The application of DEA model in enterprise environmental performance auditing

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Abstract. As a part of society, enterprises have an inescapable responsibility for environmental protection and governance. This article discusses the feasibility and necessity of enterprises environmental performance auditing and uses DEA model calculate the environmental performance of Haier for example. The most of reference data are selected and sorted from Haier's environmental report published in 2008, 2009, 2011 and 2015, and some of the data from some published articles and fieldwork. All the calculation results are calculated by DEAP software and have a high credibility. The analysis results of this article can give corporate managements an idea about using environmental performance auditing to adjust their corporate environmental investments capital quota and change their company's environmental strategies.

1. Introduction

In recent years, China's environmental problems are increasing, especially in aspects of air pollution and water pollution[1].As a part of society, enterprises have an inescapable responsibility for environmental protection and governance [2].With the improvement of environmental management, and consumer awareness of the environment, more and more enterprises are willing to assume the responsibility of environmental protection, and realize environmental protection and management will become the important factors affecting the sustainable development of enterprises [3].

With the development of the concept of environmental tax, so many scholars begin to pay close attention to the enterprise environmental performance auditing [4]. The Data Envelopment Analysis model (DEA) is a simple and effective analysis method used to calculate Input-output efficiency and widely used in management science field.

The objectives of this study were to (1) introduce the model of DEA and adjust some parameters to suit the actual situation; (2) use this model in calculating Haier's environmental performance and analyst the calculation results; (3) judge the feasibility and necessity of enterprises environmental performance auditing through Haier's environmental performance calculation analysis results.

2. Methods and materials

2.1. Data source

Haier is the leader of China's appliance brand and focus on leading china's appliance industry becoming international and environmentally friendly. Since 2005, Haier has began to publish corporate environmental report and aimed at convert environmental management into the sustained driving force for enterprise development. Haier is the pathfinder and brave practitioner of
environmental information disclosure, and also is one of the policymakers and positive participants of "the Guidelines for the Establishment of Corporate Environmental report" (HJ617-2011) and "the Guidelines for the Establishment of Corporate Environmental report in Shandong Province" (DB37/T1086-2008).

Most of the data used in this article are selected from the corporate environmental reports published in 2008, 2009, 2011 and 2015, and some of the data from some published articles and fieldworks.

2.2. The data envelopment analysis model
The Data Envelopment Analysis model (DEA) is a simple and effective analysis method used to calculate Input-output efficiency and widely used in management science field [5]. C2R is a basic DEA model used to study on multi-inputs and multi-outputs. Through the analysis of input and output data, C2R can calculate the comprehensive efficiency indexes of each Decision Making Units (DMUs), select the effective and order them. For DMUs being evaluated as inefficient, C2R can find the ineffective reasons, and address an improvement procedure to enable them to be efficient [6].

2.3. The selection of decision making units
There are three main selection principles of DMUs selection. Firstly, each DMU needs to perform the same working task and has the same working aim. Secondly, each DMU needs to operate in the same marketing environment [7]. Thirdly, each DMU needs to select the same input-factors and output-factors, and DMUs' performance is determined by the intensity or magnitude of each factor [8].

Comparing the level of environmental information disclosure and the development of enterprise scale, Haier is the only company can be selected. This article selects Haier's environmental performances in different years as DUMs in order to compare different rates of return on investment in environment protection.

2.4. The operation of the DEA model
This article selects 2 kinds of input-output index system.

| Table 1. Annual environmental performance input-output index data in 2005-2011 |
|---------------------------------|--------|--------|--------|--------|--------|--------|--------|
| Input                          | 2005   | 2006   | 2007   | 2008   | 2009   | 2010   | 2011   |
| R M \(^a\)                     | 10\(^4\) ton | 59.0   | 49.9   | 64.2   | 60.4   | 83.3   | 113    | 125    |
| Electricity \(^a\)              | 10\(^3\) kW·h | 1.0    | 2.4    | 2.5    | 2.5    | 3.8    | 4.3    | 4.5    |
| Coal \(^a\)                    | 1\(^0\) ton              | 1.9    | 2.2    | 1.7    | 1.8    | 1.7    | 2.0    | 2.4    |
| Water                          | ton    | 104    | 224    | 221    | 214    | 188    | 240    | 249    |
| E M \(^b\) yuan                | 285    | 957    | 1746   | 368    | 1016   | 1560   | 1657   |
| CO\(_2\)                       | kg/10\(^3\) yuan       | 6.4    | 6.1    | 5.9    | 5.9    | 4.6    | 4.2    | 4.1    |
| SO\(_2\)                       | kg/10\(^3\) yuan       | 34.9   | 24.4   | 17.3   | 16.9   | 15.7   | 15.2   | 14.8   |
| Waste water \(^b\)            | m\(^3\)/10\(^4\) yuan  | 5.4    | 4.1    | 3.8    | 3.7    | 3.5    | 3.4    | 3.1    |
| COD \(^b\) g/10\(^3\) yuan    | 20.3   | 19.1   | 18.1   | 17.5   | 16.8   | 15.5   | 12.9   |
| Solid waste \(^b\)            | 10\(^4\) ton          | 1.1    | 1.0    | 0.5    | 0.5    | 0.6    | 0.7    | 0.7    |
| Energy use \(^b\)             | kg/10\(^3\) yuan      | 15.2   | 14.5   | 13.9   | 12.6   | 13.1   | 12.6   | 12.2   |
| Water use \(^b\)              | m\(^3\)/10\(^4\) yuan | 6.7    | 5.1    | 4.7    | 4.6    | 4.4    | 4.2    | 3.8    |

\(^a\)Raw materials is abbreviated as R M in this table.
\(^b\)Environmental management is abbreviated as E M in this table.

The first input-output indexes system selects the environmental achievements in 2005-2011 as DMUs. Each DMU has 5 input indexes, such as the total weight of raw materials (like copper, steel,
aluminum, plastic and zinc plated sheet), the consumption amount of electric energy consumption, the consumption amount of coal, the consumption amount of water and the investment in environmental management, abbreviated as INT1-5 respectively. Each DMU has 7 output indexes, such as the emission amount of CO2, the emission amount of SO2, the emission amount of water waste, the emission amount of COD, the emission amount of solid waste (slag, phosphate slag, waste mineral oil, oil, cotton yarn, etc.), and the usage of energy and water, abbreviated as ONT1-7 respectively. The input and output indexes data per year of this system are listed in Table 1.

The second input-output indexes system selects the environmental achievements in 2008, 2009, 2011 as DMUs. The input indexes only consider the investment in environment protection, including the cost of air pollution control, the cost of water pollution control, the cost of daily monitoring, the cost of process equipment renewal and maintenance, the cost of staff environmental awareness training and the cost of environmental protection publicity, abbreviated as NINT1-6 respectively. The output indexes only consider the emission of waste gas, the emission of wastewater, the emission of solid waste (slag, phosphate slag, waste mineral oil, oil, cotton yarn, etc.), the consumption of energy, and the consumption of water, abbreviated as NOUT1-5 respectively. The input and output indexes data per year of this system are listed in Table 2-3.

| Table 2. Annual environmental performance input index data in 2008-2015 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                  | Air             | Water           | Monitor         | Equipment       | Training        | Publicity       |
| 2008             | 45              | 90              | 5               | 202             | 10.7            | 13              |
| 2009             | 80              | 30              | 10              | 853             | 30              | 13              |
| 2011             | 120             | 850             | 20              | 510             | 22              | 135             |
| 2015             | 2000            | 500             | 25              | 2410            | 55              | 95              |

| Table 3. Annual environmental performance output index data in 2008-2015 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                  | Waste gas       | Waste water     | Solid waste     | Energy cost     | Water cost      |
|                  | (kg/104 yuan)   | (m3/104 yuan)   | (103 ton)       | (kg coal/104 yuan) | (102 m3/104 yuan) |
| 2008             | 34.7            | 0.46            | 0.5             | 13.5            | 0.46            |
| 2009             | 32.6            | 0.44            | 6.6             | 13.1            | 0.44            |
| 2011             | 28.9            | 0.42            | 16.3            | 12.1            | 0.42            |
| 2015             | 11.89           | 0.215           | 3.6             | 10.27           | 0.215           |

2.5. The construction of input-output indicators

According to the characteristics of the multi-output indexes system of Haier, this article selects the C2R model to evaluate its environmental performance.

C2R model is a simple form model, which has a long history and a perfect system in its theories [9]. The thought of model building is clear, and has a strong operability. C2R model assuming that there are n comparable DMUs, each DMU has m kinds of input indexes and s kinds of output indexes [10]. The input indexes are the smaller the better, and conversely, the output indexes are the bigger the better [11]. C2R model assuming that n has a comparable decision unit, each decision unit has a M type S type input and output, the input and output of the understanding is, the smaller the better output input, the bigger the better[12]. The general enterprise to maximize the benefit but also the pursuit of such input-output ratio, but when the evaluation object is the Haier's environmental performance, the situation is not the same, in the input stage, we still pursue the minimization of raw materials, energy, environmental management costs, but in the output stage, emissions and energy consumption of water we selected pollutants consumption as the evaluation index, so the index is as small as possible. Therefore, we need to modify the data of the environmental performance indicators, that is, to take its reciprocal, so that it is in line with the DEA performance evaluation of the output indicators, the greater the better [13]. Normally, enterprises use this principle to maximize their benefits, however, when the evaluation object comes to environmental performance of Haier, the situation is totally
different. In the input stage, the evaluation object also needs smaller indexes of raw materials costs, energy costs, and environmental management costs, but in the output stage, the output indexes of pollution emission are the smaller the better. Therefore, the output indexes of environmental performance need to be modified (take its reciprocal) to suit the real needs of calculation. The modified data are listed in Table 4-7.

The next step is to take all the input indexes and output indexes to the DEAP software and write commands to calculate the order of the years' environmental performances [14]. Then, neaten all the effective data to the form of table or graph.

| Table 4. Fixed data of annual environmental performance input index data in 2005-2011 |
|---------------------------------|---|---|---|---|---|
| INT1  | INT2  | INT3  | INT4  | INT5  |
| 2005  | 59.0  | 1.0   | 1.9   | 104.0 | 285.0 |
| 2006  | 49.9  | 2.4   | 2.2   | 224.0 | 957.0 |
| 2007  | 64.2  | 2.5   | 1.7   | 221.0 | 1746.0|
| 2008  | 60.4  | 2.5   | 1.8   | 214.0 | 368.0 |
| 2009  | 83.3  | 3.8   | 1.7   | 188.0 | 1016.0|
| 2010  | 113.0 | 4.3   | 2.0   | 240.0 | 1560.0|
| 2011  | 125.0 | 4.5   | 2.4   | 249.0 | 1657.0|

| Table 5. Fixed data of annual environmental performance output index data in 2005-2011 |
|---------------------------------|---|---|---|---|---|---|---|
| OUT1  | OUT2  | OUT3  | OUT4  | OUT5  | OUT6  | OUT7  |
| 2005  | 0.156 | 0.029 | 0.185 | 0.049 | 0.909 | 0.066 | 0.149 |
| 2006  | 0.164 | 0.041 | 0.244 | 0.052 | 1.000 | 0.069 | 0.196 |
| 2007  | 0.169 | 0.058 | 0.263 | 0.055 | 2.000 | 0.072 | 0.213 |
| 2008  | 0.169 | 0.059 | 0.270 | 0.057 | 2.000 | 0.079 | 0.217 |
| 2009  | 0.217 | 0.064 | 0.286 | 0.060 | 1.667 | 0.076 | 0.227 |
| 2010  | 0.238 | 0.066 | 0.294 | 0.065 | 1.429 | 0.079 | 0.238 |
| 2011  | 0.244 | 0.068 | 0.323 | 0.078 | 1.429 | 0.082 | 0.263 |

| Table 6. Fixed data of annual environmental performance input index data in 2005-2011 |
|---------------------------------|---|---|---|---|---|---|---|
| NINT1  | NINT2 | NINT3 | NINT4 | NINT5 | NINT6 |
| 2008  | 45   | 90   | 5     | 202   | 10.7  | 13   |
| 2009  | 80   | 30   | 10    | 853   | 30    | 13   |
| 2011  | 120  | 850  | 20    | 510   | 22    | 135  |
| 2015  | 2000 | 500  | 25    | 2410  | 55    | 95   |

| Table 7. Fixed data of annual environmental performance output index data in 2005-2011 |
|---------------------------------|---|---|---|---|---|
| NOUT1  | NOUT2 | NOUT3 | NOUT4 | NOUT5 |
| 2008  | 0.029 | 2.174 | 2.000 | 0.074 | 2.174 |
| 2009  | 0.031 | 2.273 | 0.152 | 0.076 | 2.273 |
| 2011  | 0.034 | 2.381 | 0.061 | 0.083 | 2.381 |
| 2015  | 0.084 | 4.651 | 0.278 | 0.097 | 4.651 |

3. Results and discussion
The Table 8 shows that the scores of 2005, 2006, 2007, 2008 and 2009 are all equal to 1, and all of their slacks of input and output are equal to 0. That means the environmental performance in 2005-2009 of Haier all efficient on DEA efficiency and their input/output ratios are optimal.

The scores of 2010 and 2011 are less than 1 that means the environmental performance of these two years are DEA inefficient. In the aspect of the factor inputs, there are 159.38 thousand tons of raw materials, 23.158 tons of water, and 3885.76 thousand yuan of environmental management costs have not been fully utilized in 2010. In 2011, there are 181.18 thousand tons of raw materials, 4910 thousand yuan of environmental management costs have not been fully utilized. In the aspect of output
factors, all of the indexes have exceeded the aim values except the emission of CO$_2$ in unit output value in 2010. In 2011, all of the indexes have exceeded the aim values except the emission of COD in unit output value.

The Table 9 shows that the scores of 2008 and 2009 are equal to 1, and their slacks of input and output are equal to 0. That means the environmental performance in 2008 and 2009 of Haier all efficient on DEA efficiency and their input/output ratios are optimal.

The scores of 2011 and 2015 are less than 1 that means the environmental performance of these two years are DEA inefficient. In the aspect of the factor inputs, there are 156.68 thousand yuan of air pollution control costs, 3791.69 thousand yuan of water pollution control costs, 55.42 thousand of daily detective costs, and 539.84 thousand of staff to participate in environmental protection technology and management training costs have not been fully utilized in 2011. In 2015, there are 10282.76 thousand yuan of air pollution control costs, 289.96 thousand yuan of water pollution control costs, 8110.34 thousand yuan of staff to participate in environmental protection technology and management training costs and 8.69 thousand yuan of environmental protection related publicity costs have not been fully utilized. In the aspect of output factors, only the emission of waste gas hasn’t exceeded the aim values both in 2011 and in 2015.

| Year | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|------|------|------|------|------|------|------|------|
| $\theta$ | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.949 | 0.972 |
| S1- | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 15.938 | 18.118 |
| S2- | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| S3- | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| S4- | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 23.158 | 0.000 |
| S5- | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 388.576 | 491.454 |
| S1+ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.028 | 0.000 |
| S2+ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.011 |
| S3+ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.019 | 0.040 |
| S4+ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 |
| S5+ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.385 | 0.733 |
| S6+ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.019 |
| S7+ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.010 | 0.026 |

Table 8. Calculation results of environmental performance in 2005-2011

| Year | 2008 | 2009 | 2011 | 2015 |
|------|------|------|------|------|
| $\theta$ | 1.000 | 1.000 | 0.570 | 0.579 |
| S1- | 0.000 | 0.000 | 15.668 | 1028.276 |
| S2- | 0.000 | 0.000 | 379.169 | 28.966 |
| S3- | 0.000 | 0.000 | 5.542 | 0.000 |
| S4- | 0.000 | 0.000 | 53.984 | 811.034 |
| S5- | 0.000 | 0.000 | 61.738 | 17.379 |
| S6- | 0.000 | 0.000 | 0.000 | 0.869 |
| S1+ | 0.000 | 0.000 | 0.000 | 0.000 |
| S2+ | 0.000 | 0.000 | 0.168 | 1.646 |
| S3+ | 0.000 | 0.000 | 2.284 | 5.515 |
| S4+ | 0.000 | 0.000 | 0.004 | 0.117 |
| S5+ | 0.000 | 0.000 | 0.168 | 1.646 |

Table 9. Calculation results of environmental performance in 2008-2015

4. Conclusion
The above calculation results illustrate that Haier have a effective performance in 2005-2011 when the input indexes select the cost of raw materials, electric energy, coal, water and environmental management, and the output indexes select the mission of CO$_2$, SO$_2$, waste water, COD, solid waste...
and the cost of energy and water. The wastes only exist in the use of raw materials and the cost of environmental management. The possible reason is with the development of economy, the problem of resource shortage and environmental pollution gets worse, the costs of raw materials and environmental management dramatically increased which cannot have longitudinal comparison with the past years' data. Another input-output indexes system only have a effective performance in 2008 and 2009 when the input indexes select the cost of waste gas control, waste water control, daily monitor, process equipment renew and maintain, employee environmental knowledge training and environmental protection campaign, and the output indexes select the emission of waste gas, waste water, solid waste, and the cost of energy and water. The waste gas control costs include waste gas pollution discharge fee. The process renew costs include the costs of ensuring the sewage treatment facilities operating well, the costs of ensuring the reclaimed water reuse operating well and the costs of improving industrial equipment and production efficiency. The costs of training consist of the costs of environmental management, inspection technology, and other organizations' environmental protection training participation. The costs of propaganda consist of the costs of environmental protection campaign and energy saving campaign.

Half of the DMUs are DEA ineffective and have a large amount of waste in investment capital. Most of the capital wastes exist in air pollution control, water pollution control, equipment renew and maintain, and environmental protection propaganda. Only in 2015, there are 10282.76 thousand yuan have not been fully utilized. However, consult the environmental report in 2015 found that air pollution control costs in 2015 is mainly used for improved SO₂ removal equipment, so SO₂ emissions for this year equal to 0. Due to the large emissions of CO₂ emissions, the total waste gas emissions decrease is not significant. Similarly, the benefits of environmental protection propaganda and process renew and maintain are long-term and sustainable, which cannot see the effect immediately. However, the emission of wastewater has already arrived optimal, the over costs of water pollution control are useless. Therefore, Haier is suggested to reduce the cost of the related items in the next year.

To summarize, through the calculation and analysis of Haier's environmental performance in 2005-2015, corporate internal environmental performance auditing is considered to be necessary and feasible, and DEA model is considered to be a effective metering method which has a high reliability [15]. The evaluation results of input and output efficiency can helps corporate' policymakers to analyst weather their investments in each aspect are effective, and adjust their corporate' capital quota in time.

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