BENEFIT EVALUATION OF GREEN TRANSPORTATION POLICY FOR PENGHU LOW CARBON ISLAND DEVELOPMENT USING SYSTEM DYNAMICS APPROACH

C. T. Hsiao, Department of Economics, Tunghai University, 181, Section 3, Taichung Port Road, Taichung, Taiwan 40704, +886-4-2359-0121 ext. 36125, cthsiao@thu.edu.tw
Amy J.C. Trappey, Department of Industrial Engineering and Engineering Management, National Tsing Hua University, 101, Section 2, Kuang-Fu Road, Hsinchu, Taiwan 30013, +886-3-574-2651, trappey@ie.nthu.edu.tw
Jerry J.R. Ou, Department of Business Administration, Southern Taiwan University, 1, Nan-Tai Street, Yungkang Dist., Tainan, Taiwan 710, +886-2- 2772-1370, jrou@moeaboe.gov.tw
Shin-Je Li[*]*, Institute of Natural Resources Management, National Taipei University, 151, University Rd., San Shia District, New Taipei City, Taiwan 23741, +886-2-8772-2252 ext. 12, sjli@itri.org.tw*
Kevin W. P. Chen, Department of Industrial Engineering and Management, National Taipei University of Technology, 1, Sec. 3, Chung-hsiao E. Rd., Taipei, Taiwan 10608, +886-2-2771-2171 ext. 2300, t8378008@ntut.edu.tw

ABSTRACT

Carbon reduction and energy saving have become the common responsibility of international community to prevent global warming. The development of low-carbon cities or regions has become the key to the transformation of environmentally conscious society. Taiwan government has taken a challenging initiatives of Penghu Low Carbon Island Project investing US$ 0.3 billion from 2010 to 2013. The government hopes the project outcomes can reach desired policy goal of carbon reduction. This research applies system dynamics approach to construct a cost-benefit evaluation model on green transportation incentive program for the project. The results show that the combination of changing gasoline motorcycles into electric scooters and limiting two-/four-stroke gasoline motorcycle licensing can provide the best carbon reduction benefit for the policy goal.

INTRODUCTION

Owing to the global climate changes, particularly global warming, carbon reduction and energy saving become the common concerns and responsibility of government bodies and international communities. The development of low-carbon communities has gradually become one of the major trend in transforming humanity to an environmentally conscious civilization. Thus, many governments start to actively implement various kinds of low-carbon community policies and measures to reduce the consumption of energy and emission of carbon dioxide. According to the report of Intergovernmental Panel on Climate Change (IPCC), if the human race does not take immediate action, the earth's average temperature will rise 1.4-5.8 degrees Celsius [1]. Therefore, Taiwan government passed the Framework of Sustainable Energy Policy on World Environment Day in 2008 and committed to improve energy efficiency, develop clean energy, and secure stable energy supply. Further on, the Master Plan on Energy Conservation and Greenhouse Gases Emission Reduction was formulated in 2009, with 10 Landmark Programs and 35 sub-Programs. Taiwan government also announced that 2010 was the year of promoting energy saving and carbon reduction.

[*] Please send all correspondence to Mr. Shin-Je Li.

One of the sub-Programs is Penghu Low Carbon Island Development Project. Seven strategies of Renewable Energy, Energy Conservation, Green Transportation, Low-Carbon Buildings, Greening of Environment, Resource Recycling, and Low-Carbon Living were proposed. It is expected to utilize energy saving and carbon reducing technology, as well as to develop green energy to construct a clean and low carbon island to facilitate Taiwan march into a low carbon country.

Based on the above mentioned Penghu Low Carbon Island Project, this research uses the system dynamics methodology to construct a dynamic model to analyze the effectiveness of proposed Green Transportation strategies. The required capital investment and corresponding benefits of carbon reduction is studied. The overall purpose of this research is to build an system dynamics model for evaluating green transportation policies to dynamically simulate effectiveness of carbon reduction under different scenarios. In other words, the designated target of proposed energy saving and carbon reduction policies is studied.

LITERATURE REVIEW

Low Carbon Island is also known as Renewable Energy Island, Energy Island or Sustainable Energy Island. Chen et al. said that development problems of islands are mostly related to over dependence on imported fossil fuels, fresh water availability and waste management, associated with transportation and other problems [2]. Most European islands are facing serious problems of imported energy dependency. However renewable energy technology is one of the solutions, which produces energy by transforming natural resources of these islands into useful energy forms.

There are many internationally renowned renewable energy island projects, such as Greece island [3], Go¨kceada island of Turkey [4], Yakushima Island of Japan [5], etc. Among all, Denmark's Samso Island is the most successful one [6]. Nevertheless, Taiwan's Penghu Low Carbon Island is the first official attempt of such kind of energy policy in Taiwan, and is also a model not having been widely studies in literature.

METHODOLOGY: SYSTEM DYNAMICS

System Dynamics is created by Forrester who was a professor of MIT in 1956. The system dynamics (SD) is a modeling approach to describe the activities of a complex system over time. SD employs the various control factors of the system and observes how the system reacts and behaves in trends. Therefore, SD can be used to assist decision making (e.g., policy experiments) when systems are complex and dynamic [7]. Xie proposed that System Dynamics is an approach of studying dynamic behavior of organization or business system [8]. Through analyzing the feedback process on organization, computer simulation will show how the structure of organization or corporation systems, corporate policies, with the delay effect, interactively influence the growth and stability in organization or corporation system.

SD is now widely used to analyze and assess environmental issues. Wang et al. presented a system dynamics approach based on the cause-and-effect analysis and non-linear feedback loop structures with interactions among transporting, social, economic and environmental factors in urban transportation systems [9]. Jin et al. developed a dynamic ecological footprint forecasting platform to support policy making for urban sustainability improvement [10]. Han and Hayashi took the inter-city passenger transport in China as a case and developed a system dynamics model for policy assessment and CO_2 mitigation potential analysis [11].

According to the above SD literature review, many system dynamics researches are applied to environmental impact and policies' benefit assessment. So this paper focuses on green transportation policy for Penghu Low Carbon Island development to qualitatively analyze causal feedback loop and to

study the relations among different factors. A quantitative model is then constructed to evaluate the benefit of CO_2 emissions reduction after related strategies are implemented.

MODELING

The Green Transportation development strategies of Taiwan's official Penghu Low Carbon Island Project consist of following elements [12]:

1. Changing gasoline motorcycles into electric scooters: 2000 electric scooters will be introduced each year from 2011 to 2013;
2. Placing permission limits on two-stroke gasoline motorcycles;
3. Limiting gasoline motorcycles licenses' permission.

According to all of the above policies, this paper discusses operational process of total level of gasoline motorcycles, total level of substitution from electric scooters, total level of CO_2 emissions from electric scooters of Green Transportation, total level of CO_2 emissions from gasoline motorcycles of Green Transportation, and others external factors. This study uses the common approach of Group Model Building in SD methodology and interviews with experts to construct specific causal feedback loops of green transportation developments in Penghu Low Carbon Island (Figure 1). In other words, the systematic causal structure is mainly formed with variables of total levels of gasoline motorcycles and electric scooters.

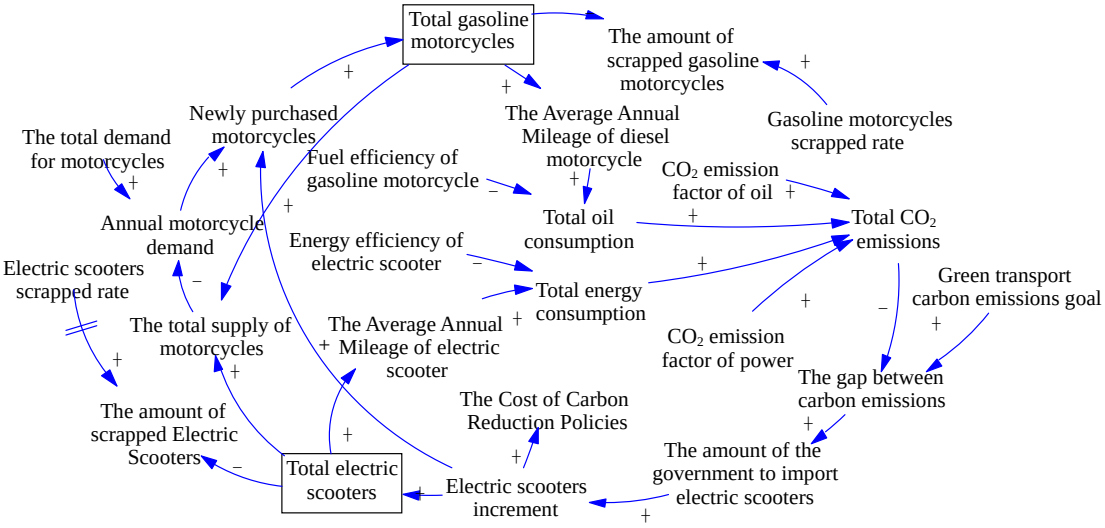

Figure 1 Causal feedback loops of green transportation developments

SYSTEM SIMULATION AND DISCUSSION

In scenario simulations, this paper designs four scenarios running till 2030. The first scenario is Business as Usual (BAU), which is not to implement green transport policy and the whole Penghu Island uses traditional gasoline motorcycles to simulate the emission of CO_2. The second scenario is to change gasoline motorcycles into electric scooters. The third scenario is besides changing gasoline motorcycles into electric scooters, permission limits on two-stroke gasoline motorcycles are also placed. The final scenario is based on third scenario plus limiting gasoline motorcycles licenses' permission. These four scenarios are used to evaluate whether Green Transportation strategies can substantially reduce carbon

emission. Results are shown in Figure 2. The fourth scenario is the best strategy for carbon reduction, with carbon emission falls from to 19.58 kilo-tonnes (KT) to 11.98 KT, and the total oil consumption is reduced to 4.11 kilo-liters. However, the total electricity consumption is significantly increased to 4309.25 MWh and the cost of carbon reduction is much higher.

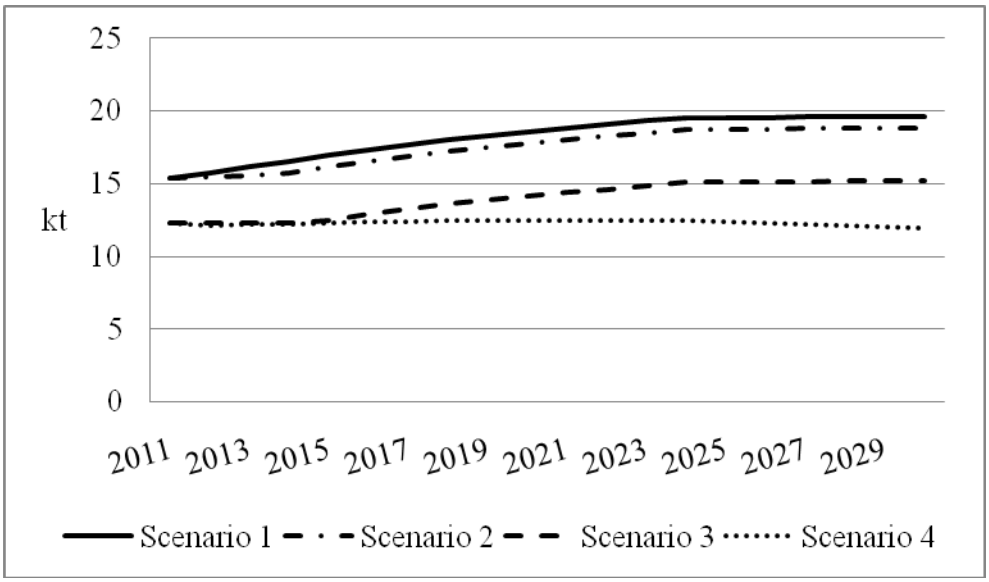

Figure 2 Simulation of carbon emissions for Green Transportation strategies

CONCLUSIONS

This paper based on the Green Transportation strategies of Penghu Low Carbon Island Project to construct a system dynamics model to analyze the effectiveness of required capital investment and the corresponding benefits of carbon emission. Four scenarios are simulated, which are “changing gasoline motorcycles into electric scooters”, “changing gasoline motorcycles into electric scooters” plus “placing permission limits on two-stroke gasoline motorcycles”, and “changing gasoline motorcycles into electric scooters” plus “placing permission limits on two-stroke gasoline motorcycles” plus “limiting gasoline motorcycles licenses’ permission”. Results show that substituting 6000 gasoline motorcycles with electric scooters does not bring significant policy effectiveness. Thus the government has to restrain the permission on two-stroke gasoline motorcycles to fulfill the target of Framework on Sustainable Energy Policy between 2016 to 2020, that is to reduce CO_2 emission back to 2008 level. So as the target of Master Plan on Energy Conservation and Greenhouse Gases Emission Reduction, which is to further mitigate CO_2 emission to 2005 level by 2020. However, the target of decreasing CO_2 emission back to 2000 level by 2025 will not be reached. Therefore, in the viewpoint of sustainable development, the government needs to mandatorily limit gasoline motorcycles license and encourage people to buy electric scooters to fulfill the CO_2 emission target of back to 2000 level by 2025, but that may increase the capital investment relatively. In summary, the evaluation model for Green Transportation strategies of Penghu Low Carbon Island constructed using SD methodology in this paper can be applied to the assessment when developing various carbon reduction policies in transportation sector for other low carbon islands or cities.

REFERENCES

[1] IPCC, 2001, “IPCC third assessment report,” Retrieved 22 November 2010 from http://www.ipcc.ch/ipccreports/tar/index.htm.
[2] Chen, F., Duic, N., Alves, L.M. and Carvalho, M.G., 2007, “Renewislands-renewable energy solutions for islands,” Renewable and Sustainable Energy Reviews, Vol. 11, No. 8, pp. 1888-1902.
[3] Oikonomou, E. K., Kilias, V., Goumas, A., Rigopoulos, A., Karakatsani, E., Damasiotis, M., Papastefanakis, D., Marini, N., 2009, “Renewable energy sources (RES) projects and their barriers on a regional scale: The case study of wind parks in the Dodecanese islands, Greece,” Energy Policy, Vol. 37, pp. 4874-4883.
[4] Demiroren, A. and Yilmaz, U., 2010, “Analysis of change in electric energy cost with using renewable energy sources in Go¨kceada, Turkey: An island example,” Renewable and Sustainable Energy Reviews, Vol. 14, pp. 323-333.
[5] Uemura, Y., Kai, T., Natori, R., Takahashi, T., Hatate, Y., Yoshida, M., 2003, “Potential of renewable energy sources and its applications in Yakushima Island,” Renewable Energy, Vol. 29, pp. 581-591.
[6] Samso energy academy: Renewable energy denmark, “Updated 10 year anniversary report,” Retrieved 21 November 2010 from http://www.onlinepdf.dk/Books/onlinepdf.aspx?onlinepdf=24054.
[7] Forrester, J. W., 1968, “Principles of System,” MIT Press.
[8] Hsieh, C. H., 1980, “System Dynamics: Theory and Application,” Chungshing Ltd., Taipei.
[9] Wang, J., Lu, H. and Peng, H., 2008, “System dynamics model of urban transportation system and its application,” Journal of Transportation Systems Engineering and Information Technology, Vol. 8, No. 3, pp. 83-89.
[10] Jin, W., Xu, L. and Yang, Z., 2009, “Modeling a policy making framework for urban sustainability: Incorporating system dynamics into the ecological footprint,” Ecological Economics, Vol. 68, No.12, pp. 2938-2949.
[11] Han, J. and Hayashi, Y., 2008, “A system dynamics model of CO2 mitigation in China’s inter-city passenger transport,” Transportation Research Part D: Transport and Environment, Vol. 13, No. 5, pp. 298-305.
[12] Bureau of Energy, 2010, Project of Penghu Low Carbon Island Development. (Translation from Chinese)