LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
Faculty of Technology
Degree Programme in Technomathematics and Technical Physics

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FORECASTING FINANCIAL WEATHER - CAN WE FORESEE MARKET SENTIMENT? QUANTITATIVE ANALYSIS OF NODAL PRICES IN THE NEW ZEALAND ELECTRICITY SPOT MARKET

Examiners: Professor Tuomo Kauranne
D.Sc. (Tech.) Matylda Jablonska-Sabuka

ABSTRACT

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Forecasting financial weather - can we foresee market sentiment? Quantitative analysis of nodal prices in the New Zealand Electricity Spot Market

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Time series of hourly electricity spot prices have peculiar properties. Electricity is by its nature difficult to store and has to be available on demand. There are many reasons for wanting to understand correlations in price movements, e.g. risk management purposes. The entire analysis carried out in this thesis has been applied to the New Zealand nodal electricity prices: offer prices (from 29 May 2002 to 31 March 2009) and final prices (from 1 January 1999 to 31 March 2009). In this paper, such natural factors as location of the node and generation type in the node that effects the correlation between nodal prices have been reviewed. It was noticed that the geographical factor affects the correlation between nodes more than others. Therefore, the visualisation of correlated nodes was done. However, for the offer prices the clear separation of correlated and not correlated nodes was not obtained. Finally, it was concluded that location factor most strongly affects correlation of electricity nodal prices; problems in visualisation probably associated with power losses when the power is transmitted over long distance.

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Lappeenranta, January, 2015.

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List of Symbols and Abbreviations

CEEMDAN	complete ensemble empirical mode decomposition with adaptive noise
DFA	detrended fluctuation analysis
NI	North Island
SI	South Island
SPD	scheduling, prices and dispatch
STD	standard deviation
TDIC	time-dependent intrinsic correlation
WITS	Wholesale and information trading system
WTI	West Texas Intermediate

1 INTRODUCTION

Time series of hourly electricity spot prices have peculiar properties. They differ substantially from time series of other commodities because electricity still cannot be stored efficiently and, therefore, electricity demand has an untempered effect on the electricity spot price (Knittel & Roberts 2005). There are many reasons for wanting to understand correlations in price movements. Perhaps the most familiar motivation is for risk management purposes, because large changes in the value of a portfolio are more likely if the prices of the assets held in the portfolio are correlated.

Numerous studies have attempted to employ correlation analysis for financial markets. Several models and approaches have been presented to understand the way how price behaviour depends on external factors, like how oil price depends on stock market indices. Other models presented, did not take into consideration some important natural factors which may cause the correlation. In this work we try to find out how the behaviour of price in one node in the New Zealand electricity stock market affect all other nodes in the same market. We try to take into account different natural factors that can affect the correlation and show it, using clear visualization.

The work is organized as follows. The next section gives a short review on some previous studies done on correlation in finance. In section 3, an overview of the New Zealand wholesale electricity market including the market participants, how the market works and a description of data used in this work is given. Basic statistical analysis is given in section 4. In section 5 the distance metric for correlation is introduced and investigation of correlation coefficient of nodal prices is presented. Section 6 provides the results of geographic analysis and the clear visualisation for them. A brief summary and discussion are provided in section 7, and finally in section 8 some conclusions are presented.

2 LITERATURE REVIEW

A number of researchers have discussed the correlation in finance. This section presents some of the studies that have been conducted in this field.

The study by Wang & Xie (2012) introduced an analysis of the cross-correlation between West Texas Intermediate (WTI) crude oil market and U.S. stock market indices (i.e., DJIA, NASDAQ and S&P 500) from perspective of econophysics. The cross-correlation at 5% significance level between WTI and U.S. stock market indices was detected using a statistical test in analogy to the Ljung-Box test. Then, employing the multifractal detrended cross-correlation analysis (MF-DCCA) method, we find that the cross-correlated behavior between WTI crude oil market and U.S. stock market is nonlinear and multifractal.

Using random matrix theory, Fenn et al. (2011) calculated the correlation matrices of asset price changes. They examined time series for 98 financial products for the period 8 Jan 1999–1 Jan 2010 from different classes and geographical regions. They indicated that correlation matrices of these asset prices are incompatible with uncorrelated random price changes. Then the principal components of the matrices were marked. The assets that had a greater impact from the principal components were found.

Kanamura (2013) used a multivariative model for analysing the correlation between carbon market and stock price indices. He was deeper interested in the impact of financial market turmoil on correlation. He found that during the sag of stock prices correlation coefficient increases.

Uritskaya & Serletis (2008) analysed price behavior in the Alberta and Mid Columbia markets and made a conclusion that the dynamic of prices is scale-dependent. The detrended fluctuation analysis (DFA) algorithm was used in this research. Using the same DFA-algorithm and the Allan factor method Alvarez-Ramirez & Escarela-Perez (2010) studied correlation factors of both price and demand dynamics. They showed that there is not only scale-dependent behaviour but also time dependent with annual cycle. But they did not analyse price-demand correlation.

In the article by Afanasyev et al. (2014) the correlation between price and demand was investigated in the two largest price zones of Russian wholesale electricity market: Europe-Ural and Siberia. These two zones were chosen for the research because they are different in many aspects (structure of electricity generation and consumption). Using a modified method of the so-called time-dependent intrinsic correlation (TDIC), based on the complete ensemble empirical mode decomposition with adaptive noise (CEEMDAN), and bootstrapping, we investigate the problems of dynamic interconnection between electricity demand and prices over different time scales (i.e. its fine structure). Three hypotheses about short-, medium- and long-runs were done. Hypotheses were checked theoretically. However, not all theoretically proved hypotheses were held in each of time zones. After analysing the results authors concluded that the behaviour of correlation in Europe-Ural and in Siberia differs so the relationship between price and demand depends on structure of electricity generation and consumption.

In the case of periodically correlated processes, Broszkiewicz-Suwaj et al. (2004) studied electricity price returns at the Nord Pool power exchange. They showed that electricity price returns has periodic correlation with daily (24h) and weekly (168h) periods. Then the standard vector autoregression model for parameter estimation was used.

Numerous other scientific models like the ones discussed above have been applied to the correlation in financial markets to try to better understand the dynamics of the prices. However, they did not take into account some factors that might have a big influence on the prices. The research proposed in this work suggested that the geographical factor may have a huge impact on the prices.

3 NEW ZEALAND ELECTRICITY MARKET

New Zealand encompasses two main islands - the North and South Islands (Te Ika-a-Māui and Te Waipounamu). The South Island is larger than the North Island (151000 km^2 vs 114000 km^2), but the North Island has over three times the population of the South Island (3.39 million vs 1.04 million). The climate on the South Island is cooler than on the North and people use electricity heaters, so the electricity consumption per capita is higher on South Island. The South Island has also the largest single electricity user in New Zealand (Tiwai Point Aluminium Smelter). In 2011, on South Island 37.1% of total New Zealand electricity was consumed and 40.9% was generated. Most of electricity on South Island was generated from hydroelectricity ($\approx$ 97%). North Island consumed 62.9% of nation's electricity and generated 59.1% from mainly hydroelectric, natural gas and geothermal generation, plus smaller amount of wind generation (Energy Information and Modelling Group 2012).

Wholesale and information trading system (WITS) is the system for regulating relationships between generators and suppliers of electricity in New Zealand. Prices are calculated for each trading period (every half-an-hour) for the next 24 hours. To rank offers which exists in WITS, the System Operator (Transpower) uses scheduling, prices and dispatch (SPD). Offers are sorted in an order based on price and the System Operator selects the lowest cost to satisfy demand (Electricity Authority

2013). "Electricity is traded at approximately 285 nodes across New Zealand every half an hour. Generators make offers to supply electricity at 59 grid injection points at power stations, while retailers and major users make bids to buy electricity at 226 grid exit points on the national grid." (Wikipedia 2014) So at each node according to its type some (bid price for exit point and offer price for injection point) of the following information is available (Electricity Authority 2011):

1. Bid price - the highest price that a buyer (i.e., bidder) is willing to pay for a good;
2. Offer price - the price a seller states she or he will accept for a good;
3. Final price - the price that a buyer will pay for a good to get it after bidding.

Bidding price is not interesting for analysis because bidders always want to buy electricity for the same price. So we will use data sets for offer prices and final prices. The original data sets contain half-hourly observations. Here, we will take the most volatile one number 31 that corresponds to the time slot between 3:30 and 4 pm. The original data includes three data sets:

- Offer prices - electricity prices for both islands from 29 May 2002 to 31 March 2009 for 120 nodes;
- Final prices for South Island - prices from 1 January 1999 to 31 March 2009 for 59 nodes;
- Final prices for North Island - prices from 1 January 1999 to 31 March 2009 for 119 nodes.

Data was downloaded from New Zealand Electricity Authority website (Electricity Authority 2014).

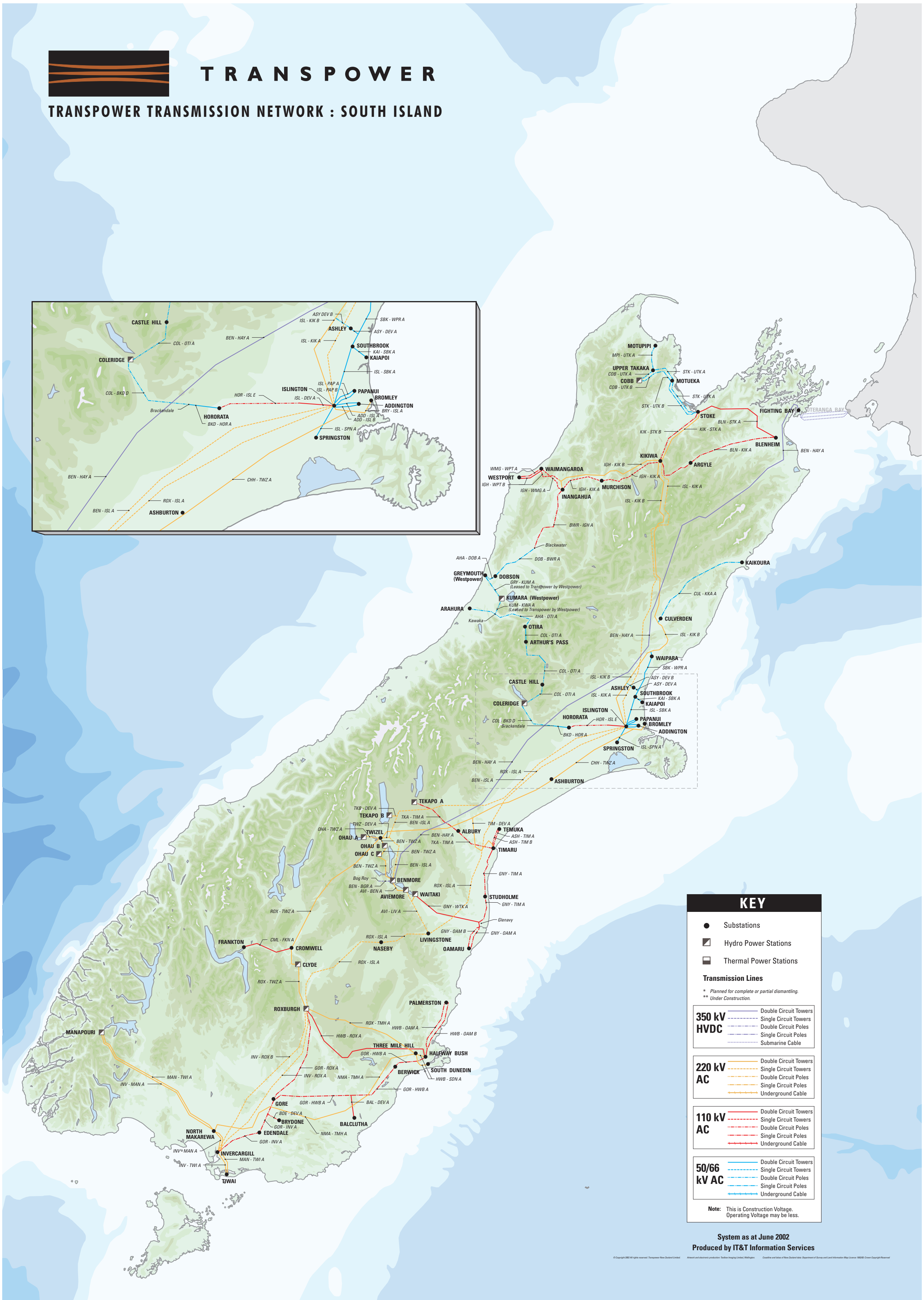

Figure 1: Southern New Zealand supply grid

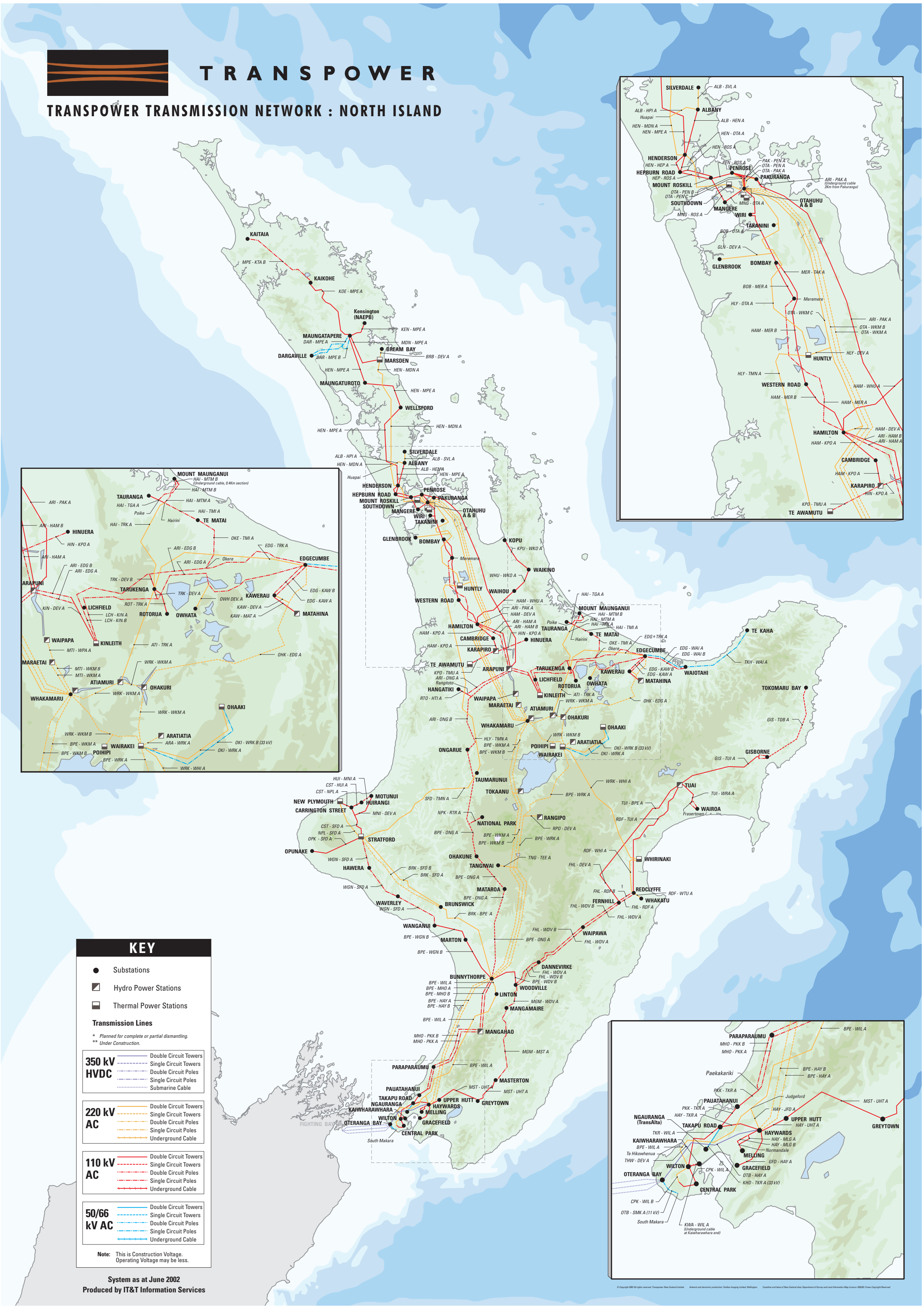

Figure 2: Northern New Zealand supply grid

4 STATISTICAL ANALYSIS OF NEW ZEALAND ELECTRICITY PRICES

4.1 General information and methods of statistical analysis

The first information on the time series can be found from graphical representation of the data and their basic statistics (Kremer 2010). For both data sets, the three most important statistic parameters were found:

- standard deviation - shows how close the data is to the mean value;
- skewness - measure of asymmetry of the distribution;
- kurtosis - measure of the "peakedness" of the distribution.

Each parameter was found in two ways:

- along the time dimension;
- along the node dimension.

For a better understanding, the foregoing calculation of standard deviation for South Island final prices will be shown step by step:

1. Matrix of final prices for South Island:

node dimension (columns); time dimension (rows)

date	*Addington*	*Albury*	⋯	*Westport*
1.1.1999	0.5	0.5	⋯	0.5
2.1.1999	2.6	2.5	⋯	2.7
⋮	⋮	⋮	⋱	⋮
31.3.2009	61.9	57.6	⋯	64.4

Table 1: Example calculation of standard deviation: matrix of final prices, South Island

2. To find standard deviation along the time dimension we should take all columns and for each column find standard deviation.

date	*Addington*	*Albury*	⋯	*Westport*
1.1.1999	0.5	0.5	⋯	0.5
2.1.1999	2.6	2.5	⋯	2.7
⋮	⋮	⋮	⋱	⋮
31.3.2009	61.9	57.6	⋯	64.4
standard deviation	**63.59**	**60.86**	⋯	**67.31**

Table 2: Example calculation of standard deviation: columns for standard deviation along the time dimension, final prices, South Island

As a result we get a row of standard deviation values. Using these values the histogram of standard deviations along the time dimension can be plotted.

3. To find standard deviation along the node dimension we should take all rows and for each row find standard deviation.

date	*Addington*	*Albury*	⋯	*Westport*	**standard deviation**
1.1.1999	0.5	0.5	⋯	0.5	**0.07**
2.1.1999	2.6	2.5	⋯	2.7	**0.35**
⋮	⋮	⋮	⋱	⋮	⋮
31.3.2009	61.9	57.6	⋯	64.4	**9.37**

Table 3: Example calculation of standard deviation: rows for standard deviation along the node dimension, final prices, South Island

As a result we get a column of standard deviation values. Using these values the histogram of standard deviations along the node dimension can be plotted.

According to this step by step instruction other statistics can also be found. If it is the case that the distribution along the time is the same as along the nodes then the time series can be called ergodic. Ergodic time series is handy for theoretical analysis.

4.2 Results of statistical analysis

4.2.1 Final prices

Visualization of distribution of prices is the first step that was done. Three nodes which correspond to three columns in the data matrix were taken for histogram of prices along time dimension (Figures 3 for South Island and 4 for North Island).

Three timestamps (three rows in data matrix) were also chosen for histogram

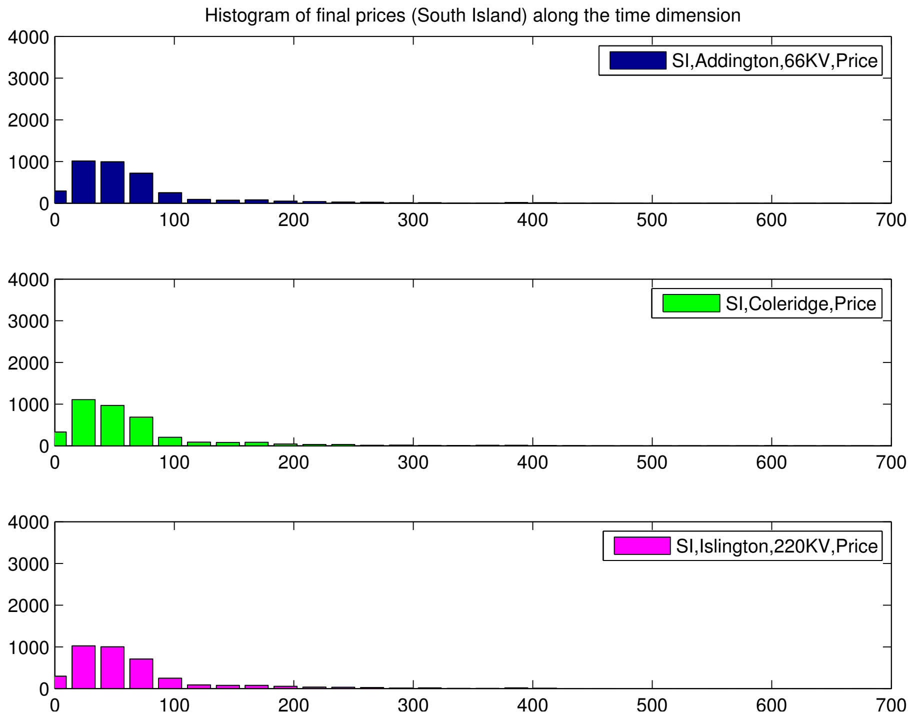

Figure 3: Histogram along the time dimension for final prices (South Island)

of prices along node dimension (Figure 5 for South Island and Figure 6 for North Island). Figures 5 and 6 show that the distribution of prices on each island is similar along the time dimension, but there is no similarity in histograms along the node dimension (Figures 3 and 4). According to the instruction for calculating the statistics, the histograms of most important statistic parameters were plotted (separately for South and North Islands) for standard deviation (Figures 7 and 8), skewness (Figures 9 and 10) and for kurtosis (Figures 11 and 12).

As we can see on the histograms of statistics, the distribution of all parameters are different along the different dimensions. So the most striking result to emerge from the data is that the distributions of the final prices for both islands are non-ergodic.

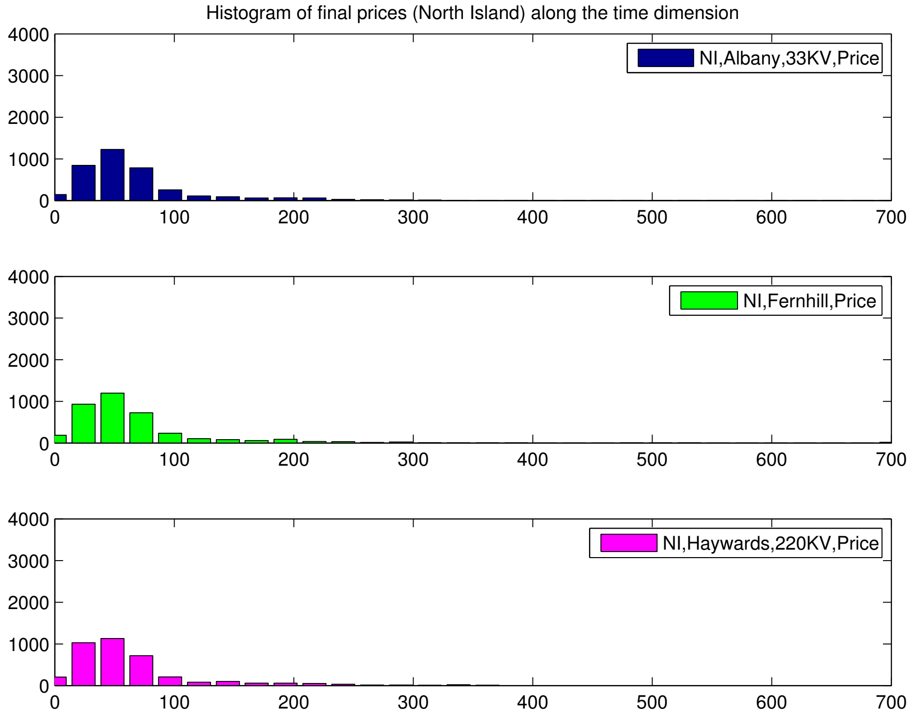

Figure 4: Histogram along the time dimension for final prices (North Island)

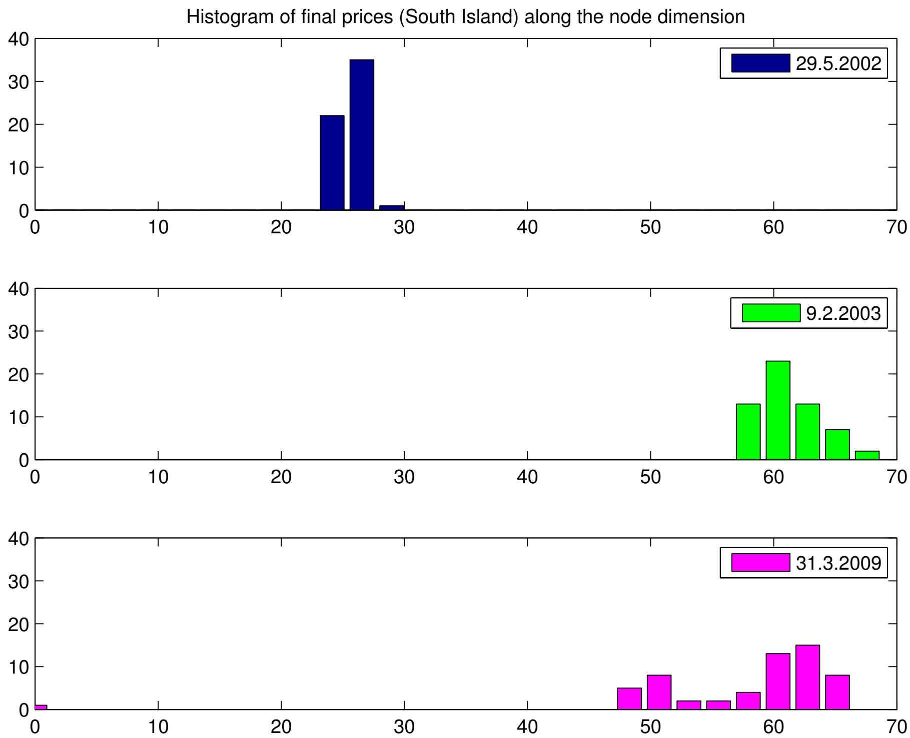

Figure 5: Histogram along the node dimension for final prices (South Island)

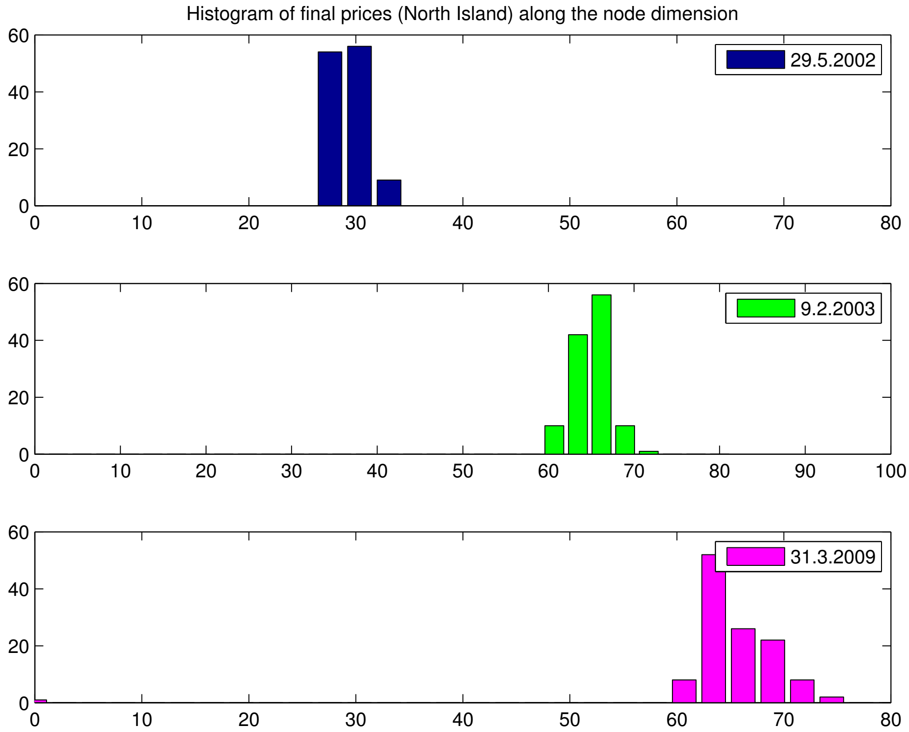

Figure 6: Histogram along the node dimension for final prices (North Island)

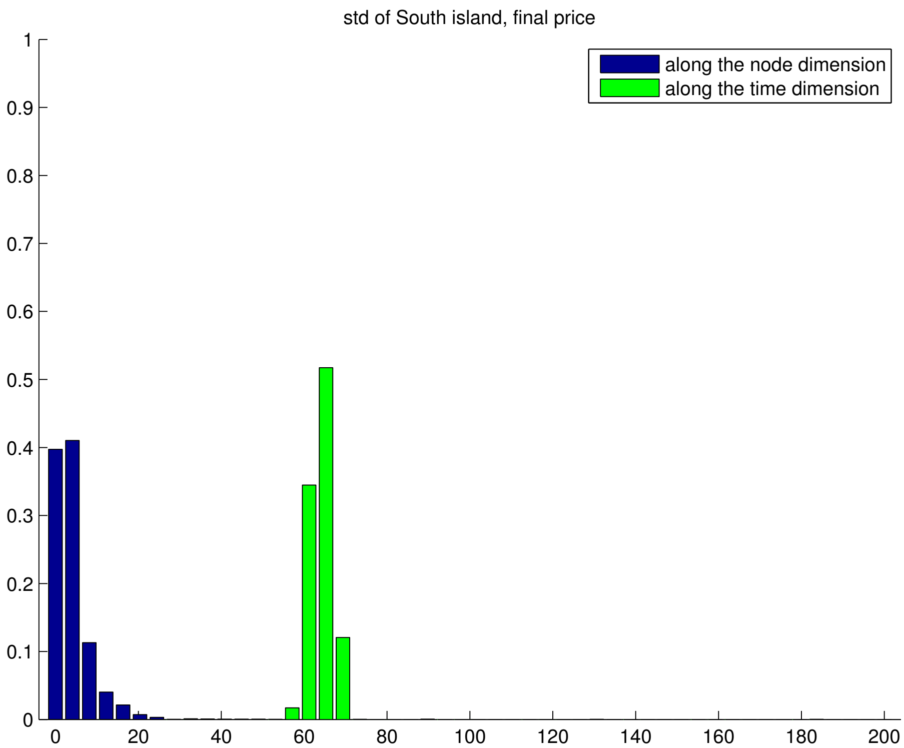

Figure 7: Behavior of standard deviation for final prices (South Island)

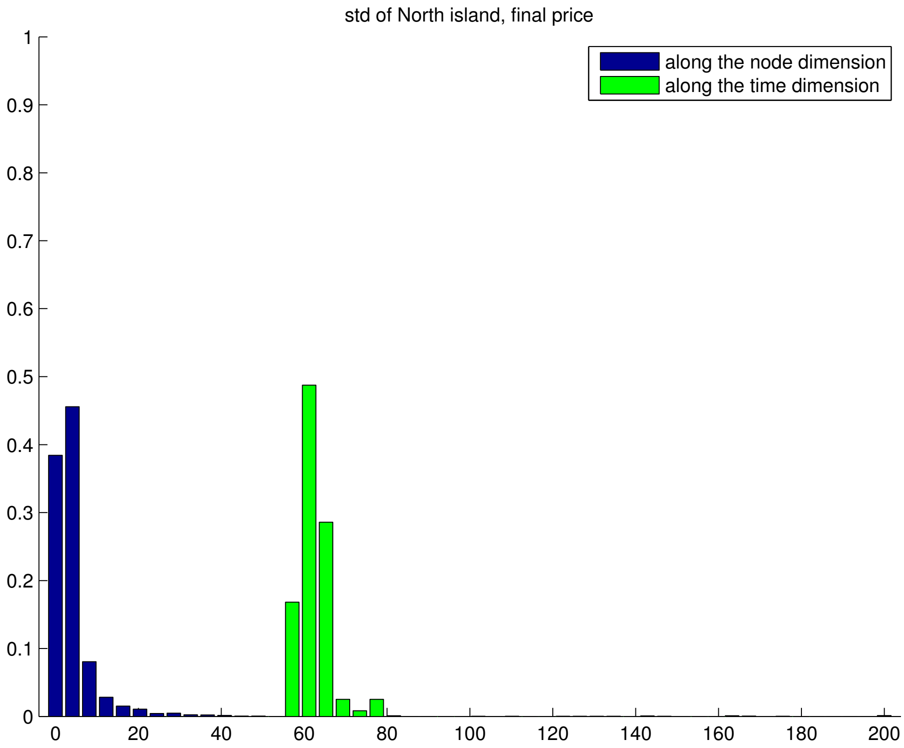

Figure 8: Behavior of standard deviation for final prices (North Island)

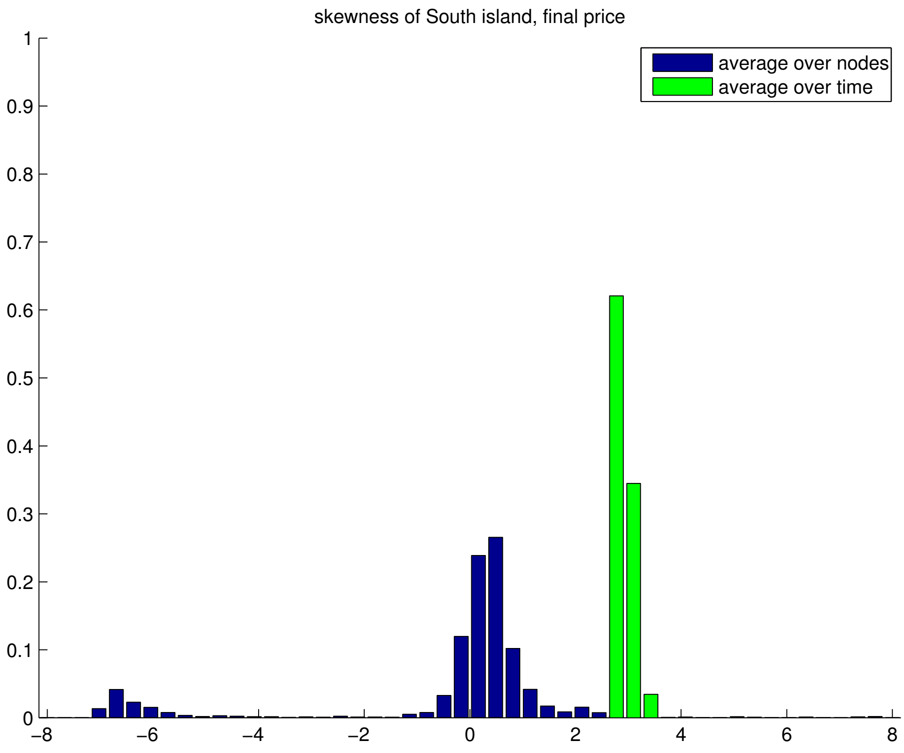

Figure 9: Behavior of skewness for final prices (South Island)

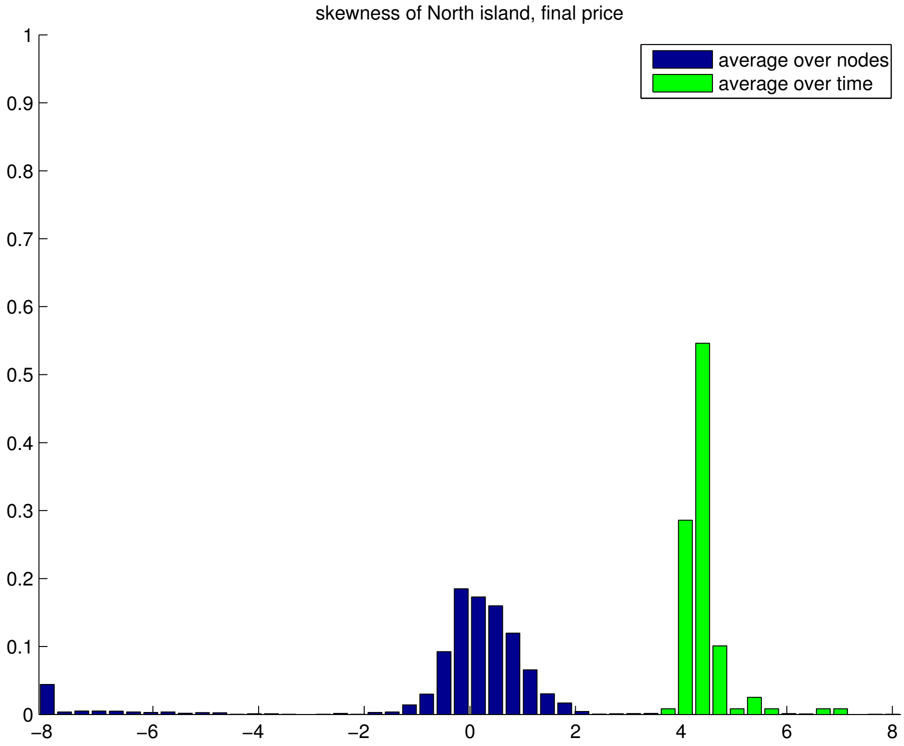

Figure 10: Behavior of skewness for final prices (North Island)

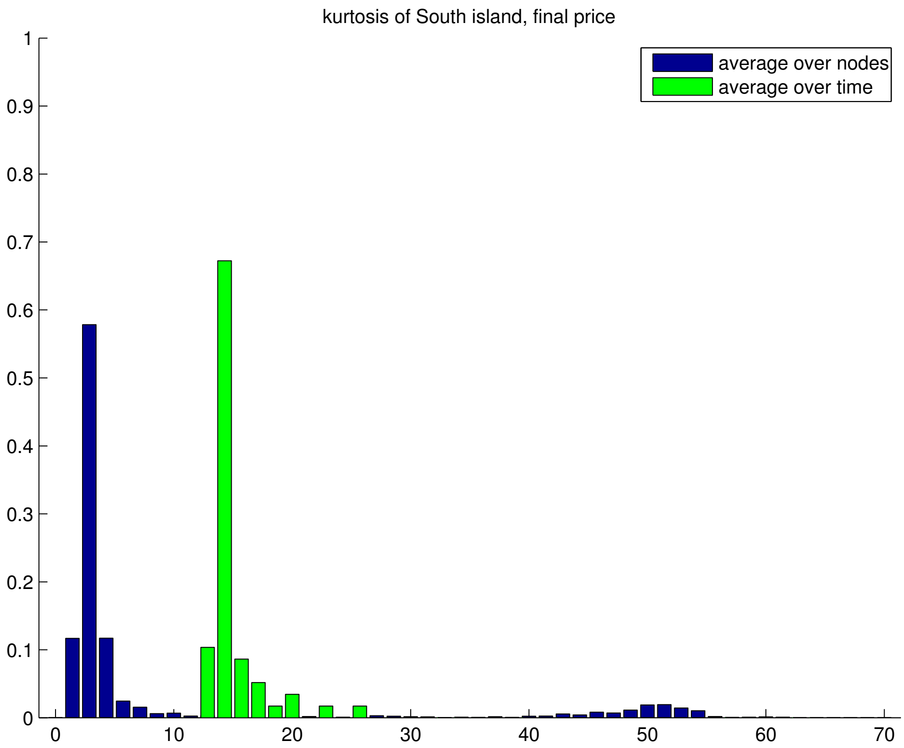

Figure 11: Behavior of kurtosis for final prices (South Island)

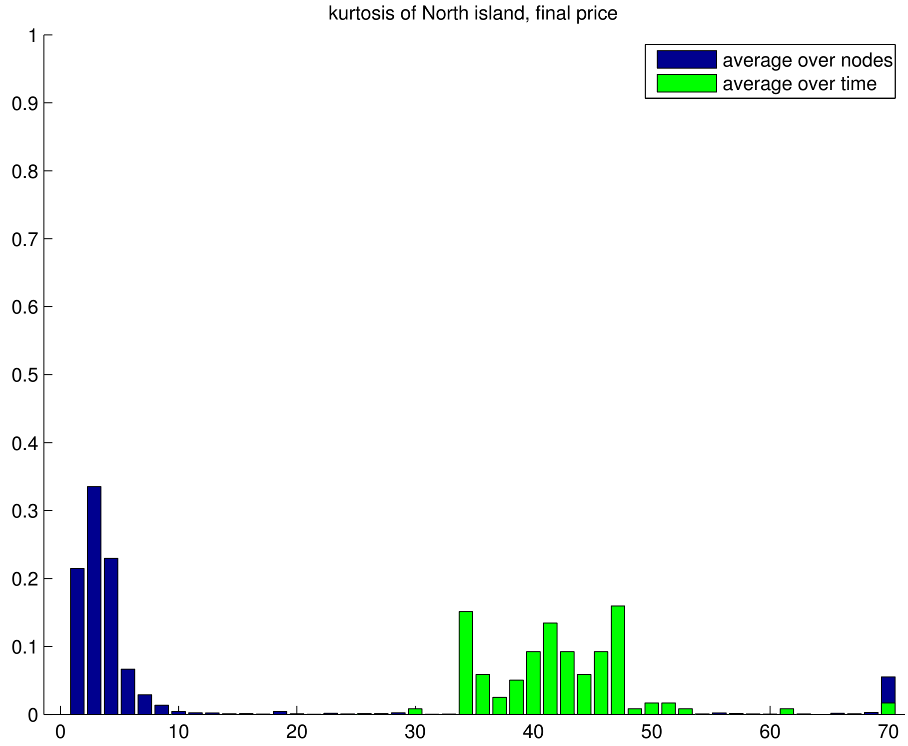

Figure 12: Behavior of kurtosis for final prices (North Island)

4.2.2 Offer prices

In the same way the histograms for offer prices were constructed: first we find the distribution of the prices along the time and node dimensions (Figures 13 and 14). Unlike the final prices, the behavior of the offer prices on the histograms is different for both along the time dimension and along the node dimension. Then the following statistics can be calculated: standard deviation (Figure 15), skewness (Figure 16) and kurtosis (Figure 17).

The results are similar to final prices: the distribution of each statistic is not identical along different dimensions. So we can conclude that the distribution of the parameters is non-ergodic. Therefore the distribution of prices is also non-ergodic.

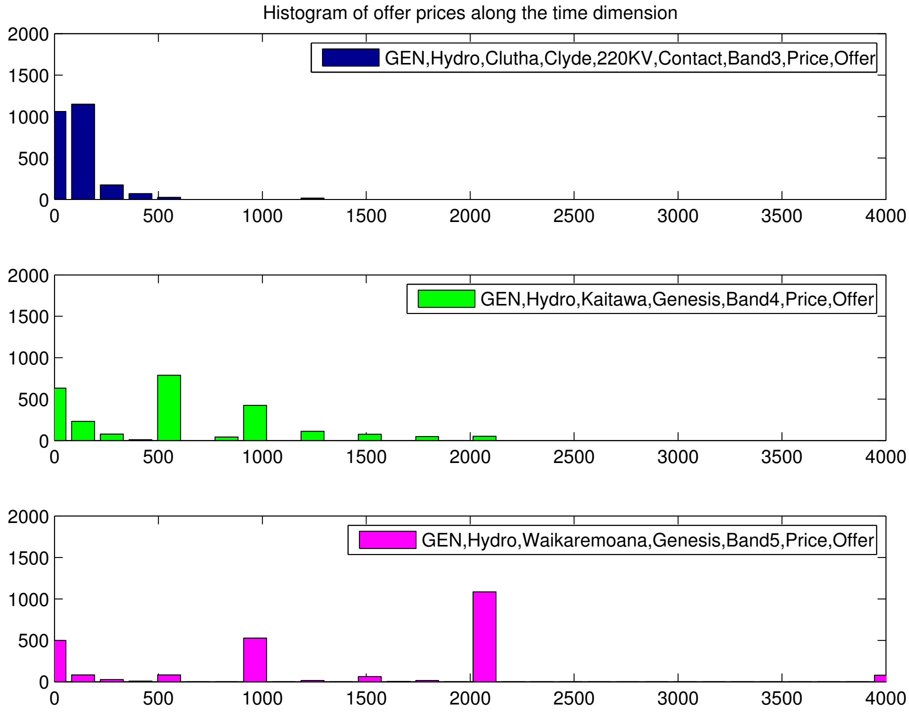

Figure 13: Histogram along the time dimension for offer prices

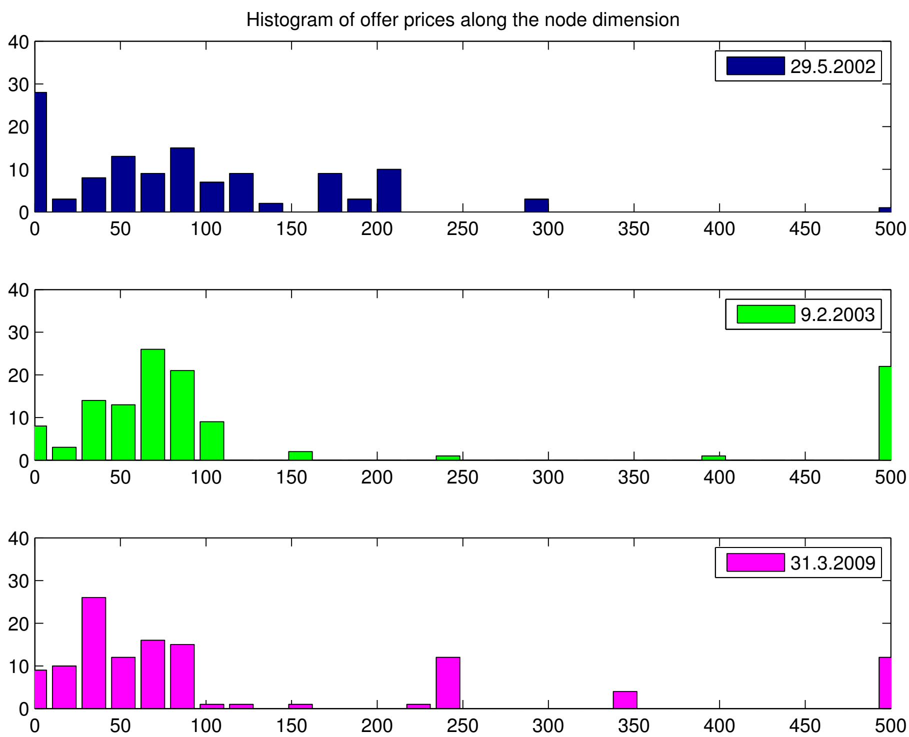

Figure 14: Histogram along the node dimension for offer prices

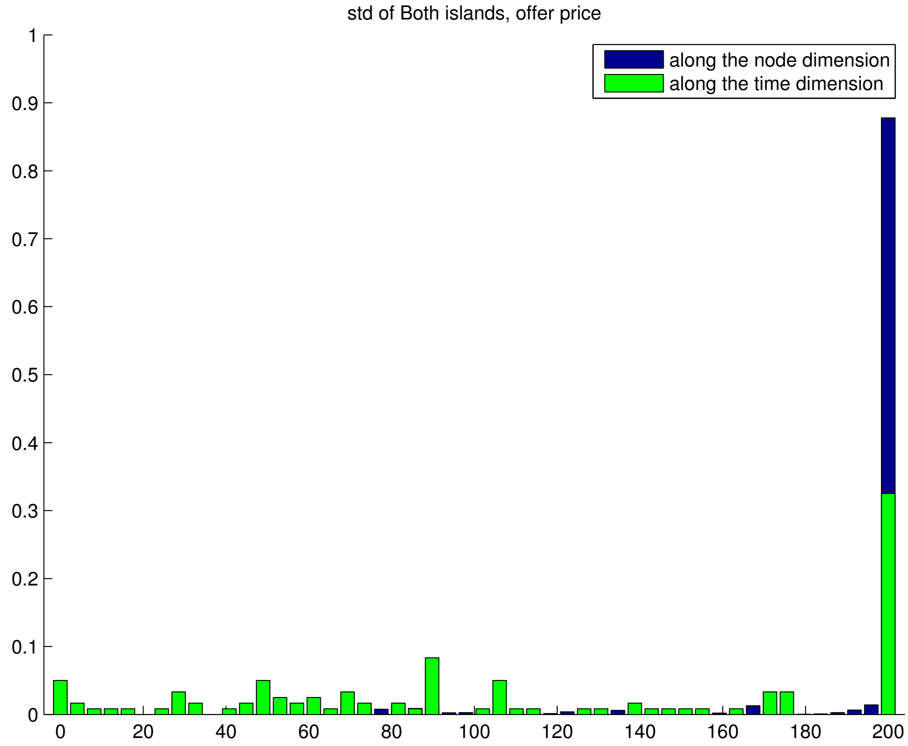

Figure 15: Behavior of standard deviation for offer prices (both islands)

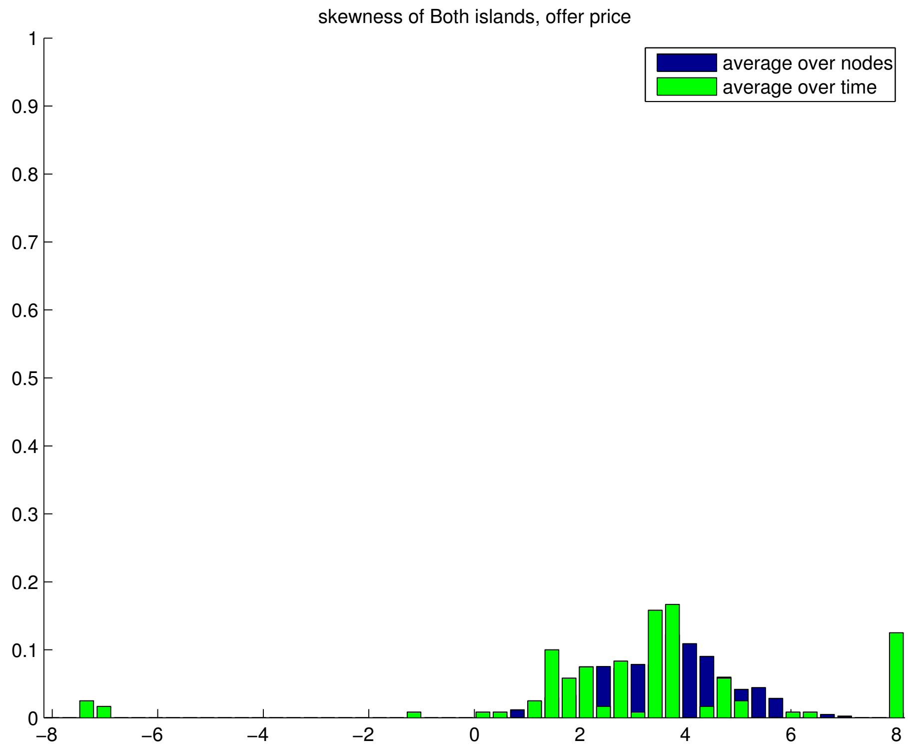

Figure 16: Behavior of skewness for offer prices (both islands)

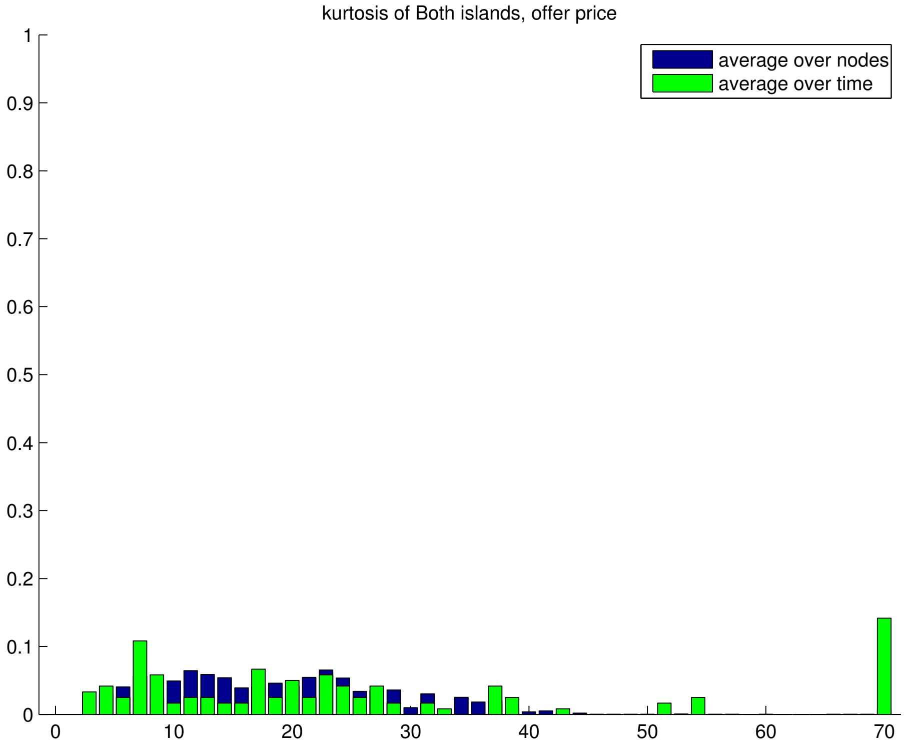

Figure 17: Behavior of kurtosis for offer prices (both islands)

5 ANALYSIS OF CORRELATION DISTANCE BY HYPERFINE TOPOLOGY

5.1 Method of correlation distance analysis

Since the data set consists of prices for different types of electricity grid nodes located all over the island, it gives an interesting base for correlation analysis. Therefore, a question arises: what affects price more - location factor or type of electricity production? For this purpose the correlation coefficient was calculated. Correlation coefficient between the electricity prices of two nodes i and j is defined as

$$\rho_{ij} = \frac{< S_i S_j > - < S_i >< S_j >}{\sqrt{< S_i^2 - < S_i >^2 >< S_j^2 - < S_j >^2 >}} \tag{1}$$

S_i can be:

- offer price for node i

- final price for node i

Correlation coefficient possible values:

$$\rho_{ij} = \begin{cases} 1, & \text{completely correlated prices;} \\ 0, & \text{uncorrelated prices;} \\ -1, & \text{completely anticorrelated prices.} \end{cases}$$

The first way to understand behaviour of prices is to find the most correlated and the most anticorrelated nodes and compare parameters (location, type) of these nodes. The other way is to plot hierarchical trees for prices (Rosario et al. 2007). The hierarchical tree diagram provides an effective visual condensation of the clustering results. We should find the similarity or dissimilarity between every pair of objects in the data set. Therefore, to perform clustering of the data, the distance metric should be introduced:

$$d_{ij} = \sqrt{2 * (1 - \rho_{ij})}. \tag{2}$$

Because equation 2 defines a Euclidean distance, the following three properties must hold:

1. $d_{ij} = 0 \Longleftrightarrow i = j$
2. $d_{ij} = d_{ji}$
3. $d_{ij} \leq d_{ik} + d_{kj}$

d_{ij} fulfils all three properties and can be chosen as a metric distance.
An example how to build a hierarchical tree:

1. Put all daily electricity prices in the matrix (for this example 5 random nodes from both islands were chosen):

$A =$

SI, Clyde	SI, Coleridge	SI, Tekapo	NI, Albany	NI, Bombay
0.5	0.5	0.5	0.6	0.6
2.5	2.3	2.5	3	3
1.7	1.6	1.7	1.8	1.8
27.9	28.7	28.4	29.2	29.2
⋮	⋮	⋮	⋮	⋮
50.8	58.9	54.5	69.8	69.6

Table 4: Example calculation of hieratical tree: matrix of electricity prices

2. Calculate the correlation coefficient:

$\rho =$

	SI, Clyde	SI, Coleridge	SI, Tekapo	NI, Albany	NI, Bombay
SI, Clyde	1.0000	0.9863	0.9915	0.8120	0.7850
SI, Coleridge	0.9863	1.0000	0.9827	0.8091	0.7827
SI, Tekapo	0.9915	0.9827	1.0000	0.8118	0.7850
NI, Albany	0.8120	0.8091	0.8118	1.0000	0.9628
NI, Bombay	0.7850	0.7827	0.7850	0.9628	1.0000

Table 5: Example calculation of hieratical tree: matrix of correlation coefficients

3. Find the distance between nodes:

$d =$

	SI, Clyde	SI, Coleridge	SI, Tekapo	NI, Albany	NI, Bombay
SI, Clyde	0	0.1657	0.1303	0.6132	0.6558
SI, Coleridge	0.1657	0	0.1861	0.6179	0.6592
SI, Tekapo	0.1303	0.1861	0	0.6136	0.6558
NI, Albany	0.6132	0.6179	0.6136	0	0.2727
NI, Bombay	0.6558	0.6592	0.6558	0.2727	0

Table 6: Example calculation of hieratical tree: matrix of distance values

4. Now we start to build a hierarchical tree (Figure 18):

   - Find two nodes with the smallest distance between them: *Clyde* and *Tekapo* (d = 0.1303) and put them in a separate region
   - Find the pair of nodes with next-smallest distance: *Clyde* and *Coleridge* (d = 0.1657). Link *Coleridge* to the already built region
   - Find the next pair: *Tekapo* and *Coleridge* (d = 0.1861). But both of them already been sorted so move to next step
   - Next pair: *Albany* and *Bombay* (d = 0.2727). Put them in a new separate region
   - Now all nodes are sorted into two regions: *Clyde-Coleridge-Tekapo* and *Albany-Bombay*. The smallest distance connecting this two regions is *Clyde* and *Albany* (d = 0.6132). This *Clyde-Albany* link completes the hierarchical tree.

5.2 Results of correlation distance analysis

5.2.1 Final prices

Regardless of the way of analysis we need to calculate the correlation coefficient. As before we start from visualising them on histograms. Correlation coefficients were calculated separately for South and North Islands. They were visualized year by

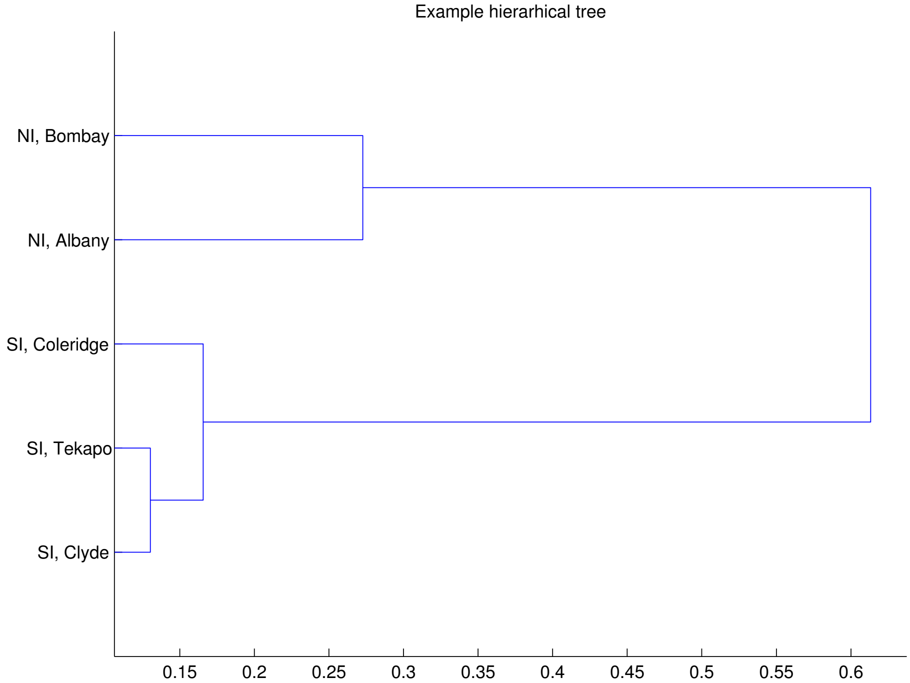

Figure 18: Example of building simple hierarchical tree

year (each row corresponds to 365 days from 1 January 1999 to 1 January 2009) in Figure 19 for South Island and Figure 20 on North Island. Judging from the histograms final prices for both islands are very correlated.

Second step is to find two most correlated nodes. Correlation coefficients between Papanui and Islington on the South Island and between New Plymouth and Moturoa on the North Island are similar and equal to 1. Prices for these most correlated nodes on the islands are shown in Figures 21 and 22. It can be easily shown on the map (Figures 23 and 24) that they are located close to each other. Types of nodes are different: three of them are subnodes and one (New Plymouth) is a thermal generator.

Third step is to find the least correlated nodes on the islands. For South Island two least correlated nodes are Gore and Ashburton with correlation coefficient 0.0409, for North Island - Tokaanu and Gisborne with correlation coefficient 0.6218. Then the prices in these nodes can be visualized (Figures 25 and 26) and put nodes on the map (Figures 27 and 28). It is clear from the above that the least correlated nodes are located on the opposite sides of the islands. All of these nodes also have a different type (thermal, hydro, cogenerator and subnode).

As we can see in Figures 25 and 26 the prices are still almost identical. But when the

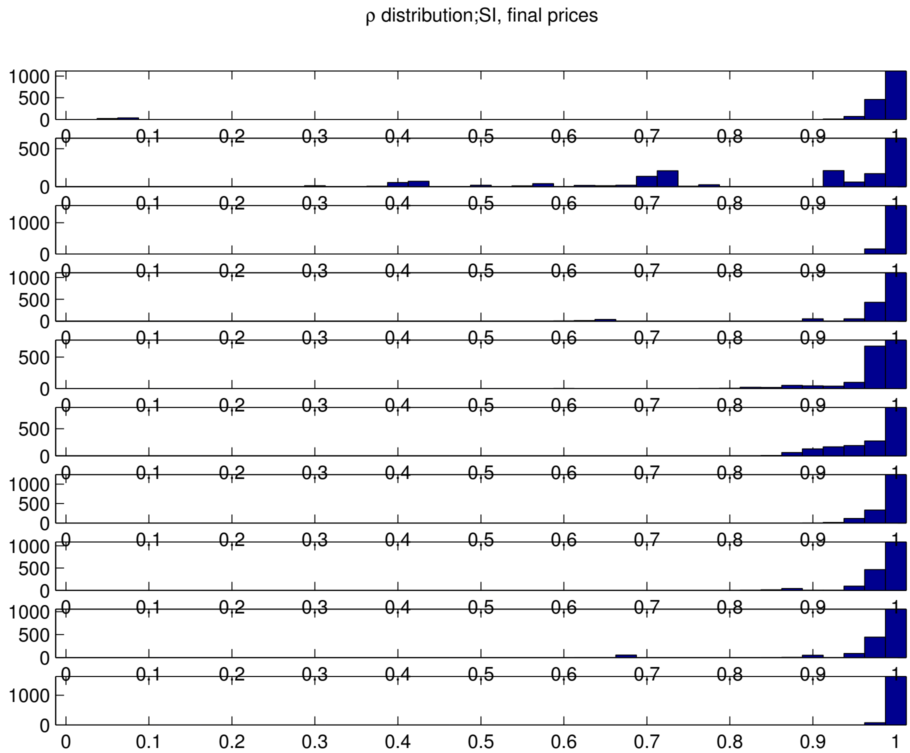

Figure 19: Correlation coefficient distribution for South Island year by year, final prices

same analysis was done for all final prices from both islands, the difference between least correlated nodes can be easily seen in the Figure 29. Correlation coefficient for this nodes is -0.0225. Location of least correlated nodes is marked on the map in Figure 30.

The other way to find correlation factors is to plot a hierarchical tree for correlation coefficients. Fifteen nodes from both islands with different generation type were taken to make clear visualization. There are two separate branches for South Island and North Island on the tree (see Figure 31) but there are no different clusters for nodes with different types.

As a summary, markets on both islands are homogeneous with the exception of a couple of spikes.

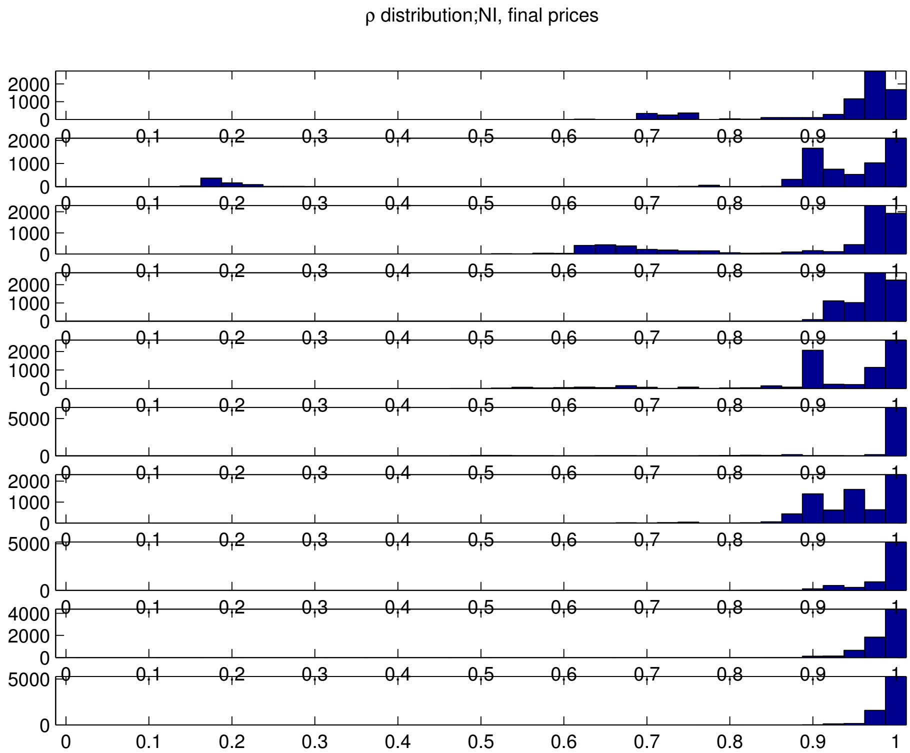

Figure 20: Correlation coefficient distribution for North Island year by year, final prices

5.2.2 Offer prices

The same steps as described before can be done for the offer prices. At first the correlation coefficients were found (see Figure 32). Correlation coefficient distribution for offer values demonstrates that offer prices are not correlated in contradistinction to final prices.

Then the correlation coefficients were calculated. Two most correlated nodes are Whakamaru and Waipapa with correlation coefficient 1. The prices for most correlated nodes (Figure 33) and location of these nodes (Figure 34) were plotted. Results are similar to final prices results: most correlated nodes are located very close to each other and the prices behaviour is similar. Both of the nodes are hydro generators.

The price distribution and map were visualized for the least correlated pair of nodes likewise for the most correlated pair (Figures 35 and 36). The strongly anticorrelated behaviour of the prices on the Figure 35 can be explained with correlation coefficient value $\rho = -0.4962$. As for the most correlated nodes, the least correlated ones are

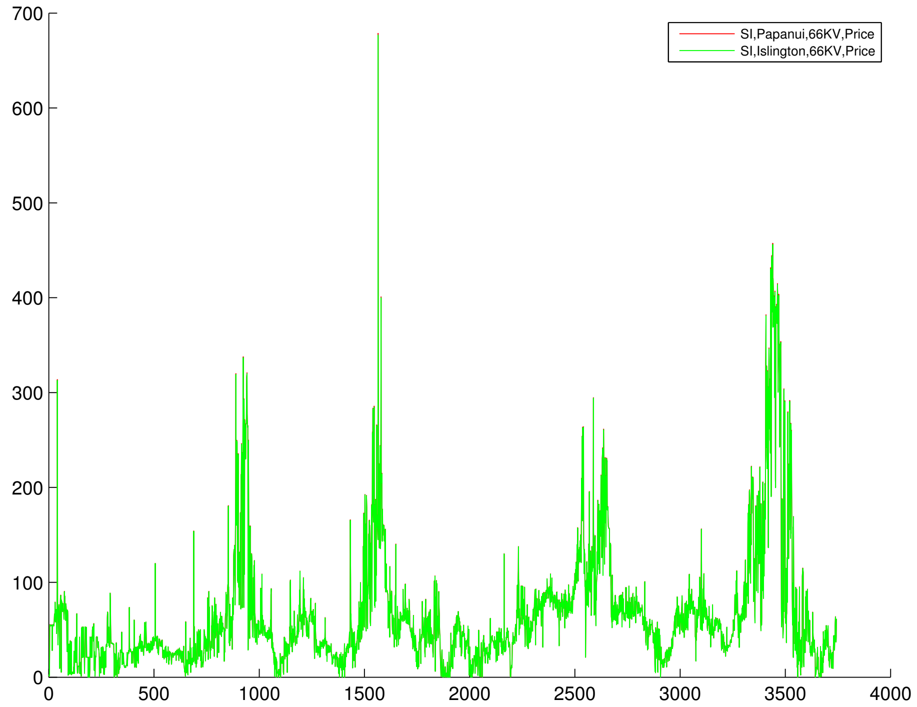

Figure 21: Prices for two maximum correlated nodes on South Island, final prices

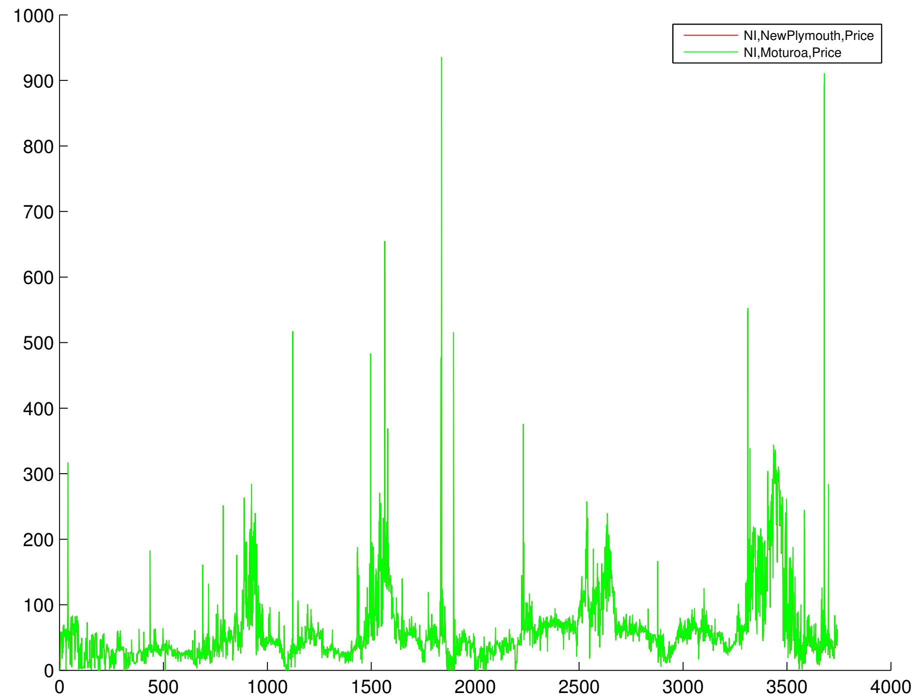

Figure 22: Prices for two maximum correlated nodes on North Island, final prices

also hydro generators. However, they are located on the opposite sides of different islands.

Figure 23: Location of two most correlated nodes on the map (South Island, final prices)

Figure 24: Location of two most correlated nodes on the map (North Island, final prices)

The last step to repeat is to find the hierarchical tree for correlation coefficients. Similarly to the results for final prices, for offer prices the tree has two separate branches for different islands.

Summarizing this section we can state that correlation of electricity prices mostly

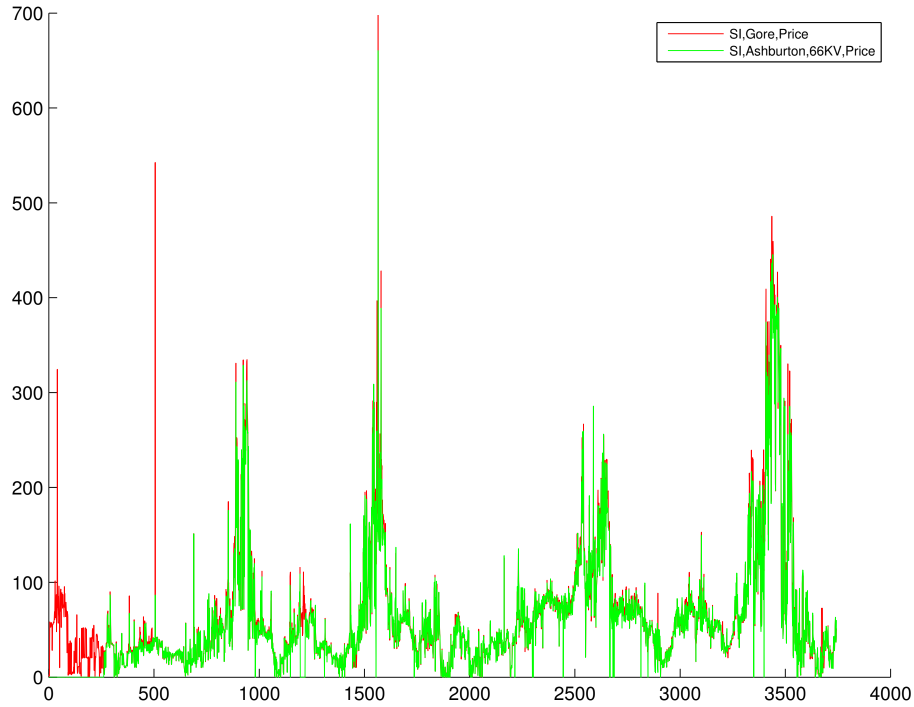

Figure 25: Prices for two least correlated nodes on South Island, final prices

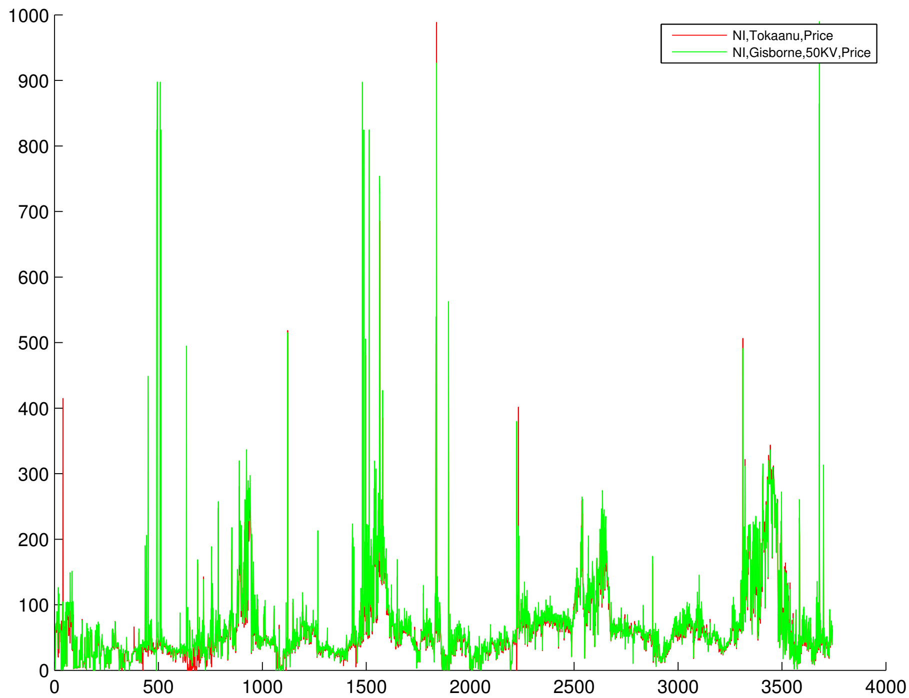

Figure 26: Prices for two least correlated nodes on North Island, final prices

depends on location factor of nodes for both final and offer prices.

Figure 27: Location of two least correlated nodes on the map (South Island, final prices)

Figure 28: Location of two least correlated nodes on the map (North Island, final prices)

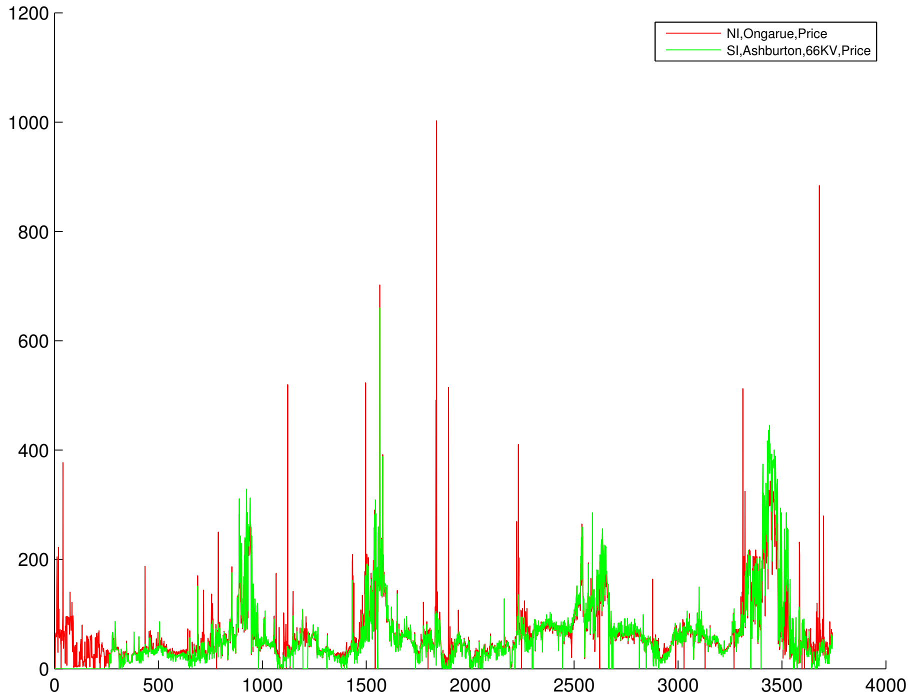

Figure 29: Prices for two least correlated nodes on both islands, final prices

Figure 30: Location of two least correlated nodes on the map (Both Islands, final prices)

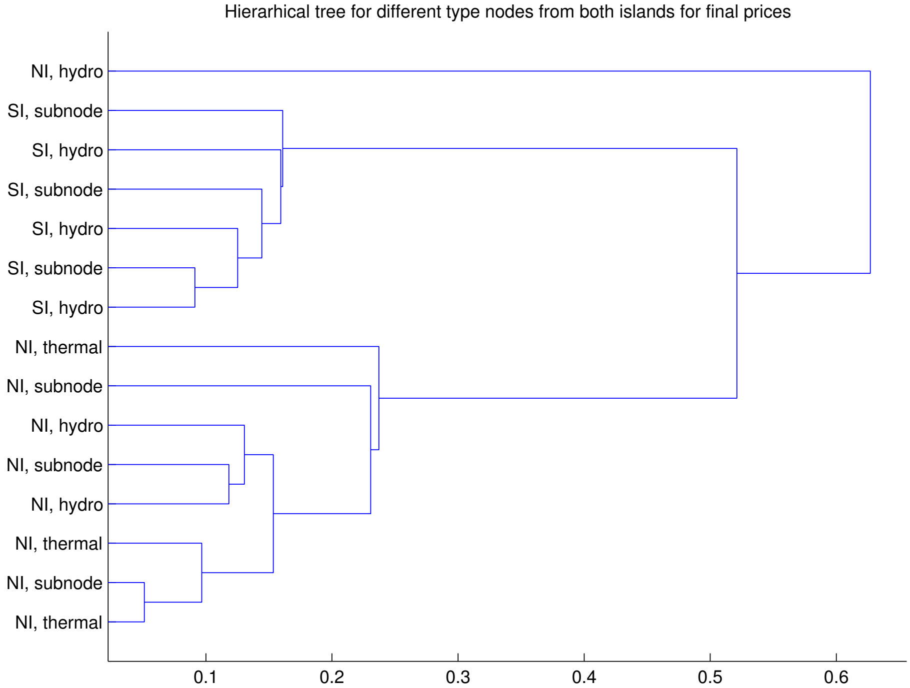

Figure 31: Hierarchical tree for different type nodes from both islands for final prices

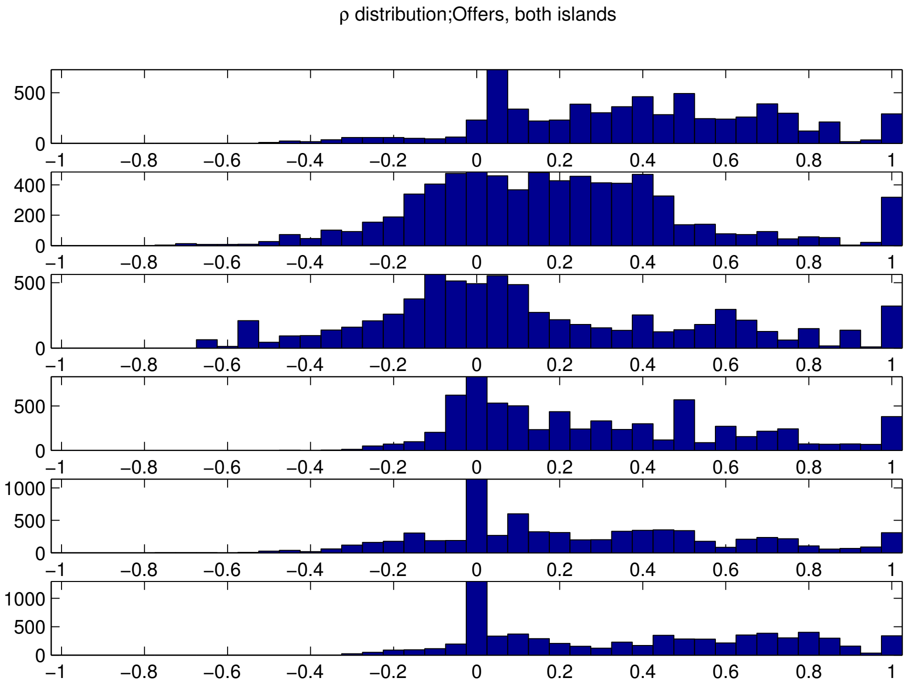

Figure 32: Correlation coefficient distribution year by year for offer prices

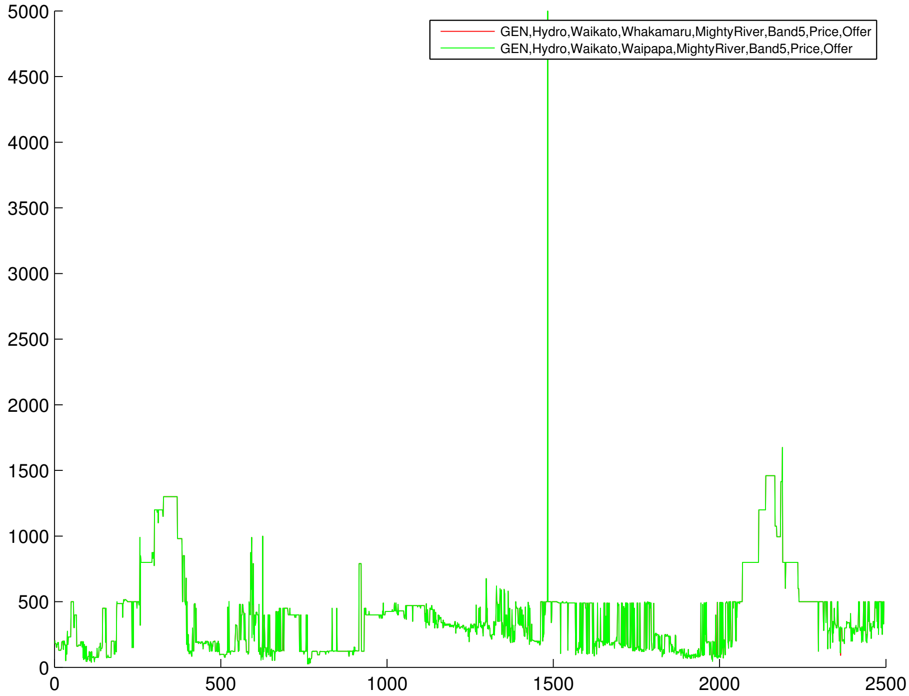

Figure 33: Prices for two most correlated nodes, offer prices

Figure 34: Location of two most correlated nodes on the map (offer prices)

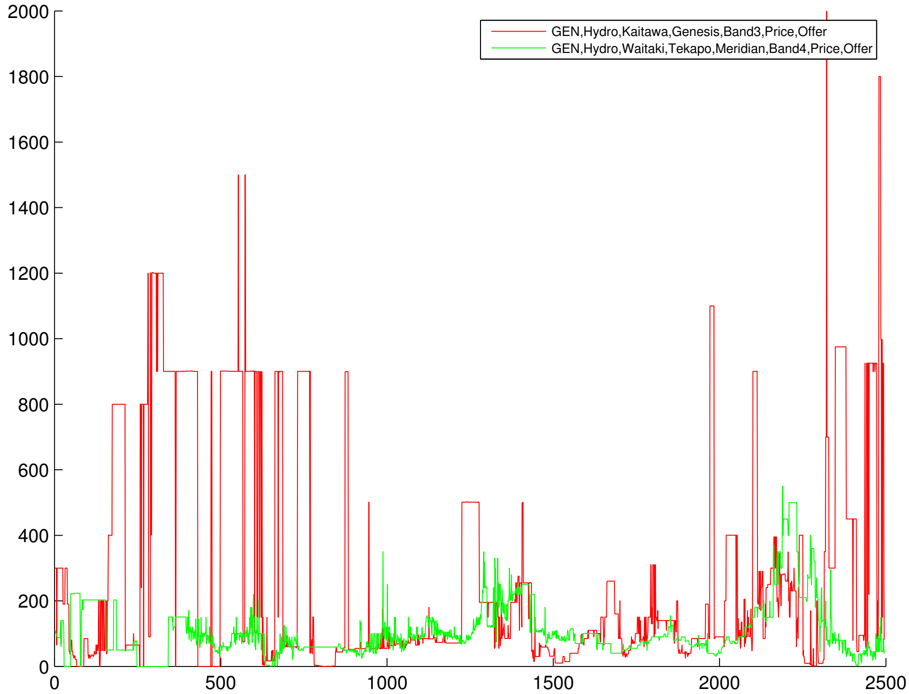

Figure 35: Prices for two least correlated nodes, offer prices

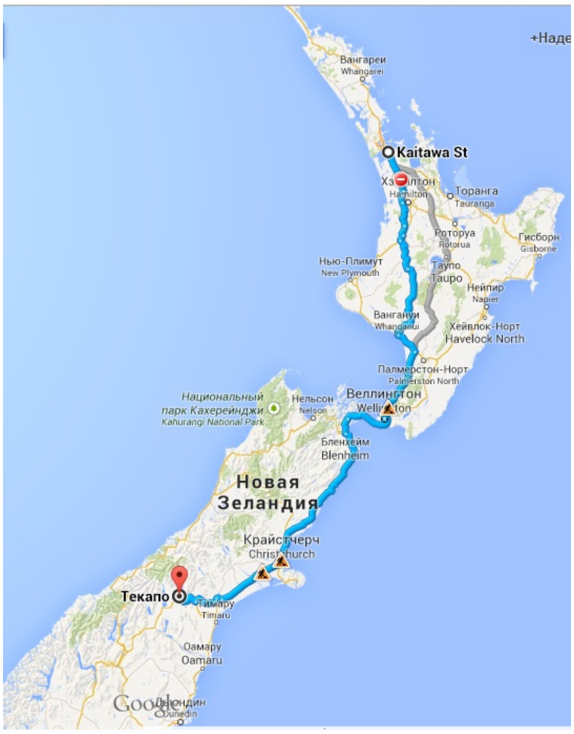

Figure 36: Location of two least correlated nodes on the map (offer prices)

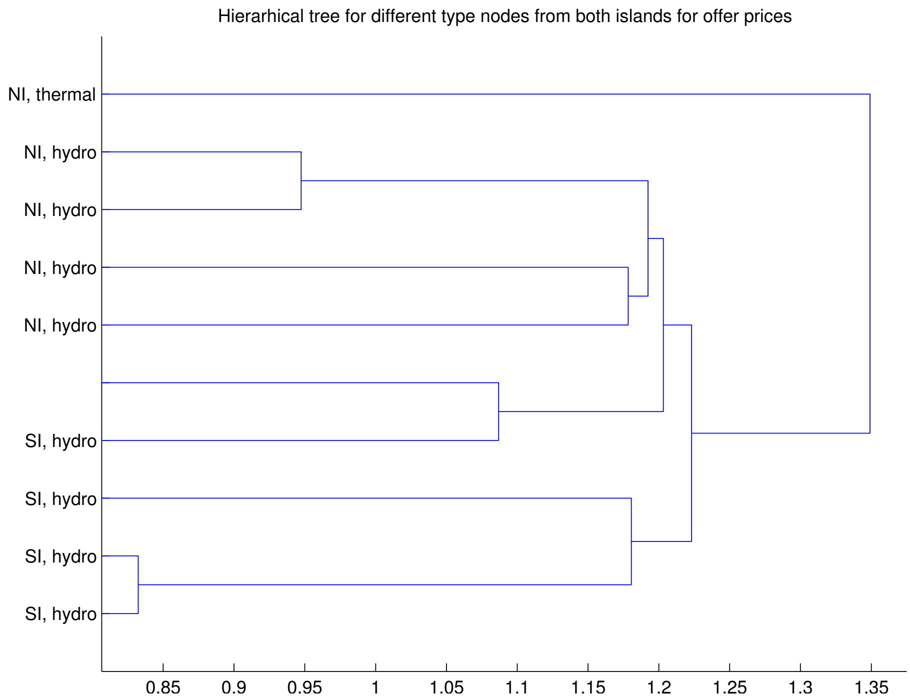

Figure 37: Hierarchical tree for different type nodes from both islands for offer prices

6 GEOGRAPHIC CORRELATION OF NODAL PRICE VARIATION

6.1 Method of geographic correlation analysis

Bearing in mind the previous point, we can now check the effect of geographical position on different nodes. For this purpose several base nodes in different parts of the island were taken. For each base node the price correlation coefficients with all other nodes were calculated. Then each node got a color according to this correlation coefficient - red for the most correlated node, blue for the least correlated node and intermediate colors for other nodes according to the correlation coefficient. Finally, all nodes were marked on map with corresponding colors.

6.2 Results of geographic correlation analysis

6.2.1 Final prices

To begin we choose four nodes in different parts of islands. Their locations are marked in Figure 38.

For each of the base nodes (they are marked with pink circle on the Figures) all the nodes were visualised on the map with corresponding color (see Figures 39, 40, 41 and 42). From the Figures we can conclude that for base nodes, situated on the North Island, the most correlated nodes (red dots) are located on the North Island and the least correlated nodes (blue dots) - on the South Island. Unlike for the base nodes form the South Island: the most correlated nodes are located on the South Island, the least correlated - on the North one.

6.2.2 Offer prices

In addition to four nodes for final prices, four nodes for offer prices were chosen (see Figure 43). And as for final prices, the colored nodes we marked on the map (Figures 44, 45, 46 and 47). On these Figures we do not see the clear separation between red and blue dots like it was for final prices.

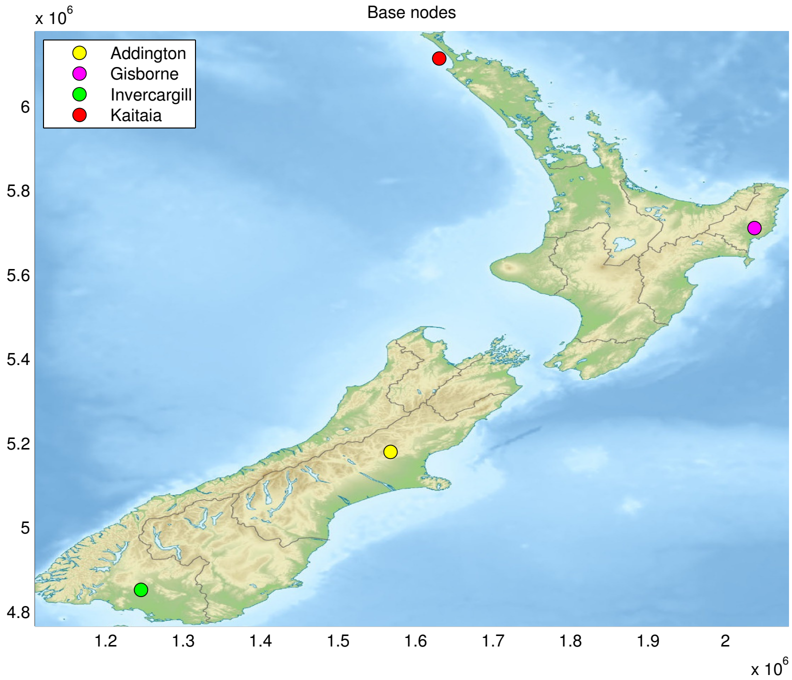

Figure 38: Location of base nodes for final prices

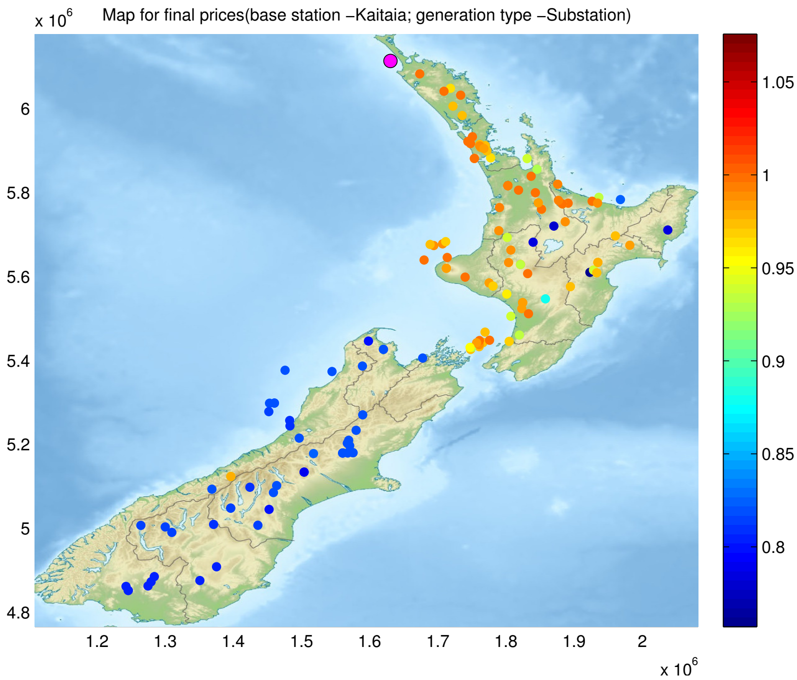

Figure 39: Map with nodes colored according to correlation coefficient; base node - Kaitaia (final prices)

This short analysis is just a visualization of behavior of correlation coefficient according to node location. In general this analysis indicates how important studying

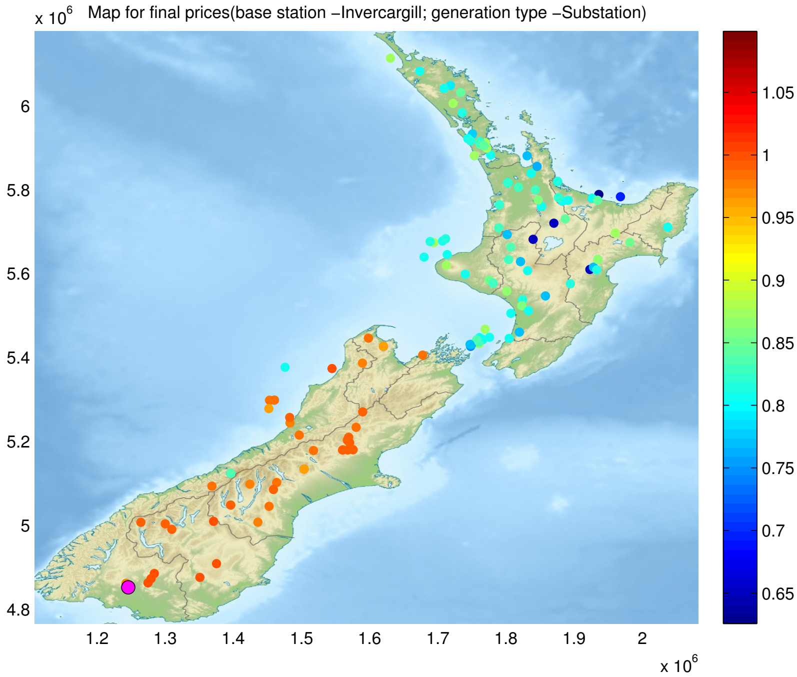

Figure 40: Map with nodes colored according to correlation coefficient; base node - Invercargill (final prices)

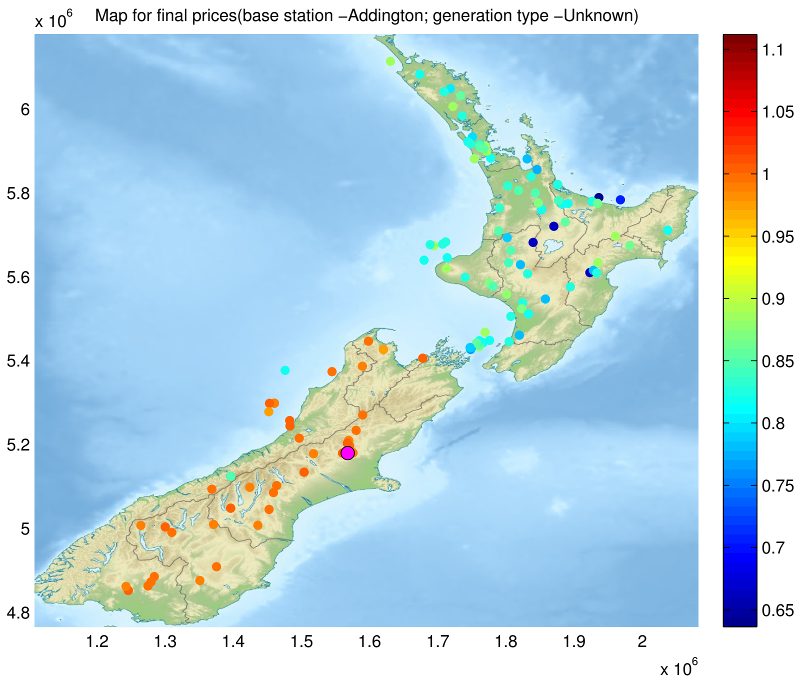

Figure 41: Map with nodes colored according to correlation coefficient; base node - Addington (final prices)

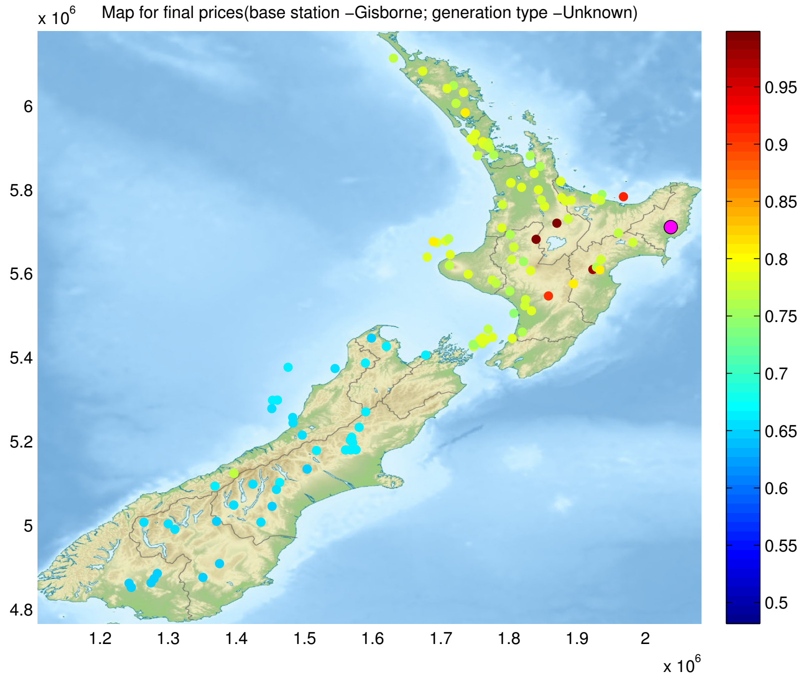

Figure 42: Map with nodes colored according to correlation coefficient; base node - Gisborne (final prices)

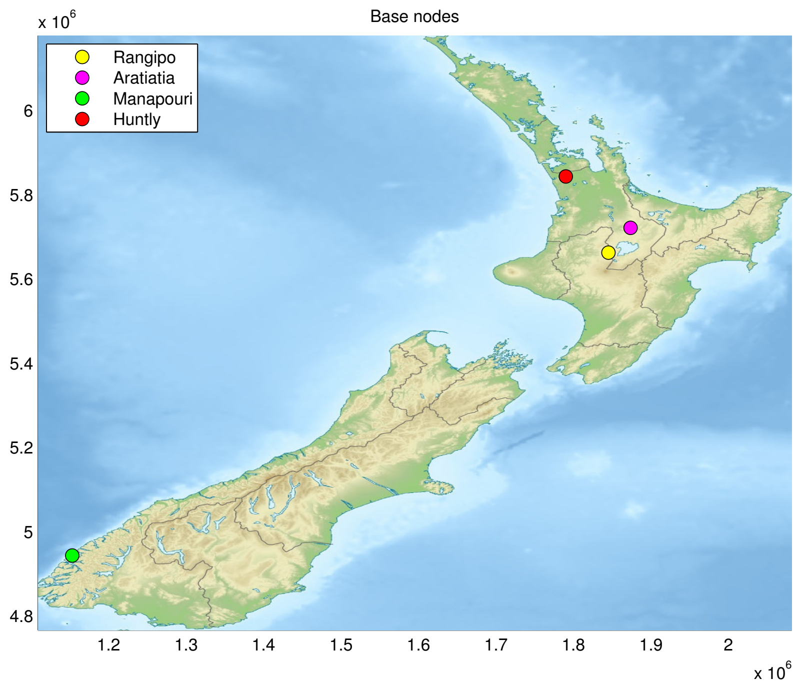

Figure 43: Location of base nodes for offer prices

the location factor in electricity spot market is. A natural reason for this effect are power losses when power is transmitted over long distance.

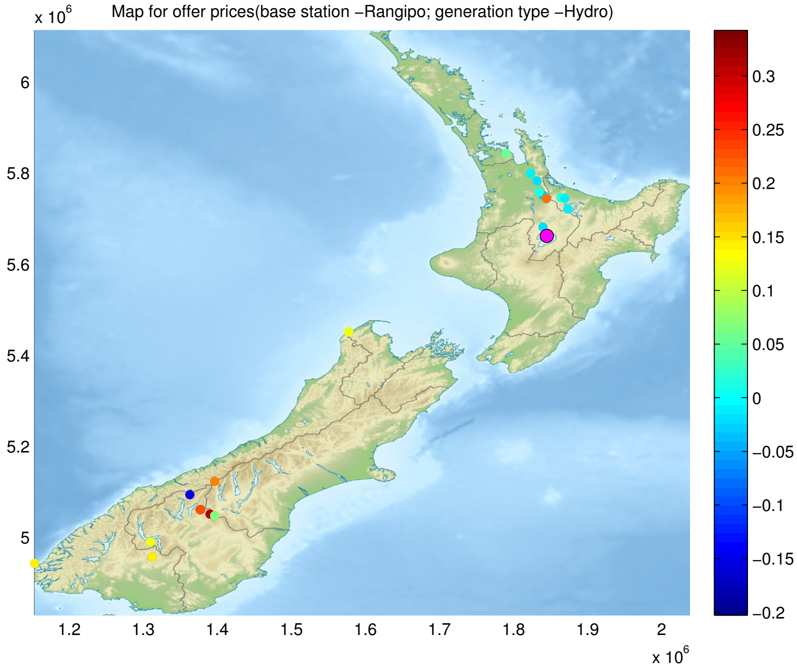

Figure 44: Map with nodes colored according to correlation coefficient; base node - Rangipo (offer prices)

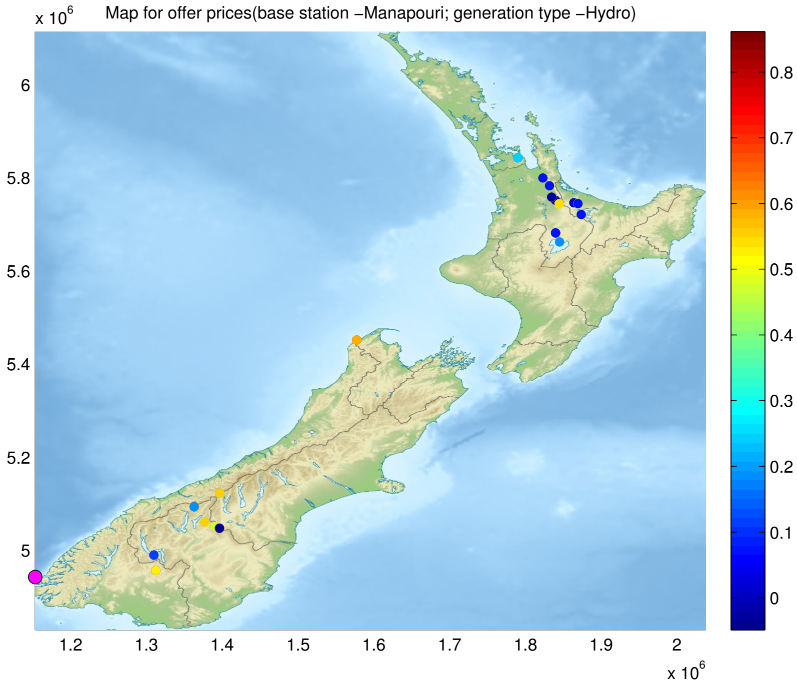

Figure 45: Map with nodes colored according to correlation coefficient; base node - Manapouri (offer prices)

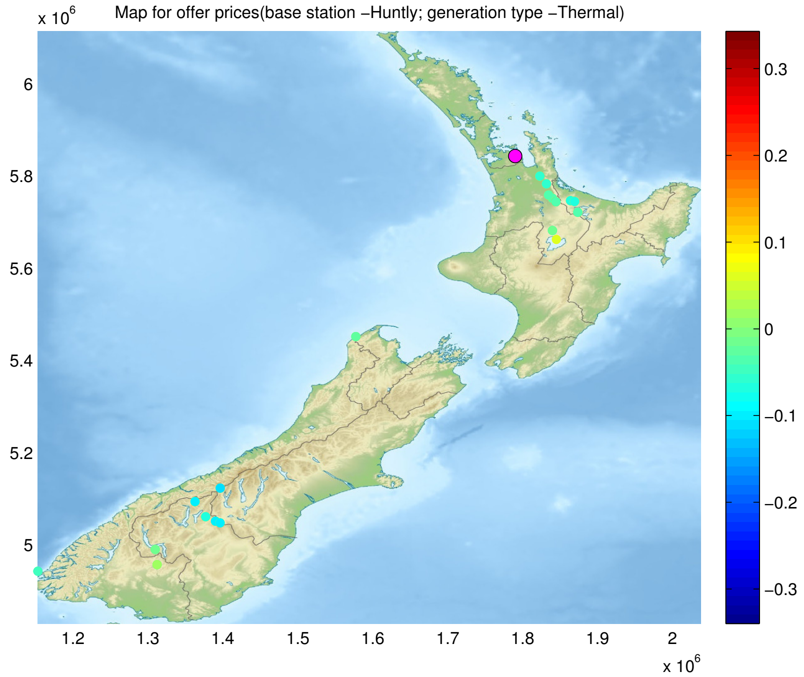

Figure 46: Map with nodes colored according to correlation coefficient; base node - Huntly (offer prices)

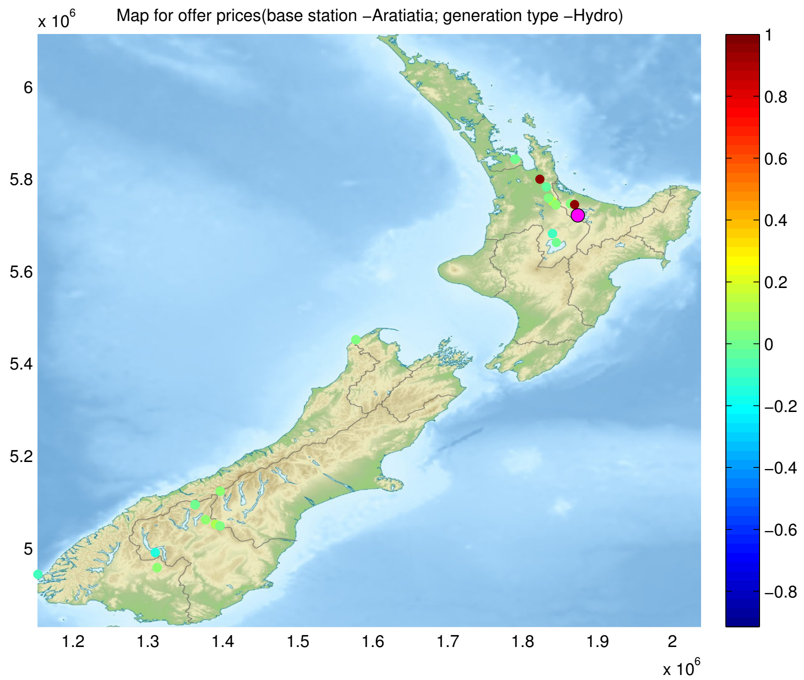

Figure 47: Map with nodes colored according to correlation coefficient; base node - Aratiatia (offer prices)

7 RESULTS SUMMARY AND DISCUSSION

This section summarizes and discusses the results obtained in this work. The results were divided into 3 parts. First, a statistical analysis of all data sets was conducted. Next, we checked the dependency of correlation distance on different natural factors, and last, a visualization for geographic correlation was done.

To classify the distribution of prices in all data sets (Final prices for South Island, Final prices for North Island, Offer prices for both islands), we calculated using Matlab software all basic statistics in two ways: through node dimension and through time dimension, then visualized them on histograms (Figures 7 - 12, 15 - 17) and compared. All these Figures proved that data is non-ergodic.

The results obtained in correlation distance analysis are presented in Figures 31 and 37. The results shows two separate branches for South and north Island nodes both for Offer and Final prices. So we can conclude that the correlation coefficient does not depend on the type of generator but does depend on the geographical position of the node.

For more detailed analysis of the geographic correlation factor, a visualization of correlation coefficients was done (Figures 39 - 47). It is clear from the visualisation that for final prices the hypothesis about geographical position of the nodes was confirmed, but we can not confirm or reject it for the offer prices. We assume that this uncertainty in results can be explained with natural factors, like power losses during transmission.

8 CONCLUSIONS

In this work, we have studied the behaviour of electricity prices in New Zealand. The original data includes three data sets: offer prices, final prices for South Island and final prices for North Island. Before we start the investigation of correlation, an analysis of the original data was made with the aim to find patterns in the data set. From the graphical presentations and basic statistics, data sets were identified as non-ergodic.

Correlation analysis was carried out to understand the electricity prices behaviour. For each data set the most and the least correlated nodes were found. It was stated that the most correlated nodes for both final and offer prices are located quite close to each other, the least correlated - on the opposite sides of the islands. Using the hierarchical tree we showed that the location factor is the most important one that defines the correlation between nodes.

To show the behaviour of correlation coefficient according to node location, a visualisation of correlation coefficients was done. For final prices we got clear results with the most correlated nodes on the same island as the base node and the least correlated nodes on the other one. The result for the offer prices is not so clear.

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