Waste Recycling Efficiency in Sub-regions: A Case Study of Taipei County

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Abstract. Waste recycling needs efforts at the local levels. This paper computes waste recycling efficiency of twenty-nine sub-regions (including ten municipalities, seven towns, and twelve villages) from 2000 to 2004. Using Taipei County in Taiwan as a case study, we apply the data envelopment analysis (DEA) and consider three inputs (environmental protection expenditures, capitals and human resources on waste recycling) and two outputs (recycling rate and amount of recycled waste) in the DEA model. The average efficiency on waste recycling is deteriorating, showing much space for recycling performance improvement. The waste recycling efficiency and regional development represent a U-shape relationship. The local county government should assist its sub-region offices to update their waste recycling technologies and to design various waste recycling programs.

Keywords: Data Envelopment Analysis (DEA), Waste Recycling Management, Environmental Kuznets Curve, Taipei County

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1. Introduction

To pursuit sustainable development, local governments often need to implement profound evaluations on their sub-regions' performance on environmental abatement in order to better allocate resources. This paper can assist a local government in building an efficiency index to evaluate its sub-regions' performance on waste recycling. Using Taipei County for a case study, this paper examines if the performance of waste recycling is related to the degree of regional development.

In Taiwan, environmental bureaus in county governments and their belonging municipalities, towns and villages offices need to take the responsibility of waste disposal. As the generated waste is more and more, the Taiwan Environmental Protection Agency decided to implement waste recycling policy in 1988. As the biggest county in Taiwan, Taipei County is the most populated region with a rapid increase in economic growth. The amount of daily waste in the region was over 3500-3800 tones in 1995-1992. Although this amount was reduced to less than 3000 tons in 1993, it still took 16-20% of the whole island's amount of waste.

This county government has implemented many programs such as the curb side collection, environmental education, recycling system, and monitoring programs to enhance the performance of waste recycling. To help the local governments find a better evaluation method, we apply the data envelopment analysis (DEA) method.

Current empirical studies on waste recycling focus on the household's recycling behaviour. For example, Perrin and Barton (2001) compare household's attitudes before and after a recycling program were implemented. Corral-Verdugo (2003) explores household's recycling behaviour in Mexico. Fenara and Missios (2005) study the relationship between recycling policy instruments and recycling behaviour. As to the literature on EKC hypothesis, it is tremendous. For example, Grossman and Krueger (1995) select 14 environmental quality data in both developed and developing countries to examine if environmental quality and per capita GDP is in a U shape. Hung and Shaw (2004) explore the Environmental Kuznets Curves in Taiwan. None of these studies has used recycling efficiency index to represent a region's environmental quality and to examine its relationship with the degree of regional development.

This paper is organised as follows: Following this section, Section 2 introduces the data envelopment analysis model and describes data sources. Section 3 analyses empirical results. Section 4 concludes this paper.

2. Method and Data Sources

2.1 Methodology of Data Envelopment Analysis

DEA is a non-parametric method that uses linear programming methods to construct a non-parametric piecewise frontier over the data for an efficiency measurement. DEA does not need to specify either the production functional form or weights on different inputs and outputs. There are K inputs and M outputs for each of these N sub-regions. The envelopment of the *i*-th sub-region can be derived from the following linear programming problem:

$$\begin{aligned} Min_{\theta,\lambda} \quad & \theta \\ s.t. \quad & -y_i + Y\lambda \geq 0 \\ & \theta x_i - X\lambda \geq 0 \\ & \lambda \geq 0 \end{aligned} \tag{1}$$

where θ is a scalar representing the efficiency score for the *i*-th sub-region; λ is an Nx1 vector of constants; y_i is an Mx1 output vector of sub-region *i*; Y is an MxN output matrix constituted by all output vectors of these N sub-regions; and x_i is a Kx1 input vector of sub-region *i*; and X is a KxN input matrix constituted by all input vectors of these N sub-regions. The efficiency score will satisfy: $0 \leq \theta \leq 1$, with a value of 1 indicating a point on the frontier and hence a technically efficient sub-region (Coelli et al., 1998). The non-negative weight λ serves to form a convex combination of observed inputs and outputs. It is an input-orientated measurement of efficiency. Equation (1) is known as the constant returns to scale (CRS) DEA model (Charnes et al. 1978). This model finds the overall technical efficiency (OTE) of each sub-region.

2.2 Data Sources

This paper studies the waste recycling performance in the twenty-nine sub-regions (including ten municipalities, seven towns, and twelve villages) in the Taipei County in northern Taiwan from 2000 to 2004.

[Insert Figure 1 here]

The sub-region described on the above model includes Banciao Municipality, Sanchong Municipality, Yonghe Municipality, Jhonghe Municipality, Sinjhuang Municipality, Sindian Municipality, Tucheng Municipality, Lujhou Municipality, Sijhih Municipality, Shulin Municipality, Yingge Town, Sansia Town, Danshuei Town, Rueifang Town, Wugu Town, Taishan Town, Linkou Town, Shenkeng Village, Shihding Village, Pinglin Village, Sanjhih Village, Shihmen Village, Bali Village, Pingsi Village, Shuangsi Village, Gongliao Village, Jinshan Village, Wanli Village, Wulai Village. The location of each sub-region is graphed on Figure 1.

[Insert Figure 1 here]

In this study, we assume the production function of waste recycling has two outputs and three inputs. The two outputs are the total amount of recycled waste and waste recycling rate in each sub-region. These data are found in the environmental statistics database of the Taiwan Environmental Protection Agency. There are three input variables: number of labour on environmental protection, total expenditure on environmental protection, and number of vehicles in waste recycling. These data can be found on the statistics overlook of Taipei County and each sub-region office's budget book.

The basic statistics of the variables are described in Table 1. The correlation coefficients of input and output variables are listed in Table 2, showing that all input and output variables satisfy the iso-tonicity property in which an output should not decrease with an increase in an input. Since the DEA results will be still the same after we adjust an output or input in the same proportion (such as the GDP deflator), the efficiency scores will be exactly the same if we use real variables instead of nominal variables.

[Insert Tables 1 and 2 here]

3. Results and Discussions

3.1 Regional recycling efficiency

[Insert Table 3 here]

The efficiency scores and rankings of sub-regions from 2000 to 2004 are listed in Table 3. During the period of 2000-2004, there are 7, 5, 2, 3, 4 regions reaching the highest efficient score respectively. These regions include both municipalities and villages. In general, among the observation years, recycling efficiency in the villages is improving while it is getting worse in the municipalities. By the year of 2002, only one municipality - Sinjhuang Municipality - was capable in reaching the highest efficiency score in waste recycling. The most extremely case is Tucheng Municipality. It was ranked first in 2001 but was ranked least in 2004. In contrast, Gongliao village was ranked 14-23 during the years of 2000-2002. However, by year 2003, it was ranked number one since then. A similar experience also can be seen on Jinshan village.

It is interesting to analyse why the performance of waste recycling in municipalities is getting worse while it is improving in villages. Taipei County faced a highly speed in population growth. The increase of population in Taipei County is mostly from the emigrants from its neighbourhood - Taipei City. The housing price in Taipei City is at least double than that in Taipei County. The other source of population growth is from workers at the other regions whom got laid-off from traditional industries. They migrate to the north side of Taiwan to look for jobs. Fast-increasing population causes waste recycling performance in municipalities is getting worse during the observation years.

In contrast to municipalities, waste recycling performance in villages is getting better and better. This is due to the success of community renaissance in these sub-regions. Local village officers become the core of this movement. They help promote the concept of waste recycling. As a result, recycling efficiency is improving dramatically in villages.

3.2 Waste Recycling Environmental Kuznets Curve

Based on the EKC hypothesis, environmental quality is highly related to National GDP. When a region's income level is low, environment only acts as an input in production, environmental quality is deterioration. However, as growth continues, the region will have more resources on environmental protection so that environmental quality improves. Therefore, the relationship between environmental quality and the level of income is in a U shape. In order to examine whether regional development affects the performance of waste recycling, regional development is categorised into village, town or municipality three levels. Since municipalities often have more business activities than towns and villages, income level in municipality is also higher. We want to test if the performance of waste recycling varies in the degree of regional development.

[Insert Figure 2 here]

Figure 2 plugs each sub-region's average overall technical efficiency score in its belonging groups (villages, towns and municipalities), indicating that the relationship regional development and waste recycling performance is in a U shape. The mean of average overall technical efficiency scores in each group is 0.588, 0.482 and 0.617 respectively. As population and income increases, waste recycling performance will get worse and will eventually turn better. The environmental Kuznets curve hypothesis does sustain in sub-regional waste recycling performance.

4. Conclusion

Using Taipei County as an example, we calculate each sub-region's overall technical efficiency score using three inputs (number of labour and total expenditures on environmental protection and number of vehicles on waste disposal) and two outputs (total amount of recycled waste and waste recycling rate).

During the observation years, Taipei County's waste recycling is deteriorating, implying that the Taipei County should assist local offices in updating their technologies on waste recycling. Moreover, it is found that recycling performance in villages is getting better while it is getting worse in municipalities. The improvement on villages can be due to the success of community renaissance. The recent movement of community renaissance enhances the local's existing social network; citizens are more willing to participate in public affairs. The local government can encourage local communities to incorporate waste recycling and environmental protection activities into their community renaissance movements.

The relationship between regional development and the performance of waste recycling is in a U shape. As population and economic development increase, the performance of waste recycling gets worse especially at town level but will eventually improves at municipality level, implying that each sub-region level indeed faces different social-economic factors.

To improve efficiency, recycling policies may need to match with each sub-region's characteristics. For example, on the village level, recycling policy can encourage public participation through social networking. At the town level, waste recycling policy can encourage develop ecological tourism due to most towns are developing tourisms. Lastly, at the municipality level, waste policy can emphasises more on economic instrument such as imposing waste discharge tax.

Future studies can incorporate the residents' recycling attitudes on the evaluation model. Moreover, if each sub-region's income level is available, one should consider incorporating it in the test of EKC hypothesis.

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Table 1: Summary Statistics of input and output variables

Variables		Maximum	Minimum	Average	Standard deviation
Inputs	Number of labour in environmental protection	727.00	14.00	166.50	184.17
	Expenditure in environmental protection Unit: millions NTD	186.81	0.96	26.05	34.02
	Number of vehicles for environmental use	295.00	7.00	60.86	58.00
Outputs	Amount of waste recycled Unit: ton	64350.12	3.34	3258.85	6713.07
	Waste recycling rate	42.70	0.10	6.55	5.30

Table 2: Input-Output Correlation Coefficients

Items	Amount of recycled waste	Recycling rate	Labour on environmental protection	Expenditures on environmental protection	Number of Vehicles on waste disposal
Amount of recycled waste	1.000				
Recycling rate	0.680	1.000			
Labour on environmental protection	0.565	0.158	1.000		
Expenditures on environmental protection	0.463	0.084	0.891	1.000	
Number of Vehicles on waste disposal	0.519	0.151	0.965	0.932	1.000

Table 3: 2000-2004 Overall Technical Efficiency (TE) and Ranking in the Taipei County

2000			2001			2002			2003			2004		
Muni. (M) Town (T) Village (V)	TE	Rank-ing	Muni. (M) Town (T) Village (V)	TE	Ranking	Muni. (M) Town (T) Village (V)	TE	Rank ing	Muni. (M) Town (T) Village (V)	TE	Rank-ing	Muni. (M) Town (T) Village (V)	TE	Rank-ing
Yonghe M	1.000	1	Yonghe M	1.000	1	Sinjhuang M	1.000	1	Sinjhuang M	1.000	1	Sinjhuang M	1.000	1
Sinjhuang M	1.000	1	Tucheng M	1.000	1	Jinshan V	1.000	1	Gongliao V	1.000	1	Shenkeng V	1.000	1
Sijhih M	1.000	1	Yingge T	1.000	1	Shulin M	0.991	3	Jinshan V	1.000	1	Gongliao V	1.000	1
Yingge T	1.000	1	Shenkeng V	1.000	1	Jhonghe M	0.963	4	Pingsi V	0.874	4	Jinshan V	1.000	1
Shenkeng V	1.000	1	Shihding V	1.000	1	Sindian M	0.963	4	Shenkeng V	0.858	5	Pinglin V	0.695	5
Shihmen V	1.000	1	Sijhih M	0.990	6	Sijhih M	0.889	6	Shihding V	0.721	6	Sanjhih V	0.671	6
Bali V	1.000	1	Wulai V	0.981	7	Shihding V	0.886	7	Shihmen V	0.696	7	Yingge T	0.653	7
Wulai V	0.994	8	Sindian M	0.969	8	Wulai V	0.873	8	Wulai V	0.661	8	Wulai V	0.653	8
Wugu V	0.952	9	Sinjhuang M	0.965	9	Yingge T	0.862	9	Sanjhih V	0.648	9	Shihmen V	0.590	9
Shuangsi V	0.946	10	Shulin M	0.965	9	Shenkeng V	0.817	10	Pinglin V	0.610	10	Shihding V	0.587	10
Jinshan V	0.890	11	Lujhou M	0.839	11	Sanjhih V	0.817	10	Shuangsi V	0.580	11	Shuangsi V	0.527	11
Tucheng M	0.799	12	Jhonghe M	0.830	12	Yonghe M	0.812	12	Bali V	0.532	12	Pingsi V	0.445	12
Lujhou M	0.785	13	Bali V	0.773	13	Lujhou M	0.758	13	Yingge T	0.466	13	Rueifang T	0.375	13
Gongliao V	0.737	14	Jinshan V	0.732	14	Pinglin V	0.723	14	Rueifang T	0.428	14	Bali V	0.355	14
Shulin M	0.709	15	Shihmen V	0.659	15	Tucheng M	0.710	15	Sijhih M	0.419	15	Sansia T	0.349	15
Jhonghe M	0.647	16	Banciao M	0.657	16	Danshuei T	0.661	16	Shulin M	0.418	16	Sijhih M	0.294	16
Sanchong M	0.628	17	Sanchong M	0.644	17	Sanchong M	0.644	17	Danshuei T	0.359	17	Shulin M	0.283	17
Shihding V	0.612	18	Gongliao V	0.624	18	Sansia T	0.599	18	Yonghe M	0.329	18	Taishan V	0.263	18
Sindian M	0.490	19	Wugu V	0.585	19	Shihmen V	0.596	19	Wanli V	0.322	19	Wanli V	0.258	19
Banciao M	0.373	20	Danshuei T	0.506	20	Banciao M	0.594	20	Sansia T	0.307	20	Yonghe M	0.252	20
Taishan V	0.314	21	Taishan V	0.456	21	Wugu V	0.487	21	Jhonghe M	0.305	21	Danshuei T	0.227	21
Sansia T	0.265	22	Sansia T	0.404	22	Bali V	0.449	22	Taishan V	0.282	22	Wugu V	0.210	22
Danshuei T	0.262	23	Linkou V	0.401	23	Gongliao V	0.408	23	Sindian M	0.270	23	Lujhou M	0.200	23
Pingsi V	0.218	24	Rueifang T	0.383	24	Linkou V	0.402	24	Tucheng M	0.245	24	Banciao M	0.190	24
Rueifang T	0.189	25	Pinglin V	0.327	25	Pingsi V	0.380	25	Lujhou M	0.205	25	Sindian M	0.160	25
Linkou V	0.185	26	Shuangsi V	0.324	26	Taishan V	0.379	26	Linkou V	0.205	26	Linkou V	0.159	26
Sanjhih V	0.164	27	Sanjhih V	0.314	27	Rueifang T	0.337	27	Wugu V	0.192	27	Tucheng M	0.126	27
Wanli V	0.161	28	Pingsi V	0.265	28	Shuangsi V	0.331	28	Banciao M	0.177	28	Jhonghe M	0.121	28
Pinglin V	0.035	29	Wanli V	0.127	29	Wanli V	0.197	29	Sanchong M	0.173	29	Sanchong M	0.090	29
MEAN	0.633		MEAN	0.680		MEAN	0.673		MEAN	0.493		MEAN	0.439	
TE=1, 7 regions (24%)			TE=1, 5 regions (17%)			TE=1, 2 regions (7%)			TE=1, 3 regions (10%)			TE=1, 4 regions (14%)		
TE<1, 22 regions (76%)			TE<1, 24 regions (83%)			TE<1, 27 regions (93%)			TE<1, 26 regions (90%)			TE<1, 25 regions (86%)		

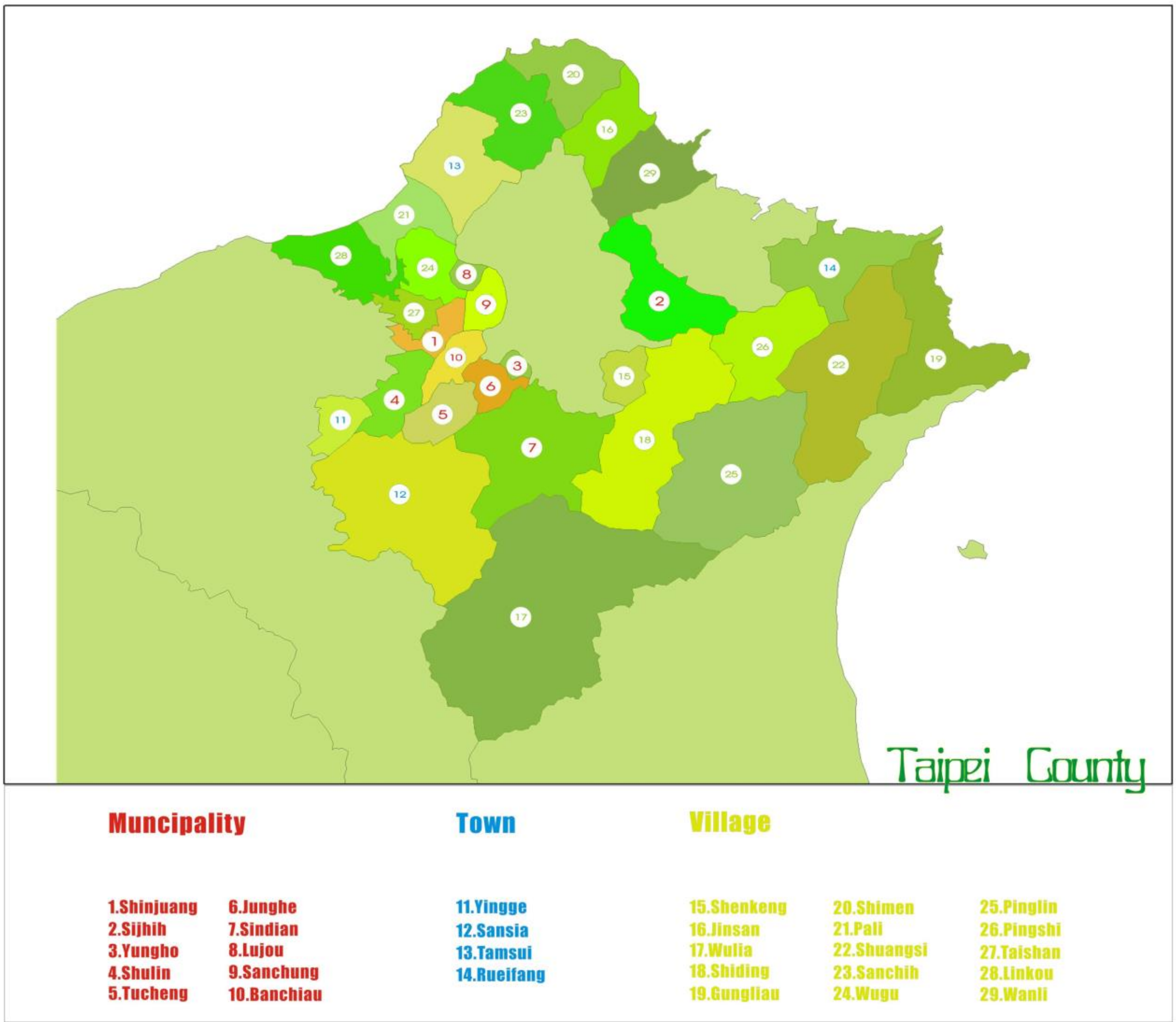

Figure 1: Villages, Towns and Municipalities in Taipei County

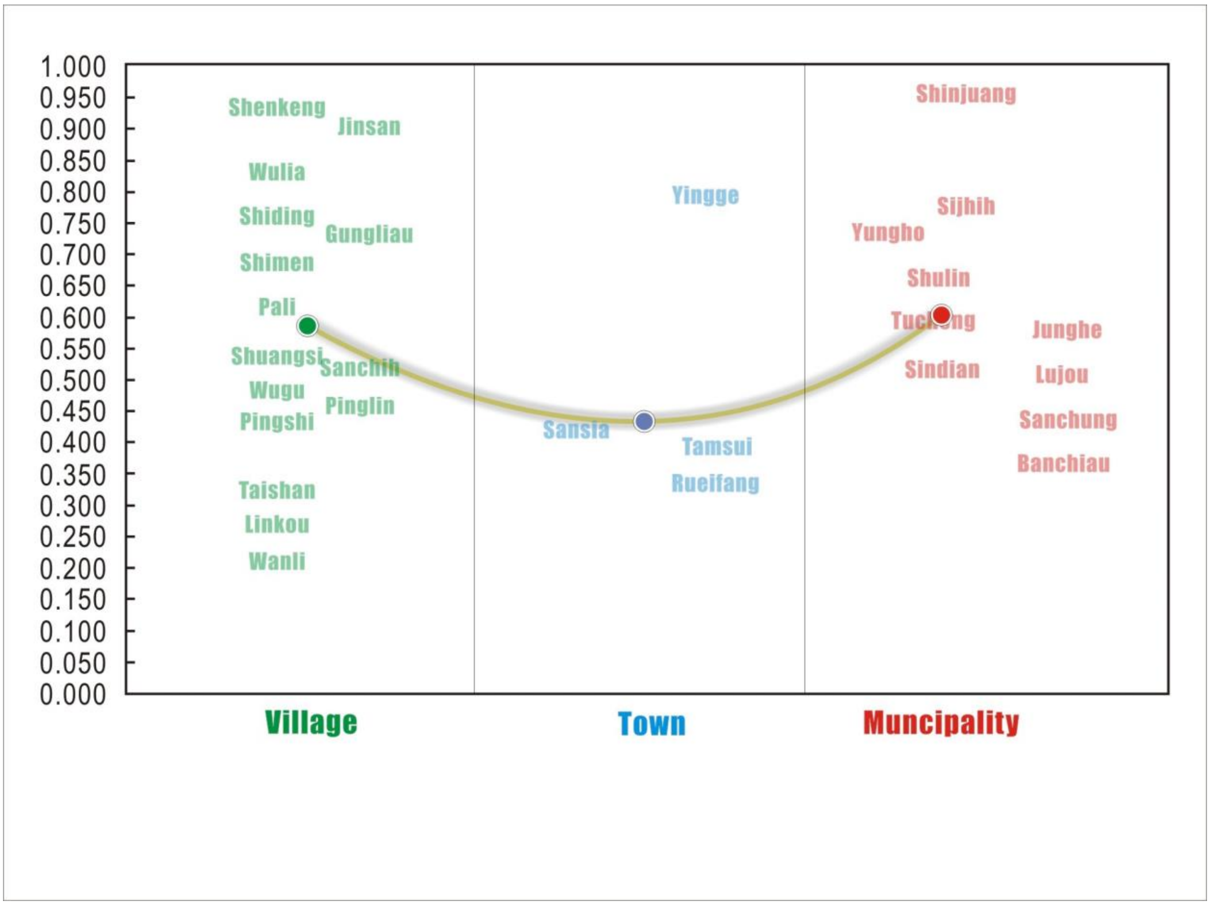

Figure 2: The Waste-recycling Environmental Kuznets Curve in Taipei County