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An evaluation model for low carbon island policy: The case of Taiwan's green transportation policy

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ABSTRACT

Conserving energy and reducing carbon emissions have become the common responsibility of the international community. During the year 2010, the Taiwan government planned a four-year project budgeted at 300 million US dollars, called "The Penghu Low Carbon Island Development Project." The policy objective is to use Penghu Island (population 85,000) as a test platform to evaluate new ways to conserve energy and reduce carbon emissions before attempting to replicate the policies on Taiwan Island. For Taiwan, a zero carbon island green transportation policy will regulate the total number of electric scooters, the total number of gasoline motorcycles, influence government subsidy incentives, and create the need for new motorcycle license issuing and control. These factors interact with each other to form a complex and dynamic system that impacts policy as well as the current way of life. In this study, a system dynamics approach is designed to construct a model for evaluating the green transportation policy on Penghu Island. Simulations are conducted to model green transportation system behavior and related policy effects in a smaller, controlled environment before creating policies for Taiwan Island that will impact the lives of over 23 million people.

1. Introduction

Due to the potential social and environmental consequences of global warming and unavoidable climate change, the international community has placed greater emphasis on energy conservation and carbon emission mitigation. One of the key strategies to resolve the above problems is to build low carbon cities or low carbon communities. In many countries and cities, low carbon community strategies and projects have been actively promoted to reduce pollution, conserve energy, and reduce carbon emissions (Acquaye and Duffy, 2010; Chang et al., 2010; Machado et al., 2001; Peters, 2008). According to the report of the Intergovernmental Panel on Climate Change (IPCC), if action is not taken to resolve this problem, the earth's average temperature will rise from 1.4 degrees to 5.8 °C this century (IPCC, 2001).

As a participant willing to share global responsibilities, Taiwan's government passed the Sustainable Energy Policy on World Environment Day in 2008 and created laws to improve energy efficiency, develop clean energy, and ensure a stable energy supply. Taiwan developed a Master Plan of Energy Conservation and Carbon Mitigation in 2009 and announced that from the year 2010, promoting energy savings and carbon reduction would be broadly advocated. As a preliminary benchmark experiment, the Taiwan government announced a project to transform Penghu Island into a Low Carbon Island (Bureau of Energy, 2010a). A budget of over 300 million US dollars for a period of four years was planned and the project launched the largest energy-environmental public policy ever devised for Taiwan. Under this project, seven specific low carbon operational policies and measures were included, covering renewable energy, energy conservation, green transportation, low carbon construction, environmental greening, resource recycling, and low carbon living. The project aims to apply energy conservation and carbon mitigation technology to build a clean low carbon island and to enable Taiwan to use these applied experimental results as a means to transform all cities and environmental practices (Trappey et al., 2012; Bureau of Energy, 2010a). However, whether the policy implementation effect will achieve the objectives of conserving energy and reducing carbon emissions have become a focus point of policy makers, academics, and the full range of stakeholders.

Building a low carbon island is a complicated system engineering challenge, since it affects factors related to environment, economy and society. On the whole, the population, the ground forest area,

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industry and commercial activities, transportation, people's daily energy usage, and carbon dioxide generation are only a few of the critical issues to consider. Even on a small island where many variables can be easily controlled, these factors interact with each other and, thereby, form a complicated and dynamic system reflecting the causal relationship of the factors in regard to the energy consumption and carbon emission issues. While there are many sub-projects included in Penghu Low Carbon Island Development Project, the demonstration of the policy's efficacy is a risky venture unless the results are valid and reliable. Considering that the green transportation policy was to include variables such as population in residence, number of tourists, number of electric scooters, government subsidies for scooter replacement, and control of motorcycle licenses, a system dynamics approach is used to develop a model for exploring the green transportation policy. Simulations are conducted to evaluate the policy effects and to enhance understanding of changing transportation system behavior given the proposed green transportation policy implementation.

2. Literature review

The use of a sustainable Low Carbon Island or Renewable Energy Island was researched by Chen et al. (2007). An island can be thought of as a controlled environment where environmental problems are related to imported fossil fuel energy dependence, fresh water availability, limited waste management, transportation and other energy consumption problems. Renewable energy technology is a feasible solution since it produces energy by transforming natural phenomena (or natural resources) into useful energy forms (Alcántara and Padilla, 2009; Chen et al., 2007; Chang et al., 2010).

There are many successful renewable energy island studies, such as the Greek Dodecanese islands (Oikonomou et al., 2009), Gökçeada Island (Demiroren and Yilmaz, 2010), and Yakushima Island (Uemura et al., 2003). The Penghu Low Carbon Island Development Project was implemented by the Taiwan government as the first large-scale green-related environmental economic policy on an outlying island county. The endeavor is an important benchmark project for future planning of renewable and sustainable energy related policies for all of Taiwan's counties (Trappey et al., 2012).

System Dynamics (SD) is frequently used to analyze and assess environmental impact (Ford, 1997; Jan and Hsiao, 2004; Trappey et al., 2011) and is an effective method to evaluate interactions between key factors in a dynamic and complex system. The most famous and classic application was "The Limits to Growth" published by Meadows et al. (1972, 2004). The book and the derived quantitative approach are considered to be one of the most important works of the 1970s. Building on these principles, Wang et al. (2008) presented a system dynamics approach based on the cause-and-effect analysis and feedback loop structures for urban transportation systems. Jin et al. (2009) developed a dynamic ecological footprint forecasting platform to support policy making for urban sustainability improvement. Han and Hayashi (2008) used the inter-city passenger transport network in China as a case and developed a system dynamics model for policy assessment and CO_2 mitigation potential analysis.

According to the above SD literature review, many system dynamics models have been successfully applied to validly assess environmental impact and form reliable policies. This paper formulates a green transportation policy for Penghu Island's low carbon development and evaluates the effect using system dynamic models. A cause-effect feedback loop analysis was conducted and the results led to the construction of a quantitative model to simulate carbon reduction efficacy after policy implementation.

3. Modeling

The specific measures of the island-wide green transportation policy consist of following two initiatives (Bureau of Energy, 2010a):

(1) Replace gasoline motorcycles with electric scooters by substituting 6000 electric scooters in years 2011 to 2013.
(2) Limit the use of two-stroke and four-stroke gasoline motorcycles and the issuing of vehicle licenses.

Based on the above policies, the variables, related to operations, total gasoline motorcycles levels, total electric scooters levels, total CO_2 emission variables, and other external factors, are discussed to create the initial causal feedback loops for the green transportation policy. Using related literature and by interviewing domain and policy experts, a group model building approach was used as the basis of the SD methodology. The Penghu zero carbon island green transportation system is complicated by the interaction of cause and effect variables controlling the number of gasoline motorcycles in use and the subsidies issued to citizens to purchase electric scooters.

3.1. Causal related number of electric scooters

The Penghu Island green transportation policy was designed to replace gasoline motorcycles with electric scooters using cash subsidies to increase purchase of electric scooters. The government calculated the total CO_2 emission volume of gasoline motorcycles on Penghu Island and measured the gap between the policy targeted CO_2 reductions. Administrators decided to implement subsidy regulations for 6000 electric scooters in three years, providing 1000 US dollars for each electric scooter. Regulations were passed to allocate a budget according to the estimated investment costs. The authorities evaluated the reasonable asset depreciation of electric scooters to calculate the CO_2 emissions when replacing gasoline engine motorcycles over time. An electric scooter dynamic flow diagram was constructed as shown in Fig. 1.

3.2. The cause and effect relations for total motorcycle CO_2 emissions

The total motorcycle emissions sub-model reflects the total CO_2 emissions for gasoline motorcycles and electric scooters. The calculation of total CO_2 emissions for gasoline motorcycles and electric scooters are derived as follows:

(1) Total oil consumption = The average annual mileage of a gasoline motorcycle/Fuel efficiency of a gasoline motorcycle,
(2) Total energy consumption = The average annual mileage of an electric scooter/Energy efficiency of an electric scooter,
(3) Total CO_2 emissions of gasoline motorcycles and electric scooters = $\sum$(Fuel consumption $\times$ CO_2 emission fuel factor).

Fig. 2 shows that the cause and effect relations of CO_2 emissions from both vehicles are dependent on related variables including the number of motorcycles, average annual mileage, energy consumption efficiency, and CO_2 emission coefficient. The consolidated parameter values and the data sources of the related variables are listed in Table 1 (Chen, 2011).

3.3. Causal relations between green transportation policy and CO_2 emissions

The substitution effect of gasoline motorcycles for electric scooters on Penghu Island and the total effect on CO_2 emissions (including annual vehicle disposal), is related to the following factors. These factors include annual demand and supply amount

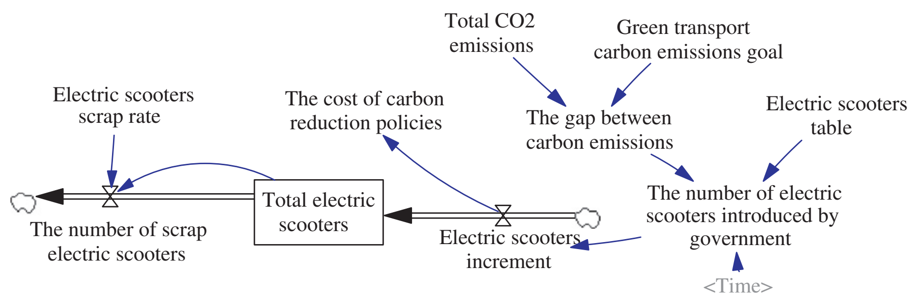

Fig. 1. Dynamic flow diagram of introducing electric scooters.

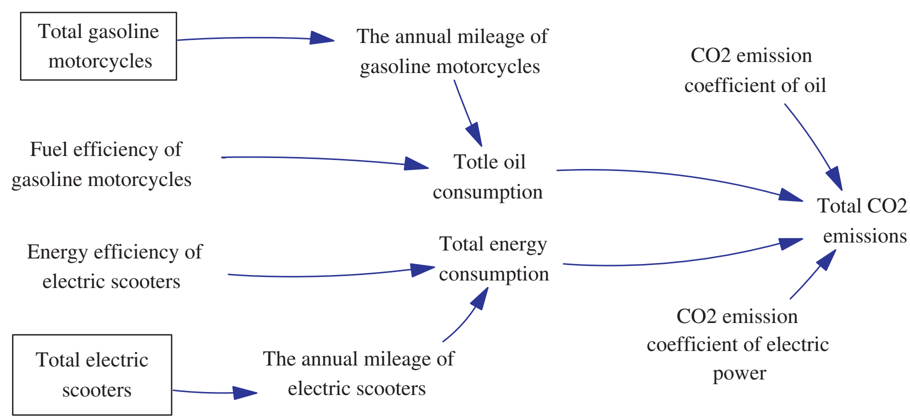

Fig. 2. Dynamic flow diagram for total motorcycle CO_2 emissions.

Table 1
Parameter values for the SD model of the Penghu Low Carbon Island Project.

Parameters	Value	Data source
CO_2 emission factor of oil	2.263 Kg-CO_2/L	Bureau of Energy, 2010b
CO_2 emission factor of power	0.623 Kg-CO_2/W	Bureau of Energy, 2010b
Fuel efficiency of gasoline motorcycles	40 km/L	Lin et al., 2008
Energy efficiency of electric scooters	20 km/W	Lin et al., 2008
Gasoline motorcycles scrap rate	1.4605%	Lai, 2010
The average annual mileage of gasoline motorcycles	4099 km/unit	Ni et al., 2006
The average annual mileage of electric scooters	3000 km/unit	Ni et al., 2006
The investment cost of electric scooters	1000 US$/unit	Chen, 2011

of motorcycles, government electric scooter subsidies, and the energy use transformation efficiency. The primary question of the policy makers is that after implementations of the plan, will the objective of reducing CO_2 emissions be achieved? In other words, whether the green transportation policy effectively achieve its carbon reduction goal is modeled and evaluated taking the causal variables (such as factors influencing the number of gasoline motorcycles and electric scooters, the total demand of residents for alternative vehicles, etc.) and their relations into consideration as shown in the system dynamics model (Fig. 3).

4. Simulation and discussion

This paper simulates four scenarios to evaluate transportation policy reform until the year 2030. The first scenario (business as usual, BAU) does not implement the green transportation policy. The second scenario subsidizes 6000 electric scooters. The third scenario subsidizes 6000 electric scooters and limits issuing of two-stroke gasoline motorcycle licenses. The final scenario is a mandatory policy, which subsidizes 6000 electric scooters and limits two-stroke and four-stroke gasoline motorcycles licensing. The four scenarios are evaluated to measure the carbon emission reduction of the green transportation policy.

The simulation results of carbon footprint emission, total oil consumption, total energy consumption and the cost of carbon reduction policies are shown in Fig. 4 through Fig. 7. The total electricity consumptions for scenarios 2 and 3 are overlapping (Fig. 6). Since scenarios 2 and 3 share the same policy of substituting 6000 electric scooters for gasoline motorcycles, with the only difference being scenario 3 further limiting the issuing of two-stroke gasoline motorcycle licenses (which may result in replacing 2-stroke with 4-stroke motorcycles). For scenario 4, two-stroke and four-stroke gasoline motorcycles licensing are limited and all new motorcycle requirements for each year thereafter are fulfilled by electric scooters. Thus, scenario 4 leads to gradual increases in total electricity consumption.

For the carbon footprint emissions shown in Fig. 4, due to the lower oil consumption in scenario 3 than that in scenario 2, there is a lower emission of carbon dioxide in scenario 3. Regarding the total oil consumption in Fig. 5, since scenario 3 places limits on the issuing of two-stroke gasoline motorcycle licenses, the oil consumption of scenario 3 is lower than that in scenario 2.

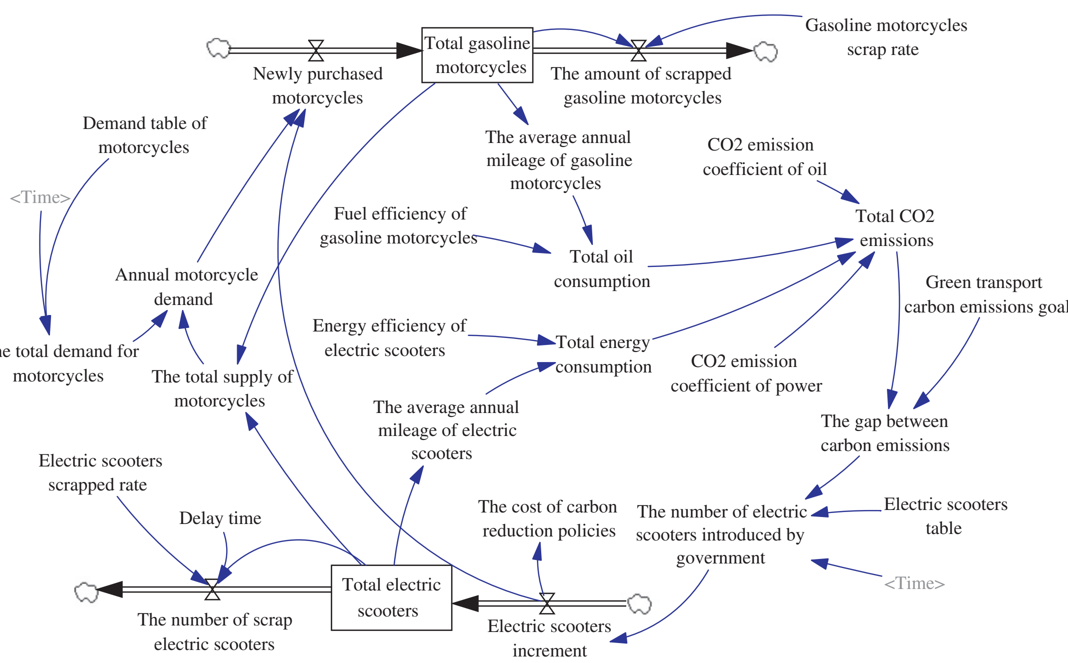

Fig. 3. A system dynamics model for Penghu Low Carbon Island green transportation policy.

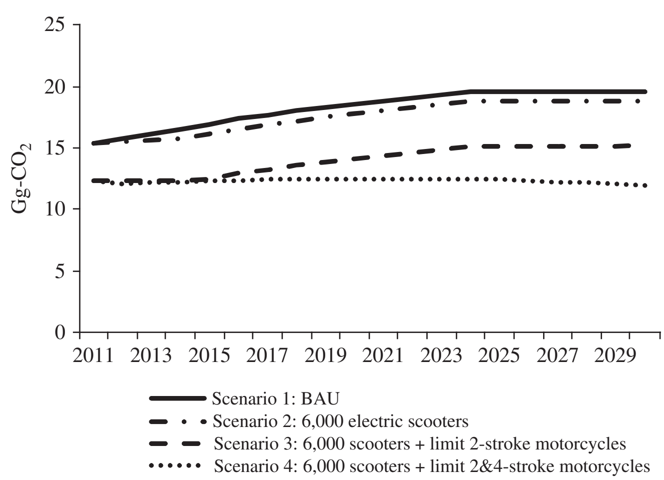

Fig. 4. Carbon footprint emission simulations under four policy scenarios.

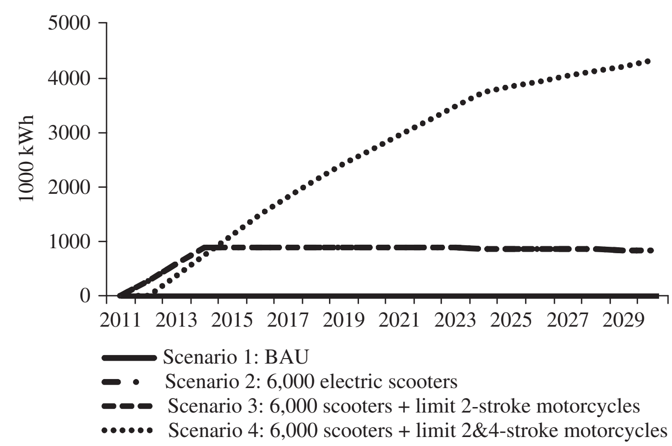

Fig. 6. Total electricity consumption simulations under the four scenarios (2 and 3 overlap).

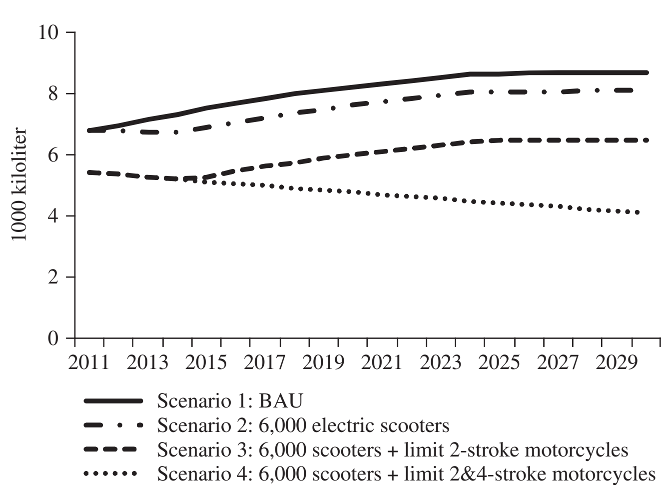

Fig. 5. Total oil consumption simulations under different scenarios.

Briefly comparing the results of four scenarios, the fourth scenario yields the best strategy for carbon reduction. The carbon footprint emissions fell to 12 (Gg-CO_2) from 20 (Gg-CO_2) and total oil consumption fell to 4000 kiloliters. However the total electricity consumption increases slightly to 4,309,250 (kWh) and the policy cost is higher compared to scenarios 1 through 3.

Fig. 8 compares the effectiveness of the proposed green transportation policies to determine whether carbon reduction targets (Table 2) can be met. Simulation shows that scenario 1 (BAU) and scenario 2 (subsidizing 6000 electric scooters) will not fulfill the carbon reduction goals. While the carbon emission of the third scenario (subsidizing 6000 electric scooters and limiting two-stroke gasoline motorcycles) will diminish to year 2008s level during year 2016 to year 2020 and fall back to 2005s level by year 2020. However, this scenario will not reduce CO_2 level to 2000s level by 2025, since after the promotion of electric scooters for three years, new four-stroke motorcycle licenses will gradually increase, as will carbon emissions. For the fourth scenario (subsidizing 6000 electric scooters plus limiting two and four-stroke gasoline

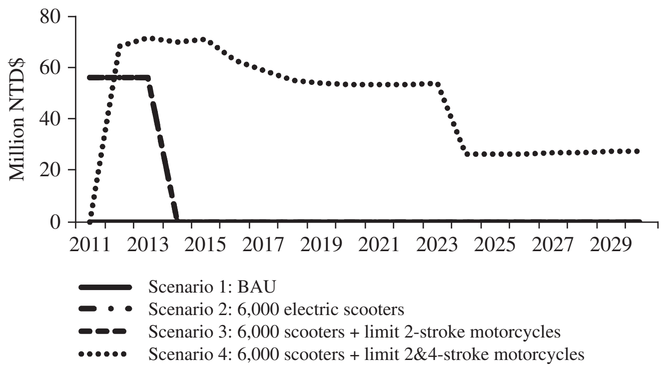

Fig. 7. Costs of carbon reduction policies under the four scenarios (2 and 3 overlap).

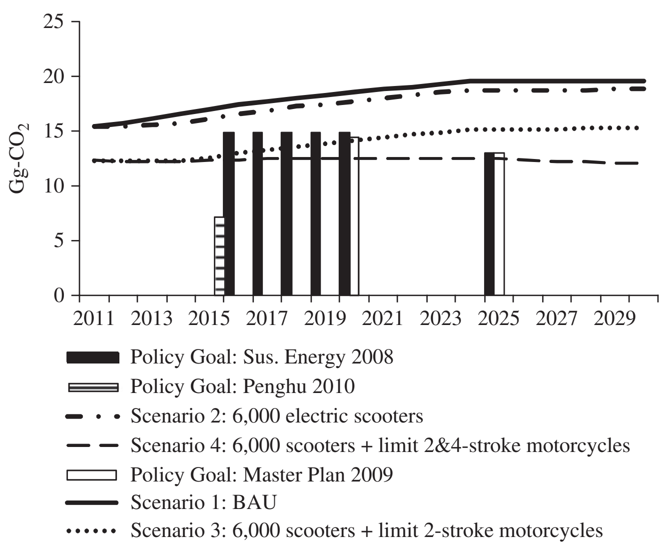

Fig. 8. Goals of carbon reduction policies and results from different scenarios.

Table 2
Goal of carbon reduction policies in Taiwan.

Carbon reduction policies	Policy goal	Target values
A. Sustainable Energy Policy 2008	This policy sets forth to reduce the national carbon emission to year 2008s level during 2016 to 2020 and then fall back to year 2000s level by 2025.	2008: 15 Gg-CO_2 2000: 13 Gg-CO_2
B. Master Plan of Energy Conservation and Carbon Mitigation 2009	This policy sets forth to reduce the national carbon emission to year 2005s level by 2020 and then fall back to 2000s level by 2025.	2005: 14 Gg-CO_2 2000: 13 Gg-CO_2
C. Penghu Low Carbon Island Development Project 2010	This policy sets forth to reduce the regional carbon emission back to 50% of year 2005s level by 2015.	2005: 7 Gg-CO_2

motorcycles), the simulation yields better results than the third scenario. The carbon emissions will be reduced to year 2000s level by year 2025. Nonetheless, the carbon reduction goal of the Penghu Low Carbon Island Project is set relatively high, so implementing the green policy in the transportation sector alone cannot achieve all policy goals in Table 2.

5. Conclusion

Taiwan has planned a four-year initiative for developing Penghu as a low carbon island beginning in year 2010. According to recent data published by Taiwan government's Ministry of Transportation and Communications in 2011, the number of passenger cars (fewer than 20,000) is much smaller than the number of motorcycles (more than 70,000) in Penghu. Because Penghu is small and rather flat, most people (approximately 93 thousand residents and a half of million visitors per year) use motorcycles for island-wide transportation. Therefore, the environmental impact of motorcycles is significantly higher than those of cars. Considering the island's demographic, social and geographical conditions, as well as the technical feasibility and cost effectiveness of implementing green transportation options, both the Bureau of Energy and Penghu County government focus on the promotion of electric scooters in their short-term action plan. Therefore, this study examines the efficacy of electric scooters, not cars, in the mitigation of carbon emission.

This research uses system dynamics (SD) to provide an assessment methodology for government policy makers to evaluate the green transportation policies. As demonstrated in the scenario analyses, none of the green transportation policies alone can achieve the 50% carbon reduction goal in 2015 for the Penghu Low Carbon Island. Therefore, the Taiwanese government has planned additional actions and measures beyond green transportation. For instance, there are plans to expand and promote a variety of renewable energy sources, substitute LED street lamps for traditional ones, and subsidize the purchase of energy-saving appliances. In the near future, the objective is to construct Taiwan's first low-carbon demonstration island through diversified policies to ensure wider successful applications. The value of this study is to propose a reliable analysis approach to evaluate the effectiveness of different measures during the formation and execution of nation-wide green policies.

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