STATISTICAL MODELLING OF ELECTRICITY PRICE
IN SINGAPORE POWER MARKET (A1020-091)

Tan Ye Wu Eugene

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NANYANG TECHNOLOGICAL UNIVERSITY

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Statistical Modelling of Electricity Price in Singapore Power Market

Submitted by: Tan Ye Wu Eugene

Matriculation Number: 072305C03

Supervisor: Associate Professor Govinda Bol Shrestha

SCHOOL OF ELECTRICAL & ELECTRONIC ENGINEERING

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Abstract

In most financial-driven markets, statistical tools are often used in the study of price behaviour. Currently, various researches have been conducted in the analysis of the electricity price behaviour using technical and mathematical tools. In addition is the widely used statistical method which is solely based on the historical data. With the deregulation of the electricity market in Singapore, such analysis of the electricity price behaviour will be crucial for both the consumers and generating companies.

In this report, the student presents the studies conducted in the analyses and modelling of the electricity price using the historical data. The price data are categorized into different time scales: half-hourly, daily, monthly and seasonal variation. Statistical models were identified using the polynomial regression technique in order to model short-term estimation of the future spot price. A Graphical User Interface (GUI) was designed in the latter part of the project to implement the findings of the statistical analysis and modelling by graphically display the results.

When fully developed, such a statistical distribution analysis and modelling of electricity price will be an invaluable tool for distribution and generating companies in their forecast of the spot prices, which will be very crucial in their operating decisions.

Acknowledgements

The student will like to extend his gratitude to the following people for their constant guidance and support for the past few months.

- First and foremost, I would like to thank my Final Year Project supervisor, Associate Professor Govinda Bol Shrestha, for his constant guidance in this whole project. His assistance and reminder in the early days of this project inspire me to ensure the project is constantly moving.
- The next person I will like to extend my gratitude is Mr Qiao Songbo, a graduate from the Power Research Lab who is pursuing his master in Power Engineering for his guidance especially in the early stage of this project, or else this project will not be able to progress smoothly.
- Also Power Research Lab and the staffs for providing guidance and software needed in the completion of this project.
- Last but not least, my acknowledgement goes to my family and friends for giving the precious support during the hard times when things does not go smoothly.

Acronyms

EMA	Energy Market Authority
EMC	Energy Market Company
GUI	Graphical User Interface
MW	Mega-Watt
MWh	Mega-Watt per hour
NEMS	National Electricity Market of Singapore
PSO	Power System Operator
USEP	Uniformed Standard Electricity Price
Pdf	Probability density function
Cdf	Cumulative distribution function
Std. dev	Standard deviation

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Chapter One: Introduction

1.1 Background

Since the 1990s, Singapore's electricity industry has undergone several major changes, including the introduction of the NEMS in 1993 to increase the economic efficiency through the competition and providing more choices for consumers[1]. Currently, five out of nine generation licensees participated in the bidding at NEMS.

In the NEMS, power generating companies submit their bids which comprise of price and quantity into the market and the PSO will forecast the next dispatch load[2]. However contestable consumer will not participate in any bidding. The Market Clearing Engine (MCE) will determine the next dispatch clearing price and quantity that each generating company has to produce, by taking account of several factors including available generation capacity, power flows in the system, transmission losses, etc [3]. Generators that submitted offers below the market clearing price will be dispatched, whereas generators whose offers are above market price will not be dispatched [4].

This related to one important factor: prices are determined by the intersection of the bids from the generators and the forecast demand. Below figure shows an illustration of how market price is being cleared in the NEMS.

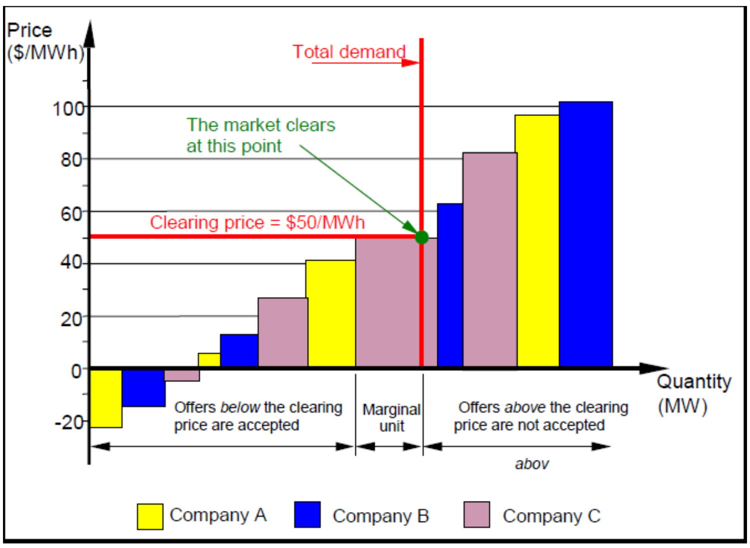

Figure 1: An example of market clearing price

Thus for the generating companies and consumers, competition has opened a new field of study in the forecast and analysis of electricity price in Singapore electricity market. The ability to fully understand the price behaviour has become a crucial part in their bidding process as a successful prediction of price movement will result in rewarding returns. In addition, it will allow generation companies to properly schedule their generators into the market.

Statistical modelling is able to provide an estimate prediction using the available information, however without the full guarantee of achieving the ideal price as the design of the model is based on the current condition or trend. In addition, amendment to rules and regulation in the market annually might result in minor change in the price behaviour. Below hierarchal sequences show the transition from data to knowledge in statistical studies [5].

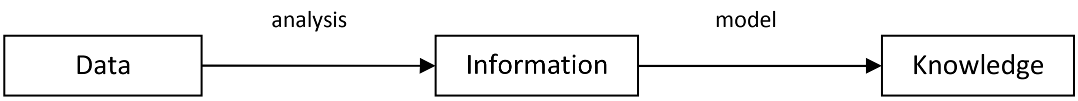

Figure 2: Sequence diagram of statistical studies

1.2 Objectives

Several research studies have being conducted in the study of the statistical behaviour of electricity prices in Singapore power market. Most of the analyses are conducted using the historical data.

The objectives of this project consist of 3 main parts: statistical analysis of price behaviour, creating the statistical model based on the different time cycle and designing a GUI for end-users.

1.3 Scope

For this project, the student analyzed the statistical behaviour of the energy prices using the historical data over the period from January 2003 to December 2009. Thereafter, he establishes the time series model using the regression techniques being used in [6] [7] and sub-divided them into different categories. A GUI will be designed to integrate all the findings in this project.

Analysis and testing for this project are conducted using the USEP and relevant prices including reserve and regulation prices are omitted.

1.4 Organisations

This report will be organised as follows:

- Chapter 2 will provide a literature review on this project.
- Chapter 3 details on the statistical analysis of past electricity prices to determine the behaviour of price movement.
- Chapter 4 details on the implementation and modelling using the regression techniques.
- Chapter 5 discuss on the GUI designed for this project.
- Chapter 6 will summarize on all the findings and recommendation for future work.

Chapter Two: Literature Review

2.1 Introduction

Since the deregulation of the electricity market in Singapore, many researchers have conducted the study of the behaviour of the price movements. Most of the analyses conducted are based on the graphical and statistical methods, in view on the prices movement. Studies based on time-series analysis were conducted, although few of them were solely based on Singapore market. In Singapore, the electricity are generated from 3 sources: natural gas, coal and oil [2], whereas in other countries they have alternative sources like nuclear plant. So price forecast model that is designed using overseas data may not be able to fully utilise in our market.

2.2 Past Research

In this research paper done by G.Michalik, M.E. Khan and W.Mielczarski [8], the targeting market is in Victoria, Australia. It formulated the weekly, monthly demand and supply data. However the article only presents a basic methodology in the analysis of the power and spot price and was based on raw data from year 1994 to 1997.

In this research "Analysis of Electricity Price in Competitive Markets – a Study in Singapore Market" [9], the authors attempt to determine the statistical distribution of the spot prices based on year 2005/2006 data. The analysis provide an important conclusion as it investigated the price's distribution at individual period, which the cumulative distribution and probability density function for the sample period 1 represent close to the Wei-bull or log-normal distribution. The above research provided readers with an overview of the statistical behaviour of the spot price in Singapore market.

In another research which provides two forecasting next-day electricity prices tools based on the time series models: dynamic regression and transfer function models [6]. Although the model provided an efficient forecasting tool, it will not be feasible to work in Singapore electricity markets as the studies were based on prices from overseas market in mainland Spain and California. Factors like the number of electricity sources, climate will result in a diverse outcome when apply in Singapore market.

2.3 Methodology – Polynomial Regression

For regression analysis, it rely the least-squares fit approach to determine the best fitting model. Moreover, least-square fit regression is one of the popular modelling method [10]. In the least-squares fit approach, it will ascertain best fit model to the data based on the goodness of fit statistics, such as residuals, sum of square error (SSE), root mean squared error (RMSE), etc.

When analysing the relationship between the response variable and the independent variable does not produce a linear line, in a case of a curved line, linear models will not be feasible. Example is the time-series analysis of the hourly electricity price in power market, the price movement usually assemble a curved line rather than linear with respect to time, thus fitting the relationship between the two variables using non-linear model will be more appropriate. Polynomial regression is one of the available non-linear models.

For polynomial regression, it uses one predictor or independent variable to compute the fit polynomial equation. The data are initially fitted with the least number of x variables, with the powers of the x variable increase gradually to improve the fitting. The general equation for polynomial regression model is given as:

$$y = \sum \beta_1 x^n + \beta_2 x^{n-1} + .. \beta_n x + \varepsilon$$

- $\beta = polynomial\ coefficient$
- $y = response\ variable$
- $x = predictor\ or\ independent\ variable$
- $\varepsilon = error\ term$

In this project, the x and y variables represent the time period (1-48) and the electricity price at the respective time interval. The implementation of the statistical model using the above methodology will be discussed in the Chapter 4.

For a better fit polynomial regression, it will be more efficient when it is built with large number of observations.

Many studies[6, 8-9] provided the student an overview in regard to the price behaviour in electricity market. However, more in-depth analysis by dividing the daily trading period into various sections might provide crucial information on the respective time scale. In addition, the inclusion of the latest price data in 2008 and 2009 will make the analysis more realistic in term of the latest price behaviour, as market regulations have changed significantly for the past few years which may lead to changes in the price behaviour.

Chapter Three: Statistical Analysis

In this project, the analysis of the electricity prices utilizes the database obtained from the EMC and EMA respectively[11-12]. EMC is the regulator of the electricity industry in Singapore and EMA operates and administers the Singapore's wholesale electricity market [11]. The final price will only be available to the public six days after the trading.

In this statistical analysis,

- Auxiliary charges like regulation, administration, etc are not involved in the analysis.
- Factors that will affect the power demand, like available capacity, outrages, etc are not involved.
- The USEP rather than WEP is used.
- All calculations are based on the standard formulas, and formulated using MATLAB and Excel functions.
- Statistical distribution and time series analysis are conducted.

Table 1: Sample details

Sample Period	January 2003 – December 2009
Total number of data	122,544[1]

The following statistical analyses are conducted using the Microsoft Excel and MATLAB. The use of Microsoft Excel allows massive raw data to be stored and uploading into MATLAB using the xlsread function to conduct various statistical analyses with the simple execution codes and designing the graphical user-interface.

[1] 122,544 sample data is based on prices sampled at every half-hour, and excluding 24-25 June 2003 prices

3.1 Background

The event of interest in the statistical analysis of electricity price is traditionally the spot price. The ideal way in using this method will be making use of the available relevant price data to plot out the frequency curve or histogram to determine the suitable distribution function. Below show the common statistical distribution functions:

a) Normal Distribution

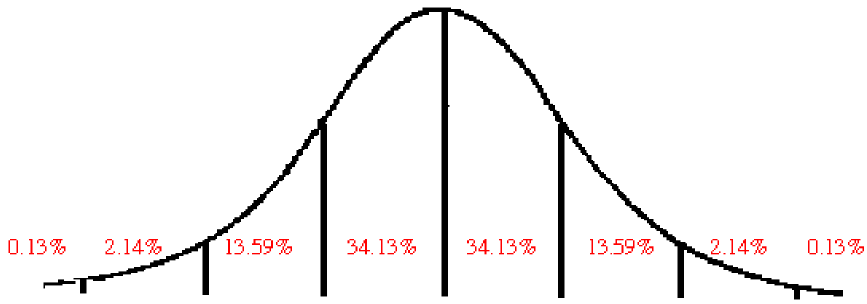

Figure 3: Normal distribution

The normal or Gaussian distribution is commonly known as the bell-shape curve as most of the data concentrated around the mean. Generally, the statistical parameters of the normal distribution which includes the mean, median and mode share the common value. The uses of the normal distribution tends to be the most easiest of all distribution, although later in this project, we find that only minority of the data falls into this distribution. In addition, the empirical rule can be used to determine the spread of the variable based on the following theorem:

Table 2: Empirical rule

Std. dev	1	2	3
Data range	68 % of the data	95 % of the data	99.7 % of the data

b) Log-normal Distribution

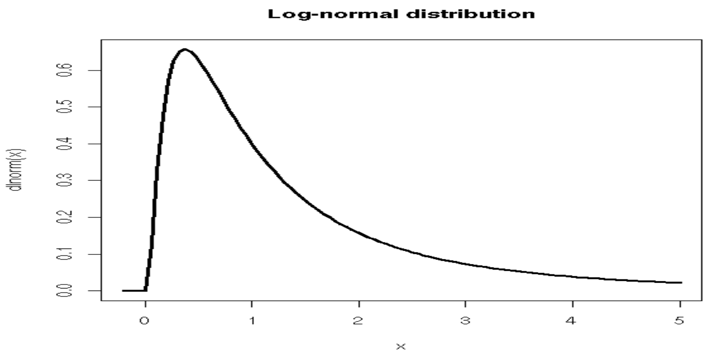

Figure 4: Log-normal distribution

Log-normal distribution, in which some of the textbooks refer as positively skewed distribution fit majority of the data that falls to the left of the mean. Based on the statistical parameters, the median falls in between the mode and the mean. However, the log-normal distribution becomes a normal distribution when the logarithms of the data are used. In log-normal distribution, the Chebyshev's theorem [13] which can be applied to any distribution is used to determine the spread of the data using the standard deviation, based the following formula:

$$P_D = 1 - \frac{1}{k} \text{ ------------- } (1)$$

- ❖ P_D represent the percentage of the data
- ❖ k represent the standard deviation of the variable

c) Weibull distribution

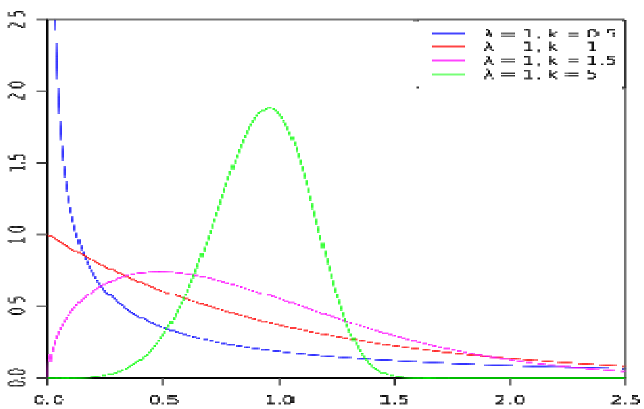

Figure 5: Wei-bull distribution

The Weibull distribution function is commonly used in life data analysis due to its flexibility. From the graph above, the main parameters for this Weibull distribution are *k* and λ.

In addition to the above distribution functions, the following mandatory statistical parameters are needed for further analysis purposes:

Mean, μ / $\bar{x}$:

$$\mu = \frac{\sum X}{n} \text{ ------------- (2)}$$

Standard Deviation, σ/s:

$$\mu = \sqrt{\frac{\sum(X-\mu)^2}{n-1}} \text{ ------------- (3)}$$

Variance, σ^2/s^2:

$$\sigma^2 = \frac{\sum(X-\mu)^2}{n-1} \text{ ------------- (4)}$$

Noted that *n* represents the number of samples used for the particular analysis.

The full parameters and equations for the respective distribution functions are shown in Appendix A.

3.2 Power Demand

Although in this project the main objective is the electricity price, it is still necessary to understand the electricity demand in Singapore as the clearing of the spot price depends heavily on the forecast demand. Instead of going straight into the analysis of the USEP, the student intends to undertake necessary understanding of the electricity demand. In Singapore due to its geographical location and electricity usage with our daily activity, the pattern of electricity demands are fairly predictable compared to most of the other countries especially where there isn't much difference in term of the overall temperature here. Time series graph are used in the study of the statistical behaviour of electricity demand over different category. The statistical results are presented in the following figures.

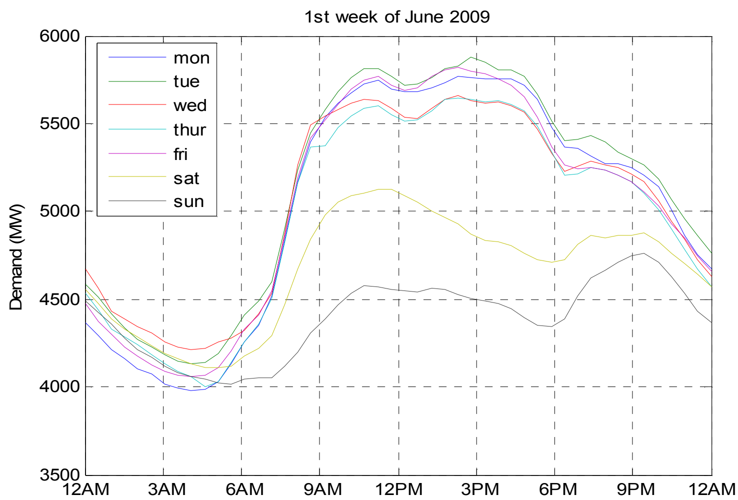

Figure 6: Hourly demand (MW) on 1 June to 7 June 2009

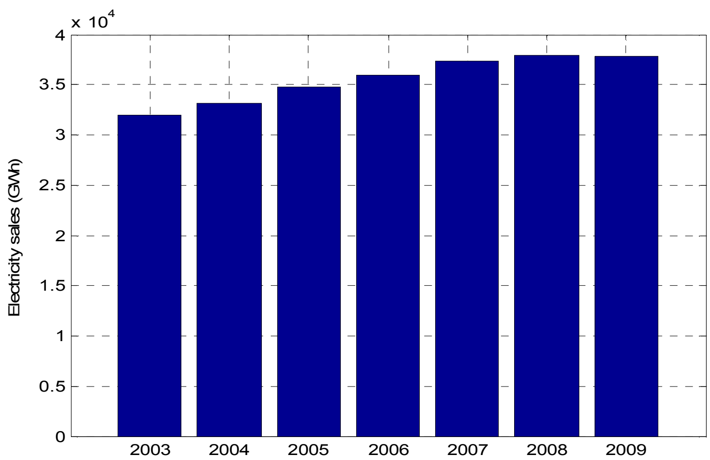

Figure 7: Yearly demand (in GWh) based on electricity sales

In the above figures, the time-series graph shows the mean hourly demand for one whole week and annual electricity demand for the past 7 years. The samples used in the hourly analysis does not involved public holiday, which will have a significant impact on the daily curve.

Based on Figure 6, weekday consumption shows a different demand pattern compared to the weekend. This is due to the fact that in Singapore, most of the working industry is a 5-day working week. In addition, the electricity demand peaks at different day. During the weekdays, the electricity demand generally peak at the period of 8AM to 6PM due to the normal working hours in most industries. Whereas during the weekend and public holiday, the patterns of the demand are slightly different in which load is higher at around late morning for Saturday and late evening in Sunday.

The average yearly demand in Figure 7 provides an exceptional view using the year 2003 to 2009 data. As Singapore continued to expand in various sectors, power consumption continued to increase for at least 3% every year. Unsurprisingly, the total demand in 2009 based on the demand sales was actually slightly lower than year 2008, as it can be explained due to the recession in late 2008 to mid June 2009, in addition to the drop in the crude oil prices. Thus there was lower power consumption from most industries during the period.

Although power demand has risen gradually since year 2003 with the exception of 2009, factors like economic crisis, unexpected virus spread also play an important part in the electricity price which will be discussed next. In addition, it was forecast that the power demand for the next coming years will be increasing gradually at a rate of at least 2.5% [2].

3.3 Preliminary Observation of USEP

In the NEMS, retailers pay wholesale electricity price (WEP) which includes the USEP, regulation, administrative like PSO fees, etc. However in this project, the student will primarily analyse the statistical behaviour of the energy prices using the USEP. Factors that will affect the pricings of the excluded price will not be discussed in this project. The study on the behaviour of the USEP will be divided into the following 4 categories:

3.3.1 Half-hourly USEP

In this segment, the student conducted a series of statistical distribution analysis in the understanding of the price behaviour at each period. As mentioned previously in this report, trading of electricity in the market is held every half hour interval. Thus the student intends to divide this segment into two main sections: peak and off-peak hours. The student uses year 2009 prices to analyse for the following sections.

❖ **Off-Peak**

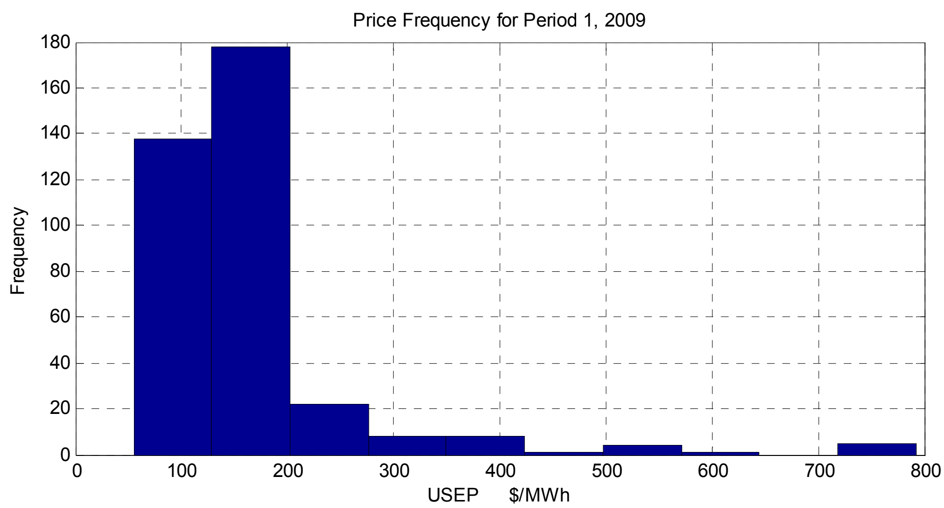

Figure 8: Period 1 in Year 2009

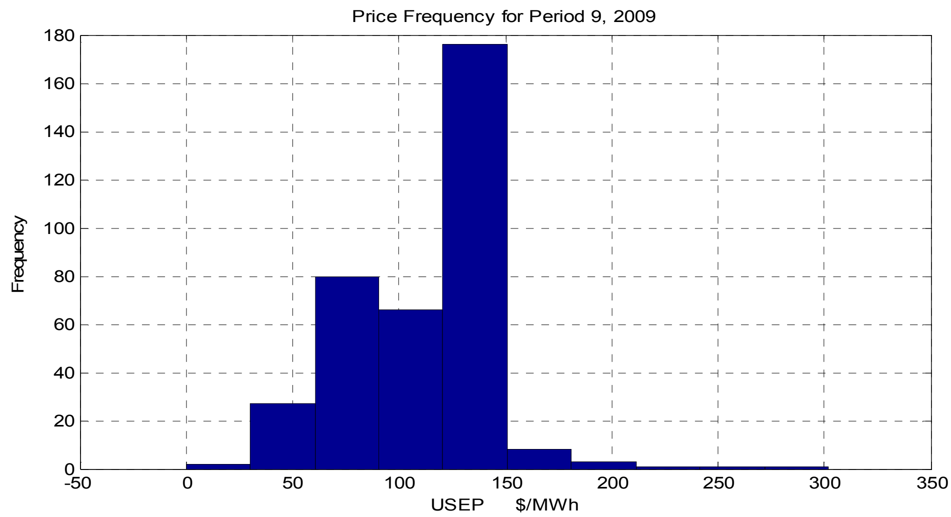

Figure 9: Period 9 in Year 2009

In the study of the prices distribution across the off-peak[2] period, respective half-hourly prices are plot onto the histogram and relevant parameters are calculated. Although majority of the off-peak assembles close to the log-normal and Weibull distribution, certain period's histogram assembles close to normal distribution with an example shown in Figure 9. To fully determine the exact distribution function, plotting the data into probability density function is needed. It will be discussed in Chapter 3.4.

It was noted that from period 4-11 in 31st January 2009 show unexpected prices, which USEP were priced from -\$5/MWh to \$0/MWh. Revising all the average periodic data consolidated in Appendix B show that in most of years from 2003-2009, negative prices often occur during the early morning period. However in Singapore electricity market, negative nodal electricity prices are allowed. The main reasons that caused the negative prices are due to two ways: generating companies offer negative bids into the market or it was due to a result of transmission loop-flow effects. The reason why generating company offers negative bid is the cost of shutting down the generator is higher than continuing to run [3]. Transmission constraints are unlikely to cause any effect on negative prices in Singapore power system, as of now.

[2] Off-peak are termed as the period of 1900 – 0700hr.

❖ Peak

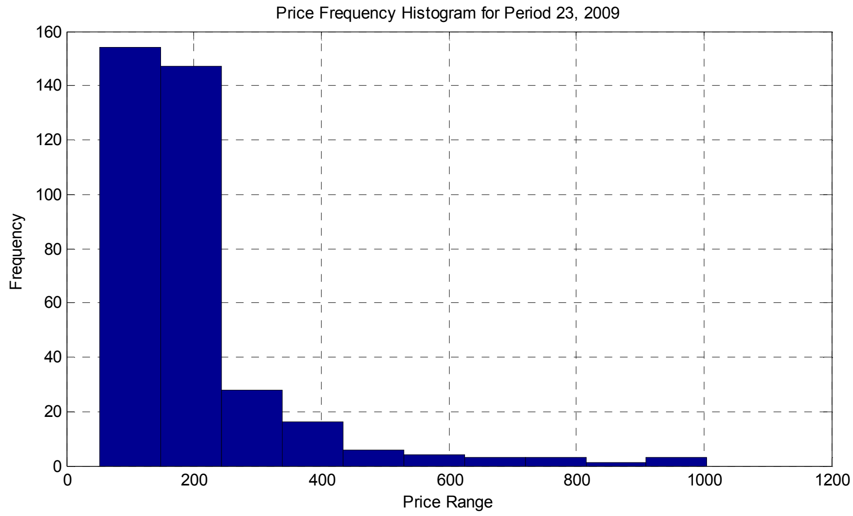

Figure 10: Period 23 in Year 2009

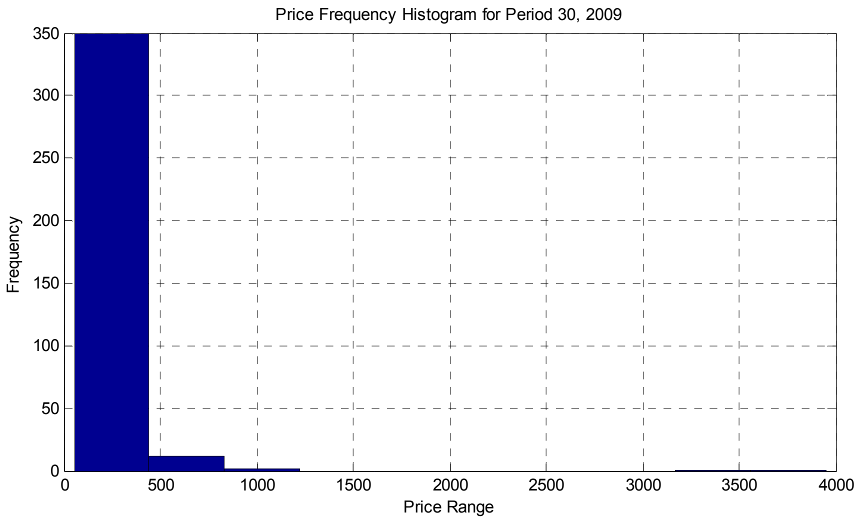

Figure 11: Period 30 in Year 2009

Table 3: Statistical parameters for period 23 and 30, 2009

Period	Std dev.	Mean	Median	Mode
23	140	191	157	151
30	288	198	151	151

In the study of the prices distribution across the peak[3] period, all the histogram assembled to the shape of the histogram represents a similar shape of a log-normal or Wei-bull distribution. This matches to the past studies which states that most of the half-hourly histogram fit well with the Weibull and log-normal distribution [9].

In addition, the variance of the USEP during the peak period is generally higher compared to those during off-peak, using the sample parameters in period 1 and 24 shown in the table below. It was noted that standard deviation was the appropriate parameter to be used to determine the diversity of the price as the unit for variance is different to the mean due to the square of the standard deviation for getting variance. High instability of prices is more likely to occur during the peak period based on the information shown below from year 2003 to 2009. An example will be in period 29 in 2009 which has a maximum value of \$4485/MWh, with a mean value of only \$209/MWh.

The full statistical parameters for the respective period are shown in Appendix B.

Table 4: Statistical parameters for period 1, 2009

Year	2009	2008	2007	2006	2005	2004	2003
Mean, μ	156	166	116	122	106	81	84
Std Dev, σ	108	52	15	47	37	33	18
Median	133	170	115	111	98	33	81
Samples, n	365	365	365	365	365	365	363

Table 5: Statistical parameters for period 24, 2009

Year	2009	2008	2007	2006	2005	2004	2003
Mean, μ	162	171	135	152	114	92	105
Std Dev, σ	103	72	64	182	70	90	30
Median	149	173	124	129	104	84	96
Samples, n	365	365	365	365	365	365	363

[3] Peak is termed as the period of 0730 – 1830hr.

3.3.2 Daily USEP

In this segment, the USEP prices are divided into two main categories: weekday and weekend. Weekday comprises the period from Monday to Friday, and weekend for Saturday and Sunday. The experiment in this section is to try and determine any common characteristics between the two different types of days. In this chapter, the student conducted an analysis on electricity prices across one full week.

❖ **Weekday**

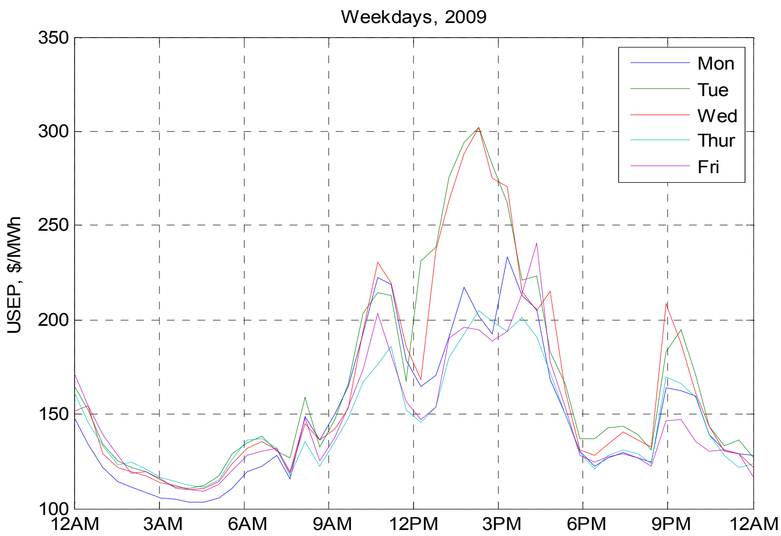

Figure 12: Hourly price for weekdays, 2009

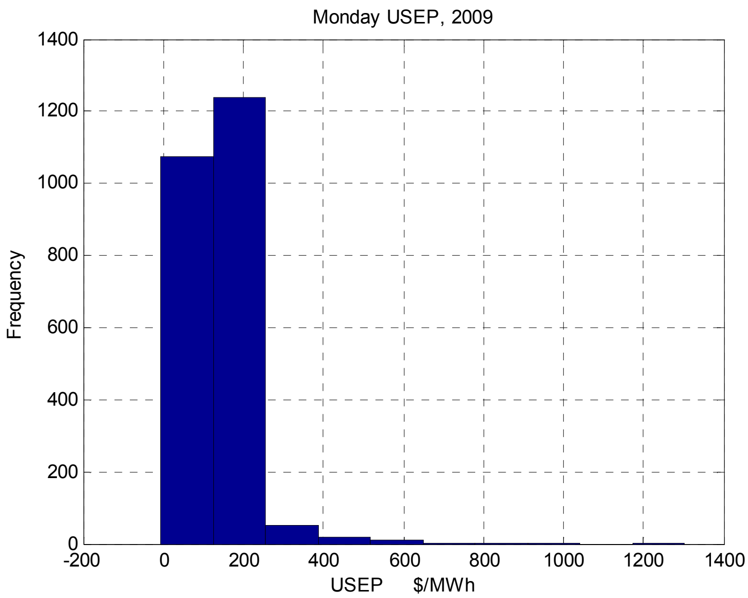

Figure 13: Histogram for Monday, 2009

Table 6: Statistical parameters for Monday - Friday, 2009

Date	Std dev.	Mean	Median	Mode
Monday	74	130	128	131
Tuesday	39	115	124	131
Wednesday	60	133	131	131
Thursday	195	178	150	161
Friday	268	195	151	151

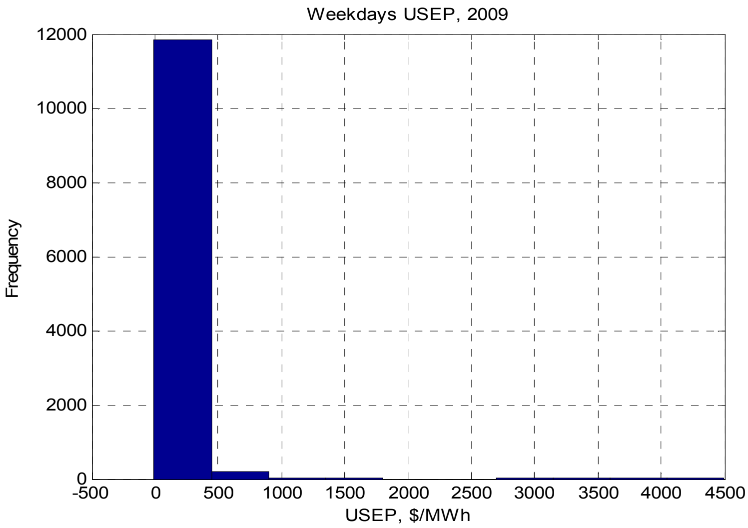

Figure 14: Histogram for Weekdays, 2009

Table 7: Statistical parameters for weekdays, 2009

Date	Std dev.	Mean	Median	Mode
Weekdays	159	151	131	131

Using the available prices data in 2009, the time-series curve for the period from Monday to Friday were executed. Based on the pdf for the mentioned period, it certified that prices in the weekdays followed a log-normal distribution function. In the next section, the weekend's analyses are carrying out.

❖ **Weekend**

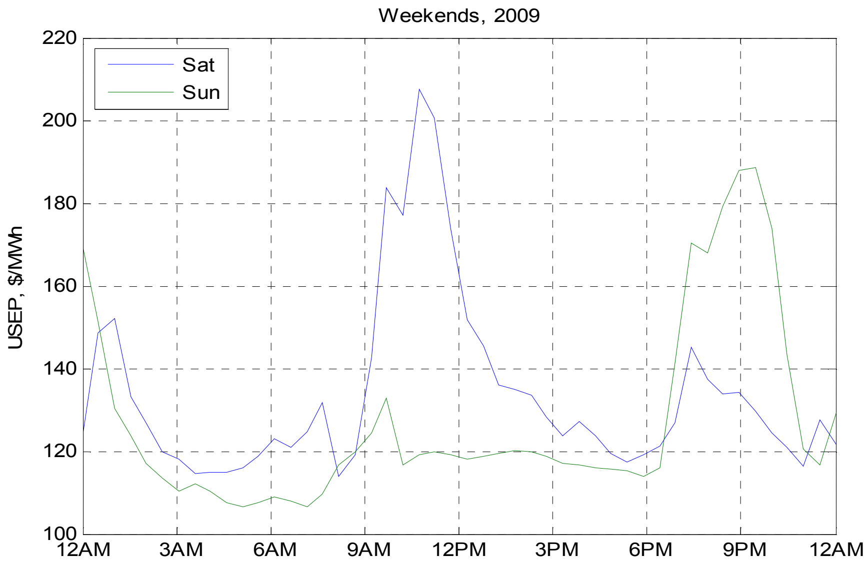

Figure 15: Hourly price for weekends, 2009

The above time-series curve provides an overview on the price behaviour during the weekend. Comparing the price in the weekend and weekdays, the latter produces higher average prices. It can be explained as average electricity demand will be higher during the weekdays. Price behaviour within the weekends also differs, as prices peak during the late morning to noon in the Saturday, whereas prices in the weekends generally peak during the night time.

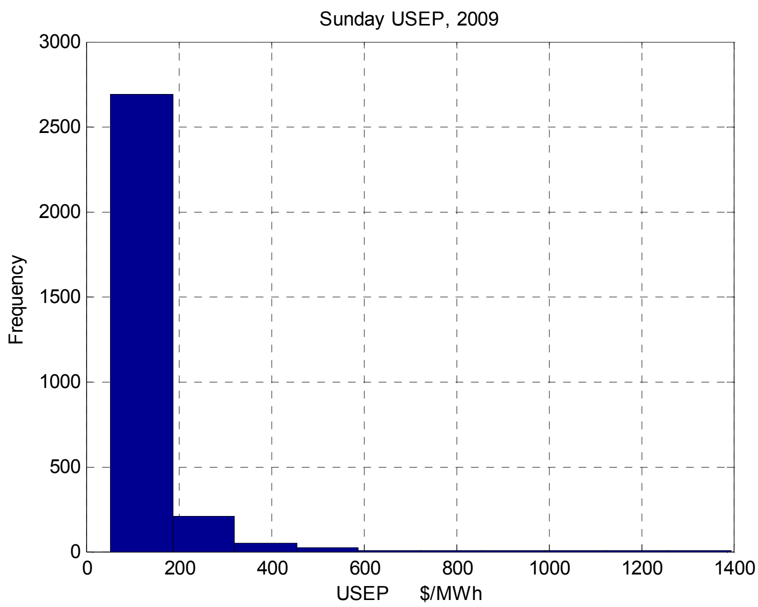

Figure 16: Histogram for Sunday, 2009

Table 8: Statistical parameters for Saturday-Sunday, 2009

Date	Std dev.	Mean	Median	Mode
Saturday	86	141	134	141
Sunday	87	142	134	141

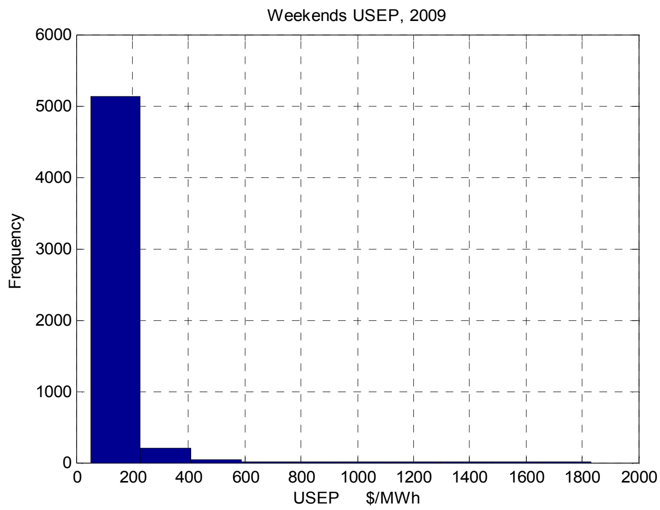

Figure 17: Histogram for weekends, 2009

Table 9: Statistical parameters for weekend, 2009

Date	Std dev.	Mean	Median	Mode
Weekend	89	143	134	141

As expected from the distribution functions for weekend, most of the data assembles to the log-normal function. In addition, the observation from the statistical parameters in weekend and weekdays show that latter has a higher standard deviation. A thorough analysis was then conducted based on one full week using the period of 1 – 7 June 2009.

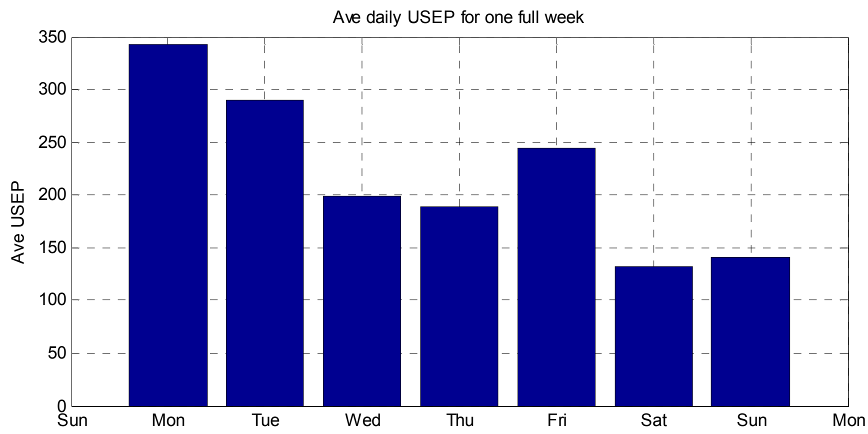

Figure 18: Bar chart for one full week, 2009

The above bar chart presents the daily average USEP for one full week. High differences of next day prices were observed in the chart. Example from Monday to Wednesday, there was almost a drop of at least $50/MWh per day. Weekend prices however show much consistent in the USEP in the two days.

3.3.3 Monthly USEP

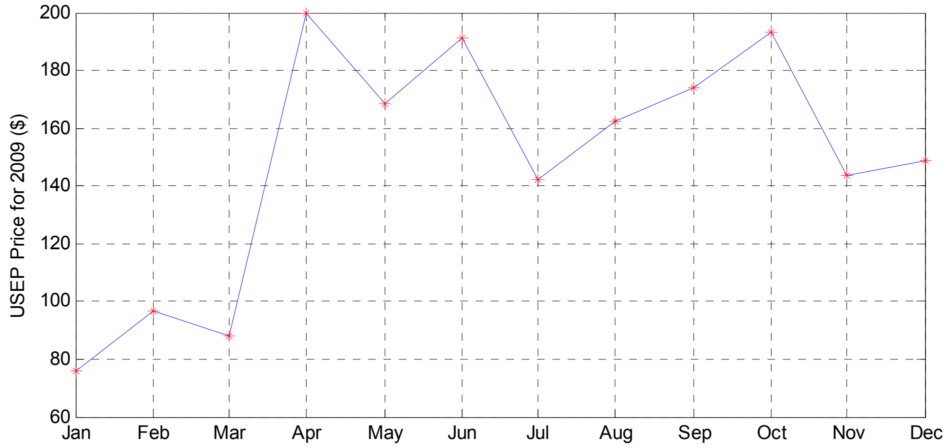

Figure 19: Monthly USEP, 2009

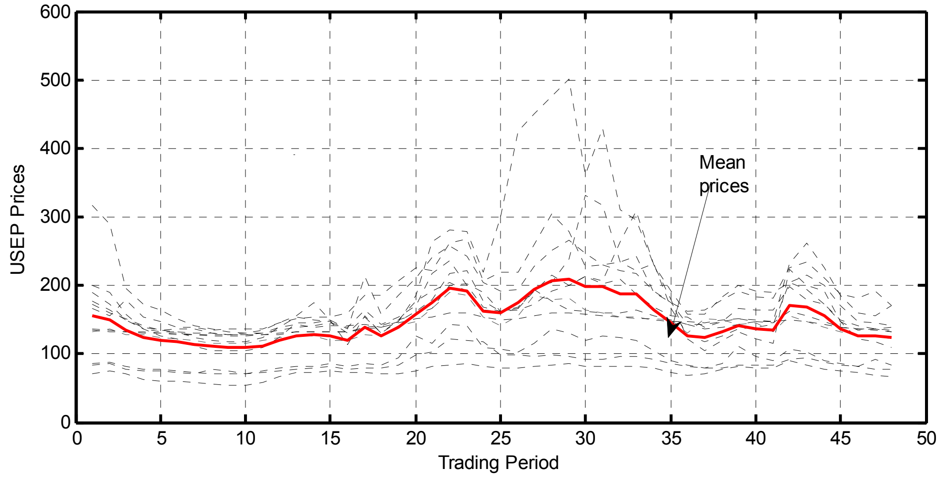

Figure 20: Periodic USEP for full month, 2009

In Figure 19, it shows the time-series graph for each month's USEP in year 2009. In the first 3 months, the USEP prices were in the lower-tier. Thereafter the prices rise by almost 100% in the next quarter, although the reason could be due to global recession in the late 2008 to early 2009.

From the graph observation, the price's instability within each quarter are fairly low, except Q4 where there is a $40/MWh drop in average price in November compared to previous month.

Figure 20 shows that the mean hourly price for each full month was considerably close. Thus the average prices for each month can be fairly consistent. With the understanding of the average monthly USEP behaviour, the student undertakes steps into understanding the statistical distribution for each month.

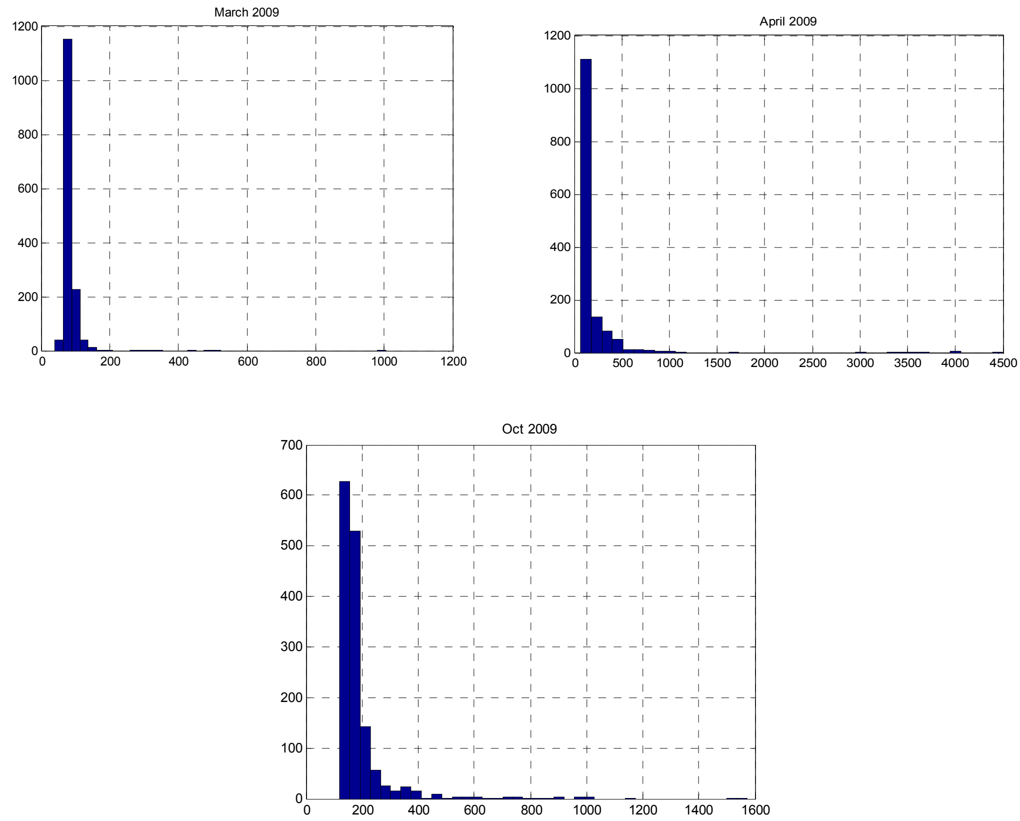

Figure 21: Histogram on Mar, Apr and Oct, 2009

Table 10: Statistical parameters for every month, 2009

Month	**January**	**February**	**March**	**April**	**May**	**June**
Mean	73.9825	95.7451	87.1784	199.1380	167.4144	189.6248
Std.dev	18.3492	49.4663	51.4560	364.8812	155.2465	106.5709
Median	73.4200	83.6600	80.0350	121.1200	136.2300	150.8550

Month	**July**	**August**	**September**	**October**	**November**	**December**
Mean	141.3490	161.7243	173.1765	191.5376	142.6770	148.8772
Std.dev	51.1273	84.8852	137.9636	122.1552	15.1208	48.3768
Median	127.2750	143.2450	145.9900	161.5750	137.9200	139.1850

Using the similar method in previous sections, the student will like to determine the distribution function by grouping the data into specific section. Histograms are plotted for every month and above figures show the histograms for March, April and October 2009 respectively. From the observations of all the 12 months histograms, it provides the similar verdict as previous sections: Weibull and log-normal distribution. A good explanation why the distribution will appear lognormal is because there is always a small amount of USEP that are unexpected high which caused skewness toward the right. This could explain why so far the findings are toward log-normal and Wei-bull distribution.

3.3.4 Seasonal Variation USEP

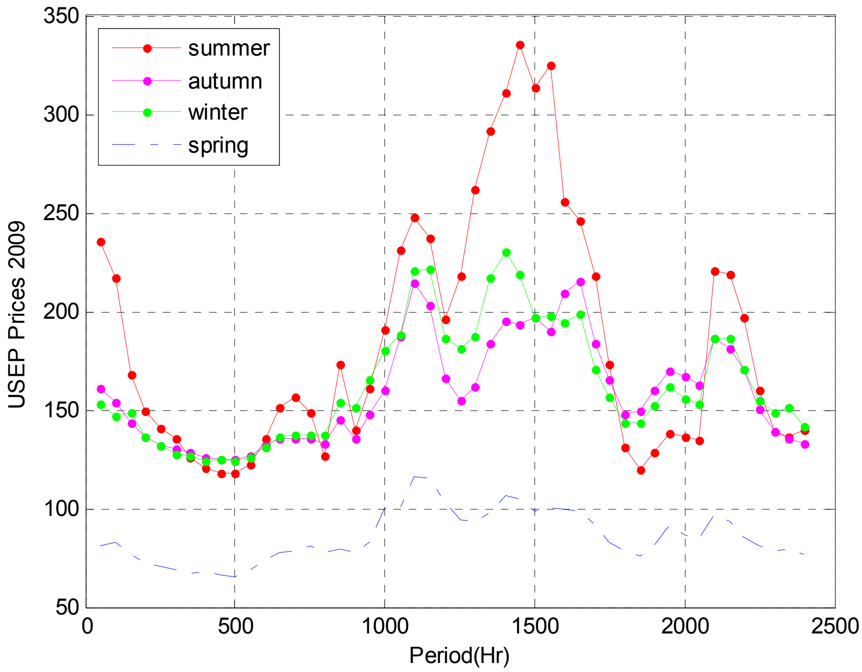

Figure 22: Half-hourly price for each season, 2009

Even though in Singapore where it hardly experience four seasons, the hourly electricity prices at different quarter of the year may experienced a slight difference due to environmental factors. Nevertheless due to the humidity of the weather in Singapore especially during the hot months in Singapore, there will be a higher demand for electricity at night as people will be switching on high power consumption cooling system like air-conditioners, fans, etc.

The student tries to make use of the historical data in year 2009 and classified each quarter data into the respective season based on the average monthly temperature in Singapore. The months are grouped according to the respective season: Spring for months of January to March, Summer for months of April to June, Autumn for months of July to September and Winter of months of October to December.

From the above observation especially during the autumn and summer, the price between 0000 to 0600HR provide a much steeper slope compared to the cooler seasons. Similar observation can be seen in the past 7 years. This could be explained due to the possibility of high power usage by air-cooling systems.

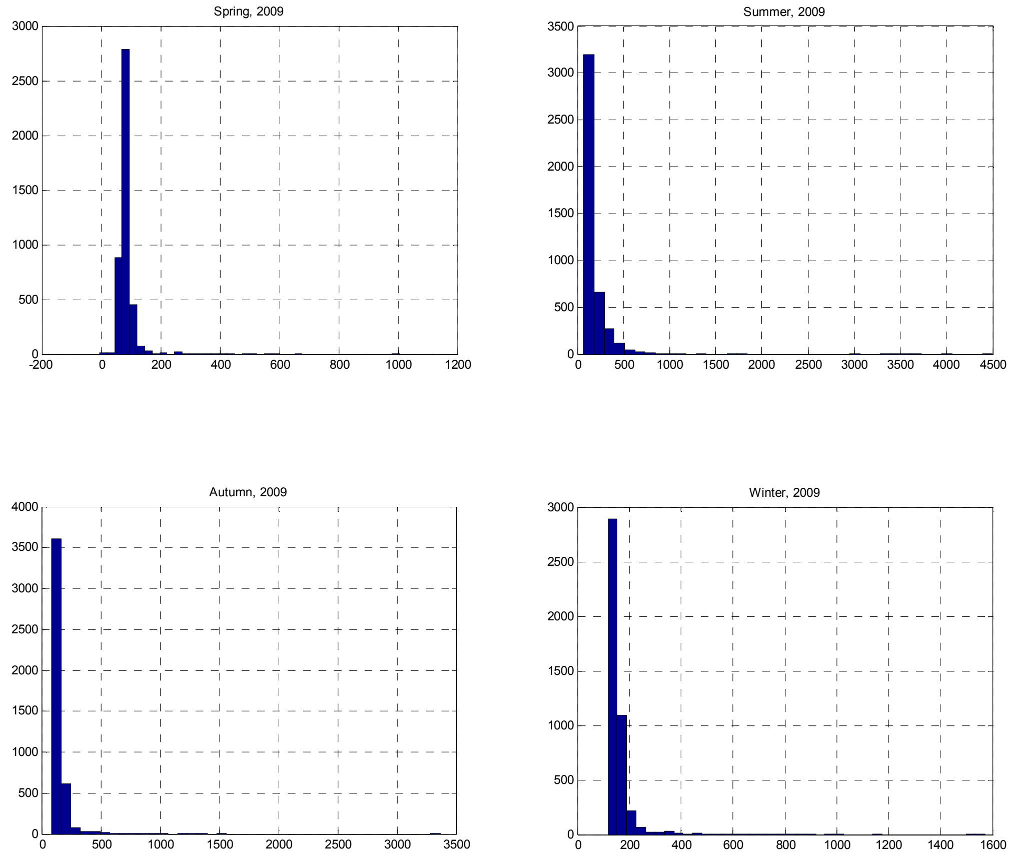

Figure 23: Histogram at various seasons, 2009

Table 11: Statistical parameters for seasonal, 2009

Month	Mean	Std.dev	Median
Spring	85.2983	43.2116	78.7900
Summer	185.1948	236.6406	136.0350
Autumn	158.5931	98.4072	140.6700
Winter	160.9507	79.3698	143.9950

From the table above, the standard deviation observed in the summer show a much higher dispersion of the price.

3.4 Tests for Normality

In statistical studies, a normally shaped or bell-shaped distribution is only one of many shapes a distribution can assume. Thus, it is important to fully determine whether the particular variable is normally shaped or others. There are several methods to determine for normality including, normal quartile plot, probability graph, Smikirov test, Pearson's index PI of skewness etc[13]. In this project, the student will be using two methods to verify whether certain variable in the specify period is normal or skewed.

The following methods are the methodologies used for determining the normality:

- Pearson's index PI of skewness:
  - PI = $\frac{3(\bar{X}-median)}{s}$ ------------- (5)
  - -1 < PI < 1, the sample is normal distribution, else otherwise.

- Probability density/ Cumulative graph:
  - Plotting of cumulative probability function (cdf) or probability density function in statistical software like MATLAB

For this project, the probability graph method is extensively used to determine the normality as MATLAB provide the capability in achieving the results with ease. However the negative prices in the USEP disallowed the plotting of the log-normal pdf in MATLAB as it required all data to be positive. Thus calculation method based on Pearson's index PI of skewness formula will be used as an alternative.

The pdf for a continuous random variable is a function that assigns a probability density to each and every value of the random variable. The following figures below show the probability density function plotted at various periods that are discussed in section 3.3. The initial histogram is plotted into a density histogram, and using the statistical parameters for the respective distribution parameters, the three main distribution functions are plotted into the figure. The following commands are used in the execution of the pdf.

Table 12: MATLAB command for respective distribution function

Distribution Function	Statistical parameters	pdf
Normal	normstat	Normpdf
Log-normal	lognstat	lognpdf
Weibull	wblstat	wblpdf

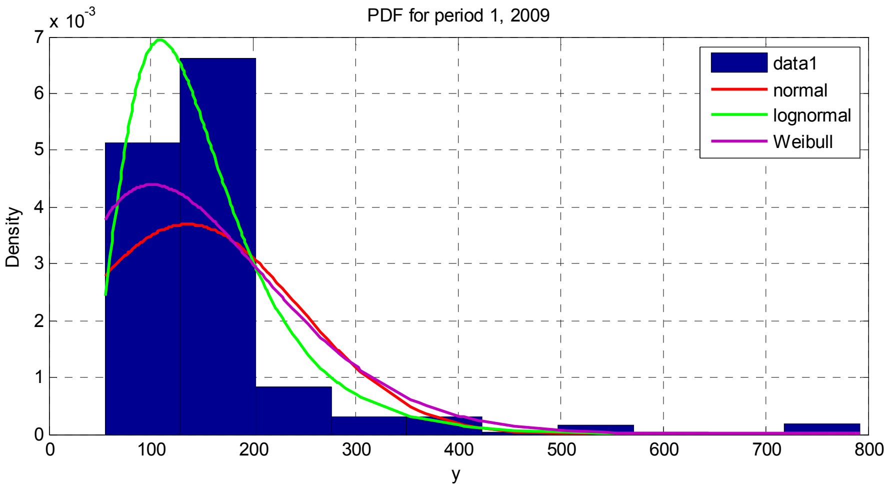

Figure 24: Density graph for period 1, 2009

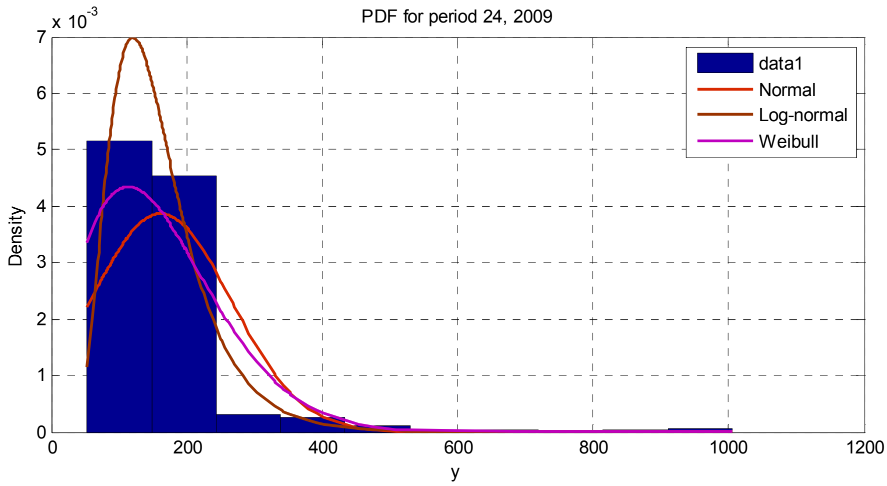

Figure 25: Density graph for period 24, 2009

The above pdf for the peak periods show the data assemble close to the log-normal distribution, which agreed to the initial experiment done by past research.

For cases like period 4-11 in year 2009 which contains negative to zero USEP, the use of manual calculation based on Pearson index was used to check if the normality of the distribution function. Based on the assumption made in the off-peak period histogram in the previous section and the calculation made using this methodology, we can confirm that some off-peak period actually fit to the normal distribution. Below are some of the calculations being made using Pearson index formula:

Table 13: Statistical parameters for period 5-9, 2009

Period	Mean	Std.dev	Median	Skewness
5	120	45	126	-0.4
6	117	40	126	-0.675
7	114	37	123	-0.729
8	111	34	122	-0.97
9	110	34	121	-0.97

3.5 Discussion

This section summarises on the discussions and findings in the previous 4 sub-sections.

In the hourly section, observation was made that the variance of the peak hour price are much higher compared to the off-peak period. An example will be the maximum price observed at period 26 in year 2009 was $4029/MWh with a mean value of only $174/MWh. The trends can be observed from all the past data from year 2003 to 2009 shown in Appendix B.

In the daily section, the hourly prices for a full week are divided into two main categories: weekday and weekend. The price behaviour in the weekday and weekend differs as figures show that weekday price generally is higher during the late morning to early evening whereas electricity prices peak in late morning and evening in the weekend.

In the monthly section, the mean prices for next month are fairly expected except for certain months, as seen in March-April 2009. In addition, the monthly prices for the whole year are pretty consistent, so we can expect not much variance of the average monthly price with the yearly price.

Lastly in seasonal variation section, the student observed that the mean prices during the summer and autumn seasons are higher than figures in winter and spring. In addition, the hourly price behaviour during early morning varies with different seasons, with a steeper drop of price seen in the hotter seasons.

The next chapter will be discussing on the statistical modelling of the electricity price based on the analysis and observations made.

Chapter Four: Polynomial Regression Model

For this project, statistical models were created to provide short-term prediction of price behaviour which will be categorized into various types: half-hourly prediction based on day-type consisting of weekday and weekend, seasonal variation, etc. As the model will be dealing with time-series analysis, the polynomial regression is identified as an ideal statistical model for price prediction.

4.1 Weekday Model

In this section, the student used the sample of the average weekday price from November to December 2009 to model out half-hourly weekday forecasting model. The data used to validate the performance for this model will be 4th to 8th January 2010. The reason for using the above data was it will not be feasible to use data that are too far away from the forecast timing, as noted that modelling only provide forecast based on the current conditions. First the data is loaded into two variable and plot into a curve. The "Basic Fitting" function in MATLAB allows the student to test and decide which the best fit to the data is. The best fit for this weekday model are the 8th to 10th degree polynomial equation. The figure below shows the best fit curves.

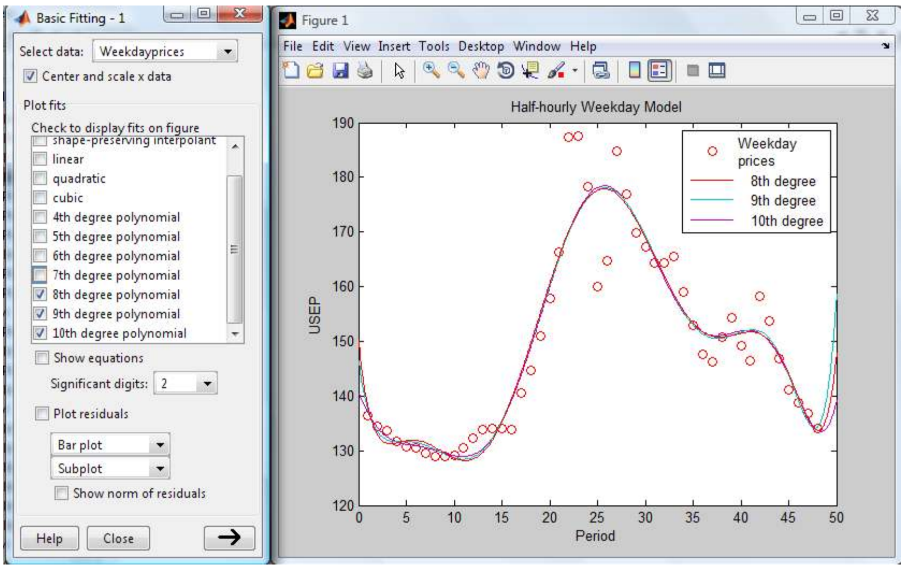

Figure 26: Fitting for weekday polynomial model

To improve the model accuracy, the x variable which represents the time period 1-48 will be normalised at the centre and scale. The normalisation is achieved using the following equations:

$$z = \frac{x - \mu}{\sigma} \quad \text{-------------} \ (6)$$

To determine the best fit for the weekday polynomial model, graphical representation and numerical results are used. In the graphical representation, the student will ascertain which curve fits well with the actual data on the graph. In the numerical results, the best fit shall be determined using the various Goodness of Fit statistics including residuals, Sum of Square Error (SSE), etc. For a best fit line, the residuals shall be at a minimum. The equation of the residuals is as followed:

$$\text{Residuals} = (y - \hat{y}) \quad \text{-------------} \ (7)$$

- $y = actual\ data$
- $\hat{y} = fit\ data$

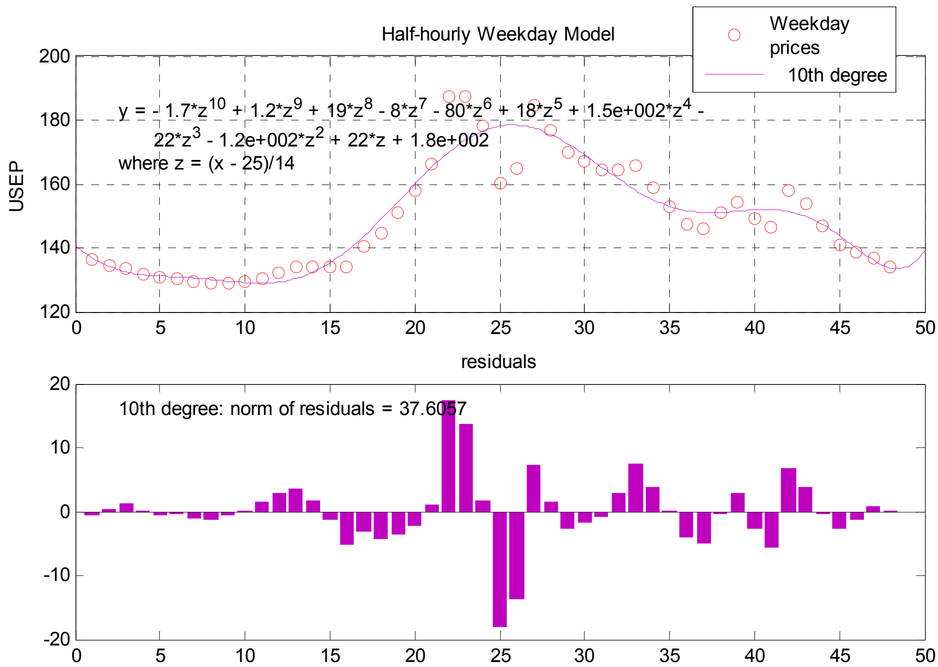

Figure 27: 10th degree polynomial model for weekday

Based on the fit statistics, the 10th degree polynomial shows the good fit for this model. After normalising using the equation, the polynomial equation is formulated. In the graphical representation at the first curve in figure 27 shown above, the model is able to fit into the data approximately well for most of the off-peak period, although not totally perfect in shape using the scaling. However on the Goodness of Fit statistics, the 10th polynomial equation provided the best fit.

The polynomial equation for the weekday model is as follows, with y variable representing the electricity price at the normalized time z variable computed using equation (6):

$$y = -1.6856z\text{^}10 + 1.1728z\text{^}9 + 19.3821z\text{^}8 - 8.0125z\text{^}7 - 80.3080z\text{^}6 + 18.1270z\text{^}5 + 148.59z\text{^}4 - 21.6806z\text{^}3 - 123.3872z\text{^}2 + 21.5292z + 177.5102$$

- ❖ $z = \frac{x - 25}{14}$ computed using equation (2), (3) and (6)

A sample of 4th to 8th January 2010 price was used to test the short-term forecast accuracy of this model. The mean half-hourly USEP for the above period are used as the actual data for validation.

Table 14: Weekday model test

Period	**2**	**6**	**10**	**20**	**32**	**40**	**44**	**48**
Actual	140	134	124	168	428	160	152	142
Forecast	134	131	129	160	162	152	147	134
Residuals	6	3	-5	8	266	8	5	8

From the sample of the validation results shown above, the forecast and actual prices are pretty similar especially in the off-peak period. However due to the uncertainty in the peak hour price during the weekday and excluding the demand in the analysis of the model, thus the prediction did not provide much accuracy in the peak period. Nevertheless, it still provides an efficient forecasting model at least for modelling the off-peak prices during the weekday in the near future. The full validation results for the half-hourly weekday model are shown in Appendix C.

4.2 Weekend Model

Based on the same concept done previously in the weekday model, the design of the weekend model was done using the mean weekend price from November to December 2009.

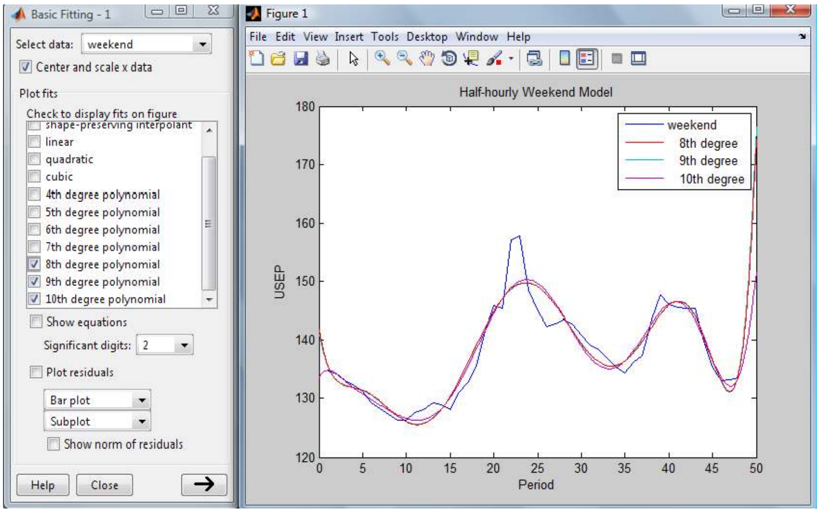

Figure 28: Fitting for weekend polynomial model

From the graphical representation, the weekend model was best fit with a 8th to 10th polynomial equation and similarly normalisation is done to improve the accuracy. To determine the ideal fit, the goodness of fit statistics is used to ascertain the 9th degree polynomial as the ideal equation.

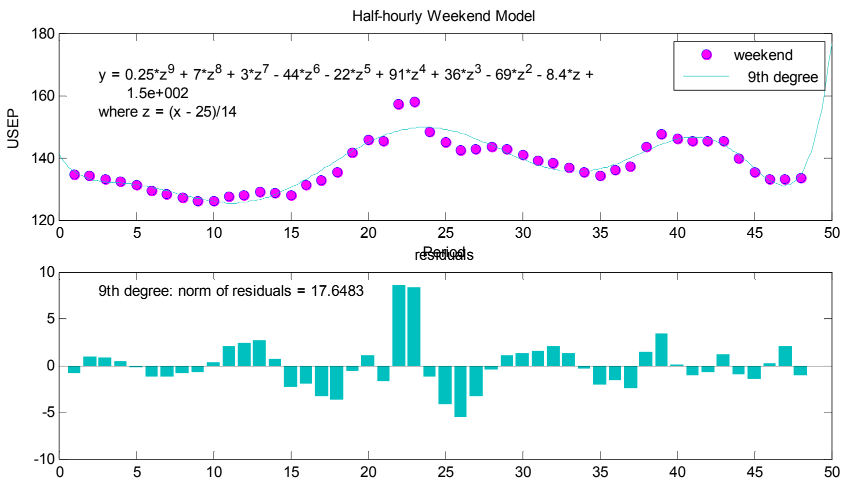

Figure 29: 9th degree polynomial model for weekend

From the model generated and based on the graph shown in the figure above, the model is able to fit most of the off-peak data and most importantly, the weekend model look more fitting compared to the weekday. This can be explained that in the previous chapter in the analysis of the data-type hourly price, uncertainty or spike in prices generally happen frequently during the weekday. After fitting the model, testing the accuracy of the polynomial model shall be conducted.

The polynomial equation for the weekend model is as follows, with y variable representing the electricity price at the normalized time z variable computed using equation (6):

$$y = 0.2468z\text{^}9 + 7.0107z\text{^}8 + 3.0283z\text{^}7 - 44.0181z\text{^}6 - 22.3106z\text{^}5 + 91.0751z\text{^}4 + 36.1575z\text{^}3 - 69.0917z\text{^}2 - 8.3664 + 149.4554$$

- $z = \frac{x-25}{14}$ computed using equation (2), (3) and (6)

The sample weekend prices from the period of 11th -12th January 2010 were used to test the accuracy of this model.

Table 15: Weekend model test

Period	2	6	10	20	32	40	44	48
Actual	146	135	130	152	143	153	150	138
Forecast	134	130	127	145	136	146	140	134
Residuals	12	5	3	7	7	7	10	4

From the sample of validation results shown above, the forecast of the weekend prices looks promising for majority of the 48 trading periods.

However the student will like to emphasize that the weekday and weekend models do provide prediction boundary of 90%, 95% and 99% confidence levels within the forecast prices, although it was not used in the validation results of the above models as the forecasting was for only a very short-period (only 1 week interval). 95%

confidence level setting for these model in the GUI was used which will be discussed in the next chapter.

With the implementation of the day-type models for short-term forecasting, the next model to be discussed will be the seasonal variation model.

4.3 Seasonal Variation Model

In the analysis of the hourly price behaviour in the various season under Chapter 4, we observed certain price behaviour which might be helpful in our modelling of the hourly season price in Singapore power market.

The following spring season model is implemented using the average hourly prices from the spring season in the year 2009. Figure 30 shows the fitting of the spring model using polynomial equation.

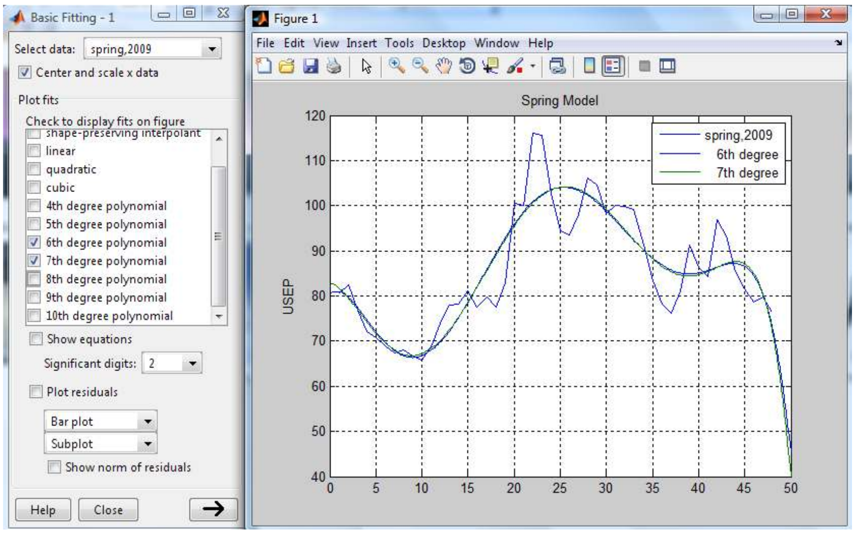

Figure 30: Fitting for spring polynomial model

Based on the above fittings, the 6^{th} and 7^{th} degree polynomial equation looks the best fit for the spring model based on the graphical representation and the typical price behaviour characteristics during the season. In the full assessment of the fitting curve based on the previous discussed criteria, 6^{th} degree polynomial was ascertained as the best fit for this spring season model.

Do note that in cooler seasons, the drop of price in the early trading periods are not as steep compared with the hotter season which is one of the factors used in choosing the above fitting curve.

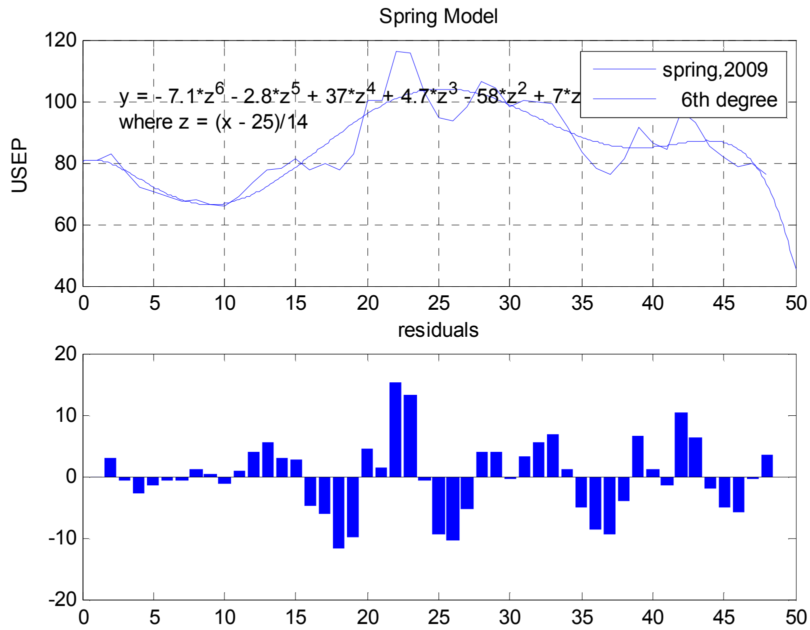

Figure 31: 6th degree polynomial model for spring

However to validate the performance of this spring season model that is fitted with 2009 prices and comparing with the latest prices in year 2010 will not feasible as average mean prices can change much within the one whole year. Thus the same 6th polynomial model is refitted with the average hourly price of January 2010 and validated by forecasting the mean price for February 2010.

The polynomial equation fitted using January 2010 prices is as follows:

- $y = -7.2402z^6 + 13.7570z^5 + 42.7757z^4 - 66.5655z^3 - 85.3678z^2 + 82.1832z + 207.3294$

The student uses 95% confidence boundary interval in this forecast due to the fact that forecasting next month spot prices require some flexibility compared to the shorter forecast period in the previous models as fuel price will play an important part in the mean monthly price.

Table 16: Spring model test

Period	2	6	10	20	32	40	44	48
Actual	188	149	139	194	322	210	219	161
Forecast, 95% confi	113-185	97-165	103-170	129-196	193-259	140-207	132-200	103-188

From the above prediction statistics based on 95% confidence boundary, majority of the prediction prices fall within the actual price. Thus based on the performance computed from the validation results, it should provide a good estimation of the coming month's hourly mean price within the particular season.

With this concept achieved from this spring season model, it should provide a good concept in designing the next 3 season's model. The winter model also follows the 6^{th} polynomial model as the price behaviour is almost identical with spring season. Thus the designing of the winter season model will not be presented as it will be replicating the same step.

The summer and autumn season model will not be implemented in this project as the latest summer and autumn prices for Year 2010 are not available for validation.

Chapter Five: GUI

In this project, the student designed a graphical user-interface (GUI) for the statistical analysis of the electricity price in Singapore Market. The purpose of the GUI is to allow users including analysts, engineers to conduct statistical analysis and prediction based on the available data and models provided with the use of intuitive controls such as pushbuttons, edit boxes [14]. Moreover, GUI allows the exhibit of multiple graphs which will be in great help when data comparison is needed. The GUI for this project is design using MATLAB which provided the capability for inexperienced designer to design a user-friendly GUI.

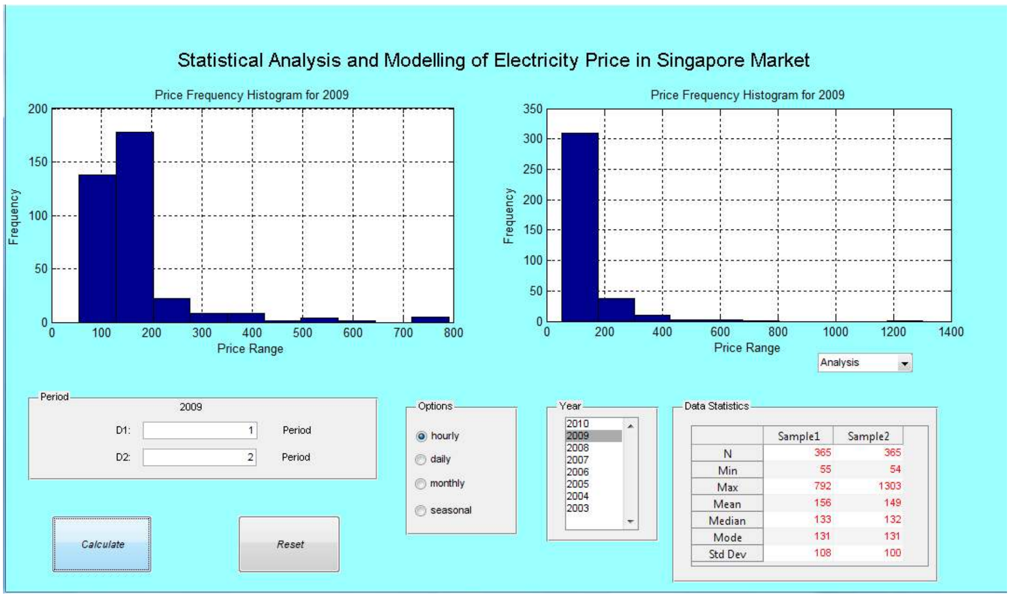

Figure 32: Layout of GUI

The design outlook of the GUI is shown in the figure above. The GUI main features are divided into four main components:

- Input function
- Options
- Statistical parameters
- Output

5.1 Input function

In this section, it allows the user to input the relevant value into the text box under "Period". The input values required vary to the options chosen in the "Options" section by the user, which will be discussed on the next section.

The two axes in the GUI display out the histogram or time series curves based on the input, option and year chosen by the user, by pressing the appropriate pushbutton. The statistical parameters at each period will be updated simultaneously. The GUI will reset all the parameters and relevant information when "Reset" button is initial. The statistical parameters at each period will be updated simultaneously.

5.2 Options

In the GUI, the program required mandatory selection at three options, "Options" radio box, "Year" list box and "Analysis/Prediction" popup menu. The available year for selection ranges from 2003 to 2010. The user input required for the various options under the Analysis selection are shown in the table below.

Table 17: GUI options

Options	User Inputs
Hourly	1-48
Daily	Mon/Tue/Wed/Thu/Fri/ Sat/Sun/Weekday/Weekend/Everyday
Monthly	January – December/All
Seasonal	Summer/Winter/Autumn/Spring/All

In the Prediction menu, only 'Daily' and 'Seasonal' options are available for price prediction using the models discussed earlier in previous chapter.

In addition, there is a "data cursor" option at the toolbar which allows users to manually move the cursor to any point of the graph to determine the relevant data.

However, errors will be prompted to users when any one of the options is not properly selected.

5.3 Statistical parameters

The table located at the bottom right of the GUI displayed out the relevant parameters. Users will be able to utilize the statistical parameters for mathematical analysis. Parameters provided are number of sample data, minimum, maximum, mean, median, mode and standard deviation.

Data Statistics

	Sample1	Sample2
N	365	365
Min	51	51
Max	1832	1007
Mean	165	145
Median	144	136
Mode	161	146
Std Dev	145	85

Figure 33: Statistical parameters in GUI

5.4 Output

The output of this GUI emphasizes two things: graph and printing of data. The display consists of two main graphs: histogram and time-series curve. Below shows some of the examples for various users's input.

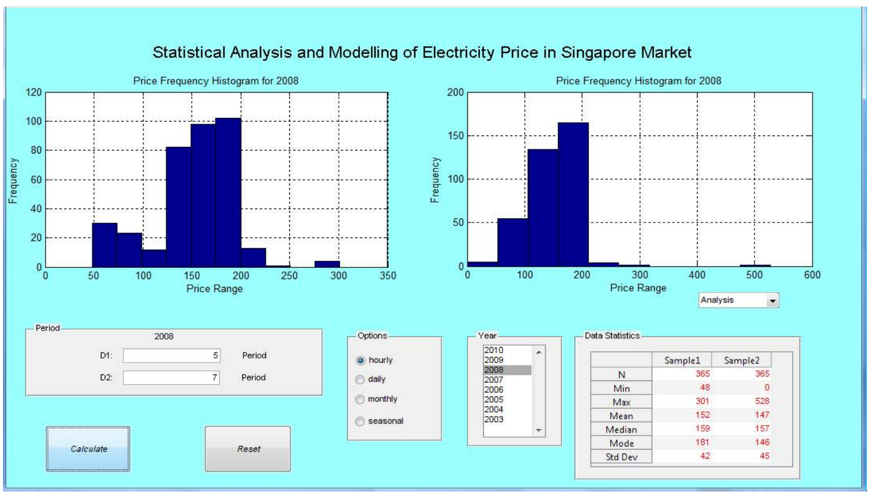

Figure 34: GUI using Hourly option

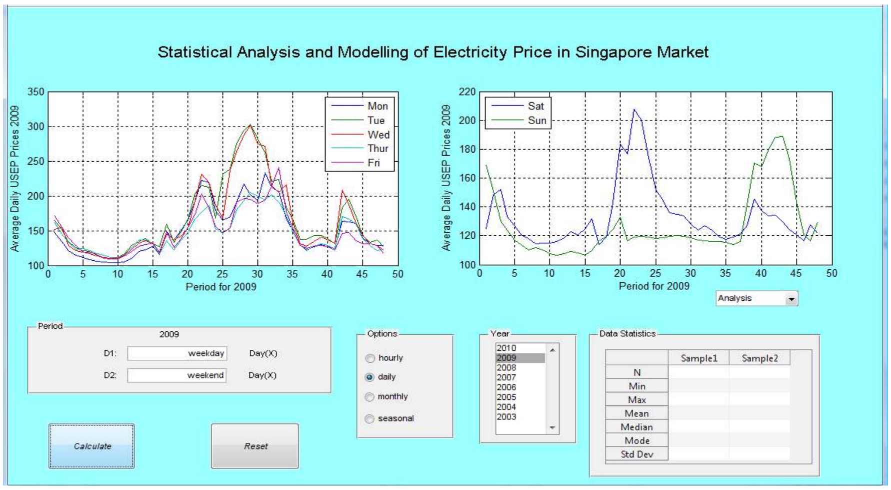

Figure 35: GUI using Daily option

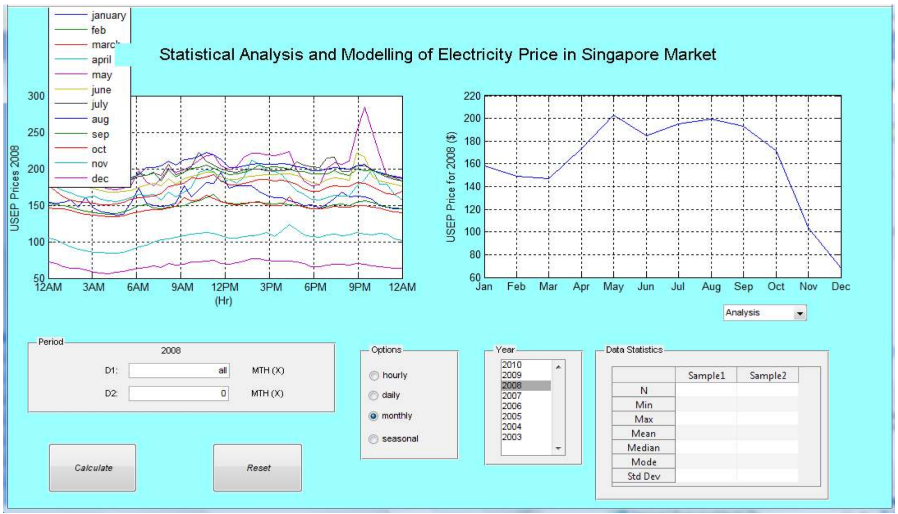

Figure 36: GUI using Monthly option

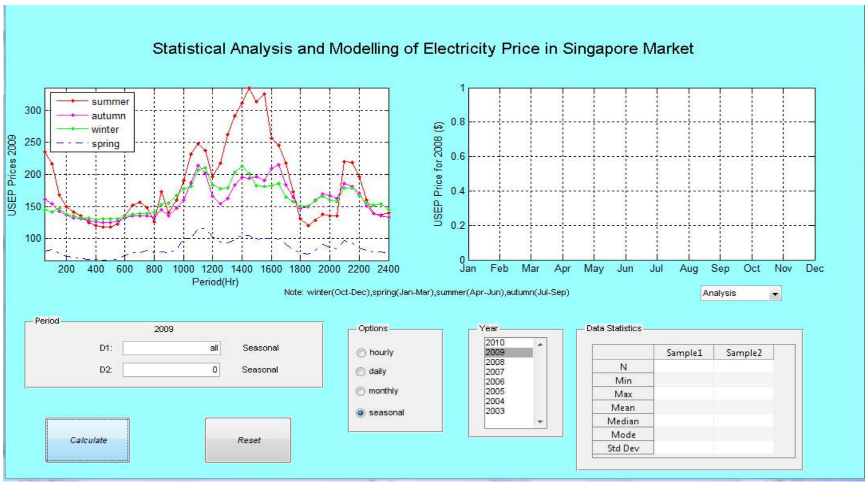

Figure 37: GUI using Seasonal option

In the daily option under "Prediction" selection, the weekday and weekend model are displayed on both graphs. With the data cursor provided on the toolbar located at the top left of the GUI, it allows users to view the forecast price at the respective x axis. In addition, the prediction boundary with 95% confidence level of the forecast value is displayed along with the actual data. 90% and 99% confidence levels are not implemented for these models in this GUI as the student felt it will provide negative visual effects on the presentation of the data, although minor changes to the coding will be able to achieve that with ease if required.

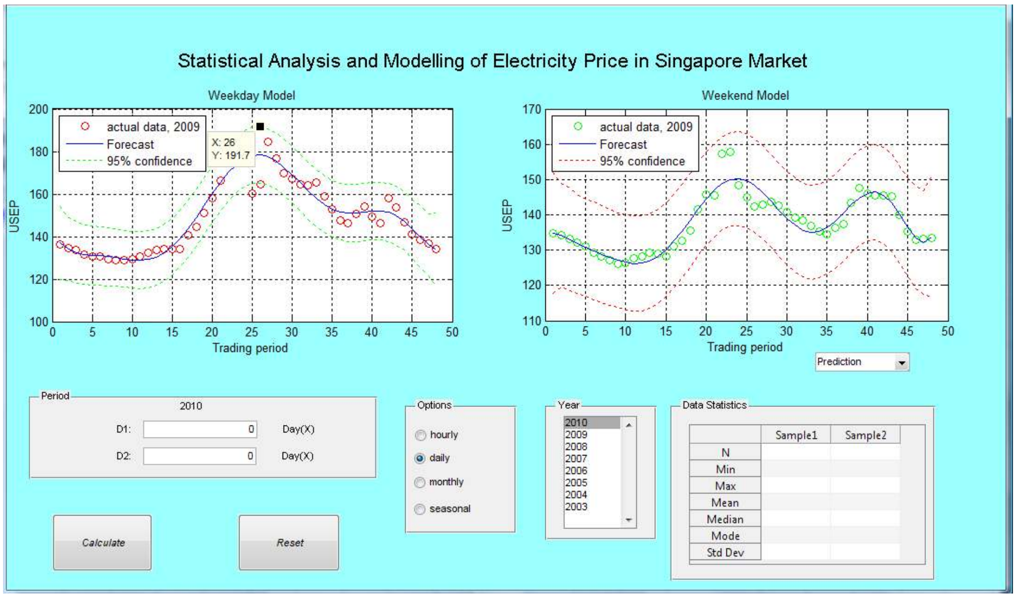

Figure 38: GUI using daily option under Prediction section

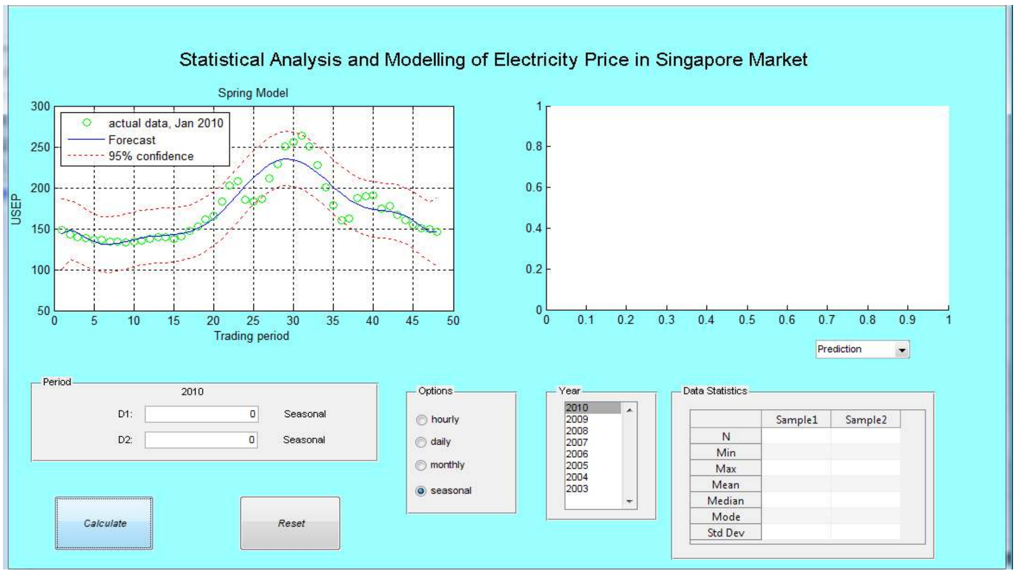

Figure 39: GUI using seasonal option under Prediction section

Chapter Six: Conclusion

6.1 Summary of Work

To be able to make accurate forecast of the electricity price using efficient analysis models will be of a great significance for the generating companies. This project presents one proper approach to the statistical analysis and modelling of the electricity price behaviour using the historical data from years 2003 to 2009.

In chapter three, statistical analyses were conducted based on half-hourly, daily, monthly and seasonal variation period. In the half-hourly analysis, it was observed that the presence of the negative price during the off-peak period can affect slightly the distribution function of the particular period. Variances of the USEP are generally higher during the peak hours in the weekday. The different trends of the peak prices during the weekday and weekend were also observed. The monthly mean prices for the whole year are pretty constant, so we can expect not much variance of the average monthly price with the yearly price.

In chapter four, the statistical models for the weekday, weekend and seasonal variation are implemented using the polynomial regression technique. The results from individual model shows promising results, although not totally perfect as the forecast error during the high demand still exist. However it still provides a blueprint in forecasting short-term electricity prices.

With the basic implementation of the statistical model, it will help to provide generating companies and consumers an estimation forecast of the USEP in the coming months.

Finally, a GUI has been developed as explained in Chapter 5, to graphically demonstrate the results of the above analyses and modelling. Users will be able to utilize it for forecasting short-term electricity prices using the various models integrated in the system.

6.2 Recommendations for Future Work

The following recommendations can be made for the respective segment:

- Analysis
  - Analysis of latest USEP to ascertain the latest price behaviour in the power market. Example will be using year 2010 prices.
- Modelling
  - Using other methodology in the statistical modelling, such as GARCH model, non-linear regression, etc.
  - The modelling of the spot price could be further categorized into different time-scale like public holiday, day and night time, etc.
  - The polynomial models designed for the various time-cycles can be refitted with the latest data for more accurate forecast in the future.
- GUI
  - Various statistical representations like pdf, density histogram can be integrated into the GUI analysis section.
  - Updating the model with latest USEP figures for future analysis and modelling purposes.

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Appendix A: Statistical Distribution Functions

Table 18: Properties of Various Statistical Distribution Functions

Distribution	Probability Density Function, *pdf*	Cumulative Distribution Function, *cdf*	Mean	Standard deviation
Normal	$\frac{1}{\sqrt{2\pi\sigma^2}}\exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$	$\frac{1}{2}\left[1+\operatorname{erf}\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right]$	μ	σ
Log-normal	$\frac{1}{x\sqrt{2\pi\sigma^2}}\,e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}}$	$\frac{1}{2}+\frac{1}{2}\operatorname{erf}\left[\frac{\ln x-\mu}{\sqrt{2\sigma^2}}\right]$	$e^{\mu+\sigma^2/2}$	$\sqrt{(e^{\sigma^2}-1)e^{2\mu+\sigma^2}}$
Weibull	$f(x)=\begin{cases}\frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1}e^{-(x/\lambda)^k} & x\geq 0\\ 0 & x<0\end{cases}$	$1-e^{-(x/\lambda)^k}$	$\lambda\Gamma\left(1+\frac{1}{k}\right)$	$\sqrt{\lambda^2\Gamma\left(1+\frac{2}{k}\right)-\mu^2}$

Appendix B: USEP Data

B.1 Year 2009

Table 19: Half-hourly USEP parameters, 2009

Period	Mean	Std dev.	Min	Max	Median	Period	Mean	Std dev.	Min	Max	Median
1	136	108	55	792	133	**25**	161	189	51	3326	146
2	149	100	54	1303	132	**26**	174	277	51	4029	146
3	134	74	51	979	130	**27**	194	295	52	4029	151
4	124	52	0	504	128	**28**	206	325	54	4499	155
5	120	45	0	491	126	**29**	209	329	53	4485	155
6	117	40	-5	400	126	**30**	198	288	54	3948	151
7	114	37	-5	307	123	**31**	199	311	54	3622	149
8	111	34	0	286	122	**32**	187	169	54	1655	151
9	110	34	0	302	121	**33**	186	221	54	3363	149
10	110	33	0	303	121	**34**	165	145	51	1832	144
11	156	108	55	792	133	**35**	145	85	51	1007	136
12	119	41	49	402	125	**36**	127	47	51	503	131
13	126	50	54	403	126	**37**	124	48	51	504	129
14	127	52	54	435	128	**38**	132	61	52	698	132
15	126	47	55	435	128	**39**	141	82	54	1004	137
16	120	43	59	642	126	**40**	137	75	54	1004	136
17	138	79	56	1007	132	**41**	135	82	53	1268	134
18	127	50	51	655	131	**42**	171	118	62	1204	146
19	140	59	51	554	138	**43**	168	124	62	1394	146
20	157	80	51	706	147	**44**	155	107	60	1207	140
21	175	112	52	804	151	**45**	137	62	60	668	134
22	196	143	52	996	158	**46**	127	50	59	724	131
23	191	140	53	1005	157	**47**	127	63	57	761	130
24	162	103	53	1005	149	**48**	124	63	56	753	127

*Off peak = Period 1 – 14 & 36-48, peak = Period 15-35

Appendix B: USEP Data

Table 20: Average half-hourly USEP per week in 2009

PERIOD	MON	TUE	WED	THUR	FRI	SAT	SUN
1	147.65673	164.94846	151.68423	161.25642	171.05962	124.69596	168.77288
2	134.01596	152.12269	154.55827	145.50887	154.67904	148.50019	151.34096
3	121.40327	133.79577	128.81038	133.41547	139.14942	152.03923	130.35038
4	114.46077	125.4525	121.23038	123.37377	128.28846	133.14135	123.64731
5	111.3525	121.68692	119.27596	124.42811	118.57538	126.75154	116.97981
6	108.07808	119.685	116.87058	121.04585	119.53788	119.94038	113.48558
7	105.46712	114.94885	113.31173	116.64755	115.63308	117.89769	110.20519
8	104.69462	111.16481	111.71635	114.47132	110.56712	114.67	111.97404
9	103.29981	110.86346	109.89673	111.70811	109.61269	115.03173	110.47846
10	103.35442	111.76519	110.81096	111.37151	109.38308	114.92654	107.38846
11	105.40173	116.95788	114.29192	115.29057	113.11423	115.80327	106.51288
12	110.76269	128.55231	123.66519	125.8183	120.38058	118.71192	107.635
13	119.6525	134.41096	131.77385	136.37585	127.90846	122.81173	109.05288
14	122.58038	138.36385	135.45135	136.69283	130.11442	120.91615	107.93827
15	128.20865	130.6375	131.08135	131.90906	131.56519	124.63731	106.45442
16	115.52365	126.94096	118.30192	117.14755	119.23885	131.74346	109.73481
17	148.32462	158.81827	144.72442	135.5	147.92827	113.88962	116.49942
18	136.52769	132.69173	136.47019	122.26792	125.37808	119.00481	119.74038
19	149.87558	147.41192	142.1925	135.08887	137.69865	142.54769	124.34308
20	164.57231	165.90154	152.82019	147.70491	153.71077	183.53808	132.93135
21	192.54808	203.57135	193.84596	166.86925	173.41327	176.93115	116.7525
22	222.30058	214.26808	230.54692	176.35698	203.17692	207.66404	119.0575
23	219.13192	212.61577	219.51885	185.92434	181.77596	200.485	119.69615
24	178.74385	167.96692	186.11	152.36208	156.49923	173.95808	119.17212
25	164.556	231.3765	168.2835	145.9362	147.2087	151.6846	118.1069
26	170.5467	238.3142	237.2385	153.9183	153.4025	145.4329	118.8398
27	190.7204	275.9833	263.3137	180.2323	190.3673	135.9454	119.506
28	217.2908	294.2787	287.8937	192.4917	196.1771	134.8498	120.1842
29	202.0871	302.4687	302.1398	205.1068	194.5808	133.59	119.656
30	192.3942	282.0813	274.7954	199.2038	188.9417	128.2481	118.6487
31	233.2335	261.7556	270.7538	194.1134	193.9388	123.6827	117.1921
32	212.8394	220.7698	214.8412	201.5345	213.4825	127.0729	116.5944
33	205.6977	222.8996	204.6642	190.9525	240.5608	123.8044	116.1219
34	168.1035	183.3094	215.3225	171.9926	177.9235	119.3181	115.7648
35	149.764	166.4265	162.5006	149.983	153.5335	117.38	115.3348
36	130.1852	137.0737	131.2619	129.5191	128.2813	119.0998	113.8225
37	122.1212	137.0644	127.8069	120.8992	124.5102	121.2788	116.0896
38	126.6627	142.4006	133.7188	127.9289	127.4417	126.7379	141.0687
39	129.7935	143.1548	140.3283	131.2147	129.1131	145.1694	170.341
40	126.3523	139.1281	136.3944	128.6379	126.4727	137.2552	168.0025
41	124.8265	130.7029	132.4408	123.7662	121.9317	133.6985	179.0198
42	163.9794	183.2683	208.4844	169.7998	146.096	134.1494	188.0392
43	162.6856	194.5923	187.3167	166.3287	146.8262	129.7121	188.7302
44	159.7852	170.5054	160.8583	158.8832	135.7927	124.4987	173.8231
45	139.2344	143.1456	143.6525	139.0128	130.5221	120.9356	143.2687
46	131.0535	133.2854	130.539	128.4411	130.8713	116.2571	120.4871
47	128.6227	136.5237	128.9977	121.3681	128.6756	127.4131	116.7596
48	128.4329	126.6523	121.3438	123.7364	116.6344	121.5252	129.4563

Noted: Computed using Microsoft Excel

Appendix B: USEP Data

B.2 Year 2008

Table 21: Half-hourly USEP parameters, 2008

Period	Mean	Std dev.	Min	Max	Median	Period	Mean	Std dev.	Min	Max	Median
1	166	52	57	547	170	**25**	166	56	60	535	170
2	164	53	56	509	170	**26**	166	59	60	659	171
3	160	51	52	493	163	**27**	169	68	58	972	172
4	156	48	53	498	162	**28**	173	79	58	1103	172
5	152	42	48	301	159	**29**	173	74	58	1076	172
6	150	50	43	739	157	**30**	171	71	58	1081	171
7	147	45	0	528	157	**31**	170	71	58	1093	169
8	146	45	0	512	154	**32**	170	71	56	1094	170
9	144	45	0	510	152	**33**	171	69	52	1025	169
10	144	46	0	512	152	**34**	166	53	52	548	168
11	166	52	57	547	170	**35**	161	45	52	505	165
12	151	45	48	519	158	**36**	158	44	52	507	159
13	158	64	50	946	161	**37**	157	43	57	507	161
14	156	45	52	491	162	**38**	163	58	57	825	165
15	157	44	52	474	161	**39**	166	60	57	756	169
16	156	47	54	535	161	**40**	164	56	56	784	168
17	164	54	55	550	166	**41**	163	53	56	543	166
18	160	44	56	409	167	**42**	174	69	61	805	175
19	167	64	56	956	173	**43**	177	88	62	1126	175
20	169	52	59	550	177	**44**	171	73	60	1037	175
21	175	73	60	651	173	**45**	163	51	58	506	170
22	178	72	61	656	177	**46**	158	45	56	540	166
23	176	69	61	705	177	**47**	155	43	53	514	161
24	171	72	61	903	173	**48**	153	43	54	509	159

*Off peak = Period 1 – 14 & 36-48, peak = Period 15-35

Appendix B: USEP Data

Table 22: Average half-hourly USEP per week in 2008

PERIOD	MON	TUE	WED	THUR	FRI	SAT	SUN
1	162.859	171.5026	169.8751	168.8537	167.98	153.7406	170.1448
2	160.0548	165.8902	164.8321	161.2069	161.0827	170.8804	165.9256
3	154.5288	162.007	159.3872	159.0954	156.1757	170.0004	156.5162
4	146.514	158.0725	153.5747	154.6398	153.3233	165.1408	157.5817
5	144.0617	151.683	151.8021	152.9004	150.3706	160.1087	150.8867
6	142.4638	148.3655	147.5753	150.5046	148.541	165.3023	149.1679
7	138.6146	146.236	147.4443	148.3044	147.2867	158.6238	146.2956
8	136.8808	145.5742	145.686	146.736	145.8239	156.3531	142.4529
9	136.484	143.5442	145.0904	145.7623	145.2647	154.6237	140.4271
10	136.8665	144.4953	143.3219	145.9487	145.6988	154.3287	140.0985
11	139.2062	146.5125	148.1092	148.6458	147.2176	150.4404	142.4758
12	144.851	152.7066	153.3685	152.7113	150.569	157.2888	143.5504
13	149.5006	162.2379	164.6485	158.7381	155.1941	167.7248	145.3519
14	152.1688	163.9045	162.126	159.921	157.2908	153.4946	144.3554
15	156.6817	165.5734	161.3451	157.7192	158.718	153.5713	143.4027
16	151.8144	166.8551	154.6075	153.6663	153.7473	162.8023	147.3819
17	162.8517	177.2909	173.3281	162.8858	163.0476	153.2902	151.5935
18	161.3444	163.9949	159.3489	158.6556	157.8549	164.8527	156.2233
19	165.1158	176.4074	160.9623	160.8162	160.9682	181.5769	159.8727
20	169.189	175.7515	165.0174	162.6387	165.1541	180.6581	164.401
21	175.5279	181.984	179.8587	164.9238	166.7516	202.2617	150.7108
22	177.3619	185.83	178.0662	166.5242	171.4957	210.1896	152.8158
23	172.6306	187.2583	184.3662	166.3621	170.8573	199.0138	153.0446
24	164.9213	173.4517	183.7074	162.3075	165.8371	193.5929	151.8133
25	168.7317	165.0787	171.5938	160.276	162.4457	180.9775	150.7931
26	169.7033	170.1936	173.8213	161.1515	162.0506	173.4773	151.4787
27	173.1667	183.7821	175.3804	164.2531	166.602	170.4033	151.7108
28	178.3713	191.0736	185.7019	167.7921	169.8618	168.5352	151.4548
29	179.825	191.0126	183.1555	168.15	172.4014	165.8948	151.911
30	178.2492	188.5162	180.3302	165.964	170.8308	161.2788	151.9987
31	175.0431	185.7634	177.976	165.2227	173.5237	159.7558	150.8125
32	172.9523	187.6721	180.7996	167.3625	173.9867	160.9117	149.3398
33	171.6479	190.0128	182.3638	167.6177	172.5765	159.3473	149.6273
34	168.3183	178.0819	175.5249	165.8423	168.268	155.2979	148.9623
35	163.5223	165.633	172.4164	162.2463	161.9278	153.5758	148.2177
36	159.7333	160.8442	159.7902	163.9563	157.4029	154.3546	147.6012
37	158.5479	158.6136	157.863	163.8523	157.5141	152.1815	150.0419
38	160.2942	161.0404	160.397	171.9144	160.0935	163.0702	162.7994
39	162.261	165.953	161.6342	171.1421	161.2678	173.3927	165.6502
40	161.8217	162.3149	159.0496	159.469	159.8076	176.5729	167.9465
41	164.5144	160.6189	158.5087	158.9215	157.6143	171.09	169.1377
42	174.7887	177.4443	170.2149	186.4131	167.7476	168.7242	170.3517
43	178.5931	186.207	168.1653	194.6004	172.5116	168.5752	168.246
44	173.4642	183.7796	172.7087	175.4733	167.3353	161.0256	161.2006
45	165.0494	168.3045	166.2189	162.0327	159.0049	156.2467	163.5698
46	157.0869	160.8438	158.03	157.4771	156.3769	153.5767	164.6306
47	159.9967	157.876	152.903	154.1583	154.4469	151.1038	154.2738
48	156.7087	152.5194	149.5409	151.6633	152.1063	147.9012	161.5313

Appendix B: USEP Data

B.3 Year 2007

Table 23: Half-hourly USEP parameters, 2007

Period	Mean	Std dev.	Min	Max	Median	Period	Mean	Std dev.	Min	Max	Median
1	116	15	84	207	115	**25**	129	39	86	512	122
2	117	17	84	202	115	**26**	128	32	86	456	122
3	118	23	84	360	115	**27**	131	32	86	466	125
4	113	16	84	158	112	**28**	134	41	85	493	127
5	111	16	83	178	109	**29**	140	154	85	2974	127
6	109	16	82	202	108	**30**	133	52	85	827	126
7	108	16	82	197	105	**31**	140	199	85	3905	126
8	106	15	81	157	104	**32**	141	123	85	4330	126
9	106	15	80	166	103	**33**	136	123	85	2348	126
10	105	16	0	148	102	**34**	130	52	85	988	124
11	116	15	84	207	115	**35**	126	21	88	357	122
12	110	16	82	190	108	**36**	121	12	88	157	119
13	114	24	84	457	112	**37**	120	13	86	163	119
14	115	26	84	416	112	**38**	122	13	87	192	119
15	114	25	82	468	112	**39**	125	22	87	435	121
16	117	25	84	404	115	**40**	125	23	92	435	121
17	122	39	85	815	119	**41**	126	40	40	825	121
18	133	178	85	3448	118	**42**	132	45	45	866	127
19	127	39	87	615	121	**43**	131	44	91	836	126
20	136	83	87	1238	123	**44**	128	41	87	777	123
21	148	131	87	1994	127	**45**	124	41	85	808	119
22	160	253	89	4500	129	**46**	121	36	84	715	117
23	154	173	91	2736	128	**47**	119	29	84	450	116
24	135	64	87	925	124	**48**	116	23	84	359	115

*Off peak = Period 1 – 14 & 36-48, peak = Period 15-35

Appendix B: USEP Data

Table 24: Average half-hourly USEP per week in 2007

PERIOD	MON	TUE	WED	THUR	FRI	SAT	SUN
1	114.8189	114.9162	113.5671	114.7	114.4077	119.3194	123.2412
2	113.8642	117.1433	116.1613	116.7906	119.07	117.449	121.229
3	111.9304	115.9002	115.435	115.9815	119.7496	125.4121	118.0815
4	109.0585	112.3252	112.1137	113.1394	113.1517	117.0717	114.9987
5	107.0874	110.8352	110.0948	111.1892	110.5023	114.5188	112.7233
6	104.8881	108.2869	108.4613	110.454	108.7563	113.4115	110.1054
7	103.3953	107.434	107.1596	108.9402	107.2512	110.6396	108.1056
8	101.3221	106.5883	106.4217	107.3346	106.1965	109.6023	106.816
9	99.95302	105.7085	105.5835	106.461	105.6248	108.8515	105.8967
10	97.64849	105.0946	105.1523	105.4465	104.9638	108.6288	105.7102
11	99.63811	106.7925	106.4488	106.656	108.3871	108.0958	105.9171
12	106.4136	110.8283	111.5813	109.6706	112.1829	109.9225	106.6979
13	111.8657	120.3796	117.0721	113.7177	115.4502	112.1852	108.2887
14	119.4706	117.22	117.8202	114.8473	118.8971	112.1708	108.0854
15	120.806	113.6383	113.6879	112.9613	114.1385	113.1152	107.775
16	126.1823	115.8781	115.2046	114.2087	118.1425	117.7396	110.8431
17	136.7934	120.1333	121.1352	120.1696	122.5804	117.9044	114.5488
18	133.773	125.634	120.3975	183.7006	121.4267	126.4413	118.1846
19	134.5564	122.1392	123.055	123.5213	125.5827	138.9938	123.2777
20	140.6234	129.9504	125.7419	128.294	128.599	173.6048	128.9244
21	144.7936	134.365	128.4898	126.7819	143.8748	224.734	133.7229
22	150.2413	158.059	131.1656	127.5552	143.966	290.186	122.54
23	139.9017	153.9715	130.3606	127.9071	139.6892	257.9888	127.6865
24	134.4474	125.286	127.7146	125.5117	133.9156	180.3263	121.2565
25	127.3636	122.6817	123.8258	121.4117	130.2029	157.3508	119.6227
26	128.0211	124.1867	124.9169	122.8537	131.5548	146.8238	120.0304
27	135.5194	128.3088	129.2412	126.4642	138.4687	136.9062	120.6623
28	143.6411	135.9887	131.5531	127.7656	146.55	132.9019	120.8846
29	134.5123	136.7981	132.4983	127.9046	148.0944	179.7748	120.5102
30	132.8053	134.529	131.6356	127.3525	145.5825	137.3723	119.3896
31	132.4913	132.8594	131.1483	127.0996	139.8604	196.4987	118.285
32	133.3819	131.1083	130.1075	128.4413	145.1673	203.6285	118.4263
33	132.8198	130.7688	129.579	128.4796	138.2529	176.0046	117.6144
34	130.7385	132.8325	127.5013	127.1544	133.0894	141.2892	121.1367
35	127.8236	126.1808	131.956	126.5077	128.0167	121.3496	120.2381
36	122.1215	121.9985	121.0771	121.4296	121.7663	117.0015	120.1852
37	120.5302	120.3623	119.4625	119.8144	120.2913	118.1173	122.8917
38	121.5658	122.1923	122.6408	122.0538	121.1327	121.4394	122.4071
39	121.9232	123.9169	123.2687	122.3765	123.64	125.3667	132.7329
40	122.1502	123.1388	124.104	121.6527	121.9098	124.0742	137.2542
41	122.2226	123.2488	122.6321	121.5723	121.0931	122.6738	146.6083
42	129.4102	133.9304	135.5954	130.8833	127.7329	122.1656	148.2113
43	129.6709	135.4952	128.7017	131.0731	125.7808	121.3685	147.1642
44	125.3681	127.1025	125.36	127.5088	124.4369	119.4192	146.2737
45	121.6498	122.5958	120.8313	120.7838	119.561	118.5444	141.0062
46	118.2023	120.8537	118.409	116.9317	117.7988	117.4879	135.4077
47	116.3415	117.6377	115.7437	115.0704	116.8769	115.9506	133.2427
48	113.6557	113.5067	114.2281	113.9762	118.2931	114.9017	126.6073

Appendix B: USEP Data

B.4 Year 2006

Table 25: Half-hourly USEP parameters, 2006

Period	Mean	Std dev.	Min	Max	Median	Period	Mean	Std dev.	Min	Max	Median
1	122	47	88	406	111	**25**	146	196	95	3708	126
2	134	54	84	467	120	**26**	145	173	93	3263	127
3	133	55	81	469	120	**27**	142	80	95	832	129
4	126	41	81	438	118	**28**	144	69	96	663	131
5	122	37	84	427	115	**29**	143	66	94	665	131
6	117	29	81	408	113	**30**	141	81	93	1293	130
7	114	21	81	304	111	**31**	139	59	93	716	128
8	112	17	80	212	110	**32**	137	55	92	716	127
9	111	16	80	183	110	**33**	137	58	92	716	126
10	111	18	0	211	110	**34**	147	234	92	4500	127
11	122	47	88	406	111	**35**	134	102	90	1889	124
12	118	31	84	467	113	**36**	125	66	88	1289	119
13	125	45	84	524	116	**37**	121	26	88	408	119
14	120	30	85	455	115	**38**	126	48	92	766	121
15	114	25	87	405	110	**39**	131	56	92	768	124
16	123	43	88	765	116	**40**	131	70	91	1023	121
17	137	165	88	3186	124	**41**	132	61	90	768	122
18	129	52	88	706	121	**42**	159	104	92	931	130
19	134	54	90	510	124	**43**	157	96	95	853	131
20	140	59	92	508	128	**44**	138	60	92	768	127
21	161	191	97	3384	132	**45**	127	47	91	767	120
22	166	216	97	3799	132	**46**	122	44	88	748	116
23	164	210	98	3782	133	**47**	117	24	88	438	114
24	152	182	95	3321	129	**48**	113	18	88	270	110

*Off peak = Period 1 – 14 & 36-48, peak = Period 15-35

Appendix B: USEP Data

Table 26: Average half-hourly USEP per week in 2006

PERIOD	MON	TUE	WED	THUR	FRI	SAT	SUN
1	110.1287	113.5433	112.5806	123.0204	117.0573	124.8615	155.576
2	118.1781	143.2746	136.9656	137.8867	136.849	124.3554	139.3932
3	120.5013	135.7442	134.3167	134.256	139.1785	137.6183	132.8708
4	113.2448	123.0756	123.5538	125.375	132.5363	137.4021	124.0089
5	112.2621	124.7125	119.1067	121.2446	120.5008	128.2569	125.1006
6	111.5896	116.6196	116.8131	118.0325	116.0625	120.67	122.2428
7	109.5529	114.8008	114.6808	115.5542	113.8373	119.7094	111.8525
8	108.6954	113.3238	113.259	113.1775	112.2969	114.7708	109.0328
9	107.1381	112.5987	113.0135	112.0792	111.7692	112.8927	107.676
10	106.6283	113.6135	114.2792	112.6594	112.4275	112.3692	107.6038
11	107.036	115.4446	120.5081	114.2648	115.1854	113.425	107.7808
12	109.5635	120.8638	126.6646	119.5821	120.4444	122.1379	108.564
13	118.7735	133.6869	137.3212	125.7419	124.5406	122.6569	109.4351
14	118.6596	123.0194	124.8008	122.9679	119.9854	120.9219	108.7128
15	114.9448	115.1277	116.8773	115.6838	112.4335	119.1938	107.3891
16	132.2438	119.7654	122.496	122.5738	117.7021	136.6446	110.2926
17	189.7408	132.3504	140.1223	136.0479	125.2067	118.9496	118.1558
18	136.3231	125.934	124.4248	125.8912	128.9542	137.9292	124.5828
19	131.3256	129.1473	127.1531	132.6385	130.4862	157.0969	133.6313
20	134.8904	128.4962	134.4823	134.6208	133.5037	174.0821	140.1687
21	146.8181	143.9292	143.4106	135.7788	131.5121	262.8556	159.737
22	150.8379	152.4308	147.1873	141.5277	138.3013	303.475	132.5804
23	148.4163	149.4908	146.2821	143.9731	136.3981	290.0015	132.3387
24	132.3862	137.7562	135.8912	141.1113	126.2577	263.6388	129.154
25	127.3298	135.6571	131.6348	136.9327	123.9102	240.4129	127.8177
26	132.991	147.7777	128.7738	139.476	125.5223	209.5973	132.3594
27	132.804	164.9673	136.4206	145.9012	132.1552	153.1	132.3104
28	134.5906	152.8625	141.761	156.3169	146.6367	141.5552	134.3275
29	132.7329	151.934	143.5558	154.5469	143.631	138.8215	139.477
30	139.9308	145.5452	140.2544	143.0598	134.7735	149.0602	136.9726
31	137.6467	146.7746	141.3006	142.8762	135.4685	132.4723	134.2925
32	134.139	145.1798	141.2783	144.3294	136.4019	127.1681	130.3062
33	133.1533	151.6896	140.1046	147.1531	134.0392	123.9367	128.0551
34	129.3479	147.1988	135.8496	231.2448	130.1254	116.3844	139.4298
35	125.8325	144.2952	129.8527	164.6513	124.4313	113.3283	132.974
36	121.2517	127.2987	120.7325	143.9838	117.6815	111.4556	132.5258
37	119.0658	123.6315	120.9354	121.0337	115.2665	112.3275	137.2308
38	120.1954	126.0848	124.1575	127.0479	116.3465	118.5094	147.44
39	122.769	127.051	125.2102	127.0642	117.5994	124.5085	168.8985
40	121.034	125.4975	127.0177	120.8135	116.7575	125.4525	179.7506
41	132.9546	125.9002	127.2819	122.3644	115.8585	125.1237	171.2085
42	160.4037	159.2288	180.6194	175.9015	130.6585	124.6344	178.0055
43	150.7608	164.5069	184.9729	173.7779	131.5888	121.3015	174.3009
44	131.8194	148.2138	145.731	142.8621	122.5179	118.3767	156.6638
45	123.6092	128.7823	132.611	129.5296	118.3692	117.589	138.1962
46	117.9254	120.9442	121.8752	124.2038	120.8517	115.4971	134.4826
47	115.5675	117.1788	119.0787	116.3277	116.9619	115.5054	121.0379
48	114.0167	111.5563	112.7587	110.8021	112.6685	116.39	115.9275

Appendix B: USEP Data

B.5 Year 2005

Table 27: Half-hourly USEP parameters, 2005

Period	Mean	Std dev.	Min	Max	Median	Period	Mean	Std dev.	Min	Max	Median
1	106	37	64	411	98	**25**	109	53	70	730	102
2	113	40	61	416	104	**26**	111	57	70	719	104
3	110	37	60	365	103	**27**	114	57	70	702	104
4	105	27	58	308	101	**28**	121	81	70	839	106
5	101	25	57	307	99	**29**	129	187	69	3410	106
6	99	22	57	235	96	**30**	125	130	69	2258	105
7	97	21	55	205	92	**31**	122	104	69	1808	107
8	96	25	55	366	90	**32**	129	197	70	3570	106
9	95	25	55	366	90	**33**	115	60	70	1002	105
10	96	28	0	366	90	**34**	110	35	70	354	104
11	106	37	64	411	98	**35**	104	24	70	293	101
12	102	40	55	471	95	**36**	99	17	70	183	98
13	107	60	57	863	98	**37**	97	16	70	153	96
14	105	45	61	565	97	**38**	98	16	71	170	97
15	94	26	62	348	89	**39**	103	32	71	403	99
16	105	114	63	2230	96	**40**	103	28	71	330	99
17	111	53	65	668	102	**41**	116	50	71	509	107
18	110	87	65	1629	103	**42**	122	67	73	816	108
19	114	66	66	865	104	**43**	122	67	73	677	107
20	127	178	66	3224	107	**44**	111	42	71	459	104
21	129	107	66	1168	108	**45**	104	26	68	320	101
22	132	115	70	1187	108	**46**	103	43	66	781	99
23	125	122	70	2023	106	**47**	109	182	66	3552	96
24	114	70	70	1069	104	**48**	110	228	64	4431	96

*Off peak = Period 1 – 14 & 36-48, peak = Period 15-35

Appendix B: USEP Data

Table 28: Average half-hourly USEP per week in 2005

PERIOD	MON	TUE	WED	THUR	FRI	SAT	SUN
1	98.80269	103.6002	105.86	98.13827	102.4469	103.8851	130.9962
2	102.9908	118.5004	111.946	114.9415	115.854	102.3587	122.2252
3	97.53269	111.0242	108.7148	112.5006	112.8331	114.7698	112.3463
4	95.85	106.0744	104.5446	108.2006	107.5958	108.8011	101.744
5	94.68981	102.5888	101.395	103.54	104.5098	103.6058	97.80615
6	93.97327	99.28154	99.30654	100.3506	100.1896	101.9979	96.13481
7	92.20442	97.2375	98.27788	98.35308	97.09538	100.0766	94.3825
8	90.24962	96.60538	100.0308	97.89596	94.96558	98.70434	92.64327
9	88.90635	94.62558	98.28596	96.56654	94.43712	100.7274	91.94327
10	88.30019	95.205	98.68519	96.26519	95.02308	105.4313	91.97096
11	88.61308	98.72712	101.2819	97.68038	98.67808	100.3291	91.76019
12	95.64	104.7083	104.8242	102.3844	107.9581	105.6962	92.10019
13	109.4312	111.5602	109.9035	107.0333	113.0637	106.4287	92.79365
14	99.16788	110.3727	110.1713	106.7444	111.7375	107.9187	91.08192
15	93.93981	91.45942	91.98077	94.43654	96.14	102.8443	90.00231
16	96.72577	98.09404	96.87885	103.9327	98.30096	148.0143	92.46346
17	108.4265	114.6587	109.1475	119.251	112.4379	112.5458	97.42481
18	101.9631	106.3238	104.2912	102.2373	112.7715	139.8096	100.4569
19	103.7192	109.9277	106.0277	110.655	137.0712	129.43	103.791
20	104.7087	115.4683	109.9412	113.6787	177.2833	158.3492	106.169
21	108.3912	130.1729	118.675	120.0165	141.4952	170.3492	112.7181
22	115.0196	131.7806	128.9146	127.4615	147.2175	159.484	113.0392
23	113.0252	116.3681	120.0992	121.7604	157.3613	146.1713	96.34442
24	107.7977	108.6694	116.4498	109.0648	129.6998	128.1677	95.71865
25	104.8075	104.6054	112.409	107.0587	120.5813	120.7262	95.13077
26	105.7194	107.3577	117.4798	108.5694	122.8556	116.6619	97.99038
27	109.3238	112.346	120.0296	113.0581	122.8217	115.8791	107.6681
28	110.7056	123.2681	127.266	113.9477	133.2348	119.1606	122.4004
29	113.7806	126.1083	188.8671	115.6058	129.4052	111.6275	119.1265
30	112.3287	127.3269	162.6077	111.2244	130.4585	110.6847	117.3913
31	114.7035	122.4663	147.1573	109.4127	120.8208	110.2375	127.0823
32	117.4133	120.9558	135	113.19	186.855	103.6564	125.4875
33	113.8071	117.121	131.5987	108.5504	117.4942	100.2772	113.9879
34	109.2046	114.21	114.3973	108.7525	114.1256	97.96283	111.6537
35	105.4854	104.355	107.4763	104.0038	103.6094	97.78453	106.2217
36	99.20058	98.54269	99.33115	98.58269	98.20308	96.50226	102.874
37	95.88135	95.3925	95.43596	96.13288	95.40423	96.89321	104.65
38	96.10077	96.40654	96.95327	96.89962	96.66173	102.5481	99.965
39	98.03538	101.7137	97.95538	100.6904	96.95404	111.7606	115.9767
40	97.84212	101.2162	98.74923	100.4175	97.90173	109.1966	116.6298
41	113.6488	134.2052	114.9302	115.3223	109.5719	110.5375	116.4221
42	117.6771	148.1163	126.1008	118.8354	115.2104	109.8292	121.0254
43	118.9512	141.1442	119.8683	129.2325	114.9938	110.9058	115.8806
44	109.37	120.7337	113.5262	115.9888	105.5965	104.1028	110.5631
45	102.7687	105.6287	105.4308	105.4271	101.3337	102.7228	105.3408
46	99.79154	105.1106	100.7042	99.17558	99.77904	115.8717	99.86154
47	98.21462	103.1619	98.21077	96.72673	98.95865	168.7253	98.80577
48	97.37846	95.13231	96.04385	94.67077	97.22462	185.9626	98.89385

B.6 Year 2004

Table 29: Half-hourly USEP parameters, 2004

Period	Mean	Std dev.	Min	Max	Median	Period	Mean	Std dev.	Min	Max	Median
1	81	33	54	670	81	**25**	90	111	60	2165	83
2	79	12	52	187	81	**26**	90	89	60	1659	83
3	78	10	54	132	80	**27**	88	49	60	715	83
4	76	10	0	105	77	**28**	88	37	59	537	83
5	75	14	0	249	75	**29**	88	38	59	517	83
6	73	10	-10	112	74	**30**	86	27	60	452	83
7	72	10	-10	100	72	**31**	86	31	60	503	83
8	72	11	0	133	71	**32**	87	29	59	451	82
9	71	11	0	127	71	**33**	86	25	59	322	82
10	71	11	0	127	71	**34**	84	22	58	301	82
11	81	33	54	670	81	**35**	81	10	58	151	81
12	74	13	0	256	74	**36**	80	24	58	527	81
13	75	9	0	108	76	**37**	80	27	58	572	81
14	75	10	0	117	75	**38**	84	69	60	1394	81
15	74	9	0	102	75	**39**	85	71	61	1261	82
16	77	8	44	119	78	**40**	86	71	61	1322	81
17	81	19	58	305	81	**41**	87	65	61	1203	83
18	80	13	59	202	81	**42**	88	66	60	1202	83
19	83	20	61	328	82	**43**	87	52	59	1017	83
20	85	25	61	428	83	**44**	83	26	59	529	82
21	88	37	61	525	84	**45**	82	22	58	436	81
22	91	42	61	547	84	**46**	92	232	56	4500	81
23	92	46	61	548	84	**47**	91	232	55	4500	81
24	92	90	60	1625	84	**48**	91	232	54	4500	81

*Off peak = Period 1 – 14 & 36-48, peak = Period 15-35

Appendix B: USEP Data

Table 30: Average half-hourly USEP per week in 2004

PERIOD	MON	TUE	WED	THUR	FRI	SAT	SUN
1	79.37962	79.84192	90.75673	79.68906	79.15358	79.65654	79.68902
2	76.91135	78.96712	81.53096	79.74925	79.16774	78.61904	79.25686
3	75.025	77.68308	78.69038	77.92566	78.84736	78.29038	77.96137
4	73.43904	76.39808	77.35577	76.68189	77.09358	77.52596	74.73353
5	71.05192	74.85231	75.68077	75.15057	78.65962	75.99404	73.09255
6	69.78385	73.38577	74.36019	73.94094	74.4666	75.30712	71.62353
7	69.15481	72.51769	73.955	72.73132	73.40981	73.86365	70.81
8	68.52423	71.81769	72.66192	72.07038	71.60019	73.84865	70.32941
9	68.10019	71.31192	72.41019	71.72717	71.27245	72.99058	69.3949
10	68.22577	71.47423	72.49808	72.09962	71.53189	72.95231	69.46157
11	69.12192	72.26827	73.47788	73.2117	73.08	74.09404	69.45804
12	71.58038	74.36731	74.88962	74.78321	75.80585	77.1525	69.84902
13	73.13365	75.66981	76.04404	76.14849	77.51849	75.24135	70.53471
14	73.73962	75.44481	75.89442	76.10868	78.04	74.63462	69.64039
15	73.98019	74.41404	74.82115	75.15057	75.78774	74.57654	68.85392
16	78.16462	77.50558	76.74654	77.04283	78.74736	77.94942	71.25843
17	86.15173	80.77308	81.51308	81.69283	85.64453	78.09077	74.03353
18	81.83577	79.64596	79.56	80.60792	81.2783	82.1925	76.46412
19	80.16231	80.77885	79.97577	81.79792	83.4883	87.42731	83.96294
20	81.63769	84.95615	81.03135	83.53038	83.80679	90.95615	86.21725
21	91.82135	84.67058	84.39058	85.52491	88.37226	92.70904	89.83608
22	98.48788	89.78442	86.21904	87.52453	94.53736	89.87827	90.27608
23	99.65346	95.98115	86.76577	86.77472	94.25113	89.97712	90.01471
24	127.3029	87.25173	83.47577	83.21887	84.90943	90.25077	90.60725
25	128.9462	85.30538	83.62115	81.26698	82.64132	88.19212	83.27078
26	123.2462	85.01654	84.39654	81.35094	83.23377	82.87673	89.66569
27	107.07	87.89115	84.06827	82.14679	85.64491	81.49288	89.19157
28	100.0017	89.17442	84.38442	83.57113	86.05057	81.01942	89.18725
29	99.60654	88.54385	86.50904	84.3934	88.92264	80.16423	89.43059
30	97.06558	88.09558	86.1525	83.19396	85.59698	79.65712	81.25431
31	95.48635	94.59	86.30788	83.26	84.67151	79.31212	81.33804
32	95.24404	94.09692	85.77154	85.66264	85.06943	79.18135	80.70902
33	91.57135	92.36423	83.73288	85.67358	85.79113	78.54615	80.49824
34	88.17923	88.64673	81.96731	84.75094	84.99566	77.74481	79.80882
35	81.61038	82.55827	80.785	80.81906	81.59302	77.22	79.48647
36	79.45788	79.96423	79.35923	79.01698	78.96868	76.91885	86.16451
37	78.49962	78.92885	78.44615	78.16717	78.49283	77.38885	87.77706
38	80.425	79.32558	79.1175	78.97113	80.82642	78.61904	107.4053
39	80.2	80.01	79.73904	79.69453	80.78962	80.05673	117.6222
40	81.58462	81.44981	79.61596	79.49906	80.35208	80.00058	118.919
41	82.55577	83.11865	87.80288	81.78396	81.43981	79.99615	115.1869
42	85.42827	83.20692	86.99038	84.03906	81.39736	79.64462	116.181
43	84.86192	86.58827	83.64019	83.21189	81.91491	79.60135	106.7906
44	82.41038	81.25442	80.72442	81.43943	82.24755	79.06	91.47275
45	81.6775	80.11	79.98077	79.73226	81.60792	78.35558	89.53529
46	79.43212	165.2933	79.25654	78.93151	78.79679	77.93923	81.26882
47	79.11885	163.5538	78.0375	78.30642	80.36849	77.95692	82.26412
48	78.7075	162.7667	77.465	77.36057	79.26377	77.59981	80.81333

Appendix B: USEP Data

B.7 Year 2003

Table 31: Half-hourly USEP parameters, 2003

Period	Mean	Std dev.	Min	Max	Median	Period	Mean	Std dev.	Min	Max	Median
1	84	18	61	312	81	**25**	100	24	69	273	96
2	87	96	61	1905	80	**26**	114	208	69	3694	96
3	83	62	61	1239	77	**27**	118	215	69	3232	96
4	81	54	56	1095	76	**28**	135	347	69	4500	100
5	79	48	56	991	74	**29**	119	233	67	4500	99
6	76	20	55	424	73	**30**	112	172	67	3344	97
7	74	10	2	111	73	**31**	103	27	67	323	96
8	73	12	0	105	72	**32**	104	35	67	531	96
9	72	14	0	105	72	**33**	104	49	68	626	96
10	72	13	-5	105	72	**34**	97	20	68	202	94
11	84	18	61	312	81	**35**	94	20	68	298	91
12	76	10	-5	106	74	**36**	89	13	66	209	88
13	77	9	0	112	75	**37**	87	11	64	148	87
14	76	8	56	119	74	**38**	90	1164	69	143	89
15	76	9	0	128	74	**39**	93	21	69	432	90
16	85	87	56	1722	79	**40**	96	29	69	366	90
17	86	12	56	126	84	**41**	95	26	69	346	89
18	92	20	61	313	90	**42**	95	28	69	352	89
19	95	19	61	243	92	**43**	94	31	68	359	88
20	100	28	66	443	96	**44**	92	25	68	360	86
21	110	94	69	1781	96	**45**	90	67	68	1313	67
22	114	83	69	1441	100	**46**	88	66	61	1313	66
23	114	80	70	1416	100	**47**	85	25	61	500	25
24	10580	30	69	292	96	**48**	82	10	61	192	10

*Off peak = Period 1 – 14 & 36-48, peak = Period 15-35

Appendix B: USEP Data

Table 32: Average half-hourly USEP per week in 2003

PERIOD	MON	TUE	WED	THUR	FRI	SAT	SUN
1	81.79231	83.09333	84.18808	87.37519	83.96	84.34231	85.35692
2	78.34154	81.95824	81.82038	82.85865	81.89788	82.47962	115.9758
3	75.63019	81.5351	80.70885	80.36346	80.32981	80.66173	102.0985
4	74.45019	80.42431	79.84385	78.16365	78.78731	79.13212	97.20096
5	72.7025	78.72412	78.07423	77.02058	76.37519	77.47673	94.02077
6	71.50904	77.58	76.98885	75.53404	75.11577	76.60577	80.95212
7	70.35596	76.31745	75.73058	73.64788	74.30481	75.47942	73.665
8	69.45019	75.34275	74.81673	73.24808	71.98596	74.64481	70.46538
9	69.48827	74.3302	73.2125	72.63865	70.89615	74.68923	67.73269
10	69.38327	74.71824	75.64442	72.96885	70.89192	74.11538	66.99635
11	69.90865	76.37961	76.70558	74.99385	73.42385	74.64788	68.76096
12	72.56923	79.14078	78.13827	76.59365	75.84962	75.35385	72.12692
13	74.00231	79.9802	78.12115	78.19327	76.94019	75.99154	73.73692
14	74.76923	78.80275	76.92308	77.38346	76.90731	75.5775	72.68115
15	76.32058	78.28647	77.00019	77.36288	76.30038	76.42058	69.95615
16	82.55462	84.26039	82.39442	112.6496	80.58712	80.70808	72.8475
17	88.29558	91.25725	88.65058	88.80115	85.08077	84.69692	75.05115
18	94.66077	96.29902	95.11423	101.2606	90.46923	91.11385	77.78288
19	97.50538	101.4475	97.95346	99.51942	92.72538	96.93	80.86827
20	101.98	106.1	103.3535	107.3377	96.225	103.8206	82.50365
21	109.4233	116.6706	109.106	113.656	99.92904	134.4383	84.04904
22	115.1004	119.8745	113.1944	129.0127	104.7362	131.3402	84.16288
23	117.1396	119.1645	114.2908	125.8944	104.6796	130.721	85.87481
24	110.8533	112.7951	108.7525	112.1623	99.7575	103.5827	85.32788
25	107.4921	105.5637	104.0212	107.1844	95.99942	98.75115	84.34942
26	175.959	139.35	103.574	104.1892	97.61058	96.11115	84.60404
27	172.5688	163.62	109.049	105.6277	100.2987	92.52904	85.17558
28	202.6808	159.54	112.6717	194.1438	102.7177	90.91	85.34981
29	123.9729	119.7267	111.5031	194.504	104.8671	90.58731	85.07077
30	113.925	114.9022	107.9915	171.5396	105.6037	88.02981	84.70615
31	113.6854	111.3988	107.6515	112.1698	103.2867	87.37192	84.09173
32	114.0879	113.5394	114.8354	111.8029	101.661	85.41327	84.02327
33	110.7063	111.6227	113.2663	114.7688	100.2112	83.44558	93.16212
34	105.2283	105.8602	104.665	102.6383	97.8925	81.46712	83.57673
35	100.3273	103.0971	100.9627	96.85731	93.21135	80.01442	82.9425
36	92.14558	94.19431	94.30058	90.03654	88.25519	79.03904	82.34308
37	89.80308	91.22667	91.87615	87.51404	85.80904	80.72096	83.54173
38	91.21769	93.31314	92.89096	89.97077	88.13923	84.51231	87.82231
39	92.27404	94.87902	95.78577	91.58808	89.84923	88.08558	98.65538
40	91.36115	103.6031	103.6087	94.87827	89.59462	88.10288	98.76096
41	92.73058	102.5263	99.46808	96.745	88.25038	87.69	96.34654
42	94.25962	101.0469	97.12808	95.91596	86.58827	87.51096	99.73654
43	92.70308	99.78353	93.585	100.4208	85.27692	87.38154	98.90635
44	88.52192	97.73157	92.05731	94.04423	83.90058	85.21981	93.74346
45	84.4375	90.06961	88.88846	87.655	83.00519	106.4033	89.69481
46	83.54615	83.28804	88.27942	86.37442	81.77885	105.5319	86.46038
47	83.22	82.30667	85.33231	85.63885	82.07769	89.91654	84.33615
48	82.62692	80.96216	83.29519	80.35442	80.655	83.02635	81.58135

B.8 Monthly USEP for Year 2003-2009

Table 33: Monthly USEP for 2003 - 2009

Year	2009	2008	2007	2006	2005	2004	2003
Jan	73.9825	158.0889	123.8722	109.7417	78.61425	78.61425	80.8474
Feb	95.7451	149.3010	126.8543	106.7043	83.71875	83.71875	91.92111
Mar	87.1784	146.9726	124.5952	124.2942	97.81586	97.81586	101.5337
Apr	199.1380	173.4394	114.1699	127.3797	99.80833	99.80833	90.46614
May	167.4144	202.6588	109.8259	154.9747	113.5504	113.5504	96.85391
Jun	189.6248	185.0074	117.5293	136.0759	113.7632	113.7632	86.08897
Jul	141.3490	195.0364	124.908	153.8711	102.7661	102.7661	89.37434
Aug	161.7243	199.6228	120.3729	167.4091	103.3999	103.3999	96.97195
Sep	173.1765	193.2016	126.7784	130.2475	147.2056	147.2056	85.30493
Oct	191.5376	171.7575	126.3826	143.6553	141.5134	141.5134	90.94022
Nov	142.6770	103.6210	139.5973	117.3304	118.4354	118.4354	103.9556
Dec	148.8772	67.7131	140.1548	114.2458	117.2077	117.2077	93.73125

Appendix C: Validation Model Results

C.1 Weekday Model

Table 34: Prediction errors for half-hourly weekday Model

Period	4^{th} – 8^{th} USEP	Forecast	Error	Period	4^{th} – 8^{th} USEP	Forecast	Error
1	145	137	8	**25**	198	178	20
2	140	134	6	**26**	228	178	50
3	138	132	6	**27**	261	177	84
4	135	132	3	**28**	319	175	144
5	134	131	3	**29**	350	172	178
6	134	131	3	**30**	350	169	181
7	134	131	3	**31**	388	165	223
8	133	130	3	**32**	428	161	267
9	133	130	3	**33**	370	158	212
10	133	129	4	**34**	322	155	167
11	134	129	5	**35**	239	153	186
12	134	129	5	**36**	160	152	8
13	135	130	5	**37**	157	151	6
14	136	132	4	**38**	168	151	17
15	135	135	0	**39**	159	151	8
16	138	139	-1	**40**	160	152	8
17	143	144	-1	**41**	155	152	3
18	148	149	-1	**42**	160	151	9
19	159	154	5	**43**	157	150	7
20	169	160	9	**44**	152	147	5
21	179	165	14	**45**	150	144	6
22	235	170	65	**46**	144	140	4
23	234	174	60	**47**	145	136	9
24	202	177	45	**48**	142	134	8

C.2 Weekend Model

Table 35: Prediction errors for half-hourly weekend Model

Period	4^{th} – 8^{th} USEP	Forecast	Error	Period	4^{th} – 8^{th} USEP	Forecast	Error
1	149	135	14	**25**	145	150	-5
2	146	134	12	**26**	145	148	-3
3	138	133	5	**27**	145	146	-1
4	140	132	8	**28**	145	144	1
5	136	131	5	**29**	145	141	4
6	135	130	5	**30**	145	139	6
7	135	129	6	**31**	143	137	6
8	135	128	7	**32**	143	136	7
9	133	127	6	**33**	138	135	3
10	130	127	3	**34**	138	135	3
11	133	126	7	**35**	136	136	0
12	135	126	9	**36**	137	138	-1
13	135	127	8	**37**	146	140	6
14	135	128	7	**38**	149	143	6
15	133	130	3	**39**	153	145	8
16	136	133	3	**40**	153	146	7
17	140	135	4	**41**	153	146	7
18	143	139	4	**42**	156	146	10
19	147	142	5	**43**	153	143	10
20	152	145	7	**44**	150	140	10
21	158	147	11	**45**	147	137	10
22	151	149	2	**46**	143	134	9
23	150	150	0	**47**	140	132	8
24	145	150	-5	**48**	138	134	4

C.3 Seasonal Variation Model

Table 36: Prediction errors for half-hourly spring season Model

Period	Mean Feb,2010	Forecast	Period	Mean Feb,2010	Forecast
1	177	101-186	**25**	208	180-245
2	188	113-185	**26**	220	188-254
3	180	109-181	**27**	239	196-262
4	165	104-174	**28**	267	200-266
5	154	100-168	**29**	279	202-269
6	149	97-165	**30**	294	202-268
7	144	97-165	**31**	265	199-264
8	142	98-166	**32**	322	193-259
9	141	101-168	**33**	305	185-252
10	139	103-170	**34**	226	177-243
11	140	106-172	**35**	199	168-234
12	146	107-174	**36**	168	159-226
13	153	108-175	**37**	166	152-219
14	147	109-175	**38**	176	146-213
15	145	110-176	**39**	184	142-209
16	153	111-177	**40**	210	140-207
17	166	113-179	**41**	207	138-206
18	170	117-183	**42**	210	137-205
19	176	122-188	**43**	206	136-203
20	194	129-196	**44**	219	132-200
21	218	138-204	**45**	201	125-195
22	249	148-214	**46**	175	118-189
23	250	159-225	**47**	169	110-182
24	226	169-235	**48**	161	103-188

Above forecast is based on 95% confidence boundary levels