31761 - Renewables in electricity markets
Assignment 1

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Contents

1. Introduction

An analysis of the Danish electricity market clearing has been performed based on some constraints and the results through the simulation have been discussed in this report. The simulation is run for two months, November and January respectively, with a time resolution of an hour. The market is cleared for each time unit, acquiring all prices, generator production and transmission data for the areas taken into study. The second section of the report presents the mathematical model implemented to obtain market clearing. The consumption and production data has been provided for Denmark which follows the zonal pricing system with two zones, DK1 and DK2 respectively. Based on the mathematical model an optimization problem is obtained which is applied as a linear program in MATLAB, the simulation tool for this study. The optimization problem has been formulated keeping in mind the real-world setup of the electricity market ensuring that the supply matches the demand at all times along with the main objective of maximizing the social welfare. The problem is subject to constraints that define relationships between consumption and production capabilities and transmission limitations.

In the third section, a thorough analysis of the obtained results has been developed. The impact of various constraints on the market-clearing price has been discussed. Then the revenues for the producers have been calculated for the given period and the effects of support schemes for wind producers have also been analyzed. Finally, a synopsis of the study has been provided in the last section, highlighting the key aspects that were observed during the course of this investigation.

2. Mathematical Model

2.1. Data Preparation

Before the formulation of the model, a directory was prepared by creating an Excel file consisting of all the crucial information and data required to solve the linear programming problem. The generated Excel file is attached as a part of the addendum and is structured as described below:

1. Day and hour : the first two columns 'A'and 'B' show a particular day and an hour respectively.
2. Demand : columns 'C' and 'D' represents the demand of DK1 and DK2 respectively and this raw data is extracted from the link given in the assignment document. Furthermore, the hourly demand is altering throughout the day due to imports and exports from neighboring countries. Import was subtracted from the demand and export was added to the demand resulting in an adjusted demand showed in columns 'G' and 'H'.
3. Wind & nuclear energy offered : columns 'R' and 'S' represent the total electricity produced by wind in DK1 and DK2 respectively. Columns 'U' and 'V' shows WW_1 and WW_2 respectively which were calculated from the overall production of DK1 and columns 'X' and 'Y' shows EW_1 and EW_2 respectively which were calculated from the overall production of DK2. Columns 'AA' and 'AC' represent a nuclear generator in DK1 and DK2 respectively which is only operated from 5 am to 10 pm.

2.2. Objective Function Formulation

The next step is to align the modified data into the formulation. The demand offers are provided as one whole value for each time unit. The optimization problem aims to maximize social welfare which is defined as the area between the supply curve and the demand curve. The general preference of converting the maximization problem into a minimization problem just by swapping the terms has been followed by this study and the optimization problem is formulated as follows :

$$min \sum_{i=1}^{N_G} \lambda_i^{N_G}.y_i^{N_G} + \lambda_{DK1}^{Lshed}.y_{DK1}^{Lshed} + \lambda_{DK2}^{Lshed}.y_{DK2}^{Lshed} \tag{2.1}$$

where, 'y' is the scheduled units which represent a vector with the dimensions of [22x1], N_G represents the number of generators in both the zones which is represented by the first nineteen elements of this vector for a given time unit. The twentieth element of this vector represents the interconnection of the system represented by 'K', indicating how much transmission exists between the two zones (DK1 and DK2) for that time unit, and the sign shows the direction of the energy (positive when flowing from DK1 to DK2 and vice versa). The last two elements represent the load shedding units and these units can never be greater than the demand.
'λ' is the dual variable associated with this linear program, which is the Lagrange multiplier related to the dual problem. The program provides an optimal solution for each time unit, thereby formulating the market-clearing price which maximizes the social welfare or minimizes cost. Since in this study there are two zones, this vector would provide prices for both DK1 and DK2, hence it has a [2x1] dimension. To present a real-world scenario the report includes load shedding and curtailment. The variable 'λ' with the subscript of 'LS' stands for the units that a zone would have to shed for a given time unit. Similarly, the corresponding 'y' would provide the cost of shedding the load for that time unit. The cost has been taken as one more than the bidding cost of the costliest generator to get scheduled in that time unit.

2.3. Constraints

The minimization problem above stated is subject to the following constraints.

1. The first & second constraint is represented by equation 2.2 and 2.3. This represents the balance equation for DK1 & DK2 respectively, for which the sum of generation must equal the sum of demand (considered as a block D^{DK1} & D^{DK2}) and transmission (K). LS_{DK1} & LS_{DK2} is the load shedding quantity, in case there is any.

$$\sum_{i=1}^{n} y_i^{DK1} = D^{DK1} + K - y_{DK1}^{Lshed} \tag{2.2}$$

$$\sum_{i=1}^{n} y_i^{DK2} = D^{DK2} + K - y_{DK2}^{Lshed} \tag{2.3}$$

   In both the above stated constraints, demand for each time unit is considered as a block. Furthermore, the transmission (K) is represented in equation 2.2 and in equation 2.3 with its absolute value: its sign will change depending on the export or import for each zone and will have opposite signs in the two equations.

2. The third constraint, equation 2.4, regards the scheduled quantities for each producer: these vary from the minimum to the maximum each can produce. Depending on the total demand for that particular time unit, a certain number of generators will be scheduled to supply a given amount (y_i) of their capacity (P_i) .

$$0 \leq y_i \leq P_i \tag{2.4}$$

3. The last constraint regards the transmission K. It can take all values till the maximum capacity of the transmission line. This is represented in equation 2.5.

$$-600 \leq K \leq 600 \tag{2.5}$$

The constraints stated above represent the formulation of a linear problem that could further be written in a more compact form and be implemented in MATLAB to be solved using the "linprog" function. We can find the optimal solution to the formulated problem in this way. The compact form is represented by the following equations:

1.
$$min_y f^T.y \tag{2.6}$$

2. Equation 2.7 represents the equality constraints. A_{eq} is a matrix of dimensions [2x22]: The two rows are used to represent the areas (DK1 and DK2) taken into consideration in this problem; the columns instead have ones and zeroes that correspond to the different generators present in each zone. In the first line the numbers of one are equivalent to the number of generators in DK1 and as many zeroes as the generators in DK2. The twentieth one represents the transmission component. Finally, the last two components indicate the load shedding components. The second line represents DK2 therefore, the zeroes and ones are defined oppositely to the first line. Also in this case the twentieth component corresponds to the transmission and has a negative sign in front of it to represent the fact that transmission enters one area and exits another. Once again the last two components are related to load shedding.
b_{eq}, sized [2x1], contains the demand values for the two areas in each time period.
$$A_{eq} \cdot y = b_{eq} \tag{2.7}$$
3. This second constraint represented by equation 2.8, represents the inequality constraints. A is an identity matrix that will be multiplied by the vector of decision variables y. The vector b, of dimension [1x22], contains all the upper bounds of production for each generator present in the market, the upper bound for transmission (third to last component) and the maximum values of load shedding, that correspond to demand at each time unit (last two components).
$$A \cdot y \leq b \tag{2.8}$$
4. The last constraint is equation 2.9. It represents the non-negative constraint of the decision variables in our model. Connected to this constraint is the vector of lower bounds 'lb' in the MATLAB code provided in the appendix. Its size is [1x22]: the first 19 zeroes are the minimum production levels of the generators of the two zones; the -600 is the lower boundary of the transmission; the last two zeroes are the minimums of the load shedding values.
$$y \geq 0 \tag{2.9}$$

2.4. Other outputs

1. Output matrix 'P' : this matrix stores all the clearing prices calculated (the lambda values). Since the clearing prices are [2x1], this matrix will be [2x1464].
2. Output matrix 'U' : this matrix stores all the scheduling for the generators, load shedding in each region and the transmitted energy from one area to the other. Its dimensions are [22x1464].

3. Analysis

3.1. Clearing the market

In this section, the market-clearing process for the two areas taken into consideration will be analyzed. The results are obtained from running the above-stated minimization problem for all the hours present in the months of November 2019 and January 2020.
In order to better analyze the processes involved in the market-clearing, two cases will be considered. The time units taken into consideration are characterized by having in one case no congestion and in the other congestion. Additionally, a description of the area prices and scheduled quantities for each participant are stated. Their revenues are discussed in the following sections. The two time units are:

1. Hour 50, No congestion, November 3rd, 1:00 - 2:00 AM
2. Hour 956, Congestion, January 10th, 19:00 - 20:00 PM

3.1.1. Hour 50 and 956 market clearing

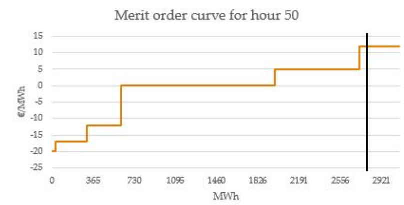
The first hour we will consider is hour 50: the prices, generation quantities, and transmission are shown in Table 3.1. Given the demand is defined as a block for each zone, the merit order curves are constructed to perform two separate market clearings with two different equilibrium points. This is only based on the single offers of each producer, but we also can exchange energy between the two sides up to 600 MWh. From the initial merit order curve definition, DK1 will have a deficit of energy compared to DK2 that will have a surplus of the same amount, which for this hour corresponds to 235 MWh. Since we have this imbalance, and since the value of this imbalance is less than the maximum capacity of the interconnection cable, energy can be transferred from the low price area (DK2) to the high price area (DK1) as indicated by the arrow in Table 3.1 where the transmission value is placed. In the merit order curves, for DK1 this energy gain from the transmission is added as an extra supply at the lowest price (0 €/MWh); for DK2 instead, this becomes an addition to demand at the highest price. The market can now be considered as one unique zone instead of 2 separate ones: the market price is, therefore, the same in the two areas and is the lowest of the two, corresponding to 12 €/MWh, as shown in figure 3.1a.

Hour 50		
	DK1	**DK2**
Price	12	12
West Wind 1	1127.2	N/A
West Wind 2	281.8	N/A
Blue Water (G13)	N/A	750
Blue Water (G14)	N/A	284
East Wind 1	N/A	32.9
East Wind 2	N/A	296.1
Transmission	235	

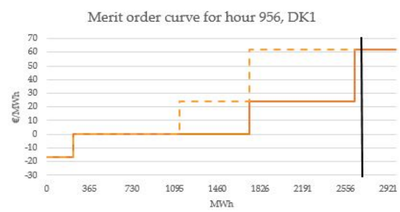
Table 3.1: Statistics on price, production and transmission for hour 50

Hour 956		
	DK1	**DK2**
Price	62	17
FlexiGas (G2)	15	N/A
Nuke22 (G6)	900	N/A
West Wind 1	908.8	N/A
West Wind 2	227.2	N/A
Nuke22 (G8)	N/A	347
Blue Water (G13)	N/A	750
Blue Water (G14)	N/A	600
East Wind 1	N/A	77.1
East Wind 2	N/A	693.9
Transmission	600	

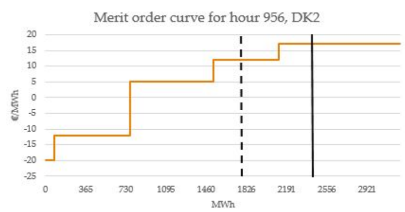
Table 3.2: Statistics on price, production and transmission for hour 956



(a) Merit order curve for hour 50. The demand for this hour is represented by the solid vertical line



(b) Merit order curve for hour 956 in DK1. Dashed line represents the supply curve without transmission



(c) Merit order curve for hour 956 in DK2. The dashed line represents original demand, solid line represents shift in demand due to transmission

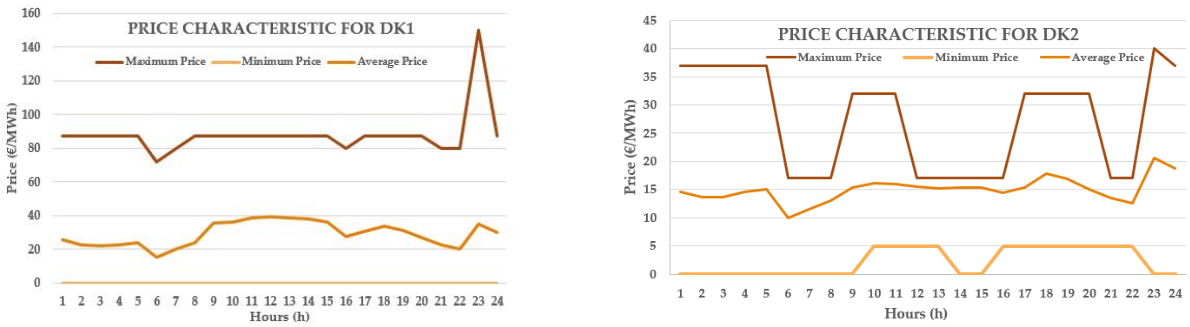
Figure 3.1

For the second time unit, the procedure is the same for the market clearing. This time though, the amount of energy to be transferred between the two zones is larger than the capacity of the interconnection cable: in this scenario we have congestion. 600 MWh are transferred from DK2 to DK1, but these are not enough to cover the imbalance. The two markets have to then be cleared separately, resulting in the two different prices. The demand curve for DK2 has been shifted to the right by 600 resulting in a higher zonal price, differently from DK1 that has its supply curve transposed by the same amount resulting in a lower price. Table 3.2 shows prices, generation quantities and transmission while figures 3.1b, 3.1c show merit order curves. All the above-mentioned steps illustrate how the market is effectively cleared: in our case, all the steps have been performed by MATLAB thanks to the LP formulation.

3.1.2. Market outcomes over November and January

A description of the results from the market-clearing in the months of November and January is undertaken in this section. Throughout the two months, prices vary as a function of the day due to different consumption and different production capabilities.

In figure 3.2a the maximum, average and minimum prices for DK1 as a function of the hour of the day are displayed. In this zone, prices remain quite constant at a not too high price, with no major fluctuation. The main reason for this is the large availability for wind that is present in this area, which enters at the lowest price in the supply curve driving the price low. The big spike in the maximum price value, occurring between the 23rd and 24th hour, signifies that in this hour a large amount of conventional generators must have been scheduled. This price spike, in fact, occurs at a time unit in which the total wind production for this area is very small (only 81 MWh) and all the generators up to producer G3 (Flexigas) have to be scheduled to cover the missing supply.

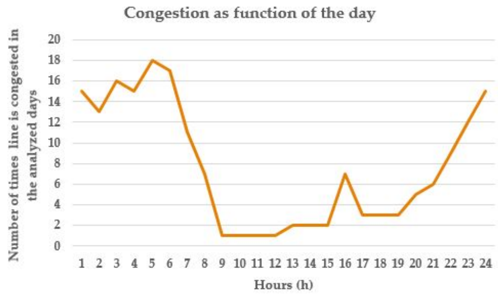


(a) Price characteristics for DK1

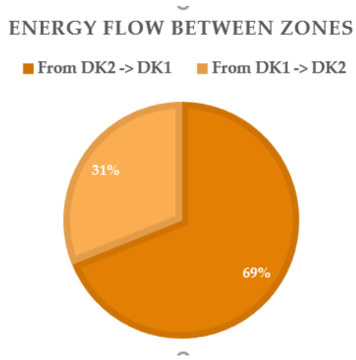
(b) Price characteristics for DK2

Figure 3.2

For DK2 price assumes a more volatile fashion: especially concerning the maximum price characteristic, one can see that there are fluctuations that occur at specific hours of the day. DK1 exports energy to Germany between 8:00 and 15:00, resulting in an extra demand that drives the price higher. Furthermore, in both zones, producer Nuke22 is active from 5:00 to 22:00: once this generator is inactive, in both areas the price increases, since more expensive units have to make up for the missing demand. Overall, DK2 has lower prices than DK1 since in this zone the big amount of hydro-power helps keep prices low. Additionally, this large capacity of Blue Water is often transferred to DK1 due to the higher demand present in this area, increasing the occurrences of flow from DK2 to DK1 as shown in 3.3b. Hence the fluctuations in price in DK2: when the cheap hydro-power is transferred, the price in DK2 goes higher. The price characteristics for the two areas corresponding with the generators scheduled is shown in figure 5.2.



(a) Occurrence of congestion in each hour for the 61 analyzed days



(b) Flow of energy from one zone to another

Figure 3.3

3.1.3. Congestion

An analysis of the times the cable is congested is undertaken. November and January together make up for 61 days: for each hour of these days the presence or lack of congestion is evaluated and shown in figure 3.3a. From this analysis, it is clear that the line is most congested at night and early morning when people are at their homes.

3.1.4. Wind generation impact and negative prices

As stated in the hourly market clearing examples, wind as a renewable energy generator enters the supply curves from the left side, before all the conventional generators, since the cost of renewable energy is 0 €/MWh. This shifts all the supply curve at a lower price: it impacts significantly the clearing of the market and its effect can be seen in the figure below.

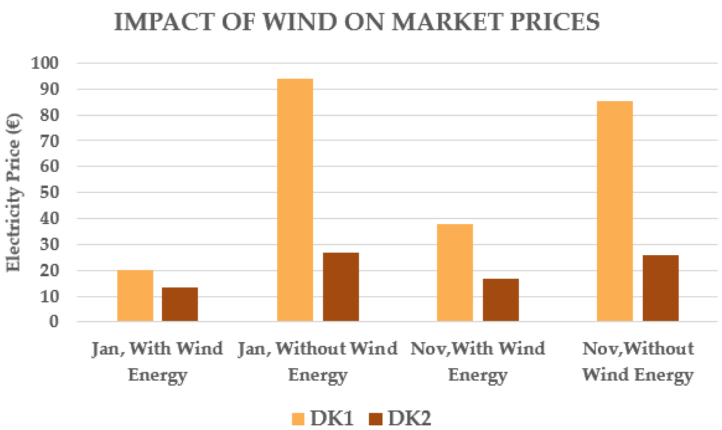


Figure 3.4: Impact of wind

It can be clearly seen that if the wind was not present as a producer, the prices would be significantly higher. In this case, wind energy production is also characterized by having support schemes. These producers have the same effect on the supply curve but have a negative price. This could result in negative prices when finding the equilibrium point. For this market scenario though, these cases do not occur since WW2 would need to be able to cover demand completely in order to have such prices. WW1 is the next producer, setting the price at 0 €/MWh. Finally one can see that there is a seasonality in wind prices: January is a windy month and lower prices with respect to November, a less windy month, can be seen.

3.2. *Generation scheduling*

3.2.1. *Conventional generators scheduling*

Conventional generators mainly includes all the suppliers except wind suppliers i.e. WW_1, WW_2, EW_1 and EW_2. Conventional generators are only scheduled when electricity production through wind energy is lower than demand. As represented in figure 3.4, the abscissa represents the total number of days in November and January and the ordinate shows how many times the conventional generator is scheduled in a day for DK1 and DK2 (If a conventional generator is scheduled in a particular hour it is represented by 1 and if the conventional generator is not scheduled then it is represented by 0. These values are added throughout the day and the maximum value that can be reached in a day is 24).

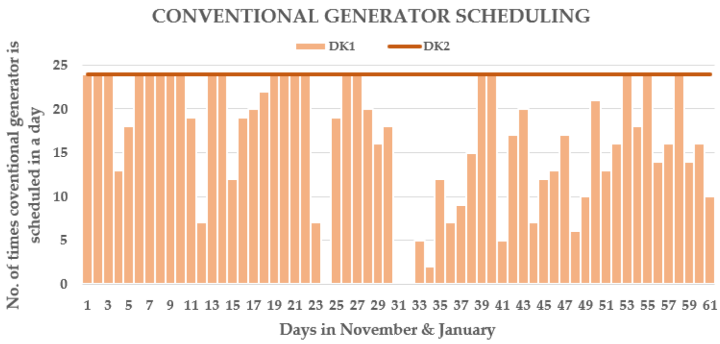


Figure 3.5: Conventional generators scheduling in DK1 and DK2.

As shown, DK1 requires conventional generators almost every day to meet the demand. On days 24, 31 and 32 the electricity produced by wind suppliers (WW_1 and WW_2) is exceeding the DK1 demand and in these cases, the conventional generators are not scheduled. DK2 is fully dependent on conventional generators because the electricity produced by wind suppliers (EW_1 and EW_2) never meets DK2 demand.

3.2.2. *Statistics of wind curtailment*

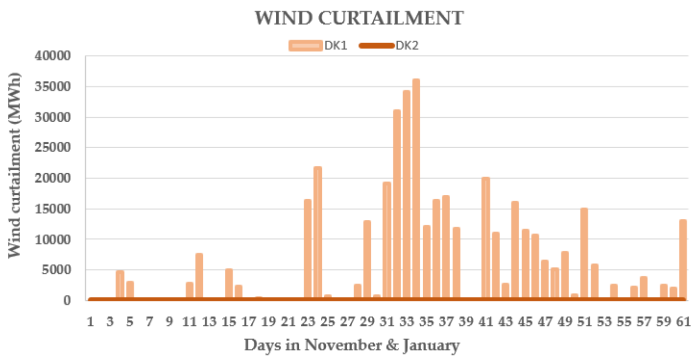


Figure 3.6: Wind curtailment in DK1 and DK2.

Wind curtailment, where the system operator cuts the amount of wind generation that can be sold onto the power grid, it is usually caused by one of the two factors: a transmission system that is incapable of accommodating the full dispatch of wind generation(involuntary curtailment) or when electricity through wind energy exceeds the demand (voluntary curtailment).
Figure 3.5 represents the statistics of wind curtailment in November and January. The abscissa represents the total number of days in November and January and the ordinate shows how much quantity (MWh) should be curtailed. DK1 curtails wind a dozen times because wind production exceeds DK1 demand and the excess amount of energy should be reduced or

exported. DK2 does not curtail any wind because the demand exceeds wind production and the additional electricity should be produced by conventional generators. Also, WW_1 and EW_2 face curtailment every time because they produce electricity at a higher price compared to their wind competitors (WW_2 and EW_1 respectively).

3.3. Load shedding

Load shedding occurs when the demand on the system is greater than the available supply and to prevent an imbalance and subsequent blackout we have to shed load. Many suppliers offer cost incentives for operators or consumers to voluntarily load shed during peak usage periods. The load shedding price is always higher than the maximum offering price in the market and if the load shedding in price is lower then the linear programming problem would shed load because it is cheaper than producing electricity. In this case, the load shedding price is set as 261 €/MWh and 236 €/MWh which is 1 € more compared to maximum offering price (260 €/MWh and 235 €/MWh) in both the zones.

It is important to remark that for the whole period of 61 days we did not find any case in which the demand was higher than the generation offered for both market areas, even when the full transmission capacity is used and this implies no load shedding for DK1 and DK2.

3.4. Revenue Computation

This section provides an in-depth analysis of the revenue earned by different generators participating in the market for the given timeline. The revenue could be defined as the monetary income a company generates before any expenses are deducted. The revenue earned by each generator for a given period mainly depends on four factors.

- If the individual producer is getting scheduled or not.
- The number of units that the producer is getting scheduled for.
- The market-clearing price.
- Support schemes, if made available for that producer.

Renewable energy-driven energy systems need concrete financial mechanisms to sell their generated electricity under uncertainty in a highly competitive environment. Hence three out of the four wind generators in the market have been provided with the following support schemes.

- **Feed in Tariff**: FIT is provided to EW1 a wind producer in DK2. FIT provides a guaranteed price hence the producer doesn't participate in the market and does not receive the market-based revenue. Thus the generator has a guaranteed income for the scheduled number of units. The FIT support for the market is set at 20 €/MWh.
- **Feed in Premium**: On the other hand FIP is being provided to WW2 a wind producer in DK1 and EW2 a wind producer in DK2. When under the FIP, the generator gets a market-based revenue for the scheduled units but on top of the market-based revenue (i.e market-clearing price times the amount produced), they will also receive fixed support. The FIP support for WW2 is set at 17 €/MWh and 12 €/MWh for EW2.

WW1 does not receive any support scheme in this study and this affects the producer's bidding price in the market which is an interesting point to note.

3.4.1. Revenue computation for a given time unit

In the current study, the day-ahead electricity market has been considered. As mentioned above the market is cleared by applying the optimization problem in MATLAB as a linear program. The scheduling depends on the offering price of the generators and the demand for that time unit. Table 3.3 shows how the revenue of both wind (with their support scheme) and conventional generators (with their revenue being entirely dependent on the clearing price) is summed up.

Supplier	Market	Schedule (MWh)	Clearing Price (€)	Support Type	Net Support (€/MWh)	Revenue (€)
WestWind1	**DK1**	908.8	62	N/A	N/A	56345.6
WestWind2	**DK1**	227.2	62	FIP	17	17948.8
Flexigas (G1)	**DK1**	0	62	N/A	N/A	0
Flexigas (G2)	**DK1**	15	62	N/A	N/A	930
Flexigas (G3)	**DK1**	0	62	N/A	N/A	0
Peako (G4)	**DK1**	0	62	N/A	N/A	0
Peako (G5)	**DK1**	0	62	N/A	N/A	0
Nuke22 (G6)	**DK1**	900	62	N/A	N/A	55800
CoalAtLast (G7)	**DK1**	0	62	N/A	N/A	0
EastWInd1	**DK2**	77.1	17	FIT	20	1542
EastWind2	**DK2**	693.9	17	FIP	12	20123.1
Nuke22 (G8)	**DK2**	347	17	N/A	N/A	5899
RoskildeCHP (G9)	**DK2**	0	17	N/A	N/A	0
RoskildeCHP (G10)	**DK2**	0	17	N/A	N/A	0
Avedovre (G11)	**DK2**	0	17	N/A	N/A	0
Avedovre (G12)	**DK2**	0	17	N/A	N/A	0
BlueWater (G13)	**DK2**	750	17	N/A	N/A	12750
BlueWater (G14)	**DK2**	600	17	N/A	N/A	10200
CoalAtLast (G15)	**DK2**	0	17	N/A	N/A	0

Table 3.3: Revenues for all the producers at hour 956

3.4.2. Revenue computation for November & January

Table 3.4 & 3.5 presents the revenues earned by the producers from DK1 and DK2 respectively. The program was run for 1464 hours covering both the months (November and January).
It is also important to note that these revenues are not equivalent to the profits since the marginal costs for the generators and O&M costs have not been taken into account.

Revenue for DK1				
	Offering Price (\euro/MWh)	**Revenue for November (\euro)**	**Revenue for January (\euro)**	**Total Revenue (\euro)**
FlexiGas (G1)	72	4378276	799324	5177600
FlexiGas (G1)	62	6424876	1787158	8212034
FlexiGas (G1)	150	3900	0	3900
Peako (G4)	80	2231710	249710	2481420
Peako (G5)	87	729372	19488	748860
Nuke22 (G6)	24	15950868	5293848	21244716
CoalAtLast (G7)	250	0	0	0
WW1	0	19596778.4	17642848.8	37239627.2
WW2	-17	7982710.7	8370637.8	16353348.5

Table 3.4: Revenue for all the producers in DK1

As expected the revenues for wind and hydro producers are quite high compared to other producers due to their low offering price, moreover the high capacity of wind and hydro also comes into the play, making sure they cover most of the demand at a given time unit. On the other hand, Nuke22 being a conventional generator can earn considerable revenue even after being restricted to limited hours in a day, this is due to their low offering price, hence in the absence of wind, Nuke22 becomes the first producer to be scheduled in the market. Another interesting point to be noted is that Nuke22 and the wind producers in the DK1 zone showcase a higher revenue over this timeline as shown in figure 3.7. This is due to a higher average price in DK1 compared to DK2. The offering price is also key to define if the producer would get scheduled or not for a given time unit, hence it is beneficial to bid at a lower price to increase their probability to get scheduled. For wind producers, the support schemes allow them to put negative bids into the market thereby pushing the price towards the negative region in order to guarantee their production being scheduled every hour.

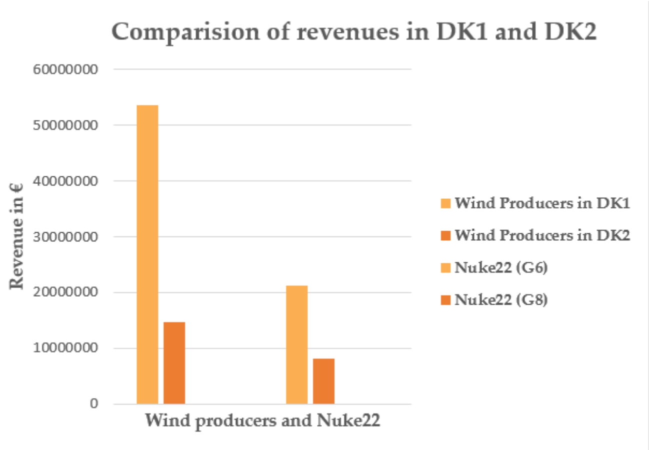


Figure 3.7: Revenues for Wind producers and Nuke22

Producers with different support schemes act differently in the market setup, for example, WW2 and EW2 receive a FIP support, this means their optimal strategy would be to offer at -17 €/MWh for WW2 and -12 €/MWh for EW2 which is their respective negative FIP values. This would make sure that they get at least 0 from the market. On the other hand for EW1 with the FIT support the producer gets fixed support hence turning the producer independent of the market price, hence an optimal strategy for EW1 would be to go as low as the Nordpool allows for a bid which is -500 €/MWh.In the real world, measures have been applied in order to restrict producers from misusing the scheme in the market but for this study, those constraints have not been included.

Revenue for DK2				
	Offering Price (€/MWh)	Revenue for November (€)	Revenue for January (€)	Total Revenue (€)
Nuke22 (G8)	17	5088913	3015237	8104150
RoskildeCHP (G9)	44	0	0	0
RoskildeCHP (G10)	40	3880	3840	7720
Avedovre (G11)	37	242031	125400	367431
Avedovre (G12)	32	908416	546976	1455392
BlueWater (G13)	5	9086370	6884175	15970545
BlueWater (G14)	12	6711624	4852152	11563776
CoalAtLast (G15)	235	0	0	0
EW1	-500	499754	643066	1142820
EW2	-12	5934939.6	7625268	13560207.6

Table 3.5: Revenue for all the producers in DK2

4. Conclusion

This study tries to create a realistic model of the day ahead electricity market for Denmark. Both the DK1 & DK2 have been included within the study with constraints such as export, import, and transmission which have a major impact on the demand of both the zones which goes on the effect the market-clearing prices. This report also highlights the benefits of support schemes for renewable energy systems in a competitive electricity market.

The outcomes from the analysis shows no load shedding, transmission mainly occurring from DK2 to DK1, wind producers in DK1 ended up with a higher revenue due to higher production and market clearing price compared to DK2. Overall renewables have a significant impact on electricity markets.

5. Appendix

```
T1 = readtable('Directory.xlsx');  %reading the excel file Directory.xlsx
A = eye(22);
f = [24 62 72 80 87 150 260 0 -17 17 44 40 37 32 5 12 235 -500 -12 0 261 236];
Aeq = -[1,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,1,1,0; 0,0,0,0,0,0,0,0,0,1,1,1,1,1,1,1,1,1,1,-1,0,1]; % A equivalent
lb =  [0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,-600,0,0]; % lower bounds of all generators,transmission and load shedding
P=zeros(2,1464);
U=zeros(22,1464);

for j = 1:1:1464
WW1 = T1.WW1;
ww1 = WW1(j);
WW2 = T1.WW2;
ww2 = WW2(j);
NN = T1.Nuke_west;
nuke_west = NN(j);
EW1 = T1.EW1;
ew1 = EW1(j);
EW2 = T1.EW2;
ew2 = EW2(j);
NN_East = T1.Nuke_east;
nuke_east = NN_East(j);
b=[nuke_west,350,380,370,480,320,1200,ww1,ww2,nuke_east,300,380,360,320,750,600,860,ew1,ew2,600,T1.Demand_1(j),T1.Demand_2(j)];
beq = -[ T1.Demand_1(j); T1.Demand_2(j)];
[units,obj,z,w,price] = linprog(f,A,b,Aeq,beq,lb)

U(:,j)=units;  %units scheduled for each generators in a form of a table
Prices = price.eqlin;
P(:,j)=Prices;  %making a market clearing price table for DK1 and DK2
end
```

Figure 5.1

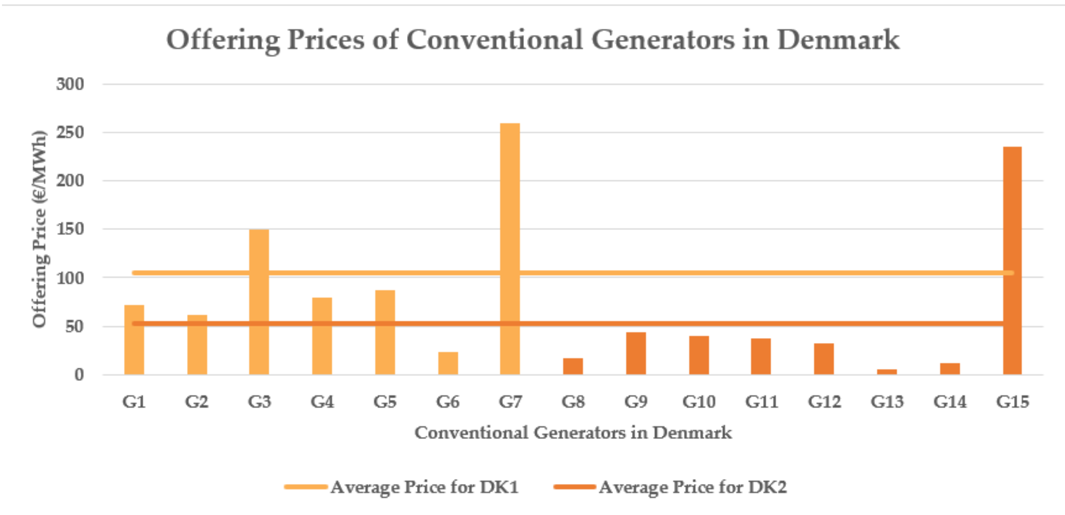


Figure 5.2: Offering Prices of conventional generators