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Article

"Bridging Knowledge to Policy"

Measuring the Efficiency and Productivity of Regional Water Utility Company (PDAM) in Indonesia from 2012 to 2016

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Abstract

Sufficiently clean water is accessible in Indonesia, where municipally-owned cooperation (BUMD) handles the management of the PDAM. It allows local governments authority over water management in their administrative districts. This organization is responsible for maintaining the region's water supply while earning income from water business operations. However, this effort is not deemed effective since having many PDAMs results in inadequate water quality, low water distribution, and even financial losses. However, the assumption lacks factual evidence as they are not assessed alongside the government audit. To analyze the inefficiencies of water supply services and the productivity growth of PDAMs from 2012 to 2016, this research proposes to use a non-parametric technique, namely data envelopment analysis (DEA) and Malmquist Index Calculation, respectively. The research findings reveal significant inefficiencies among PDAM from various regions in Indonesia. It was found that PDAMs outside Java performed better than those in Java; thus, PDAMs need policy intervention. The operations of larger municipal PDAMs should be restructured to increase productivity. There was no TFP growth (TFPCH) in PDAMs, evidenced by the reduction in pure technical (TECH) and scale efficiency change (SECH). In addition, the positive technological adjustment (TECCH) did not significantly improve efficiency. Regarding the increase in the number of PDAMs resulting from technological improvement, productivity was primarily due to technological advancement.

Keywords: regional water utilities; data envelopment analysis; Malmquist index; Indonesia.

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I. Introduction

Water is urgently needed at this time, but its availability is uncertain. In 2015, the United Nations anticipated that the global population would have increased by around 55% by 2050, increasing water consumption (United Nations Development Program, 2016). The combination of climate change and high population expansion exacerbates the situation. As a result of the overuse of water resources, scarcity of water, and excessively polluted groundwater, the water supply will experience a severe decline (Food and Agriculture Organization of United, 2003).

The government plays a big part in managing and resolving water concerns since they control the decision-making and regulatory authority (Davis, 2012). Regulations are required to ensure adequate water management. The government has responsibilities in solving water issues, including resource management, collaborating with the public and stakeholders, and cooperatively managing the water industry (United Nations Development Program, 2016).

According to Article 33 (2) and (3) of the 1945 Constitution of the Republic of Indonesia, the country shall regulate water management to assure its availability and sustainability. The construction of Indonesia's water supply system gives local governments the authority over water management in their administrative areas by establishing PDAM (Regional Water Utility Company). The establishment aims to manage water supply for the public in its administrative area while also profiting from water business operations.

PDAM is responsible for reporting its performance to the government during the implementation and management phases. Due to the limitations of the PDAM audit reports received by the government auditor, the Ministry of Public Works and Public Housing cannot analyze the performance of all PDAMs in Indonesia. Indonesia had 375-387 PDAMs in 2012 and 2016, with only 344-387 PDAMs assessed by governments. As seen in Table 1, Java has the highest density of PDAMs, followed by Sumatra, Papua, and Maluku.

Table 1. Total number of audited PDAMs in Indonesia based on regions

Subnational region	2012	2013	2014	2015	2016	Total
Sumatera	91	97	100	101	104	493
Java	106	108	108	108	108	538
Kalimantan	49	50	52	52	53	256
Sulawesi	55	57	58	60	62	292
Papua and Maluku	14	16	18	18	19	85
Nusa Tenggara and Bali	29	31	32	32	32	156
Total	344	359	368	371	378	1820

Source*:* Ministry of Public Works and Public Housing of Indonesia, elaborated by the author

PDAM, on the other hand, has fasevereious obstacles in operating its water supply business. According to the Ministry of Public Works and Public Housing (PUPR) report, over 300 PDAMs were in debt in 2013, with only 20% remaining solvent. Furthermore, E.coli bacteria contaminate the drinking water, posing a health concern to humans (Ika, S., 2013). However, according to Bambang Sudiatmo (the Director of Indonesia's Agency for the Improvement of Drinking Water Supply System), PDAM will frequently experience difficulties operating a water business due to dirty water, a dense population, and limitations of technologies. PDAM must continue to maintain its productivity despite various manufacturing input constraints. The government should ascertain which PDAMs truly require assistance as they will require assistance and funding from several sources, including local governments (Pra/S-25, 2019).

The obstacles to water management can be solved in many ways. However, most professionals and academics agree that increasing the efficiency and productivity of water resource consumption is a critical and beneficial strategy. Therefore, scientifically and objectively examining the efficiency pattern of PDAMs in Indonesia and arguing their growth has become an important issue to study. For that reason, this study aims to address the following questions to serve as a guide for Indonesian policymakers dealing with PDAMs. This study raises several concerns regarding the efficacy and productivity of PDAMs in Indonesia, especially in more detailed regions than government assessments.

1. Are PDAMs in Indonesia running efficiently?
2. How is PDAMs productivity growth in Indonesia?
3. Which regions should the government prioritize to improve PDAMs efficiency and productivity?

This research aims to measure the relative input-output efficiency of the Regional Water Utility Company (PDAM) in Indonesia using the data envelopment method (DEA). The following is a breakdown of how this article is organized. The study's background, key objectives, and research questions are all presented in Chapter 1. The research methodology, model formulation, and data description are covered in Chapter 2. The empirical findings and their interpretation are presented in Chapter 3. The final chapter provides the conclusions and policy implications to improve the efficiency of PDAMs in Indonesia to improve their service to the public.

II. Methods/Methodology

2.1. Method

2.1.1. Measuring efficiency under data envelopment analysis (DEA)

We used the data of 344-378 PDAMs from 2012 to 2016. DEA, a linear programming technique, envelops observable input-output vectors as deeply as feasible to quantify the efficiency of decision-making units (DMUs) that use inputs to generate outputs (Boussofiane, Dyson, & Thanassoulis, 1991). DEA constructs a surface acknowledged as a "frontier" using the best practice in the observed DMUs, connecting all DMUs with the best relative performance and representing the maximum achievable output possible with any input (Cooper, Seiford, & Tone, Introduction to Data Envelopment Analysis and Its Uses, 2006). Despite generating assumptions regarding data distribution, DEA permits numerous input-outputs to be simultaneously analyzed for efficiency measurement. The DEA model could differentiate between an input-oriented model by minimizing inputs while satisfying the given output levels; and an output-oriented model that maximizes outputs without changing input values.

Weight constraints were implemented to split DEA models regarding returns to scale. The efficiency measurement of DMUs was initially proposed by Charnes, Cooper, & Rhode (1978) for Constant Returns to Scale (CRS). The model derives the frontiers connecting with all virtual DMUs at their optimal scale. Constant Returns to Scale technological efficiency represents a score calculated by the CRS model (CRSTE). Thus far, Banker, Charnes, & Cooper (1984) developed the Variable Returns to Scale (VRS) efficiency measurement approach. The model derives the frontiers connecting with all DMUs at optimal managerial performance.

An efficiency score from zero to one was assigned to each DMU as one is considered a measure of efficiency. However, if it is less than one, it indicates a sign of inefficiency. The scores for overall technical efficiency (*oe*) and pure-technical efficiency (*pe*) were calculated using Charnes, Cooper, & Rhode (1978) and Banker, Charnes, & Cooper (1984) models, respectively (CCR and BCC models). The scale efficiency score was defined as the ratio of *oe* to *pe*. The *pe* score evaluates the DMUs efficiency in resource utilization, whereas the *se* score evaluates DMU's efficiency in resource allocation (Alexakis & Tsolas, 2013; Kataoka, 2019). DEA can be applied to evaluate the relative input-output efficiency of DMUs in public sectors, such as hospitals, water supply, transportation systems, and private sectors, such as the branches of the banks and retail stores (Huguenin, 2012).

The local governments of provinces, municipalities, and cities are deemed eligible for sustaining the quality of PDAMs in Indonesia. Furthermore, the governments directly mandate the management of Local Government Owned Enterprises (BUMD), acknowledged as PDAM (Regional Water Utility Company). As a result, PDAMs practically manage all community water in Indonesia under the government's assistance. Therefore, PDAMs have strived within the imperfect competition in their daily operations. PDAMs confronting imperfect competition, government interference, financial restraints, and other factors might experience difficulty operating at an optimal scale (Coelli, 2005).

This study performs data envelopment analysis PDAMs using the VRS output-oriented DEA model. The VRS is a form of frontier scale used in DEA that enables efficiency calculation when an increase or reduction in inputs or outputs does not result in a corresponding change in outputs or inputs (Cooper, Seiford, & Zhu, 2011). As a result, VRS may display increasing, constant, or decreasing returns to scale when used to examine the efficiency of PDAMs. An output-oriented model measures how DMU becomes efficient by changing the number of outputs without changing inputs. This output-oriented DEA is deemed appropriate because PDAMs have limited input resources (such as funds for business operations, employees, and infrastructure) but should continually try to raise their outputs (such as quality water and water distribution to all customer's profits). Indonesia has n PDAMs; PDAM i ($i=1,\ldots, n$) was treated as a DMU. The assumption was based on the details that each PDAM i ($i=1,\ldots, n$) used l inputs X_{ij} ($j=1,\ldots,l$) to produce m output as the result of running the business Y_{ik} ($k=1, \ldots, m$).

Furthermore, the following linear programming routine was run to obtain the $pei0$ score of one of the l PDAMs under evaluation, denoted as PDAM $i0$, $pei0$ $(=1/\theta)$ $(0 \leq pei0 \leq 1)$.

$$Max_{\theta,z}\theta = \theta^* \tag{1}$$

Subject to

$$\sum_{i=1}^{n} zi.Xij \leq Xi0j \ldots (j = 1, \ldots, l) \tag{1a}$$

$$\sum_{i=1}^{n} zi.Yik \geq \theta.Yi0k \ (k = 1, \ldots, m) \tag{1b}$$

$$\sum_{i=1}^{n} zi = 1 \ (i = 1, \ldots, n) \tag{1c}$$

$$zi \geq 0 \tag{1d}$$

where θ and z are regarded as the decision variables in the model, the equation was performed to produce DEA ratings, pe_{i0}, for all DMUs. The target PDAM $i0$ evaluated with $pe_{i0} = 1$ was considered as DEA efficient, while those with $pe_{i0} < 1$ were considered as DEA inefficient. The oe_{i0} scores were obtained under the CRS model[2] by removing the second-last constraint. Then, the scale efficiency score denoted as se_{i0}, the relative ratio of pe_{i0} to oe_{i0}, was derived from the following equation.

$$oe_{i0} = pe_{i0} \times se_{i0} \tag{2}$$

2.1.2. Measuring total factor productivity change by Malmquist Index (MI)

To measure the relative efficiency of each unit in a given period, DEA created a piecewise linear frontier based on the best performance of the observed DMUs with multiple inputs and outputs. MI analysis divides the difference in TFP between two periods with shifting efficiency frontiers into efficiency change (TC: movement of a DMU toward or away from the border) and technological change (EC: movement of the border) (Coelli et al., 2006). The efficiency change indicates how an organization has caught up with best practices. The frontier between Frontier t and t+1 for each observation. At the same time, technological change is a change in productivity due to changes in input to produce output or the replacement of machines for labor.

Furthermore, by referring to Fare et al. (1994), Hashimoto et al. (2009), and Kataoka (2020), the DEA-based MI in the PDAM of interest, i_0 from base year t_0 to targeting year $t(t=1,\ldots, T)$, was denoted as $MI_{i0}[t_0,t]$, articulated as:

$$MI_{io}[t0,t] = \frac{g_{io}[D^t,F^t]}{g_{io}[D^t,F^{to}]} x (\frac{g_{io}[D^t,F^{to}]}{g_{io}[D^{to},F^t]} x \frac{g_{io}[D^t,F^{to}]}{g_{io}[D^t,F^t]})^{1/2} = EC_{io}[t_0,t] \, x \, TC_{io}[t_0,t] \tag{3}$$

As mentioned previously, $MI_{i0}[t_0,t] \gtreqless 1$ implies that PDAM $i0$ experienced positive TFP growth from $t0$ to t, remained stable, or experienced negative growth (Kataoka, 2020). In periods $t0$ and t, the constant return to scale (CRS) DEA efficiency scores for PDAM $i0$ were $g_{i0}[D^{t0}, F^{t0}]$ and $g_{i0}[D^t, F^t]$. The result, ranging from 0 to 1, indicated that if $g_{i0}[D^t, F^t]$ and $g_{i0}[D^{t0}, F^{t0}]$ =(<)1, PDAM $i0$ is efficient (inefficient). These are single-period measures with PDAMs produced from the same frontier. Compared, $g_{i0}[D^{t0}, F^t]$ and $g_{i0}[D^t, F^{t0}]$ were mixed period measures with distinct PDAMs.

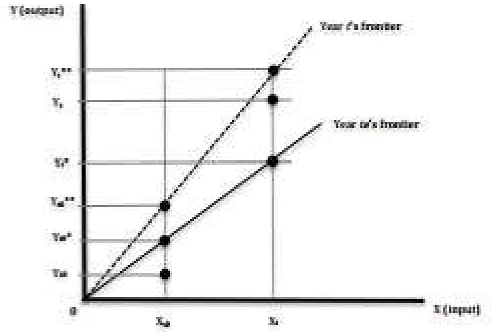

Figure 1. Graphical presentation of Malmquist Productivity Index

Figure 1 shows equation (3), where X_{t0} (X_t) and Y_{t0} (Y_t) denote the actual values of a set of PDAM inputs and outputs in years t_0 (t). The variable Y_{t0}^{**} (Y_t^{**}) are output values in years t_0 (t) projected by year t's frontier. The output value with a single superscript indicates the corresponding values projected by year $t0$'s frontier. The single period measures indicates (Y_{t0}/Y_{t0}^*) (=g_{i0} [D^{t0}, F^{t0}]) and (Y^t/Y^{t**}) (=g_{i0} [D^t, F^t]), whereas the mixed ones indicate (Y_t/Y_t^*) (=g_{i0} [D^t, F^{t0}]) and (Y^{t0}/Y^{t0**}) (=g_{i0} [D^{t0}, F^t]) (Kataoka, 2020).

The efficiency change index denoted by the ratio outside the parentheses is $EC_{i0}[t_0, t]$. When $EC_{i0}[t_0, t] \gtreqless 1$, PDAM $i0$'s relative efficiency has increased, remained constant, or worsened with time. The technical change index is the geometric mean of the two parenthesized ratios, $TC_{i0}[t_0, t]$. TC_{i0} [t 0,t] $\gtreqless 1$ indicates technological advancement and an upward movement in the frontier over time, no border shifting and no technological change, technological decline, and a downward move in the frontier. $TC_{i0}[t_0, t]$ > one signals a shift in the frontier to create more output with less input.

Furthermore, $EC_{i0}[t_0,t]$ can be multiplicatively decomposed as

$$EC_{i0}[t_0,t] = PECH_{i0}[t_0, t] \times SECH_{i0}[t_0, t] \tag{4}$$

where PECH and SECH stand for pure technical efficiency changes (changes in resource utilization efficiency) and scale efficiency changes (changes in resource allocation efficiency). PECH was derived from the frontiers based on various returns to scale (VRS) assumptions in years $t0$ and t as

$$PECH_{i0}[t0,t] = \frac{g_{io}[D^{t},F_{vrs}^{t}]}{g_{io}[D^{t0},F_{vrs}^{t0}]} \tag{5}$$

where F_{vrs} is a VRS frontier, we have the following equation.

The application of TFP measurement varies according to the business's competitive system. Since PDAM is a regulated entity, it lacks actual competition and cannot compare its productivity to other businesses. Regulators usually involve settlement processes to get broad agreement on a regulatory method. It is time for regulated businesses to assess their productivity and advocate for the plan that works best for them. In contrast, competitive corporate activity is generally distinct (Ondrej & Jiri, 2012). The differences are summarized in Table 2.

Table 2. The use of TFP in competitive and regulated business

Competitive		**Regulated business**
Evaluated subject	Firm	Regulatory agency
Staff	No experts in TFP	Experts in TFP
Data on firm	Accurate	Possible deliberate distortions (gaming)
Data on market	Lack of access to data	The regulator has access to market data
Level	Organization	Industry
Aim	Evaluate and improve own productivity	Maximize revenue requirements

2.2. Data

The data employed in this research were obtained from the Water Supply System Development Agency (BPPSPAM) under the Ministry of Public Works and Public Housing. The information summarizes the PDAM performance auditing report by the Republic of Indonesia's Financial and Development Supervisory Agency (BPKP).

This research was limited to the findings of audit reports that the government had successfully conducted on PDAMs. The Ministry of Public Works and Housing cannot evaluate the performance of all PDAMs in Indonesia due to the limits of the PDAM audit reports they received from government auditors. Between 2012 and 2016, Indonesia had 375-387 PDAMs, whereas the overall number of PDAMs audited by governments was 344-387. In other words, the data employed in this research does not cover all PDAMs. The data employed in this study covers the PDAMs that only disclose the financial and operational data, not all PDAMs. Although the coverage increased monotonically, this could derive a sample. A sample bias is expected to continue encouraging the submission of various auditable reports by PDAMs, and it is believed that future studies will address this limitation. In addition, the information pertains to a subset of all PDAMs that the agency has successfully assessed (see Figure 1). From this figure, it can be seen that the number of audited PDAMs monotonically increased.

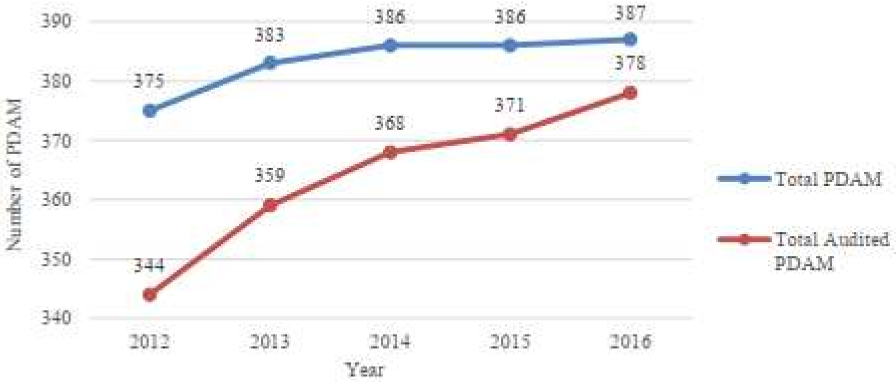

Figure 2. Total number of PDAM in Indonesia from 2012 to 2016
Source: PDAM performance report from 2012-2016, elaborated by the author

2.2.1. Selection of variables

This research employed the input variables of the total employee, asset, installed capacity, and operational cost. Meanwhile, the output variables were the water connection length and water pressure (CWCP), total revenue, total customers served, and total domestic water consumption. The selection variables followed several previous studies regarding the efficiency of water management. For example, Guerrini et al. (2015) measured the efficiency of Danish wastewater services through Data Envelopment Analysis, using operation costs, the volume of water inflow, and sewer length as wastewater management inputs and population served and population sewerage ratio as the wastewater management. Yang (2021) evaluated water-resource utilization efficiency using labor force, capital stock, the number of water resources as the water-resource utilization input, and Gross Domestic Bruto and water discharge as the output.

According to Boussofiane, Dyson, & Thanassoulis (1991), the lower constraint on the number of DMUs should be multiple inputs and outputs to gain good discriminatory power from the CCR and BCC models regarding the number of observed DMUs and input-output variables. Bowlin (1998) recommended that the number of DMUs is three times the number of input and output variables. The purpose of such guidelines is to develop more specific productivity models. In this research, we used four input and output variables to calculate the PDAMs' efficiency as follows:

Table 3. Selection of variables

A. Input variables **Variables**	**Definition**	**Literature Survey**
Total assets	The total amount of all assets owned by the company or the financial institution used to support the company's operations and the financial institution	Wang (2017) ; Molinos-Senante, Maziotis & Sala Garrido (2015)
Total employees	Total number of employees who are actively working in one PDAM unit	Kulshrestha & Vishwakarma (2013) Wang (2017); Wang et al. (2018)

Total installed capacity	The capacity of all the machine and water connection	Guerrini et al. (2015) Wang et al. (2018)
Total operational costs	The costs incurred to carry out the daily activities of a company, such as administrative costs, installation, and chemistry costs	Kulshrestha & Vishwakarma (2013); Wang et al., (2018); Guerrini et al. (2015)
B. Output variables		
Variables	**Definition**	**Literature survey**
Costumer water connection pressure	The average water pressure in the water connection received by the customer at the time of peak usage (0-100%)	Kulshrestha & Vishwakarma (2013); Molinos-Senante, Maziotis & Sala Garrido (2015)
Total income	The entire company operating income of PDAM from water and non-water revenues	Wang (2017)
Total customers	All registered PDAM customers, including domestic customers (households) and non-domestic customers (social, commercial, industrial, and port)	Guerrini et al., (2015) ; Wang et al. (2018)
Total domestic water consumption	The total household water consumption (m3) from active domestic customers	Kulshrestha & Vishwakarma (2013)

2.2.2. Descriptive statistics

Table 4. Summary statistics of data

Year: 2012, n=344

Variables and unit measurement	**Minimum**	**Mean**	**Maximum**	**Coefficient of variation**	**Standard deviation**
Total assets (rupiah)	768,331.53	47,520,790	1,233,000,000	2.15	102,400,000
Total employees (person)	8	143.87	2,937	1.49	215.66
Total installed capacity (m^2)	15	488.94	18,075	2.58	1,262.91
Total operational costs (rupiah)	528,000,000	21,610,000,000	406,300,000,000	2.12	45,900,000,000

Customer water connection pressure (%)	1	44	105	90	40
Total revenue (rupiah)	10,985,726	23,170,000,000	602,200,000,000	2.46	56,960,000,000
Total customer served (household)	271	25238.12	800,093	2.40	60,503.16
Domestic water consumption (m^3)	1.10	17.33	41.60	0.29	5.04

Year: 2013

Variables and unit measurement	Minimum	Mean	Maximum	Coefficient of variation	Standard deviation
Total assets (rupiah)	526,548.81	53,591,761	1,256,000,000	2.08	111,500,000
Total employees (person)	8	144.66	2,842	1.52	220.11
Total installed capacity (m^2)	10	480.00	15,150	2.35	1,132.28
Total operational costs (rupiah)	452,308	52,491,980	7,802,000,000	8.20	430,800,000
Customer water connection pressure (%)	1	44	100	90	39
Total revenue (rupiah)	2	34,231,227	2,423,000,000	4.18	143,000,000
Total customer served (household)	221	25,794.62	803,601	2.36	60,919.07
Domestic water consumption (m^3)	1.1	17.18	46.80	0.29	5.04

Year: 2014

Variables and unit measurement	Minimum	Mean	Maximum	Coefficient of variation	Standard deviation
Total assets (rupiah)	1,203,103.40	59,097,059	1,302,000,000	2.02	119,500,000
Total employees (person)	8	144.39	2,763	1.47	212.03
Total installed capacity (m^2)	10	495.45	18,050	2.49	1,235.78
Total operational costs (rupiah)	639,900,000	33,310,000,000	2,463,000,000,000	4.14	138,000,000,000

Customer water connection pressure (%)	1	46	101	84	39
Total revenue (rupiah)	2	35,524,78	2,557,000,000	4.18	148,500,000
Total customer served (household)	261	26,706.77	813,356	2.32	61,941.03
Domestic water consumption (m^3)	1.08	17.44	304.01	0.91	15.86

Year: 2015

Variables and unit measurement	Minimum	Mean	Maximum	Coefficient of variation	Standard deviation
Total assets (rupiah)	1,210,889.50	65,233,924	1,309,000,000	1.97	128,500,000
Total employees (person)	11	146.84	2,775	1.46	214.59
Total installed capacity (m^2)	16	510.53	17,961	2.42	1235.84
Total operational costs (rupiah)	990,600,000	35,900,000,000	2,526,000,000,000	3.95	141,900,000,000
Customer water connection pressure (%)	1	42	100	88	37
Total revenue (rupiah)	625,460	39,879,327	2,673,000,000	3.93	156,600,000
Total customer served (household)	743	28,658.41	830,857	2.27	65,102.90
Domestic water consumption (m^3)	1.10	16.32	43.43	0.31	5.05

Year: 2016

Variables and unit measurement	Minimum	Mean	Maximum	Coefficient of variation	Standard deviation
Total assets (rupiah)	1,056,372.50	70,929,890	1,304,000,000	1.90	134,900,000
Total employees (person)	8	147.32	2,495	1.38	203.90
Total installed capacity (m^2)	15	526.50	19,082	2.42	1274.15
Total operational costs (rupiah)	319,400,000	37,180,000,000	2,589,000,000,000	3.88	144,300,000,000

Customer water connection pressure (%)	1	41.20	100	89.20	36.80
Total revenue (rupiah)	2	40,379,505	2,783,000,000	3.96	160,100,000
Total customer served (household)	685	29,491.38	839,393	2.23	65,841.05
Domestic water consumption (m^3)	1.03	15.72	38.91	0.31	4.95

Table 4 provides the descriptive statistics of variables employed in the DEA-based frontier analysis of PDAM in Indonesia from 2012 to 2016. Before approaching the calculation and analysis stage, data processing involves several phases. First, the author verified that the data had no zeroes or negative values as they would hinder DEA calculations. We added a value of 20 to each variable's minimum value arbitrarily. This conversion eliminated the variables of all zeroes and negative values. The efficiency frontier was unaffected by adding modest numbers for all DMUs in the data set. Thus, Bowlin (1998) argued that an output variable with a small value is unlikely to contribute to a high-efficiency score and vice versa for a variable with a negative value. As a result, such modifications typically had less effect on the efficiency score (Ji & Lee, 2010). However, this increased value could not exceed any other value obtained from the data collection. The data shows a large standard deviation depicting the significant variation between the maximum and minimum values for all the parameters.

Furthermore, the magnitude of variables varies by year; thus, we treated the data to equalize the scale or magnitude of each variable using the Mean Normalization method. This technique ensures the data were of the same or similar magnitude across and within the data sets in Table 4. It was performed in two basic processes. The first step was to calculate the average for each variable and then divide each value in every variable by the average calculated before (Ji & Lee, 2010). This technique was used to ensure that all variables were scaled similarly. Then, we computed the annual mean values for each variable and divided the value of each variable in a single DMU by the annual mean value. It manipulated the data so that the scale or magnitude of each variable per year was equalized.

III. Results, Analysis, and Discussions

3.1. Measuring the relative efficiency of PDAM for 2012-2016

We measured the relative efficiency of 344-378 PDAMs from 2012 until 2016. Those are PDAMs that governments successfully audited. Table 5 displays the descriptive statistics of the three scores using the VRS output-oriented models.

First, Table 5 shows the mean values, and inter-PDAM inequality of efficiency between pe and se vary by observation years. The pe mean shows higher values in some years than the se mean, while it does not in other years. This is also true for the coefficient of variation.

Table 5. Descriptive statistics of efficiency scores and returns to scale of PDAMs in Indonesia from 2012 to 2016

Year	Vars	N	Min	P50	P75	Mean	Max	Cv	Skewness	Kurtosis	Efficient
2012	*oe*	344	0.24	0.73	0.89	0.72	1.00	0.26	-0.13	2.00	46
	pe	344	0.28	0.85	0.99	0.81	1.00	0.21	-0.71	2.45	84
	se	344	0.40	0.94	0.99	0.88	1.00	0.14	-1,22	3.80	64
2013	*oe*	359	0.09	0.50	0.7	0.54	1.00	0.45	0.46	2.24	32
	pe	359	0.27	0.75	0.96	0.74	1.00	0.27	-0.30	1.94	76
	se	359	0.13	0.75	0.93	0.72	1.00	0.31	-0.46	2.06	42
2014	*oe*	368	0.18	0.78	0.87	0.76	1.00	0.21	-0.43	2.74	43
	pe	368	0.19	0.84	0.97	0.82	1.00	0.19	-0.77	3.07	85
	se	368	0.45	0.98	1.00	0.93	1.00	0.11	-2,21	7.78	110
2015	*oe*	371	0.10	0.69	0.82	0.69	1.00	0.26	-0.04	2.33	32
	pe	371	0.10	0.82	0.95	0.80	1.00	0.20	-0.64	2.90	69
	se	371	0.29	0.89	0.98	0.86	1.00	0.16	-1,14	4.25	55
2016	*oe*	378	0.04	0.35	0.44	0.40	1.00	0.53	1,55	4.82	24
	pe	378	0.06	0.66	0.87	0.67	1.00	0.34	-0.01	1.88	50
	se	378	0.05	0.59	0.82	0.62	1.00	0.37	0.10	1.99	31

Source*:* Author's elaboration as the result of DEA-VRS Output orientation two-stage calculation Cv indicates the coefficient of variation

In detail, the mean values of *se* are lower than *pe* in 2013 and 2016. It indicates that most PDAMs faced inefficiency in resource allocation more severely than inefficient managerial performance. The inter PDAMs efficiency gap in operation scale also became higher in these years. While in 2012, 2014, and 2015, mean values of *se* were higher than pe. Most PDAMs encountered managerial performance inefficiency more heavily than resource misallocation during these periods. At the same time, the inter PDAMs gap in managerial performance (resource utilization) was higher than the operation scale (resource allocation).

Figure 3. Mean values and coefficient of variation of efficiency scores (pure technical efficiency and scale efficiency)

Source*:* Author's elaboration as the result of DEA-VRS output orientation two-stage

Cv indicates the coefficient of variation.

The different trend in 2013 and 2016 (see figure 3) was triggered by the increasing number of rivers that did not achieve clean water standards (heavily polluted rivers) in Indonesia as rivers are one of the primary sources of PDAM water (Scholastica Gerintya, 2018). As a consequence, PDAM, as the Regional Water Utility Company, had a significant cost burden in handling polluted drinking water (the United States Environmental Protection Agency, 2019). It put additional strain on the current PDAM systems, implying that significant investments in drinking water infrastructure will be necessary to avoid pathogenic loads in PDAM systems (OECD, Better Policies for Better Lives, 2017).

Second, comparing the number of efficient PDAMs in three scores (overall technical efficiency, pure technical efficiency, and scale efficiency) from 2012 to 2016, the number of pure technical efficient PDAMs exceeds the scale efficient PDAMs in all sub-national regions. However, in terms of the annual *pe* and *se* score of all PDAMs, *pe* is bigger than *se* except in 2014 (see Table 6). It indicates that the inefficiency of PDAMs in all subnational regions in Indonesia is mainly due to scale inefficiency concerns. Aside from water and technical constraints, the long-term goal of optimal scale operation should appeal to PDAM management. The management and government of PDAM rarely share information about scale operation and other long-term strategies. Returns to scale are a notion in production theory that refers to the long-run relationship between output and input. To handle operational scale, PDAM must consider rescaling. In such cases, the PDAM may review its efficiency and solve the situation progressively (Rödder, Kleine, & Dellnit, 2018).

Additionally, PDAMs have a local monopoly power on water supply services, as those are regulated to achieve universal coverage for all residential areas. In a monopoly market, the pricing mechanism does not work adequately, and thus inefficient resource allocations occur in PDAM operations due to the absence of signals from the market forces. Thus, the information about returns to scale is essential for PDAMs to improve resource allocation efficiency as a substitute for the price mechanism.

Table 6. The share of relative pure-technical efficiency and scale efficiency PDAMs in Indonesia from 2012 to 2016 by sub-national regions (%)

Year	Sumatera		Jawa		Kalimantan		Sulawesi		Papua-Maluku		Bali-Nusa Tenggara		The share of relative efficiency score compares to total observations per year	
	pe	*se*	*pe*	*se*	*pe*	*se*	*pe*	*se*	*pe*	*se*	*pe*	*se*	*pe*	*se*
2012	24,18	14,29	20,75	22,64	30,61	20,41	29,09	20,00	28,57	14,29	17,24	13,79	24,42	18,60
2013	16,49	9,28	18,52	9,26	18,00	18,00	33,33	10,53	31,25	25,00	22,58	12,90	21,17	11,70
2014	15,00	21,00	25,00	37,96	15,38	21,15	31,03	39,66	33,33	27,78	34,38	28,13	23,10	29,89
2015	12,87	11,88	19,44	13,89	21,15	13,46	21,67	21,67	33,33	16,67	15,63	15,63	18,60	14,82
2016	15,38	11,54	8,33	0,93	15,09	13,21	17,74	6,45	15,79	15,79	9,38	12,50	13,23	8,20
The share of relative efficiency score compares to total observations per sub-national regions	16,63	13,59	18,40	16,91	19,92	17,19	26,37	19,52	28,24	20,00	19,87	16,67	20,00	16,59

Source*:* Author's elaboration as the result of DEA-VRS Output orientation two-stage calculation Cv indicates the coefficient of variation

In Table 6, we divided the regions of Indonesia into six sub-national regions: Sumatera, Java, Kalimantan, Sulawesi, Papua-Maluku, and Bali-Nusa Tenggara. This approach is helpful to see more details in the regional pattern of PDAM performance efficiency.

The pure technical efficiency and scale efficient PDAMs are primarily located in Sulawesi and Papua-Maluku regions (Table 6). Lower population, plentiful water supplies support it, and fewer PDAMs are audited in those regions than in other subnational regions (Caesaria, 2021). Meanwhile, PDAMs in Java, Bali, and Nusa Tenggara struggle to be efficient. This might be because of the low frequency of rainfall, insufficient water sources, and a limited budget to develop the water business of PDAMs. In addition, due to the large number of PDAMs and high population in the Java region and Sumatera, the percentage of efficient PDAMs has become lower. This type of difficulty requires high operating costs, operational scale regulation (split or merging), significant investment in water infrastructure, and specific policy adjustments by PDAMs to respond to changing circumstances and increase efficiency (Caesaria, 2021).

Regional heterogeneity, as previously stated, affects both the quality and quantity of natural water (Wang et al., 2016). Indonesia's changing environment and extreme hydrological events occur often. Water resources are affected by spatial and temporal variations (rainfall or drought). Due to the increased unpredictability of water availability over time and the rapid environmental changes, future water supply and distribution research should tackle this issue.

Table 7. Regional heterogeneity by district level in Indonesia

Variables and unit measurement	Minimum	Mean	Maximum	Coefficient of variation
Population in the Administrative Area of PDAM (Person)	13,199	493,813.4	5,073,116	1.20
Longitude (°)	95.29	113.28	140.77	0.09
Latitude (°)	-10.67	-3.20	5.83	-1.20
Rainfall Intensity (mm)	760	2,509.97	6,041	1.45
Rainy days (days)	88	191.15	256	0.80

Source*:* Central Bureau of Statistics of Indonesia, 2013

As illustrated in Table 7, latitude and longitude form the grid system that enables humans to position themselves on the Earth's surface in absolute or precise locations. There is a link between latitude and temperature throughout the world, as temperatures often increase as they approach the Equator. Indonesia is positioned on the equator, which leads to higher temperatures; nonetheless, the intensity of rainfall and the number of wet days vary greatly across municipalities, as indicated by their coefficient of variation. Additionally, population numbers differ by the municipality, with some having a large population and others having a small one. Additional examination of these qualities may contribute to developing a complete understanding of Indonesia's water supply.

Moreover, Tables 8 and 9 show that efficient PDAMs are not typically located in provincial capitals or supporting municipalities. Due to expanding population, contaminated water supplies, limited funds, and the inability of management to adjust to these circumstances, significant municipalities have issues fulfilling the demand for clean water and increasing their efficiency (Kulshrestha & Vishwakarma, 2013). The following are PDAMs with pure technical efficiency and scale efficiency in more than two consecutive years.

Third, the measurements of return to scale may assist PDAM management and the government in making policy concerning PDAM scale operation. In Figure 4 below, 49.89% of DMUs exhibit Increasing Returns to Scale (IRS) in operating their companies. It means that roughly half of all PDAMs in Indonesia run at a less than optimal scale. By increasing the operation size, resource allocation efficiency can be improved (Coelli, 2005). Thus, according to Table 9, about 59.59 % of PDAMs in Sulawesi demonstrate IRS and the efficiency of resource allocation can be enhanced by increasing the size of the operation.

On the other hand, 40.33% DMUs from 2012 to 2016 show Decreasing Returns to Scale. A percentage increase in all inputs results in a lesser percentage increase in output (Coelli, 2005). Considering PDAMs signifies an inability to manage the production process, resulting in company decentralization, splitting and shrinking the PDAM organizational structure (Drinking Water and Environmental Sanitation Working Group, 2015). According to Table 9, approximately 59.67 % PDAMs in the Java region encountered this DRS condition, implying that PDAM management should consider procedures related to changing the size of the scale operation of PDAM, as a percentage increase in all inputs results in a lower percentage increase in production.

Table 8. PDAMs with pure technical efficiency for 3-5 consecutive years

Year	Province	PDAM unit
2013-2016	Aceh	PDAM Kabupaten Bireuen
2012-2015	Bali	PDAM Kabupaten Buleleng
2012-2015	Bali	PDAM Kota Denpasar
2012-2016	Banten	PDAM Kabupaten. Tangerang
2014-2016	Central Java	PDAM Kabupaten Kudus
2012-2015	Central Kalimantan	PDAM Kabupaten Murung Raya
2012-2016	Central Kalimantan	PDAM Kabupaten Sukamara
2012-2016	Central Sulawesi	PDAM Kabupaten Banggai
2014-2016	Central Sulawesi	PDAM Kabupaten Buol
2012-2016	DKI Jakarta	PDAM DKI Jakarta
2012-2015	East Java	PDAM Kabupaten Banyuwangi
2014-2016	East Java	PDAM Kabupaten Magetan
2012-2015	East Java	PDAM Kabupaten Malang
2012-2015	East Java	PDAM Kota Malang
2012-2016	East Java	PDAM Kota Surabaya
2012-2016	East Kalimantan	PDAM Kabupaten Berau
2012-2015	East Kalimantan	PDAM Kota Balikpapan
2014-2016	East Nusa Tenggara	PDAM Kabupaten Alor
2012-2015	Lampung	PDAM Kabupaten. Lampung Barat
2012-2016	North Kalimantan	PDAM Kabupaten Malinau
2012-2016	North Maluku	PDAM Kabupaten Halmahera Selatan
2013-2016	North Sulawesi	PDAM Kabupaten Bolaang Mongondow
2013-2016	North Sulawesi	PDAM Kabupaten Kepulauan Siau Tagulandang Biaro
2013-2016	North Sulawesi	PDAM Kabupaten Kepulauan Talaud
2013-2016	North Sulawesi	PDAM Kabupaten Minahasa
2013-2016	North Sulawesi	PDAM Kabupaten Minahasa Selatan
2012-2016	North Sulawesi	PDAM Kepulauan Sangihe
2013-2015	North Sulawesi	PDAM Kota Bitung
2013-2015	North Sulawesi	PDAM Kota Tomohon
2012-2016	North Sumatera	PDAM Kota Padang Sidempuan
2012-2016	North Sumatera	PDAM Provinsi Sumatera Utara
2012-2016	Papua	PDAM Kabupaten Kepulauan Yapen
2012-2015	South Kalimantan	PDAM Kota Banjarmasin
2014-2016	South Sumatera	PDAM Kabupaten Lahat
2014-2016	South Sumatera	PDAM Kabupaten Ogan Komering Ulu Timur
2014-2016	West Java	PDAM Kota Bogor
2013-2015	West Java	PDAM Kota Depok
2012-2015	West Nusa Tenggara	PDAM Kota Mataram

Table 9. PDAMs with scale efficiency for 3-5 consecutive years

Year	Province	PDAM unit
2012-2015	Bangka Belitung	PDAM Kabupaten. Bangka Tengah
2012-2016	Central Kalimantan	PDAM Kabupaten Sukamara
2012-2015	Central Sulawesi	PDAM Kabupaten Banggai
2013-2016	East Nusa Tenggara	PDAM Kabupaten Alor
2014-2016	East Nusa Tenggara	PDAM Kabupaten Ende
2013-2016	North Sulawesi	PDAM Kabupaten Kepulauan Talaud
2014-2016	North Sulawesi	PDAM Kabupaten Minahasa Selatan
2014-2016	North Sumatera	PDAM Kabupaten Mandailing Natal
2012-2016	North Sumatera	PDAM Kota Padang Sidempuan
2012-2016	Papua	PDAM Kabupaten Kepulauan Yapen
2014-2016	South Sumatera	PDAM Kabupaten Lahat
2013-2015	West Java	PDAM Kota Depok

Furthermore, there are relatively some PDAMs that indicate the Constant Return to Scale condition. Figure 4 displays that only 9.78% PDAMs are in the stage of constant return to scale (CRS). That is an optimal status for the combination of input factors and production scale,and there is no need for any improvement (Lee, 2009). This is particularly noticeable in PDAMs in Papua and Maluku, with 17.65 % of PDAMs operating at an ideal level for managing the water business (see Table 10).

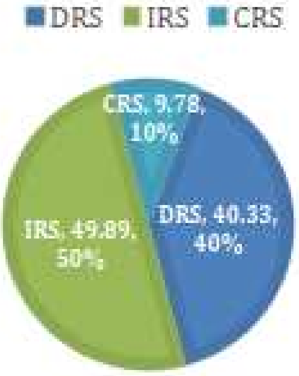

Figure 4. The share of PDAMs in Indonesia from 2012 to 2016 based on a return to scale, percentage wise

Source*:* Author's elaboration as the result of DEA-VRS output orientation two-stage

Table 10. The share of PDAMs in Indonesia from 2012 to 2016 based on a return to scale peregions, percentage wise

Year	**Sumatera**			**Java**			**Kalimantan**			**Sulawesi**			**Papua-Maluku**			**Bali-Nusa Tenggara**		
	DRS	**IRS**	**CRS**	**DRS**	**IRS**	**CRS**	**DRS**	**IRS**	**CRS**	**DRS**	**IRS**	**CRS**	**DRS**	**IRS**	**CRS**	**DRS**	**IRS**	**CRS**
2012	42.86	46.15	10.99	49.06	36.79	14.15	40.82	44.90	14.29	34.55	49.09	16.36	21.43	64.29	14.29	48.28	44.83	6.90
2013	28.87	61.86	9.28	67.59	25.93	6.48	28.00	62.00	10.00	33.33	57.89	8.77	31.25	43.75	25.00	35.48	54.84	9.68
2014	21.00	71.00	8.00	42.59	46.30	11.11	25.00	65.38	9.62	20.69	63.79	15.52	27.78	50.00	22.22	37.50	50.00	12.50
2015	40.59	51.49	7.92	58.33	35.19	6.48	30.77	59.62	9.62	23.33	60.00	16.67	27.78	61.11	11.11	34.38	59.38	6.25
2016	35.58	55.77	8.65	80.56	18.52	0.93	32.08	60.38	7.55	27.42	66.13	6.45	21.05	63.16	15.79	50.00	40.63	9.38
The ratio of RTS of PDAM to the total observed PDAMs in 5 years	33.67	57.40	8.92	59.67	32.53	7.81	31.25	58.59	10.16	27.74	59.59	12.67	25.88	56.47	17.65	41.03	50.00	8.97

Source*:* Author's calculation as the result of DEA-VRS output orientation two-stage

Fourth, we followed the method proposed by Chen T. (1997) and Chen T. & Yeh T. (1998) to differentiate the efficiency of PDAM by reference set. The reference set consisted of fully efficient best-practice DMUs (Leader) and inefficient DMUs (Followers). The frequency in which an effective PDAM appears in a reference set of inefficient PDAMs indicates a leading firm performance. PDAMs with higher frequency have more followers that can be efficient. The names of the best-practice DMU and the number of followers are listed in Table 11, showing the best-practice PDAMs with a frequency as a reference more than 100 times.

Table 11. Best practice PDAMs from 2012 to 2016

Province	**PDAM unit**	**Regions**	**Frequency count**	**Additional explanation**
North Sumatera	PDAM Kota Padang Sidimpuan	Sumatera	425	Pure technical efficiency and scale efficiency in 2012-2016
DKI Jakarta	PDAM DKI Jakarta	Java	336	Pure technical efficiency in 2012-2016
East Java	PDAM Kabupaten Banyuwangi	Java	326	Pure technical efficiency in 2012-2015
East Java	PDAM Kota Blitar	Java	321	
Papua	PDAM Kabupaten Kepulauan Yapen	Papua-Maluku	319	Pure technical efficiency and scale efficiency in 2012- 2016
North Sumatera	PDAM Kabupaten Mandailing Natal	Sumatera	295	Scale efficiency in 2014-2016
East Kalimantan	PDAM Kota Bontang	Kalimantan	294	
Central Kalimantan	PDAM Kabupaten Seruyan	Kalimantan	277	
Central Java	PDAM Kabupaten Temanggung	Java	259	
North Sulawesi	PDAM Kabupaten Minahasa Tenggara	Sulawesi	251	
Jambi	PDAM Kota Jambi	Sumatera	188	
Papua	PDAM Kabupaten Jayapura	Papua-Maluku	187	
West Java	PDAM Kota Depok	Java	166	Pure technical efficiency in 2013-2015
North Sumatera	PDAM Provinsi Sumatera Utara	Sumatera	153	Pure technical efficiency in 2012-2016
Bangka Belitung	PDAM Kabupaten Bangka Tengah	Sumatera	140	Scale efficiency in 2012-2015
West Java	PDAM Kabupaten Bekasi	Java	135	
North Kalimantan	PDAM Kabupaten Malinau	Kalimantan	134	Pure technical efficiency in 2012-2016
East Nusa Tenggara	PDAM Kabupaten Alor	Bali-Nusa Tenggara	133	Pure technical efficiency in 2014-2016 and Scale

				efficiency in 2013-2016
East Java	PDAM Kabupaten Malang	Java	123	Pure technical efficiency in 2012-2015
South Sumatera	PDAM Tirta Musi Palembang	Sumatera	122	
Maluku	PDAM Kabupaten Maluku Tenggara Barat	Papua-Maluku	122	
East Java	PDAM Kota Surabaya	Java	114	Pure technical efficiency in 2012-2016
Riau Islands	PDAM Kabupaten Lingga	Sumatera	113	
Central Kalimantan	PDAM Kabupaten Sukamara	Kalimantan	111	Pure technical efficiency and scale efficiency in 2012-2016

Source*:* Author's elaboration as the result of DEA-VRS Output orientation two-stage

Table 11 shows that those PDAMs that mostly experienced pure technical efficiency and/or scale efficiency for 3 to 5 years tend to be classified as best practice PDAMs. For instance, PDAM Yapen Islands Regency, PDAM Padang Sidempuan City, and PDAM Sukamara which have shown 3 to 5-year ability to utilize resources and optimize the operation scale, seem like the best practice PDAMs which serve as models for other PDAMs in Indonesia. Additionally, PDAM DKI Jakarta and other surrounding PDAMs such as PDAM Bekasi and PDAM Depok are included in the PDAM best practice and thus, serve as excellent models for other PDAMs. However, the efficiency level is not steady over the corresponding years.

3.2. Productivity growth of PDAM using Malmquist Index

This research conducted the PDAM's Total Factor Productivity (TFP) growth analysis using the DEA-based Malmquist index approach. Our TFP growth computations employed the balanced panel data covering 342 PDAM for 2012-2016. To set the balanced panel data, we removed several existing PDAMs observations that were not presented in 2012 or 2016 for the computations.

Table 12. Descriptive statistics of PDAM Malmquist Index calculation

		Minimum value	**Mean**	**Maximum value**	**Coefficient of variation**
Total Factor Productivity Growth	TFPCH	0.04	0.74	3.59	0.57
Technological Change	TECCH	1.03	1.49	2.19	0.14
Pure Technical Efficiency Growth	TECH	0.20	0.82	2.41	0.38
Scale Efficiency Growth	SECH	0.04	0.62	1.37	0.35
Single Period Overall Efficiency Scores	2012	0.31	0.72	1.00	0.27
	2016	0.04	0.40	1.00	0.20

Source*:* Malmquist Index calculation by author

Observing the mean value in Table 12, PDAMs experienced average negative TFP growth (TFPCH). The negative efficiency growth is due to negative purely technical (TECH) and scale efficiency growth (SECH). In addition, the positive progress of technological change (TECCH) in PDAM has not been accompanied by a significant increase in efficiency growth. Since the number of PDAMs with technological change is higher than technical efficiency change, productivity gains are primarily technological progress (see Table 13).

Although all PDAMs from 2012 to 2016 experienced technological change, as we see in Tables 12 and 13, this number could not offset the majority of PDAMs with the negative efficiency growth (technological-led growth). That might be because the Indonesian government is constantly attempting to improve the country's water supply technology and innovation. The numerous competitions organized by the government encourage innovation in the water supply system5. Therefore, PDAM constantly enhances its productivity by using cutting-edge technology and innovation (Viva. news, 2019).

Table 13. Descriptive statistics of Malmquist productivity index by regions

Sumatera	**Observations**	**Mean**	**Min. value**	**Max. value**	**Coefficient of variation**
Total Factor Productivity Growth	90	0.70	0.08	2.38	0.49
Scale Efficiency Growth	90	0.66	0.11	1.36	0.35
Pure Technical Efficiency Growth	90	0.81	0.20	2.41	0.45
Technological Change	90	1.45	1.03	1.97	0.14
Efficiency Score 2012	90	0.67	0.34	1	0.30
Efficiency Score 2016	90	0.37	0.07	1	0.56
Java	**Observations**	**Mean**	**Min. value**	**Max. value**	**Coefficient of variation**
Total Factor Productivity Growth	106	0.70	0.31	2.48	0.34
Scale Efficiency Growth	106	0.55	0.24	1.09	0.27
Pure Technical Efficiency Growth	106	0.87	0.42	1.95	0.27
Technological Change	106	1.52	1.18	2.07	0.11
Efficiency Score 2012	106	0.76	0.38	1	0.22
Efficiency Score 2016	106	0.36	0.19	1	0.33
Kalimantan	**Observations**	**Mean**	**Min. value**	**Max. value**	**Coefficient of variation**
Total Factor Productivity Growth	48	0.70	0.04	2.91	0.69
Scale Efficiency Growth	48	0.61	0.04	1.30	0.39
Pure Technical Efficiency Growth	48	0.76	0.42	1.55	0.27
Technological Change	48	1.50	1.09	2.08	0.16
Efficiency Score 2012	48	0.73	0.41	1	0.26
Efficiency Score 2016	48	0.43	0.04	1	0.61

Sulawesi	**Observations**	**Mean**	**Min. value**	**Max. value**	**Coefficient of variation**
Total Factor Productivity Growth	55	0.77	0.22	3.59	0.71
Scale Efficiency Growth	55	0.69	0.24	1.17	0.33
Pure Technical Efficiency Growth	55	0.77	0.28	2.24	0.47
Technological Change	55	1.47	1.09	2.19	0.17
Efficiency Score 2012	55	0.70	0.31	1	0.29
Efficiency Score 2016	55	0.39	0.14	1	0.52
Papua-Maluku	**Observations**	**Mean**	**Min. value**	**Max. value**	**Coefficient of variation**
Total Factor Productivity Growth	14	0.71	0.35	1.20	0.38
Scale Efficiency Growth	14	0.68	0.42	1.03	0.25
Pure Technical Efficiency Growth	14	0.74	0.40	1.34	0.32
Technological Change	14	1.39	1.19	1.53	0.07
Efficiency Score 2012	14	0.74	0.38	1	0.29
Efficiency Score 2016	14	0.49	0.18	1	0.56
Bali-Nusa Tenggara	**Observations**	**Mean**	**Min. value**	**Max. value**	**Coefficient of variation**
Total Factor Productivity Growth	29	0.89	0.10	3.32	0.80
Scale Efficiency Growth	29	0.66	0.23	1.37	0.40
Pure Technical Efficiency Growth	29	0.85	0.29	1.88	0.42
Technological Change	29	1.50	1.21	1.80	0.10
Efficiency Score 2012	29	0.72	0.35	1	0.27
Efficiency Score 2016	29	0.43	0.07	1	0.58

Source*:* Malmquist Index calculation and DEA result by author

Table 14. The share of positive growth PDAM by component and region (%)

	Total PDAM	**TFPCH**	**TECH**	**TECCH**	**SECH**
Sumatera	90	15,56 %	17,78 %	100 %	10.00 %
Jawa	106	4,72 %	20,75 %	100 %	0.94 %
Kalimantan	48	12,50 %	8,33 %	100 %	8.33 %
Sulawesi	55	7,27 %	20,00 %	100 %	3.64 %
Papua-Maluku	14	64,29 %	7,14 %	100 %	35.71 %
Bali-Nusa Tenggara	29	10,34 %	27,59 %	100 %	3.45 %
Total Number	342	41	62	342	22
Percentage Share	100 %	11,99 %	18,13 %	100 %	6,43 %

Source*:* Malmquist Index calculation by author

In terms of productivity growth by region, Table 14 shows that only 41 PDAMs, accounting for 11,99% of all PDAMs, exhibited positive TFP growth from 2012 to 2016. When the number of existing PDAMs in subnational regions was examined, it became clear that PDAMs in Papua and Maluku had the largest percentage of TFP growth in the corresponding year. TFP growth occurred in around 64% of PDAMs in the Maluku and Papua regions. Given abundant good quality resources that decrease operational costs associated with water treatment and a low population density, PDAMs in Maluku and Papua could demonstrate productivity growth.

Moreover, positive TFP growth occurred in less than 5% of all PDAMs in Java regions. This suggests that 95% of Java's PDAM was ineffective at increasing productivity. Additionally, governments should enhance their support for PDAMs that are less efficient and productive to actively promote management model change (Chen, Ding, Wang, & Yu, 2019).

Since innovation is a continuous process that adapts to a constantly changing society and environment, the entire process is supported by all of PDAM's resources. PDAM's investment in technology enables the company to grow sustainably and achieve its primary strategic objectives. Thus, PDAMs must consider existing technical improvements connected with productivity and efficiency targets and constraints.

IV. Conclusion and Recommendation

This paper used a DEA approach to calculate Regional Water Utility Company (PDAM) efficiency in Indonesia using a panel dataset of 344–378 PDAMs for 2012–2016. Afterward, the productivity was analyzed using the Malmquist Index Calculation.

The significant findings of this study are as follows. First, the rising quantity of extremely contaminated rivers and water resources in Indonesia was a significant factor in the divergent patterns in the pure technical and scale efficiency scores of PDAMs in 2013 and 2016. Contamination caused problems in the PDAM water systems, which endanger public health. PDAM bore considerable responsibility for dealing with contaminated drinking water in response to this problem. Drinking water infrastructure is required to prevent pathogenic and organic pollutants in the PDAM systems. Second, in all regions, the pure technical efficiency of PDAMs exceeded the scale efficiency. Apart from concerns about water supply and technical issues, PDAM management should prioritize long-term optimal scale operation. PDAMs should consider the advantages of expanding and contracting their activities. The PDAM's efficiency and scale operation should be re-evaluated as they shrink or expand.

Third, half of the PDAMs operated at a less than optimal scale. Increasing the operation size improved the efficiency of allocation. PDAMs in the Sulawesi had a high prevalence of this problem. PDAMs in Java, on the other hand, often showed a decline in return to scale. It is a sign that the manufacturing process is getting out of control and will lead to mergers, acquisitions, and organizational structure downsizing. Only a few PDAMs had constant-return-to-scale (CRS), with the majority concentrated in Papua and Maluku. The combination of input parameters and scale of production resulted in the best condition of PDAMs in the areas, even though with little space for improvement. Fourth, most PDAMs outside Java were the best leaders of PDAM, such as in Papua, Sumatra, Kalimantan, and Sulawesi. Also, when PDAMs exhibit 3-5 consecutive years of pure technical efficiency and/or scale efficiency, these PDAMs tend to serve as a good example in the business.

Regarding the productivity growth using Malmquist Index Calculation, in general, PDAMs experienced negative TFP growth (TFPCH) caused by a decrease in pure technical (TECH) and scale efficiency growth (SECH). In addition, the useful technological modification (TECCH) demonstrated in PDAM had not yet resulted in a significant increase in inefficiency. With the increase in the number of PDAMs due to technological growth, productivity increased mainly due to technological advancement. The Indonesian government continues to improve technology and innovation in providing clean water, evidenced by the large number of competitions seeking to encourage innovation in the water delivery system. Meanwhile, PDAM increases productivity through the application of cutting-edge technology and creativity.

This study has several limitations. First, this research did not study all PDAMs in Indonesia. Indonesia owned 375-387 PDAMs between 2012 and 2016, and governments audited 344-387 PDAMs. This research used the sample data as a data set. Our inability to eliminate sampling bias in the sample data was one of the research limitations. This DEA analysis ignores sample errors; thus, the bootstrapping DEA approach and the parametric frontier analysis of the SFA approach could provide possible solutions. Second, due to the limited access to government data, this research only used panel data for five years. Therefore, the future study is expected to evaluate the panel data from PDAMs over a longer period and refer to additional data to clarify trends in the country's efficiency and productivity of PDAMs in the country. This will significantly assist the government in mapping the future of water utilities in Indonesia. Further research is advised to explain regional heterogeneity utilizing natural water quality, area coverage, and population density. This may affect the firm's efficiency in Indonesia, and examining it even further clarifies the country's water management. Another extension for the further study could be applying this study’s analysis to other economies in different development stages. More factual findings on the performance of the regional water supplier at different development stages will contribute to further discussions and understanding of the policy implications in various economies.

Based on the research findings, it is suggested that the government and PDAM management must take proactive actions to meet Indonesia's water situation and demography in developing future business plans. DEA analysis results can determine how to improve resource allocation and utilization to ensure the smooth supply and distribution of water to the public. In addition to the technical aspects of business development, such as water use, budgeting, and staffing, PDAM and the government must evaluate the ideal size of business operation. This will certainly affect the efficiency of PDAM performance in the future, assuming that the PDAM can operate optimally.

Regarding the heterogeneity of Indonesia, in places with arid natural conditions, dense populations, and contaminated water supplies, PDAMs reduce efficiency and production. Since most of them are located in Java, PDAMs operating in areas with these characteristics are advised to exercise caution and cooperate with the government to consider appropriate solutions, such as increasing the budget for water treatment, consolidating PDAM units, and adaptation for new technology. Along with promoting innovation and adoption of cutting-edge technology in water utilities, PDAM and the government should leverage this technology to boost production and efficiency. Although not discussed in the report, this technology may boost PDAM productivity in water supply by establishing adequate standard operating procedures and regular staff training.

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