Semarang Tawang Train Station or Mangkang for the domestic and foreign tourists, who intend to go to Karimunjawa and use air transportation to go to Semarang.

The findings of this study are significant, as the estimation of CO2 emission from tourist travel can provide the basis for modeling how the government policies will affect the choice of routes and modes of transportation by tourists. The findings of this study are also significant as they highlight the challenges that the Indonesian Government and tourism industry face in meeting their environmental responsibilities in the coming years, especially for CO2 emissions resulting from tourist travel. Integral to global concern about CO2 emission, its target of reducing emissions is to develop new ways of undertaking the tourists to the tourism destination. It will require the adoption of the effort to change the behavior patterns and thoughts of tourists to choose the ways of travel that are more environmentally friendly. The tourists are at the center of analysis because they are the source of the environmental impact resulting from their travel behavior. Then, an example of a real application that can be taken to overcome the absence of effective governmental policies dealing with CO2 emission from tourist travel to Karimunjawa is that the government should encourage travel agencies to propagate the idea of low-carbon tourism and especially develop low-carbon tourism products and routes to meet the needs of tourists on low-carbon tourism. For instance, the travel agency can properly design travel routes to guide tourists to Karimunjawa from Mangkang Bus Station and Kendal Port or Semarang Tawang Train Station and Tanjung Mas Port. Moreover, the government could establish special funds for low-carbon tourism to support tourism travel agencies to develop low-carbon projects for tourists traveling to Karimunjawa. On the other hand, as the tourists with low-carbon demand will lead to low-carbon supply in tourism, the other real application that can be taken by the government is strengthening the public's environmental awareness on understanding the low-carbon tourism and promoting the public initiative to low-carbon tourism. It can be done through formal and informal education (website, blogs, wikis, forums and educational portals, as well as virtual environments where the user has the opportunity to navigate and sometimes interact with the presented environment). Examples of such websites are www.gdrc.org/uem/eco-tour/envi/one.html, www.earthtimes.org and www.theworldcounts.com/challenges/consumption/transport-and-tourism.

The implication of the findings of this theory is filling the literature gap of the effect of tourism growth from two perspectives, namely, tourist travel behavior and environmental. The modeling of tourist transport and CO2 emission will provide an overview of the selection of the mode of tourist transportation that can give a significant contribution to the reduction of greenhouse gas emissions. Changing the tourist travel behavior is generally not effective in triggering CO2 emission reduction unless it is accompanied by the strict policy related to the tourist route. The implication of the findings to the practices can be explained as follows. The implementation of a scenario that maximized the comparison ratio of foreign and domestic tourists using the private car and mini-tour bus and the departure point intervention has several implications for the government and also to the local society. For the scenario that maximized the comparison ratio, the government (in this case the Central Java Tourism Agency) should frequently conduct socialization the route of a mini-tour bus that can use by tourist to go to Kartini or Kendal Port as well as the socialization about the contribution of tourist travel to the CO2 emission. Then, related to the facility, the Central Java Tourism Agency should be aware that change of tourist behavior can be separated from their needs for good, comfortable and easily accessible facilities; tourist require good facilities that can be reached easily. So, this scenario will force the Central Java Culture Tourism to improve the number of buses and services provided (safety, comfort and cleanness) as well as the bus parking area at the pick-up place, port and around the tourist area in Karimunjawa. Although the number of the vehicle will decrease as the tourists change from private car to mini-tour bus, this scenario requires a parking space with the adequate area as the size of the bus is bigger than a private car. Moreover, this scenario needs fully supported by the travel agency by inserting the bus route into their promotion to brochures. Then, for the scenario that is related to the departure point intervention, the Central Java Culture Tourism can arrange a quantity discount and specific facility which will encourage the local tourists to choose Semarang Tawang Train Station as the departure point as well as use Tanjung Mas Port to take a ferry or choose Mangkang as the departure point as well as use Kendal Port to take a ferry.

Like the other studies, this study also has some limitations. First, the model used in this study only considers two variables as the drivers for the level of change of the capacity of tourist destination, namely, the demand from tourists and the road condition. Moreover, the model used in this study only considers the value of VCR as the driver for the level of change of the capacity of the road. It can be said that the model does not include the government budget as a constraint to make any investment to change the capacity of Karimunjawa as well as the capacity of the road. The model does not include the land availability as a constraint for increasing the level of capacity of Karimunjawa and the road and the willingness of the private sector to invest in Karimunjawa. In response to this limitation, suggested future research may lie in trying to add the variable government budget and land availability as the constraint for increasing the level of capacity of Karimunjawa and the level capacity of the road. Moreover, future research may lie in trying to add the variable that can explain the relationship between the condition of Karimunjawa and the willingness of the private sector to invest. Second, in this model, the growth rate of domestic and foreign tourists is only determined by the data on tourism growth in the past, the capacity of tourist destination and the road condition. In response to this limitation, suggested future research should identify other variables that affect the tourist growth and put it into the model, such as the existence of new tourist attractions in Jepara and Karimunjawa, the high-level promotions, the levels of tourist satisfaction and the rising prices because of inflation. By including these factors, the result of simulation can illustrate the government about the important variables that contribute in achieving the target of tourism growth rate. Third, a further limitation of some studies is their focus on CO2 emission from the direct impacts of tourist travel. This study does not consider the indirect impact of tourism activity on CO2 emissions, which are associated with the outputs of each industry associated with supplying inputs to the tourism industry. Fourth, international air travel was not included in the present study although it is likely to increase the total emissions if this component of travel is included. In response to this limitation, suggested future research should estimate both the direct and indirect CO2 emissions as well as international air travel to provide a complete picture of tourism's carbon footprint.

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