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DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Gonalo B Rendeiro

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DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Síntese/Abstract

Desde a liberalização do mercado energético nos países Nórdicos, anos 90, o Nordpool, criado em 1996, sofreu uma grande evolução na sua capacidade instalada, valores dos consumos e, acima de tudo, nos diferentes tipos de centrais eléctricas que fazem parte do sistema eléctrico de produção.

Nos últimos 15 anos, a preocupação pelo meio ambiente cresceu e as políticas relativas ao Mercado Energético mudaram com esta. Houve ainda uma imposição de limites às emissões de CO₂ que, caso ultrapassados, teriam de ser pagas multas. Neste contexto, novas ideias sobre como abordar o sistema eléctrico de produção emergiram e com elas os investimentos em Energias Renováveis tais como a Energia Eólica. Mais tarde, os limites de CO₂ ficaram mais restritos e isso levou a um aumento ainda maior dos investimentos nas Energias Renováveis. Na Dinamarca os investimentos em Energia Eólica começaram na década de 80 e 90, o que fez com que o país seja o país com maior percentagem do seu consumo produzido por Energia Eólica.

Este estudo irá analisar os efeitos causados por um sistema com percentagens de Energia Eólica elevadas no Mercado de Electricidade nos preços dos mercados.

O estudo irá utilizar a Energia Eólica prevista e não a Energia Eólica produzida e irá avaliar como é que o preço do mercado Spot varia com a injeção desta.

Irá ainda observar o impacto dos erros nas previsões da Energia Eólica no preço do Mercado de Regulação.

O presente estudo inclui também uma pequena análise de como os erros das previsões da Eólica podem ser reduzidos apenas recorrendo ao Mercado de Ajustes (ELBAS).

No final, o estudo conclui que a Energia Eólica prevista irá afectar o preço do mercado Spot e que os erros nas previsões desta energia não irão afectar significativamente o preço do Mercado de Regulação.

Palavras Chave: Energia Eólica, Previsão de Eólica, Mercados Energéticos.

Since liberalization of electricity market in the Nordic countries, occurred in 90s, the Nordpool, created in 1996, has suffered a huge progression in its installed capacity, on demand and, above all, in different types of energy plants that are part of the electricity production system.

For the past 15 years, the concern regarding the environment has grown and the politics around the Energy Market have changed with it. There was also an imposition of limits on CO₂ emissions that, if passed, countries would have had to pay fees. In this context, new ways of thinking about how to produce energy, and the need to start investing in renewable energies, such as wind power, emerged. A few years ago the above mentioned fees became stricter making the investments, which were already high, even higher. In Denmark, these investments start early, making Denmark by far the country with the highest share of its energy supply produced by wind turbines.

This study will observe the effects of having high wind power shares in the electricity supply system on the market prices.

Since the study will use the forecasted wind power instead of the produced wind power, it will look at how the Dk-West spot price varies with the injection of this energy and how this energy should be treated.

It will also observe the impact that the imbalances between the forecasts and the real values for wind power will have on the regulating market, and how these imbalances can be reduced.

The study also has a small analysis of how the imbalances between forecasts and real values can be reduced when the Elbas market is used.

In the end the study concludes that the forecasted wind power will affect the spot price and that the imbalances between that energy and the real wind power produced will not significantly affect the regulating price.

Keywords: Wind Power; Wind Imbalances; Energy Markets.

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Table of Contents

Table of Contents

Acknowledgments	ii
Abstract	iii
List of Figures	vii
List of Graphics	xi
List of Tables	xv
Glossary	xix
1. Introduction	1
1.1. Problem Description	1
1.2. System Description	3
1.3. Energy Market Description	7
2. Variables' Description	15
3. Models	21
3.1. Consumption	21
3.2. Dk-West Spot Price	22
3.3. Dk-West Regulating Price	34
3.3.1. Down Regulation	35
3.3.2. Up Regulation	40
4. Conclusions	45
References	49
Appendix	51

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

List of Figures

List of Figures

1. Introduction**1.2. System Description**

<i>Figure 1 - UCTE and Nordel Systems</i>	3
<i>Figure 2- HDVC (High Voltage Direct Current) Interconnections Between UCTE and Nordel Systems</i>	3
<i>Figure 3 - Danish Transmission System Grid and interconnections to UCTE and Nordel Systems</i>	4
<i>Figure 4 - Evolution of the Power Plants in Denmark from 1980 to 2000</i>	4
<i>Figure 5 - Grid connections to the offshore wind farms</i>	4
<i>Figure 6 - Distribution of Wind Turbines across DK-West zone</i>	5
<i>Figure 7 - Distribution of System Units across DK-West and DK-East in 2008</i>	6
<i>Figure 8 - Evolution of the Consumption and Production for DK-West</i>	6

1.3. Energy Market Description

<i>Figure 9 - Example of an Unbundled structure</i>	7
<i>Figure 10 - Example of Supply Curve for an Asymmetric Pool System</i>	8
<i>Figure 11 - Example of Supply and Demand Curve for a Symmetric Pool System</i>	8
<i>Figure 12 - Example of Curves for System price and Dk-West price with bottlenecks</i>	10
<i>Figure 13 - Example of Up- and Down-Regulation Curves at the NOIS List</i>	10
<i>Figure 14 - Time-line for start and stop of the Reserves</i>	11
<i>Figure 15 - Time-line for start and stop of the Reserves</i>	12
<i>Figure 16 - Timeline for the Nordpool Electricity Market</i>	14

2. Variables' Description

<i>Figure 17 - Curve of power versus wind speed for a wind turbine</i>	17
--	----

List of Figures

3. Models**3.2. Dk-West Spot Price**

<i>Figure 18 - Example of Supply Curves for an hour of operation with and without Wind Energy</i>	23
<i>Figure 19 - Example of Supply Curve for demand without wind energy</i>	23
<i>Figure 20 - Example of Dk-West spot price in function of wind energy</i>	23
<i>Figure 21 - Autocorrelation Graphicic for Dk-West spot price</i>	31
<i>Figure 22 - Partial Autocorrelation Graphicic for Dk-West spot price</i>	31

3.3. Dk-West Regulating Price**3.3.1. Down Regulation**

<i>Figure 23 - Regulating Market scheme for variables</i>	34
<i>Figure 24 - Cross-correlation between Price for Down Regulate and Dk-West Spot Price - Full Data</i>	35
<i>Figure 25 - Cross-correlation between Price for Down Regulate and Dk-West Spot Price - Limited Data</i>	35
<i>Figure 26 - Cross-correlation between Price for Down Regulate and Wind Imbalances - Full Data</i>	35
<i>Figure 27 - Cross-correlation between Price for Down Regulate and Wind Imbalances - Limited Data</i>	35
<i>Figure 28 - Cross-correlation between Price for Down Regulate and Consumption minus Wind Energy - Full Data</i>	36
<i>Figure 29 - Cross-correlation between Price for Down Regulate and Consumption minus Wind Energy - Limited Data</i>	36
<i>Figure 30 - Cross-correlation between Price for Down Regulate and the need for down regulation - Full Data</i>	36
<i>Figure 31 - Cross-correlation between Price for Down Regulate and the need for down regulation - Limited Data</i>	36
<i>Figure 32 - Cross-correlation between Need for Down Regulate and Wind Imbalances - Full Data</i>	39

3.3.2. Up Regulation

<i>Figure 33 - Cross-correlation between Price for Up-Regulate and Dk-West Spot Price - Full Data</i>	40
<i>Figure 34 - Cross-correlation between Price for Up-Regulate and Dk-West Spot Price - Limited Data</i>	40

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

List of Figures

<i>Figure 35 - Cross-correlation between Price for Up-Regulate and Wind Imbalances - Full Data</i>	40
<i>Figure 36 - Cross-correlation between Price for Up-Regulate and Wind Imbalances - Limited Data</i>	40
<i>Figure 37 - Cross-correlation between Price for Up-Regulate and Consumption - Wind Energy - Full Data</i>	41
<i>Figure 38 - Cross-correlation between Price for Up-Regulate and Consumption - Wind Energy - Limited Data</i>	41
<i>Figure 39 - Cross-correlation between Price for Up-Regulate and Need for Up-Regulation- Full Data</i>	41
<i>Figure 40 - Cross-correlation between Price for Up-Regulate and Need for Up-Regulation - Limited Data</i>	41

Appendix

<i>Figure 41 - Autocorrelation Graphic for Mondays Data</i>	54
<i>Figure 42 - Partial Autocorrelation Graphic for Mondays Data</i>	54
<i>Figure 43 - Autocorrelation Graphic for Tuesdays Data</i>	56
<i>Figure 44 - Partial Autocorrelation Graphic for Tuesdays Data</i>	56
<i>Figure 45 - Autocorrelation Graphic for Wednesdays Data</i>	57
<i>Figure 46 - Partial Autocorrelation Graphic for Wednesdays Data</i>	57
<i>Figure 47 - Autocorrelation Graphic for Thursdays Data</i>	59
<i>Figure 48 - Partial Autocorrelation Graphic for Thursdays Data</i>	59
<i>Figure 49 - Autocorrelation Graphic for Fridays Data</i>	61
<i>Figure 50 - Partial Autocorrelation Graphic for Fridays Data</i>	61
<i>Figure 51 - Autocorrelation Graphic for Saturdays Data</i>	63
<i>Figure 52 - Partial Autocorrelation Graphic for Saturdays Data</i>	63
<i>Figure 53 - Autocorrelation Graphic for Sundays Data</i>	64
<i>Figure 54 - Partial Autocorrelation Graphic for Sundays Data</i>	64

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

List of Graphics

List of Graphics

2. Variables' Description

<i>Graphic 1 - Evolution of the Consumption from the 1st of June 2008 until the 1st of June 2009</i>	15
<i>Graphic 2 - Evolution of the Wind Power Production from the 1st of June 2008 until the 1st of June 2009</i>	15
<i>Graphic 3 - Evolution of the Wind Power Imbalances between forecasted and real production from the 1st of June 2008 until the 1st of June 2009</i>	15
<i>Graphic 4 - Evolution of the DK-West Spot Price from the 1st of June 2008 until the 1st of June 2009</i>	15
<i>Graphic 5 - Evolution of the Regulating Price for Up Regulation from the 1st of June 2008 until the 1st of June 2009</i>	15
<i>Graphic 6 - Evolution of the Regulating Price for Down Regulation from the 1st of June 2008 until the 1st of June 2009</i>	17
<i>Graphic 7 - Evolution of the Fuel Prices from the 1st of June 2008 until the 1st of June 2009</i>	18
<i>Graphic 8 - Relation between Reserves of capacity Price and Spot Price from the 1st of June 2008 until the 1st of June 2009</i>	18
<i>Graphic 9 - Relation between Elbas Average Price and Spot Price from the 1st of June 2008 until the 1st of June 2009</i>	18
<i>Graphic 10 - Relation between Regulating Price for Down Regulate and Spot Price from the 1st of June 2008 until the 1st of June 2009</i>	18
<i>Graphic 11 - Relation between Regulating Price for Up Regulate and Spot Price from the 1st of June 2008 until the 1st of June 2009</i>	19
<i>Graphic 12 - Relation between need for Regulating Power and Wind Imbalances from the 1st of June 2008 until the 1st of June 2009</i>	19

3. Models**3.1. Consumption**

<i>Graphic 13 - Real and Forecasted hourly consumption since 1st of June 2008 until 1st of June 2009</i>	21
--	----

3.2. Dk-West Spot Price

<i>Graphic 14 - Dk-West spot price vs. Wind Forecast</i>	22
<i>Graphic 15 - System spot price vs. Wind Forecast</i>	22
<i>Graphic 16 - Dk-West spot price vs. Demand</i>	24

List of Graphics

<i>Graphic 17 - Dk-West spot price vs. Demand - Wind Forecast</i>	24
<i>Graphic 18 - Spot Prices Dk-West, System and EEX - Average model</i>	25
<i>Graphic 19 - Average Dk-West spot price based on average values for the corrected demand - Average model</i>	25
<i>Graphic 20 - Average Dk-West spot price based on average values for the corrected demand with a trend line - Average model</i>	26
<i>Graphic 21 - Dk-West spot price and forecasted spot price - Average model</i>	27
<i>Graphic 22 - Dk-West hourly spot price and forecasted hourly spot price - Average model</i>	27
<i>Graphic 23 - Dk-West spot price and forecasted spot price - Average model 2</i>	28
<i>Graphic 24 - Dk-West hourly spot price and forecasted hourly spot price - Average model 2</i>	28
<i>Graphic 25 - Dk-west real and forecasted spot price - Matlab model for Dk-West Spot without fuel prices</i>	29
<i>Graphic 26 - Dk-west real and forecasted spot price - Matlab model for Dk-West Spot with fuel prices</i>	30
<i>Graphic 27 - Dk-west real and forecasted spot price - Regressive model for Dk-West Spot without fuel prices</i>	31
<i>Graphic 28 - Dk-west real and forecasted spot price - Dk-West Spot ARIMA (1,0,0) model</i>	32
<i>Graphic 29 - Dk-west real and forecasted spot price - Dk-West spot final model</i>	33

3.3. Dk-West Regulating Price**3.3.1. Down Regulation**

<i>Graphic 30 - Dk-West real and forecasted Down Regulate price - full data</i>	37
<i>Graphic 31 - Dk-West real and forecasted Down Regulate price - w/o outliers</i>	38
<i>Graphic 32 - Dk-West real and forecasted Down Regulate price - w/o outliers and w/o Wind Imbalances</i>	39

3.3.2. Up Regulation

<i>Graphic 33 - Dk-West real and forecasted Up Regulate price - w/o outliers and w/o Wind Imbalances</i>	42
--	----

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

List of Graphics

Appendix

Graphic 34 - Evolution of the Consumption from the 1 st of January 2000 until the 1 st of June 2009	52
Graphic 35 - Evolution of the Consumption from the 1 st of January 2008 until the 23 rd of June 2009	52
Graphic 36 - Evolution of the demand divided in weekdays from the 1 st of January 2008 until the 23 rd of June 2009	52
Graphic 37 - Evolution of the Consumption for Mondays from the 1 st of January 2000 until the 23 rd of June 2009	53
Graphic 38 - real and forecasted Consumption - ARIMA model for Mondays	55
Graphic 39 - Evolution of the Consumption for Tuesdays from the 1 st of January 2000 until the 23 rd of June 2009	55
Graphic 40 - real and forecasted Consumption - ARIMA model for Tuesdays	57
Graphic 41 - Evolution of the Consumption for Wednesdays from the 1 st of January 2000 until the 23 rd of June 2009	57
Graphic 42 - real and forecasted Consumption - ARIMA model for Wednesdays	58
Graphic 43 - Evolution of the Consumption for Thursdays from the 1 st of January 2000 until the 23 rd of June 2009	59
Graphic 44 - real and forecasted Consumption - ARIMA model for Thursdays	60
Graphic 45 - Evolution of the Consumption for Fridays from the 1 st of January 2000 until the 23 rd of June 2009	60
Graphic 46 - real and forecasted Consumption - ARIMA model for Fridays	62
Graphic 47 - Evolution of the Consumption for Saturdays from the 1 st of January 2000 until the 23 rd of June 2009	62
Graphic 48 - real and forecasted Consumption - ARIMA model for Saturdays	64
Graphic 49 - Evolution of the Consumption for Sundays from the 1 st of January 2000 until the 23 rd of June 2009	64
Graphic 50 - real and forecasted Consumption - ARIMA model for Sundays	65
Graphic 51 - Average distribution of the consumption during the day	66
Graphic 52 - real and forecasted Consumption - Hourly consumption since 1 st of June 2008 until 1 st of June 2009	67
Graphic 53 - Dk-west real and forecasted spot price - Regressive model for Dk-West Spot with fuel prices	68
Graphic 54 - Dk-West real and forecasted Up Regulate price - full data	68
Graphic 55 - Dk-West real and forecasted Up Regulate price - w/o outliers	69

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

List of Tables

List of Tables

3. Models**3.2. Dk-West Spot Price**

<i>Table 1 - Spot Prices Dk-West, System and EEX - Average model</i>	25
<i>Table 2 - Constants for the model - Average model</i>	27
<i>Table 3 - Error for the model - Average model</i>	27
<i>Table 4 - Errors for the model applied to hourly values - Average model</i>	27
<i>Table 5 - Errors for the model applied to hourly values - Average model 2</i>	28
<i>Table 6 - Train and Test Errors - Matlab model for Dk-West Spot without fuel prices</i>	29
<i>Table 7 - Train and Test Errors - Matlab model for Dk-West Spot with fuel prices</i>	29
<i>Table 8 - Model Parameters - Regressive model for Dk-West Spot without fuel prices</i>	30
<i>Table 9 - Train and Test Errors - Regressive model for Dk-West Spot without fuel prices</i>	30
<i>Table 10 - Model Parameters - Dk-West Spot ARIMA (1,0,0) model</i>	32
<i>Table 11 - Train and Test Errors - Dk-West Spot ARIMA (1,0,0) model</i>	32
<i>Table 12 - Train and Test Errors - Dk-West final model</i>	33

3.3. Dk-West Regulating Price**3.3.1. Down Regulation**

<i>Table 13 - Model Parameters - Dk-West Down Regulation price - full data</i>	37
<i>Table 14 - Train and Test Errors - Dk-West Down Regulation price - full data</i>	37
<i>Table 15 - Model Parameters - Dk-West Down Regulation price - w/o outliers</i>	37
<i>Table 16 - Train and Test Errors - Dk-West Down Regulation price - w/o outliers</i>	37
<i>Table 17 - Model Parameters - Dk-West Down Regulation price - w/o outliers and w/o Wind Imbalances</i>	38
<i>Table 18 - Train and Test Errors - Dk-West Down Regulation price - w/o outliers and w/o Wind Imbalances</i>	39

List of Tables

3.3.2. Up Regulation

<i>Table 19 - Model Parameters - Dk-West Up Regulation price - w/o outliers and w/o Wind Imbalances</i>	42
<i>Table 20 - Train and Test Errors - Dk-West Up Regulation price - w/o outliers and w/o Wind Imbalances</i>	42

Appendix

<i>Table 21 - Model Parameters - ARIMA model for Mondays</i>	54
<i>Table 22 - Train and Test Errors - ARIMA model for Mondays</i>	54
<i>Table 23 - Some Data from the train group of values for the ARIMA model for Mondays</i>	55
<i>Table 24 - Some Data from the test group of values for the ARIMA model for Mondays</i>	55
<i>Table 25 - Model Parameters - ARIMA model for Tuesdays</i>	56
<i>Table 26 - Train and Test Errors - ARIMA model for Tuesdays</i>	56
<i>Table 27 - Some Data from the train group of values for the ARIMA model for Tuesdays</i>	56
<i>Table 28 - Some Data from the test group of values for the ARIMA model for Tuesdays</i>	56
<i>Table 29 - Model Parameters - ARIMA model for Wednesdays</i>	58
<i>Table 30 - Train and Test Errors - ARIMA model for Wednesdays</i>	58
<i>Table 31 - Some Data from the train group of values for the ARIMA model for Wednesdays</i>	58
<i>Table 32 - Some Data from the test group of values for the ARIMA model for Wednesdays</i>	58
<i>Table 33 - Model Parameters - ARIMA model for Thursdays</i>	59
<i>Table 34 - Train and Test Errors - ARIMA model for Thursdays</i>	59
<i>Table 35 - Some Data from the train group of values for the ARIMA model for Thursdays</i>	60
<i>Table 36 - Some Data from the test group of values for the ARIMA model for Thursdays</i>	60
<i>Table 37 - Model Parameters - ARIMA model for Fridays</i>	61

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

List of Tables

<i>Table 38 - Train and Test Errors - ARIMA model for Fridays</i>	61
<i>Table 39 - Some Data from the train group of values for the ARIMA model for Fridays</i>	62
<i>Table 40 - Some Data from the test group of values for the ARIMA model for Fridays</i>	62
<i>Table 41 - Model Parameters - ARIMA model for Saturdays</i>	63
<i>Table 42 - Train and Test Errors - ARIMA model for Saturdays</i>	63
<i>Table 43 - Some Data from the train group of values for the ARIMA model for Saturdays</i>	63
<i>Table 44 - Some Data from the test group of values for the ARIMA model for Saturdays</i>	63
<i>Table 45 - Model Parameters - ARIMA model for Sundays</i>	65
<i>Table 46 - Train and Test Errors - ARIMA model for Sundays</i>	65
<i>Table 47 - Some Data from the train group of values for the ARIMA model for Sundays</i>	65
<i>Table 48 - Some Data from the test group of values for the ARIMA model for Sundays</i>	65
<i>Table 49 - Average distribution of the consumption during the day</i>	66
<i>Table 50 - Errors - Hourly consumption since 1st of June 2008 until 1st of June 2009</i>	67
<i>Table 51 - Model Parameters - Regressive model for Dk-West Spot with fuel prices</i>	67
<i>Table 52 - Train and Test Errors - Regressive model for Dk-West Spot with fuel prices</i>	67
<i>Table 53 - Model Parameters - Dk-West Up Regulation price - full data</i>	68
<i>Table 54 - Train and Test Errors - Dk-West Up Regulation price - full data</i>	68
<i>Table 55 - Model Parameters - Dk-West Up Regulation price - w/o outliers</i>	69
<i>Table 56 - Train and Test Errors - Dk-West Up Regulation price - w/o outliers</i>	69
<i>Table 57 - Forecast Errors - Spot and Persistence Models</i>	69
<i>Table 58 - Errors of Spot and Persistence forecasts from 1st of June 2008 and 1st of June 2009 - Energy values</i>	70

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Glossary

Glossary

Day of operation - This is the day when the energy dealt is going to be delivered.

Hour of operation - It is the hour when the energy will be delivered.

Bottlenecks - whenever a connection between two different areas of the Nordpool system gets to its limit of capacity, it will cause a separation between these two areas and this separation is called the bottleneck. This situation will probably cause differences between these two areas' prices.

Balance Responsible Player - is any player on the market that makes an agreement with the transmission system operator for ensuring a trade of energy and its respective values of time of operation, energy traded, etc...

System and Area Prices - A system price is the price that the Nordpool retrieves for the spot market and it does not include the bottlenecks. The Area Price is the final price for a specific area and is the price every player from that area has to pay for each unit of energy traded. If there are no bottlenecks at the Nordpool system then this price is the same as the system price, otherwise these two prices will be different.

Trades of Energy - A trade of energy is any contract done between two balance responsible players. This contract implies a player buying, a player selling, and a specific amount of energy circulating through the electricity transmission system from the seller to the buyer on a specific time.

Imbalances - An imbalance is the difference between two comparable values. This error can be related to production or consumption. An example of an imbalance is the difference between the energy a plant is supposed to produce and the real value of energy that it produces during a certain hour of operation. During this paper I'll use the imbalances between the forecasted production of the wind power plants and their real production to create my model.

Notification - A notification is a paper that describes a trade of energy. It includes data as name of the balance responsible players included in the trade of energy (might be one (only production or consumption with adjustable consumption) or more (trade between two players) BRPs per notification) value of energy traded for a specific hour, etc.

1. Introduction

1.1. Problem Description

I came to Denmark to do my final graduation report because my Master is in Energy Markets and the Nordpool market is the best example of a well functioning liberalized energy market, hence my interest in wanting to know more about it.

The evolution of the wind power energy in Denmark has been huge and the investments made in this area are enormous and also expected to continue as such, or even grow more until the system achieves a bigger percentage of wind power in order to fulfill the national CO₂ emissions' goals for reduction.

The stability of the energy system which is being created will be highly dependent on the quality of wind forecasting, and the imbalances between real and forecasted values will have to be covered by flexible "backup" plants at the Elbas and Regulating markets. This will reduce the need for continuous working fuel based plants but increase the need for the flexible backup plants to deal at the Elbas and the

Regulating markets immensely.

The idea of this study is to explore a specific part of the Nordpool Electricity Market called Regulating Market for the West Denmark zone (DK-West). Since very few research as been done on this market it is a challenge to conduct research on such an underdeveloped area due to a lack of data and studies one can use.

This report will study if the market can ensure the development of a system such as this and conclude how it will evolve. In order to reach these conclusions, within this paper, there is the need to describe the functioning of the entire market, from the beginning of the energy deal for a specific hour of operation, until the respective hour of operation in a small introduction. However the focus will be on the Regulating market to explore this flexible supply problem.

The report will be composed in four major parts:

1. Description and analysis of the markets, description of the markets and of all the main mechanisms behind each one of them.
2. Introduction to some variables with some graphics to help the reader familiarize himself with these variables.
3. Creation and analysis of models that represent the regulating market and how it reacts to some variables to ensure the system's stability. These models will depend on Dk-west spot price so this will also have to be modeled. The variables available for this study are:
 - ♦ Consumption;
 - ♦ Wind Forecast;
 - ♦ Wind Imbalances;
 - ♦ Fuel prices;
 - ♦ Bottlenecks;
 - ♦ Dk-west spot and regulating market prices.
4. Conclusions

There are some studies in this area already, trying to explain the market and how the wind power affects it, but not nearly enough with models to represent the market, and not unlike this study, where it will not only use the real wind production but also the forecasted wind production and its imbalances which, in my view, will make all the difference. The studies that have already been conducted conclude that there is no correlation between the prices and the wind power, but the fact that these studies are based in *real values* and not the *forecasted values* may well make all the difference.

Note: All the data available, except for fuel prices is in hourly values and the variable for the analysis of the regulating market will be its price of energy (DKK/MWh).

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Introduction

System Description

1.2. System Description

The energy system in Denmark is divided in two different areas, DK-West and DK-East. The DK-West area includes the *Jutland Peninsula* and the *Funen Island* and the DK-East area includes many islands from which the biggest ones are *Zealand*, where Denmark's capital Copenhagen is, and *Lolland*. These two areas are not connected to each other. DK-West is connected to Germany by synchronous AC (Alternate Current) cables, 950MW capacity to import and 1500MW capacity to export, to Norway by a 1000MW (Export) and a 950MW (Import), both DC (Direct Current) cables, and to Sweden through a 740MW (Export) and a 680MW (Import), both DC cables. The fact that it is only connected by DC cables to Norway and Sweden means that the imbalances in these two countries will not affect the system's stability in the DK-West area. For this reason, DK-West is considered part of the UCTE (Central Europe) system with which it has an AC interconnection. The DK-East area is connected to Germany too but by a DC cable, so is not a part of the UCTE system and connected to Sweden by AC cables thus making it part of the Scandinavian Nordel system (Nordic Electricity System). Since there is no connection between the two areas (West and East Denmark), the Danish system can be divided into two completely independent systems, which is what this study will focus on, so during this report, only the DK-West system inside the Nordpool will be studied. In 2010, Dk-West and DK-East will be connected by a HVDC cable, which does not change that they are part of two different electrical systems, Dk-West is part of UCTE system and Dk-East is part of Nordel system. This connection will almost not affect the prices because the connections between these two areas through Sweden and Germany already have enough capacity, which is easy to explain after looking at the Dk-west and Dk-east prices which tend to be equal or very similar. It can be seen in figures 1, 2 and 3 which countries are part of which Electrical system and the interconnections between the

UCTE and Nordel systems through DK-West and DK-East borders.

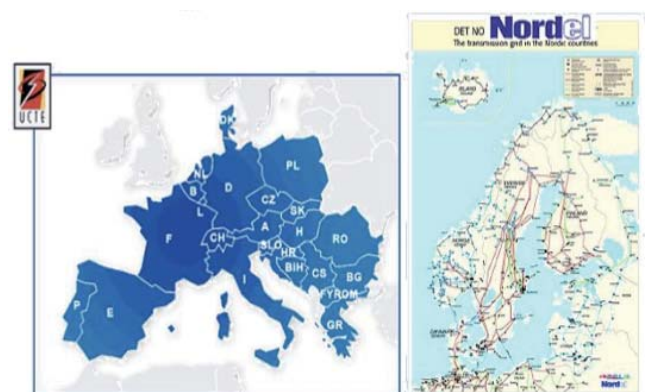


Figure 1 - UCTE and Nordel Systems
(Source: System Description Slides, Flemming Nissen)



Figure 2 - HDVC (High Voltage Direct Current) Interconnections Between UCTE and Nordel Systems
(Source: Internet - www.abb.com)

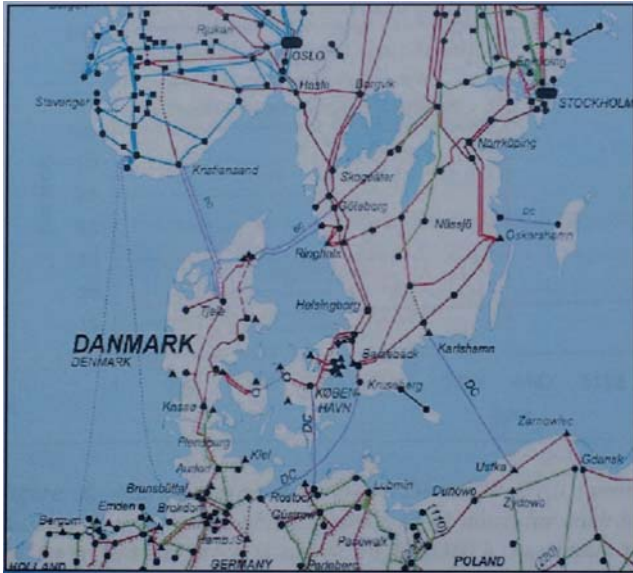
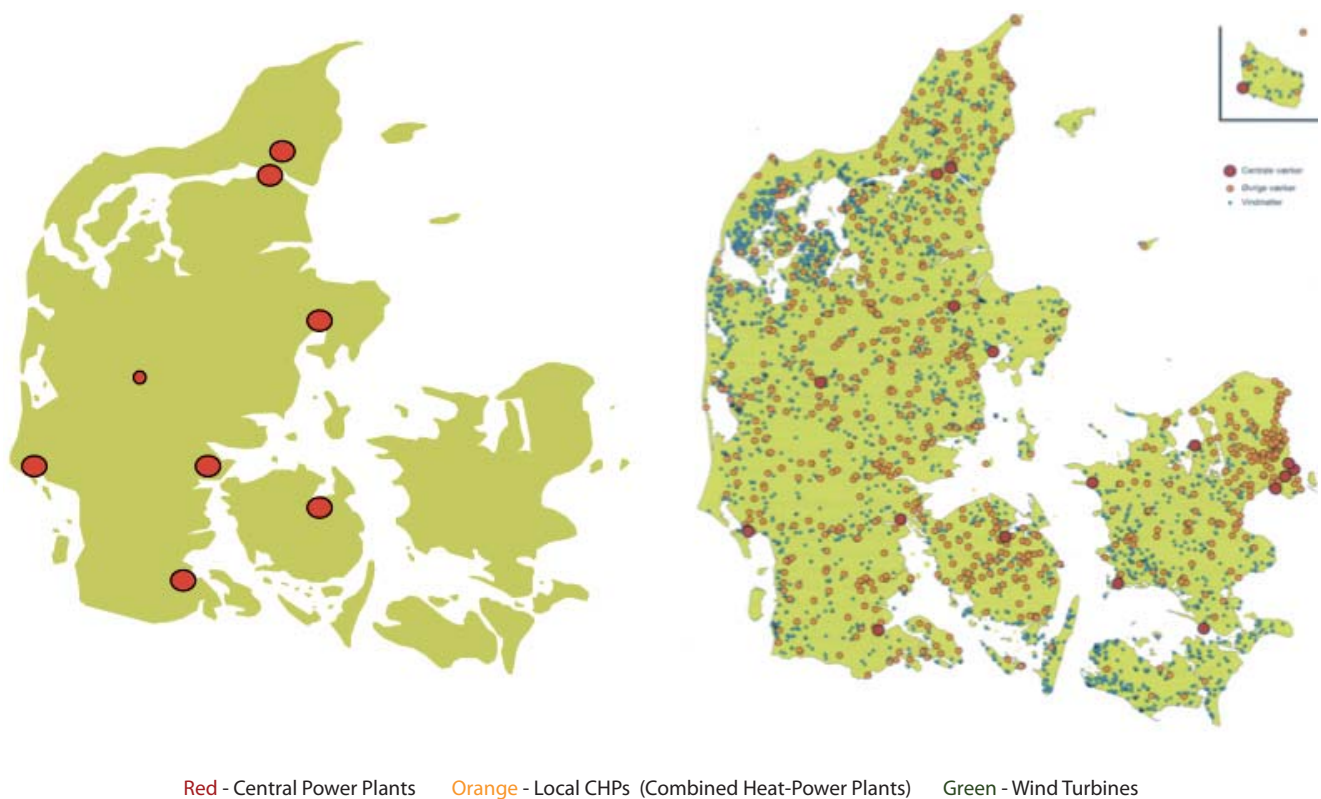


Figure 3 - Danish Transmission System Grid and interconnections to UCTE and Nordel Systems
(Source: "Optimal electricity market for wind power", H. Holttinen, 2004)



Figure 5 - Grid connections to the offshore wind farms
(Source: Internet - <http://power-kite.blogspot.com/2007/11/windpower-for-dummies.html>)



Red - Central Power Plants Orange - Local CHPs (Combined Heat-Power Plants) Green - Wind Turbines

Figure 4 - Evolution of the Power Plants in Denmark from 1980 to 2000
(Source: System Description Slides, Flemming Nissen)

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Introduction

System Description

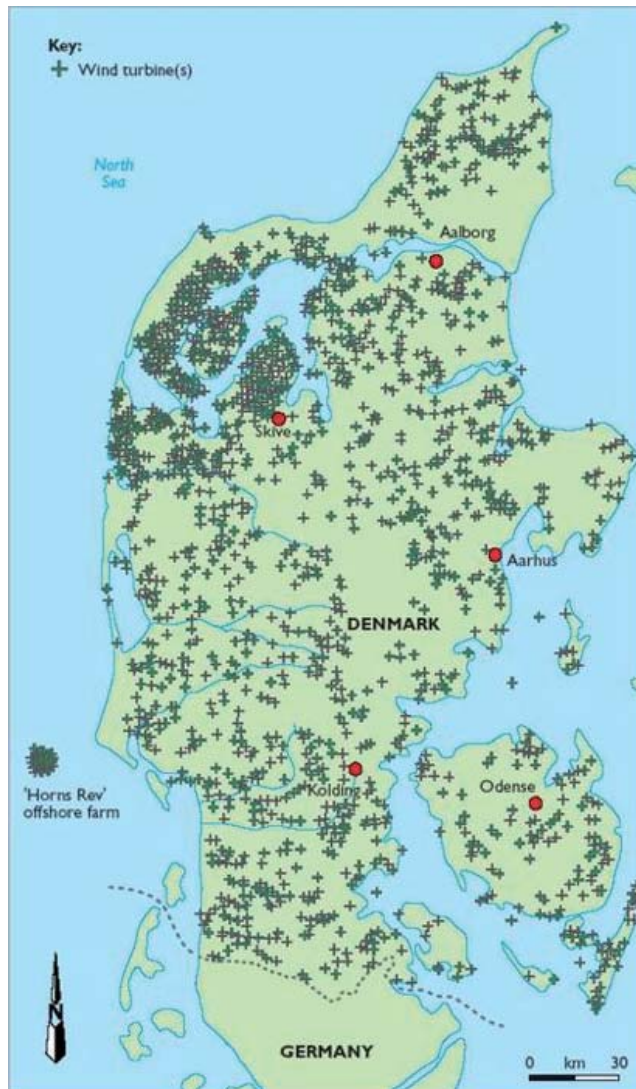


Figure 6 - Distribution of Wind Turbines across DK-West zone
(Source: Internet - <http://europe.theoil drum.com>)

Although it is not influenced by the imbalances of the rest of the Nordpool areas, the DK-West is part of Nordpool, is managed under Nordpool rules and is connected to the rest of the Nordpool meaning it can help maintain the Scandinavian Nordel system stability by regulating the power/energy supplied to that system.

In figure 4 it is visible how the electricity production evolved in the last decades.

There is a huge tendency to create a system with smaller power plants distributed all over the country. This can easily be explained for there will be fewer losses in the energy transportation, and the transport grid can be less loaded, meaning there will be available capacity for the transportation of energy from Nordel to UCTE or from UCTE to Nordel. In addition, a grid that is usually not overloaded has considerably less problems with damaged components than one that is always working at full capacity. One can also see the effort by Danish electricity companies to invest in renewable energies, more specifically the wind power energy. In Figures 5 and 6 the distribution of the wind turbines all across the West Denmark (DK-West Zone), as well as the grid connections to the offshore wind farms, is shown.

As already mentioned, there is a huge intention to create a system with many small plants, in order for the transmission line not to get overloaded and because it is easier to guarantee the system stability and be able to create the so called "Islanding" that is, basically, the capacity to isolate an area and create small independent systems. For example, if for some reason a certain area becomes isolated because there was some defect on the transmission line (short-circuit, some component damaged, or even a transformer that goes out of service) which supplied that area, this area will be able to hold the demand with the local CHPs until the defect is repaired, most likely at a higher cost than it had before, but will avoid a blackout in that area. The problem with this small-scale CHPs is that, usually, they don't have capacity for automatic regulation (regulation by frequency deviations) implying there has to be an equilibrium of small-scale CHPs, central CHPs and Wind turbines. In Figure 7 one can see the distribution, the number of units and their power for the generating units in West and East Denmark for 2008:

	West		East	
	Number	Power (GW)	Number	Power (GW)
Primary Power Stations (CHP)	11	3,5	9	4,1
Small-scale CHP Plants	550	1,8	185	0,7
Wind Turbines	4000	2,4	1200	0,7
Maximum Load		3,7		2,7

Figure 7 - Distribution of System Units across DK-West and DK-East in 2008

(Source: "The Power Market in Denmark", Henning Parbo, Energinet.dk)

In the Figure 8 there is an analysis of the consumption and production development, with the production being for total, local CHPs and Wind Power production. The evolution of the Wind Power production and its share in the final consumption is also visible. Of course these values depend, not just on the capacity installed, but most of all, on the wind throughout the year. Since there was a growth of almost 45% of the wind power produced from 2001 to 2005, and this has an impact when looked at the share of wind power, a renewable energy, at the total consumption, Denmark is one of the countries in Europe where, not only this share is among the highest, but also where this values keep growing still today. This brings some concerns to the approach of the market and of course it influences the prices for the electricity in DK-West, which is what is going to be studied on this paper.

	2001	2002	2003	2004	2005	2006
Consumption (TWh)	20,9	20,9	21	21,3	21,3	21,8
Production (TWh)	23,1	23,5	27,4	24,7	21,9	26,3
CHP Production (TWh)	6,8	6,7	6,8	6,8	6,4	6
Wind Power (TWh)	3,4	3,8	4,4	4,9	5	4,6
Wind Power/Consumption (%)	16,27%	18,18%	20,95%	23,00%	23,47%	21,10%
Interconnections (TWh)	-2,2	-2,6	-6,3	-3,4	-0,6	-4,5

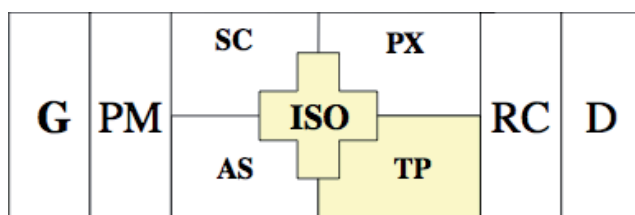
Figure 8 - Evolution of the Consumption and Production for DK-West

(Source: System Description Slides, Flemming Nissen)

1.3. Energy Market Description

Structure of an unbundled Energy Market:

Since the liberalization of the market there has been the need for the so called unbundling, meaning that there was a separation between the different stages of electricity: Production, Transportation, Distribution and Consumer. Therefore, a market structure like the one in figure 9, was created:



G - Generation
 PM - Power Marketer
 SC - Schedule Coordinator
 AS - Ancillary Services
 PX - Market Operator
 TP - Transmission Company
 ISO - Independent System Operator
 ISO + TP -> TSO - Transmission System Operator
 RC - Commercializer
 D - Distributor

Figure 9 - Example of an Unbundled structure
 (Source: "Mercados de Electricidade - Introdução", João Tomé Saraiva, FEUP 2007)

The Generation (G) and the Power Marketer (PM) configure the Production stage, the Schedule Coordinator (SC), Ancillary Services (AS), Market Operator (PX), Transmission Company (TP) and Independent System Operator (ISO) configure the Transmission stage and the Commercializer (RC) and Distributor (D) configure the Distribution stage.

The Market Operator is the company which ensures the communication between producers, consumers, distribution

companies and, of course, with the ISO. It is the company responsible for receiving all the bids for the spot market, for ancillary services, and to get a market price for every hour of the day. The Nordpool is the market operator for the Nordic countries. The ISO is responsible for guaranteeing that the ancillary services needed are available, and for maintaining the system stability (frequency and voltage) by controlling the equilibrium between production and consumption and bottlenecks. Whenever the ISO is the owner of the grid, then it means it is the Transmission Company too, and it is called the TSO, which for Denmark is the Energinet.dk, while some of the generation companies are Dong Energy and Energi Fyn.

The Pool Model:

The Pool is represented by the Market Operator and it is responsible for doing the dispatch based on the buying and selling of bids from the demand and supply respectively for each hour of the next day (It might do for each half an hour, but the hour model is more commonly used). There are two models of Pool, the symmetric and the asymmetric pool. In both of them there will be a market price for each hour of the next day and all the energy traded in the pool for that specific hour will be paid at that hour's price.

The asymmetric pool:

In this model the *demand* buys the energy at any cost. This implies that only the *supply* bids for the energy, and then the market only sees the market price corresponding to the capacity asked by *demand*. The supply bids on the market as normal, with a bid for a specific hour, a certain amount of energy (MWh) and the respective price per unit of energy (\$/MWh).

Introduction

Energy Market Description

Faculty of Engineering

Electrical Power Engineering Program

After receiving all the bids, at twelve o'clock the day before, the pool organizes the supply bids by price and creates the supply curve with which they can develop a figure like Figure 10 for each hour:

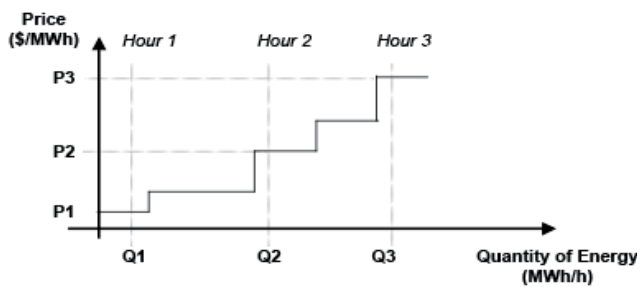


Figure 10 - Example of Supply Curve for an Asymmetric Pool System
(Based on: "Mercados de Electricidade - Introdução", João Tomé Saraiva, FEUP 2007)

As seen in Figure 10, as the load (demand) is inelastic the pool only checks the price, which means that if the supply curve was the same for three different hours of the next day, the result would be a graphic like the one above, where for each hour (hour 1, 2 or 3) there is an asked load from the demand (Q_1 , Q_2 and Q_3) and a corresponding price for that load (P_1 , P_2 and P_3), which will be the market price for that specific hour. In this type of pool the load is totally dispatched in the pool. This system was used in England and Wales from the beginning of the liberalization until October 2000. This model is also used at the Regulating Market where the demand has to be all dispatched in order to maintain the system's stability.

The symmetric pool:

In the symmetric model both demand and supply send their bids to the pool. The bid system is the same as the asymmetric pool (Bids for a specific hour, energy and price per energy). When the pool market closes (at twelve o'clock the day before the operation day), the market operator gathers all the bids from demand and supply and builds up their respective curves on a figure similar to Figure 11:

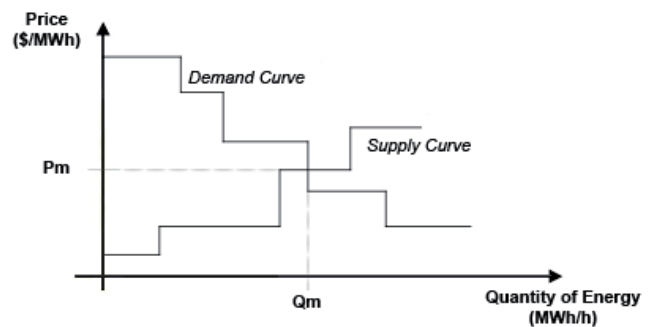


Figure 11 - Example of Supply and Demand Curve for a Symmetric Pool System
(Based on: "Mercados de Electricidade - Introdução", João Tomé Saraiva, FEUP 2007)

The point where the two curves cross defines the market price (Price of market - P_m) and the correspondent quantity of energy (Q_m) dealt in the pool market. This analysis is done for every hour of the following day separately, so there will be different market prices for every hour. A certain amount of energy requested by the demand to the pool is not dispatched on the pool which means it has to be dealt in another market or the demand can avoid consuming this energy. There are some consumers that, if the price paid is higher than a certain value, prefer not to consume during a specific hour. An example of this is the energy spent in Norway for melting the ice or snow on the sidewalks. If the price is too high, then people either take the snow away with a shovel, or wait for a cheaper energy period to turn on the heating system. The best example of a liberalized market, that uses this pool system, is the Nordpool.

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Introduction

Energy Market Description

Nordpool Energy Market:

The Nordpool Energy Market is the market where all the Energy for the Nordic countries is traded. This includes Norway, Sweden, Finland and Denmark. All the companies that want to enter this market have to be Balance Responsible Players (BRP)¹, where they agree with the TSO of their area to be responsible for fulfilling their contracts as Producers (supply) or Consumers (demand).

Structure of the Nordpool Electricity Market:

The Electricity Market is divided into three different sub-markets:

The Elspot - The first market for dealing energy, which is open until 12:00 of the day before the day of operation.

The Elbas - The market for adjustments, which is open from 17:00 of the day before the day of operation until one hour before the hour of operation.

The Regulating Market - The market to guarantee the system's stability, in which the bids are submitted until 45 minutes before the hour of operation. Even though the trade of energy, if needed, will only take place during the hour of operation. There is also a period of time (until 9:30 a.m. the day before the day of operation) where plants can bid for availability of capacity for the reserves used in the regulating market (secondary and tertiary reserves) where they get paid, if accepted, for not bidding some capacity in the spot market and putting it available at the regulating market.

Parallel to the Nordpool market, the demand and supply are able to do some contracts between them directly without even going to the market. In order to do so, they just need to communicate these agreements to the TSO of their areas, so that this trades of energy are included in the TSO study of the grid for that hour to avoid bottlenecks. These contracts are called Bilateral Contracts and can be

done until the end of the Elbas market. These contracts can be done on a long-term basis or in a short-term basis, parallel to the Nordpool. These contracts are done between companies in order to avoid the transaction costs of trades done at the pool. Every transaction made at the pool has a small cost that goes to insurance funds. If some player A does not pay B (the other) for an energy transaction they both committed themselves to do at the pool market, B can ask the pool for insurance and have the money from those funds. However, in bilateral agreements, players do not have access to these insurance funds.

The Elspot:

The Elspot is a market based on the Symmetric Pool model, an open market for producers, as sellers, and consumers, as buyers. In this market every Balance Responsible Player (BRP) submit their its bids for a specific hour as a price (DKK/kWh) and a value for Energy (kWh)². At twelve o'clock the day before, the Market Operator (Nordpool) gathers all the bids and builds the supply and demand curves for each specific hour of the next day, from the hour 0 to 1 until the hour 23 to 24, and publishes the market price and energy dealt for each hour. In case of a bottleneck on a connection between the different Nordpool Areas, Dk-west and Norway for example, the spot prices for both areas will be different. After a bottleneck occurs, the area isolated by that bottleneck will not be able to use bids from producers of the other area, so the supply curves for each area, after the point where the bottleneck occurs, will diverge. The Figure 12 is a graphic created with consecutive values on the X axis, simulating a demand, and with 3 curves representing the system price and the Dk-West price in case of a bottleneck formation at unit 46. The Dk-West price is divided in two curves because one represents a bottleneck while *exporting* (Dk-West Price B-out) while the other represents a bottleneck while *importing* (Dk-West Price B-in). If the system has no bottleneck, the Dk-West price will be the same as the System price.

1 - For more information about BRP please consult the Regulation C2_Balancing Market from Energinet.dk

2 - For more information on how to bid in the Nordpool please consult the Regulation C2_Balancing Market from Energinet.dk

Introduction

Energy Market Description

Faculty of Engineering

Electrical Power Engineering Program

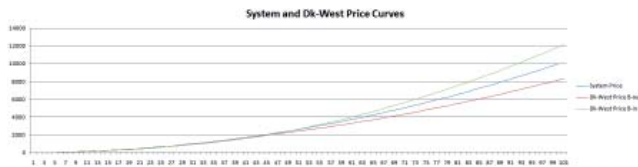


Figure 12 - Example of Curves for System price and Dk-West price with bottlenecks

These bottlenecks occur when Dk-West is producing a big amount of wind power (bottleneck in exportation), or when the wind power production is low and Norway has high Hydro power production that has also low costs of production (bottleneck in importation).

As mentioned above, some energy will be needed by the consumers that will not be accepted by the Elspot because the price paid for it by the demand is lower than the price asked for the same energy by the supply, so it either has to be negotiated afterwards in the other markets, or has to be avoided by demand.

The Elbas:

The Elbas is a market for adjustments and is used for dealing the energy that was not accepted at the Elspot, the forced outages and the forecasting imbalances. In this market, the BRPs make their bids for the market and if some other BRP accepts it, then they both communicate this agreement to the TSO of their areas. This means that this market is done by the BRPs only, and that there are not curves for buying or selling; the BRPs merely make trades of energy between them at the price they both agree as a good price for what they want. The prices in this market are analyzed and stored as minimum, maximum and average price paid by unit of energy (DKK/MWh) for each hour of the day.

The Regulating Market:

The regulating market is the market used to assure the system stability. In this market the consumers with variable load bid to up- or down-regulate the demand and the producers bid to up- or down-regulate the supply. There will be a list of bids for up regulating power and a list of

bids to down regulating power ordered by price of bid with bids from both demand and supply (the bids from the demand are inverse, i.e. a bid done by a consumer to down regulate goes to the up regulation list and a bid to up regulate goes to the down regulation list). This list is called the NOIS (Nordic Operational Information System³). With the bids from the NOIS list the TSOs can build a curve for up- and down-regulation like the one in Figure 13:

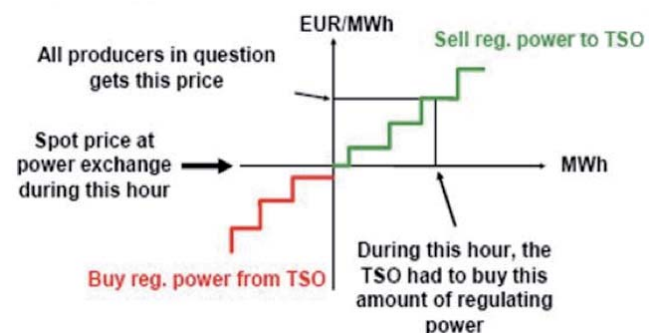


Figure 13 - Example of Up- and Down-Regulation Curves at the NOIS List

(Based on: System Description Slides, Flemming Nissen)

The “sell reg. power to TSO” curve is the curve for up-regulation and the “buy reg. power from the TSO” is the curve for down-regulation. In Figure 13, as it happens in the spot supply and demand curves graphics, at the NOIS list curves there is also an amount of energy - which in this case is the need for balancing power (MWh) - and a price paid for each unit of that power (EUR/MWh). The difference to the spot market is that here there is only a supply curve, so it works based on the asymmetric pool model. The reason for this, is that, while in the Elspot there is no problem if the demand is not fully supplied, the rest of the demand can be dealt in other markets until the hour of operation; in the Regulating Market if the demand is not fully supplied the system will lose its stability. Because both demand and supply bid to this list, if the Nordic

3 - The NOIS is a common platform with all the regulating power bids submitted by the suppliers in Norway, Sweden, Finland and Denmark

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Introduction

Energy Market Description

electricity system has a need for up regulating, which means that the demand is higher than the supply, the TSO for the area that needs this regulation, goes to the NOIS list and chooses the cheapest way possible (the TSO has to be sure that there are no bottlenecks preventing this energy trade) to compensate this imbalance of the grid, which can be by down regulating the consumption, reducing the demand, or by up regulating the production, increasing supply. The same happens for down regulation by the TSO, with the difference that the options will be up regulate the consumption or down regulate the production. The price for this market will be defined by the last bid accepted on the NOIS list for that area. If there is a bottleneck, then the area separated from the system by the bottleneck will have a different price than the rest of the system. The limit for bid at this market is 45 minutes before the hour of operation and the activation of the bids is during the hour of operation, according to the system's necessities, so it is possible to have both up and down regulation in the same hour of operation. There is a phase of this market on the day before the day of operation until 9:30 a.m., where the interested producers can bid for capacity availability in the NOIS list. This takes place because each TSO chooses the capacity they want to assure to be available at the regulating market, essentially meaning that companies bid the compensation they want for a certain capacity availability in the NOIS list. The companies usually use this market to make profit and then they bid to the regulating market with their marginal costs of production, so, in the regulating market, they only receive what they spend producing the asked for regulation power. There is a relationship between the availability compensation and the difference between the expected spot price and the marginal costs. This is because if they are risking not being asked to produce in the regulating market, because their bid is too high or because there was no need for regulating power for a specific hour, then they do not want to lose the profit they could get over the Elspot if they bid that capacity on it.

Reserves:

The regulating power is divided in three reserves, the primary, secondary and tertiary. Sometimes there are two tertiary reserves but the way they work is the same as if there was only one.

The primary and secondary reserves are dealt with on a monthly basis, for now, but will probably start to be dealt with on a daily basis like the tertiary reserve, over the next year or so. The primary reserve is done automatically by the plants which are qualified to do so, which means they have automatic power regulation capability, and react to frequency deviations. The secondary reserve is activated by the TSO remotely and it is also called automatic reserve or Low-Frequency Control (LFC). The tertiary reserve only start/stop producing, depending on if there is a necessity to up/down regulate, after the TSO sends a notification to the plants saying the regulation they have to perform, regarding power and period. In Dk-west, this notification is done through the operational schedules every 5 minutes and in Dk-east, a message is sent by the TSO to the plant, where the power, time for start and total time of operation is specified.

In Figure 14 is represented an imbalance and the activation of bids to suppress it. The bids correspond to the tertiary reserve and the LFC is the secondary reserve.

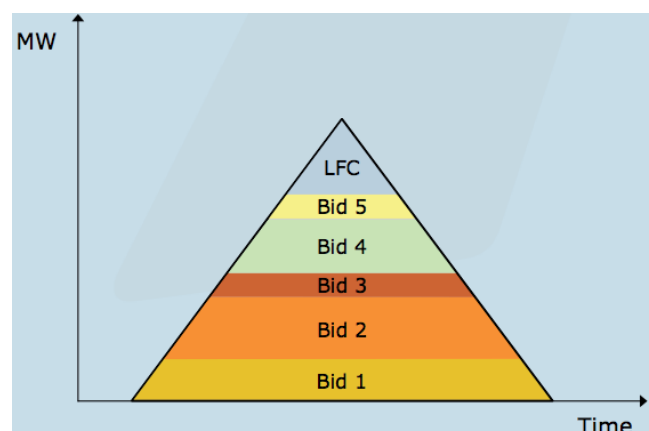


Figure 14 - Activation of Bids for the Reserve Market
(Source: Henning Parbo Slides, Energinet.dk)

The primary reserve is supposed to act within 5 seconds after the beginning of the imbalance and goes on until 5 minutes after it. The secondary reserve begins 5 minutes, maximum, after the beginning of the imbalance and ends 15 minutes later, so that is when the tertiary reserve has to be fully operational. The tertiary reserve can go on until one hour after the imbalance occurred. Figure 15 exemplifies these timings for start and stop of the reserves.

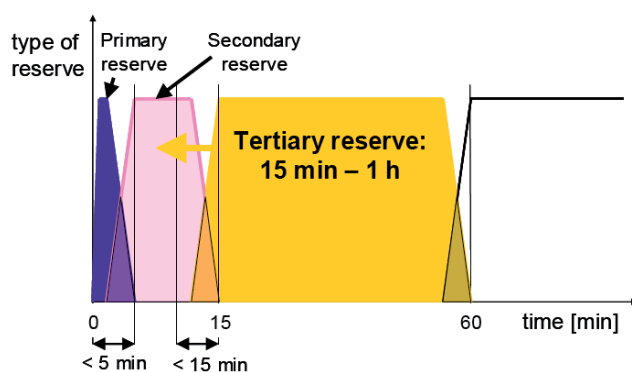


Figure 15 - Time-line for start and stop of the Reserves
(Source: "Description of the required positive tertiary reserve energy", Eva Marie Kurscheid)

Notifications:

The notifications are done either for production, consumption or a simple trade of energy between two Balance Responsible Players. They are on a hourly basis and they describe the total energy that the Units/Power Plants should deliver for a specific hour. The way this energy is distributed within that hour is specified on the operational power schedules. Every day one notification is created works like like a time-series of all the hourly notifications for the next day (day of operation). These hourly notifications can be adjusted until the hour of operation. All the adjustments to the hourly notifications have to be approved by the transmission system operator (Energinet.dk, for DK) and will be attached to the original notification (the one from the day before), so that the original cannot be changed. The notifications are divided in three types as followed:

The **original notification** as a time series for all the hours of the next day (day of operation). These notifications are

submitted by the Balance Responsible Players until 3 p.m. of the day before and have to be accepted by the TSO (Energinet.dk). These notifications cannot be changed. The **notifications for adjustments** are notifications that can be submitted to the TSO (Energinet.dk) for adjustments to the original notification until 45 minutes before the hour of operation. These notifications, if accepted by the TSO, have to be indexed to the original notification and under no circumstance can the original notification be changed.

The **operational power schedules** are notifications that describe the energy or power that a certain Unit (if power superior than 10MW) or Plant (if power for each unit of this plant is lower than 10MW) is supposed to supply. In Eastern Denmark, the time series/power schedules are done as hourly notifications of energy for the next hour (MWh/h). In Western Denmark, the time series/power schedules, which are submitted by the West Danish BRPs for production and West Danish BRPs for consumption with adjustable consumption, are done on a five minute basis (updated every 5 minutes) and include the power that the unit/plant will supply in the next five minutes of operation (MW). The Operational Schedule is the set of power schedules for a specific unit/plant for the 24 hours of the day and it is indexed to the original notification at the end of the day of operation. In Eastern Denmark, this operational schedule consists in a set of 24 hourly time series of energy (MWh/h) and in Western Denmark the set is for 5 minutes power schedules (MW) for the 24 hours of the day, which means there will be 288 power schedules indexed to the original notification and the adjustments notifications for each unit/plant, every day.

The final set of original notification, plus adjustments notifications, plus the time series/power schedules are used the day after the day of operation for the settlement of power imbalances.

Settlement of balancing power:

The settlement of the balancing power is paid on a monthly basis on the 25th day of every month. However, if it is not a working day, it will be paid at the next working day after the 25th. The settlements are done separately to the production, consumption and trades.

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Introduction

Energy Market Description

For balancing power pricing, for production, Energinet.dk uses the two-price model:

- If the imbalance of a BRP has the same direction of the system's total imbalance, which means that it will increase the system's total imbalance, it will be paid at the area's Regulating Power price;
- If the imbalance of a BRP has the opposite direction of the system's total imbalance, that means that it will decrease the system's total imbalance, so it will help the system and it will be paid at the area's electricity spot price.

For balancing power pricing, for consumption and trades, Energinet.dk uses the one-price model:

- Any imbalance, regardless of the direction, is settled at the area's Regulating Price.

Settlement of power imbalances:

To settle the power imbalances in Denmark, the TSO (Energinet.dk) uses the power schedule values and the real (metered) values converted to quarter-hourly values. The power imbalances are the difference between these two values. The power imbalances are only settled if the difference between the sum of the quarter-hourly power schedules energy and the sum of the quarter-hourly metered values for all the balance responsible players exceeds 2.5 MWh/quarter-hour. This means that if the difference is lower than 2.5 MWh/quarter-hour the TSO accepts this imbalance and does not charge players for it. If the difference is higher than 2.5 MWh/quarter-hour the TSO will proceed to calculate the power imbalances for each balance responsible player and the correspondent amount they have to pay for these imbalances.

Settlement prices for the power imbalances:

To the settlement prices for power imbalances, two prices are used:

- A price for balancing power, either for up-regulating and down-regulating (BAL_{up} and BAL_{down} respectively).
- A price for the automatic reserves power, again for up-regulating and down-regulating (AUT_{up} and AUT_{down} respectively).

Power imbalances are settled at different prices according to the differences between notification, power schedule and metered results for a given hour. As the metered results and the power schedules are in a quarter-hourly basis, these values have to be converted into hourly values before settling the prices for power imbalances. The way to calculate the prices, depending on variables above described is the following:

If $Metered\ Result > Power\ Schedule > Notification$ then:

$$Price = (Metered\ Result - Power\ Schedule) * (BAL_{down} - AUT_{down})$$

If $Power\ Schedule > Metered\ Result > Notification$ then:

$$Price = (Metered\ Result - Power\ Schedule) * (BAL_{down} - AUT_{up})$$

If $Metered\ Result > Notification > Power\ Schedule$ then:

$$Price = (Metered\ Result - Power\ Schedule) * (BAL_{up} - BAL_{down})$$

If $Notification > Power\ Schedule > Metered\ Result$ then:

$$Price = (Metered\ Result - Power\ Schedule) * (BAL_{up} - AUT_{up})$$

If $Notification > Metered\ Result > Power\ Schedule$ then:

$$Price = (Metered\ Result - Power\ Schedule) * (BAL_{up} - AUT_{down})$$

If $Power\ Schedule > Notification > Metered\ Result$ then:

$$Price = (Metered\ Result - Power\ Schedule) * (BAL_{down} - BAL_{up})$$

If the settlement prices ($BAL_{down} - AUT_{down}$ and $AUT_{up} - BAL_{up}$) for a specific hour have a negative value, then they will assume the value 0 DKK/MWh. This means that if a player incurs in an imbalance, he either has to pay a cost or pay nothing for the settlement price, but never receives money for that imbalance.

As in the settlement for balancing power, the invoices for settlement prices are done in a monthly basis.

Timeline for the Nordpool Electricity Market:

Balance responsible parties	07:30	Energinet.dk/Nord Pool
Deadline for submission of daily forecasts for facilities expected to be in operation, see 5.1.2	09:00	
Deadline for submission of bids for capacity auctions to E.ON Netz	10:00	E.ON Netz announces capacity on the interconnection to Germany
Deadline for submission of bids to Nord Pool Elspot	12:00	- E.ON Netz announces auction results - Nord Pool Spot announces binding trading capacities
Deadline for submission of notifications to E.ON Netz	14:00	
Deadline for submission of notifications for the next day of operation	14:30	- Nord Pool Spot announces prices and volumes - Nord Pool Elbas announces transfer capacities
Deadline for submission of adjusted notifications	15:00	
Deadline for submission of adjusted notifications	16:00	Energinet.dk publishes preliminary confirmation report
- Deadline for submission of operational schedules for the next day of operation - Deadline for submission of regulating power bids in certain cases	17:00	Deadline for publishing of final confirmation report
Before the day of operation		
Deadline for trade on Nord Pool Elbas for the next delivery hour 01:00–02:00	00:00	
	00:15	During the day of operation (Illustrated by the delivery hour 00:00 - 01:00)
- Deadline for submission of adjusted notifications for the next delivery hour - Deadline for regulating power bids and adjustment of bids for the next delivery hour	01:00	Energinet.dk publishes confirmation reports immediately after receipt of adjusted notifications in case of balance
Start of next delivery hour		

Figure 16 - Timeline for the Nordpool Electricity Market
(Source: "Regulation C3_Handling of notifications and schedules",
Energinet.dk)

DANISH ENERGY MARKET

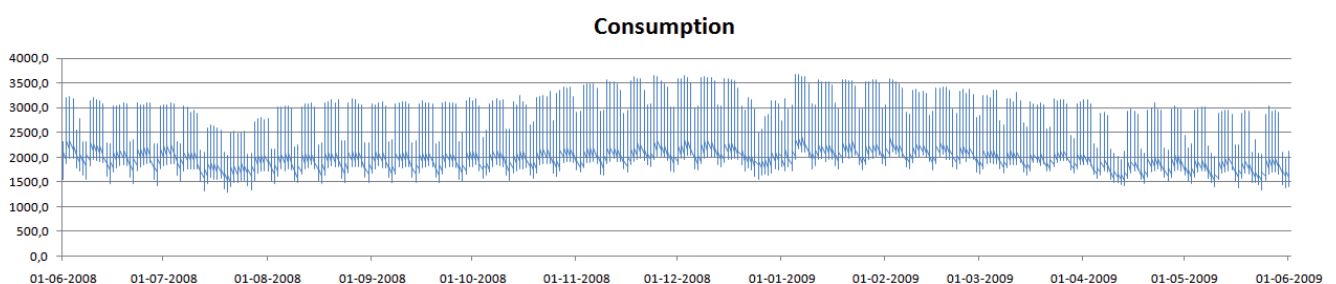
The Regulating Market & Renewable Energies

Variables' Description

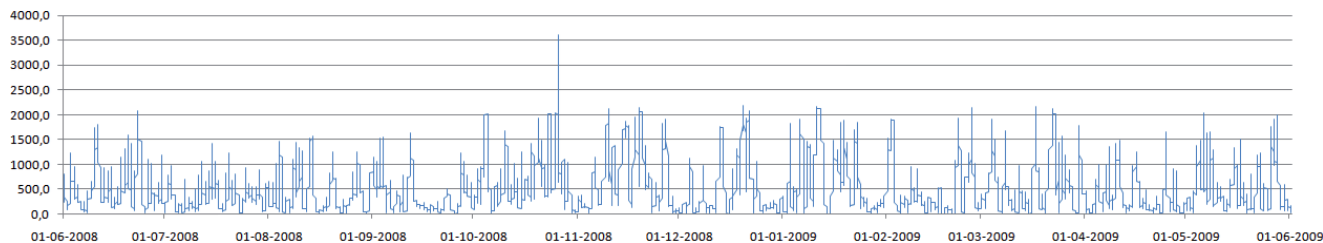
2. Variables' Description

This chapter goes through some of the values for the variables that will be used in the models, in order for the readers to familiarize themselves with the terms. It shows the range of the variables and how they have evolved throughout the past year. All the data is shown on an hourly basis since the 1st of June 2008 until the 1st of June 2009. Some graphics that describe the relations between two variables, just as basic analysis, will also be shown on this chapter, but further on, once going through the elaboration of the models, this analysis will be deeper.

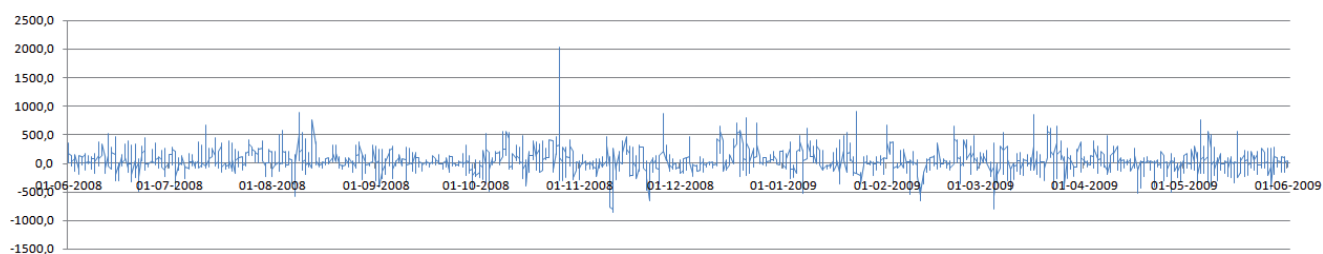
The first graphic is the one for consumption. In Graphic 1, one can see the presence of week seasonally consumption. That is why, latter on, at the creation of the model for consumption, the data will be divided in every weekday and worked separately creating this way seven different models. Besides this, it also has the effect of seasons (Winter, Spring, Summer and Autumn) but this is easier to see when divided in weekdays. The unit used for consumption is MWh/h.



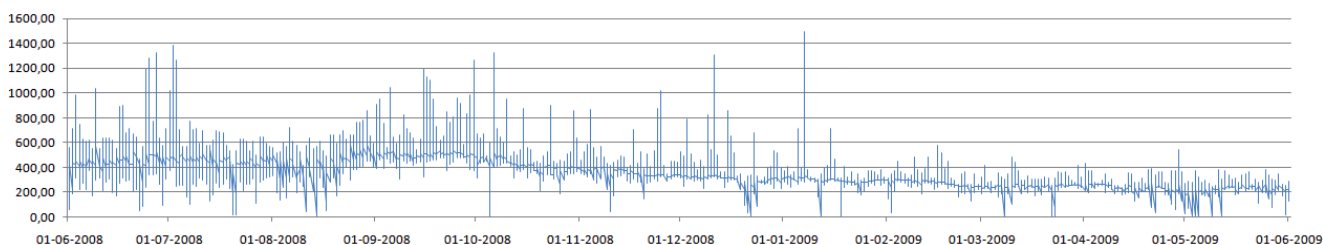
Graphic 1 - Evolution of the Consumption from the 1st of June 2008 till the 1st of June 2009

Variables' Description**Wind Power Production**

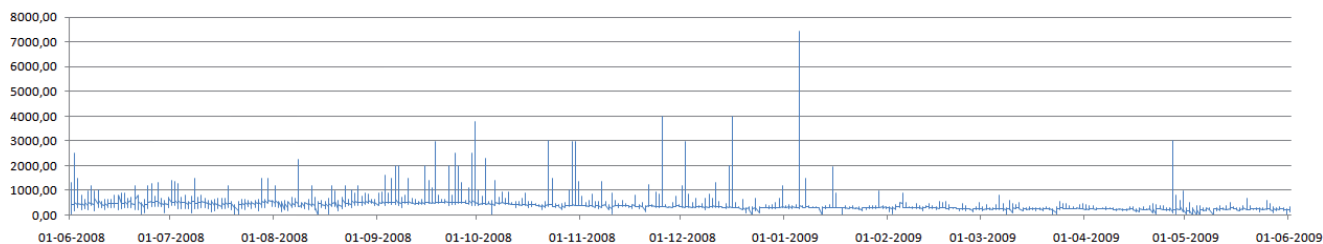
Graphic 2 - Evolution of the Wind Power Production from the 1st of June 2008 till the 1st of June 2009

Wind Imbalances

Graphic 3 - Evolution of the Wind Power Imbalances between forecasted and real production from the 1st of June 2008 till the 1st of June 2009

DK-West Spot Price

Graphic 4 - Evolution of the DK-West Spot Price from the 1st of June 2008 till the 1st of June 2009

Regulating Price - Up Regulation

Graphic 5 - Evolution of the Regulating Price for Up Regulation from the 1st of June 2008 till the 1st of June 2009

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Variables' Description

The next variable analyzed is the Wind Power Production. This variable depends on the installed capacity of wind turbines, of course, but most importantly, it depends on the speed the wind has at the high of the rotor of the turbine. This is easily explained by the characteristic curve of power of this type of turbines (power versus wind speed), which is shown below:

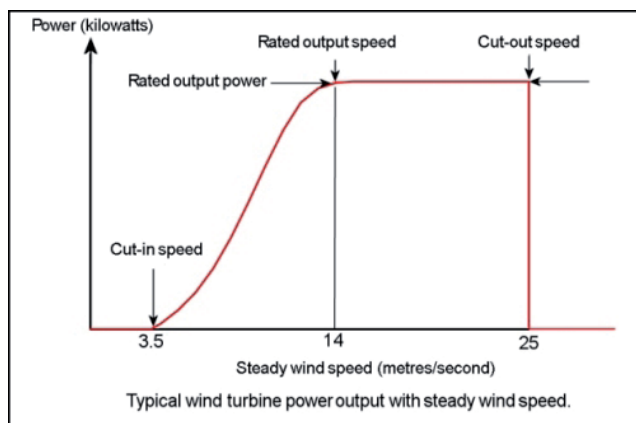


Figure 17 - Curve of power versus wind speed for a wind turbine
(Source: Internet - <http://www.wind-power-program.com>)

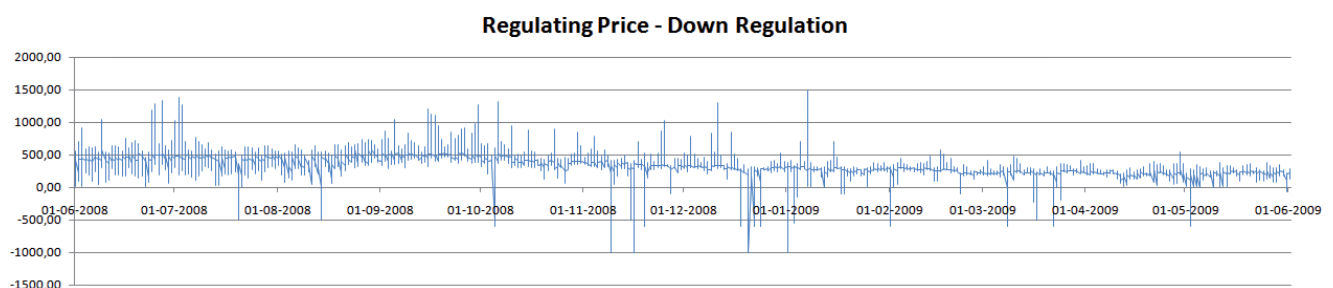
The wind turbine will not work with a wind speed below 3,5m/s and if the wind's speed is higher than 25m/s the turbine has to stop working for security reasons. All in all, the range of wind's speed in order for the wind turbine to be able to produce energy is between 3,5 and 25m/s. Graphics 2 and 3 show the total wind power hourly production in West Denmark in MWh/h for the analyzed period, and

also the imbalances between the forecasted and the real production. In the Nordpool system the Wind Power goes to the pool at a cost of zero, so it is right in the beginning of the supply curve, which means it is the first to be dispatched. This implies that its instability and variations will be present in the price of energy, but more about that over the DK-West spot price modeling. The imbalances shown on Graphic 3 are useful to compare with need for Regulating Power and with the regulating prices.

As already mentioned, the DK-West spot price is very unstable, and because of that, it is very hard to model. This price depends on so many variables that even in consecutive hours the prices can change 100% or 200% easily, and sometimes varying much more than this. Graphic 4 shows this instability and its behaviour through out a year. The average price also changes.

The Regulating Market price for DK-West is similar to the Spot price in shape because it is directly indexed to the Spot price as explained above in the Regulating Market introduction. Graphics 5 and 6 describe the Regulating Power price for Up- and Down-Regulate, respectively.

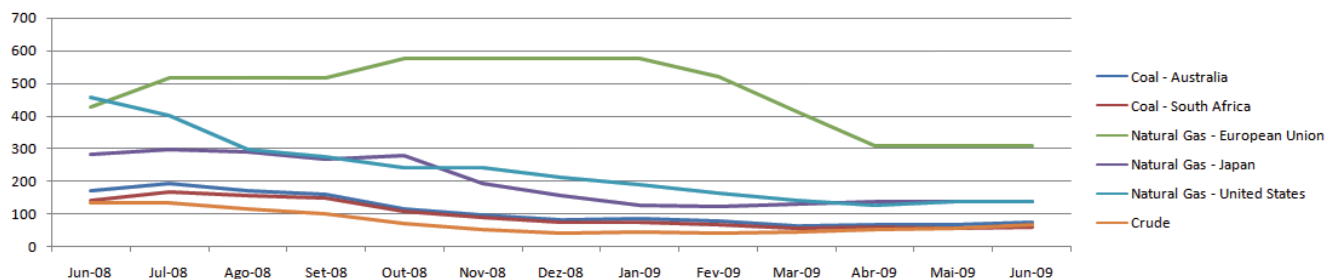
One really important variable in the electricity market is the price of fuels, coal, oil and natural gas. As showed in the system description almost 70% of the installed capacity in western Denmark depends on these fuels, so their prices are



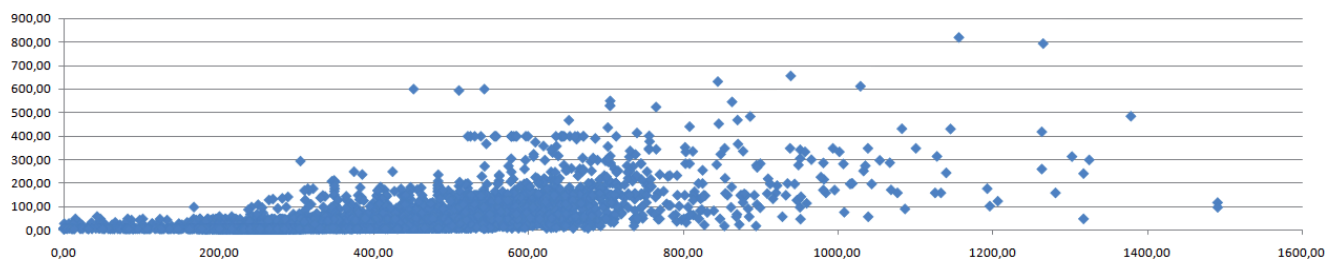
Graphic 6 - Evolution of the Regulating Price for Down Regulation from the 1st of June 2008 till the 1st of June 2009

Variables' Description

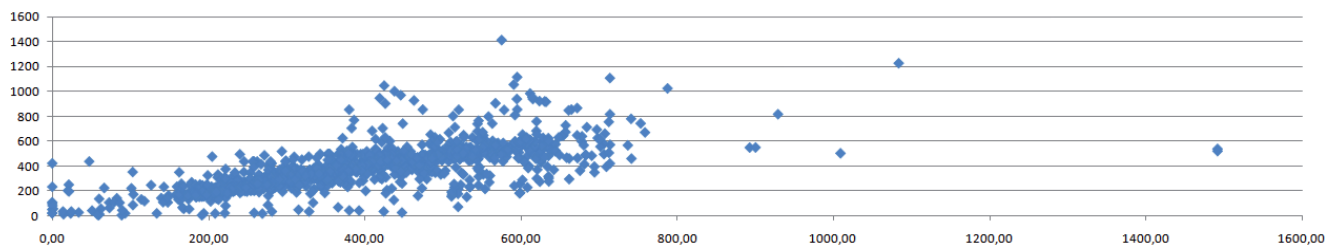
Fuel Prices

Graphic 7 - Evolution of the Fuel Prices from the 1st of June 2008 till the 1st of June 2009

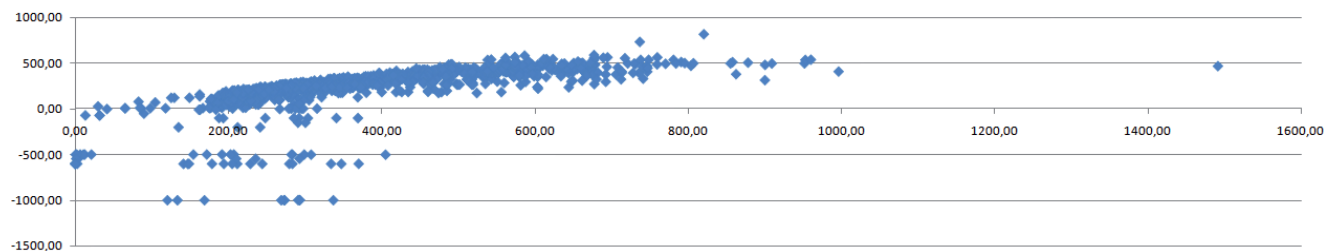
Reserves 9:30 Up-Reg - DK-West Spot Price

Graphic 8 - Relation between Reserves of capacity Price and Spot Price from the 1st of June 2008 till the 1st of June 2009

Elbas Average Price - Dk-West Spot Price

Graphic 9 - Relation between Elbas Average Price and Spot Price from the 1st of June 2008 till the 1st of June 2009

Regulating Price for Down Regulation - Dk-West Spot Price

Graphic 10 - Relation between Regulating Price for Down Regulate and Spot Price from the 1st of June 2008 till the 1st of June 2009

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Variables' Description

really important. Graphic 7 has the monthly average prices for each fuel in the markets that Europe usually buys from.

Beginning on Graphic 8, are shown the relationships between prices for reserve of capacity market (9:30a.m. day before operation), Elbas and Regulating market with the Dk-West Spot Price and between need for regulating power and wind imbalances.

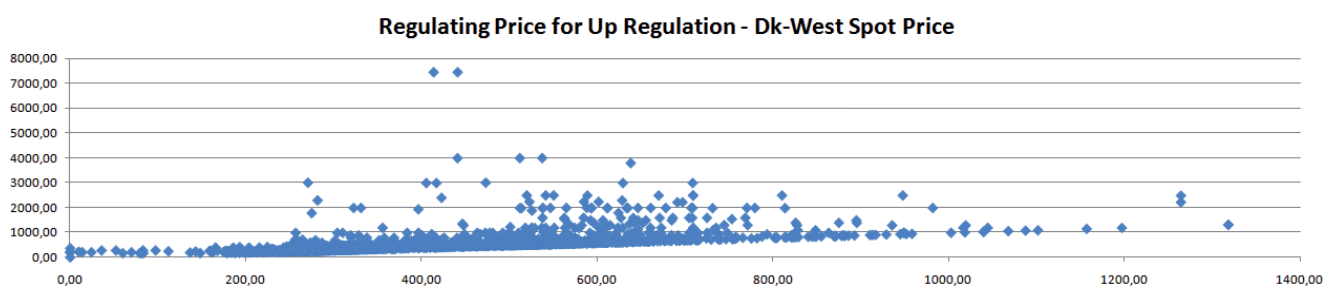
In Graphic 8 there is a correlation between the reserve of capacity price and the spot price, which was expectable for the plants bid on this market the difference between the expected spot price and their marginal costs, explaining why, if the spot price is high, then the price for reserve of capacity for regulation also tends to increase. Of course, either the spot price or the marginal cost depend on the costs of fuels and other variables that are not common to both, so, even though the correlation is not linear, it is there.

On Graphic 9, it is easy to see that there is a correlation between the prices of almost one to one, which means that

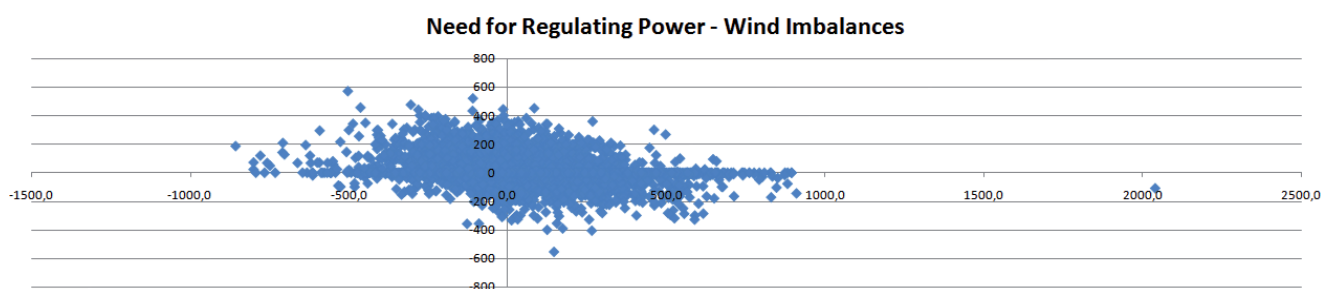
the Elbas average price is near the spot price.

In Graphics 10 and 11 one can see the correlation between Regulating Prices for both Up- and Down-Regulation and Dk-West Spot Prices. As it happened with the Elbas prices, these prices tend to be equal to the spot price but in these two cases, the correlation is stronger and it is almost possible to draw a tendency line with a straight line. For 62% of the time the relation between down regulation price and spot price is between 0.95-1.05 (down regulation price divided by the spot price) and for the up regulation price this value goes up to 77%. This is consistent with the theory of the regulating power being around the spot price - either going up or down for Up- or Down-regulation respectively - as explained in the introduction to the Regulating Market.

A correlation between the need for regulating power and the wind power imbalances was expected, but there is no visible correlation in Graphic 12. More of these studies will be shown latter on the modeling.



Graphic 11 - Relation between Regulating Price for Up Regulate and Spot Price from the 1st of June 2008 till the 1st of June 2009



Graphic 12 - Relation between need for Regulating Power and Wind Imbalances from the 1st of June 2008 till the 1st of June 2009

Variables' Description

All in all, the prices for Dk-west spot depend on many variables, being one of them the forecasted Wind Power, which is one of the most important variables to explain the oscillations on this price. The fuel prices are also important because the costs of production to the fuel based plants are directly indexed to these prices but the production costs are not calculated on an hourly basis so the fuel prices are not responsible for the hourly variations. On the other hand, these prices, in particular, the price for Natural Gas, has a trend similar to the spot price trend. This can be explained by the fact that in Dk-West there is a big concentration of CHP Plants and these work on Natural Gas. A further issue is the correlation between the Dk-West Regulating prices and the spot price. This is the main reason why this report will focus its studies on the Dk-West spot price first, and then on the Regulating Market.

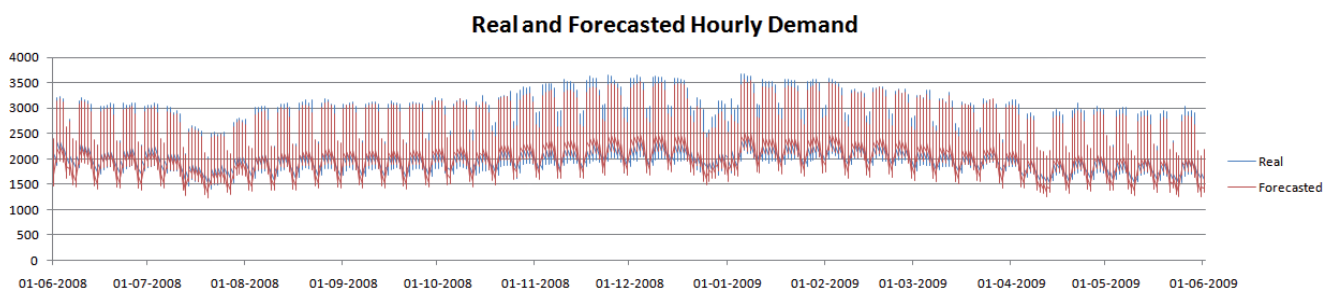
3. Models

3.1. Consumption

Because the Consumption is an entry for the models studied latter on, it will be an important variable to this study, so there is a necessity to study and forecast it in order to be able to include it in the market studies.

For this model in particular, it is easier to work with daily data instead of hourly data. This because this way, the week seasonly can be included in the model as well as the year seasonly. The data used was the data available at Energinet.dk webpage, which resumes to data from the 1st of January 2000 until the 23rd of June 2009. After the forecast, the models' results are converted again into hourly values. For that, a new study of the distribution of the

consumption during the hours of the day was made. This study is also good to see that this distribution during the day has not changed in for the past 10 years, and it is good to understand how the distribution of consumption has to evolve in order to achieve an equilibrium of consumption during the day, which would minimize the need for extra plants to supply the consumption over the "full hours". All these studies are explained in the Appendix. In the end, the MAPE error, which is the mean absolute percentage error, was 4,88% and Graphic 13 shows the real and the forecasted consumption for the period used for the models studied latter.



Graphic 13 - Real and Forecasted hourly consumption since 1st of June 2008 till 1st of June 2009

3.2. Dk-West Spot Price

In the beginning, the objective of this part of the study was to create a model that would show the correlation between the Dk-West spot price and the Wind Power Forecasts. It was supposed to be a model that had the Wind forecast, the ones used by Energinet.dk, as an entry and the spot price as an output. The first thing to do was to analyze the graphic that relate these two variables. The result was graphic 14, shown bellow.

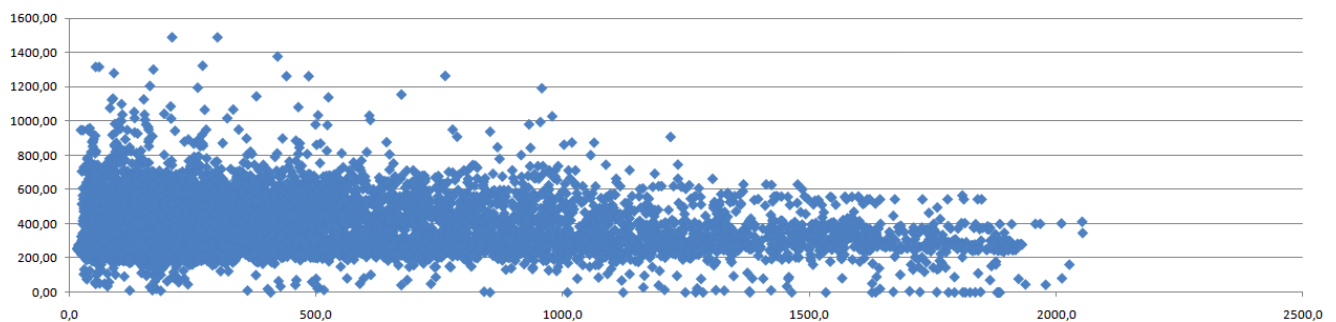
The same correlation but for the system spot price instead of the Dk-West spot price, was also analyzed and the result is shown on graphic 15.

On both graphics, 14 and 15, a correlation between the two variables is not visible, but one can see that in the system

price analysis the values are more concentrated and do not vary as much as in the Dk-West spot price. This is easily explained because for the system price, the demand, during a summer day, varies between 20000MW and 30000MW and for Dk-West, these values vary between 1000MW and 2000MW, almost twenty times less than the system demand, so, the injection of wind power in the Dk-West transmission grid has more impact in the Dk-West system than in the Nordpool system.

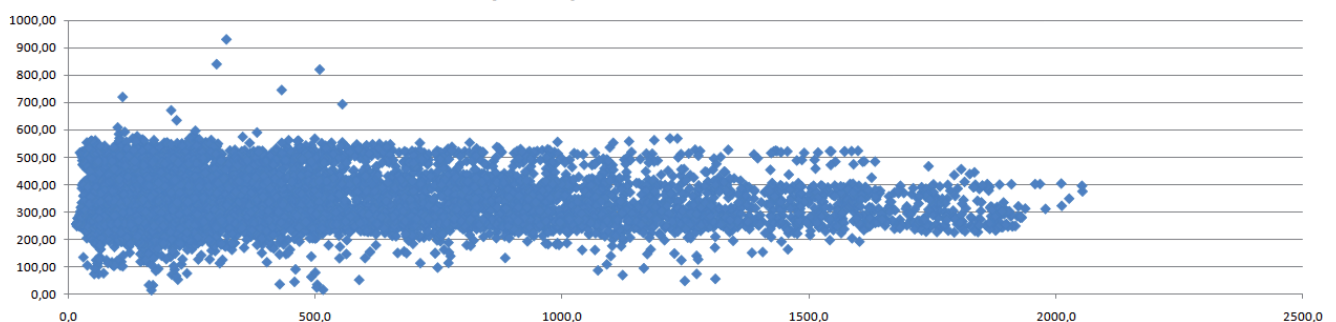
This idea of the Wind Power not having a direct correlation with the Dk-West price was theoretically wrong, so there was a need to find what was “hiding” this correlation and the most obvious conclusion was demand. The problem is that for the same amount of Wind Power forecasted, there

Dk-West Spot Price vs. Wind Forecast



Graphic 14 - Dk-West spot price vs. Wind Forecast

System Spot Price vs. Wind Forecast



Graphic 15 - System spot price vs. Wind Forecast

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Models

Dk-West Spot Price

was a huge disparity between values of demand, which would obviously affect the market price. The theory behind the market would explain exactly what does the Wind Power represent on the Electricity Market. As the Wind Power goes to the market with a zero cost, 0DKK/MWh, because this energy does not have any cost to produce, it is the first energy to be dispatched and it will correspond to an amount of energy that appears in the supply curve with zero cost, so, overlapped to the “X” axis. Figure 18 shows this effect.

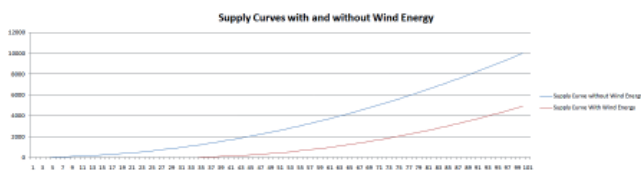


Figure 18 - Example of Supply Curves for an hour of operation with and without Wind Power

From figure 18 one can conclude that the injection of Wind Power on the system does not do anything more than to shift the supply curve a certain number of units (MWh), where this number is the amount of wind power forecasted. And, taking into account that the supply curves can be described by the exact same expression - just with the translation caused by the wind power - then, if instead of having the demand on the X axis there was the consumption minus forecasted wind power, the expression would be exactly the same as the supply curve without any wind power. This can be done, because, as this energy has a zero cost, then, it can be seen as negative demand. If the variable used in the X axis is only the demand, when modeling the supply curve, as the supply curve is always moving around with the forecasted wind power, it would be incredibly hard to get any reliable result. On the other hand, when the forecasted wind power is considered as a negative demand the variations on the supply curve caused by the wind power forecast are avoided so it is easier to see the supply curve. The variations on the price for each value of consumption minus forecasted wind power will only be caused by variations on the bids by each plant and not because of wind power production. Figure 19 shows another way of explaining the same. In the figure, Q1 is

the demand, and the supply curve does not include the Wind Power. If the Wind Power was included as a negative demand then the initial demand (Q1) that had a price (P1) would be subtracted by the wind power getting this way a new demand (Q2) and a new price (P2). The wind power is nothing more than the difference between Q1 and Q2.

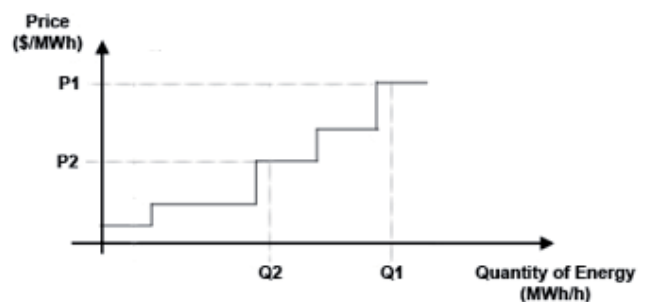


Figure 19 - Example of Supply Curve for demand without wind power (Based on: “Mercados de Electricidade - Introdução”, João Tomé Saraiva, FEUP 2007)

This means that, in fact, if a curve where the consumption was fixed and the wind power forecast was variable could be done, the curve would be exactly the symmetric of this one. Figure 20 exemplifies this. Q1 and Q2 are two different amounts of forecasted wind power for the same hour which means the same demand, consumption.

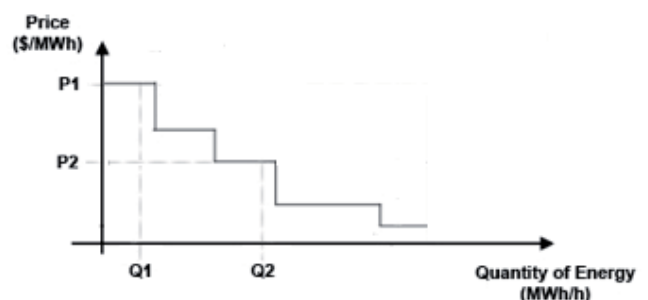
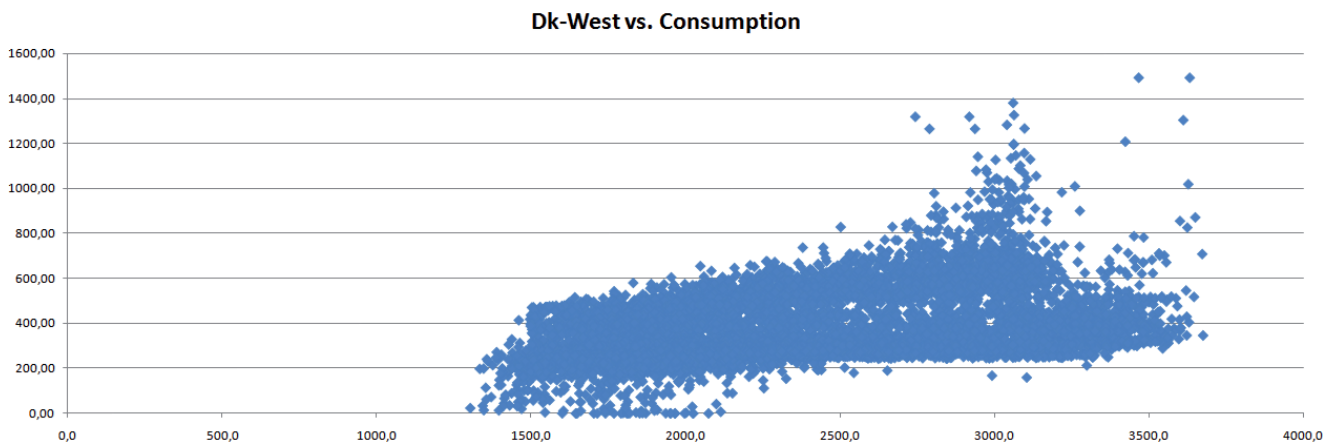
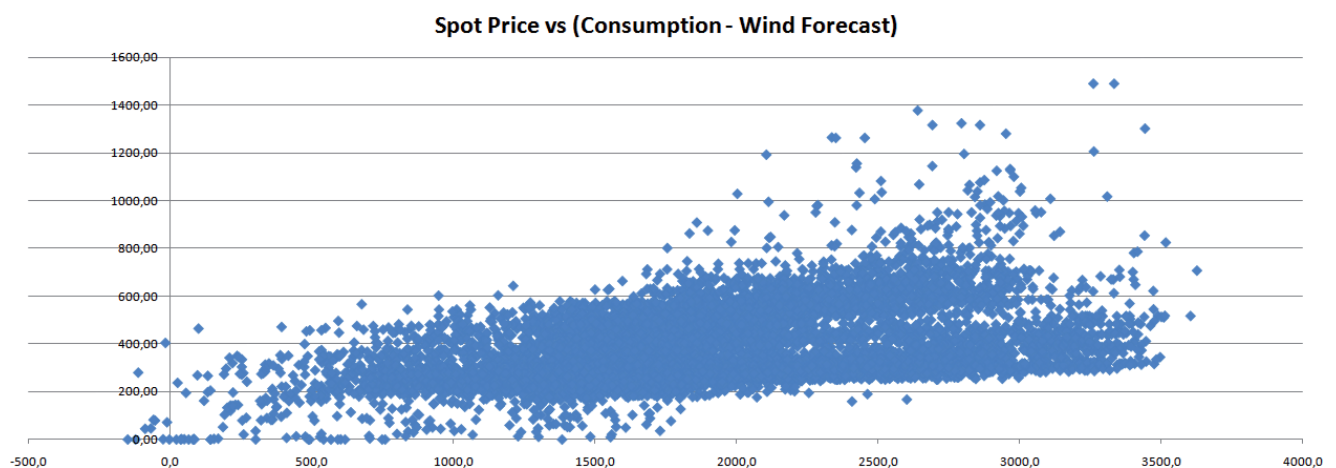


Figure 20 - Example of Dk-West spot price in function of wind power (Based on: “Mercados de Electricidade - Introdução”, João Tomé Saraiva, FEUP 2007)

Graphics 16 and 17 are computed based on the data received from Energinet.dk.



Graphic 16 - Dk-West spot price vs. Demand



Graphic 17 - Dk-West spot price vs. Demand - Wind Forecast

Graphics 16 and 17 show the difference between calculating the Dk-West spot price with only the demand or with the consumption minus wind power. In Graphic 16 the demand starts around 1250-1300MWh/h, which means that this was the lowest demand over the period of 1st of June 2008 to 1st of June 2009, probably a day of summer, and ends with the highest demand around 3600MWh/h, most likely, on a cold day of winter. For an analysis of consumption, this is probably a good choice of graphic analysis, but, if the variable to study is the price, then in Graphic 16, as explained above, the wind power influences the price and it is not quantified so the viewer of the graphic receives the wrong impression of the market supply curves done by the other sources of energy external to wind power. The problem is that, in Graphic 16, if a random

number of consumption is picked up, 1500MWh/h for example, there is no way, looking at the graphic, to know if the wind power was 0MWh/h or 1500MWh/h and that variation has a big influence on the price of energy because the energy needed to be produced by the fuel based plants - which is equal to demand minus wind power - can be 1500MWh/h or 0MWh/h, respectively, and obviously the costs for producing these two amounts of energy are different. Of course, variations on capacity of energy supply also happen in the fuel based plants but they are not so significant in value and they do not happen that frequently, but these explain the fact that on Graphic 17, even with the wind power influence avoided, there is not a perfect curve but an accumulate of values for each different value for consumption minus wind power. Another reason for this

DANISH ENERGY MARKET

Models

The Regulating Market & Renewable Energies

Dk-West Spot Price

to happen are the bottlenecks that affect a lot the supply curves, as explained above in the market discription chapter in spot market analysis, and the price of fuels and politics around the energy market - fees for the CO₂ emissions and subsidies, for example. All in all, with the translation done from Graphic 16 to 17, it is possible to work the data and get the average supply curve for fuel based plants. This was the first analysis to be done.

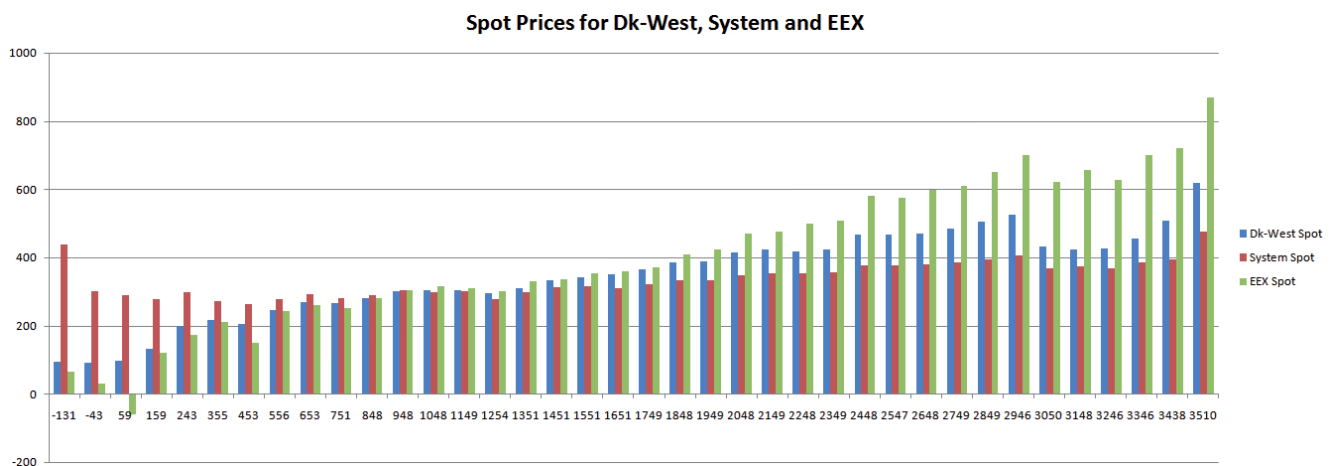
For this analysis, the corrected hourly demand, consumption minus wind power, was divided in intervals of 100MWh, and then calculated the average corrected demand values and the respective prices for each of those intervals. This analysis was made for System, Dk-West and EEX spot prices. The results are shown on table 1.

There are three things that are worth focusing on Graphic 19. The first one is the fact that there are negative values for the corrected demand, which means that the wind power

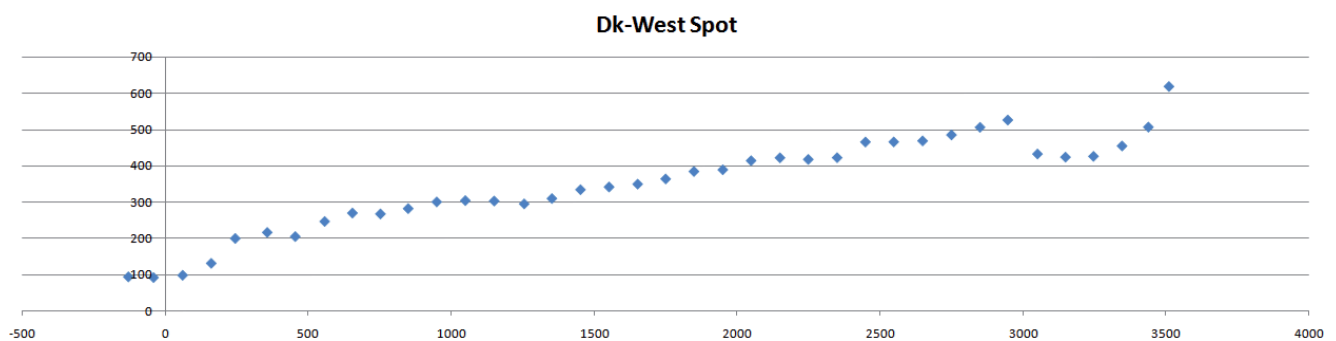
Cons-Wind Energy	Int(Cons-WE)	Dk-West Spot	System Spot	EEX Spot
-130,4333333	-131	93,50666667	439,2433333	66,50333333
-42,6625	-43	91,49625	302,225	31,19625
59,68333333	59	97,77583333	289,8366667	-61,26416667
159,7923077	159	130,7369231	276,7646154	121,0369231
243,9761905	243	199,45	298,8738095	173,8642857
...	...	...	...	...
3148,765686	3148	423,7859804	375,2218627	656,6831373
3246,479832	3246	426,0545378	366,5531933	626,0123529
3346,418841	3346	454,653913	386,0823188	700,327971
3438,436667	3438	506,7106667	395,4736667	721,254
3510,966667	3510	618,7233333	475,51	869,5

Table 1 - Spot Prices Dk-West, System and EEX - Average model

for some hours is higher than the consumption and then the price for this values is different from zero and positive. On a first look this seems strange because, as the wind power is sold in the market at a zero cost, it would be expected that the spot price would be zero. The problem is that, stopping a big coal plant for only one or a few hours has huge costs implied and sometimes it is not even possible, so the big energy companies like Dong Energy and Vattenfall buy energy on the Dk-West spot market and then they sell it on



Graphic 18 - Spot Prices Dk-West, System and EEX - Average model



Graphic 19 - Average Dk-West spot price based on average values for the corrected demand - Average model

Models

Dk-West Spot Price

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EEX market. This way they can pull up the market price on Dk-West and receive some money instead of offering energy at zero cost to the market or having the costs of stopping the plants. The second thing to talk about is that some steps appear on the Dk-West spot price values when moving around the corrected demand. These steps are caused by the different techniques of producing energy. The coal plants, for example, vary their prices between them, but they all use the same fuel, they have the same costs with it, so these variations are small and explained by the differences on the used technologies to produce energy from coal, because these vary in efficiency. The third point worth talking about is the behavior of the curve in the last values for corrected demand, higher than 3000MWh/h. In this part of the supply curve, shown by the average prices, there is a huge drop on the price of energy paid for these high values. This can be explained by looking at the graphic that shows the price for Dk-West spot price as a function of the consumption minus wind power. In this graphic it is visible that the prices for corrected demands higher than 3000MWh/h are more stable. In this period the prices vary from 300DKK/MWh till 600DKK/MWh and in the values lower than 3000MWh/h and higher than 1250MWh/h, the prices float between 200-800DKK/MWh. These differences are explained by the technologies of the plants present in the Nordpool electrical system. The supply curve, as mentioned above is built in a crescent fashion since the cheapest plants, usually the hydro plants, if the wind power is considered as negative demand and not as supply, until the most expensive ones, the oil and natural gas plants. The hydro plants have constant costs and their production varies with the water available to create

energy. When they lack capacity to produce, then the coal and nuclear plants start producing and after these two, the oil and the natural gas plants start. The Uranium price is cheaper than the coal price so this energy comes first. The coal prices vary a lot so that is why the prices vary so much on the middle part of the supply curve. The last part of this curve is fulfilled by the natural gas plants and this fuel is dealt in very long term contracts, usually 20 years' contracts, so that is why the variations on the natural gas price do not affect the price on the supply curve on a short term, and that is the reason why it is more stable in the end than in the rest of the curve. On the other hand, the variations on the Natural Gas prices are corrected in a long term which will provoke a trend on the market prices.

To create the model to represent Graphic 19, the easier way was to draw a trend line on the graphic and check which function would better represent the values. The result for this model was a sixth degree polynomial function. (Graphic 20)

Now it was time to use the expression of a sixth degree polynomial function and calculate the constants on it to create the model:

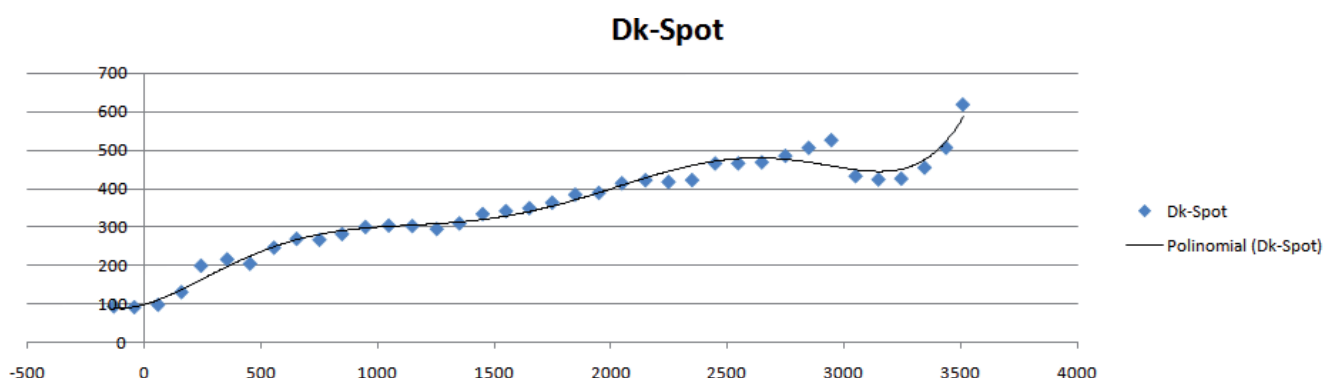
$$Y(x) = \delta + \varnothing_1 \cdot x + \varnothing_2 \cdot x^2 + \varnothing_3 \cdot x^3 + \varnothing_4 \cdot x^4 + \varnothing_5 \cdot x^5 + \varnothing_6 \cdot x^6$$

Where:

$Y(x)$ - Dk-West Spot price for corrected demand (x)

x - value of average corrected demand (Consumption - Wind Power)

$\varnothing_1, \varnothing_2, \varnothing_3, \varnothing_4, \varnothing_5, \varnothing_6$ - model constants



Graphic 20 - Average Dk-West spot price based on average values for the corrected demand with a trend line - Average model

DANISH ENERGY MARKET

Models

The Regulating Market & Renewable Energies

Dk-West Spot Price

The way to proceed to calculate the constants is to calculate the error and the quadratic error for each value of “x” and then calculate the square root of the average quadratic error (RMSE). The application solver was the application used to minimize this error by modifying the constants of the model. The results were:

δ	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6
105,2946848	12,13451702	-100,012	262,7276	-172,208	-226,142	402,6222

Table 2 - Model parameters - Average model

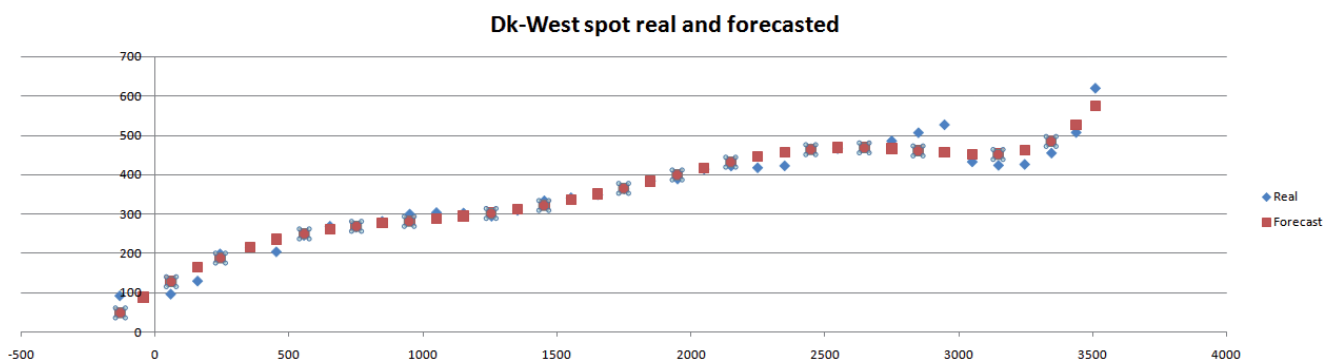
RMSE
23,7061491
MAE
17,04
MAPE
6,41%

Table 3 - Model errors - Average model

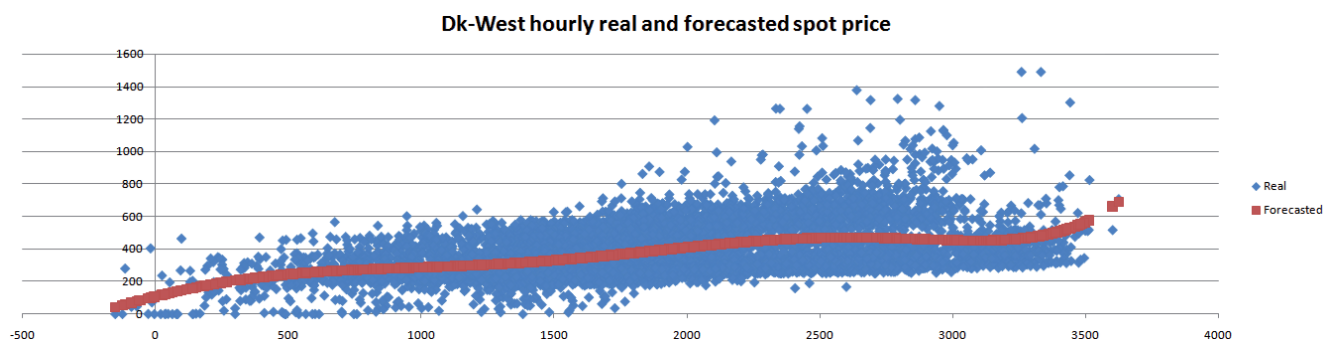
After calculated, the model was applied to the hourly data and the results were:

Train	Test
RMSE	RMSE
143,4045182	120,4908875
MAE	MAE
1028,50	105,12
MAPE	MAPE
54,90%	76,36%

Table 4 - Errors for the model applied to hourly values - Average model



Graphic 21 - Dk-West spot price and forecasted spot price - Average model



Graphic 22 - Dk-West hourly spot price and forecasted hourly spot price - Average model

Models

Faculty of Engineering

Dk-West Spot Price

Electrical Power Engineering Program

As this model is based on average values and not on the real values, instead of using only one function to represent the comportment of the supply curve, it can be divided it in four parts:

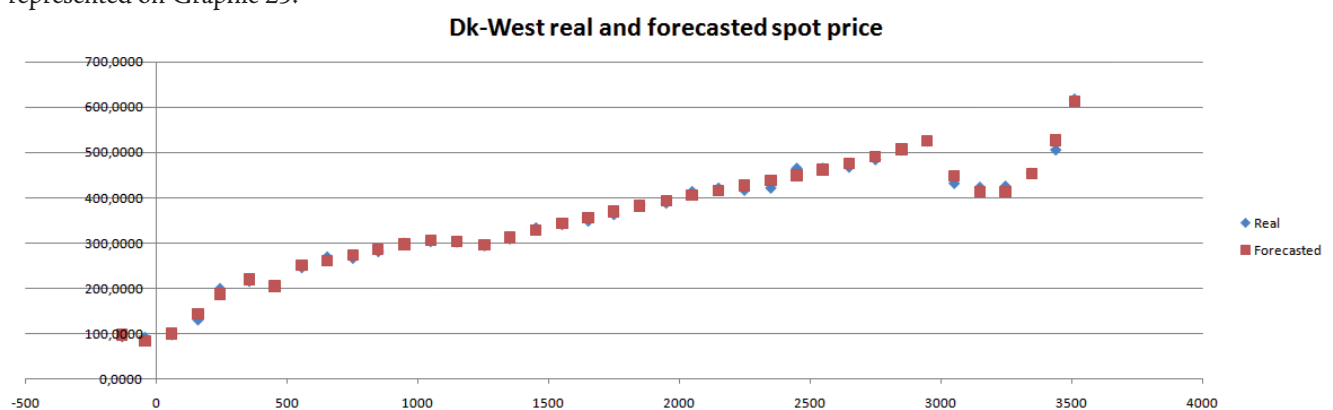
- Lower than 500MWh/h;
- Between 500 and 1250MWh/h;
- Between 1250 and 3000MWh/h;
- Higher than 3000MWh/h.

The results for each part, in the average values, are represented on Graphic 23.

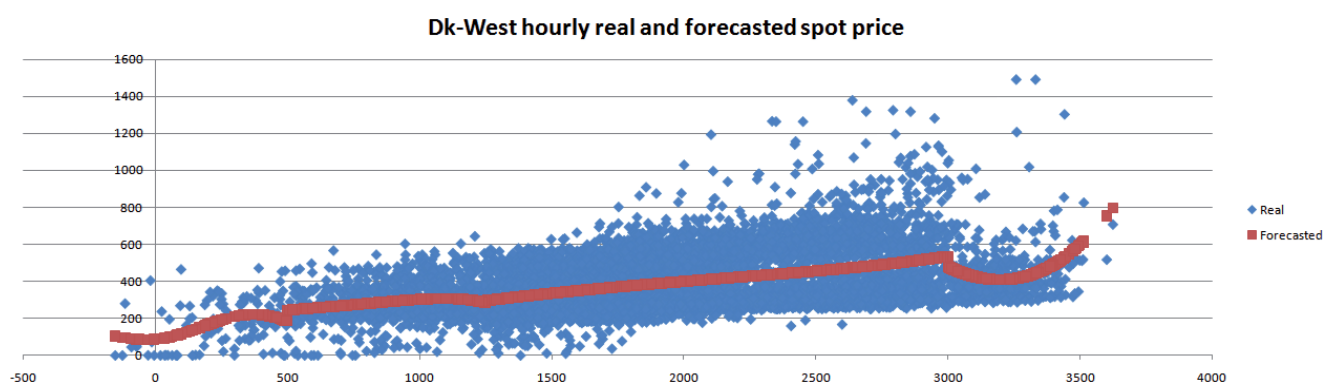
After applying this model to the hourly data, the results were:

Train	Test
RMSE	RMSE
142,4416994	119,3184447
MAE	MAE
115,51	105,51
MAPE	MAPE
52,85%	76,57%

Table 5 - Errors for the model applied to hourly values - Average model 2



Graphic 23 - Dk-West spot price and forecasted spot price - Average model 2



Graphic 24 - Dk-West hourly spot price and forecasted hourly spot price - Average model 2

As seen above the errors for these models were huge. The reason for this was that the model calculates the average values, even though the market price is very unstable with a high amplitude of values meaning that the average price is not a good approximation. For this reason, the model to represent the market price had to include more variables than just the wind power. The variables that might be important and influence the modeling of the spot market price are:

- Consumption;
- Wind Forecast;
- Consumption minus Wind forecast;
- Bottlenecks;
- Price of fuels;
- Day of the week;
- Weather;
- Capacity available on the hydro plants on Nordpool;
- Holidays.

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Models

The Regulating Market & Renewable Energies

Dk-West Spot Price

From all of these variables the Bottlenecks had to be taken away, because it is really hard to predict if there is going to be or not a bottleneck; Weather, because there was no available data for the weather in the last year, but, this variable is already included in the consumption forecast so there is not a need to consider it again; Hydro power capacity available, also because there is not data available of this variable to study; and Holidays because their influence is in the consumption so they should be already included in the demand forecast. All in all, the only variables available were:

- Consumption;
- Wind Forecast;
- Consumption minus Wind forecast;
- Price of fuels;
- Day of the week.

The variable time (year, month, day and hour) was added to the model to introduce a trend effect on it.

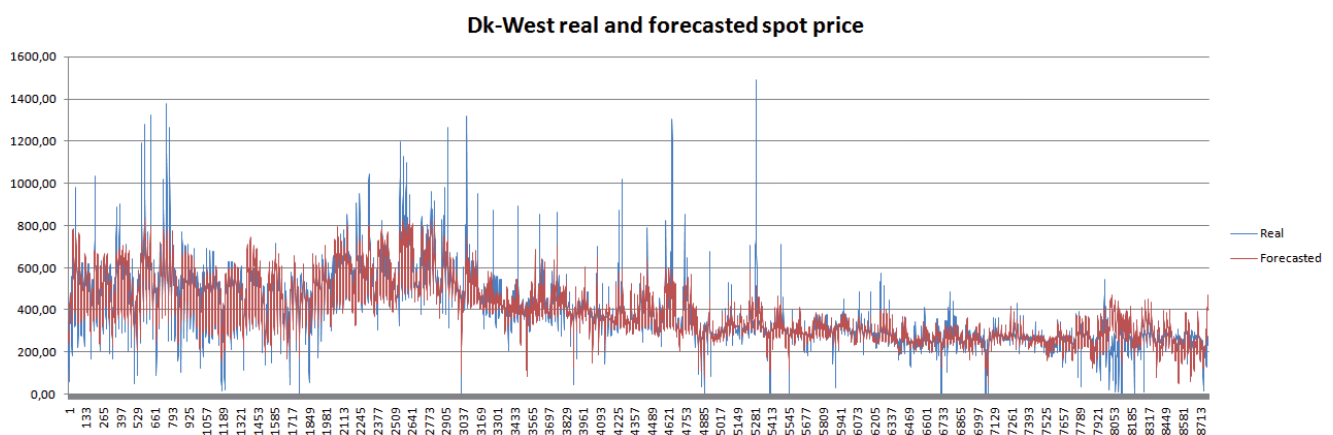
The first model created was a Neural Network using Matlab. The entries for the model were:

- Year;
- Month;
- Day;
- Hour;
- Weekday (numerical, 1 to Sunday, 2 to Monday, etc...);
- Wind Forecast;
- Consumption;
- Consumption - Wind Forecast.

In this model the price of fuels was not used because by this time there was no data for that yet. The results were:

Train	Test
RMSE	RMSE
59,89990089	84,00046107
MAE	MAE
36,2	59,7
MAPE	MAPE
24,59%	47,43%

Table 6 - Train and Test Errors - Matlab model for Dk-West Spot without fuel prices



Graphic 25 - Dk-west real and forecasted spot price - Matlab model for Dk-West Spot without fuel prices

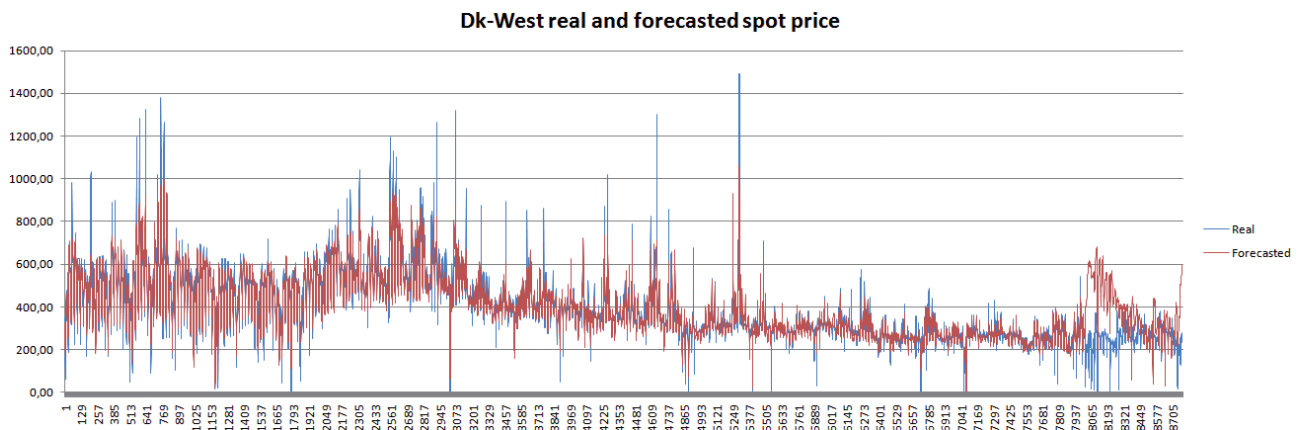
This model reduced almost 30% of the error from the average values model, but still had a high error on the Test group of data and most of all, it does not respond right in the transition from the Train group of data (from hour 1 till hour 7991) to the Test group of data (from hour 7992 till hour 8783).

When the data for the fuel costs was available, it was created a new Neural Network now with the fuel costs

included. The data for fuel prices found was only on a monthly basis. The results for this new model are shown bellow.

Train	Test
RMSE	RMSE
49,21650448	191,4824242
MAE	MAE
31,6	147,8
MAPE	MAPE
18,06%	102,05%

Table 7 - Train and Test Errors - Matlab model for Dk-West Spot with fuel prices



Graphic 26 - Dk-west real and forecasted spot price - Matlab model for Dk-West Spot with fuel prices

As one can see by the results' analysis of this two models, the introduction of the fuel prices yields worse results than without these values. This can be explained by the values used, which were monthly average values. If these values were on a daily basis, the results would most likely be better. Another thing that can be seen is that the Neural Networks has some problems at the beginning of the Test group of data.

After the Neural Networks, it was time to try a Regressive model. These models are usually used for long term forecastings because they are really best at describing trends. Some models were created using different variables and then the results were compared. Here is the model that had better results.

The variables used in this model were:

- Year;
- Month;
- Day;
- Hour;
- Wind Forecast;
- Consumption;
- Consumption - Wind Forecast.

The model expression was:

$$\text{Dk-West Spot} = \delta + \phi_1 \cdot \text{Year} + \phi_2 \cdot \text{Month} + \phi_3 \cdot \text{Day} + \phi_4 \cdot \text{Hour} + \phi_5 \cdot \text{Wind} + \phi_6 \cdot \text{Cons.} + \phi_7 \cdot (\text{Cons.} - \text{Wind})$$

Where:

Wind - Wind Forecast

Cons. - Consumption

(Cons. - Wind) - Consumption minus forecasted wind power

$\phi_1, \phi_2, \phi_3, \phi_4, \phi_5, \phi_6, \phi_7$ - model constants

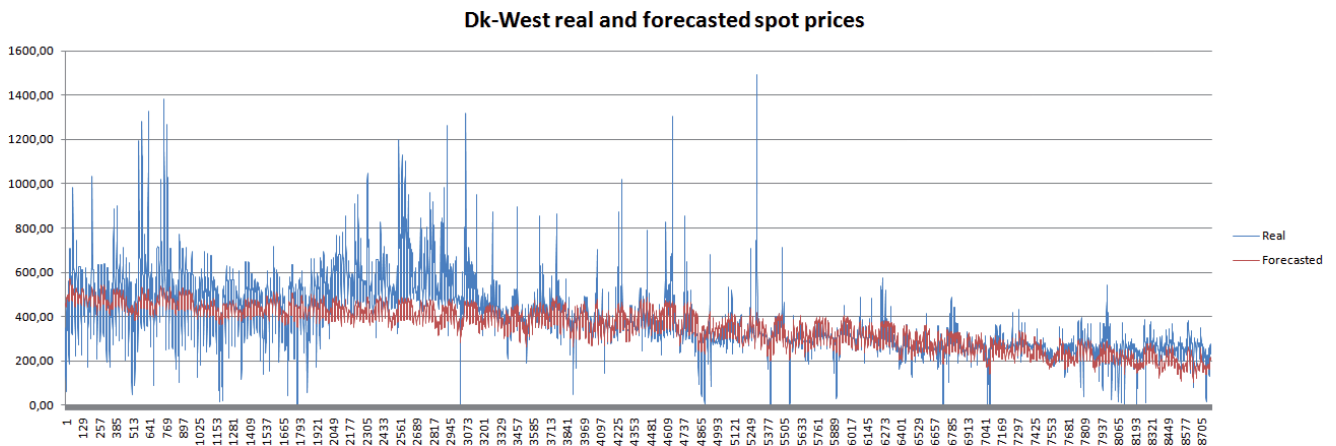
The way to calculate the regressive model parameters is the same as the one used in the model for average values. The results were:

δ	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6	ϕ_7
0,305693	-0,18481	-0,1526	-0,02464	0,010447	0,005451	0,033351	0,134428

Table 8 - Model Parameters - Regressive model for Dk-West Spot without fuel prices

Train	Test
RMSE	RMSE
109,4683985	66,91214833
MAE	MAE
70,4	59,3
MAPE	MAPE
48,59%	39,71%

Table 9 - Train and Test Errors - Regressive model for Dk-West Spot without fuel prices



Graphic 27 - Dk-west real and forecasted spot price - Regressive model for Dk-West Spot without fuel prices

In this case, the model, as predicted, represents very well the long term trend but is not able to forecast all the variations on the price yielding a big error on the Train group of data because it has more fluctuations of the price, while in the Test group of data, as it is more stable, it had better results than the Matlab model. One of the models also tried to include the fuel costs as a variable, but once again the results were worse with the fuel prices included than without them. That model's results are shown in the Appendix.

At this stage, there is a model that forecasts the fluctuations of the price well, but loses a little in long term trend and has some problems with the short term forecast, that corresponds to the first values of the Test group of data; and there is another model that reflects well the trend of the spot price but misses the fluctuations of the price.

The best models to short term forecasting are the autoregressive models so an autoregressive model was also studied. In order for this model to be done, the first thing to do was to analyze on SPSS if the variable Dk-West spot price had an auto-correlation, and if it did, in which degree.

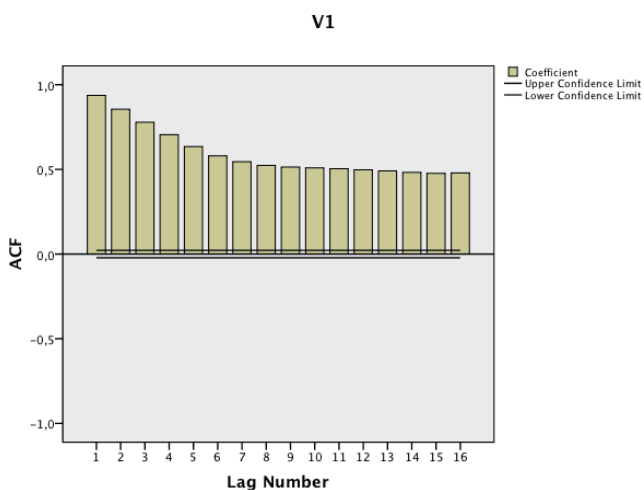


Figure 21 - Autocorrelation Graphic for Dk-West spot price

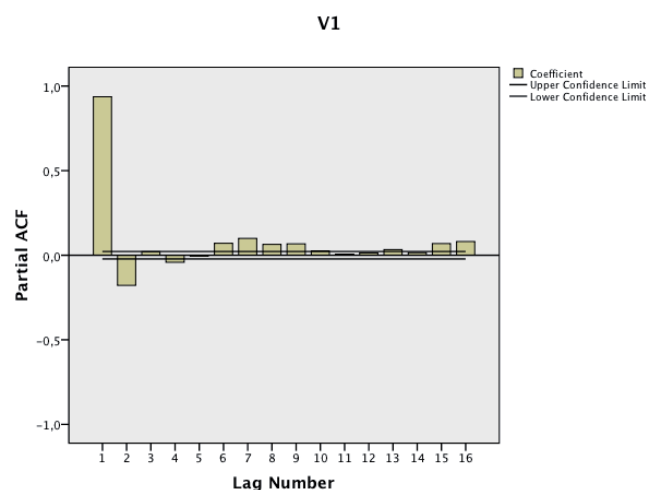


Figure 22 - Partial Autocorrelation Graphic for Dk-West spot price

Models

Dk-West Spot Price

Faculty of Engineering

Electrical Power Engineering Program

The ARIMA model for Dk-West spot price will be an ARIMA (1,0,0) model with seasonality of 24, defined by:

$$(1 - \phi_1 \cdot B^1) \cdot (1 - \phi_1 \cdot B^{24}) \cdot X_t = \delta$$

Which after developed stays like:

$$X_t = \delta + \phi_1 \cdot X_{t-1} + \phi_1 \cdot X_{t-24} - \phi_1 \cdot \phi_1 \cdot X_{t-25}$$

Where:

X_t - Value to calculate

X_{t-1} - Last Value of the variable to calculate

X_{t-24} - Value of the variable 24 times before the value to calculate

X_{t-25} - Value of the variable 25 times before the value to calculate

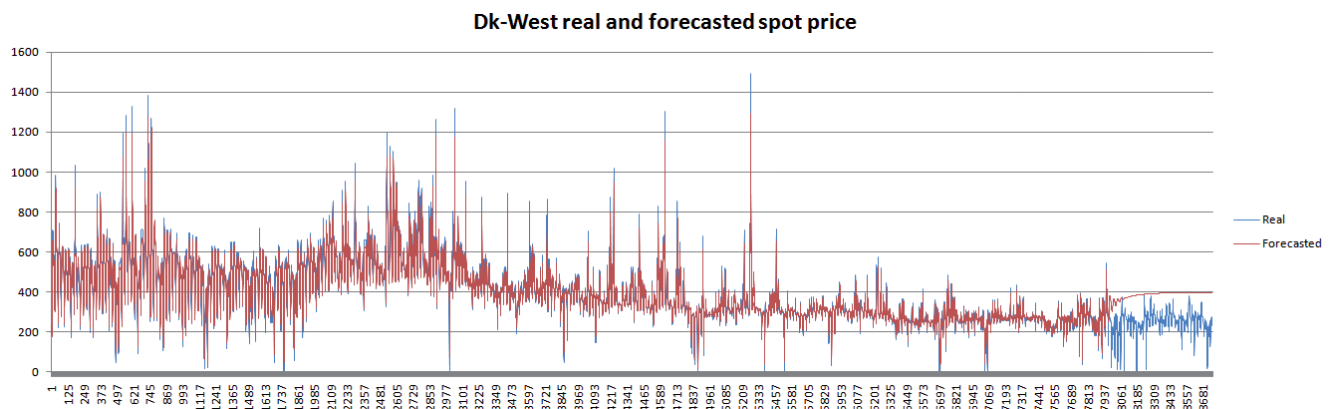
The procedure is again using solver and minimizing the RMSE.

δ	ϕ_1	ϕ_2
14,5145	0,828815	0,073686

Table 10 - Model Parameters - Dk-West Spot ARIMA (1,0,0) model

Train	Test
RMSE	RMSE
53,93790144	154,575628
MAE	MAE
29,6	142,9
MAPE	MAPE
19,17%	104,02%

Table 11 - Train and Test Errors - Dk-West Spot ARIMA (1,0,0) model



Graphic 28 - Dk-west real and forecasted spot price - Dk-West Spot ARIMA (1,0,0) model

This model was by far the worst, even though it behaves well until the test zone where its values, instead of depending on the past spot prices, start depending on the past forecasted values for Dk-West. The model was also tested without the seasonality and the results were essentially the same, a little bit more on the MAPE error but almost the same. Although the SPSS acf and pacf showed a good auto-correlation, as seen in Figures 21 and 22 respectively, the auto-regressive model cannot be used with this variable because it was not able to return a decent result.

The last thing to do is to mix the best Neural Network model with the best regressive model in order to obtain the best of both models, the good forecast of the price fluctuations by the neural network and the long term forecast trend from the Regressive model. In theory the

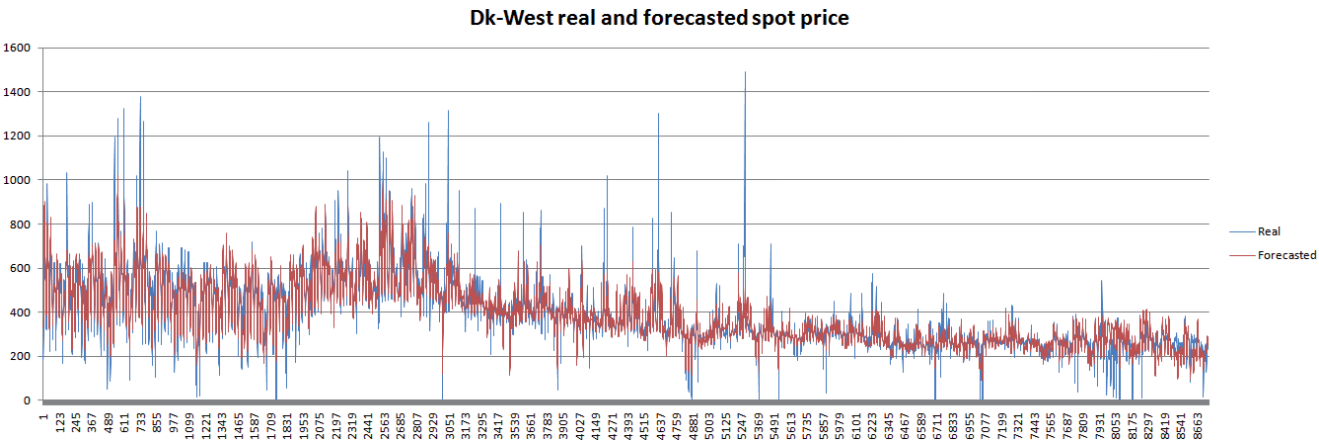
autoregressive model would produce a good short term forecast so it would be used also on this mix of models to suppress the errors on the beginning of the test data seen in the neural network model.

All in all, the last model will be a new Neural Network that has as entries the results from the best of the first neural networks, the one without the fuel prices, and the results from the regressive model presented above.

So, the entries for the model are:

- Dk-West forecast from first Matlab model
- Dk-West forecast from Regressive model

The results were:



Graphic 29 - Dk-west real and forecasted spot price - Dk-West spot final model

Train	Test
RMSE	RMSE
58,91637731	60,97466214
MAE	MAE
35,8	45,0
MAPE	MAPE
28,70%	39,90%

Table 12 - Train and Test Errors - Dk-West final model

After all this manipulation of data and all the models created and tested, the best result achieved was this last model. For the Test group of data the MAPE is solely higher than on the just regressive model because of the errors on the short term forecasting provoked by the first neural network model, errors that the autoregressive would suppress, but the Train part has almost half the error than the regressive model and in general lines, this

last model behavior is more similar to the real behavior than the regressive model. Unfortunately, the best results were a MAPE of 28,70% and 39,90%, for Train and Test respectively. This is explained by the lack of more precise data that was not found, or available, and to the high difficulty of forecasting such an unstable variable.

All in all, the Dk-West spot price is very hard to model because of its instability and the big amplitude of values it has. The Wind Power affects its price but to be studied it has to be transformed to avoid the influence of the demand variations or both variables have to be included in the model so the model can do its own transformation. This way it can be studied like a new variable of demand.

3.3. Dk-West Regulating Price

The model for the Regulating Market was the main objective of this study. This part of the study is trying to characterize the regulating market, trying to understand what is really important to its price and what is not. Energinet.dk supplied the values for the forecasted wind power which, when subtracted to the real values of wind power produced, available on Energinet.dk's web page, would give the imbalances of the forecasts for wind power. These imbalances between the forecasted values and the real values can be used in the model for regulating market price. Similar to the Wind imbalances, there are some other variables that influence the Dk-West regulating price and this is what is represented in Figure 23.

This scheme is the same for both up- and down-regulation, the only difference being the supply curve. There are more variables that affect the spot price as seen in its modeling, but if Dk-West spot price is included, then it already includes those variables, and the bottlenecks include bottlenecks to Norway, Sweden and Germany. Unfortunately, there are no data or information for "Forced Outages" or for "Consumption Imbalances". The Spot price's importance cannot be understated because the regulating curves for up- and down-regulate are directly correlated

to this price, because they start at the spot price. The need for regulating power depends on Forced Outages, Wind Imbalances and Consumption Imbalances, and from these three only the values for Wind Imbalances are available. The bottlenecks can be studied by their history divided by interconnection. And the last variable is the supply curve that will be different for up- and down-regulation and that corresponds to the NOIS list. This, of course, varies with the plants available for regulation so it depends on the consumption minus wind forecast variable. The Bottlenecks had to be taken away because it is incredibly hard to forecast them. The Fuel prices were also taken away because, as it had happened in the Dk-West spot modeling, the fuel prices were not helping the model for being monthly values. SPSS was once again used, this time to check the cross-correlations between the Regulating Price and for the last four variables available: Dk-West spot; Wind Imbalances; Need for Regulating Power; and, Consumption minus demand. The data was divided in two separate analysis, one for up-regulate and one for down-regulate. For each, the SPSS graphics were computed using the entire data, 8760 hours, and using only the hours where there was a need of the regulation studied, to see if it would make any difference in the correlation between variables.

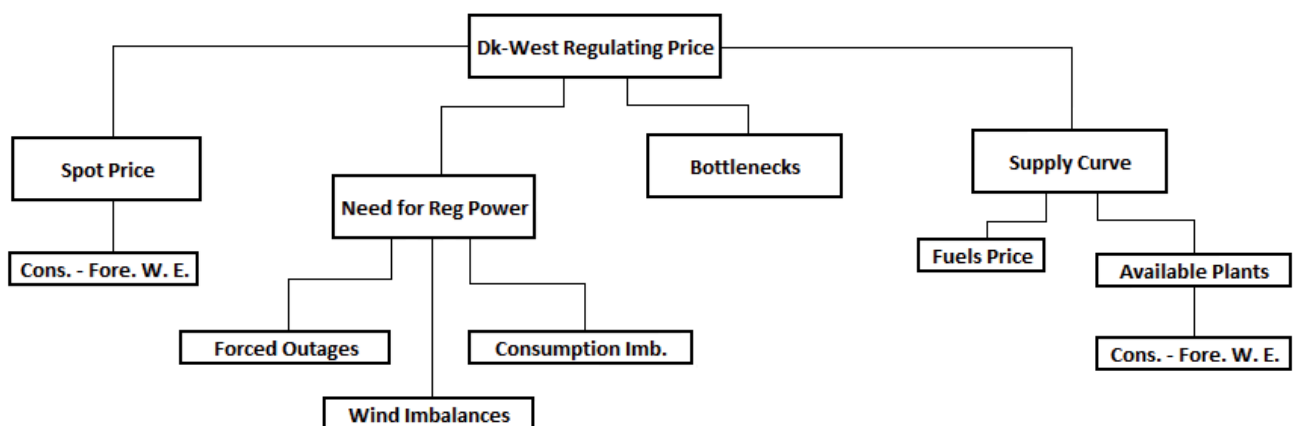


Figure 23 - Regulating Market scheme for variables

3.3.1. Down Regulation

DK-West: Price for balancing power – down regulation with DK-West

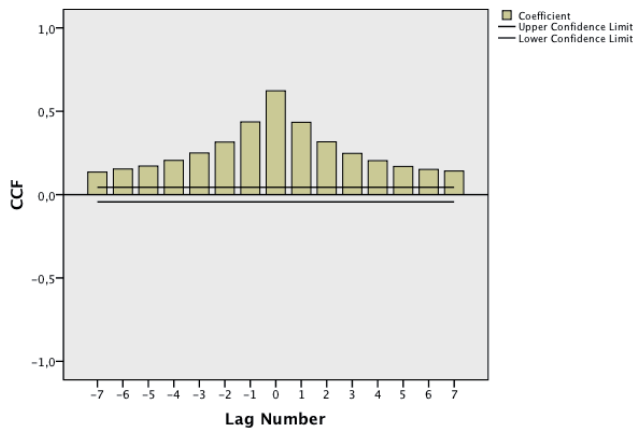


Figure 24 - Cross-correlation between Price for Down Regulate and Dk-West Spot Price - Full Data

DK-West: Price for balancing power – down regulation with DK-West

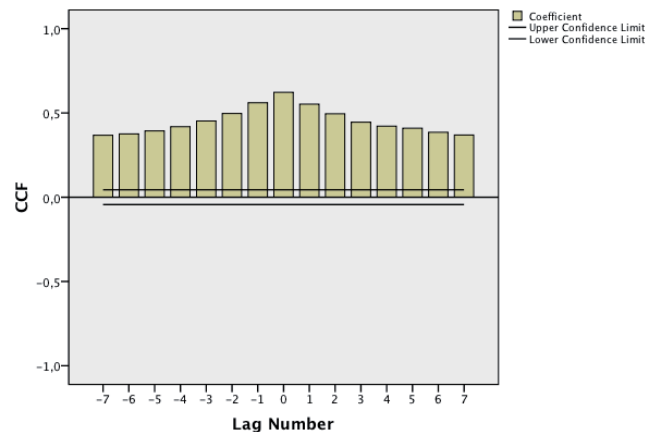


Figure 25 - Cross-correlation between Price for Down Regulate and Dk-West Spot Price - Limited Data

DK-West: Price for balancing power – down regulation with DK-West
Wind Imbalances

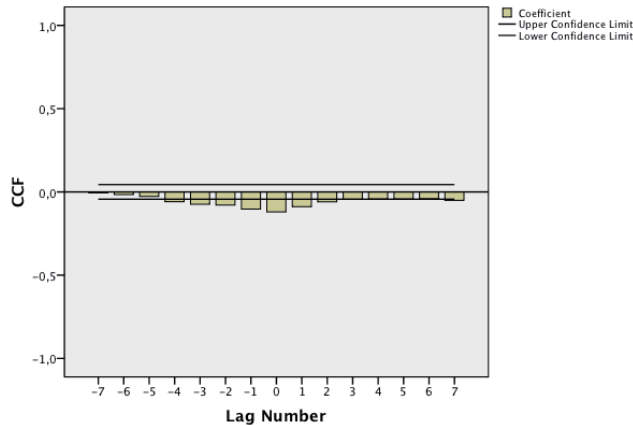


Figure 26 - Cross-correlation between Price for Down Regulate and Wind Imbalances - Full Data

DK-West: Price for balancing power – down regulation with DK-West
Wind Imbalances

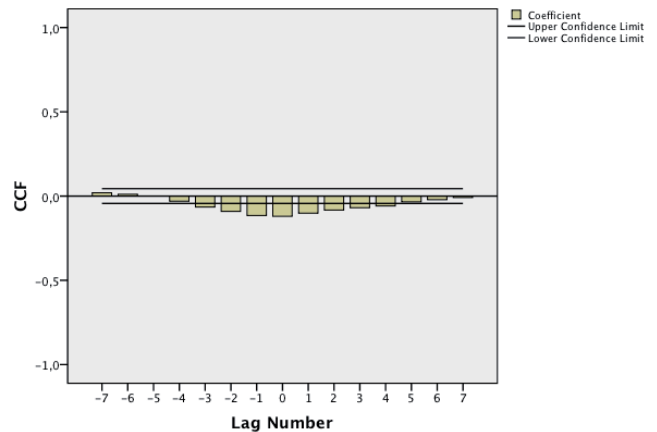


Figure 27 - Cross-correlation between Price for Down Regulate and Wind Imbalances - Limited Data

The first variable studied was the Down-regulation. For Figure 24 and 25, in the full data analysis there is a strong correlation between the present values but not so strong with the last and next values. In the limited data, the strong correlation between present values stills there but the correlations with the last and next values have grown a little. The reason for this is because on the limited data used, only the data where there was a need for Down-regulate was selected and in the full data the hours that didn not need any regulation, or at least not down-regulation, were also included. Other than this, they are very similae and they

both show a good correlation between the two variables.

The Figures 26 and 27 are the cross-correlation graphics between Down Regulation price and Wind Imbalances, but there is not a high correlation. By looking at the graphics, one would normally not use this variable, but since this report is about the Wind Power impact on the market, its imbalances will also be included, so, studies with and without this variable will be conducted and then the results compared.

DK-West: Price for balancing power – down regulation with DK-West:
Consumption – Wind Power

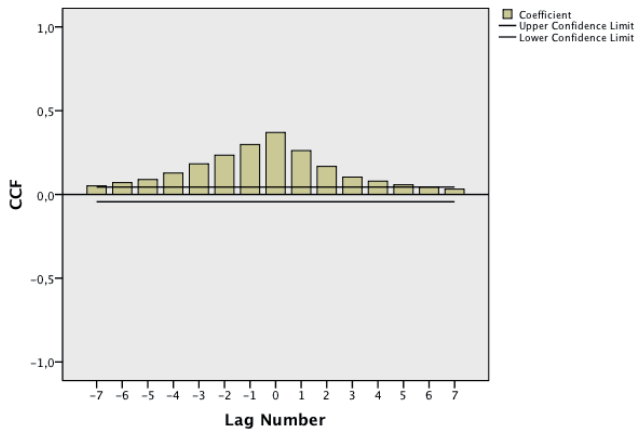


Figure 28 - Cross-correlation between Price for Down Regulate and Consumption minus Wind Power - Full Data

DK-West: Price for balancing power – down regulation with DK-West:
Consumption – Wind Power

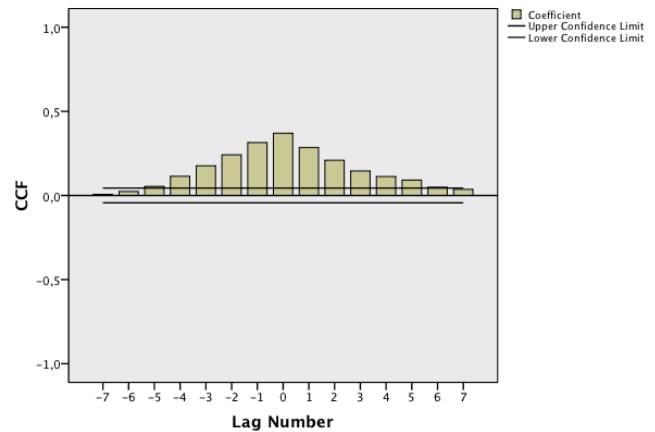


Figure 29 - Cross-correlation between Price for Down Regulate and Consumption minus Wind Power - Limited Data

DK-West: Price for balancing power – down regulation with DK-West:
Regulating power – downward regulation, MWh/h

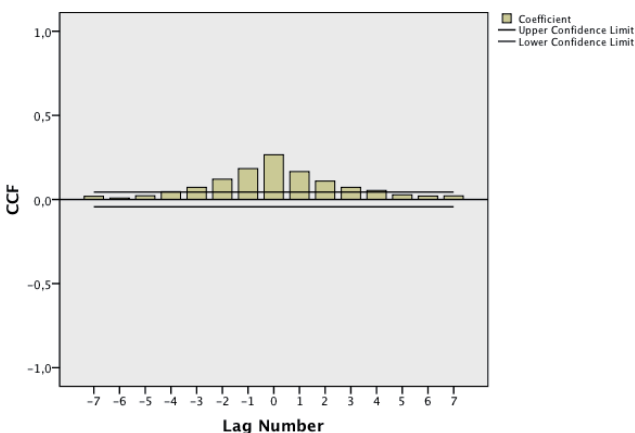


Figure 30 - Cross-correlation between Price for Down Regulate and the need for down regulation - Full Data

DK-West: Price for balancing power – down regulation with DK-West:
Regulating power – downward regulation, MWh/h

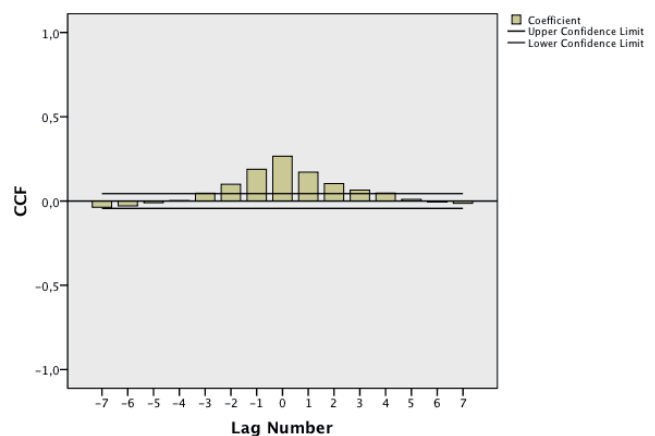


Figure 31 - Cross-correlation between Price for Down Regulate and the need for down regulation - Limited Data

The results for the consumption minus wind power are reasonable and they show a good correlation so this variable will be included in the model.

There is a reasonably high correlation of the price for down regulation with the need for down regulation. This variable corresponds to the demand so a correlation with the price was expected, because the supply depends on the demand.

Once the graphics with all the data or with the limited data are similar, all the data will be used.

For modeling the regulating price for down regulation a Regressive model was used where the entries were the four variables described above, plus the date:

- Year;
- Month;
- Day;
- Hour;

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Dk-West Regulating Price

Down Regulation

- Dk-West spot price;
- Wind Imbalances;
- Consumption minus wind power;
- Need for down regulating energy (DR demand).

The model expression was:

$$\text{Dk-West RM DR} = \delta + \phi_1 \cdot \text{Year} + \phi_2 \cdot \text{Month} + \phi_3 \cdot \text{Day} + \phi_4 \cdot \text{Hour} + \phi_5 \cdot \text{Dk-West spot} + \phi_6 \cdot \text{Wind Imb.} + \phi_7 \cdot (\text{Cons.} - \text{Wind}) + \phi_8 \cdot \text{DR Demand}$$

Where:

Dk-West RM DR - Dk-West Regulating Market price for Down Regulation

Dk-West spot - Dk-West spot price

Wind Imb. - Wind Imbalances

(Cons. - Wind) - Consumption minus forecasted wind

power

DR Demand - Down Regulation Demand

$\phi_1, \phi_2, \phi_3, \phi_4, \phi_5, \phi_6, \phi_7, \phi_8$ - model constants

The results were:

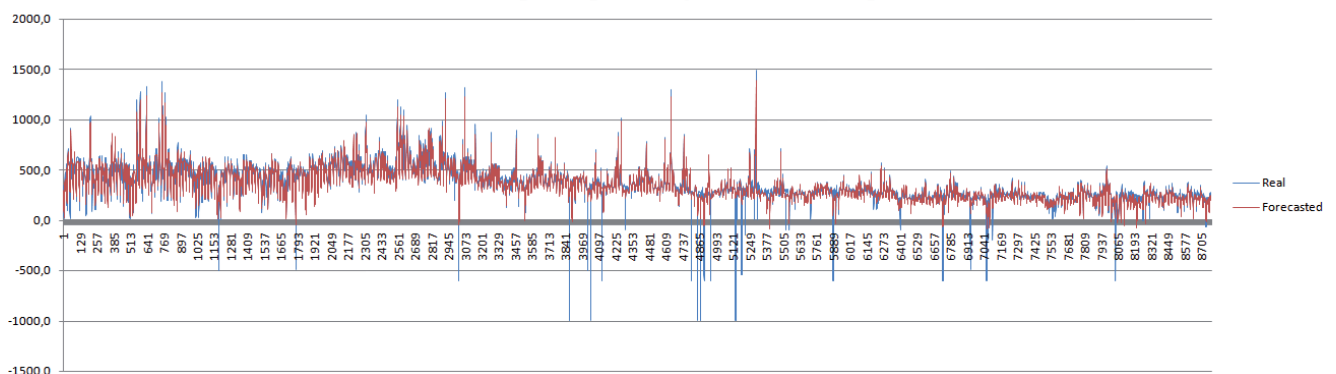
δ	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6	ϕ_7	ϕ_8
0,417992	-0,01165	-0,00445	0,003188	0,009503	0,537327	-0,11285	0,000185	0,036935

Table 13 - Model Parameters - Dk-West Down Regulation price - full data

Train	Test
RMSE	RMSE
85,29468899	52,23643773
MAE	MAE
43,6	37,1
MAPE	MAPE
27,99%	39,32%

Table 14 - Train and Test Errors - Dk-West Down Regulation price - full data

Results for Regulating Market price for Down Regulation



Graphic 30 - Dk-West real and forecasted Down Regulate price - full data

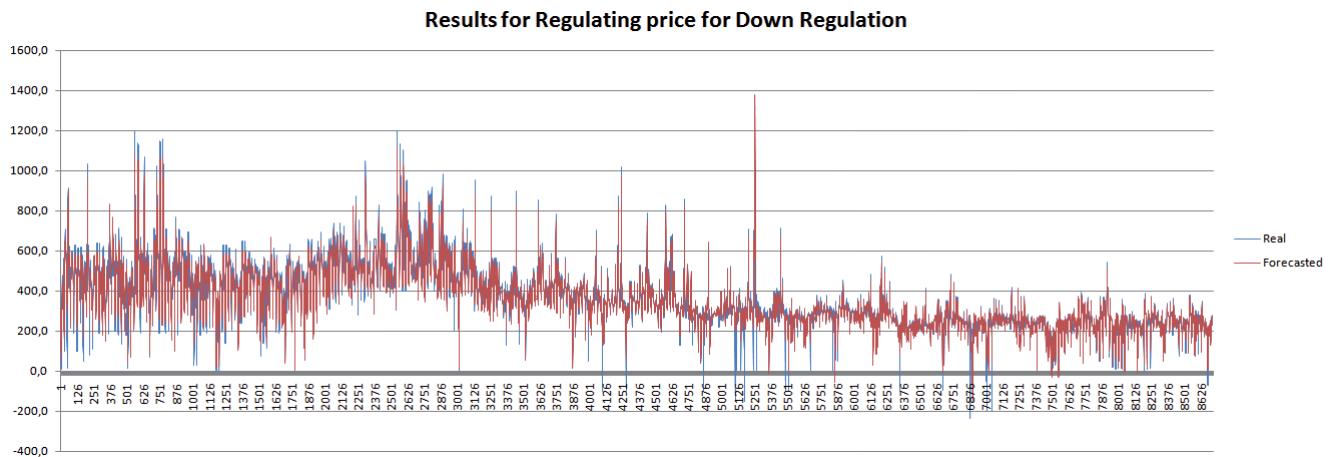
The results for this model were not as good as they could have been because of the presence of some outliers. The outliers are values that do not represent the normal functioning of the variable and influence the model towards the skewed values. For this reason, values that were lower than negative four hundred or higher than twelve hundred were taken out of the data and the model was simulated again. These 63 out of the 8783 values represent only 0,72% of the total amount values, and as mentioned, they do not represent the normal functioning of the variable so they can be taken away without harming the model veracity. The results are shown below:

δ	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6	ϕ_7	ϕ_8
-0,10875	0,005587	0,017132	-0,00071	0,011361	0,948504	-0,07394	0,281072	0,01561

Table 15 - Model Parameters - Dk-West Down Regulation price - w/o outliers

Train	Test
RMSE	RMSE
50,55727296	28,37038906
MAE	MAE
31,3	18,2
MAPE	MAPE
21,86%	22,65%

Table 16 - Train and Test Errors - Dk-West Down Regulation price - w/o outliers



Graphic 31 - Dk-West real and forecasted Down Regulate price - w/o outliers

The decision of not including the outliers reduces the MAPE error in almost 50%, from 39,32% to 22,65%. This is still a big error but, by looking at Graphic 31, the model has a good approximation of the real values and the trend of the variable modeled is very well represented in the forecasted values.

Now the model is the same but without the Wind Imbalances variable once the SPSS results were that there was almost no correlation between this variable and the Dk-West regulating price for Down Regulate. The model expression is the same just without the Wind imbalances.

$$\text{Dk-West RM DR} = \delta + \phi_1 \cdot \text{Year} + \phi_2 \cdot \text{Month} + \phi_3 \cdot \text{Day} + \phi_4 \cdot \text{Hour} + \phi_5 \cdot \text{Dk-West spot} + \phi_6 \cdot (\text{Cons.} - \text{Wind}) + \phi_7 \cdot \text{DR Demand}$$

Where:

Dk-West RM DR - Dk-West Regulating Market price for Down Regulation

Dk-West spot - Dk-West spot price

(Cons. - Wind) - Consumption minus forecasted wind power

DR Demand - Down Regulation Demand

$\phi_1, \phi_2, \phi_3, \phi_4, \phi_5, \phi_6, \phi_7$ - model constants

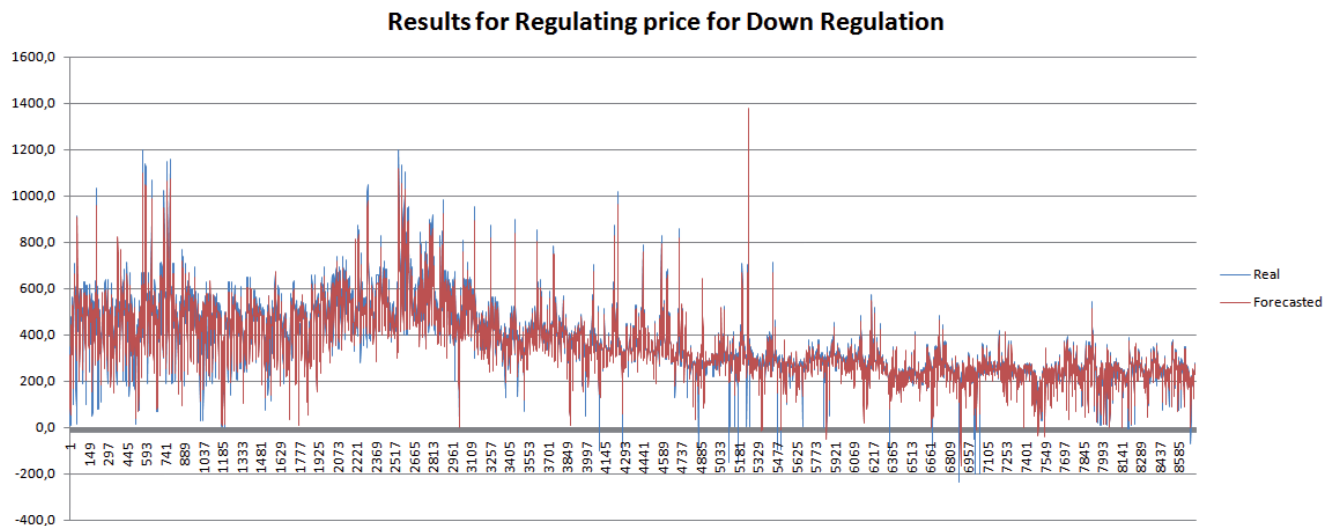
The results were:

δ	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6
0,148541	-0,00997	0,006768	-0,00051	0,012089	0,918021	0,038738

Table 17 - Model Parameters - Dk-West Down Regulation price - w/o outliers and w/o Wind Imbalances

Train	Test
RMSE	RMSE
50,96144734	28,37594865
MAE	MAE
32,0	17,3
MAPE	MAPE
22,74%	22,41%

Table 18 - Train and Test Errors - Dk-West Down Regulation price - w/o outliers and w/o Wind Imbalances



Graphic 32 - Dk-West real and forecasted Down Regulate price - w/o outliers and w/o Wind Imbalances

After analyzing these new results, the similarity between the models can be seen in their graphics of results, which means that the variable Wind Imbalances has a really small correlation, and proves what was already seen in the SPSS Figures 26 and 27. The small correlation it has with the price is due to a reasonable correlation with the variable “Need for Regulating Power, Down Regulation”, however, even with this variable the correlation is not as strong as it is visible in the SPSS Figure 32.

DK-West: Regulating power – downward regulation, MWh/h with DK-West: Wind Imbalances

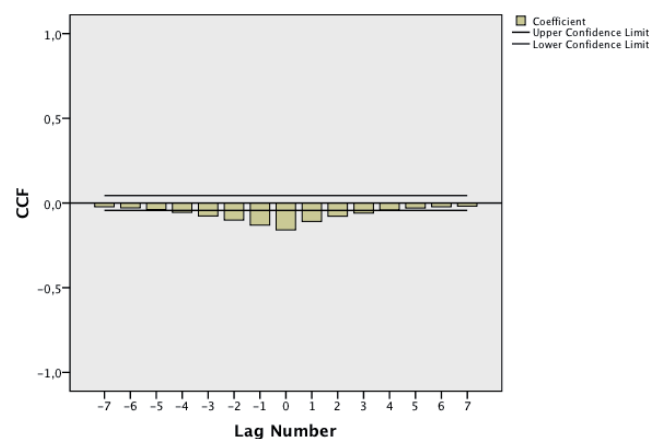


Figure 32 - Cross-correlation between Need for Down Regulate and Wind Imbalances - Full Data

3.3.2. Up Regulation

DK-Vest: Price for balancing power – up regulation with DK-West

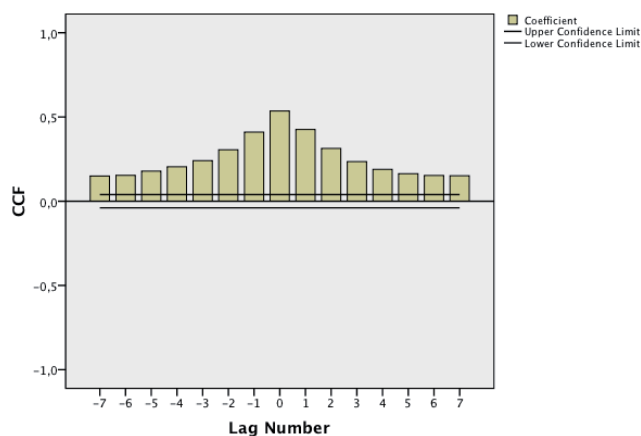


Figure 33 - Cross-correlation between Price for Up-Regulate and Dk-West Spot Price - Full Data

DK-Vest: Price for balancing power – up regulation with DK-West

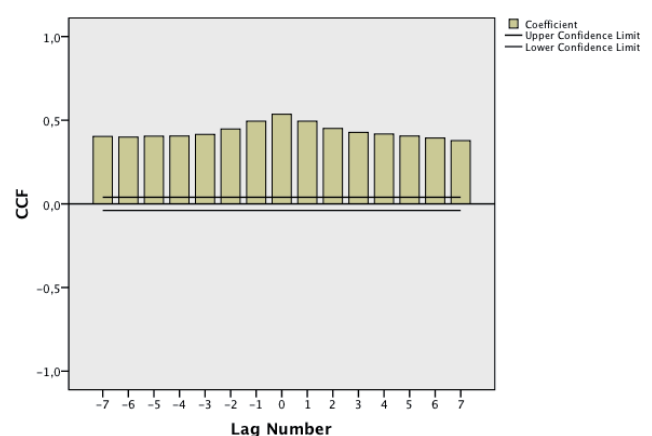


Figure 34 - Cross-correlation between Price for Up-Regulate and Dk-West Spot Price - Limited Data

DK-Vest: Price for balancing power – up regulation with DK-West: Wind Imbalances

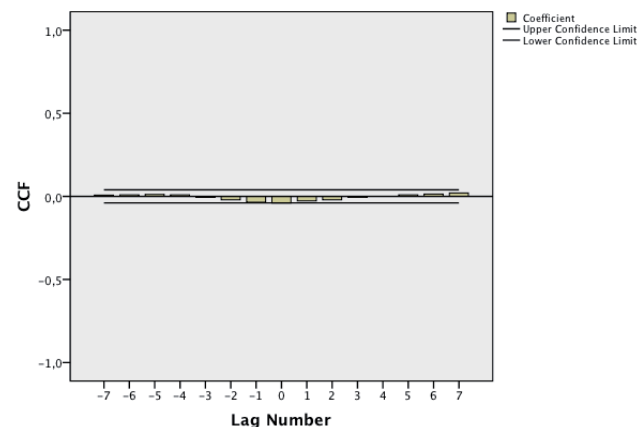


Figure 35 - Cross-correlation between Price for Up-Regulate and Wind Imbalances - Full Data

DK-Vest: Price for balancing power – up regulation with DK-West: Wind Imbalances

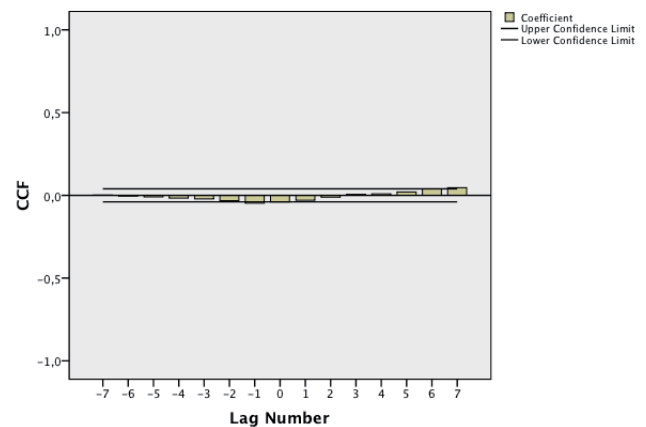


Figure 36 - Cross-correlation between Price for Up-Regulate and Wind Imbalances - Limited Data

As mentioned in the beginning of the regulating prices study, the variables that influence the prices for up-regulation are the same that influence the prices for down-regulation so the study turned to the SPSS graphics that explain the correlations between the price for up-regulation and the other variables. As well as for down-regulation, the correlations were done for the full data and for only the hours where there was a need for up-regulation.

From these two variables's analysis, the results were similar to the down-regulate results, as expected. The only difference is that the correlation between the price and the Wind Imbalances is even lower in this case, (Figures 35 and 36). Therefore it can be concluded that the wind power forecast usually returns values lower than the real values so its imbalances are usually positive and not negative. The prices for Up-regulation depend on the need for this

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Dk-West Regulating Price

Up Regulation

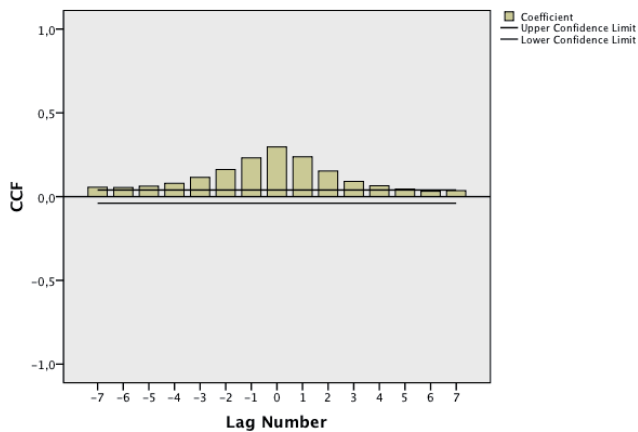
DK-Vest: Price for balancing power – up regulation with DK-West:
Consumption – Wind Power

Figure 37 - Cross-correlation between Price for Up-Regulate and Consumption - Wind Energy - Full Data

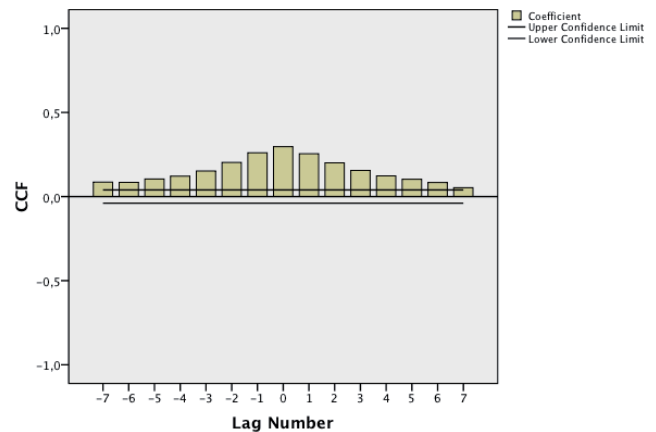
DK-Vest: Price for balancing power – up regulation with DK-West:
Consumption – Wind Power

Figure 38 - Cross-correlation between Price for Up-Regulate and Consumption - Wind Power - Limited Data

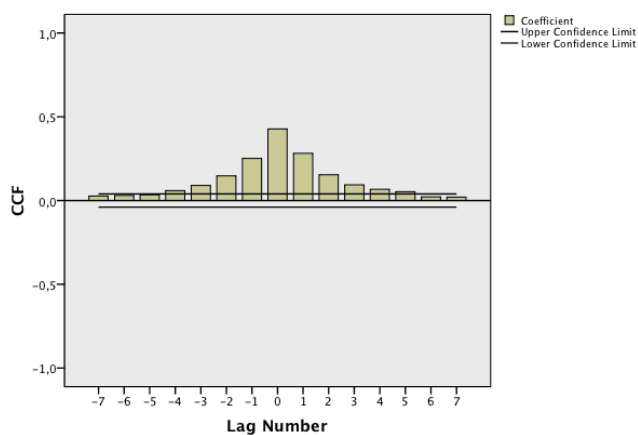
DK-Vest: Price for balancing power – up regulation with DK-West:
Regulating power – upward regulation, MWh/h

Figure 39 - Cross-correlation between Price for Up-Regulate and Need for Up-Regulation - Full Data

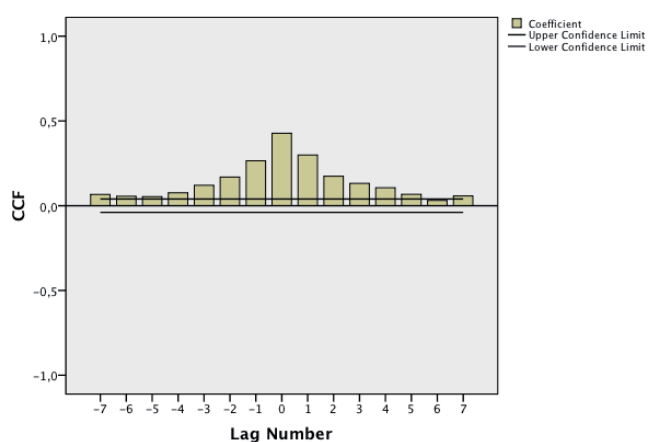
DK-Vest: Price for balancing power – up regulation with DK-West:
Regulating power – upward regulation, MWh/h

Figure 40 - Cross-correlation between Price for Up-Regulate and Need for Up-Regulation - Limited Data

regulation and this need depends on the wind imbalances. The negative imbalances will increase the need for up-regulating power and the positive imbalances will decrease it.

For the consumption minus forecasted wind power and the need for up-regulation the results were the same as in the down-regulation studies. As the correlations are, as expected, all similar to the down regulation, the studies done for the up-regulation prices were exactly the same as

the ones done for the down-regulation prices. Here are only shown the results of the last study and the rest can be seen in the appendix. For the Up-Regulating model the outliers were the values with prices above 2000DKK/MWh/h, which corresponded to 43 of the 8783 hours (0,49%). These values appeared, most likely, because of problems in the transmission lines during or after the upgrading of the interconnections with other countries, hence creating bottlenecks at low capacity.

Models

Dk-West Regulating Price

Faculty of Engineering

Up Regulation

Electrical Power Engineering Program

The model expression was:

Dk-West RM UR = $\delta + \phi_1 \cdot \text{Year} + \phi_2 \cdot \text{Month} + \phi_3 \cdot \text{Day} + \phi_4 \cdot \text{Hour} + \phi_5 \cdot \text{Dk-West spot} + \phi_6 \cdot (\text{Cons.} - \text{Wind}) + \phi_7 \cdot \text{UR Demand}$

Where:

Dk-West RM DR - Dk-West Regulating Market price for Down Regulation

Dk-West spot - Dk-West spot price

(Cons. - Wind) - Consumption minus forecasted wind power

DR Demand - Down Regulation Demand

$\phi_1, \phi_2, \phi_3, \phi_4, \phi_5, \phi_6, \phi_7$ - model constants

And the results were:

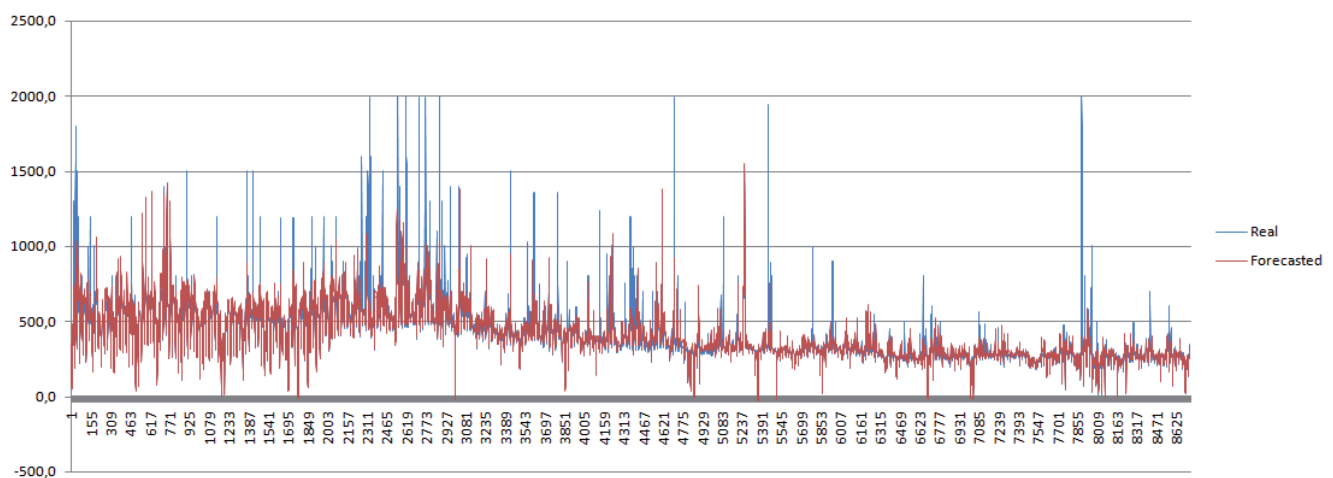
δ	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6	ϕ_7
-0,02659	0,010213	0,021158	-0,00081	-0,00015	0,760507	0,222321	0,033737

Table 19 - Model Parameters - Dk-West Up Regulation price - w/o outliers and w/o Wind Imbalances

Train	Test
RMSE	RMSE
99,6175964	38,71941154
MAE	MAE
37,4	22,7
MAPE	MAPE
9,95%	8,98%

Table 20 - Train and Test Errors - Dk-West Up Regulation price - w/o outliers and w/o Wind Imbalances

Results for Regulating price fo Up Regulation



Graphic 33 - Dk-West real and forecasted Up Regulate price - w/o outliers and w/o Wind Imbalances

Similarly to the model for Down Regulation the model yields better results in the Test group of data without using the variable Wind Imbalances proving, once again, that these imbalances do not affect the price of the Regulating Market either for up- or down-regulate.

By modeling the Regulating Market this study concluded that the Wind Imbalances do not affect this market. In fact, one expected a correlation between these two variables, but the market models return better results without the

wind imbalances variable included then with it included. In theory, this variable should affect the regulating price through the need for regulating power, but the correlation graphics show that in the real values available - from the last year - the need for the regulating power is correlated with this imbalances, but this correlation is not strong, explaining that this correlation dilutes with the rest of the other variables when calculating the Regulating Market prices. On the other hand, the imbalances on consumption forecasts and the forced outages counter-balance the wind

imbalances, which also helps to reduce the impact of the wind imbalances on the regulating price.

Even though the models show that the wind imbalances do not affect the price for regulating power, a small study was done regarding the impact of dealing the wind power imbalances in the Elbas, reducing this way the imbalances in the regulating market. For this, the model used was a persistence model for the wind forecast. This model consists in the wind power companies assuming that the wind power produced in a certain hour of operation would be equal to the energy produced two hours before. This way they still have one hour of the Elbas market to deal the differences between the wind forecast done for the spot market and the wind produced two hours before the hour of operation, avoiding thus higher imbalances in the regulating market. This strategy, if adopted by the wind power companies, would reduce the need for regulating power in approximately 60%. The imbalances that had the same direction as the need for regulation were taken into account and used as negative need because they help to avoid more regulation. The calculations for the reduction of the imbalances by using the persistency model and the reduction of need for regulating power will be included in the appendix.

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Conclusions

4. Conclusions

The objective of this report was to study the influence of the Wind Power on the Electricity markets, especially the Regulating Market. One important thing to mention about this study is that it uses the Forecasted Wind Power and also the Real Wind Power. The Forecasted Wind Power will be used on the studies for the day-a-head market and the imbalances between the forecasted and real values will be used for the real-time market. There were two major points studied:

- The influence of the wind power forecasts in the price for the spot market, day-a-head market;
 - The influence of the wind power forecasts imbalances, differences between real and forecasted values, in the Regulating Market, real time market for system regulation.
-

Theoretical conclusions:

The first part of this report was to describe the entire system and its functioning and then to analyze the role of the wind power forecasts in the system, which already gives some conclusions of what should, in theory, happen.

The first conclusion drawn from this theoretical analysis was that the price for regulation is highly correlated to the day-a-head market price and that this correlation is not affected by the wind power on the system.

Secondly, that the Wind Power, as it is put on the market at a cost of 0DKK/MWh/h, can be seen as a negative demand when calculating the Spot Market price. This means that

Conclusions

the market price will be exactly the same if it is calculated including the wind power zero cost bids in the supply curve, and not considering this energy as negative demand, so, using the total demand, or if it is calculated excluding the wind power from the supply curve, and subtracting its value to the total demand.

Finally, that in theory, the price for regulation on Dk-West had to be correlated with wind power imbalances. This is explained because the Regulating price depends on the demand needed for regulation and this demand depends on the wind imbalances. Of course the wind imbalances are not the only cause for the need for regulating energy, but as part of it, it would be expected that this imbalances were correlated with the regulating price. This theory was proven to be wrong in the practical part of this report.

Practical conclusions:

After the theoretical part of the report, comes the part where all the data available was studied and modeled. Some of these studies prove what was expected in theory but others did not.

The first studies concluded were about the forecasted wind power and the day-a-head market. The objective of these studies was to test how the wind power affects the price of the market and one concluded that there is a good correlation between these two variables.

Similarly to what was concluded in the theoretical part of this study, the analysis of the data proved that with the transformation of the demand from total demand to the total consumption minus forecasted wind power, the graphic that correlates the spot price with this new demand yielded better results explaining this price than the graphic with the total demand.

As for the studies regarding the spot price, it was shown that the inclusion of the wind power in the spot price models is indispensable to have good results in its forecast.

The studies for the regulating market initially showed that it is the same to study this variable with all the data,

including all the hours where there was not any need for regulation, implying that this price will be the same as the spot market, or to do it only for the hours where there was a need for regulation.

As the data used for the studies was the full data and not only data where there was need for regulation, and as the regulating price for an hour without regulation is the same as the spot price, a big share of the values used had the regulating price equal to spot price, which could provoke that the model would give all the importance to this price and none to the other variables.

To prove that this did not happen with the models created, the studies were compared with the solution assuming that the regulating price would always be the same as the spot market, and the results achieved were better with the other models created.

In the end, the studies concluded that the wind imbalances are not important to the regulating price with the models that exclude these imbalances, giving even better results than the models which included the imbalances. This result is unlike the theory had predicted, which says that there should be a correlation between the imbalances and the price for regulation. However, this lack of correlation is understandable after a deep analysis of the wind imbalances. The last study was created to explain both this issue and the fact that the wind imbalances can be reduced if dealt during the Elbas. In this study the imbalances were analyzed to see when they had, or not, the same sign as the need for regulating market. In the end, the conclusion was that the imbalances, in the period tested, from 1st June 2008 until 1st June 2009, increased the need for regulating power in 592534MWh and decreased this need in 545522MWh, which means that the final yearly result was merely 47032MWh of prejudicial imbalances when the total need for regulation was 214010MWh. Also the distribution of the imbalances for helping or not the system is 41,23% and 58,77%. This means that the imbalances in the consumption and the forced outages also have a big share of responsibility in the need for regulating power and that most of the times the wind imbalances are compensated by the consumption imbalances, or vice-versa.

The other part of this study proved that, if the wind forecast was corrected on the Elbas using a persistency

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Conclusions

model two hours before the hour of operation, the final yearly result for prejudicial imbalances would be of 18582MWh which is a reduction of 60,49% to the value using the spot forecasts for wind power.

In the future, the wind power production will increase, and the analysis of how this will affect the prices has to be divided in 3 situations:

- Bottlenecks importing;
- No Bottlenecks on the system;
- Bottlenecks exporting.

If one assumes that the need for regulation stays constant regardless of the increase in the wind power:

If the increase in the wind power is low and there are still some bottlenecks importing energy, then both spot and regulating prices will decrease but not that much because of the high cost plants in Dk-West which still have to work.

If the increase in the wind power is enough to remove the bottlenecks importing energy but not enough to create bottlenecks exporting, then both spot and regulating prices will decrease and stay with the same prices as the rest of the system price which is lower than the prices with bottlenecks importing.

In a limit situation, there can be a problem of over-exportation and bottlenecks in the exportation caused by over-production of wind power. Of course this would imply a huge production of wind power, which does not even make sense to have that capacity in the system and not having the transmission capacity to supply it. However, if this limit situation is achieved, this means that there will be more wind power on the system than the capacity of the system to spend this energy. In this situation, the prices increase because of the costs to spend this extra energy.

Limitations of the report:

Both price models, but most of all, the model for Dk-West, were incredibly hard to forecast and a lot of models had to be created and tested to reach conclusions and get to the best result possible.

During this study there were some limitations in accessing the needed data for modeling. The two more important

were: the hourly based fuel prices, or at least daily prices; and the capacity available in the hydro plants on Nordpool. For the capacity of hydropower, the weather conditions like precipitation also help the modeling. There were also difficulties in the modeling, which most likely the missing variables would have helped to avoid. In addition, there was not a forecast for consumption available so a model had to be created and, again, there were important missing variables which made modeling harder and not as rigorous. When studying the regulating market, there was a need to use the variable "Need for regulating power" to model the price for this market and this variable is impossible to forecast. If it was possible, then the values would be used in the day-a-head market so there would not be any need for regulating market and the price would always be the spot price. The regulating market is the response of the system to this need, so it is not possible to forecast the price for regulating, and this report studies which variables affect this market.

Future research:

Based on this report, a study for forecasting the regulating price can be done if the need for regulating market is assumed before it happens. For example, if in the study, the entries of need for regulation are the maximum values expected for that variable then the model can return a maximum price for regulating market. All in all, these models can be used to forecast average or maximum prices expected for the regulating market. It is important to refer that, for the technical reasons explained above, the model for Dk-West does not return reliable values and the Regulating market model depends on the Dk-West values as an entry to work, so in case of forecasting, it would be better to create a more reliable model for Dk-West.

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

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DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Appendix

Appendix

Consumption Forecast Modeling

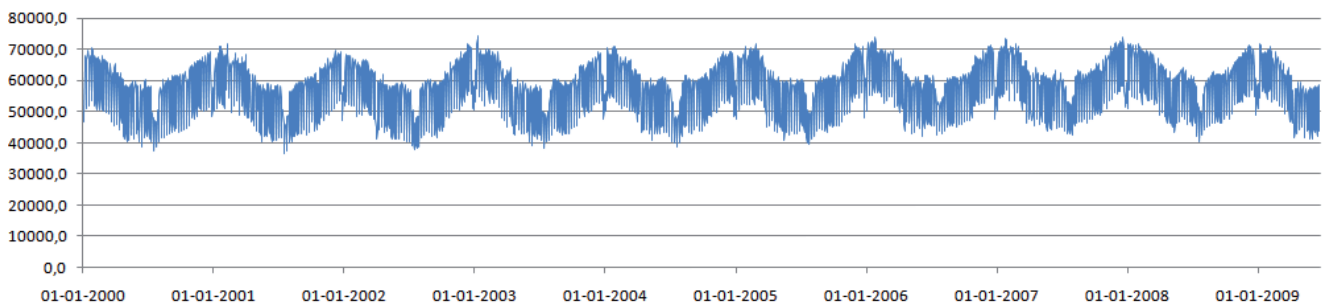
The objective of creating this model is that if the consumption will be an entry point for DK-West Spot and Regulating Market prices, then it has to be forecasted. For consumption model, the daily consumption was used and, in the end, a study for the distribution of the consumption during the day was undertaken. As the demand is in daily values, and it does not depend on the wind forecast that is the only data which is limited for the last year, the data used was the one available in the Energinet.dk web-page. This resumes in data since the 1st of January 2000 until the 23rd of June 2009. Unfortunately, there is no data for daily temperatures and humidity or the consumption divided in industrial, commercial and domestic consumption because if there was, a regressive model could be created, which would have been better for a long term forecasting and usually yields more accurate results. Just the consumption divided by industrial, commercial and domestic

consumption, makes a huge difference in the models' results because it is easier to calculate each one of these three and then merely sum them, in comparison to calculating the full consumption, because this increases immensely the number of variables which can affect consumption. For example, the temperature affects the usage of Air conditioning, but the way this usage affects the industrial consumption is different from the way it affects the commercial and domestic consumption, and in a total consumption analysis, these effects of some of the variables are disguised ultimately creating bigger errors in the end.

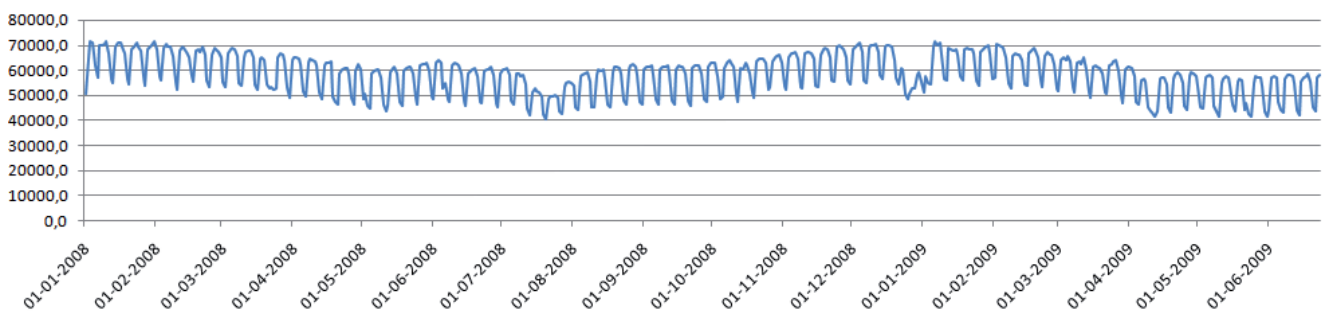
The Graphics 34 and 35 show the daily values for all the data; Graphic 34 from 1st of January 2000 until the 23rd of June 2009; and the daily values for the past year and an half - from 1st of January 2008 until the 23rd June 2009, on Graphic 35.

Appendix

Daily Demand for DK-West

Graphic 34 - Evolution of the Consumption from the 1st of January 2000 until the 1st of June 2009

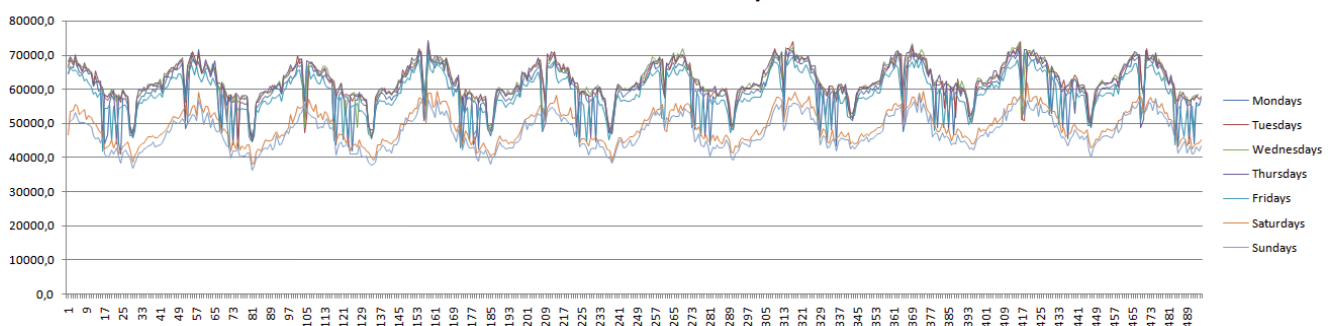
Daily Demand for Dk-West

Graphic 35 - Evolution of the Consumption from the 1st of January 2008 until the 23rd of June 2009

In Graphic 34 a seasonly year is visible, the behaviour of the demand during the year repeats year after year, while Graphic 35 has a week seasonly, meaning that besides the yearly repetition, the consumption on the weekdays is

related to the same weekday of the week before. In order to have this into account it is better to divide the consumption in weekdays and then create a model for each weekday. This way both year and week seasonly can be used in the model.

Demand in Weekdays

Graphic 36 - Evolution of the demand divided in weekdays from the 1st of January 2008 until the 23rd of June 2009

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Appendix

After the consumption was divided in weekdays, it was entered into SPSS to see the Autocorrelation (ACF) and Partial Autocorrelation (PACF) graphics. This program shows the degree and what type of ARIMA model should be used. The ACF graphic tells if the variable is suitable for an Autoregressive model and the PACF tells the degree of the model. Because of the seasonality present on the demand and the results on the ACFs graphics, the ARIMA models are expected to work reasonably well with this variable.

The general expression for an ARIMA (p,d,q) model is:

$$(1 - B)^d \cdot (1 - \phi_1 B^1 - \dots - \phi_p B^p) \cdot (1 - \theta_1 B^s) \cdot X_t = \delta + a_t \cdot (1 - \theta_1 B^s - \dots - \theta_q B^q) \cdot (1 - \Theta_1 B^s)$$

Where the “p” is the autoregressive degree, the “d” is for differential, the “q” is for the movable average degree and the “s” is for its seasonality.

For all the weekdays, the data was divided in two groups of data: train and test. For the training group it was used the data from the first week until week 399 and for the test group from week 400 until the end. To the train values, the values used as late values are the real consumption, while for the test part the ones used were the real values

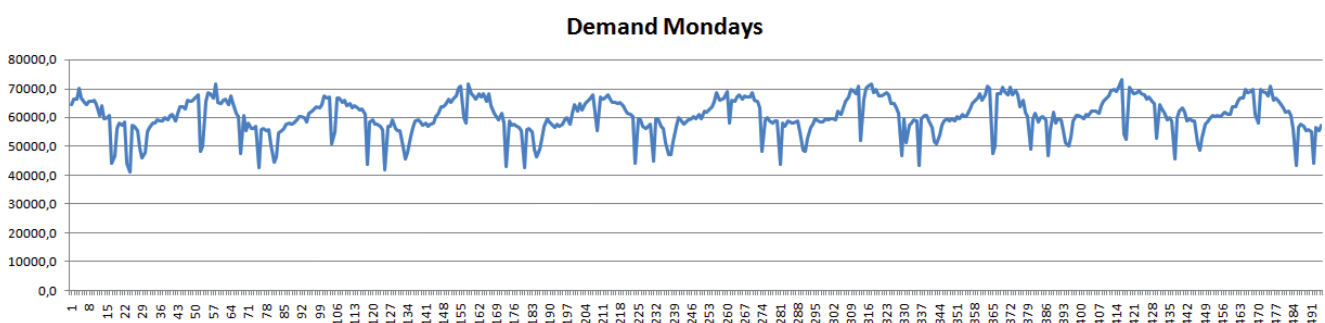
until when possible, this means these values had to be until week 399. If the value the model is using is from a week after week 399 then it will use the value it has forecasted before. This means that the model will forecast based on already forecasted values increasing this way the possibility of errors, however, it also means that it is simulated as a real situation, as if there is a need to forecast the future so there are not any real values to use. This way it is exactly the same thing as forecasting the demand for the next trimester and then at the end of the trimester go back and check the error on the forecast done three months before.

The errors used are:

- Square root of the Average Quadratic Error (RMSE);
- Average Absolute Error (MAE);
- Mean Absolute Error in percentage (MAPE).

Note: The MAPE error is the average of all the absolute errors in percentage, which is not the same as summing all the absolute errors and all the real values and then divide the total errors by the total real values and multiply it by 100 to get a percentage. The MAPE error usually yields errors significantly higher than this error.

Mondays



Graphic 37 - Evolution of the Consumption for Mondays from the 1st of January 2000 until the 23rd of June 2009

As mentioned above there is a year seasonality present on the consumption that is also visible in Graphic 37. The numbers on the “X” axis are the week numbers from

the 1st Monday of 2000. The drops that appear on the graphic are Holidays and that is why there is a drop in the consumption.

Appendix

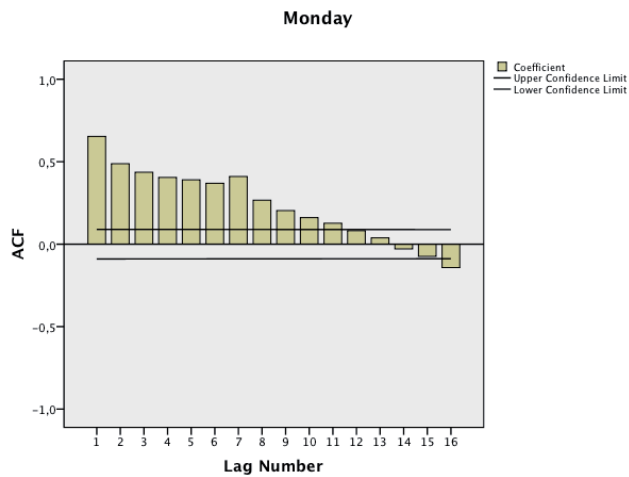


Figure 41 - Autocorrelation Graphic for Mondays Data

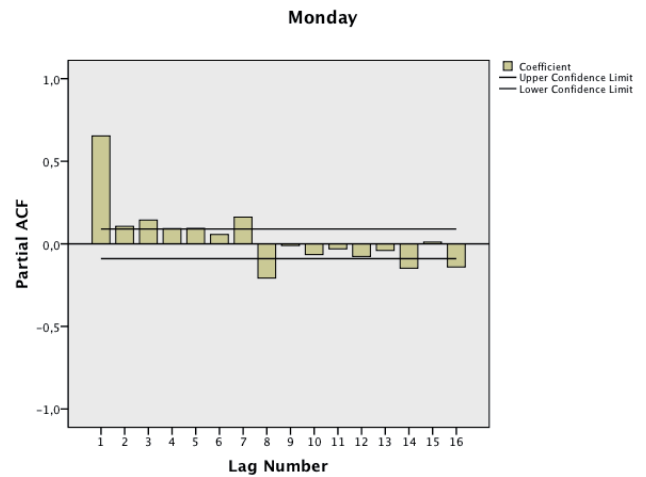


Figure 42 - Partial Autocorrelation Graphic for Mondays Data

As one can see in the ACF graphic and PACF graphic, Figures 41 and 42 respectively, this ARIMA will be an ARIMA (1,0,0), which means it is autoregressive in the first degree and it does not have movable average.

So for Monday's model the expression will be:

$$(1 - \phi_1 \cdot B^1) \cdot (1 - \phi_1 \cdot B^{52}) \cdot X_t = \delta$$

Which after developed stays like:

$$X_t = \delta + \phi_1 \cdot X_{t-1} + \phi_1 \cdot X_{t-52} - \phi_1 \cdot \phi_1 \cdot X_{t-53}$$

Where:

X_t - Value to calculate

X_{t-1} - Last Value of the variable to calculate

X_{t-52} - Value of the variable 52 times before the value to calculate

X_{t-53} - Value of the variable 53 times before the value to calculate

Because the value to forecast depends on the past, more precisely fifty-three weeks before, the model starts in the fifty-fourth week.

To calculate the constants of the model, " δ ", " ϕ_1 " and

" ϕ_1 ", the program used was Excell, with the help of the Solver application. The model calculates the error, then the quadratic error, and then the Solver minimizes the square root of the average quadratic error by changing the constants values. The results from this computation were the following:

Constants:

δ	ϕ	Φ
10138,04419	0,229056727	0,493135468

Table 21 - Model Parameters - ARIMA model for Mondays

Errors:

Train	Test
RMSE	RMSE
4018,89216	4006,114357
MAE	MAE
2483,4	2660,3
MAPE	MAPE
4,48%	4,55%

Table 22 - Train and Test Errors - ARIMA model for Mondays

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Appendix

Data:

Train

Week N°	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
1	64474,5					
2	66406,3					
...	...	...	...	...	...	...
54	65524,0	61641,4	3882,6	3882,6	5,93%	15074261,0
55	68650,4	65311,6	3338,8	3338,8	4,86%	11147846,1
56	68214,5	67927,8	286,7	286,7	0,42%	82171,8
57	66576,9	66497,6	79,3	79,3	0,12%	6294,5
...	...	...	...	...	...	...
394	51181,2	54609,4	-3428,2	3428,2	6,70%	11752745,6
395	50225,6	52773,0	-2543,4	2543,4	5,06%	6468895,5
396	53261,4	53967,6	-706,2	706,2	1,33%	498681,5
397	58935,1	56751,6	2183,5	2183,5	3,70%	4767597,8
398	60510,0	59155,5	1354,5	1354,5	2,24%	1834552,5
399	60678,4	59918,2	760,2	760,2	1,25%	577956,7

Table 23 - Some Data from the train group of values for the ARIMA model for Mondays

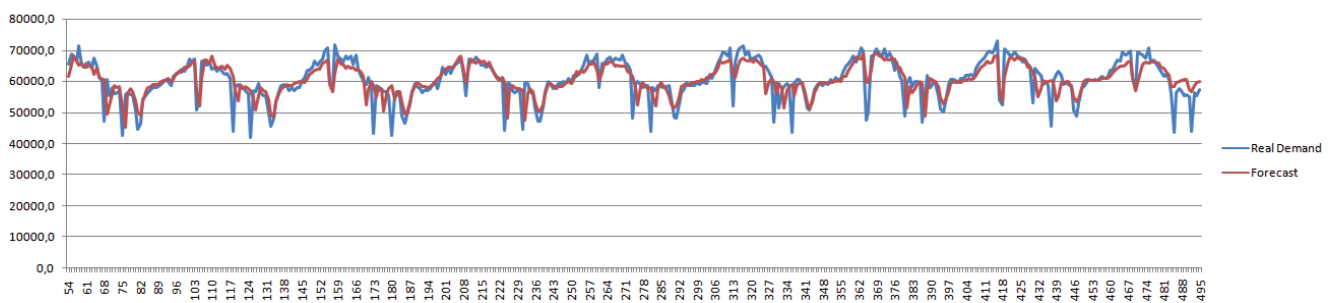
Test

Week N°	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
400	60261,3	59653,0	608,3	608,3	1,01%	369993,6
401	59690,4	59846,0	-155,6	155,6	0,26%	24200,0
402	60980,0	59624,3	1355,7	1355,7	2,22%	1838049,8
403	60768,7	60243,3	525,4	525,4	0,86%	276035,7
404	61945,6	60198,2	1747,4	1747,4	2,82%	3053452,3
...	...	...	...	...	...	...
486	56386,5	59665,3	-3278,8	3278,8	5,81%	10750532,3
487	57653,2	60022,5	-2369,3	2369,3	4,11%	5613770,4
488	56948,4	60191,9	-3243,5	3243,5	5,70%	10520469,3
489	55207,6	60423,5	-5215,9	5215,9	9,45%	27205981,6
490	55612,9	60359,8	-4746,9	4746,9	8,54%	22532696,2
491	54882,5	57177,5	-2295,0	2295,0	4,18%	5266908,2
492	43982,5	56476,1	-12493,6	12493,6	28,41%	156090280,7
493	56320,8	58675,7	-2354,9	2354,9	4,18%	5545529,9
494	55428,4	59577,1	-4148,7	4148,7	7,48%	17211956,0
495	57297,2	59935,2	-2638,0	2638,0	4,60%	6958824,3

Table 24 - Some Data from the test group of values for the ARIMA model for Mondays

Graphic:

Results for Mondays Demand model



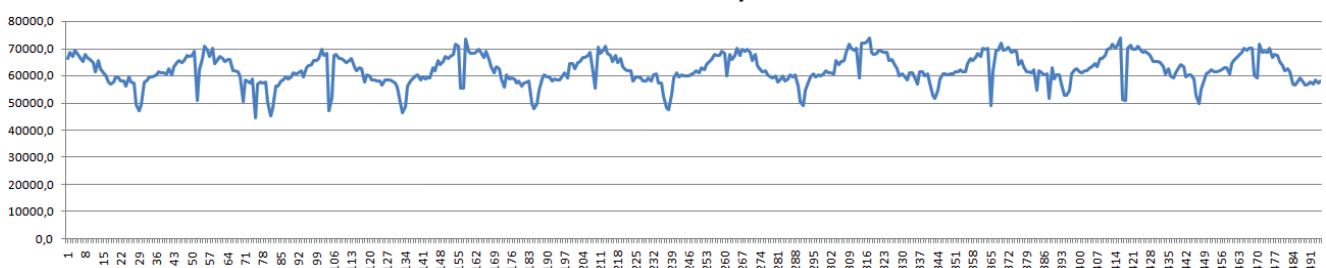
Graphic 38 - real and forecasted Consumption - ARIMA model for Mondays

Graphic 38 shows the series of values for Real Demand and Forecasted Demand. The model was able to adapt itself to the seasonally and to retrieve values very similar to the real ones ending up with only a 4.55% of average absolute error

on the test group of values. This means that on average, the model gives a value 4.55% lower or higher than the real value, which in terms of energy is 2660 MWh of error on an average demand of around 60000 MWh.

Tuesdays

Demand Tuesdays

Graphic 39 - Evolution of the Consumption for Tuesdays from the 1st of January 2000 until the 23rd of June 2009

Appendix

Once again there is a year seasonality which is visible in the

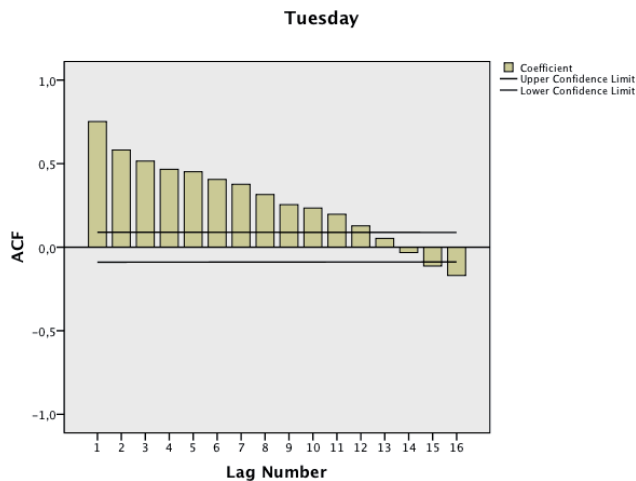


Figure 43 - Autocorrelation Graphic for Tuesdays Data

Once more, the ARIMA model will be an ARIMA (1,0,0) which means its expression will be:

$$(1 - \phi_1 B^1) \cdot (1 - \phi_1 B^{52}) \cdot X_t = \delta$$

Which after developing the expression stays like:

$$X_t = \delta + \phi_1 \cdot X_{t-1} + \phi_1 \cdot X_{t-52} - \phi_1 \cdot \phi_1 \cdot X_{t-53}$$

Where:

X_t - Value to calculate

X_{t-1} - Last Value of the variable to calculate

X_{t-52} - Value of the variable 52 times before the value to calculate

X_{t-53} - Value of the variable 53 times before the value to calculate

The results for the Tuesdays model were:

Constants:

δ	ϕ	Φ
6772,119583	0,159871647	0,632913498

Table 25 - Model Parameters - ARIMA model for Tuesdays

Errors:

Train	Test
RMSE	RMSE
2408,212296	2684,23136
MAE	MAE
1608,7	1963,5
MAPE	MAPE
2,68%	3,17%

Table 26 - Train and Test Errors - ARIMA model for Tuesdays

History for the demand on Tuesdays, Graphic 39.

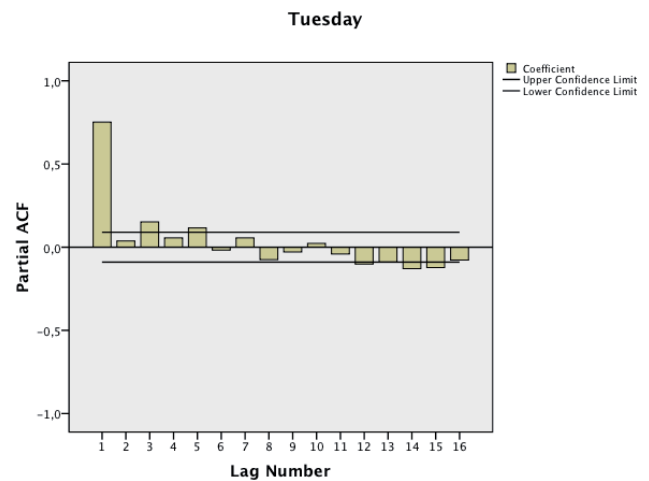


Figure 44 - Partial Autocorrelation Graphic for Tuesdays Data

Data:

Train

Week Nº	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
1	66141,6					
2	68575,8					
...	...	...	...	...	...	...
54	66190,9	66823,0	-632,1	632,1	0,95%	399490,7
55	70920,1	66713,5	4206,6	4206,6	5,93%	17695267,3
56	69439,5	68832,8	606,7	606,7	0,87%	368100,5
57	67095,5	67843,2	-747,7	747,7	1,11%	559002,2
...	...	...	...	...	...	...
394	52819,8	54964,7	-2144,9	2144,9	4,06%	4600784,1
395	52643,0	53088,8	-445,8	445,8	0,85%	198700,3
396	54360,2	54969,7	-609,5	609,5	1,12%	371479,6
397	60626,6	58171,4	2455,2	2455,2	4,05%	6027921,6
398	61985,0	60687,9	1297,1	1297,1	2,09%	1682493,4
399	62609,0	61067,2	1541,8	1541,8	2,46%	2377098,6

Table 27 - Some Data from the train group of values for the ARIMA model for Tuesdays

Test

Week Nº	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
400	61276,4	61019,2	257,2	257,2	0,42%	66158,5
401	60947,2	60890,3	56,9	56,9	0,09%	3232,3
402	61705,6	60873,4	832,2	832,2	1,35%	692590,0
403	61825,9	61355,1	470,8	470,8	0,76%	221643,4
404	62882,3	61707,2	1175,1	1175,1	1,87%	1380765,4
...	...	...	...	...	...	...
486	58022,7	62243,7	-4221,0	4221,0	7,27%	17817239,4
487	59111,2	59407,6	-296,4	296,4	0,50%	87845,9
488	57433,5	60353,9	-2920,4	2920,4	5,08%	8528830,4
489	56611,2	61367,1	-4755,9	4755,9	8,40%	22618578,2
490	56773,7	61376,0	-4602,3	4602,3	8,11%	21181249,5
491	57400,7	61335,4	-3934,7	3934,7	6,85%	15482256,7
492	56836,8	57749,7	-912,9	912,9	1,61%	833427,6
493	58188,3	60051,7	-1863,4	1863,4	3,20%	3472431,9
494	57005,3	60539,6	-3534,3	3534,3	6,20%	12491225,8
495	58015,5	60842,4	-2826,9	2826,9	4,87%	7991549,1

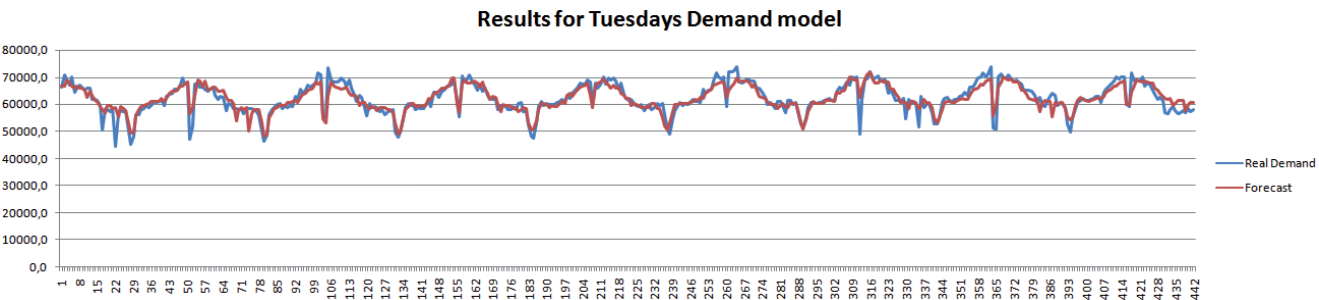
Table 28 - Some Data from the test group of values for the ARIMA model for Tuesdays

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Appendix

Graphic:

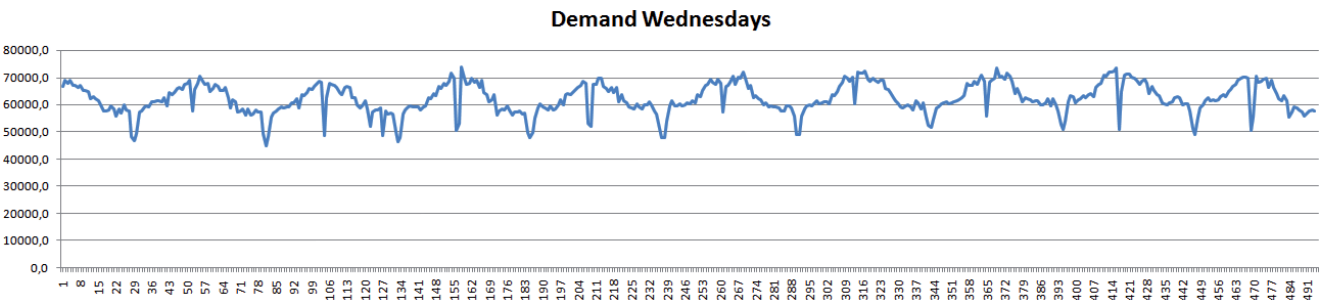


Graphic 40 - real and forecasted Consumption - ARIMA model for Tuesdays

The model for the demand on Tuesdays adapted itself well to the series as the one for Mondays did, and it had better

results than the one for Monday ending up with a test MAPE error of 3,17%.

Wednesdays



Graphic 41 - Evolution of the Consumption for Wednesdays from the 1st of January 2000 until the 23rd of June 2009

The year seasonality is present in the History for the demand

on Wednesdays as expected and one can see above.

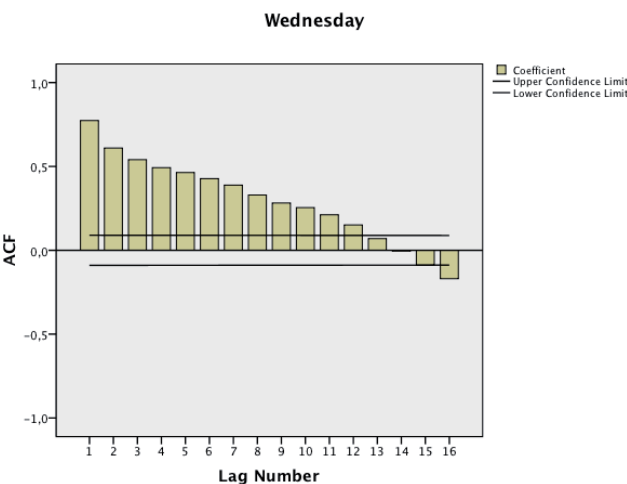


Figure 45 - Autocorrelation Graphic for Wednesdays Data

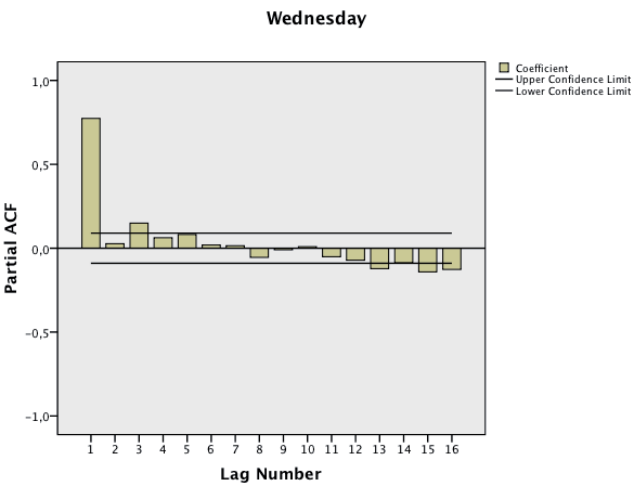


Figure 46 - Partial Autocorrelation Graphic for Wednesdays Data

Appendix

The ARIMA model will be an ARIMA (1,0,0) defined by:

$$(1 - \phi_1 \cdot B^1) \cdot (1 - \phi_1 \cdot B^{52}) \cdot X_t = \delta$$

Data:

Train

Which after developing the expression stays like:

$$X_t = \delta + \phi_1 \cdot X_{t-1} + \phi_1 \cdot X_{t-52} - \phi_1 \cdot \phi_1 \cdot X_{t-53}$$

Where:

X_t - Value to calculate

X_{t-1} - Last Value of the variable to calculate

X_{t-52} - Value of the variable 52 times before the value to calculate

X_{t-53} - Value of the variable 53 times before the value to calculate

Week Nº	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
1	66717,7					
2	69132,8					
...	...	...	...	...	...	...
54	67717,5	67823,8	-106,3	106,3	0,16%	11289,4
55	70633,1	67496,4	3136,7	3136,7	4,44%	9839193,4
56	68686,3	68616,9	69,4	69,4	0,10%	4810,5
57	67589,7	67255,6	334,1	334,1	0,49%	111652,5
...	...	...	...	...	...	...
394	52762,2	54897,8	-2135,6	2135,6	4,05%	4560855,3
395	50857,4	53404,5	-2547,1	2547,1	5,01%	6487475,9
396	54089,1	54825,2	-736,1	736,1	1,36%	541905,2
397	61055,4	58228,7	2826,7	2826,7	4,63%	7990449,4
398	63204,4	60083,2	3121,2	3121,2	4,94%	9741884,7
399	62889,5	61111,4	1778,1	1778,1	2,83%	3161744,1

Table 31 - Some Data from the train group of values for the ARIMA model for Wednesdays

The model results for Wednesdays were:

Test

Constants:

δ	ϕ	Φ
6620,481896	0,159968488	0,6356721

Table 29 - Model Parameters - ARIMA model for Wednesdays

Errors:

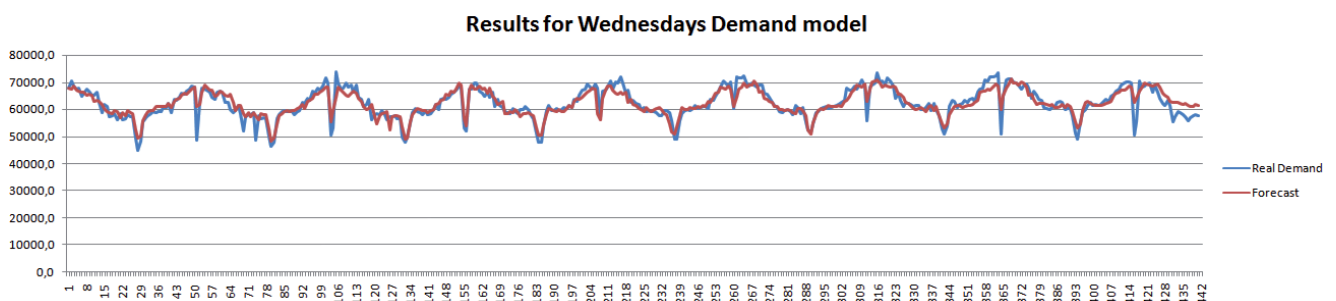
Train	Test
RMSE	RMSE
2234,02167	3043,546962
MAE	MAE
1567,1	2226,6
MAPE	MAPE
2,58%	3,66%

Table 30 - Train and Test Errors - ARIMA model for Wednesdays

Week Nº	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
400	60889,7	61539,7	-650,0	650,0	1,07%	422514,9
401	61755,3	61452,1	303,2	303,2	0,49%	91948,6
402	62188,1	60956,8	1231,3	1231,3	1,98%	1516010,2
403	63195,4	61202,9	1992,5	1992,5	3,15%	3970184,0
404	62759,9	61432,8	1327,1	1327,1	2,11%	1761093,9
...	...	...	...	...	...	...
486	59357,5	62573,8	-3216,3	3216,3	5,42%	10344774,8
487	58809,3	62251,5	-3442,2	3442,2	5,85%	11848777,4
488	58112,0	62103,3	-3991,3	3991,3	6,87%	15930135,7
489	57378,1	62139,3	-4761,2	4761,2	8,30%	22668652,1
490	55767,3	61600,6	-5833,3	5833,3	10,46%	34027821,7
491	57000,4	61278,7	-4278,3	4278,3	7,51%	18303924,8
492	57747,8	61377,4	-3629,6	3629,6	6,29%	13174049,9
493	57962,0	62106,9	-4144,9	4144,9	7,15%	17180497,0
494	57636,3	61513,7	-3877,4	3877,4	6,73%	15034417,3
495	58015,5	60842,4	-2826,9	2826,9	4,87%	7991549,1

Table 32 - Some Data from the test group of values for the ARIMA model for Wednesdays

Graphic:



Graphic 42 - real and forecasted Consumption - ARIMA model for Wednesdays

The Wednesdays' model in the end has a small deviation with a maximum error of 10,46%, however it still has a test

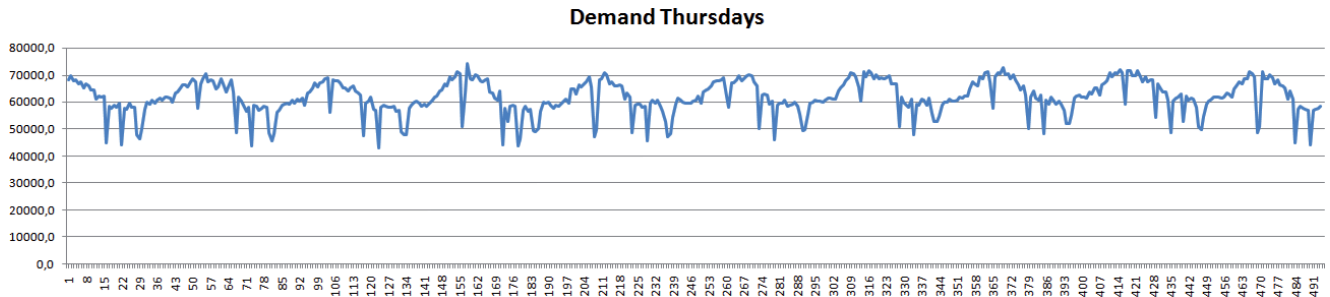
MAPE error of 3,66%, which is a very satisfactory value.

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Appendix

Thursdays

Graphic 43 - Evolution of the Consumption for Thursdays from the 1st of January 2000 until the 23rd of June 2009

Similarly to other weekdays already analyzed, the year

seasonly is present in the History for the demand on Thursdays.

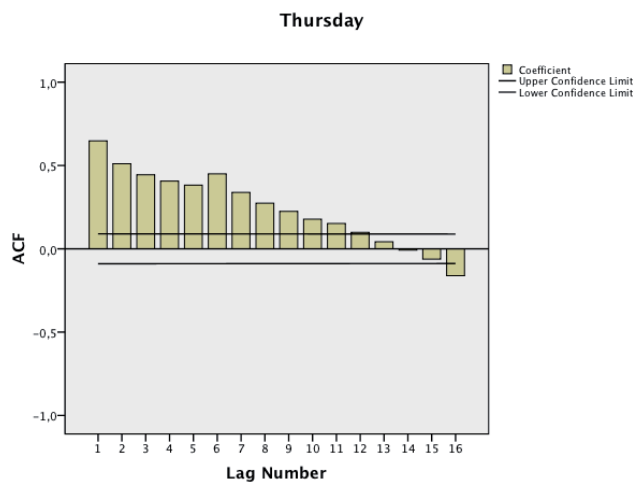


Figure 47 - Autocorrelation Graphic for Thursdays Data

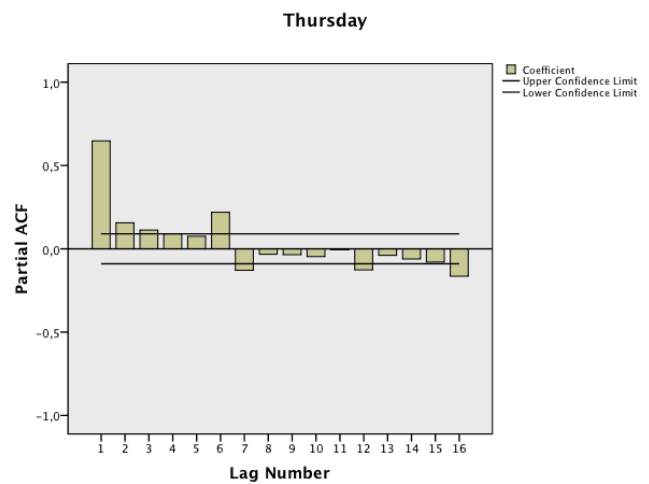


Figure 48 - Partial Autocorrelation Graphic for Thursdays Data

The ARIMA model will, again, be an ARIMA (1,0,0) defined by:

$$(1 - \phi_1 B^1) \cdot (1 - \phi_1 B^{52}) \cdot X_t = \delta$$

Once the expression is developed it yields:

$$X_t = \delta + \phi_1 \cdot X_{t-1} + \phi_1 \cdot X_{t-52} - \phi_1 \cdot \phi_1 \cdot X_{t-53}$$

Where:

X_t - Value to calculate

X_{t-1} - Last Value of the variable to calculate

X_{t-52} - Value of the variable 52 times before the value to calculate

X_{t-53} - Value of the variable 53 times before the value to calculate

The results for Thursdays were:

Constants:

δ	ϕ	Φ
9574,627048	0,300826052	0,419908553

Table 33 - Model Parameters - ARIMA model for Thursdays

Errors:

Train	Test
RMSE	RMSE
4036,307919	4456,567314
MAE	MAE
2446,3	2980,3
MAPE	MAPE
4,32%	5,14%

Table 34 - Train and Test Errors - ARIMA model for Thursdays

Appendix

Data:

Train

Week Nº	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
1	67987,1					
2	69492,4					
...	...	...	...	...	...	...
54	68452,5	67429,02673	1023,47	1023,473274	1,50%	1047497,542
55	70300	67479,46074	2820,54	2820,539255	4,01%	7955441,691
56	67537,8	67904,59865	-366,8	366,798652	0,54%	134541,2511
57	68033,9	66454,02534	1579,87	1579,874661	2,32%	2496003,945
...	...	...	...	...	...	...
394	51909,9	56028,70885	-4118,8	4118,808853	7,93%	16964586,37
395	52200,2	54067,5125	-1867,3	1867,312497	3,58%	3486855,96
396	55053,5	54944,74431	108,756	108,7556856	0,20%	11827,79915
397	61522,1	57722,94529	3799,15	3799,154714	6,18%	14433576,54
398	62249,8	60589,6469	1660,15	1660,153098	2,67%	2756108,307
399	62458,5	61066,25997	1392,24	1392,240031	2,23%	1938332,304

Table 35 - Some Data from the train group of values for the ARIMA model for Thursdays

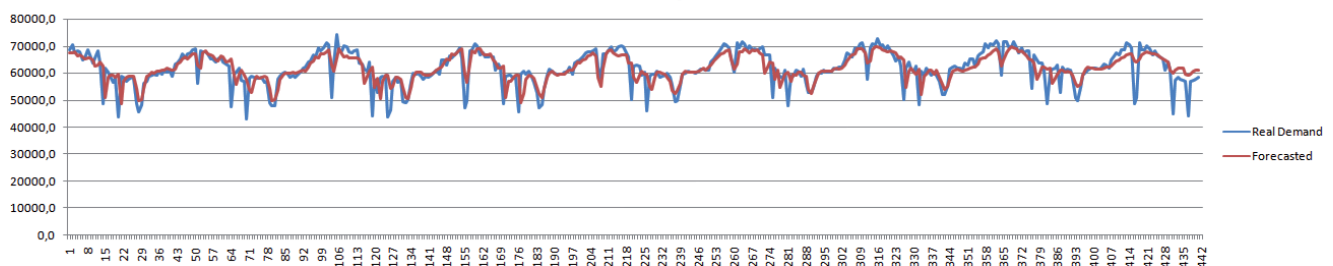
Test

Week Nº	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
400	61738,6	61541,98899	196,611	196,6110085	0,32%	38655,88868
401	61657	61140,52188	516,478	516,4781173	0,84%	266749,6457
402	61574,5	60841,03359	733,466	733,4664088	1,19%	537972,9728
403	63607	60985,94543	2621,05	2621,054573	4,12%	6869927,075
404	63094,6	61495,32044	1599,28	1599,279561	2,53%	2557695,114
...	...	...	...	...	...	...
486	58359,8	61948,39492	-3588,6	3588,594921	6,15%	12878013,51
487	57842,1	61879,23328	-4037,1	4037,133283	6,98%	16298445,15
488	57272	61959,42108	-4687,4	4687,421081	8,18%	21971916,39
489	57036,7	59697,64168	-2660,9	2660,941683	4,67%	7080610,639
490	44097,2	59052,80031	-14956	14955,60031	33,92%	223669980,8
491	56857,4	59724,07966	-2866,7	2866,679662	5,04%	8217852,284
492	57373,4	60657,85086	-3284,5	3284,450862	5,72%	10787617,47
493	57700,6	61165,86847	-3465,3	3465,268475	6,01%	12008085,6
494	58543,7	61083,26607	-2539,6	2539,566072	4,34%	6449395,835

Table 36 - Some Data from the test group of values for the ARIMA model for Thursdays

Graphic:

Results for Thursdays Demand model



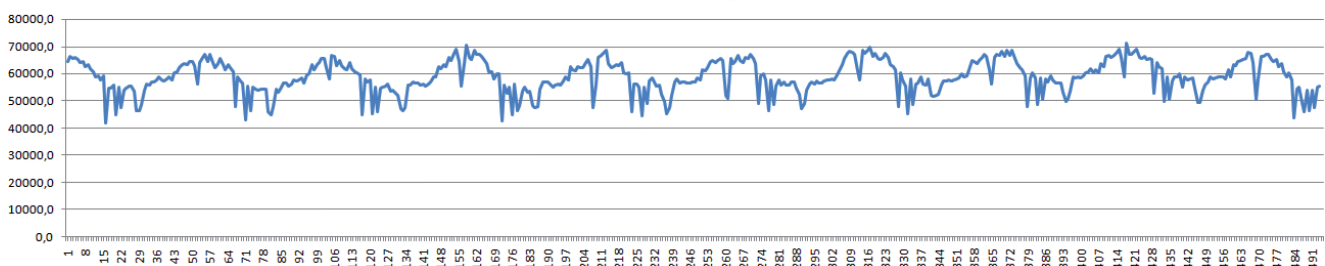
Graphic 44 - real and forecasted Consumption - ARIMA model for Thursdays

Once again the model had some difficulties in forecasting the Holiday brakes on consumption in the end of the test group of data, having an error of 33,56% and 33,92%

for the last two brakes which one can see on Graphic 44, the highest values for this error, even though it still has a reasonable MAPE Test error of 5,14%.

Fridays

Demand Fridays

Graphic 45 - Evolution of the Consumption for Fridays from the 1st of January 2000 until the 23rd of June 2009

Similarly to the other weekdays already analyzed, the year

seasonally is present in the History for the demand on Fridays.

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Appendix

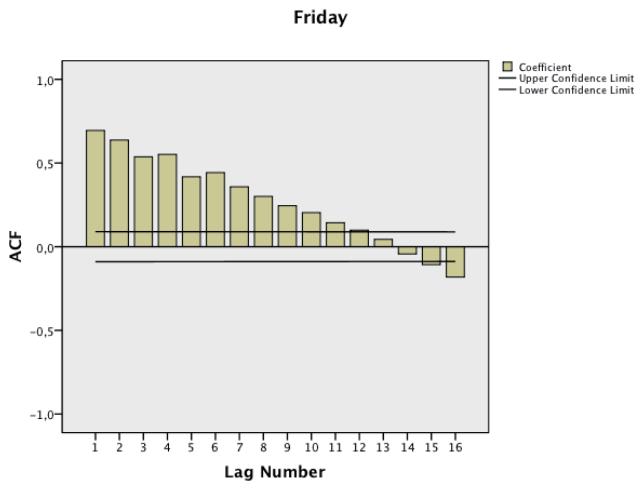


Figure 49 - Autocorrelation Graphic for Fridays Data

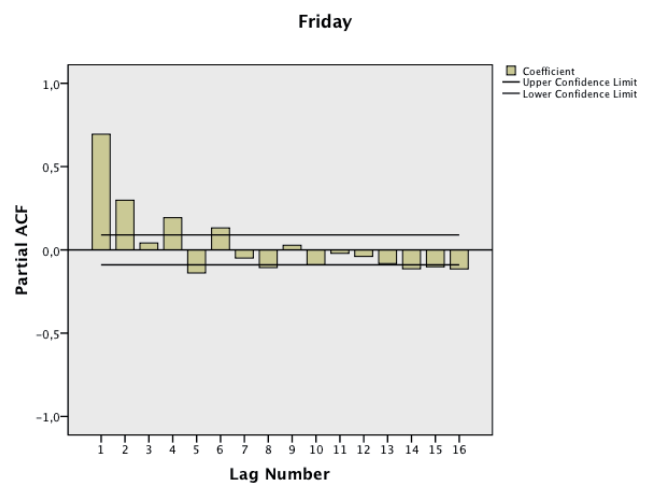


Figure 50 - Partial Autocorrelation Graphic for Fridays Data

The ARIMA model for Fridays could be an ARIMA (2,0,0) because the second column on the PACF graphic, figure 50, is almost half of the first one, but it is only because the first one is not as strong as usual and it is still below the 0.5 value. Furthermore, both models were studied - the ARIMA (1,0,0), the ARIMA (2,0,0) - and since the ARIMA (1,0,0) had better results, it will be the one presented here. Its expression is:

$$(1 - \phi_1 \cdot B^1) \cdot (1 - \phi_1 \cdot B^{52}) \cdot X_t = \delta$$

Once the expression is developed, it yields the following:

$$X_t = \delta + \phi_1 \cdot X_{t-1} + \phi_1 \cdot X_{t-52} - \phi_1 \cdot \phi_1 \cdot X_{t-53}$$

Where:

X_t - Value to calculate

X_{t-1} - Last Value of the variable to calculate

X_{t-52} - Value of the variable 52 times before the value to calculate

X_{t-53} - Value of the variable 53 times before the value to calculate

The results were:

Constants:

δ	ϕ	Φ
7892,950547	0,286999521	0,451454598

Table 37 - Model Parameters - ARIMA model for Fridays

Errors:

Train	Test
RMSE	RMSE
3651,456513	3883,424742
MAE	MAE
2345,2	2778,7
MAPE	MAPE
4,28%	4,91%

Table 38 - Train and Test Errors - ARIMA model for Fridays

Appendix

Data:

Train

Week Nº	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
1	46732,2					
2	53519					
...	...	...	...	...	...	...
54	52351,7	52049,33483	302,365	302,365167	0,58%	91424,69423
55	54947,5	53159,40658	1788,09	1788,093416	3,25%	3197278,063
56	55197,8	54901,92101	295,879	295,8789851	0,54%	87544,37385
57	52145,3	55063,9034	-2918,6	2918,6034	5,60%	8518245,808
...	...	...	...	...	...	...
394	45143,5	46316,54803	-1173	1173,048027	2,60%	1376041,675
395	43977,8	45790,98701	-1813,2	1813,187014	4,12%	3287647,149
396	44018,2	45162,92053	-1144,7	1144,720534	2,60%	1310385,102
397	45934,6	45189,82968	744,77	744,7703215	1,62%	554682,8318
398	48736,6	46606,27115	2130,33	2130,328854	4,37%	4538301,026
399	47642	48397,51398	-755,51	755,5139753	1,59%	570801,3668

Table 39 - Some Data from the train group of values for the ARIMA model for Fridays

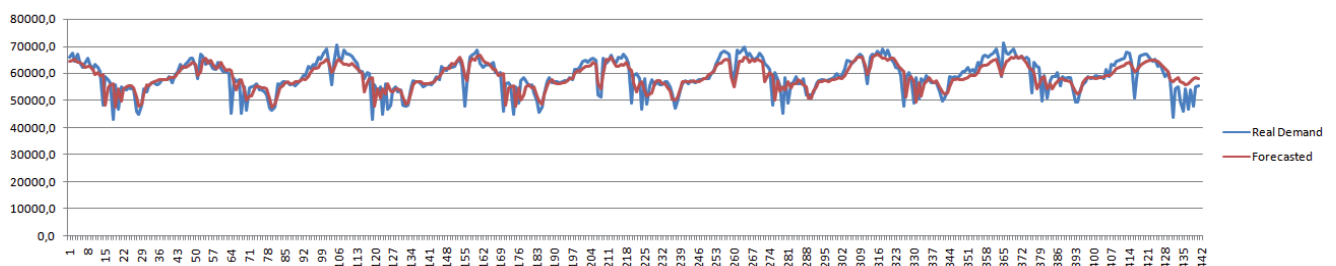
Test

Week Nº	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
400	58340,2	58158,22361	181,976	181,9763924	0,31%	33115,40739
401	58964,8	57867,18814	1097,61	1097,611858	1,86%	1204751,79
402	60383,9	57876,43696	2507,46	2507,463042	4,15%	6287370,908
403	60649,7	58110,61951	2539,08	2539,080485	4,19%	6446929,71
404	61851,5	58349,85318	3501,65	3501,646816	5,66%	12261530,42
...	...	...	...	...	...	...
486	54991,1	58700,19021	-3709,1	3709,09021	6,74%	13757350,18
487	49540,9	56898,88879	-7358	7357,988786	14,85%	54139998,98
488	45938,9	56607,21303	-10668	10668,31303	23,22%	113812902,9
489	53966,9	55924,88173	-1958	1957,981726	3,63%	3833692,441
490	46549,5	56308,55788	-9759,1	9759,057882	20,96%	95239210,74
491	53868,4	57094,10665	-3225,7	3225,706645	5,99%	10405183,36
492	47588,1	57983,56204	-10395	10395,46204	21,84%	108065631
493	54883,6	58391,21241	-3507,6	3507,612408	6,39%	12303344,8
494	55246,4	58191,40038	-2945	2945,000383	5,33%	8673027,256

Table 40 - Some Data from the test group of values for the ARIMA model for Fridays

Graphic:

Results for Fridays Demand model



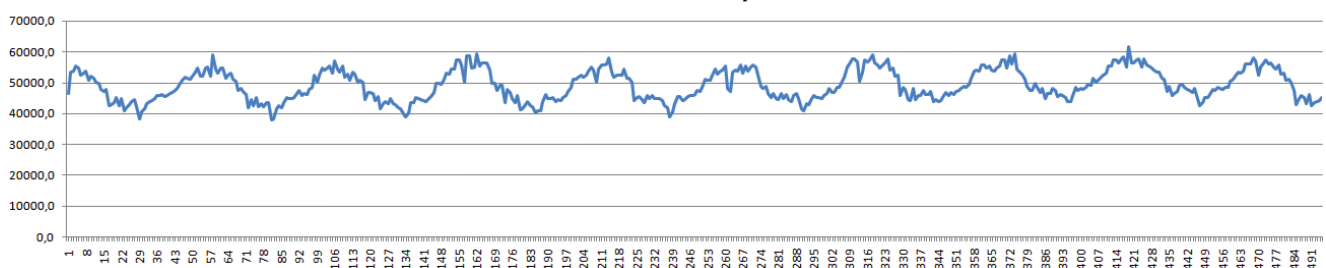
Graphic 46 - real and forecasted Consumption - ARIMA model for Fridays

On Graphic 46 the difficulties of the model to forecast variations to the normal curve of the variable are visible. In the end of this model's Test group of data, there is a portion

of small drops on the consumption that the model almost does not react to, and even with that, has a MAPE error of only 4,91%.

Saturdays

Demand Saturdays

Graphic 47 - Evolution of the Consumption for Saturdays from the 1st of January 2000 until the 23rd of June 2009

Similarly to other weekdays analyzed above, the year

seasonally is present in the History for the demand on Saturdays.

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Appendix

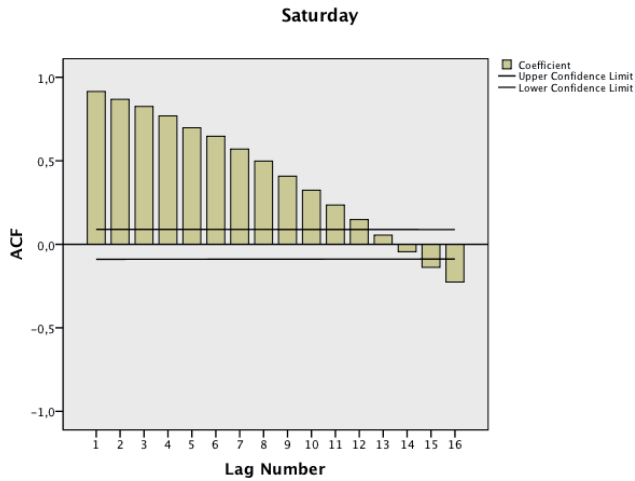


Figure 51 - Autocorrelation Graphic for Saturdays Data

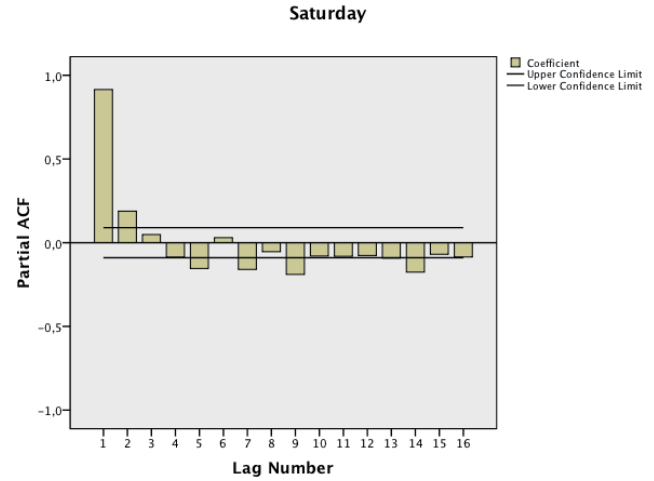


Figure 52 - Partial Autocorrelation Graphic for Saturdays Data

The ARIMA model for Saturdays will be the ARIMA (1,0,0) model defined by:

$$(1 - \phi_1 B^1) \cdot (1 - \phi_1 B^{52}) \cdot X_t = \delta$$

Which after the expression is developed stays like:

$$X_t = \delta + \phi_1 \cdot X_{t-1} + \phi_1 \cdot X_{t-52} - \phi_1 \cdot \phi_1 \cdot X_{t-53}$$

Where:

X_t - Value to calculate

X_{t-1} - Last Value of the variable to calculate

X_{t-52} - Value of the variable 52 times before the value to calculate

X_{t-53} - Value of the variable 53 times before the value to calculate

The results for Saturday were:

Constants:

δ	ϕ	Φ
5765,106785	0,464720848	0,292868732

Table 41 - Model Parameters - ARIMA model for Saturdays

Errors:

Train	Test
RMSE	RMSE
1751,116189	2818,453393
MAE	MAE
1417,5	2190,8
MAPE	MAPE
2,92%	4,45%

Table 42 - Train and Test Errors - ARIMA model for Saturdays

Data:

Train

Week Nº	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
1	46732,2					
2	53519					
...	...	...	...	...	...	...
54	52351,7	52049,33483	302,365	302,365167	0,58%	91424,69423
55	54947,5	53159,40658	1788,09	1788,093416	3,25%	3197278,063
56	55197,8	54901,92101	295,879	295,8789851	0,54%	87544,37385
57	52145,3	55063,9034	-2918,6	2918,6034	5,60%	8518245,808
...	...	...	...	...	...	...
394	45143,5	46316,54803	-1173	1173,048027	2,60%	1376041,675
395	43977,8	45790,98701	-1813,2	1813,187014	4,12%	3287647,149
396	44018,2	45162,92053	-1144,7	1144,720534	2,60%	1310385,102
397	45934,6	45189,82968	744,77	744,7703215	1,62%	554682,8318
398	48736,6	46606,27115	2130,33	2130,328854	4,37%	4538301,026
399	47642	48397,51398	-755,51	755,5139753	1,59%	570801,3668

Table 43 - Some Data from the train group of values for the ARIMA model for Saturdays

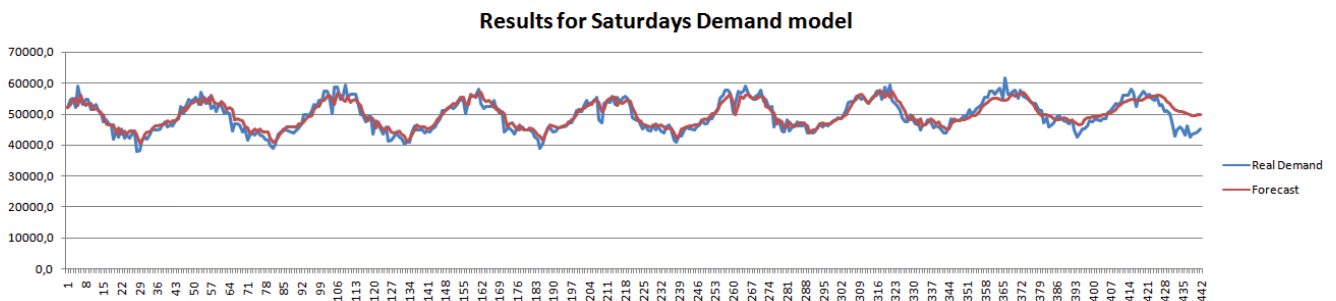
Test

Week Nº	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
400	48228,1	47768,92063	459,179	459,179369	0,95%	210845,693
401	47781	47976,65922	-195,66	195,6592158	0,41%	38282,52873
402	48727	48011,2224	715,778	715,7775985	1,47%	512337,5705
403	49567,5	48230,23905	1337,26	1337,260946	2,70%	1788266,838
404	49329,1	48520,58833	808,512	808,5116658	1,64%	653691,1138
...	...	...	...	...	...	...
486	45045,5	51005,64736	-5960,1	5960,147364	13,23%	35523356,6
487	45861	50880,72414	-5019,7	5019,724143	10,95%	25197630,48
488	45441,5	50665,7592	-5224,3	5224,259197	11,50%	27292884,15
489	43415,3	50456,76622	-7041,5	7041,466217	16,22%	49582246,49
490	46169,9	50097,27742	-3927,4	3927,377416	8,51%	15424293,37
491	42500,9	49709,04194	-7208,1	7208,141941	16,96%	51957310,24
492	43492	49491,1621	-5999,2	5999,162104	13,79%	35989945,95
493	44040,9	49549,47934	-5508,6	5508,579336	12,51%	30344446,31
494	44216,9	49728,87741	-5512	5511,977409	12,47%	30381894,96
495	45222,7	49688,91364	-4466,2	4466,21364	9,88%	19947064,28

Table 44 - Some Data from the test group of values for the ARIMA model for Saturdays

Appendix

Graphic:

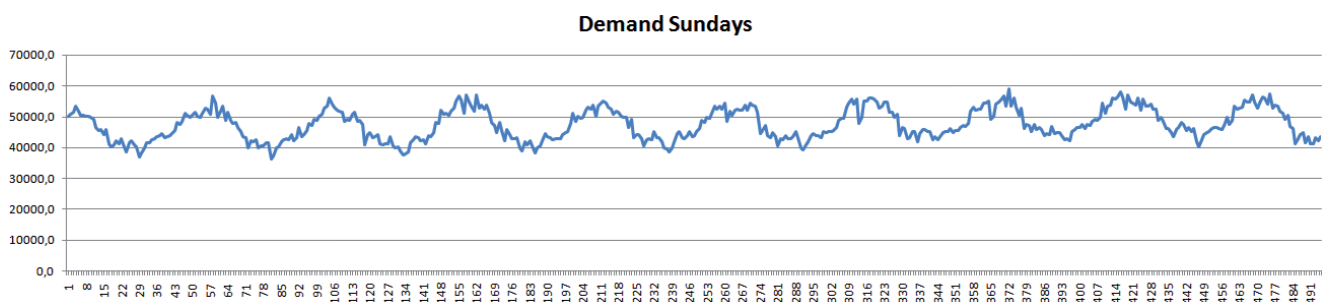


Graphic 48 - real and forecasted Consumption - ARIMA model for Saturdays

Because of the tendency of the consumption for Saturdays to balance its values along the year, the model finishes the

forecast with errors of around 13%, however, it still yields a Test MAPE error of only 4,55%.

Sundays

Graphic 49 - Evolution of the Consumption for Sundays from the 1st of January 2000 until the 23rd of June 2009

Similarly to other weekdays analyzed above, the year

seasonally is present in the History for the demand on Sundays.

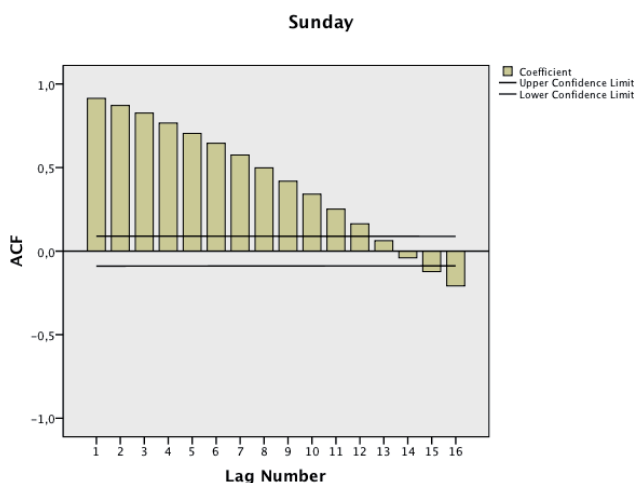


Figure 53 - Autocorrelation Graphic for Sundays Data

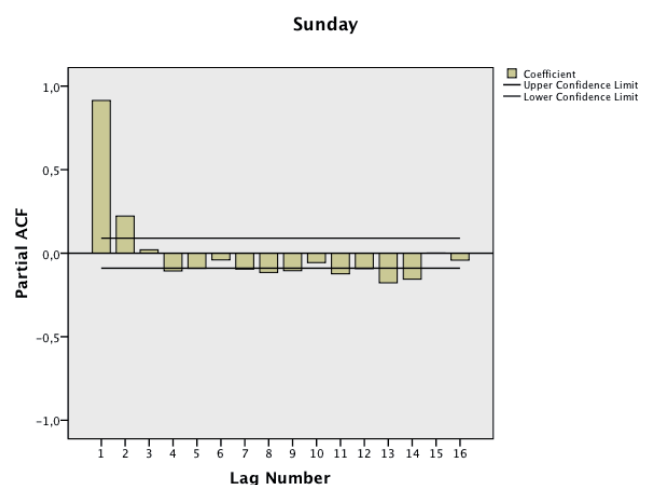


Figure 54 - Partial Autocorrelation Graphic for Sundays Data

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Appendix

The ARIMA model for Sundays will be the ARIMA (1,0,0) model defined by:
 $(1 - \phi_1 \cdot B^1) \cdot (1 - \phi_1 \cdot B^{52}) \cdot X_t = \delta$

After the above expression is developed, it yields the following:

$$X_t = \delta + \phi_1 \cdot X_{t-1} + \phi_1 \cdot X_{t-52} - \phi_1 \cdot \phi_1 \cdot X_{t-53}$$

Where:

X_t - Value to calculate

X_{t-1} - Last Value of the variable to calculate

X_{t-52} - Value of the variable 52 times before the value to calculate

X_{t-53} - Value of the variable 53 times before the value to calculate

And the results were:

Constants:

δ	ϕ	Φ
6584,923991	0,317552024	0,41819705

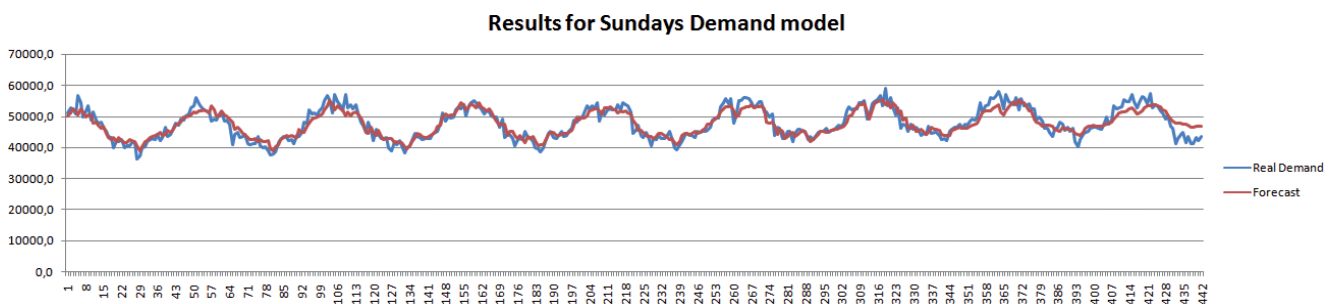
Table 45 - Model Parameters - ARIMA model for Sundays

Errors:

Train	Test
RMSE	RMSE
1692,562363	2634,435615
MAE	MAE
1405,5	2116,7
MAPE	MAPE
2,99%	4,34%

Table 46 - Train and Test Errors - ARIMA model for Sundays

Graphic:



Graphic 50 - real and forecasted Consumption - ARIMA model for Sundays

Data:

Train

Week Nº	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
1	50132,6					
2	50595,8					
...	...	...	...	...	...	...
54	50970,6	50252,09101	718,509	718,5089864	1,41%	516255,1636
55	52594,9	51024,09154	1570,81	1570,808456	2,99%	2467439,207
56	52284,2	52398,08995	-113,89	113,8899532	0,22%	12970,92143
57	50886,7	51915,38696	-1028,7	1028,686961	2,02%	1058196,864
...	...	...	...	...	...	...
394	42653	44317,97721	-1665	1664,977215	3,90%	2772149,126
395	42752,3	44018,13722	-1265,8	1265,837222	2,96%	1602343,873
396	42196,4	43809,02287	-1612,6	1612,622872	3,82%	2600552,528
397	45191,3	43913,21769	1278,08	1278,082307	2,83%	1633494,384
398	45961,1	45439,7194	521,381	521,3806043	1,13%	271837,7345
399	46486,1	46078,51814	407,582	407,5818625	0,88%	166122,9746

Table 47 - Some Data from the train group of values for the ARIMA model for Sundays

Test

Week Nº	Real Value	Forecasted Value	Error	Absolute Error	Absolute Error (%)	Quadratic Error
400	46587	46226,77439	360,226	360,2256052	0,77%	129762,4867
401	47595,9	46525,79909	1070,1	1070,100906	2,25%	1145115,95
402	46070,8	46191,52949	-120,73	120,7294925	0,26%	14575,61036
403	47511,2	46230,40202	1280,8	1280,797982	2,70%	1640443,472
404	47204,7	46340,35898	864,341	864,3410238	1,83%	747085,4054
...	...	...	...	...	...	...
486	42761,7	47842,03605	-5080,3	5080,336051	11,88%	25809814,39
487	44202,9	47750,66345	-3547,8	3547,763449	8,03%	12586625,49
488	44846,5	47697,42726	-2850,9	2850,927257	6,36%	8127786,226
489	41450,5	47620,01271	-6169,5	6169,512706	14,88%	38062887,03
490	43585,5	47146,92516	-3561,4	3561,425162	8,17%	12683749,19
491	41223,4	46705,81111	-5482,4	5482,411111	13,30%	30056831,59
492	41272,8	46464,59436	-5191,8	5191,794361	12,58%	26954728,69
493	43185,4	46799,10318	-3613,7	3613,70318	8,37%	13058850,67
494	42089,5	46936,44592	-4846,9	4846,945917	11,52%	23492884,72
495	43524,5	46828,39933	-3303,9	3303,899326	7,59%	10915750,76

Table 48 - Some Data from the test group of values for the ARIMA model for Sundays

Appendix

In the model for Sundays, the same happens as on the Saturdays' model, but this time not as strongly. The MAPE error for the Test group of data was of 4,34%.

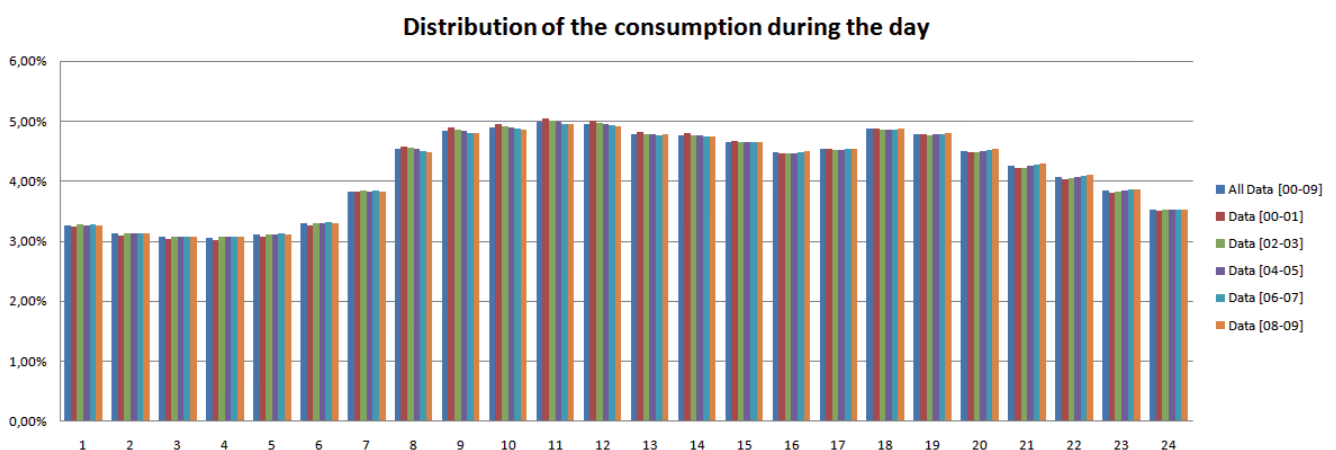
Although the autoregressive models are not the best choice to a long term forecasting, the results were reasonably good, the errors were around 4% which is not that high. Of course, the objective here is to minimize the error and the best way to do it would be to get more data about daily atmospheric conditions, money generated in the country, exportations, level of life in the country, etc..., for there are a lot of factors that influence consumption. As already mentioned an additional significant help would be to have

a separated consumption for industrial, commercial and domestic consumptions.

After having the daily forecasts a study was conducted around the average distribution of the consumption during a day, so that the daily consumptions could be transformed in hourly consumptions. For this study, all the consumptions for each hour were separated and then their average consumption was calculated. This was done for all the years first, and then to the two years file to analyze if this distribution has changed for the past 10 years. The results were:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
All Years	3,27%	3,13%	3,07%	3,06%	3,10%	3,29%	3,83%	4,53%	4,84%	4,90%	4,99%	4,95%	4,78%	4,76%	4,65%	4,48%	4,53%	4,87%	4,78%	4,50%	4,25%	4,07%	3,84%	3,52%
2000-2001	3,24%	3,10%	3,04%	3,03%	3,07%	3,26%	3,82%	4,58%	4,90%	4,95%	5,04%	5,01%	4,82%	4,80%	4,67%	4,47%	4,53%	4,88%	4,78%	4,48%	4,22%	4,04%	3,81%	3,50%
2002-2003	3,27%	3,14%	3,08%	3,07%	3,11%	3,30%	3,83%	4,55%	4,86%	4,92%	5,00%	4,96%	4,78%	4,76%	4,65%	4,47%	4,52%	4,86%	4,76%	4,48%	4,22%	4,05%	3,83%	3,53%
2004-2005	3,27%	3,13%	3,08%	3,07%	3,11%	3,30%	3,83%	4,53%	4,84%	4,90%	4,98%	4,95%	4,78%	4,76%	4,64%	4,47%	4,53%	4,86%	4,78%	4,51%	4,26%	4,07%	3,84%	3,52%
2006-2007	3,27%	3,14%	3,08%	3,08%	3,13%	3,32%	3,84%	4,50%	4,81%	4,87%	4,95%	4,92%	4,77%	4,75%	4,64%	4,49%	4,54%	4,86%	4,78%	4,52%	4,28%	4,10%	3,85%	3,53%
2008-2009	3,27%	3,13%	3,07%	3,07%	3,11%	3,30%	3,83%	4,49%	4,79%	4,86%	4,95%	4,92%	4,77%	4,75%	4,65%	4,50%	4,54%	4,87%	4,80%	4,54%	4,30%	4,11%	3,86%	3,53%

Table 49 - Average distribution of the consumption during the day



Graphic 51 - Average distribution of the consumption during the day

By looking at the table of values, or at the graphic above, one can see that, the distribution of consumption during the day has been almost constant for the past 10 years. After computing these hourly coefficients for every hour, they were multiplied by the forecasted daily consumption to get the forecasted hourly consumption needed to the models for DK-West spot and regulating market prices:

$$\text{Consumption (Day x; Hour y)} = \text{Coefficient (Hour y)} * \text{Consumption (Day x)}$$

After all the model errors and all the approximations and errors done by using the coefficient for distribution of the consumption during the day based on average values, the MAPE error for the period 1st of June 2008 to 1st of June

DANISH ENERGY MARKET

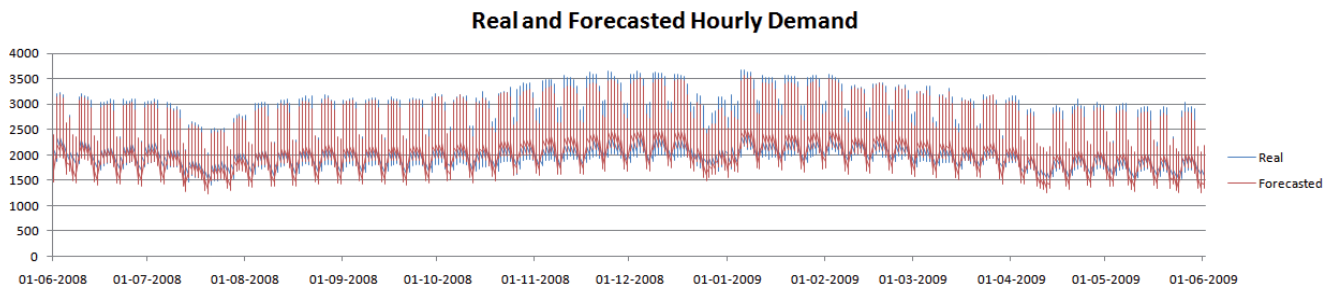
The Regulating Market & Renewable Energies

Appendix

2009 was of 4,88%. It is important to refer that the MAPE error is an absolute error, so the negative errors do not balance with the positive ones because all the errors are modified to absolute before computing their average. On Table 50 one can see all the errors represented while on Graphic 52 the real and forecasted hourly values:

RMSE
137,1592753
MAE
110,2340141
MAPE
4,88%

Table 50 - Errors - Hourly consumption since 1st of June 2008 until 1st of June 2009



Graphic 52 - real and forecasted Consumption - Hourly consumption since 1st of June 2008 until 1st of June 2009

Spot Market Modeling

The Regressive model done for the spot price model will be looked at here, but including now the fuel prices so the reader has an idea of what happened to the model when the fuel prices were included.

The model expression was:

$$\text{Dk-West Spot} = \delta + \phi_1 \cdot \text{Year} + \phi_2 \cdot \text{Month} + \phi_3 \cdot \text{Day} + \phi_4 \cdot \text{Hour} + \phi_5 \cdot \text{Wind} + \phi_6 \cdot \text{Cons.} + \phi_7 \cdot (\text{Cons.} - \text{Wind}) + \phi_8 \cdot \text{CoalAU} + \phi_9 \cdot \text{CoalSA} + \phi_{10} \cdot \text{NGasEU} + \phi_{11} \cdot \text{NGasJP} + \phi_{12} \cdot \text{NGasUS} + \phi_{13} \cdot \text{OilBrent}$$

The Results were:

Train	Test
RMSE	RMSE
86,8559562	130,2122043
MAE	MAE
58,9	122,3
MAPE	MAPE
39,35%	53,96%

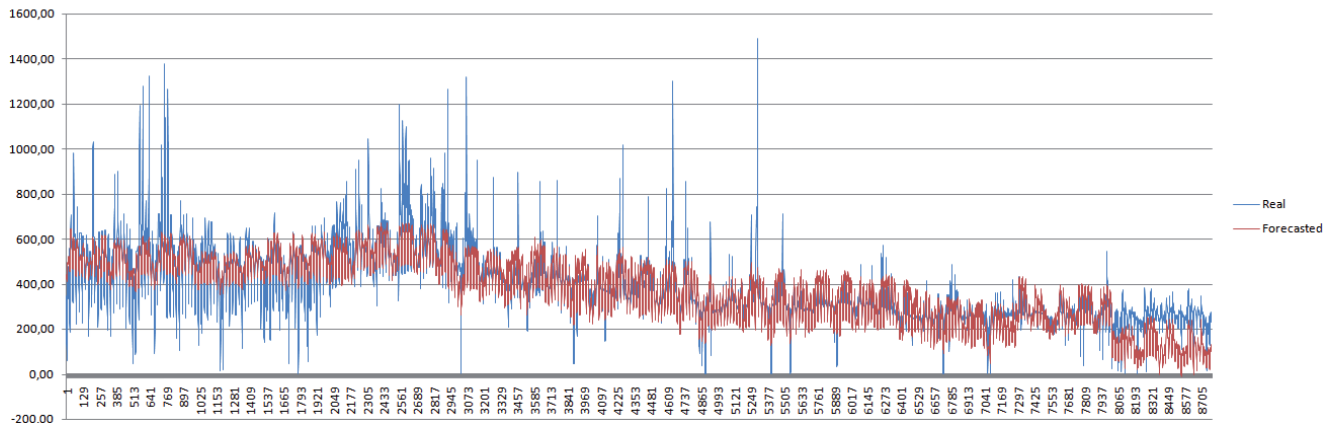
Table 52 - Train and Test Errors - Regressive model for Dk-West Spot with fuel prices

δ	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6	ϕ_7	ϕ_8	ϕ_9	ϕ_{10}	ϕ_{11}	ϕ_{12}	ϕ_{13}
0,34762	-0,18329	-0,24347	-0,01207	0,021561	0,021612	0,100764	0,185679	0,480284	0,224956	-0,25845	0,22239	0,196954	0,917394

Table 51 - Model Parameters - Regressive model for Dk-West Spot with fuel prices

Appendix

Results for Dk-West Spot Market price



Graphic 53 - Dk-west real and forecasted spot price - Regressive model for Dk-West Spot with fuel prices

Regulating Market Modeling

Up regulation

The results from the two models used for up regulation, which were not put on the modeling part of the report, will be looked at here. There were many more models conducted but the ones presented below are only the ones which were also made to down regulate and that have their results shown in the down regulation modeling part of the report.

First model's expression:

$$\text{Dk-West RM UR} = \delta + \phi_1 \cdot \text{Year} + \phi_2 \cdot \text{Month} + \phi_3 \cdot \text{Day} + \phi_4 \cdot \text{Hour} + \phi_5 \cdot \text{Dk-West spot} + \phi_6 \cdot \text{Wind lmb.} + \phi_7 \cdot (\text{Cons.} - \text{Wind}) + \phi_8 \cdot \text{UR Demand}$$

And the results were:

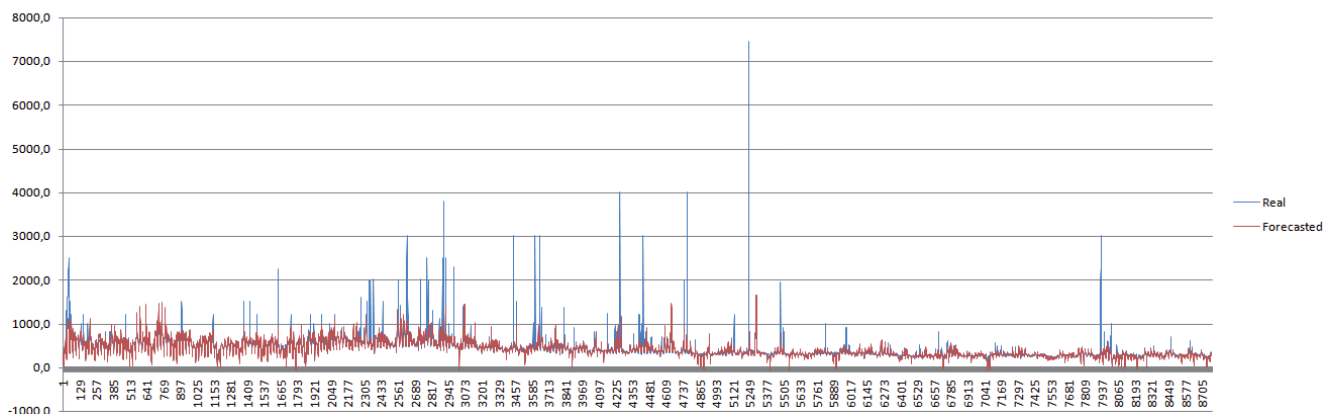
δ	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6	ϕ_7	ϕ_8
-0,0025	0,003823	0,00724	-2,6E-05	-0,00103	0,215283	-0,03391	0,090206	0,01522

Table 53 - Model Parameters - Dk-West Up Regulation price - full data

Train	Test
RMSE	RMSE
200,960603	59,34706099
MAE	MAE
58,2	31,8
MAPE	MAPE
17,67%	12,41%

Table 54 - Train and Test Errors - Dk-West Up Regulation price - full data

Results for Regulating Market price for Up Regulation



Graphic 54 - Dk-West real and forecasted Up Regulate price - full data

DANISH ENERGY MARKET

The Regulating Market & Renewable Energies

Appendix

The second model is the same as the first one, merely changing the data and taking the outliers out:

$$\text{Dk-West RM UR} = \delta + \phi_1 \cdot \text{Year} + \phi_2 \cdot \text{Month} + \phi_3 \cdot \text{Day} + \phi_4 \cdot \text{Hour} + \phi_5 \cdot \text{Dk-West spot} + \phi_6 \cdot \text{Wind Imb.} + \phi_7 \cdot (\text{Cons.} - \text{Wind}) + \phi_8 \cdot \text{UR Demand}$$

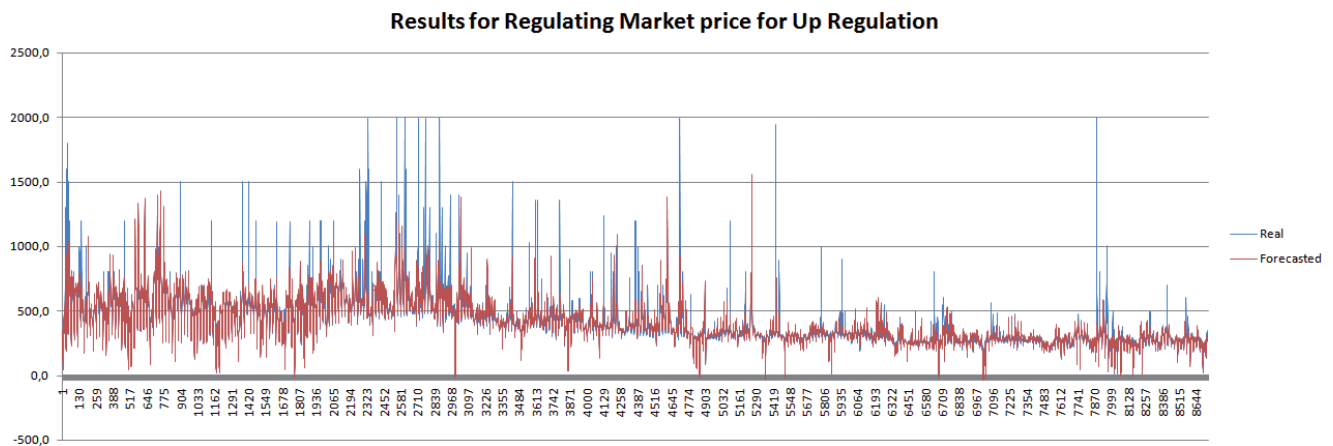
The results were the following:

δ	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6	ϕ_7	ϕ_8
0,006547	0,006174	0,017369	-9,6E-05	-9,3E-06	0,756078	-0,08862	0,211924	0,031764

Table 55- Model Parameters - Dk-West Up Regulation price - w/o outliers

Train	Test
RMSE	RMSE
99,02050276	38,63147802
MAE	MAE
37,9	23,0
MAPE	MAPE
9,86%	9,64%

Table 56 - Train and Test Errors - Dk-West Up Regulation price - w/o outliers



Graphic 55 - Dk-West real and forecasted Up Regulate price - w/o outliers

Persistence Modeling

This study was conducted to see if the imbalances on the wind power forecasts can be reduced. For this, the persistence model was adapted. This model claims that the values after a chosen point will all have the same value as that point. The way to put this together with reducing the imbalances is to use the Elbas market and set the wind power for a certain hour of operation to the same value it had 2 hours before. This way companies that have wind turbines will use the energy for the last hour as the forecast to the energy they will produce two hours later. After the

calculations were done the results for the errors on both forecasts were:

Spot Forecast	Persistence
RMSE	RMSE
185,1809956	135,5527071
MAE	MAE
129,6	88,9
MAPE	MAPE
63,80%	29,07%

Table 57 - Forecast Errors - Spot and Persistence Models

Appendix

As one can see on Table 57, the MAPE error using the persistence model is almost half of the MAPE error using only the spot forecast and not correcting the imbalances during the Elbas. The next study was to see how much this would have been saved in need for regulating energy if this persistence model was used on the last year. The imbalances that have the same sign as the need for regulation⁴ for that hour⁵, are computed as negative values, because in this situation the imbalances were actually helping the system by decreasing the need for regulating power, and the imbalances that have the opposite sign of the need for regulation are computed as positive values. If the sum of positive and negative values is negative it means that this imbalances help more the system than they harm it. If this sum is positive it means that the imbalances harm more the system than they help it.

The study is assuming the imbalances that helped the system would be paid to the wind companies at the same price of the imbalances that were against the system so the sum of the imbalances with the corrected signs as described above returns the total need for regulating power and in practice these values are paid at spot price so the savings would be even higher.

The results were:

Spot Forecast	Persistence
Negative	Negative
592553,7	399824,5
Positive	Positive
545522,0	381242,2
Total	Total
47031,70	18582,30

Table 58 - Errors of Spot and Persistence forecasts from 1st of June 2008 and 1st of June 2009 - Energy values

One can conclude that in this one year period, the usage of the persistence model to correct the forecast would reduce 60,49% in the need for regulation because of the wind imbalances. This means that if the regulating price was the same as spot price and the average spot price for this period was 384,17DKK/MWh and the average Elbas price was 344,86DKK/MWh, this model could save in this period around 1.118.210DKK.

Money Saved = (Average Dk-West Spot Price - Average Elbas Price) * Difference between Total Imbalances

Money Saved = (384,17 - 344,86) * 28.449,40 = 1.118.210DKK

A simple correction on the forecasts over the Elbas market would save to all the companies with wind turbines around 1MDKK every year.

The study also concluded that without the corrections on the imbalances made over Elbas, 48,02% of the hours studied the imbalances are actually helping the system, meaning, 51,98% of the hours, the summed regulation for that hour, has the opposite way of the imbalances, meaning the imbalances are harming the system. In the case of the corrections on the imbalances over the Elbas, the results would be of 49,53% and 50,47% respectively.

All in all, this persistence model is not only better to reduce the total yearly need for regulation caused by the wind imbalances, as it also has more hours of the year helping the system in the regulation than the model using the spot forecasts.

4 - (positive imbalance and positive need for regulation or negative imbalance and negative need for regulation)

5 - (this is the sum of both positive and negative need for regulation so they are the total for the hour)