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MALAYSIAN WATER UTILITIES PERFORMANCE WITH THE PRESENCE OF UNDESIRABLE OUTPUT: A DIRECTIONAL DISTANCE FUNCTION APPROACH

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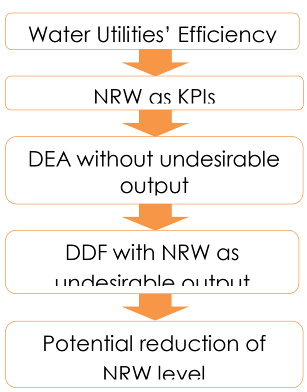
Graphical abstract



Abstract

Non-Revenue Water (NRW) is water losses in the distribution process and it affects water supply management worldwide. Malaysia is not excluded and the authority has put a high priority on NRW as it affects the revenue collection. Consequently, NRW is established as one of the Key Performance Indicators (KPIs) to assess the efficiency of Malaysia water supply industry. However, the current policy is impractical; the assessment of all the water utilities is against a single NRW target. Moreover, NRW should be considered as an undesirable product in the water supply system. Therefore, an alternative to Data Envelopment Analysis (DEA)-based approach called Directional Distance Function (DDF) is applied to measure the performance of the integrated production of desirable and undesirable outputs. The result shows that the measurement of water technical efficiency is more explicit using DDF model, where the potential reduced level of NRW for each inefficient water utility can be determined in order to improve their performance. This is in line with the government's aim to reduce the NRW level countrywide.

Keywords: DEA model, DDF model, NRW, undesirable outputs

1.0 INTRODUCTION

No doubt, water is the most crucial natural resources as the fate of many societies and communities are really affected by water and it will become more critically important in the future. Worryingly, water distribution systems around the world are faced with water losses, particularly in the developing countries. In consequence, the level of water losses has become one of the most vital issues in water supply management, globally. This issue gives rise to an intense debate over water industry to look for the most efficient management of water resources.

Malaysia as well as many other countries commonly used percentage of Non-Revenue Water (NRW) as a terminology to measure the water losses. NRW can be defined as the difference between the amount of supply treated water from water treatment plant and the amount of water billed to customers. NRW is the volume of water supplied into the water distribution system that does not bring income or revenue to the water supply authorities concerned. Since 1986, NRW has been a high profile issue in Malaysia because it gives a major impact on revenue collection to the country. Various actions have been taken to reduce NRW targeting less than 25% towards the year 2020 [1].

In addition, the concept of Performance Indicators (PIs) was initiated in 1994 by Malaysian Water Association (MWA) to assess and monitor the performance of the water supply industry and NRW was selected as one of the key performance indicators (KPIs) to measure efficiency of water entities. For NRW indicator, a national average of percentage of NRW has been used to surmise a reflection of the countrywide status. But in some cases, the performance indicators derived from national averages may not reflect actual performance of a country [1].

Liemberger [2] emphasized that the UK National Water Council has warned the use of percentages is inaccurate and deceptive. Liemberger [2] also cited that International Water Association (IWA) as well as other national water organizations are also warned that the percentage of NRW is not relevant for many reasons, particularly because of the sometimes high level of unauthorized consumption. The IWA best practice manual recommends NRW itself can only be used as a financial performance indicator, but strictly insists that it is inapt for evaluating the efficiency of management for distribution systems.

Furthermore, Mohammad Salleh [1] questioned the propriety of the usage of PIs developed for Malaysia water industry. The PIs are classified under three generic factors which are physical, services, and financial. Those KPIs, including the percentage of NRW, do not really show the relation to the concept of efficiency. The measure of performance should include those related factors (such as financial and physical factors) as inputs and or outputs in one single measurement for assessing the efficiency of water supply systems. For that reason, he [1] has applied Data Envelopment Analysis (DEA) to measure performance of NRW and leakage control actions for Malaysia water industry by joining inputs and outputs into a single efficiency score rather than depending solely to the percentage of NRW.

Moreover, as stated in [1], Malaysian current policy sets a single NRW target as KPIs and the performance of each water utility is assessed against the target. Since a uniform NRW target for all the water utilities is not practical, it is recommended for each utility to determine their own economic level of NRW. Besides evaluating the performance, Data Envelopment Analysis (DEA) technique, can also be employed to determine the potential improvement level of NRW for each water utility. This information can assist NRW targets to be regulated in order to direct the inefficient utilities to improve their performance.

Nevertheless, most of the existing DEA-based water utility efficiency studies specifically in Malaysia, either excluded the NRW factor [3], or treated inappropriately as a classical input factor [1, 4] in their performance evaluation. This might offer unfairly evaluation of performance as this might lead to conceptual confusion because the conventional DEA model only consider two groups of variable namely input and the desirable output. However, if the undesirable output is present, the validity of standard DEA is disrupted.

Generally, treated water that has been distributed in the water supply system can be divided into two components, namely authorized consumption and water losses. Authorized consumption, which is billed from customers and generate revenue could be considered as desirable output. While water losses in the water system are classified as NRW and could be considered as an undesirable output since the aims is to reduce the NRW. Hence, outputs from water supply system can be separated into desirable and undesirable outputs.

Therefore, to resolve this separation of undesirable output in the model, the Directional Distance Function (DDF) established by Chung et al. [5] can be employed, since this model includes undesirable output in the analysis of measuring efficiency.

In this study, the authors employed DDF method proposed by [5] to analyze the water service sector efficiency. This study evaluates the performance of Malaysian water supply services at a state level over the period of 2008 until 2012 by using a joint production framework consist of desirable (revenue) and undesirable outputs (NRW) concurrently. In addition, this study also compares the results with and without the incorporation of NRW to look into the impact of negligence of the undesirable output in the performance analysis.

Sidelong, the potential reduced level of NRW for each inefficient water utility can be determined in order to improve their performance. Our main concern is to propose the optimal potential reduced level of NRW since it is impossible to reduce the NRW levels to zero and some level of NRW is unavoidable.

2.0 A REVIEW OF RELATED RESEARCH WORKS

Data Envelopment Analysis (DEA) was initially established by Charnes et al. [6]. The model seeks to measure a set of decision making units (DMUs) in term of their relative efficiency, which used similar inputs to produce the similar outputs. The outcomes indicate how efficient each DMU has performed as compared to other DMUs in converting inputs to outputs. DEA follows Farrell [7], measured of productive efficiency, which extends the approach to the technical efficiency measurement involving multiple input and multiple output. DEA evaluates the comparative performance of peer units that allows the combinations of efficient units of a set to generate an efficient frontier to be used as a benchmark to measure the relative efficiency of inefficient peer units.

As a non-parametric technique, DEA has been successfully used by scholars to measure the efficiencies of water utilities. Hundreds of studies about performance of water industry using a DEA approach have been done worldwide since the work of Byrnes et al. [8]. Some of the papers are Lambert et al. [9], Thanassoulis [10], Anwandter and Ozuna [11], Cubbin [12], Garcia-Sanchez [13], Storto [14], and many more. According to Romano and Guerrini [15], most of the studies have multi-output and have used input-oriented DEA technique and using CRS and VRS models and majority of researchers used similar input and output factors.

In some conventional DEA studies regarding water service performance, the presence of undesirable output as joint production variables has always been ignored. To name a few, undesirable outputs in water services could be bad water quality, water services complaints, water service interruptions, non-revenue water and other qualitative outputs that can lead to customer dissatisfaction. Only in a few studies[1, 4], water losses is used as indicator for the technical quality of water services, but it was treated as an input factor in the performance evaluation.

Contrarily, Picazo-Tadeo [16] has considered water losses as an undesirable output and employed another approach under the DEA framework, called directional distance function (DDF) proposed by [5]. DDF is a notably approach for measuring efficiency while incorporating undesirable output. This approach allows desirable outputs to be increased while undesirable outputs are decreased simultaneously. DDF is most frequently discussed in the area of assessing environmental performance. Some of the studies that applied DDF are Mandal and Madheswaran [17] which studied the environmental efficiency of the Indian cement industry and also Riccardi et al. [18] that evaluated the impact of CO2 emissions on the efficiency score of the world cement industry. As another sample, Ramli and Munisamy [19] studied the environmental efficiency of the manufacturing sector in Malaysia.

In Malaysia, several DEA-based papers on the efficiency of water utilities [1, 4] have used NRW as a proxy for the technical quality of water services and treated NRW as input factor. This concept will lead to the improper DEA result since it will not describe the real production process as stated by [20]. In contrast to the above Malaysian studies, this paper intends to evaluate the efficiency of the Malaysian water service sector with the presence of NRW as undesirable output by applying DDF approach.

3.0 METHODOLOGY

DEA measurement uses multiple inputs to produce a multiple outputs whereby it includes a set of decision making units (DMUs) or units of assessment. The efficient DMUs with 100% scores are referred as "best practice" will be identified and DMUs with less than 100% scores are referred as inefficient DMUs. Their efficiency level is derived by matching them to a boundary created from the "best practice" DMUs. For this analysis, $x \in R_+^I$ is set to be the input vector and $y \in R_+^J$ to be the output vector. Then, x_i is the i^{th} input, and y_j is the j^{th} output for a DMU.

$$S = \{(x, y): x\ can\ produce\ y\} \quad (1)$$

Equation (1) represents the production technology that describe the possibilities of the production as the set of both input-output vectors are obtainable. Thus, the formula for output oriented DEA-CRS model for DMU *m* based on the above mention production technology is set as follows:

$$\begin{aligned} & Max\ \theta_m \\ & Subject\ to \\ & \textstyle\sum_{n=1}^{N} z_n x_{in} \le x_{im}\,;\, i = 1, 2, \ldots, I \\ & \textstyle\sum_{n=1}^{N} z_n y_{jn} \le \theta_m y_{jm}\,;\, j = 1, 2, \ldots, J \\ & z_n \ge 0; n = 1, 2, \ldots, \mathrm{N} \end{aligned} \quad (2)$$

Where z_n as the intensity variables, x_{in} as the i^{th} input of the n^{th} DMU, y_{jn} as the j^{th} desirable output of the n^{th} DMU, x_{im} is set as the i^{th} input of the m^{th} DMU, y_{jm} as the j^{th} desirable output of the m^{th} DMU and lastly n represent the number of DMUs with value of $1, 2, \ldots, \mathrm{N}$.

The DEA approach usually focuses on a set of z values. It seeks to maximize the θ_m as well as finding out a point in the production possibilities set. This means that the output levels of DMU *m* can be increased as high as possible proportion, whereas the input will maintain at its current level. The DMU's efficiency scores in this model are between zero and one. DMUs with an efficiency score of one are considered as a best performing DMU while DMUs with an efficiency score of less than one are considered as inefficient.

Conventional DEA model engaged only two categories of variable, namely the input and the desirable output and it is no longer valid with the presence of undesirable outputs. Therefore, to consider these undesirable outputs, Directional Distance Function (DDF) approach is employed. DDF model measures the efficiency score by considering the production of desirable and undesirable outputs. The aim of DDF is to expand desirable outputs and reduce the inputs. The model also cater the undesirable outputs simultaneously. With a given direction vector, DDF approach is more precise compared to the DEA approach when desirable and undesirable outputs are jointly produced [5].

For DDF model, Equation (1) is expanded by adding some notations to the formula. The additional notations used for DDF are quite similar to the previous DEA models. The model set $x \in R_+^I$ to be an input vector and $y \in R_+^J$ to be a desirable output vector while $u \in R_+^K$ will be considered as an undesirable output vector. The above mention description of the model also describes the "environmental output set" for production technology T.

$$T = \{(x, y, u): x\ can\ produce\ (y, u)\} \quad (3)$$

The DDF model of the technology T is as follows:

$$\vec{D}_T\left(x, y, u;\ g_y, g_u\right) = Max\{\beta: (y + \beta g_y, u - \beta g_u \in T\} \quad (4)$$

The distance function seeks to find the appropriate extension of desirable outputs in the g_y direction and reduction of undesirable outputs in the g_u direction. Simultaneously, proportion β can increase the desirable outputs and reduce the undesirable outputs. This study applied the DDF model by [7] where it is formulated as follows:

$$\begin{aligned} & Max\ \beta_m \\ & \quad Subject\ to \\ & \quad \textstyle\sum_{n=1}^{N} z_n x_{ni} \leq x_{mi}\ ; i = 1, 2, \dots, I \\ & \quad \textstyle\sum_{n=1}^{N} z_n y_{nj} \geq y_{mj} + \beta_m g_{yj}\ ; j = 1, 2, \dots, J \\ & \quad \textstyle\sum_{n=1}^{N} z_n u_{nk} = u_{mk} - \beta_m g_{uk}\ ; k = 1, 2, \dots, K \\ & \qquad\qquad z_n \geq 0; n = 1, 2, \dots, \mathrm{N} \end{aligned} \tag{5}$$

where z_n is the intensity variables, x_{in} is the i^{th} input of the n^{th} DMU, x_{im} is the i^{th} input of the m^{th} DMU, y_{jn} is the j^{th} desirable output of the n^{th} DMU, y_{jm} is the j^{th} desirable output of the m^{th} DMU, u_{kn} is the k^{th} undesirable output of the n^{th} DMU, u_{km} is the k^{th} undesirable output of the m^{th} DMU, g_y represent the direction vector of desirable output and g_u represent the direction vector of undesirable output.

For this analysis, 14 states as the entities in Malaysian water services are observed between 2008 and 2012. The data were obtained from the Malaysian Water Industry Guide 2010-2013, [21-24] issued by the Malaysian Water Association (MWA). The input used for this study is the operating expenditure (OPEX) which includes all variable resources expended to distribute treated water to customers. The desirable output of this study is revenue generated from authorized consumption while NRW has been included as an undesirable output in this analysis.

4.0 DATA ANALYSIS

In this study, the authors attempt to measure efficiency of Malaysian water utilities with and without NRW as undesirable output by using the DEA-CCR model in equation (2) and DDF model in equation (5). Firstly, the technical efficiency is assessed using the DEA model subject to desirable output only. Table 1 reveals the results of technical efficiency by applying the conventional DEA approach in the equation (2). Efficiency scores for each state together with their ranking were computed for five years. States with a 100 % efficiency score is defined as efficient while any inefficient state will have an efficiency score less than 100%. This shows that while maintaining the existing inputs, the degree of unproductive use of outputs for each state to increase their output is possible. For example, in 2008, Negeri Sembilan was 49.0% efficient. This score indicates that Negeri Sembilan could increase their revenue roughly by 51%, while maintaining the current input level.

The results exhibited in Table 1 show that Perak ranked first as the state achieves nearly 100% technically efficient over the five years, except for 2008 in which the efficient score is 77.5%. With an average efficiency score of 95.5%, Perak water utility is nearly on the production frontier line and it is efficient in principle. On the second ranked, Selangor consistently has high efficiency scores (above 90%) for four consecutive years but drop to 65.6% in 2012. Johor, Melaka, and Perlis over the study period showed a decline in their efficiency scores. Johor ranked first in 2008 but showed a declining trend over the following years. Melaka has the same trend with Johor. While Perlis has good technical efficiency scores in 2008 and 2009, but from 2010 towards 2012, the efficiency scores decreased. Kedah and Kelantan maintained in ascending trend throughout the five years. Similarly for Sarawak and Pulau Pinang, but, their technical efficiency scores are slightly drop in 2009 and 2012 respectively.

Terengganu, Negeri Sembilan, Pahang, Sabah and Labuan constantly have technical efficiency scores less than 50% over the five years. Meanwhile, Labuan consistently ranked last throughout the study period with an average technical efficiency score of 33.8%. Labuan has the biggest potential to increase revenue up to 66.2%, while maintaining the level of operating cost. These five states should imitate Perak as a benchmark in order to improve their technical efficiency.

The technical efficiency of states across 2008-2012 ranges from low as 24.3% to up 100%. Looking at the second last column in Table 1, the results also indicate that eight out of fourteen Malaysian states in water supply services experience high technical efficiency with score more than 60% during this five years' time. As mention earlier, the model with the absence of undesirable outputs will have an unfair and unreliable results. Therefore, efficiency test which mutually counts in the desirable and undesirable outputs will be calculated by applying the DDF model as in Equation (5), and the results are presented in Table 2.

The DDF efficiency model employed the same input and output variables and at the same time count in the NRW as undesirable output. From the scores, it indicates how far the desirable output will expand and how far the undesirable output will reduce. For example, in 2008, Perak was 71.2% efficient. The result suggests that Perak could increase its desirable output by as much as 28.8%, while diminishing its undesirable outputs by 28.8% simultaneously to attain full efficiency.

The results exhibited in Table 2 show that Johor ranked first as the state performs 100% efficient over the five years. The high level of NRW is concurrent with a high level of operating cost and revenue. On the second ranked, Selangor exhibited good efficiency scores, 97.1% in 2008, 99% in 2009, fully efficient in 2010 and 2011 but a slight drop to 87.7% in 2012. Pulau Pinang also can be considered as one of the most efficient because had scores ranges from above 85% up to 99.6%. Whilst, Labuan and Melaka were in ascending trend throughout the five years and the scores were quite encouraging with average scores were more than 80%. Sarawak also exhibited an ascending trend, from 63.9% up to 75.6%.

On the other hand, Kedah and Negeri Sembilan seemed to be on an upward trend, while Kelantan and Terengganu were fluctuated throughout the study period, but their efficiency scores were less than 50%. This result indicates that, these states have a potential to expand its revenue by up to 50%, while at the same time contracting their NRW level by about 50%, since these states was significantly below the efficient frontier. Perlis, which was fully efficient in 2008 and 2009, performed worse for the subsequent years. Meanwhile, the result disclosed Pahang consistently was the least efficient states for five years. The poor performance could be due to Pahang's high level of NRW in five studied years as shown in the original data.

Comparing the DEA technical and DDF efficiency scores, Table 1 and Table 2 show some disruptions on both the efficiency models. Obviously, when NRW is disregarded in the technical efficiency analysis using DEA, we can see that on a year by year basis, there are not more than one state is efficient. But, if the NRW is included into the efficiency evaluation, there are 2 to 3 states are having the perfect efficiency (100%) in a yearly basis. On average, as for the DDF efficiency evaluation, it can be seen that one state which is Johor was fully efficient. Whereas, none of the states gained fully efficiency in the DEA technical efficiency average scores. It also infers that when the variables used is increasing, it also increases the efficiency score of the states as well as the increasing number of fully efficient states. For example, the outcome revealed that Labuan had the least DEA technical efficiency scores, but obviously gained quite encouraging in DDF efficiency scores. Besides it, mostly exhibit lower technical efficiency scores (on total averages) compared to DDF efficiency scores. This point out that in the absence of undesirable output, misleading results are produced.

5.0 CONCLUSION

Based from the analysis findings, it can be concluded that the DDF model is a relevant efficiency measurement approach for the water services sector as water supply activities suffer water losses. Neglecting the effect of water losses (NRW) in the efficiency measurement, can affect the results of performance. It can be observed from the analysis, inefficient water utilities on basic DEA technical efficiency measurement, might as well be efficient under DDF efficiency assessment. This is also revealed by the results that showed the overall average scores exhibit lower DEA technical efficiency scores than DDF efficiency scores. Apart from that, the ranking order is different for both performance evaluations. As for the conclusion, the presence of NRW as undesirable output, has an impact on the technical efficiency measurement of water utilities. Undoubtedly, this model can be employed as performance benchmarks for the water utilities, instead of the usual key performance indicators (percentage of NRW) that has been used in Malaysian water industry.

This empirical study suggests way to improve the level of efficiency and also the potential reduction level of NRW simultaneously, in line with the government's intention to address the issue of NRW in Malaysia. The findings can be used as direction for improvements in management practice and amendments in the design of public procedures. Furthermore, this approach is relatively simple and easy to implement.

Table 1 Result of DEA technical efficiency score and rank between 2008 and 2012

	2008		2009		2010		2011		2012		Average	
	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank
Johor	100	1	98	2	62.2	6	59.1	7	69.8	2	77.82	3
Kedah	46.7	9	51.6	9	54.4	8	50.8	11	61.1	8	52.92	9
Kelantan	56.4	8	63.9	6	63	4	63.6	4	64.2	7	62.22	6
Labuan	31.1	14	41	11	31	14	30.5	14	35.2	13	33.76	14
Melaka	73.9	5	55.5	7	55	7	58.6	8	65.9	4	61.78	7
N.Sembilan	49	11	35.1	13	41.8	11	52	10	57.6	9	47.1	11
Pulau Pinang	67.7	6	68.9	5	71	3	71.8	3	68.6	3	69.6	4
Pahang	38.1	13	36.9	12	40.8	12	42.2	12	46	12	40.8	12
Perak	77.5	3	100	1	100	1	100	1	100	1	95.5	1
Perlis	75.5	4	73	4	53.3	9	60.5	6	56.4	10	63.74	5
Sabah	49.9	10	24.3	14	38.1	13	39.4	13	35	14	37.34	13
Sarawak	63.3	7	51.7	8	62.4	5	61.3	5	65.5	6	60.84	8
Selangor	93.2	2	97.7	3	92.1	2	94.8	2	65.6	5	88.68	2
Terengganu	46.4	12	48.1	10	47.4	10	53.2	9	53.1	11	49.64	10
Average	62.05		60.41		58.04		59.84		60.29		60.12	

Table 2 Result of DDF efficiency score and rank between 2008 and 2012

	2008		2009		2010		2011		2012		Average	
	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank
Johor	100	1	100	1	100	1	100	1	100	1	100	1
Kedah	34.1	13	37.7	13	48.5	11	46.8	11	52.9	11	44	12
Kelantan	37.5	11	46.4	11	50.7	8	47.4	10	53.2	10	47.04	11
Labuan	66.1	7	89.7	5	87.7	6	84.4	6	84.4	6	82.46	6
Melaka	75.1	5	82.1	7	88.4	5	92.8	5	91.8	4	86.04	5
N.Sembilan	36.8	12	44	12	50.7	9	53.1	9	60.9	8	49.1	10
Pulau Pinang	89.5	4	86.2	6	96.4	4	99.6	4	93.2	3	92.98	4
Pahang	28.4	14	26.7	14	31.5	13	29.3	14	27.6	14	28.7	14
Perak	71.2	6	100	1	100	1	100	1	100	1	94.24	3
Perlis	100	1	100	1	38.8	12	35.2	12	27.6	13	60.32	8
Sabah	50.9	9	56.2	9	29.8	14	31.1	13	42.4	12	42.08	13
Sarawak	63.9	8	66.9	8	73.5	7	70.3	7	75.6	7	70.04	7
Selangor	97.1	3	99	4	100	1	100	1	87.7	5	96.76	2
Terengganu	44.5	10	47.8	10	50	10	54.6	8	53.5	9	50.08	9
Average	63.94		70.19		67.57		67.47		67.91		67.42	

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References

[1] Mohammad Salleh, H. 2000. Evaluation of Non-Revenue Water and Leakage in Public and Private Water Supply Systems. PhD thesis, Heriot-Watt University, Edinburgh.

[2] Liemberger, R. 2002. Do You Know How Misleading the Use of Wrong Performance Indicators Can Be. *IWA Specialised Conference, Leakage Management- A Practical Approach*. Cyprus, November 2002.

[3] Lee, Y.H., and C., Lee. 2009. Efficiency in the Malaysian Water Industry: A DEA and Regression Analysis. *17th Annual Conference of the European Association of Environmental and Resource Economists*, Amsterdam, The Netherlands, 24-27 June 2009.

[4] Munisamy, S. 2009. Efficiency and Ownership in Water Supply: Evidence from Malaysia. *International Review of Business Research Papers.* 5(6): 148-260.

[5] Chung, Y. H., R., Färe, and S., Grosskopf. 1997. Productivity and Undesirable Outputs: A Directional Distance Function Approach. *Journal of Environmental Management*. 51(3): 229-240.

[6] Charnes, A., W. W., Cooper, and E., Rhodes. 1978. Measuring the Efficiency of Decision Making Units. *European Journal of Operational Research.* 2(6): 429-444.

[7] Farrell, M. J. 1957. The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society. Series A (General).* 120(3): 253-290.

[8] Byrnes, P., S., Grosskopf, and K., Hayes. 1986. Efficiency and Ownership: Further Evidence. *Review of Economics and Statistics.* 68(2): 337-341.

[9] Lambert, D. K., D., Dichev, and K., Raffiee. 1993. Ownership and Sources of Inefficiency in the Provision of Water Services. *Water Resources Research*. 29(6): 1573-1578.

[10] Thanassoulis, E. 2000. The Use of Data Envelopment Analysis in the Regulation of UK Water Utilities: Water Distribution. *European Journal of Operational Research.* 126(2): 436-453.

[11] Anwandter, L., and Jr, T., Ozuna. 2002. Can Public Sector Reforms Improve the Efficiency of Public Water Utilities?. *Environment and Development Economics*. 7(4): 687-700.

[12] Cubbin, J. 2005. Efficiency in the Water Industry. *Utilities Policy*. 13(4): 289-293.

[13] Garcia-Sanchez, I. 2006. Efficiency Measurement in Spanish Local Government: The Case of Municipal Water Services. *Review of Policy Research.* 23(2): 355-371.

[14] lo Storto, C. 2013. Evaluating Technical Efficiency of Italian Major Municipalities: A Data Envelopment Analysis Model. *Procedia-Social and Behavioral Sciences*. 81(2013): 346-350.

[15] Romano, G., and A., Guerrini. 2011. Measuring and Comparing the Efficiency of Water Utility Companies: A Data Envelopment Analysis Approach. *Utilities Policy*. 19(3): 202-209.

[16] Picazo-Tadeo, A. J., F. J., Sáez-Fernández, and F., González-Gómez. 2008. Does Service Quality Matter in Measuring the Performance of Water Utilities?. *Utilities Policy*. 16(1): 30-38.

[17] Mandal, S. K., and S., Madheswaran. 2010. Environmental Efficiency of the Indian Cement Industry: An Interstate Analysis. *Energy Policy*. 38(2): 1108-1118.

[18] Riccardi, R., G., Oggioni, and R., Toninelli. 2012. Efficiency Analysis of World Cement Industry in Presence of Undesirable Output: Application of Data Envelopment Analysis and Directional Distance Function. *Energy Policy*. 44(2012): 140-152.

[19] Ramli, N. A., and Munisamy, S. 2013. A Study on Eco-Efficiency of the Manufacturing Sector in Malaysia. *Actual Problems of Economics.* 12(2013): 480-491.

[20] Seiford, L. M., and J., Zhu. 2002. Modeling Undesirable Factors in Efficiency Evaluation. *European Journal of Operational Research.* 142(1): 16-20.

[21] Malaysian Water Association. 2010. *Malaysia Water Industry Guide 2010.* Kuala Lumpur: Malaysian Water Association.

[22] Malaysian Water Association. 2011. *Malaysia Water Industry Guide 2011.* Kuala Lumpur: Malaysian Water Association.

[23] Malaysian Water Association. 2012. *Malaysia Water Industry Guide 2012.* Kuala Lumpur: Malaysian Water Association.

[24] Malaysian Water Association. 2013. *Malaysia Water Industry Guide 2013.* Kuala Lumpur: Malaysian Water Association.