*Sustainability* **2014**, *6*, 3825-3842; doi:10.3390/su6063825

OPEN ACCESS

*sustainability*

**ISSN 2071-1050**

www.mdpi.com/journal/sustainability

*Article*

# Evaluation of the Efficiency of Low Carbon Industrialization in Cultural and Natural Heritage: Taking Leshan as an Example

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*Received: 18 March 2014; in revised form: 3 June 2014 / Accepted: 6 June 2014 / Published: 13 June 2014*

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**Abstract:** This paper concentrates on the evaluation of the efficiency of low carbon industrialization in the tourism sector. Combining the general indices of the regional industrialization with the specific characteristics of low carbon development in the tourism sector, a comprehensive index system is scientifically designed. Due to the complexity of the index system and the tight correlation among some indices, rough set theory (RST) is applied to reduce the dimensions of the index system and delete some overlapped information. Then, the data envelopment analysis (DEA) is used to evaluate the efficiency of low carbon industrialization in every year, in order to investigate the development of regional economy, where the year is considered as the Decision-Making Unit (DMU). Furthermore, the super efficiency value of each DMU is calculated to compare the level of low carbon industrialization in each year. Finally, Leshan city, which is a typical representative of a World Cultural and Natural region in China, is considered as a practical application to show the effectiveness of the proposed model. Then, some valuable suggestions are given to help decision makers improve regional development.

**Keywords:** evaluation; low-carbon industrialization; rough set theory; DEA

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## 1. Introduction

Massive carbon dioxide emissions from large-scale human activities have resulted in a significant environmental crisis and even some disastrous consequences. However, there must be a conflict that the regional economic development usually accelerates the growth in the carbon dioxide emissions. For tourism regions, although the huge tourism revenue promotes rapid economic development, the global $CO_2$ emissions caused by the tourism industry are predicted to grow at an average rate of 3.2% per year up to 2035 [1]. Especially, cultural and natural heritage are increasingly threatened by a series of developmental issues. Xu, Yao and Mo [2] presented a differential dynamic system model with fuzzy coefficients to simulate the carbon intensity of Leshan City, which is a famous world natural and cultural heritage area in China, and claimed that the increasing energy consumption and waste emission accelerate the growth of the carbon intensity. Therefore, how to develop low carbon industry and operation efficiency on low-carbon industrialization in the tourism area becomes a significant research in order to protect the World Cultural and Natural heritage but also promote the development of regional economy.

Low carbon industrial development aims at improving the regional economy in a sustainable way by reducing the industrial pollution and energy consumption. To scientifically assess whether the way of industrial development is sustainable, the connotative meaning of low carbon industrialization should be accurately defined. To some extent, the low carbon industrialization lies in promoting the development of information technology, creating a high-tech, good economic returns, low resource consumption, less environmental pollution and full displaying of the advantages in human resources industrialization and finally reducing the carbon intensity in the region. Characteristics include promoting industrialization though information, intensive growth, making full use of comparative advantage, coordinating mechanization and employment, optimizing industrial structure, and appropriately synchronizing with urbanization [3,4]. In the process of achieving low-carbon industrialization in those regions, the evaluation of the efficiency of regional low-carbon industrialization processes become indispensable. Performance measurement and assessment are fundamental to management planning and control activities. Hence, some efficient methods should be considered to analyze the complicated system structure of low carbon industrialization.

Evaluation of the development process of low-carbon industrialization is the significantly indispensable guide for regional planning and has been paid considerable attention by both management practitioners and theorists [5,6]. Some scholars proposed many powerful methods and theories to discuss the decarbonization problem of industrial sectors. Mandal [7] applied the DEA method to estimate energy use efficiency in the presence of energy related undesirable emission and revealed that energy efficiency estimates were biased if only desirable output was considered. In order to investigate the energy use efficiency of the manufacturing sector, Mukherjee [8] proposed the DEA method to measure it and developed the second-stage regression analysis to simulate the relationship between the energy-intensive industries and energy efficiency. In addition, Mukherjee [9] also developed a nonparametric method combined with DEA to analyze the energy use efficiency in U.S. manufacturing. Mukherjee [10] also paid much attention to the energy efficiency in the context of an emerging economy. Mandal and Madheswaran [11] used the DEA and Directional Distance Function to analyze the environmental efficiency of the Indian cement and developed some useful suggestions. Oggioni, Riccardi and Toninelli [12,13] focused on the eco-efficiency of the world cement industry by DEA combined with directional distance function and proposed some efficient suggestions to improve the energy efficiency and reduce the emission of $CO_2$. Mandal and Madheswaran [14] used the panel vector error correction model to investigate the causality between energy consumption and out growth in the Indian cement industry. Although these scholars developed some evaluation measures to estimate the efficiency for some special industries and sectors, few literatures pay their attentions to the tourism region and even the efficiency of the low carbon industrialization. This research propose an improved DEA based on rough set theory to evaluate the efficiency of low carbon industrialization in a world cultural and natural heritage.

The current theory to design the index system of industrialization is narrowed to the general principle of regional economic development, but doesn't cover some indices reflecting the low carbon characteristics [15,16]. This research develops the index system for low carbon industrialization including not only the general indices of the industrialization of regional economy but also some evaluation indices specifically representing low carbon development in the tourism sector. Considering the complexity of the index system, the rough set theory is used to reduce the dimensions and further form some comprehensive indices. According to these, data envelopment analysis is suggested to evaluate the efficiency of low carbon industrialization in every year. The remainder of the paper is organized as follows. Section 2 presents the index system for the evaluation of low carbon industrialization and proposes the the DEA model based on the rough set theory. Section 4 illustrates the practical application to show the efficiency of the proposed model. Final conclusions are reported in Section 5.

## 2. Modeling

The low carbon industrialization in a world cultural and natural heritage has some specific characteristics which are different from the general regional development. Therefore, a detailed index system should be established in order to accurately measure the efficiency before developing the evaluation model.

### *2.1. Index System*

This research refers to the definition and evaluation index systems of low-carbon industrialization of some other regions in China, and combines the local factors of the world cultural and natural heritage, and finally designs the index system according to the scientific principles including systematicness, objectivity, comparability and operability [17,18]. Three perspectives including the level, quality and degree of the low carbon industrialization are integrated the index system to evaluate the efficiency of low carbon industrialization [19,20].

Considering the theory and historical experiences of industrialization, the following indices are selected to reflect the overall level of industrialization: per-capita GDP which directly represents the level of industrialization or development stage of a region; urbanization rate which reflects the rationalization of the urban fabric; ration of employment in primary industry, which reflects the level of rural industrialization and agricultural modernization; ratio of the output value of the second and third industry, which reflects the adjustment of the industrial structure with the continuous economic and social development; ration of industrial manufactured goods in total exported goods, which accurately describe the level of industrialization and the international competitiveness in industry of one region [21].

The indices to measure the quality of industrialization are designed from the following four aspects: economic benefits, technology, information and resource utilization. Economic benefits mainly evaluate the quality and efficiency of economic growth in one region. It contains the following phases: the rate of profit based on the second industrial cost [22]; contribution rate of gross asset, which reflects the profitability and performance of all the assets of the industrial enterprise; industrial added value, which reflects the production capacity of industrial enterprises; average labor productivity of all employees, which is the overall performance of production technology, business management, staff technical proficiency and labor enthusiasm. Technology mainly concerns about the level of technological innovation, research and development capabilities in economic and social development of one region. It contains the following phases: ratio of R&D funds in GDP, which denotes the level of development of high-tech industries; rate of new product value, which reflects the level of scientific research and development and the capacity of scientific research results into commodity and economic advantage; number of patents and technological achievements, which reflects the ability of independent innovation. Information concerns about the situation of information technology to promote industrialization in the process of low-carbon industrialization. It contains the following phases: ratio of output of information industry in total output of industry, which largely reflects the size of the information industry; ratio of fixed asset investment on information industry in total industrial fixed asset investment, which reflects the level of information input; ratio of employees of information industry in number of employees, which reflects the size of the information industry from the perspective of labor force. The new industry usually focus on how to reduce resource consumption, so the resource utilization can be denoted by the indices of electricity consumption per 10 thousand output and comprehensive energy consumption per 10 thousand GDP.

The degree of low-carbon industrialization is used to evaluate the impact on the environment, social stability and development from the industrialization [23]. Some indices for environment are summarized as follows: the disposal and use rate of industrial solid waste, discharge rate of industrial wastewater, treatment rate of industrial waste gas, growth rate of environmental investments, urban green coverage rate. The indices that denote the social stability and development include the growth rate of the second industrial employees, the urban registered unemployment rate, the ratio of the population holding the college diploma or above in total population, the ratio of urban per-capita net income to rural per-capita net income, the ratio of urban Engel index to rural Engel index.

### *2.2. Evaluation System*

The proposed index system for low carbon industrialization in Table 1 has a complicated structure and some of the indices have a tight correlation. The overlapped information in these indices should be deleted in order to accurately evaluate the efficiency. As known, the rough set theory (RST) proposed by Pawlak [24–26] is a powerful tool for reduction of attributes [27]. It can simplify the indices in the premise of retaining key information and obtain the minimum expression of the knowledge.

**Table 1.** Index system for low carbon industrialization.

| Subsystem layer | | Indices | Symbol | Unit |
|---|---|---|---|---|
| Level of industrialization | | per-capita GDP | $x_1$ | $10^4$Yuan |
| | | urbanization rate | $x_2$ | % |
| | | ration of employment in primary industry | $x_3$ | % |
| | | ratio of the output value of the second and third industry | $x_4$ | % |
| | | ratio of manufactured goods in exported goods | $x_5$ | % |
| Quality of industrialization | Economic benefit | rate of profit based on the second industrial cost | $x_6$ | % |
| | | contribution rate of gross asset | $x_7$ | % |
| | | industrial added value | $x_8$ | $10^4$Yuan |
| | | average labor productivity of all employees | $x_9$ | $10^4$Yuan/person |
| | Tech | ratio of R & D funds in GDP | $x_{10}$ | % |
| | | rate of new product value | $x_{11}$ | % |
| | | number of patents and technological achievements | $x_{12}$ | No dimension |
| | Information | ratio of total output of information industry in total output of industry | $x_{13}$ | % |
| | | ratio of fixed assets investment of information industry to industry | $x_{14}$ | % |
| | | ratio of employees of information industry in number of all employees | $x_{15}$ | % |
| | Resource utilization | electricity consumption per 10 thousand output | $x_{16}$ | $kwh$ |
| | | comprehensive energy consumption of 10 thousand GDP | $x_{17}$ | $10^{-3}$TCE |
| The degree of low-carbon industrialization | | disposal and use rate of industrial solid waste | $x_{18}$ | % |
| | | discharge rate of industrial waste water | $x_{19}$ | % |
| | | treatment rate of industrial waste gas | $x_{20}$ | % |
| | | growth rate of environmental investment | $x_{21}$ | % |
| | | urban green coverage rate | $x_{22}$ | % |
| | | growth rate of industrial employees | $x_{23}$ | $10^4$people |
| | | urban registered unemployment rate | $x_{24}$ | % |
| | | The share of college degree or above in total population | $x_{25}$ | % |
| | | ratio of urban per capita net income to rural per capita net income | $x_{26}$ | No dimension |
| | | ratio of urban Engel index to rural Engel index | $x_{27}$ | % |

Pawlak and Hampton [27–31] defined a 2-tuple $S = (U, R)$ to describe the information system, where $U$ is the universe, $R$ is a nonempty finite set of attributes. Let $r \in R$ be a property of $U$, $[x]_r$ be the equivalence classes on the properties of the elements of $U$, and $P \subseteq R$, $P \neq \emptyset$, $P = \{r_{i1}, \cdots, r_{ik}\}$, the intersection of all equivalence relations of $P$ is defined by $\bigcap P = \bigcap_{j=1}^{k} r_{ij}$, then $\bigcap P$ is an equivalence relation, noted $IND(P)$. Through the equivalence relation, some indices with similar information can be merged and a concise index system for low carbon industrialization can be obtained.

After the index reduction by RST, the data envelopment analysis (DEA) can be used to evaluate efficiency of low carbon industrialization in every year in order to investigate the development of regional economy. Thus, the year is considered as the Decision-Making Unit(DMU), then the efficiency of each DMU is assessed by the reduced index system. Data envelopment analysis first introduced by [32], is well established as a theoretically framework for conducting performance analysis, and its application by practitioners has resulted in some significant performance improvements [33–35]. It commonly possess many advantages over other techniques such as performance ratios and regression analysis, which makes it a very suitable tool for management in a wide variety of industries [36,37]. DEA evaluates the efficiency of DMU by using mathematical programming model. The results is divided into two types of efficient and inefficient parts and the evaluation conclusion can be obtained according the relative efficiency of DMU.

To evaluate the efficiency of low-carbon industrialization in $n$ years, we assume $n$ DMUs where each year is considered as one DMU with $m$ inputs and $s$ outputs. Some notations are listed below:

**Decision variables**

$v_i$ : the weight of the input $i$, $i = 1, 2, \cdots, m$;

$u_k$ : the weight of the output $k$, $k = 1, 2, \cdots, s$;

**Parameters**

$IdI_{ij}$ : the $i$-th input of DMU $j$, $i = 1, 2, \cdots, m$, $j = 1, 2, \cdots, n$;

$IdO_{kj}$ : the $k$-th output of DMU $j$, $k = 1, 2, \cdots, s$, $j = 1, 2, \cdots, n$;

**Objective function**

$\max \frac{\sum_{k=1}^{s} u_k IdO_{kj}}{\sum_{i=1}^{m} v_i IdI_{ij}}$ : to maximize the efficiency of low carbon industrialization in the $j$-th year ( DMU $j$), $i = 1, 2, \cdots, m$;

**Constraints**

$\frac{\sum_{k=1}^{s} u_k IdO_{kj}}{\sum_{i=1}^{m} v_i IdI_{ij}} \leq 1$ : the efficiency of low carbon industrialization of the $j$-th year( DMU $j$) can not exceed 1, $i = 1, 2, \cdots, m$, $j = 1, 2, \cdots, n$. If it achieves 1 in the $j$-th year, it means that the productivity is the highest. If it is less than 1 in the $j$-th year, it means that the productivity needs to be improved compared to other years.

$v_i \geq 0$ : the weight of the $i$-th input should be greater than 0;

$u_k \geq 0$ : the weight of the $k$-th output should be greater than 0.

Let $t = \frac{1}{\sum_{i=1}^{m} v_i x_{ij}}$, $\mu_i = tu_i$, $\omega_i = tv_i$, then the dual problem is defined as $\min\ \Theta$, where $\Theta$ is the efficiency value. If the objective value $\Theta = 1$ in the $j$-th year, the low carbon industrialization is efficient. If $\Theta < 1$, the low carbon industrialization is inefficient. $1 - \Theta$ is the largest proportion of diminished input. Thus, if $\Theta$ is closer to 1, it is more efficient in this year. Figure 1 illustrates the relevant ideas of the efficiency evaluation. Finally, the constraints are transformed into $\sum_{j=1,j\neq k}^{n} \lambda_j IdI_j \leq \Theta IdI_k$ and $\sum_{j=1,j\neq k}^{n} \lambda_j IdO_j \leq IdO_k$, where $\lambda_j$ is a re-constructed combined ratio of $j-a$ Year of an efficient year combination, $\lambda_j \geq 0,\ \ j = 1, 2, \cdots, n$. When evaluating the efficiency of $k-a$ decision making units, let the input and output of $k-a$ years be substituted by the linear combination of inputs and outputs of all the other years by excluding $k-a$ years. For an efficient year, its inputs can be increased in proportion but the efficient value won't be changed. The increased proportion is the super efficiency evaluation value(see Figure 2), so the larger the efficiency value of efficient year, the more efficient this year [38,39].

**Figure 1.** Evaluation model of DEA.

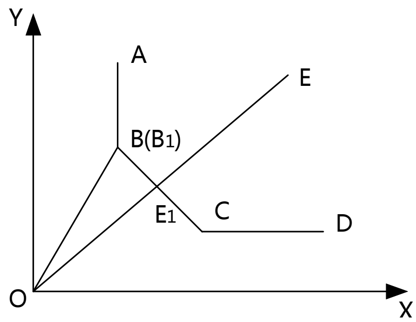
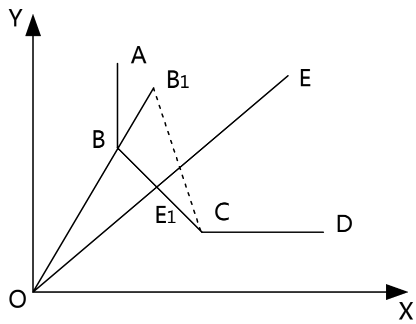



**Figure 2.** Evaluation model of improved DEA.




## 3. Practical Application

Leshan is a world natural and cultural heritage region in western China. It is an ancient city with three thousand years history. Leshan Giant Buddha is the largest stone seated Buddha in the world. Mount Emei is a mountain scenic area that a set of Buddhist culture and natural beauty as one. In 1996, Leshan Giant Buddha-Mount Emei is enrolled into *Natural and Cultural Heritage*. What's more, this region is also a developing area of industrialization with electronics and polysiliconas, pharmaceutical chemical, silk textile and machine casting as dominant industries. During "Eleventh Five-Year" period, the industrial development of this region has been greatly accelerated. The industrial added value has increased from 2.72391 billion Yuan in 2005 to 5.53676 billion Yuan in 2009 with the contribution 45% of the regional economic growth rate. In the following part, the RST-based DEA model is applied to evaluate the efficiency of low carbon industrialization in Leshan city.

### *3.1. Evaluation of Low Carbon Industrialization*

The data of the index system during the period from 2000 to 2009 are shown in Table 2. Let the DMUs be $U = \{2000,\ 2001,\ 2002,\ 2003,\ 2004,\ 2005,\ 2006,\ 2007,\ 2008,\ 2009\}$, the attribute set be $R = \{X_1, X_2, X_3, \ldots, X_{27}\}$. Set a threshold limitation for each index, and 1 denote that it meets the standards, that is it exceeds the threshold limitation, 2 denote that it does not meet the standards. For example, the threshold is $1.2$ for $x_1$, then the situation that the data greater than 1.2 will be denoted 1, otherwise 0.

**Table 2.** 2000–2009 indices of low carbon industrialization.

| Symbol | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| $x_1$ | 0.6 | 0.65 | 0.72 | 0.83 | 0.99 | 1.07 | 1.25 | 1.53 | 1.87 | 2.16 |
| $x_2$ | 48.4 | 49.2 | 50.3 | 51.7 | 52.5 | 53.4 | 54.6 | 55.5 | 56.7 | 58.2 |
| $x_3$ | 59.22% | 57.42% | 45.81% | 47.65% | 44.39% | 42.7% | 42.1% | 41.6% | 42% | 36.6% |
| $x_4$ | 89.5% | 94.9% | 98.0% | 98.8% | 123.0% | 110.0% | 100.4% | 95.6% | 87.6% | 92.4% |
| $x_5$ | 93.6% | 94.1% | 94.5% | 94.9% | 95.2% | 97% | 97.7% | 98.1% | 98.8% | 99% |
| $x_6$ | 2.4% | 2.69% | 1.81% | 4.5% | 6% | 6.3% | 5.69% | 6.74% | 13.66% | 14.81% |
| $x_7$ | 6.53% | 7.15% | 4.86% | 6.9% | 8.6% | 10% | 11.35% | 14.62% | 21.62% | 21.37% |
| $x_8$ | 358,553 | 364,171 | 425,253 | 399,841 | 460,406 | 579,924 | 754,533 | 972,897 | 462,845 | 1,587,506 |
| $x_9$ | 4.33 | 4.96 | 7.25 | 8.72 | 7.04 | 9.21 | 11.3 | 14.6 | 19.2 | 23.6 |
| $x_{10}$ | 0.00% | 0.00% | 0.07% | 0.00% | 0.00% | 0.08% | 0.00% | 0.13% | 0.00% | 0.00% |
| $x_{11}$ | 5.9% | 6.2% | 8.6% | 6.7% | 7.3% | 9.0% | 10.9% | 7.9% | 16.4% | 6.5% |
| $x_{12}$ | 7 | 13 | 22 | 32 | 40 | 52 | 69 | 113 | 172 | 182 |
| $x_{13}$ | 2.2% | 2.6% | 2.7% | 4.7% | 3.1% | 24.4% | 22.1% | 19.1% | 16.1% | 16.9% |
| $x_{14}$ | 24.8% | 26.5% | 27.8% | 29.7% | 31.1% | 32.1% | 33.6% | 34.7% | 36% | 37.8% |
| $x_{15}$ | 8.3% | 8.7% | 9.7% | 11.5% | 12.7% | 14.0% | 15.3% | 15.5% | 16.1% | 14.1% |
| $x_{16}$ | 780.2 | 776.3 | 768.9 | 731.5 | 718.0 | 657.4 | 561.9 | 587.5 | 480.5 | 486.7 |
| $x_{17}$ | 1.78 | 1.71 | 1.62 | 1.54 | 1.47 | 1.40 | 1.35 | 1.41 | 1.23 | 1.17 |
| $x_{18}$ | 95.5% | 97.1% | 98.9% | 95.7% | 40.3% | 97.4% | 96.0% | 95.8 % | 99.4% | 96.8% |
| $x_{19}$ | 69% | 43% | 42% | 46.13% | 96% | 81.3% | 97.7% | 99.0% | 98.9% | 97.9% |
| $x_{20}$ | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 10.110% | 8.90% | 11.20% |
| $x_{21}$ | 13.6% | −100% | 16.1% | 16.5% | −9.2% | 16.6% | −46.3% | 16.9% | 62.1% | −46.1% |
| $x_{22}$ | 31.5% | 28.3% | 30.1% | 32.6% | 34.0% | 27.7% | 40.3% | 38.8% | 45.5% | 45.6% |
| $x_{23}$ | 1.8% | 1.7% | 1.9% | 1.9% | 2.6% | 4.7% | 4.6% | 2.5% | 0.4% | 6.4% |
| $x_{24}$ | 3.30% | 3.90% | 3.20% | 3.01% | 3.92% | 4.80% | 4.30% | 4.20% | 4.00% | 4.08% |
| $x_{25}$ | 3.1% | 3.5% | 3.8% | 4.1% | 4.4% | 5.0% | 5.4% | 5.8% | 6.2% | 6.5% |
| $x_{26}$ | 2.26 | 2.31 | 2.36 | 2.36 | 2.27 | 2.13 | 2.19 | 2.41 | 2.45 | 2.60 |
| $x_{27}$ | 81.11% | 79.22% | 76.90% | 72.88% | 70.22% | 90.51% | 90.20% | 70.66% | 80.00% | 78.45% |

Based on evaluation indices of efficiency of low carbon industrialization, we set the threshold of $1.2$ for $x_1$, $53.05$ for $x_2$, $45.9$ for $x_3$, $97.6\%$ for $x_4$, $96.3\%$ for $x_5$, $6.5\%$ for $x_6$, $11.3\%$ for $x_7$, $460,000$ for $x_8$, $11.02\%$ for $x_9$, $1.2\%$ for $x_{10}$, $8.9\%$ for $x_{11}$, $70$ for $x_{12}$, $11.4$ for $x_{13}$, $31.4\%$ for $x_{14}$, $12.6\%$ for $x_{15}$, $654.9$ for $x_{16}$, $1.40$ for $x_{17}$, $91.3\%$ for $x_{18}$, $77.1\%$ for $x_{19}$, $10.00\%$ for $x_{20}$, $15\%$ for $x_{21}$, $35.4\%$ for $x_{22}$, $4.5\%$ for $x_{23}$, $3.8\%$ for $x_{24}$, $4.8\%$ for $x_{25}$, $2.33\%$ for $x_{26}$, $80.1\%$ for $x_{27}$. It follows from the rule defined above, Table 3 can be obtained. As can be seen, the corresponding values of $x_1, x_7, x_9, x_{16}, x_{22}$ are the same, then $x_1$ is chosen. The corresponding values of $x_2, x_5, x_{13}, x_{14}, x_{25}$ are the same, then $x_2$ is chosen. Therefore, Table 4 are obtained.

The next step is to reduce the attributes in Table 4 including $U = \{2000, \cdots, 2009\}$ and the property set $R = \{x_1, x_2, x_3, x_4, x_8, x_{10}, x_{11}, x_{12}, x_{17}, x_{18}, x_{20}, x_{21}, x_{23}, x_{24}, x_{26}, x_{27}\}$.

$$\begin{aligned}
U/IND(R) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}.\\
U/IND(R-\{x_1\}) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005,2006\},\{2007\},\{2008\},\{2009\}\}\\
&\neq U/IND(R)\\
U/IND(R-\{x_2\}) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&= U/IND(R)\\
U/IND(R-\{x_3\}) &= \{\{2000\},\{2001,2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&\neq U/IND(R)\\
U/IND(R-\{x_4\}) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&= U/IND(R)\\
U/IND(R-\{x_8\}) &= \{\{2000\},\{2001\},\{2002,2004\},\{2003\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&\neq U/IND(R)\\
U/IND(R-\{x_{10}\}) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&= U/IND(R)\\
U/IND(R-\{x_{11}\}) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&= U/IND(R)\\
U/IND(R-\{x_{12}\}) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&= U/IND(R)\\
U/IND(R-\{x_{17}\}) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007,2008\},\{2009\}\}\\
&\neq U/IND(R)\\
U/IND(R-\{x_{18}\}) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&= U/IND(R)\\
U/IND(R-\{x_{20}\}) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&= U/IND(R)\\
U/IND(R-\{x_{21}\}) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&= U/IND(R)\\
U/IND(R-\{x_{23}\}) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007,2009\},\{2008\}\}\\
&\neq U/IND(R)\\
U/IND(R-\{x_{24}\}) &= \{\{2000\},\{2001\},\{2002,2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&\neq U/IND(R)\\
U/IND(R-\{x_{26}\}) &= \{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&= U/IND(R)\\
U/IND(R-\{x_{27}\}) &= \{\{2000,2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\\
&\neq U/IND(R)
\end{aligned}$$

**Table 3.** Evaluation Information.

| Symbol | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| $x_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| $x_2$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| $x_3$ | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $x_4$ | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| $x_5$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| $x_6$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| $x_7$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| $x_8$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| $x_9$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| $x_{10}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $x_{11}$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| $x_{12}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| $x_{13}$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| $x_{14}$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| $x_{15}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| $x_{16}$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| $x_{17}$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 |
| $x_{18}$ | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| $x_{19}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| $x_{20}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| $x_{21}$ | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
| $x_{22}$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| $x_{23}$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| $x_{24}$ | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| $x_{25}$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| $x_{26}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| $x_{27}$ | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 |

After that, $x_2, x_4, x_{10}, x_{11}, x_{12}, x_{18}, x_{20}, x_{21}, x_{26}$ can be omitted. Finally, we reduced the number of indices from 27 to 7 including per-capita GDP, ratio of first industrial in all employees, industrial added value, comprehensive energy consumption per 10 thousand GDP, growth rate of the second industrial employees, urban registered unemployment rate, ratio of urban Engel index to rural Engel index. They are denoted $IdI_1, IdI_2, IdI_3, IdI_4, IdI_5, IdI_6, IdI_7$, respectively. According to the requirements of the development of low carbon industrialization and the future development in this area, we set the output indices: growth rate of industrial added value (%), output value of information industry ($10^4$ Yuan), output value of industry "Three wastes" utilization products ($10^4$ Yuan), that $IdO_1, IdO_2, IdO_3$ in Table 5 [40,41].

**Table 4.** Preliminary reduction of evaluation information.

| Symbol | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| $x_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| $x_2$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| $x_3$ | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $x_4$ | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| $x_8$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| $x_{10}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $x_{11}$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| $x_{12}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| $x_{17}$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 |
| $x_{18}$ | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| $x_{20}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| $x_{21}$ | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
| $x_{23}$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| $x_{24}$ | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| $x_{26}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| $x_{27}$ | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 |

**Table 5.** Evaluation system of DEA.

| Symbol | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Input | $IDI_1$ | 0.6 | 0.65 | 0.72 | 0.83 | 0.99 | 1.07 | 1.25 | 1.53 | 1.87 | 2.16 |
| | $IDI_2$ | 0.59 | 0.57 | 0.46 | 0.48 | 0.44 | 0.43 | 0.42 | 0.42 | 0.42 | 0.37 |
| | $IDI_3$ | 358,553 | 364,171 | 425,253 | 399,841 | 460,406 | 579,924 | 754,533 | 972,897 | 462,845 | 1,587,506 |
| | $IDI_4$ | 1.78 | 1.71 | 1.62 | 1.54 | 1.47 | 1.40 | 1.35 | 1.41 | 1.23 | 1.17 |
| | $IDI_5$ | 0.018 | 0.017 | 0.019 | 0.019 | 0.026 | 0.047 | 0.046 | 0.025 | 0.04 | 0.064 |
| | $IDI_6$ | 0.033 | 0.039 | 0.032 | 0.03 | 0.039 | 0.048 | 0.043 | 0.042 | 0.04 | 0.041 |
| | $IDI_7$ | 0.81 | 0.79 | 0.77 | 0.73 | 0.70 | 0.91 | 0.90 | 0.71 | 0.80 | 0.78 |
| Output | $IDO_1$ | 0.089 | 0.089 | 0.095 | 0.17 | 0.21 | 0.26 | 0.27 | 0.31 | 0.2 | 0.27 |
| | $IDO_2$ | 0 | 0 | 9604 | 11,676 | 13,301 | 15,017 | 15,625 | 19,840 | 20,190 | 32,702 |
| | $IDO_3$ | 0.001 | 0.0012 | 0.0015 | 0.0018 | 0.002 | 0.003 | 0.004 | 0.005 | 0.0045 | 0.007 |

In order to calculate the efficiency value of $Year_1$, the following Equation (1) is developed by inputing the values of the indices in Table 5.

$$
\min \quad \Theta
$$
$$
s.t \begin{cases}
0.65\lambda_2 + 0.72\lambda_3 + 0.83\lambda_4 + 0.99\lambda_5 + 1.07\lambda_6 + 1.25\lambda_7 + 1.53\lambda_8 + 1.87\lambda_9 \\
+2.16\lambda_{10} \le 0.6\Theta \\
0.57\lambda_2 + 0.46\lambda_3 + 0.48\lambda_4 + 0.44\lambda_5 + 0.43\lambda_6 + 0.42\lambda_7 + 0.42\lambda_8 + 0.42\lambda_9 \\
+0.37\lambda_{10} \le 0.59\Theta \\
364171\lambda_2 + 425253\lambda_3 + 399841\lambda_4 + 460406\lambda_5 + 579924\lambda_6 + 754533\lambda_7 + 972897\lambda_8 \\
+462845\lambda_9 + 1587506\lambda_{10} \le 358553\Theta \\
1.71\lambda_2 + 1.62\lambda_3 + 1.54\lambda_4 + 1.47\lambda_5 + 1.4\lambda_6 + 1.35\lambda_7 + 1.41\lambda_8 + 1.23\lambda_9 \\
+1.17\lambda_{10} \le 1.78\Theta \\
0.017\lambda_2 + 0.019\lambda_3 + 0.019\lambda_4 + 0.026\lambda_5 + 0.047\lambda_6 + 0.046\lambda_7 + 0.025\lambda_8 + 0.04\lambda_9 \\
+0.064\lambda_{10} \le 0.018\Theta \\
0.039\lambda_2 + 0.032\lambda_3 + 0.03\lambda_4 + 0.039\lambda_5 + 0.048\lambda_6 + 0.043\lambda_7 + 0.042\lambda_8 + 0.04\lambda_9 \\
+0.041\lambda_{10} \le 0.033\Theta \\
0.79\lambda_2 + 0.77\lambda_3 + 0.73\lambda_4 + 0.70\lambda_5 + 0.91\lambda_6 + 0.90\lambda_7 + 0.71\lambda_8 + 0.80\lambda_9 \\
+0.78\lambda_{10} \le 0.81\Theta \\
0.089\lambda_2 + 0.095\lambda_3 + 0.17\lambda_4 + 0.21\lambda_5 + 0.26\lambda_6 + 0.27\lambda_7 + 0.31\lambda_8 + 0.2\lambda_9 \\
+0.27\lambda_{10} \ge 0.089 \\
9604\lambda_3 + 11676\lambda_4 + 13301\lambda_5 + 15017\lambda_6 + 15625\lambda_7 + 19840\lambda_8 + 20190\lambda_9 + \\
32702\lambda_{10} \ge 0 \\
0.0012\lambda_2 + 0.0015\lambda_3 + 0.0018\lambda_4 + 0.002\lambda_5 + 0.003\lambda_6 + 0.004\lambda_7 + 0.005\lambda_8 \\
+0.0045\lambda_9 + 0.007\lambda_{10} \ge 0.001 \\
\lambda j \ge 0, \quad j = 1, 2, \ldots, 10
\end{cases} \tag{1}
$$

Through solving Equation (1), we get the efficiency value of the year 2000 is 1.18. Similar to that, we can get the efficiency values of other DMUs as shown in Table 6.

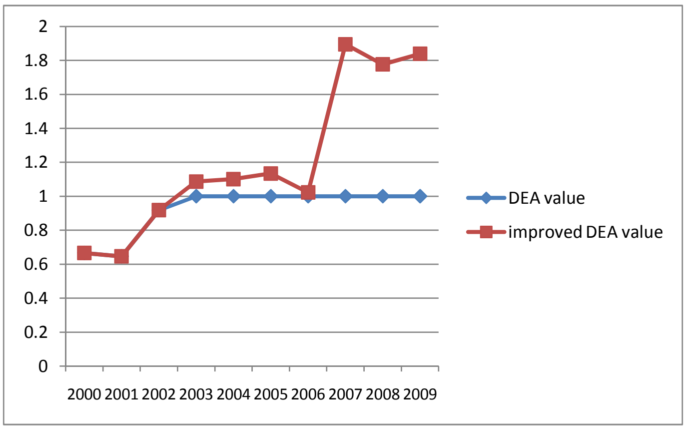
**Table 6.** The super-efficiency values of 10 DMU.

| Year | DEA value | Improved DEA value | Ranking |
|---|---|---|---|
| 2000 | 0.666342 | 0.666342 | 9 |
| 2001 | 0.646348 | 0.646348 | 10 |
| 2002 | 0.918112 | 0.918112 | 8 |
| 2003 | 1 | 1.086637 | 6 |
| 2004 | 1 | 1.101138 | 5 |
| 2005 | 1 | 1.134015 | 4 |
| 2006 | 1 | 1.022493 | 7 |
| 2007 | 1 | 1.894515 | 1 |
| 2008 | 1 | 1.776512 | 3 |
| 2009 | 1 | 1.838593 | 2 |

### *3.2. Analysis*

The trend of the efficiency of low carbon industrialization of Leshan in each year is shown in Figure 3. The efficiency of low carbon industrialization shows a trend of increasing during 2000 to 2009. Because the industrial development of the region is in the initial stage of industrialization before 2003, and lack of an effective strategy for economic guidance and relying solely on agricultural products processing, textile, machinery casting, industrial efficiency of the years before 2003 is invalid but increased rapidly.

**Figure 3.** The super-efficiency values of 10 years.




Industrial efficiency in the years after 2003 is valid, and from 2003 to 2005 it increased slowly. Through reform and opening, the region initially formed regional industrial system supported by electronic machinery, pharmaceutical, cosmetic, agricultural and sideline products processing, building materials, textile. The industry added value increased from 1.04040 billion yuan in 2000 to 2.60314 billion yuan in 2006. But in this time the region is only in the transition form the early to middle stage of industrialization; numerous conflicts still plague the region's industrial development, in which structural contradictions are the most critical factor. In the ratio of light and heavy industry, light industry weighted only 26%; Traditional heavy and high energy industry is the major participant; The contribution of key industrial enterprises is not obvious. In 2006, there were 11,000 industries in the region, and 526 above-scale enterprises but with only four businesses of above 1 billion on sales, and neither enterprises with above 1 billion on sales. After 2007, the region has fully carried out the new industrialization strategy and vigorously adjusted and optimized industrial structure, and the industrial economy has developed rapidly , and the efficiency of industrial operation has greatly improved. A stable domestic environment has provided a broad space for the region's economic development, and Chinese deepen economic reform is conducive to further liberate the productive forces in this region. Competitive industries, such as electronics and silicon materials, machinery manufacturing, pharmaceutical, cosmetic, textile has played significant supporting role in the regional industry, by 2009 the industrial added value of this region reached 4.09 billion yuan, accounted for 73.9% of the whole region's industrial added value. The key enterprises increased technological transformation, then new product output rate boosted, by 2009 output value of new products accumulated 2.78 billion yuan. However, the unreasonable current industry structure was still the biggest problem, and pharmaceutical industry has been a marked decline, subject to the requirements of environmental protection and others, the development of paper making, casting and others were restricted heavily.Besides, polysilicon, textiles and machinery manufacturing industry were still in the primary production stage, with poor profitability. Due to 2008 global financial crisis, the efficiency of industry declined.

### *3.3. Suggestions*

It is urgent to promote industrialization for the integration of resources, optimization of structure, improvement of efficiency, and enhancement of the technological content of industy. This is a long and complex process and is an important entry point to raise the level of industrial development. Focus on the following key points:

(1) Optimizing the industrial structure and constructing low-carbon industry support system. It must vigorously promote clean energy industry and develop low-carbon industry cluster. Wind and solar power will most likely become the mainstream of the energy future.

(2) Accelerating the development of carbon sink, forest and grass industry, and giving full play to the potential of carbon sinks. It should expand urban green space and enhance the protection of trees.

(3) Building eco-industrial and increasing emission reduction of pollutants; forcing the development of ecological agriculture, launching the clean ecological cultivation and agricultural circular economy, focusing on the collection, transportation and treatment of rural solid waste: Creating an ecological city.

(4) Increasing financial support for low-carbon industry. It should establish local financial environment fund, that used to support low-carbon industry projects, environmental protection projects, low-carbon technology research, development and application, and promote the development of low carbon technology market. Meanwhile, it must formulate a number of incentives to encourage businesses to find better techniques and methods of energy saving, and vigorously apply with carbon capture and sequestration technology, reduction techniques, re-use technology, green consumer technology, and ecological restoration technology, improve resource productivity and energy efficiency.

(5) Strengthening personnel training and institution-building for low-carbon industry. Development of low-carbon industry is a new concept and development model, it need to train the person and institution for low-carbon industry, especially to enhance the low-carbon consciousness of enterprise decision makers.

(6) Promoting low carbon lifestyles of public culture. It should establish a advocacy mechanisms combined government, media, business and public, and advocate the lifestyle and production of low-carbon economy.

## 4. Conclusions

In this paper, we developed a method to evaluate the efficiency of regional low-carbon industrialization, based on the rough set and super-efficiency DEA models, has analyzed the level of industrialization, quality of industrialization and degree of low-carbon industrialization from the perspective of input-output. This method was applied to Leshan from 2000 to 2009, a World Cultural and Natural Heritage area. Compared with other region's industrialization, the evaluation of double heritage area pays more attention on ecological environment maintenance and low-carbon.

The empirical analysis shows that in dealing with multi-input and multi-output problems, especially when the indicator system of input and output of a decision-making unit is complex, it's effective to apply rough set to reduce indexes and super-efficiency DEA model to evaluate the relative efficiency of multiple decision making units. The assessment result is a more satisfactory, and the evaluation result is more scientific and accurate to obtain the sort of the relative efficiency of multiple decision making units, and basically they can reflects the real efficiency of decision-making units.

We think this method is not only useful for Dual Heritage area, but also for various cities and regions in order to develop long-term low-carbon, healthy industry and society and action plans. As a contribution to policy making process, the method and tool can support the discussion among decision-maker by providing explicit understanding on the current level of industrial development, and as the basis for action plans on future development.

It is especially effective for cities in developing countries, which intend to achieve high economic growth within the next few decades, as well as improve the ecological environment.

## Acknowledgments

This research was supported by the National Natural Science Foundation of China (Grant No. 71301109), the Chinese Universities Scientific Fund (Grant No. 2010SCU22009), the Western and Frontier Region Project of Humanity and Social Sciences Research, Ministry of Education of China (Grant No. 13XJC630018), and the Initial Funding for Young Teachers of Sichuan University (Grant No. 2013SCU11014). The authors would like to thank the anonymous referees for their insightful comments and suggestions to improve this paper, as well as Uncertainty Decision-Making Laboratory and low carbon Technology and Economy Research Center of Sichuan University for helpful comments and discussion.

## Author Contributions

The individual contribution and responsibilities of the authors were as follows: Jiuping Xu: Research idea and design, grant holder of research financing, participation in related article writing. Yifan Li: Literature review, participation in related data collection, data analysis, article writing and formatting. Liming Yao: Grant holder of research financing, modelling, data collection, data analysis.

## Conflicts of Interest

The authors declare no conflict of interest.

## References

1. Peeters, P.; Dubois, G. Tourism travel under climate change mitigation constraints. *J. Transp. Geogr.* **2010**, *18*, 447–457.
2. Xu, J.; Yao, L.; Mo, L. Simulation of low-carbon tourism in world natural and cultural heritage areas: An application to Shizhong District of Leshan City in China. *Energy Policy* **2011**, *39* 4298–4307.

3. Weiss, S.; Gooding, E. Estimation of differential employment multipliers in a small regional economy. *Land Econ.* **1968**, *44*, 235–244.
4. Zhang, Z.X. China in the transition to a low-carbon economy. *Energy Policy* **2010**, *38*, 6638–6653.
5. Buyya, R.; Giddy, J. An evaluation of economy-based resource trading and scheduling on computational power grids for parameter sweep applications. In *Active Middleware Services: From the Proceedings of the 2nd Annual Workshop on Active Middleware Services*; Springer US: New York, NY, USA, 2000; Volume 221, p. 13.
6. Kazdin, A.; Bootzin, R. The token economy: An evaluative review. *J. Appl. Behav. Anal.* **1972**, *5*, 343–372.
7. Mandal, S.K. Do undesirable output and environmental regulation matter in energy efficiency analysis? Evidence from Indian Cement Industry. *Energy Policy* **2010**, *38*, C6076–C6083.
8. Mukherjee, K. Energy use efficiency in Indian manufacturing sector: An interstate analysis. *Energy Policy* **2008**, *36*, 662–672.
9. Mukherjee, K. Energy use efficiency in US manufacturing: A nonparametric analysis. *Energy Econ.* **2008**, *30*, 76–97.
10. Mukherjee, K. Measuring energy efficiency in the context of an emerging economy: The case of Indian manufacturing. *Eur. J. Oper. Res.* **2010**, *201*, 933–941.
11. Mandal, S.K.; Madheswaran, S. Environmental efficiency of the Indian cement industry: An interstate analysis. *Energy Policy* **2010**, *38*, 1108–1118.
12. Oggioni, G.; Riccardi, R.; Toninelli, R. Eco-efficiency of the world cement industry: A data envelopment analysis. *Energy Policy* **2011**, *39*, 2842–2854.
13. Riccardi, R.; Oggioni, G.; Toninelli, R. Efficiency analysis of world cement industry in presence of undesirable output: Application of data envelopment analysis and directional distance function. *Energy Policy* **2012**, *44*, 140–152.
14. Mandal, S.K.; Madheswaran, S. Causality between energy consumption and output growth in the Indian cement industry: An application of the panel vector error correction model (VECM). *Energy Policy* **2010**, *38*, 6560–6565.
15. Sen, A. Control areas and accounting prices: An approach to economic evaluation. *Econ. J.* **1972**, *82*, 486–501.
16. Svensson, C.; Barfod, A. Limits and opportunities in mass customization for build-to-order SMEs. *Comput. Ind.* **2002**, *49*, 77–89.
17. Perez-Alonso, J.; Callejkn-Ferre, J.; Carreno-Ortega, A.; Sanchez-Hermosilla, J. Approach to the evaluation of the thermal work environment in the greenhouse-construction industry of se spain. *Build. Environ.* **2011**, *46*, 1725–1734.
18. Xu. J.; Li, X. The establishment of Rough-ANN Model for pre-warning of enterpr ise financial crisis and its application. *Syst. Eng. Theory Pract.* **2004**, *24*, 8–14.
19. Bell, M.; Ross-Larson, B.; Westphal, L. Assessing the performance of infant industries. *J. Dev. Econ.* **1984**, *16*, 101–128.
20. Shimada, K.; Tanaka, Y.; Gomi, K.; Matsuoka, Y. Developing a long-term local society design methodology towards a low-carbon economy: An application to Shiga Prefecture in Japan. *Energy Policy* **2007**, *35*, 4688–4703.

21. Chow, P. Causality between export growth and industrial development: Empirial evidence from the NICs. *J. Dev. Econ.* **1987**, *26*, 55–63.
22. Demetriades, P.; Hussein, K. Does financial development cause economic growth Time-series evidence from 16 countries. *J. Dev. Econ.* **1996**, *51*, 387–411.
23. Gomi, K.; Shimada, K.; Matsuoka, Y. A low-carbon scenario creation method for a local-scale economy and its application in Kyoto city. *Energy Policy* **2010**, *38*, 4783–4796.
24. Pawlak, Z. Rough sets. *Int. J. Comput. Inf. Sci.* **1982**, *11*, 341–356.
25. Pawlak, Z. *Rough Sets: Theoretical Aspects of Reasoning About Data*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1991.
26. Pawlak, Z. Rough set approach to multi-attribute decision analysis. *Eur. J. Oper. Res.* **1994**, *72*, 443–459.
27. Pawlak, Z. *Rough Sets and Data Mining*; Kluwer Academic Publisher: Dordrecht, The Netherlands, 1997.
28. Hampton, J. Rough set theory: The basics (part 1). *J. Comput. Intell. Financ.* **1997**, *5*, 25–29.
29. Hampton, J. Rough set theory: The basics (part 2). *J. Comput. Intell. Financ.* **1998**, *6*, 40–42.
30. Hampton, J. Rough set theory: The basics (part 3). *J. Comput. Intell. Financ.* **1998**, *6*, 35–37.
31. Tay, F.; Shen, L. Economic and financial prediction using rough sets model. *Eur. J. Oper. Res.* **2002**, *141*, 641–659.
32. Charnes, A.; Cooper, W.W.; Rhodes, E. Evaluating program and managerial efficiency: An application of data envelopment analysis to program follow through. *Manag. Sci.* **1981**, *27*, 668–697.
33. Asmild, M.; Paradi, J.C.; Reese, D.N.; Tam, F. Measuring overall efficiency and effectiveness using DEA. *Eur. J. Oper. Res.* **2007**, *178*, 305–321.
34. Diaz-Balteiro, L.; Casimiro Herruzo, A.; Martinez, M.; Gonzalez-Pachon, J. An analysis of productive efficiency and innovation activity using DEA: An application to Spain's wood-based industry. *For. Policy Econ.* **2008**, *8*, 762–773.
35. Fecher, F.; Kessler, D.; Perelman, S.; Pestieau, P. Productive performance of the French insurance industry. *J. Product. Anal.* **1993**, *4*, 77–93.
36. Bowlin, W. Measuring performance: An introduction to data envelopment analysis (DEA). *J. Cost Anal.* **1998**, *3*, 3–28.
37. Thore, S.; Phillips, F.; Ruefli, T.W.; Yue, P. DEA and the management of the product cycle: The US computer industry. *Comput. Oper. Res.* **1996**, *23*, 341–356.
38. Chen, Y.; Motiwalla, L.; Khan, M.R. Using super-efficiency DEA to evaluate financial performance of e-business initiative in the retail industry. *Int. J. Inf. Technol. Decis. Mak.* **2004**, *3*, 337–351.
39. Zhu, J. Super-efficiency and DEA sensitivity analysis. *Eur. J. Oper. Res.* **2001**, *129*, 443–455.
40. Khodabakhshi, M. A super-efficiency model based on improved outputs in data envelopment analysis. *Appl. Math. Comput.* **2007**, *184*, 695–703.

41. Li, S.; Jahanshahloo, G.R.; Khodabakhshi, M. A super-efficiency model for ranking efficient units in data envelopment analysis. *Appl. Math. Comput.* **2007**, *184*, 638–648.

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