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# 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 distribution[2]

[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 Pollittc (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)<br>(i) total number of customers (CUST), (ii) units of energy delivered (ENGY), and (iii) total network length (NETL) | *continuity dimension of quality:<br>(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)<br>* 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 e ciency and cross-e ciency in Taiwan's electricity distribution sector | 22 distribution districts with the data source being an o cial 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)<br>•MV lines (km) •HV lines (km) •transf. cap. HV to | •No. of LV custom.<br>•no. of MV/HV custom,<br>•service area •units sold<br>•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) | omparison 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<br>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<br>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<br>*labour<br>*losses<br>*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 $j = 1, 2, 3,..n$. Mathematically, the maximization of this ratio represents as:

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

where $u_r$, $v_i$, $x_{io}$, $y_{io}$ 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 $s_i^{+*} \neq 0$ for some i or r in some alternate optima. The mathematical solution is presented in two steps:

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

Subject to

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

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

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

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

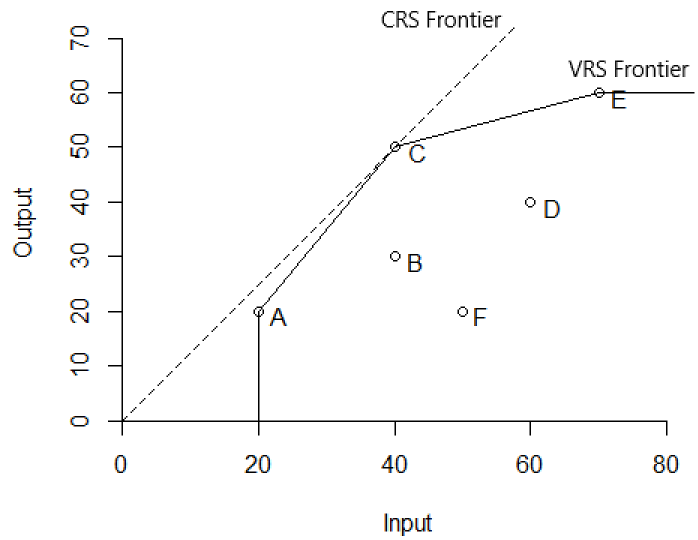



**Figure 1**: Concepts of Constant Returns to Scale and Variable Returns to Scale

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:

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

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 demand[5].

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

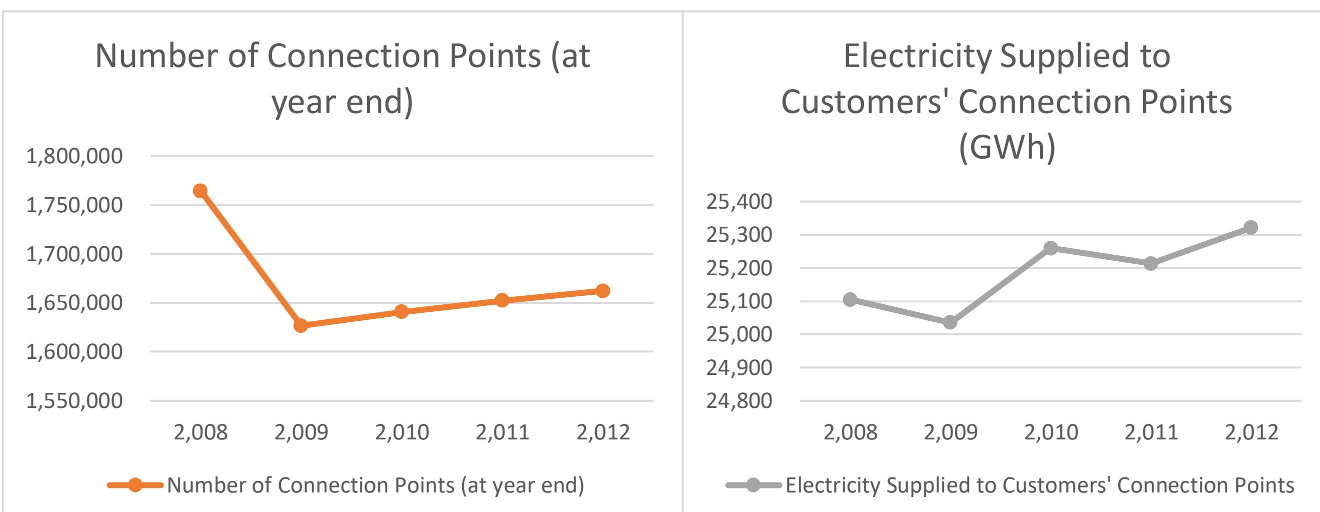
[5] Explained in Executive Summary of Report from Efficient Energy International and Norman Smith, Senior Adjunct Associate/Senior Research Fellow-New Zealand, April 2017 : Toward 100% Renewable Electricity

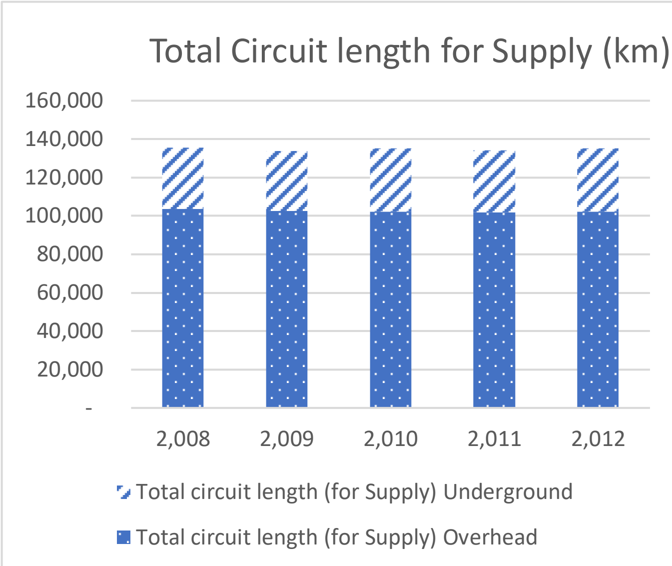
- ❖ Output: Electricity volumes carries (ES)
- ➢ Input: Total circuit length (for supply) Overhead (CLO)
- ➢ Input: Total circuit length (for supply) Underground (CLU)
- ➢ Input: Total distribution transformer capacity (DTC)

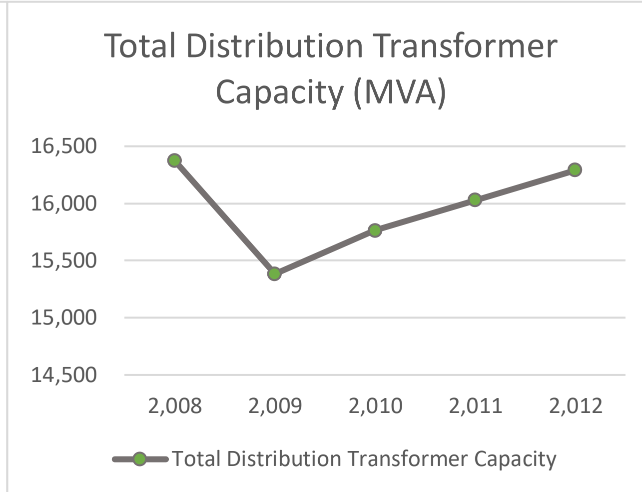
**Model 2: Quality efficiency model – Input-oriented model**

- ❖ 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.





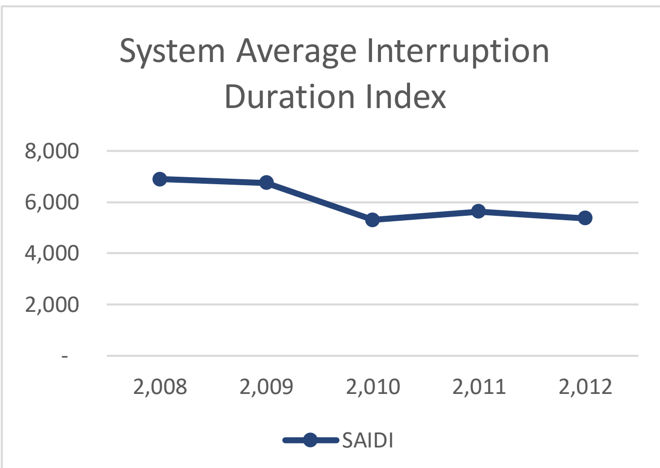




**Figure 2**: Summary of Input data based on model variables (time is measured in fiscal years)[6]

## 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 preresent 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 pointed 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 distant 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 explaination 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 scores 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 thirdteenth 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 $\theta$, 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 | 1.0000 | | | | |
| CRS | 0.9243 | 1.0000 | | | |
| Quality efficiency model | | | | | |
| VRS | 0.9839 | 0.9128 | 1.0000 | | |
| CRS | 0.9755 | 0.9430 | 0.9884 | 1.0000 | |
| CLU/(CLU+CLO) | 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 $\theta$. 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 $\theta$ 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 technifical 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 $\theta$. 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 $\theta$ | 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.

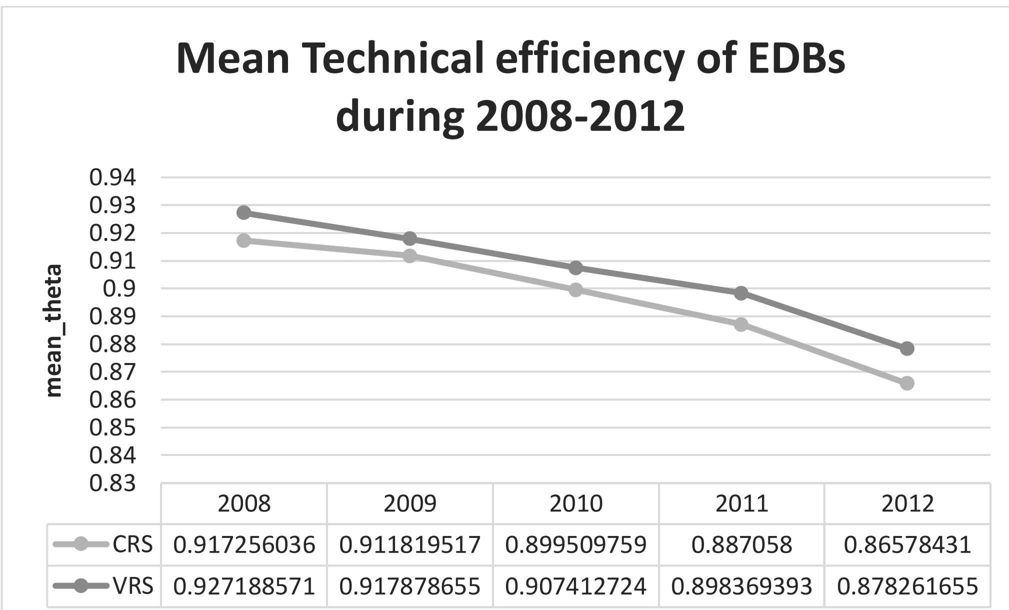



**Figure 3**: Mean technical efficiency of EDBs in Quality efficiency model during 2008-2012

## 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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