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An Exploration of Efficiency and Influencing Factors of Low Carbon City

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1 ABSTRACT

Recent years due to global environmental change, environmental protection and carbon dioxide reduction have become urgent issues. At the same time, it is also required to ensure the maintenance of urban economic activities and human life. The priority of economic development and environmental protection has caused much controversy. The tradeoff between economy and environment implies the concept of urban efficiency. And this corresponds to the viewpoint of low carbon economy:"the least carbon emission in exchange for the largest urban benefits".

Therefore, this paper takes the concept of eco-efficiency to simulate the process that a city consumes natural resources in exchange for social and economic development, and adopts Data Envelopment Analysis as a tool to analyze the urban efficiency performance and the factors of urban efficiency. First, this paper assesses urban development efficiency of Taiwan cities and counties, and analyzes the room for improvement of inputs and outputs. Second, this paper explores the influential factors of urban efficiency and the effects of these factors. Final result is expected to provide a reference to low carbon strategies of Taiwan cities and counties, and it will be helpful to future urban management, so that cities will develop towards low carbon economy and achieve the goal of sustainable development.

2 INTRODUCTION

In the face of global environmental change, carbon dioxide reduction is an urgent issue. However, a city can't sustain the basic needs of urban development by only considering for the environment. It is also required to ensure the maintenance of urban economic activities and human life.

Therefore, how to consume the least environmental resources while improving the effectiveness of urban development, so that the use of environmental resources will be more efficient under the condition of limited resources is an important issue. And this issue corresponds to the viewpoint of low carbon economy: "the least carbon emission in exchange for the largest urban benefits".

In view of this, this paper explores the impacts on the environment during the period of urban development from the viewpoint of low carbon economy, and measures the status of urban development by the evaluation of urban efficiency. Furthermore, this paper tries to construct an evaluation method of sustainable urban development in order to providing the reference of the future urban management.

3 RELATED THEORIES

3.1 Low Carbon Economy

British Government announced "Energy White Paper" in which the "low carbon economy" was first proposed in 2003. It points out that low carbon economy is to obtain more economic outputs through less consumption of natural resources and environmental pollution to create the opportunities of better quality of life.

Low carbon economy contains "low carbon" and "economy". "Low carbon" means that we must minimize or stop the dependence on carbon-based fuels in economic development; "economy" means that we should maintain the stability and sustainability of economic growth while achieving the transformation of the energy.

Low carbon economy suits the main points of sustainable development, and it could essentially show that economic growth is towards the direction of sustainable development or not. Furthermore, low carbon economy is easier to monitor and to measure the progress of sustainable development than "clean production", "green economy" and "ecological economy".

3.2 Low Carbon City

Cities are the major sources of carbon dioxide emissions, and the critical locations where emissions can be effectively managed. Adopting low carbon urban development model is the pathway towards reducing the emissions(Stanley C.T.YIP, 2010).

The core of low carbon city is low carbon economy, which intends to get more economic outputs through less consumption of natural resources and environmental pollution, and achieves better quality of life. Low carbon city development is aimed at achieving an ecological economic mode of low consumption, low pollution, high performance and high efficiency, so that we would get more economic and social benefits relatively through consuming fewer natural resources.

In the face of the trade-off between environmental protection and socio-economic development, low carbon city is the response to climate change issues with its emphasis on protecting the environment while ensuring the social and economic development. The concept of low carbon economy and low carbon city is put forward under the background that all people over the world is taking action to deal with climate change. Low carbon economy is the trend and the construction of low carbon city is necessary for future development.

3.3 Urban Development Efficiency

In the beginning, urban development efficiency was mainly used to assess the administrative efficiency of organizational performance and planning policy. And then, urban development efficiency was used to evaluate the urban efficiency by labor, income or expenditure. Later it gradually transferred to the study of the environmental and economic aspects.

Schaltegger and Sturm proposed the concept of eco-efficiency in 1990 (Schaltegger, S. and Sturm, A., 1990), and defined it as the ratio of the environmental impact and the value. "Eco-" is the prefix of economical and ecological. The original intent of eco-efficiency includes both economic and ecological benefits. World Business Council for Sustainable Development (WBCSD) has developed the following equation, which merges value and ecological aspects into an efficiency ratio:

$$\text{Eco} - \text{efficiency} = \frac{\text{Product or service value}}{\text{Environmental influence}}$$

Whitford et al (Whitford, V., Ennos, A. R. and Handley, J. F., 2001) and De Koeijer et al (De Koeijer et al., 2003) applied the concept of eco-efficiency in the urban development efficiency. They thought that we should reduce the environmental damage in the urban development process, and improve the efficiency of urban development.

4 METHODOLOGY

This study takes cities and counties in Taiwan as the spatial units, and the research year is 2009. The input of urban efficiency is carbon emissions in a city, including carbon dioxide emissions of residential sector, industrial sector and commercial sector. And the outputs are disposable income and public facilities area, which represent economic and social benefits of a city.

4.1 Calculation of Carbon Emissions

The calculation method of carbon emissions is according to the "sectoral approach" in 2006 IPCC Guidelines for National Greenhouse Gas Inventories. And the energy emission information of Taiwan is from Energy Balance Sheet.

This study calculates the carbon dioxide emissions of industrial sector and commercial sector in every counties and cities by the proportion of number of establishments, and calculates the carbon dioxide emissions of residential sector by the proportion of number of households.

4.2 Data Envelopment Analysis

This study takes cities and counties in Taiwan as the decision making units (DMUs).The inputs of urban development efficiency are: 1.carbon dioxide emissions of the residential sector 2.carbon dioxide emissions of the industrial sector 3.carbon dioxide emissions of the commercial sector. The outputs of urban development efficiency are: 1.disposable income per capita of economic aspect 2.public facilities area per

capita of social aspect. And then this paper conducts data envelopment analysis through DEA-solver software.

4.2.1 Overall Efficiency

It represents the efficiency that carbon dioxide emissions convert to urban development benefits. The value is between 0 and 1. The higher the value, the more efficient the urban development is.

4.2.2 Technical Efficiency

It represents the relative efficiency that compares the urban development benefits of DMUs which have similar degree of environmental loss (inputs of environmental resources). The value is between 0 and 1. And it implies that the inputs are used effectively to get the maxima of outputs or not.

4.2.3 Scale Efficiency

It represents the relative efficiency that compares the status of environmental loss and urban development benefits of one DMU with another DMU which is in optimal scale.

5 ANALYSIS RESULT

5.1 Urban Development Efficiency Analysis

The evaluation results of urban development efficiency could be an initial view of urban status in different counties and cities. According to the performances of the overall efficiency, technical efficiency and scale efficiency of DMUs, we could figure out where the efficiency problem is in different cities.

Figure 1 shows the result of the overall efficiency, technical efficiency and scale efficiency value of Taiwan counties and cities. Because the efficiency of Penghu County and Taitung County is much greater than the other 21 counties and cities, we remove Penghu County and Taitung County from this analysis, so that we will be easier to tell the differences in the remaining DMUs.

Table 1 and Figure 2 shows the result of overall efficiency, technical efficiency and scale efficiency in 21 counties and cities. And Figure 3 shows the result of overall efficiency in Taiwan map. Hsinchu County, Chiayi County, Hualien County, Keelung City, Hsinchu City and Chiayi City whose overall efficiency are 1.0 are efficient cities and counties; Other cities and counties are inefficient.

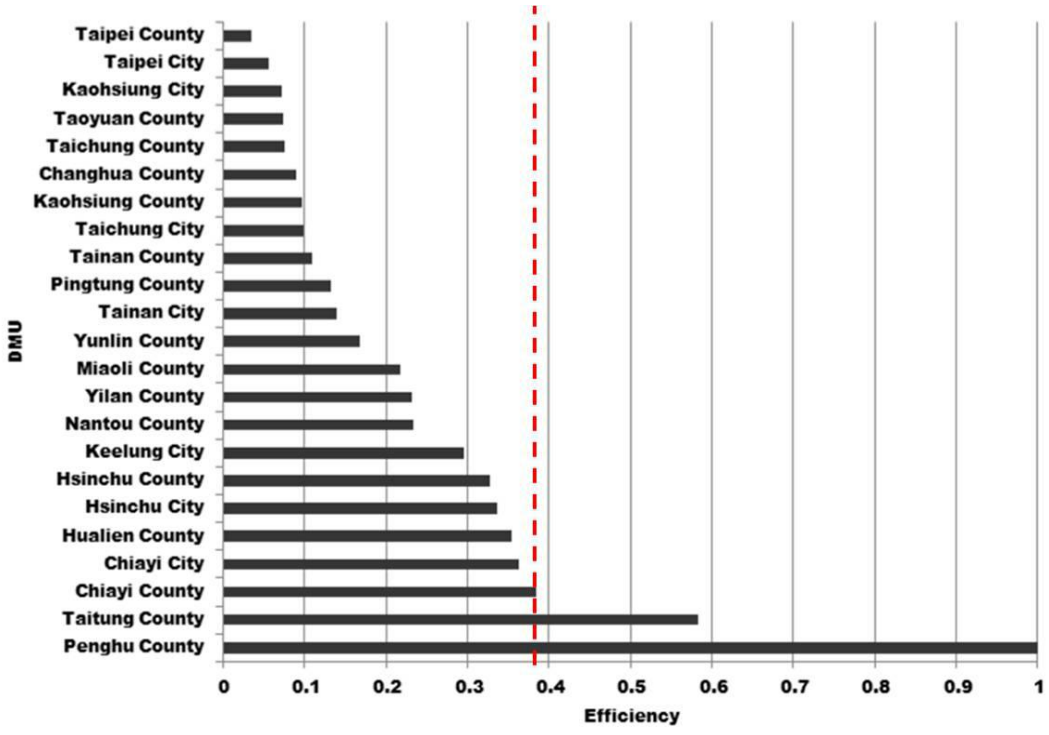

Fig. 1: The results of overall efficiency, technical efficiency and scale efficiency in Taiwan.

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In non-efficient cities and counties, the technical efficiency of Taipei City is 1.0, which shows that the inefficiency is due to "scale inefficiency". Taipei City should change its amount of resources use to improve the efficiency performance. And the reason of other non-efficient cities and counties is mainly from "technical inefficiency", which implies the inputs are not used effectively to reach the output maximization. These cities and counties should maintain the consumption of natural resources, and make further improvements for economic and social policies.

DMU	Overall Efficiency	Technical Efficiency	Scale Efficiency	Reference times
Taipei City	0.2098	1.0000	0.2098	0
Kaohsiung City	0.2337	0.3081	0.7586	0
Taipei County	0.1060	0.1113	0.9519	0
Yilan County	0.7327	0.7909	0.9264	0
Taoyuan County	0.2203	0.2293	0.9605	0
Hsinchu County	1.0000	1.0000	1.0000	8
Miaoli County	0.6801	0.7958	0.8546	0
Taichung County	0.2324	0.2669	0.8707	0
Changhua County	0.2785	0.3364	0.8281	0
Nantou County	0.7742	0.7905	0.9794	0
Yunlin County	0.5543	0.6386	0.8680	0
Chiayi County	1.0000	1.0000	1.0000	1
Tainan County	0.3534	0.3995	0.8845	0
Kaohsiung County	0.3110	0.3312	0.9388	0
Pingtung County	0.4701	0.4924	0.9547	0
Hualien County	1.0000	1.0000	1.0000	11
Keelung City	1.0000	1.0000	1.0000	5
Hsinchu City	1.0000	1.0000	1.0000	11
Taichung City	0.2742	0.2812	0.9754	0
Chiayi City	1.0000	1.0000	1.0000	6
Tainan City	0.4098	0.4258	0.9624	0

Table 1: The result of overall efficiency, technical efficiency scale efficiency and reference times.

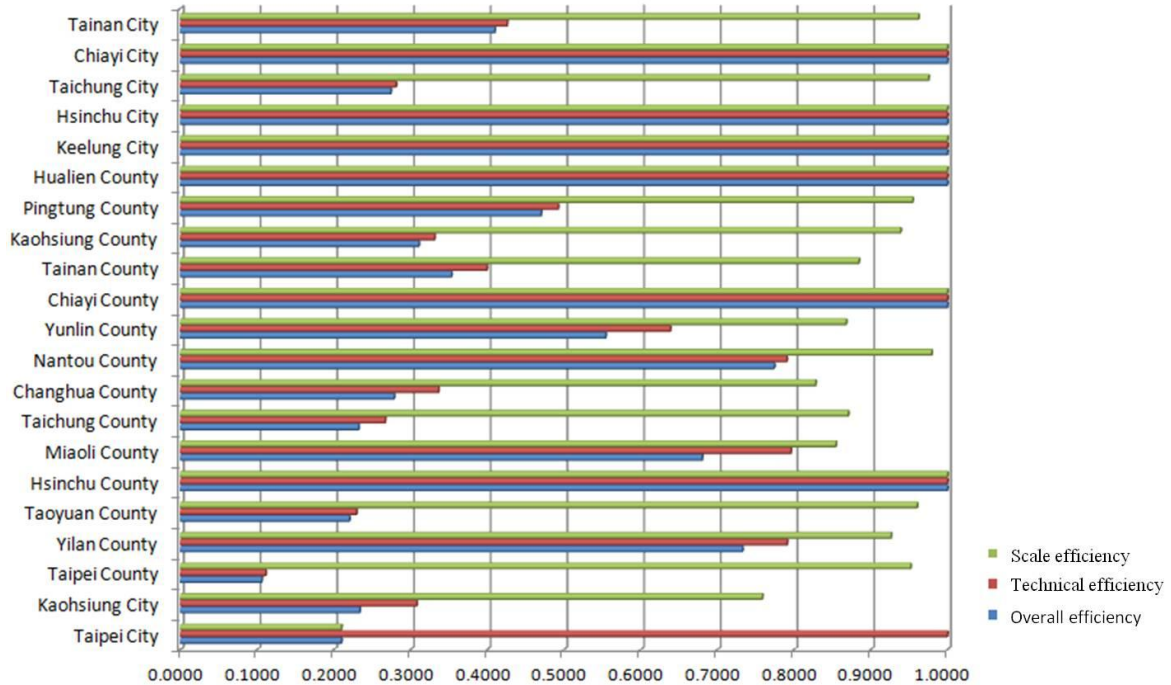

Fig. 2: The result of overall efficiency, technical efficiency and scale efficiency in 21 counties and cities.

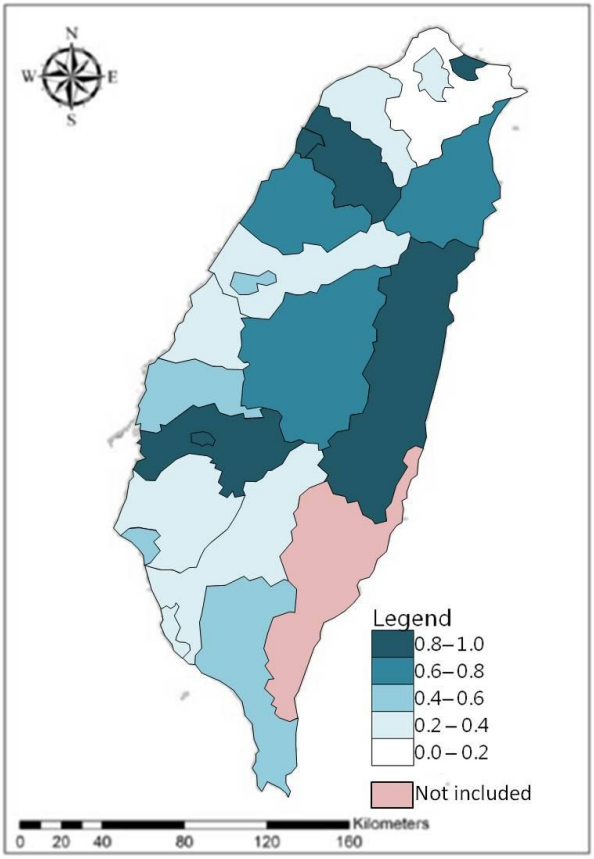

Fig. 3: The result of overall efficiency in Taiwan map.

Norman and Barry (Norman, M., Barry, S., 1991) distinguish four types of efficiency performance: "Robustly Efficient units", "Marginal Efficient Units", "Marginal Inefficient Units" and "Distinctly Inefficient Units". Taiwan counties and cities are classified by these four types as shown in Table 2.

Efficiency type	Description	DMUs
Robustly Efficient Units	The value of overall efficiency, technical efficiency and scale efficiency of the DMUs is 1.0. And the DMUs appear in many reference sets.	Hsinchu County, Hualien County, Keelung City, Hsinchu City, Chiayi City
Marginal Efficient Units	The value of overall efficiency of the DMUs is 1.0. And the reference times of the DMUs is only one or two.	Chiayi County
Marginal Inefficient Units	The value of overall efficiency of the DMUs is between 0.9-1.0. And the DMUs will be relative efficiency by adjusting the inputs and outputs.	-
Distinctly Inefficient Units	The value of overall efficiency of the DMUs is less than 0.9. And the DMUs with overall efficiency less than 0.75 will maintain the inefficient status if there are no big changes in those DMUs.	Nantou County, Yilan County, Miaoli County, Yunlin County, Pingtung County, Tainan City, Tainan County, Kaohsiung County, Changhua County, Taichung City, Kaohsiung City, Taichung County, Taoyuan County, Taipei City, Taipei County

Table 2: Efficiency types of Taiwan counties and cities.

5.2 Slack Variable Analysis

In slack variable analysis, the input variables represent the input volume should be reduced, and the output variables represent the volume should be increased. DMUs will obtain the best efficiency by reducing inputs and increasing outputs. In other words, we could analyze improvement direction and potential improvement

space of urban inputs and outputs in different cities. The result of slack variable analysis are given in Table 3.

Taipei County, Taoyuan County, Taichung County, Nantou County, Yunlin County, Tainan County, Kaohsiung County and Pingtung County could improve their urban development efficiency by reducing carbon dioxide emissions of residential sector. And there are more required improvements in Taipei County, Taoyuan County and Yunlin County. Taipei City and Pingtung County could improve their urban development efficiency by reducing carbon dioxide emissions of commercial sector. And there are ten couties and cities that could improve their urban development efficiency by reducing carbon dioxide emissions of industrial sector. It shows that the carbon dioxide emissions of industrial sector is the main factor to affect the efficiency of urban development in Taiwan.

In addition, there are no couties and cities could improve their urban development efficiency by increasing disposable income. And Taipei City, Kaohsiung City, Taipei County and Taichung City could improve their urban development efficiency by increasing public facilities area per capita.

DMU	Inputs			Outputs	
	CO_2 emissions of residential sector	CO_2 emissions of industrial sector	CO_2 emissions of commercial sector	Disposable income per capita	Public facilities area per capita
Taipei City	0	0	55503.4048	0	46.1747
Kaohsiung City	0	0	0	0	8.2798
Taipei County	21843.5571	482014.1919	0	0	2.0741
Yilan County	0	0	0	0	0
Taoyuan County	14322.1528	292910.5545	0	0	0
Hsinchu County	0	0	0	0	0
Miaoli County	0	35067.2683	0	0	0
Taichung County	4654.8890	1745083.1595	0	0	0
Changhua County	0	1145262.3776	0	0	0
Nantou County	3999.0850	163775.9297	0	0	0
Yunlin County	12607.7986	0	0	0	0
Chiayi County	0	0	0	0	0
Tainan County	6621.0496	541655.8918	0	0	0
Kaohsiung County	1162.1181	234140.7705	0	0	0
Pingtung County	4570.3247	0	1826.7951	0	0
Hualien County	0	0	0	0	0
Keelung City	0	0	0	0	0
Hsinchu City	0	0	0	0	0
Taichung City	0	251773.9167	0	0	9.2942
Chiayi City	0	0	0	0	0
Tainan City	0	260306.7231	0	0	0
Sum	69780.9749	5151990.7836	57330.1999	0	65.8228
Number of DMUs	8	10	2	0	4
Mean	8722.6219	515199.0784	28665.1000	0	16.4557

Table 3: The result of slack variable analysis.

6 CONCLUSION

The tradeoff between economy and environment implies the concept of urban efficiency. This paper tries to explore the environmental impacts of urban development from the viewpoint of low carbon economy, and evaluates the status of urban development by measuring the urban efficiency. And then this paper assesses urban development efficiency of Taiwan cities and counties through data envelopment analysis.

The evaluation results of urban development efficiency could be an initial view of urban status. And then we could analyze potential improvement of urban inputs and outputs by slack variable analysis, so that we could provide suggestions of improvement direction to those cities with poor urban efficiency and set up the different development goals to cities with different urban efficiency.

This paper constructs an evaluation method of sustainable urban development through the evaluation of urban development efficiency from the perspective of carbon efficiency. We could examine that the urban development is towards sustainable development or not by this method. And it will be helpful to future urban management, so that it will achieve the goal of low carbon economy and develop towards sustainable development.

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