



Quality efficiency of Electricity Distribution Companies in New Zealand

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Abstract

Controlling and improving the quality standard of products is a must-do strategy for all companies in competitive market. By applying DEA method to analyze technical efficiency in Efficiency model and Quality efficiency model for 29 electricity distribution businesses (EDBs) in New Zealand, the author is giving a benchmark for those companies to improve their performance. The paper also points out the problems in efficiency and quality management for each EDBs.

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1. Introduction

Electricity invention is one of biggest invention of human in controlling and using the energy of nature. Since then there are hundreds of inventions and improvements for using electricity process and electricity distribution is one of focused area. Electric power moves from generating station through a step-up transformer where the voltage is increased to a level appropriate for transmission. Electricity from each generating station, when flowing in the transmission system, is merged with one from other sources. It then goes through a substation step-down transformer before being delivered to customers. At this point, the transmission voltage is reduced to a specific level depending on the need of individuals or factories. The whole process to deliver electricity from the generating stations to the end users is call electricity distribution.

Electricity is transport from the national grid to homes and businesses across New Zealand, by means of overhead wires and underground cables. The electricity distribution process is provided by 29 distribution companies. Some of the largest distribution companies are listed on the stock exchange, but most are owned by trusts or local councils. In New Zealand, the national grid includes 11,700 route km of high voltage transmission line and 40,600 supporting towers and poles. Total consumption of electricity in New Zealand was almost 39,000 gigawatt hours (GWh) of electricity in 2014, 32 per cent of which was consumed by residential consumers.¹

There are many electricity companies attended to distribution industry which will provide a better competitive market. Hence, it is important for each company to know their position in the relationship with other companies in New Zealand electricity market to have a right strategy for future development. Moreover, in a competitive market quality of product can be considered as one of biggest goals, the companies have to achieve. From that perspective, it is interesting to research about “Quality efficiency of electricity distribution companies in New Zealand.

2. Literature review

Table 1: Overview of studies of benchmarking electricity distribution²

¹ Data provided in “Electricity in New Zealand” report, published in January, 2016 by The Electricity Authority. The Electricity Authority is an independent Crown entity responsible for overseeing and regulating the New Zealand electricity market.

² This is my updated table of research collection which initially published in Jamasb, T. and Pollitt, M., 2000. Benchmarking and regulation: international electricity experience. Utilities policy, 9(3), pp.107-130.

Author	Paper	Data	Input	Output	Method
Pombo, C. and Taborda, R., (2006)	Performance and efficiency in Colombia's power distribution system: Effects of the 1994 reform	from 12 large electricity distribution companies in Colombia			DEA, Malmquist productivity index
Bertram, G. and Twaddle, D., 2005	Price-cost margins and profit rates in New Zealand electricity distribution networks since 1994: the cost of light handed regulation	Data for the financial years 1995–2002 comes from the annual financial statements			pricing model
Dimitrios Giannakis, Tooraj Jamasb, , Michael Pollitt (2004)	Benchmarking and incentive regulation of quality of service: an application to the UK electricity distribution networks	14 DNOs in the UK (including the 12 utilities in England and Wales as well as the distribution activity of the two vertically integrated Scottish companies) for the period from 1991/92 to 1998/99	Opex and total expenditures (Totex) (i) total number of customers (CUST), (ii) units of energy delivered (ENGY), and (iii) total network length (NETL)	*continuity dimension of quality: (i) the number of customers interrupted per 100 connected customers (security of supply) and (ii) the average customer minutes lost per connected customer (avail- ability of supply) * security of supply and availability of supply: (i) number of interruptions (NINT) and (ii) customer time lost due to interruptions (TINT)	
Jamasb, T. and Pollitt, M., (2003)	International benchmarking and regulation: an application to European electricity distribution utilities	63 regional electricity distribution utilities in six European countries: Italy, the Netherlands, Norway, Portugal, Spain, and the United Kingdom			DEA, COLS, SFA
Tser-yieth Chen (2001)	An assessment of technical efficiency and cross-efficiency in Taiwan's electricity distribution sector	22 distribution districts with the data source being an official report on the Taiwan Power Company; the data year is 1997 and 1998	labor, capital equipment and general expenses delivered (ENGY), and (iii) total network length (NETL)	service provided to its customers	
Grifell-Tatje and Lovell (2000)	Cost and productivity	9 Spanish distribution utilities 1995	•LV lines (km) •MV lines (km) •HV lines (km) •transf. cap. HV to	•No. of LV custom. •no. of MV/HV custom, •service area •units sold •service reliability	DEA

			MV/LV •transf. cap. MV to LV		
Pardina and Rossi (2000)	Technical change and catching-up: the electricity distribution sector in South America	36 Latin American distribution utilities 1994—1997	•Units sold •no. of employees •transformer capacity •service area •network size •residential/tot. sales (%)	•No. of customers	SFA
IPART (1999)	Regulatory Tribunal of New South Wales	219 Australian, New Zealand, UK, US dist. utilities 1995-1998	•OPEX •network size •transform, cap.	•Electricity delivered •no of custom. •peak demand (MW)	Malmquist and Tornqvist indexes
Filippini (1998)	Are municipal electricity distribution utilities natural monopolies?	39 Swiss municipal dist. utilities 1988-1991	•Labour •load factor •purchased power	•Units delivered •load factor •service area •no. of custom.	Cost function
Forsund and Kittelsen (1998)	Productivity development of Norwegian electricity distribution utilities	150 Norwegian dist. Utilities 1983-1989	•Labour •losses •capital •materials	•Distance index (density) •no. of custom, •energy supplied	DEA-Malmquist
Goto and Tsutsui (1998)	Comparison of productive and cost efficiencies among Japanese and US electric utilities	9 Japanese and 14 US utilities 1983-1993	•Generation cap. •fuel (kCal) •labour •power purchases	•Residential sales (GWh) •non-residential sales (GWh)	DEA
Meibodi (1998)	Efficiency considerations in the electricity supply industry: The case of Iran	26 LDCs, 30 Iranian plants and dist utilities (1995)	•No. of employees •labour •network size •transform, cap. •generating cap. •fuel efficiency	•Sales — residential •sales — industrial •no. of resid. customers •no. of ind. custom.	SFA DEA
Zhang and Bartels (1998)	The effect of sample size on the mean efficiency in DEA with an application to electricity distribution in Australia, Sweden and New Zealand	32 Australian power authorities, 51 New Zealand power boards, 173 discos in Sweden	•No. of employees •total km of distribution lines •total transformer cap.	•Total no. of customers served	DEA Monte Carlo simulation
Yunos and Hawdon (1997)	The efficiency of the national electricity board in Malaysia: An intercountry comparison using DEA	27 LDCs (1987), Malaysia, Thailand, and UK (1975- 1990)	*Installed cap *labour *losses *generation cap. Factor (%)	Gross electricity production (GWH)	DEA cross-section and time-series
Bagdadioglu et al. (1996)	Efficiency and ownership in electricity distribution: a non-parametric model of the Turkish experience	76 Turkish retail distribution organisation 1991	•Labour •transformer cap. •network size •general expenses •network losses	•No. of customers •units supplied •max demand •service area	DEA

Burns and Weyman-Jones (1996)	Cost functions and cost efficiency in electricity distribution: a stochastic frontier approach	UK RECs 1980/1981 to 1992/1993	•Max. demand •no. of custom. •customer dispersion •service area •units sold •network •transf. cap. •ind. demand •user CAPEX and labour cost •OPEX	•OPEX	SFA — cross-sectional and panel data
Pollitt (1995)	Ownership and performance in electric utilities: the international evidence on privatization and efficiency	129 US transmission firms 136 US and 9 UK distribution firms 1990	T: •labour •length*voltage •transf. cap. D: 'labour •transf. cap. •network size	T: •electricity input, •max. demand, •network size, D: •no. of custom, •sales — residential •sales — non-residential •service area	•DEA and OLS
Berry (1994)	Private ownership form and productive efficiency: Electric cooperatives versus investor-owned utilities	US rural co-operatives and private utilities 1988	•Capital •labour •fuel •bulk power purchased	Power sold to: 'other utilities •indust, custom, functions •resid./commercial custom.	Translog cost functions
Burns and Weyman-Jones (1994)	The performance of the electricity distribution business-England and Wales, 1971-1993	UK RECs in England 1973-1993	•No of full time employees •network size •transf. capacity •customer density •share of industrial energy	•No of custom. •units of domestic custom, •units to commercial users •units to ind. users •max. demand	•Non-parametric programming •Malmquist index
Claggett (1994)	Ownership form and rate structure: an examination of cooperative and municipal electric distribution utilities	157 TVA distributors 1982-1989 (108 municipals and 49 co-operatives)	•No. of full-time and fulltime equivalent employees •book value of the dist. system, •purchased electricity	•Energy delivered and sold retail •no. of custom. <50 kWh •no. of custom. >50 kWh •dist. load factor •service area	Translog cost function
Miliotis (1992)	Data envelopment analysis applied to electricity distribution districts	45 dist. Districts of the Greek Public Power Corporation (PPC)	•Network size •transf. cap. •general expenses •administrative labour (hrs) •technical labour (hrs)	•No. of custom. •energy supplied •network size •transf. cap. •dummies for urban centres •service area	DEA
Weyman-Jones (1991)	Productive efficiency in a regulated industry: The area electricity boards of England and Wales	12 UK Area Boards 1986/1987	•No. of employees •capital value •network size	Retail sales to: 'domestic •commercial •ind. customers	DEA
Charnes et al. (1989)	An introduction to data envelopment analysis with some of its models and their uses	75 Texas electric co-operatives	•OPEX •maintenance •custom, account cost •admin, costs •network/custom. •wages •outage •% system unload •losses •plant size •inventories	•Net margin •units sold •revenues from sale	•DEA •regression and ratios

Table 1 is an overview of current studies and benchmarking method for electricity distribution with input and output variables. It is clear that there are a number studies about the efficiency of electricity distribution based on cost, pricing model or technical model however, there is only one paper trying to capture the quality of this industry by reliability value. Therefore, focusing on this side could open a new approach to understanding this industry.

3. Methodology

Data Envelopment Analysis (DEA) is a nonparametric method which is focusing on approaching data for evaluating the performance of entities by generating multiple inputs into multiple outputs. These entities are called as Decision-making Units (DMUs). This method is initially developed based on the application of linear programming which was used to measure performance.

Table 2: Milestone of Data Envelopment Analysis Model

Authors	Article	Journal	Contribution
Farrell, M.J., 1957.	The measurement of productive efficiency	Journal of the Royal Statistical Society. Series A (General), 120(3), pp.253-290.	Authors pointed out the usual index number problems of the current attempts to measure efficiency. Then they introduced a new model which take accounts of all inputs and avoid current problems based on linear method.
Charnes, A., Cooper, W.W. and Rhodes, E., 1978.	Measuring the efficiency of decision-making units	European journal of operational research, 2(6), pp.429-444.	A method for determining weights by observing data for the multiple outputs and inputs provided to apply a scalar measure of the efficiency of each decision-making unit. Using dual linear programming models, authors introduced a new way to estimate the relationship from observational data.
Banker, R.D., Charnes, A. and Cooper, W.W., 1984.	Some models for estimating technical and scale inefficiencies in	Management science, 30(9), pp.1078-1092.	The variable returns to scale (VRS) efficiency measurement model had been introduced which allow the breakdown of

	data envelopment analysis.		efficiency into technical and scale efficiency in DEA.
Norman, M. and Stoker, B., 1991.	Data envelopment analysis: the assessment of performance	John Wiley & Sons, Inc..	At that time this book gave an overview about DEA model and upcoming discussion and provided detailed mathematical explanation to widen the improvement and applicability of this model.
Cooper, W.W., Seiford, L.M. and Zhu, J., 2004.	Data envelopment analysis.	Handbook on data envelopment analysis	This handbook can be considered as a dictionary for DEA model. Cooper and his co-authors provided a well organized, comprehensive review and discussion of DEA models, extensions to basic method. The applicability of DEA model to many different fields such as engineering, banking, health care... is also described.

The obvious strength of DEA model is basing on linear programming techniques to encase observed inputs and output vectors as strictly as possible without any assumption on data distribution. In this DEA model, we assume that we observe n Decision-making units (DMUs). These DMUs convert m different inputs to s different outputs. Technically, DMUs will consume x_{ij} of input i and produce a number y_{rj} of output r . At the same time, we assume that $x_{ij} > 0$ and $y_{rj} > 0$ and in each observed DMU contains at least one positive input and one positive output. The measurement of DEA method to compute efficiency of DMUs is a ratio-form between outputs and inputs to illustrate the relative efficiency of $DMU_j = DMU_0$ with $j = 1, 2, 3, \dots, n$. Mathematically, the maximization of this ratio represents as:

$$\max h_0(u, v) = \frac{\sum_r u_r y_{ro}}{\sum_i v_i x_{io}}$$

where u_r, v_i, x_{io}, y_{ro} are the observed outputs and inputs.

To measure the efficiency of Electricity distribution companies in New Zealand, the weakly DEA efficient and DEA efficient definitions for an input-oriented model which described by Cooper et al. (2010) in Handbook of DEA has been chosen. (1) The performance of DMU_0 is fully

efficient if and only if both $\theta^* = 1$ and all slacks $s_i^{-*} = s_r^{+*} = 0$. (2) The performance of DMU₀ is weakly efficient if and only if both $\theta^* = 1$ and $s_i^{-*} \neq 0$ and/or $s_r^{+*} \neq 0$ for some i or r in some alternate optima. The mathematical solution is presented in two steps:

$$\min \theta - \varepsilon \left(\sum_{i=1}^m s_i^- + \sum_{r=1}^s s_r^+ \right)$$

Subject to

$$\sum_{j=1}^n x_{ij} \lambda_j + s_i^- = \theta x_{io} \quad i = 1, 2, \dots, m;$$

$$\sum_{j=1}^n y_{rj} \lambda_j - s_r^+ = y_{ro} \quad r = 1, 2, \dots, s;$$

$$\lambda_j, s_i^-, s_r^+ \geq 0 \quad \forall i, j, r$$

Where: ε is a non-Archimedean element smaller than any positive real number and $\frac{u_r}{\sum_{i=1}^m v_i x_{io}} \geq \varepsilon > 0$, s_i^-, s_r^+ are slack variables which is used to convert the inequalitied in to equivalent equations.

The input-oriented efficiency method which I apply for this paper is measurement linear programming captures how efficiently DMUs convert inputs with given outputs. The computing of technical efficiency (TE) is basing on Constant returns to scale (CRS) and Variable (Returns to scale) which are illustrated by figure 1. The figure 1 is a simple DEA model with 6 companies and

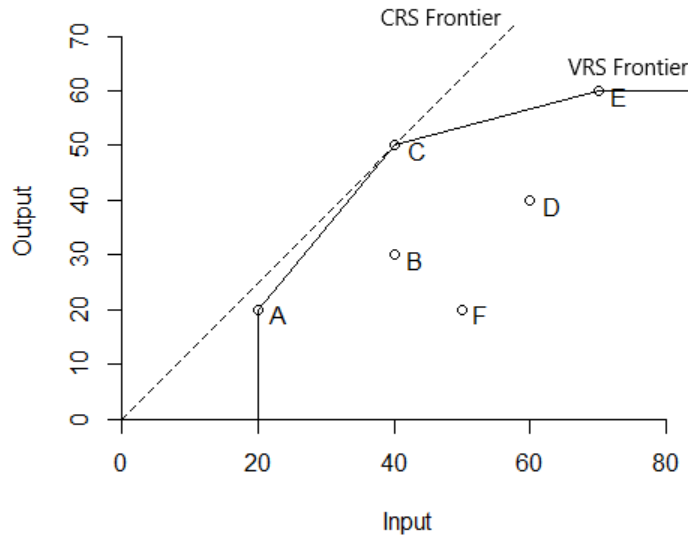


Figure 1: Concepts of Constant Returns to Scale and Variable Returns to Scale

1 input and 1 output. They generated their input into output and has been plotted in the graph. The companies lied on the frontier are the most efficient companies and get $\theta = 1$, the others will get value from 0 to 1 depended on distances of this company with the frontier. The TE with VRS will be used as a main value for discussion in this paper due to the fact that it is referred in BCC (Banker et al. 1984) model while CRS refered in CCR (Charnes et al. 1978) model.

4. Data and model specification

4.1. Choice of variables

To analyze the performance of EDBs and then measuring the difference of that model when we add quality factor to that model, there are two question we have to answer: (1) which variables we should choose to measure the performance of electricity distribution system and (2) which variable we should use to stand for quality measurement.

(1) Choosing variables for performance measurement is an observing and learning process. There are a lot of research about electricity distribution discussed in section 2, comparing those model and reported values in our data of performance measurement I choose these variables to evaluate electricity distribution performance for my paper: total circuit length (for supply) overhead, total circuit length (for supply) underground, total distribution transformer capacity, electricity volumes carries, and number of connection points.

(2) To evaluate the quality of EDBs, there are two features which are most used: System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI)³. However, in this paper I aim to have an overview about the general of electricity distribution quality, I decided to choose SAIDI as an only value to evaluate the quality. This is the average outage duration for each customer served, and is calculated as:

$$SAIDI = \frac{\text{Total duration of customer Interruptions}}{\text{Total number of customers served}} = \frac{\sum U_i N_i}{N_T}$$

Where N_i is the number of customers and U_i is the annual outage time for the location i and N_T is the total number of customers served. SAIDI is lower the better quality is. Therefore the target of EDBs is to minimize the value of SAIDI. Value of SAIDI contains the advantage of modern

³ The features SAIDI and SAIFI to measure the quality of EBDs are widely accepted by distributor companies and authorized. They are set as a standard of quality or EBDs and reported in “Default price-quality paths for electricity distributors from 1 April 20015 to 31 March 2020” Section 6, published 28 November 2014 by Commerce Commision Department of New Zealand.

technology which will decrease the frequency of electricity interruption, the efficiency of managing and solving electricity problems during distribution periods.

4.2. Data

The data used for this empirical data analysis were collected and published by Commerce Commission Department of New Zealand under the requirement for information disclosure under Part 4 of the Commerce Act for Electricity Distribution Businesses (EDBs). All required data collected from all 29 EDBs in New Zealand for the period ended 31 March 2008, 2009, 2010, 2011 and 2012.

Reported data contains these categories:

- (1) Financial Statements Information
- (2) Asset Value Information
- (3) Measurement Performance Information
- (4) Asset Management Information

which organized into factors and subfactors. However, in this paper, I aim to figure out the efficiency of electricity distribution segment in the comparison with adding quality factor so I just focus on the value presented in Measurement performance information.

With chosen variables above, disclosure database provided the input data for empirical data analysis with the summary as follow:

Table 3: Summary of input data

Variables	Observation	Mean	Std. Dev.	Min	Max
Decision-making Units	143	14.8951	8.381496	1	29
year	143	2010.007	1.416684	2008	2012
Number of connection points	143	68259.03	114740	4320	679612
Electricity volumes carries (GWh)	143	1032.336	1734.49	43.538	10650.12
Total circuit length (for supply) Overhead (km)	143	3794.571	4170.779	32.4	23183.92
Total circuit length (for supply) Underground (km)	143	1344.693	2200.392	27.5	11669.14
Total distribution transformer capacity (MVA)	143	650.2811	971.0384	34	5643.044
System average interruption duration index	143	213.4144	150.3191	16.935	915.1562

Each EDB is a decision-making unit, therefore we observed total 29 DMUs and each DMU has been observed in 5 years from 2008 to 2012 so the total observation could be 145. However, values

of Orion New Zealand was missing in 2011 and of Wellington Electricity Limited was missing in 2008, those values will be skipped that why there are only 143 observations in total.

4.3. Model specification

Benchmarking electricity efficiency using DEA model, we don't need a parametric model to estimate the relationship between selected variables because this is a method for computing the efficiency based on the linear frontier. However, choosing the right input and output variables and the DEA method is the most important step for this methodology.

Choosing this model is based on the goal of this paper which is estimated the quality efficiency of electricity distribution businesses by SAIDI. SAIDI needs to be as small as possible to reach higher distribution quality level. Therefore, input-oriented DEA model which aims to minimize input resources to get a certain level of outputs is selected. Using this model, output variables must have negligible variations and come from external sources. That is why "Number of connection points" and "Electricity volume carries" are selected. A connection point is the point agreed in the connection contract form at the boundary between the electrical installations belonging to the distribution system operator and the customer being connected ⁴. Consequently, this value correlated with the number of households and industrial companies which are quite stable in New Zealand and not increase or decrease with the desire of electricity companies. Electricity volume carries mainly depends on consumption of all customer in New Zealand because the supply from power companies has exceeded the demand⁵.

Those variables contain total circuit length overhead, total circuit length underground, total distribution transformer capacity and system average interruption duration index will be input variables. EDBs will try to minimize those values to increase the efficiency.

Furthermore, to highlight the impact of SAIDI in the comparison with electric efficiency, benchmarking test will be run in 2 model.

Model 1: Efficiency model – Input-oriented model

- ❖ Output: Number of connection points (nofcp)

⁴ This definition was given by Kymenlaakson Sähkö Oy Group in Finland. Their main business sectors are electric energy sales, electricity distribution, and contracting. <https://www.ksoy.fi/en/electricity-distribution/instructions-and-advice/connection-point-connection-cable-and-metering-centre>

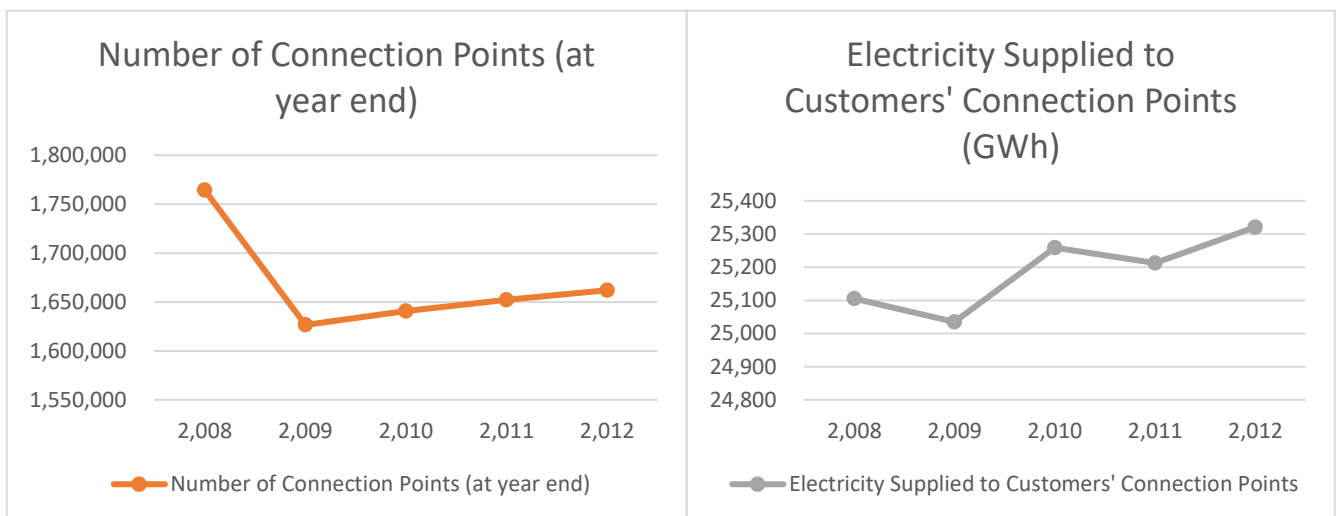
⁵ Explained in Executive Summary of Report from Efficient Energy International and Norman Smith, Senior Adjunct Associate/Senior Research Fellow-New Zealand, April 2017 : Toward 100% Renewable Electricity

- ❖ Output: Electricity volumes carries (ES)
- Input: Total circuit length (for supply) Overhead (CLO)
- Input: Total circuit length (for supply) Underground (CLU)
- Input: Total distribution transformer capacity (DTC)

Model 2: Quality efficiency model – Input-oriented model

- ❖ Output: Number of connection points (nofcp)
- ❖ Output: Electricity volumes carries (ES)
- Input: Total circuit length (for supply) Overhead (CLO)
- Input: Total circuit length (for supply) Underground (CLU)
- Input: Total distribution transformer capacity (DTC)
- Input: System average interruption duration index (SAIDI)

Figure 2 reveals the trend of input data. While the circuit length for supply underground and overhead remain consistent during analyzing time, there is a tone down of numbers of connection points, electricity supplied to customer and distribution transformer capacity in 2009. The shortage of these values due to the impact of financial crisis on New Zealand economic. Households, industrial factories reduce energy consumption to react to the crisis.



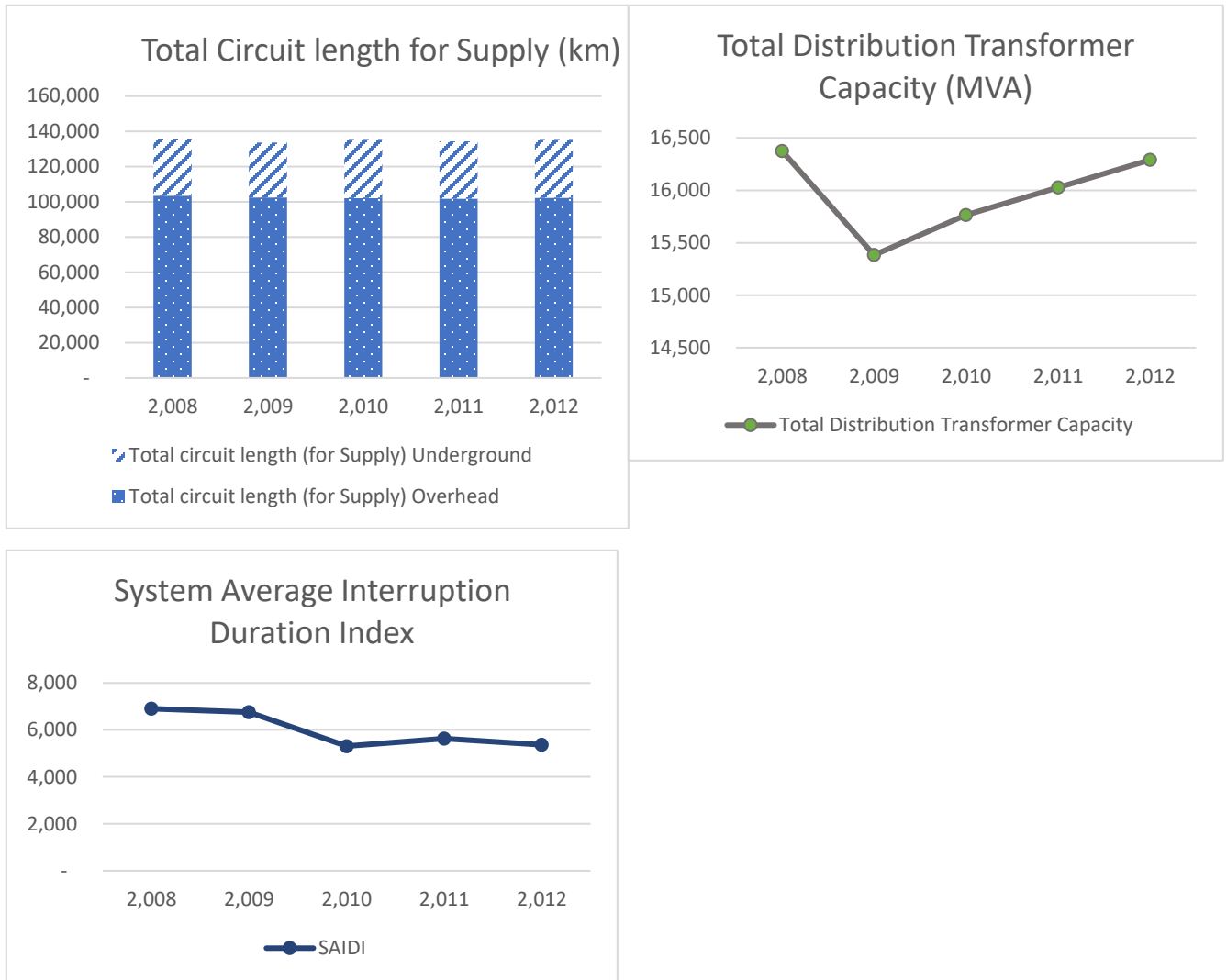


Figure 2: Summary of Input data based on model variables (time is measured in fiscal years)⁶

5. Results

5.1. Technical efficiency scores

The technical efficiency scores for EDBs in New Zealand was computing by Stata according to the method presented by Yong-bae Ji, Korea National Defense University and Choonjoo Lee, Korea National Defense University in 2010. VRS and CRS input-oriented two-stage DEA model were applied to measure 143 observations data. Corresponding with each observation we receive each technical efficiency score of VRS and CRS which mean that there are 5 VRS and CRS values

⁶ As explained above we missed 2 values of Orion New Zealand in 2011 and Wellington Electricity Limited in 2008, which may lead to wrong calculation when we sum the input values in years. On that account, the summary of data in this figures disregard all values of thos companies to create a relevant comparision in time series.

for each decision-making unit. Therefore, the average of technical efficiency scores ($\bar{\theta}$) of each electricity distribution business calculated to present for the efficiency of that company. Each company will manage and generate their resources to outputs in their own way however comparing the efficiency scores will help them point their position relatively with others. The rank of $\bar{\theta}$ computed based on the size of $\bar{\theta}$ value.

Table 4 shows the result from analyzing processes. VRS_Q and CRS_Q are variable return to scale and constant return to scale values generated by Quality efficiency model, while VRS and CRS are variable return to scale and constant return to scale values generated by Electricity efficiency model. The technical efficiency scores are computed by the distance of efficiency point of a decision-making unit to efficiency frontier $\bar{\theta}$.

It is obvious that Welling Electricity Limited, Electricity Invercargill, Vector Lines Limited, Nelson Electricity Limited and Electra Limited are five best electricity distribution in efficiency. With variable return to scale method, mean thetas of the seven highest ranked companies are varied from 0.993 to 1, it is clear that those companies are reaching or on the efficiency curve. The average mean theta and median values of 29 EDBs with VRS and CRS in efficiency model are respectively 0.90, 0.91 and 0.87, 0.88 which are comparatively close to each other. Therefore, we can come with the conclusion that the efficiency of EDBs in New Zealand are well distributed and the difference in management and technology of those companies are close to each other. However, there is a special company – The power company who reach $\bar{\theta} = 0.9926$ in VRS and ranked seventh but in CRS $\bar{\theta} = 0.7991$ and only ranked twenty-third. The only reasonable explanation for this case is that The power company is the first or the last company on variable return to scale linear which has a high score for VRS but lowest score for CRS in comparison with other companies in VRS linear. This reason could also use to explain why this company ranked the first of VRS in Quality efficiency model but took thirteenth of CRS in Quality efficiency model. According to our methodology of DEA for VRS, The power company is using their input resources effectively and hardly to reduce input values to create the same level of current outputs.

Top Energy Limited, Centralines limited, Aurora Energy, Marlborough Line Limited and Mainpower New Zealand are 5 worst EDBs in efficiency in New Zealand. Their efficiency scores are just got 0.67 to 0.80 which mean that they can reduce their inputs by 20% to 37% and still reach their current outputs. They have to focus to improve their performances in increase efficiency.

Table 4: Technical efficiency scores with Variable return to scale and Constant return to scales in Efficiency model and Quality efficiency model

Company name	dmu	VRS		CRS		VRS_Q		CRS_Q	
		$\bar{\theta}$	Rank $\bar{\theta}$	$\bar{\theta}$	Rank $\bar{\theta}$	$\bar{\theta}$	Rank $\bar{\theta}$	$\bar{\theta}$	Rank $\bar{\theta}$
Wellington Electricity Limited	28	1	1	0.99902175	1	1	1	0.99915525	1
Electricity Invercargill	9	0.9982408	2	0.9959994	3	0.9982408	4	0.9959994	4
Vector Lines Limited	25	0.9974942	3	0.9957796	4	0.9999704	3	0.9986338	2
Nelson Electricity Limited	13	0.9972872	4	0.9937426	5	0.9972872	5	0.99479	5
Electra Limited	7	0.9968214	5	0.9967358	2	0.996828	6	0.996758	3
Buller Electricity	3	0.9929584	6	0.9585592	9	0.9957512	7	0.9653322	10
The Power Company	22	0.9926482	7	0.7990562	23	1	1	0.9566066	13
Network Waitaki Limited	15	0.982167	8	0.9802514	6	0.987452	9	0.987179	7
OtagoNet Joint Venture	18	0.9786462	9	0.975823	7	0.9861358	10	0.984454	8
Horizon Energy Distribution	10	0.9670572	10	0.9657464	8	0.9789512	11	0.9770536	9
Northpower Limited	16	0.9585554	11	0.956391	10	0.9891492	8	0.9886046	6
Counties Power	5	0.9481622	12	0.941606	11	0.9659362	13	0.9632676	11
The Lines Company	21	0.9257936	13	0.8776306	16	0.9257936	15	0.9209468	15
WEL Networks	27	0.9218134	14	0.915166	12	0.9297978	14	0.9294066	14
Scanpower Limited	20	0.9128556	15	0.8921572	13	0.9762232	12	0.9592318	12
Waipa Networks Limited	26	0.9074584	16	0.8780172	15	0.9075708	17	0.8881376	16
Westpower Limited	29	0.9057748	17	0.8800834	14	0.9110948	16	0.8813808	17
Powerco Limited	19	0.8978476	18	0.8173662	19	0.8978476	18	0.8623322	18
Electricity Ashburton	8	0.8800054	19	0.8556904	17	0.8800054	19	0.8556904	19
Eastland Network	6	0.8547228	20	0.804439	21	0.8550904	20	0.8477944	20
Orion New Zealand	17	0.8366108	21	0.83656525	18	0.85268975	21	0.844482	21
Alpine Energy Limited	1	0.8255958	22	0.8113346	20	0.8383758	22	0.8355594	22
Network Tasman Limited	14	0.8072436	23	0.800221	22	0.8172966	23	0.803302	25
Unison Networks	24	0.8023906	24	0.7926284	25	0.805362	25	0.8036944	24
Top Energy Limited	23	0.7961128	25	0.7942796	24	0.7961128	26	0.7942796	26
Centralines Limited	4	0.777056	26	0.7379246	27	0.8111948	24	0.804805	23
Aurora Energy	2	0.7766608	27	0.7713052	26	0.7893378	27	0.7875662	27
Marlborough Lines Limited	12	0.682248	28	0.6590854	29	0.684542	29	0.6769102	29
Mainpower New Zealand	11	0.6791718	29	0.670031	28	0.700233	28	0.6967914	28

5.2. Effect of Quality efficiency model

The VRS and CRS of Quality efficiency model are also reported in Table 4. The top 5 EDBs in Efficiency model again appear in top 5 of Quality efficiency model implied that besides investing their effort to reduce total circuit length for supply both Overhead and underground and total distribution transformer capacity, they also minimize their SAIDI to reach highest technical efficiency in Quality efficiency model. To do that, they have to apply new technology, enhanced inspection, and maintenance of electric distribution systems to increase electricity interruption frequency during deliver electricity process. Furthermore, the ability to react to unexpected incidents with a team of technicians is also focused.

In the opposite direction, although there are small changes in top 5 worst technical efficient values in Quality efficiency model, they still reveal their bad performance in managing their inputs which could be reduced from 20 to 30% and still reach the same outputs.

From the values in table 4, it is easy to realize the technical efficiency in both models moving in the same direction. To test the correlation between those θ , Pearson correlation test was applied with original θ from DEA analysis and the results presented in table 5. The correlation values vary from 0.92 to 0.99 between those θ giving a strong evidence for their strong correlation.

Table 5: Pearson correlation of technical efficiency in 2 model

		Efficiency model		Quality efficiency model		
		VRS	CRS	VRS	CRS	CLU/(CLU+CLO)
Efficiency model VRS CRS Quality efficiency model VRS CRS CLU/(CLU+CLO)		1.0000				
		0.9243	1.0000			
		0.9839	0.9128	1.0000		
		0.9755	0.9430	0.9884	1.0000	
		0.2412	0.3577	0.2059	0.2491	1.0000

Modern technology was mentioned as a key factor higher technical efficiency. It comes to a prediction that the company which higher rate of underground circuit length also has more advanced techniques hence having higher θ . To test that prediction, another Pearson correlation was applied between the rate of Underground circuit length for supply over the circuit length for supply and other θ and also showed in table 5. The value r of these correlation ranging from 0.24 to 0.36 which represent for very small correlation or in the other way we don't have evidence to

conclude that the rate of underground circuit length can represent for technology level of that company.

5.3. Reduction rate in Quality efficiency model

The mean theta ($\bar{\theta}$) of VRS_Q in table 4 represent how near efficiency curve of mentioned decision-making unit and by calculate function: $C = (1 - \theta) \times 100\%$ ⁷ we can know how much of input variable values can reduce and still reach current output levels. These values should use as a reference for improvement quality technical efficiency process at EDBs in New Zealand.

Using dea command for Stata analyzing program developed by Y.B. and Lee, C. (2010), we received islark value for SAIDI. These values defined as a level of SAIDI in which electricity distribution business could down grade after reducing a certain level of inputs C based on θ . The rate of SAIDI islark out of SAIDI imply the quality level of that decision-making unit. The higher rate of SAIDI that company can reduce the lower quality of electricity distribution process.

Table 6: Possible SAIDI reduce rate of EDBs in New Zealand

Company	DMU	year	rank $\bar{\theta}$	VRS_Q $\bar{\theta}$	islark: SAIDI	SAIDI	Reduction rate
Nelson Electricity Limited	13	2011	5	0.991691	95.4818	114.66	83.27%
Nelson Electricity Limited	13	2012	5	0.994745	45.8392	63.47	72.22%
Electra Limited	07	2009	6	0.995959	536.538	683.10	78.54%
Electra Limited	07	2012	6	0.988181	45.8463	131.90	34.76%
Waipa Networks Limited	26	2008	17	0.973826	351.586	497.29	70.70%
Waipa Networks Limited	26	2009	17	0.909351	24.6841	236.99	10.42%
Waipa Networks Limited	26	2010	17	0.887698	48.8617	284.02	17.20%
Waipa Networks Limited	26	2012	17	0.88242	51.9939	274.30	18.96%
Electricity Ashburton	08	2008	19	0.873155	78.5609	199.27	39.42%
Electricity Ashburton	08	2009	19	0.937012	209.206	337.32	62.02%
Electricity Ashburton	08	2010	19	0.922898	65.3229	186.06	35.11%
Electricity Ashburton	08	2011	19	0.913422	136.019	262.68	51.78%
Electricity Ashburton	08	2012	19	0.75354	70.5757	192.70	36.63%
Powerco Limited	19	2008	18	0.988576	91.2588	358.76	25.44%
Powerco Limited	19	2009	18	0.893017	117.182	320.09	36.61%
Powerco Limited	19	2010	18	0.878949	54.0735	253.20	21.36%
Powerco Limited	19	2011	18	0.863601	96.116	306.42	31.37%
Powerco Limited	19	2012	18	0.865095	177.95	400.52	44.43%

⁷ Explained in Ji, Y.B. and Lee, C., 2010. Data envelopment analysis. *The Stata Journal*, 10(2), pp.267-280

Electricity Invercargill	09	2008	4	0.998157	21.5586	54.66	39.44%
Electricity Invercargill	09	2009	4	0.993047	18.0363	51.43	35.07%
Westpower Limited	29	2009	16	0.919388	128.447	382.47	33.58%
Westpower Limited	29	2010	16	0.971721	40.8363	279.31	14.62%
Westpower Limited	29	2011	16	0.916539	50.6551	330.82	15.31%
Top Energy Limited	23	2008	26	0.845125	442.137	818.30	54.03%
Top Energy Limited	23	2009	26	0.816851	499.331	915.16	54.56%
Top Energy Limited	23	2010	26	0.796051	122.555	463.03	26.47%
Top Energy Limited	23	2011	26	0.765972	95.7474	440.02	21.76%
Top Energy Limited	23	2012	26	0.756565	91.3511	434.98	21.00%
Eastland Network	06	2010	22	0.848847	17.3443	322.73	5.37%
Eastland Network	06	2011	22	0.849316	25.1999	340.80	7.39%
Eastland Network	06	2012	22	0.843331	99.1464	437.60	22.66%
OtagoNet Joint Venture	18	2010	10	0.98221	66.1448	341.20	19.39%
OtagoNet Joint Venture	18	2012	10	0.948469	42.0338	320.77	13.10%
Unison Networks	24	2012	25	0.797971	32.3727	249.24	12.99%
The Lines Company	21	2009	15	0.962083	25.5392	297.13	8.60%
The Lines Company	21	2010	15	0.919627	11.5657	293.26	3.94%
The Lines Company	21	2011	15	0.88781	1.86509	292.43	0.64%
The Lines Company	21	2012	15	0.859448	6.71777	324.52	2.07%
Alpine Energy Limited	01	2010	22	0.852824	26.2724	332.37	7.90%

The possible SAIDI reduction rate in table 6 reveals the worst quality electricity distribution company in New Zealand. Although Nelson Electricity Limited, Electra Limited get high level of efficiency scores ($\theta=0.99$) but they are the worst ones to handle electricity interruption. They can reduce upto 83% system average interruption duration index. Therefore, it is a must-do problem in maintaining and upgrade the solving system for electricity interruption in top 5 companies. Their future efforts will help increase customer satisfaction.

5.4. Further discussion about technology in New Zealand

There is a question about technical efficiency of whole electricity distribution industry in New Zealand raising during empirical analyze this paper. We are analyzing and comparing efficiency scores between EDBs to figure out which companies are doing their better job. So what happened with technical efficiency scores during years of whole industry ? And is the later year better previous year? And which is the role of government with current development of this industry?

To answer these questions, VRS input-oriented two-stage DEA for quality efficiency model was run with decision-making units in this test are the year (2008, 2009, 2010, 2011, 2012) instead of EDBs. Then the mean theta of results is calculated and illustrated in figure 3.

Once again, figure 3 shows a strong correlation of CRS and VRS in DEA model. The downward trend of mean theta from 2008 to 2012 implies that the ability to generate inputs to output of electricity distribution industry is getting worse. Or in other words, technology was using for that industry out of date and being less efficiency during time. It opens a new need for government to support this industry.

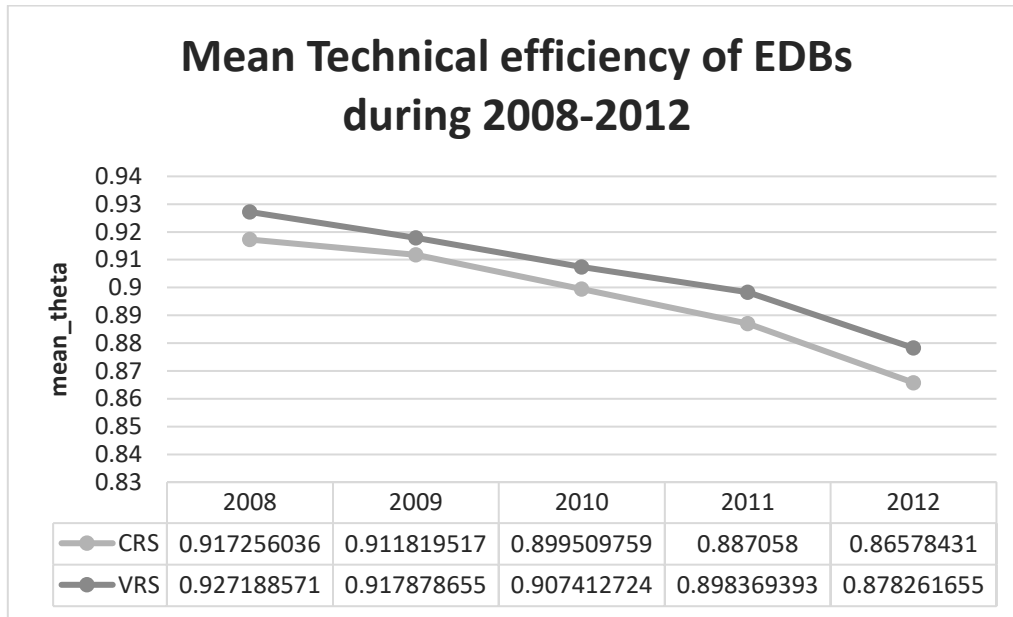


Figure 3: Mean technical efficiency of EDBs in Quality efficiency model during 2008-2012

6. Conclusions

In this paper, by analyzing efficiency level of efficiency model and quality efficiency model we pointed the exact name of companies who did their best to reach highest efficiency level compare with others. The performance and model of those top companies can be useful case studies for the rest EDBs especially the worst companies in that table. The analyzing results also give suggestion level of SAIDI, mentioned companies can reduce to increase customer satisfaction and open a new approach for future studies about electricity distribution industry in New Zealand.

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Affidavit

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Kassel, August 31st, 2017



Tri Dung Huynh