

# Danish Wind Power Export and Cost



By

**Henrik Lund, Frede Hvelplund, Poul Alberg Østergaard, Bernd Möller, Brian Vad Mathiesen**  
*Department of Development and Planning, Aalborg University, Aalborg, Denmark*

**Anders N. Andersen**

*EMD International, NOVI Research Park, Aalborg, Denmark*

**Poul Erik Morthorst, Kenneth Karlsson, Peter Meibom and Marie Münster**

*Risø DTU, National Laboratory for Sustainable Energy, Roskilde, Denmark*

**Jesper Munksgaard**

*Pöyry Energy Consulting AS, Copenhagen, Denmark*

**Peter Karnøe**

*Department of Organization, Copenhagen Business School, Copenhagen, Denmark*

**Henrik Wenzel,**

*Institute of Chemical Engineering, University of Southern Denmark, Odense, Denmark*

**Hans Henrik Lindboe**

*Ea Energy Analyses, Copenhagen, Denmark*

# **Danish Wind Power Export and Cost**

© The authors

February 19<sup>th</sup> 2010

## **Authors:**

Henrik Lund, Frede Hvelplund, Poul Alberg Østergaard, Bernd Möller, Brian Vad Mathiesen, Anders N. Andersen, Poul Erik Morthorst, Kenneth Karlsson, Peter Meibom and Marie Münster, Jesper Munksgaard, Peter Karnøe, Henrik Wenzel, Hans Henrik Lindboe

## **Publisher:**

Department of Development and Planning,  
Aalborg University  
Fibigerstraede 13  
DK9220 Aalborg  
Denmark

Pdf of this study can be downloaded freely from the following link  
[www.energyplanning.aau.dk/](http://www.energyplanning.aau.dk/)

ISBN 978-87-91830-40-2

## **Cover photo:**

Kristen Skelton

## **Acknowledgement**

This study is part of the research project Coherent Energy and Environmental System Analysis (CEESA), partly financed by the Danish Council for Strategic Research. The rest has been financed by the companies and institutions of the authors.

This study has been initiated and conducted solely on the initiative of the authors and involve no additional financing or involvement by any political or commercial interests.

# Content

About the authors of this report	4
Abstract	6
Introduction	7
1. Wind Power and Export	9
1.1 Why is the CEPOS statement on export not correct?	9
1.2 What is correct then?	14
1.3 How can more wind power be integrated in the future?	19
1.4 Conclusions on wind power and export	20
2. The Financing of Danish Wind Power	22
2.1 Why is the CEPOS statement on financing not correct?	22
2.2 How is Denmark really financing wind power?	23
2.3 Conclusions on the financing of Danish Wind Power	26
3. Can the Danish experience regarding wind power's effects on employment be transferred to the US?	27
Appendix 1: Statistical analysis of the correlation between wind power and export	30
Appendix 2: Statistical analysis of the correlation between changes in wind power and export	32
Appendix 3: Wind power and electricity prices	34
References	36

# About the authors of this report

This report is written by a group of energy researchers and experts from Danish universities and independent consultants. The group represents many years of experience within a wide range of expertise covering academic studies as well as hands on experience with the operation and management of the Danish energy system.

## **Aalborg University (Department of Development and Planning)**

Dr.Techn. Henrik Lund, Professor in Energy Planning and Editor-in-Chief of Elsevier international journal ENERGY, is the main developer of the energy system analysis model EnergyPLAN and author of the book “Renewable Energy Systems” (Academic Press, Elsevier 2010).

Dr.Techn. Frede Hvelplund, Professor in Energy Planning, has a background in economy and social anthropology, and many years of experience in the analysis and design of energy policy strategies. In 2008, he was awarded the European Solar Prize.

Ph.D. Poul Alberg Østergaard, Associate Professor in Energy Planning, researches large scale integration of renewable energy from a technical as well as from an organisational perspective. He also has experience trading electricity on the Nord Pool Market for small and medium-sized power plants.

Ph.D. Bernd Möller, Associate Professor in Energy Planning and Geospatial Analysis, has key competence within energy systems analysis and their geographical perspective, and is board member of Samsø Energy Academy, the Danish Renewable Energy Island of Samsø.

Ph.D. Brian Vad Mathiesen, Assistant professor in Energy Planning, is the main author of the technical and economic analyses behind the two energy strategies of the Danish Society of Engineers, IDA Energy Plan 2030 and IDA’s Climate Plan 2050.

## **Technical University of Denmark (Risø DTU, National Laboratory for Sustainable Energy)**

M.Econ. Poul Erik Morthorst is Senior Research Specialist in the Systems Analysis Department at Risø National Laboratory for Sustainable Energy, the Technical University of Denmark. He has participated in a large number of projects related to wind power, takes part in several national and international committees and is member of the board of the Danish TSO, Energinet.dk.

Ph.D. Peter Meibom, Senior scientist in energy system analysis, is one of the main developers of the Wilmar Planning tool which is widely used for wind integration studies in Europe. He has co-authored around 50 international papers about modelling of power systems with large shares of wind power.

Ph.D. Kenneth Karlsson, Senior scientist at DTU Climate Centre, working with scenario analysis and the interaction between macro-economic and energy system models. He has been involved in the Danish Society of Engineers’ *IDA’s Climate Plan 2050* and is at present working on scenarios for the Danish Commission on Climate Change.

Ph.D. Marie Münster, Research Assistant at the System Analysis Division, recently completed her Ph.D. in Energy System Analysis of Waste-to-Energy Technologies with focus on flexible use of waste for energy in energy systems with high percentages of wind power.

## **Copenhagen Business School**

Ph.D. Peter Karnøe, Professor in Innovation, Technology and Market Architectures at Copenhagen Business School, is an expert on the creation of the Danish wind turbine industry and is co-editor of the book “Path Dependence and Path Creation”, Lawrence Earlbaum Press, 2001).

## **University of Southern Denmark**

### **(Institute of Chemical Engineering, Biotechnology and Environmental Technology)**

M.Sc. Henrik Wenzel, Professor in Environmental Engineering, is an expert in environmental assessment in a system perspective with extensive experience in energy systems. Henrik Wenzel was project leader of the development of the Danish EDIP methodology for environmental assessment of products and

systems for which he received the most significant Danish environmental prize, the DADES prize, and co-received the great Nordic Nature and Environment prize.

**EMD International Ltd. (Department of Energy Systems)**

Head of Department Anders N. Andersen, in charge of the development of e.g. the modelling software package, energyPRO, for combined techno-economic design, analysis and optimisation of cogeneration and trigeneration projects as well as other types of complex energy projects.

**Pöyry Energy Consulting AS**

Ph.D. Jesper Munksgaard is a senior consultant at Pöyry with special expertise in wind power, energy policy and energy markets. He is an economist and has a record of more than twenty years of experience in the energy sector including an extensive list of publications and presentations on different topics within wind power.

**Ea Energy Analyses**

M.Sc. Hans Henrik Lindboe is one of the founders and partners in the consultancy and research company Ea Energy Analyses. In recent years, Hans Henrik has contributed to analyses of the utility value of investments in the Nordic transmission grid and the economic conditions of integrating large amounts of renewable energy in the electricity system. He was previously a systems planner with the TSO in Eastern Denmark.

## Abstract

In a normal wind year, Danish wind turbines generate the equivalent of approx. 20 percent of the Danish electricity demand. This paper argues that only approx. 1 percent of the wind power production is exported. The rest is used to meet domestic Danish electricity demands.

The cost of wind power is paid solely by the electricity consumers and the net influence on consumer prices was as low as 1-3 percent on average in the period 2004-2008. In 2008, the net influence even *decreased* the average consumer price, although only slightly.

In Denmark, 20 percent wind power is integrated by using both local resources and international market mechanisms. This is done in a way which makes it possible for our neighbouring countries to follow a similar path. Moreover, Denmark has a strategy to raise this share to 50 percent and the necessary measures are in the process of being implemented.

Recently, a study made by the Danish think tank CEPOS claimed the opposite, i.e. that most of the Danish wind power has been exported in recent years. However, this claim is based on an incorrect interpretation of statistics and a lack of understanding of how the international electricity markets operate. Consequently, the results of the CEPOS study are in general not correct. Moreover, the CEPOS study claims that using wind turbines in Denmark is a very expensive way of reducing CO<sub>2</sub> emissions and that this is the reason for the high energy taxes for private consumers in Denmark. These claims are also misleading. The cost of CO<sub>2</sub> reduction by use of wind power in the period 2004-2008 was only 20 EUR/ton. Furthermore, the Danish wind turbines are not paid for by energy taxes.

Danish wind turbines are given a subsidy via the electricity price which is paid by the electricity consumers. In the recent years of 2004-2008, such subsidy has increased consumer prices by 0.54 €/kWh on average. On the other hand, however, the same electricity consumers also benefitted from the wind turbines since the wind power decreased the electricity market price on Nord Pool. On average during 2004-2008, such effect decreased the consumer prices by 0.27 €/kWh and consequently the net influence during this period increased consumer prices by only 0.27 €/kWh equal to only 1-3 percent of the final consumer prices. In 2008, the net influence of wind power actually *decreased* the consumer price slightly by approx. 0.05 €/kWh. Consequently, the influence of Danish wind turbines on the consumer electricity price is negligible.

## Introduction

In a normal wind year, Danish wind turbines generate the equivalent of approx. 20 percent of the Danish electricity demand. In 2008, the number was 19.3 percent.

In the report “*Wind energy – The case of Denmark*” September 2009 [1], the Danish think tank CEPOS claims 1) that most of the Danish wind power has been exported in recent years, and 2) that wind turbines in Denmark are very costly to Danish taxpayers and electricity consumers.

The CEPOS report has been used in the US to cast serious doubt on whether other countries can learn from the Danish case. Among others, the CEPOS report cites President Obama:

*”America produces less than 3 percent of our electricity through renewable sources of energy like wind and solar — less than 3 percent. In contrast, Denmark produces 20 percent of their electricity through wind.”*

Relating to this statement, the CEPOS report has been quoted

*“to refute the claim that Denmark generates 20 percent of its power from wind stating that its high intermittency not only leads to new challenges to balance the supply and demand of electricity, but also provides less electricity consumption than assumed.” [2]*

Moreover, the CEPOS report has been used to say that due to wind power

*“Danish ratepayers are forced to pay the highest utility rates in Europe.” [3]*

But - as will be documented in the following – the CEPOS conclusions are in general not correct and the above statements are misleading.

1.

The CEPOS study claims on page 2 that wind power “*has recently (2006) met as little as 5% of Denmark’s annual electricity consumption with an average over the last five years of 9.7%*”.

The statement is not correct. This paper argues that approx. only 1 percent of Danish wind power production is exported. The rest is used to meet domestic Danish electricity demands, thus implying that wind power meets close to 20% of Danish electricity consumption.

2.

The CEPOS study claims on page 19 that “*a significant fraction of the charges and taxes paid for by Danish domestic consumers is recycled to support ..... the feed-in tariffs that make it attractive ... to invest in wind power*”. (see full citation in section 2.1).

This statement is not correct. No taxes are recycled to support the established wind turbines<sup>1</sup> and the net influence on consumer electricity prices is as low as 1-3 percent on average in the period 2004-2008. In 2008, the influence even *decreased* the average

---

<sup>1</sup> Only with regard to research, development and demonstration are taxpayers involved in payments to wind power as well as other new technologies. The payment for already established wind turbines is made by power consumers.

consumer price slightly. Moreover, the payment to wind power does not make Danish electricity prices any higher than those in other countries. In fact, Danish electricity prices (excl. tax and VAT) inclusive of all payments for 20 percent wind power are among the cheapest in Europe.



# 1. Wind Power and Export

The CEPOS study claims on page 2 that wind power “*has recently (2006) met as little as 5% of Denmark’s annual electricity consumption with an average over the last five years of 9.7%*”.

## 1.1 Why is the CEPOS statement on export not correct?

We have been able to replicate the calculations of CEPOS by using the same data, namely hourly production data, which can be downloaded from the website of the Danish TSO Energinet.dk: [www.energinet.dk](http://www.energinet.dk). By using these data, one can see hour by hour consumptions and productions divided into 1) wind power, 2) large power plants (Extraction combined heat and power and Condensing plants) and 3) small CHP (combined heat and power) plants in the two separate supply areas of Denmark, i.e. east and west.

If one presumes that ***all export by default is wind power*** (until the export exceeds the wind power production), we can replicate the same numbers as the CEPOS study, i.e. the 5 percent of electricity consumption in 2006 mentioned above. This implies that CEPOS statement of 5 percent wind power in 2006 must build on an assumption that export, when present, is by default wind power. For the most recent year, 2008, the number will, on the same assumption, be 12 percent. However, if one presumes that ***all export by default is large and small power stations***, the same number is 17 percent in 2006 equal to the total wind power production of that year. In this respect, export of wind is only as little as 0.01 percent of the demand. The same pattern shows for 2008.

Consequently, the whole claim of the CEPOS study originates from the presumption that ***all export by default is wind power***.

However, this assumption is not correct, and it builds on an erroneous interpretation of statistics and a lack of understanding of the Nordic electricity market.

The CEPOS study’s main argument for making the presumption that ***all export by default is wind power*** is that the Danish export of electricity is generally higher during hours of high wind production than during hours of low wind production. The CEPOS study shows (on pages 15 and 16) diagrams of such correlation for western Denmark 2007 and eastern Denmark 2006 and concludes the following:

*“.. the coincidence of so much wind output with net outflows makes the case for claiming that there is a large component of wind energy in the outflow, indisputable”.*

Based on this argument, the CEPOS study then implicitly presumes that all export by default is wind power (until the export exceeds the wind power production). However, the assumption is not correct. As will be shown in the following, one cannot conclude that this means that all export by default is wind power. On the contrary, almost all wind power is consumed in Denmark.

We have reconstructed a diagram in Fig. 1 plotting wind power production on the x-axis and export on the y-axis using data from 2008 for western Denmark. As one can see, there is a tendency that the higher the wind power production, the higher the export.

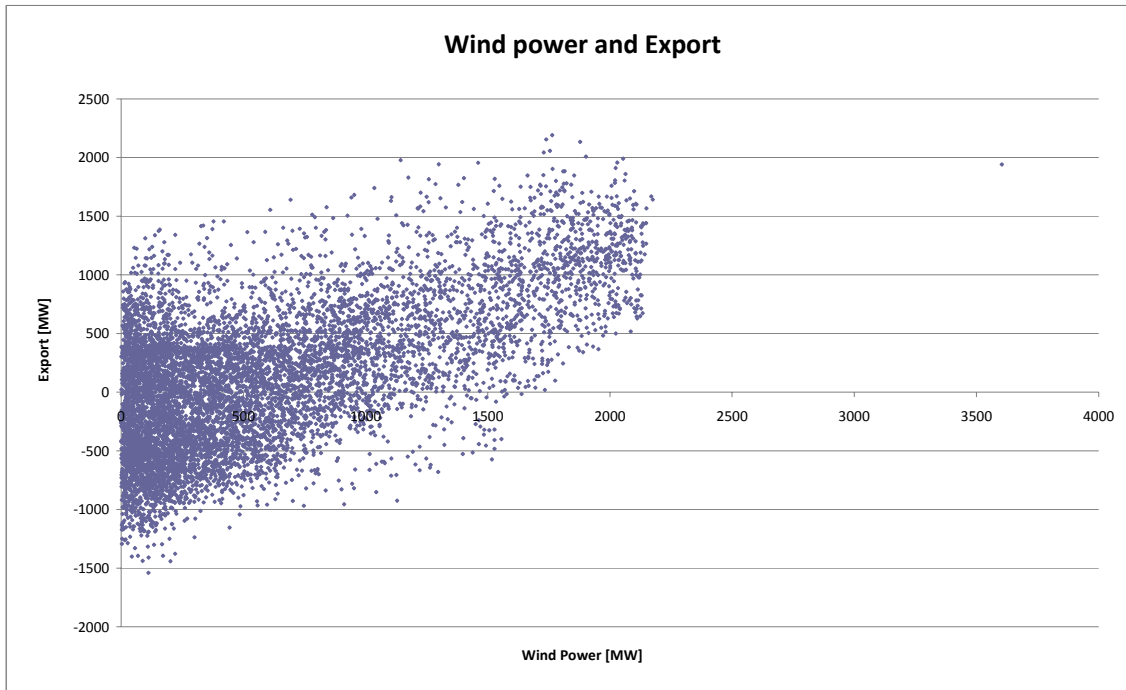


Fig 1: Correlation between hourly Wind Power and Export in western Denmark 2008

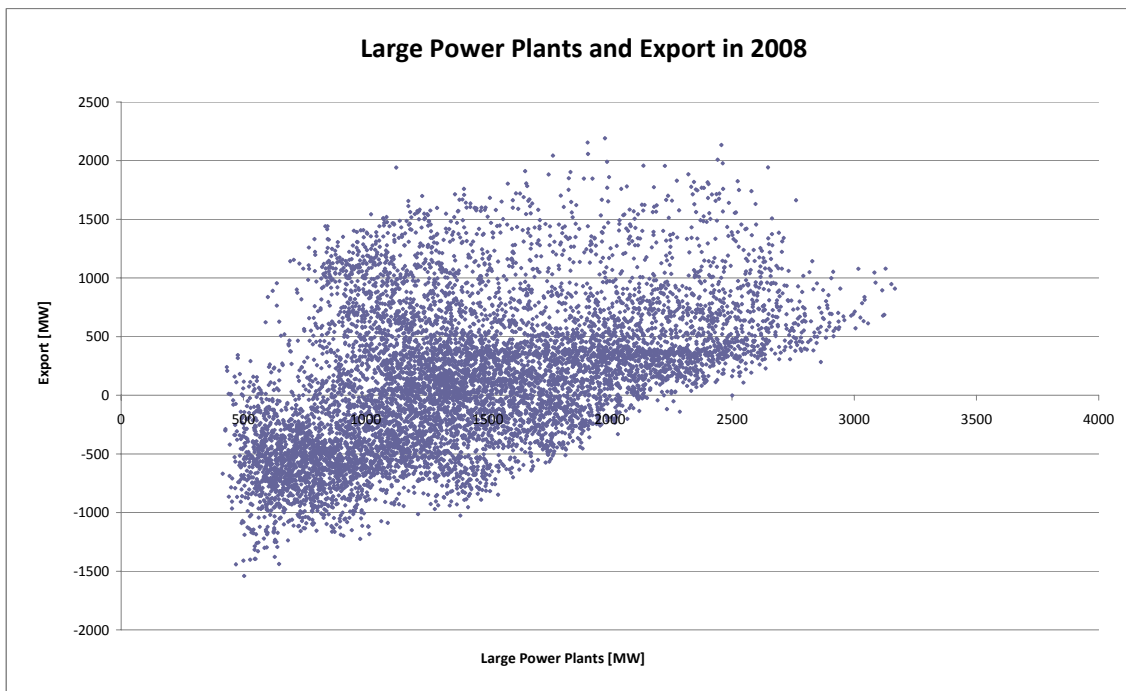


Fig 2: Correlation between hourly power from Large Power Plants and Export in western Denmark 2008

However, this is not unique for wind power. This is general for all types of production units in the Danish electricity system. We have made the same analysis for the Large

CHP and Power plants with the result illustrated in Fig. 2. As one can see, there is no real difference between the plot of wind power vs. export and the plot of Large CHP vs. export. Accordingly, one could use more or less the same argument for large power plants as for wind power. In both cases, however, the argument would be wrong. The causal relation behind export is more complex and involves understanding market mechanisms and cost implications of the various power suppliers on the Nordic grid.

Appendix 1 shows similar diagrams for all production units in the Danish system divided into 1) Wind turbines, 2) Large power plants and 3) Small CHP plants. The diagrams show the tendency that high export more frequently takes place during hours of high wind production than during hours of low wind production. However, the same is the case for production on both Large and Small CHP's. For wind power, the correlation coefficient  $R$  is as low as 0.62 and  $R^2$  is only 0.39. Such a correlation is *very* poor and cannot justify any conclusion about causal relation. Therefore, none of these diagrams say anything about the causal relation, i.e. which units cause the export. It is not possible, based on any of these diagrams, to conclude (as CEPOS does) that all export by default is caused by wind power.

In order to look for the causal relation, we have also analysed whether changes in export from one hour to another are derived from wind power more than from other production units. Such analysis has been made by calculating all hourly changes in wind production and export during 2008. The results were then plotted x,y in a diagram as shown in Appendix 2. Moreover, we have made the same diagram for large power plants. Normally one would require a correlation coefficient resulting in  $R^2$  around 0.9 or above to conclude that there is a strong correlation between the changes, and even then one cannot directly interpret correlation as causal relation. In this case, the correlation coefficient between changes in wind power and import/export is as low as 0.30 ( $R^2 = 0.09$ ) which is extremely weak. On the other hand, the correlation coefficient between changes in large power plants and import/export is  $R=0.65$ , which is still very weak, but stronger than the wind vs. export correlation. Therefore, such analysis does not in any way suggest that changes in import/export are generated by changes in wind power.

Consequently, none of these diagrams showing only correlations over time can be used to establish a causal relation between wind power and export. On the contrary, they indicate that wind power in general does not influence export any differently than other production units.

Moreover, as a general comment, the use of hourly statistics for trying to determine the impact of wind power on other production units inherently gives a faulty time perspective. Due to the impact of hydro power with storage capacity it is necessary to look at longer time spans if one wishes to determine which plants have been affected by the wind. Another approach can be by looking at marginal costs which will be elaborated on below.

To establish a causal relation, one has to examine WHY the Danish energy system ends up exporting or importing electricity. Such causal relation has to do with the functionality of international (Nordic) electricity markets and how the independent power generators respond to price incentives. Most export is generated in power plants

for the simple reason that it is financially attractive for the Danish power producers to generate power and sell it on the international power market. Such export is highly influenced by the fact that Denmark has a lot of CHP rendering fossil-based power plants competitive to foreign power plants mainly due to the financial advantage of district heating and the consequential lower marginal cost of operation per kWh of power.

The following two examples illustrate why the causal relation can only be established by observing the electricity markets.

Fig. 3 compares two different hours of production in 2008: one hour in January with significant export taking place and one in March with no export taking place. In both situations, the production from wind turbines is approx. 1000 MW and the total Danish consumption is around 3200 MW. The large difference is evident in the production at the large CHP and power stations. On March 10<sup>th</sup>, the production at these was approx. 1000 MW while on January 5<sup>th</sup>, the production was more than 1900 MW. Moreover, the production on the small distributed CHP plants was a little higher in March than in January.

It is obvious that wind power in this situation can hardly explain WHY Denmark chose to export in January and not in March.

Nevertheless, the CEPOS study calculates as if all export in the January situation is based on wind power while all the electricity produced at the power plants is used in Denmark.

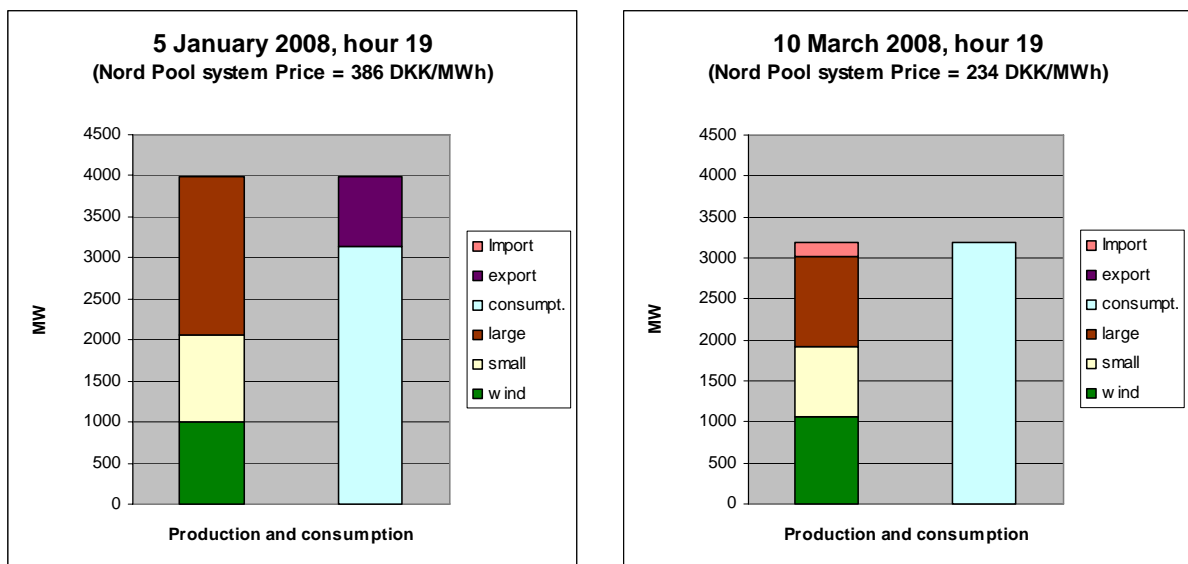


Fig. 3: Consumption and production in two 2008 situations with the same wind power production but different export figures.

However, if we look at Fig. 3 and examine the contribution of the different generators, it is clear that large power stations generated much more electricity in the January situation than in the March situation. In both situations, wind power production was about 1000 MW as mentioned. Therefore, we infer that the reason for the difference

between the two hours is the financial incentive for mainly the large power stations to produce (or not produce). The price on the Nord Pool international electricity market was only 234 DKK/MWh on March 10<sup>th</sup> and substantially higher on January 5<sup>th</sup>, namely 386 DKK/MWh. Consequently, the power stations make a profit on exporting in January but not in March.

Fig. 4 is even more effective at illustrating the ‘causality’ of energy production causing export from wind power and power plants.

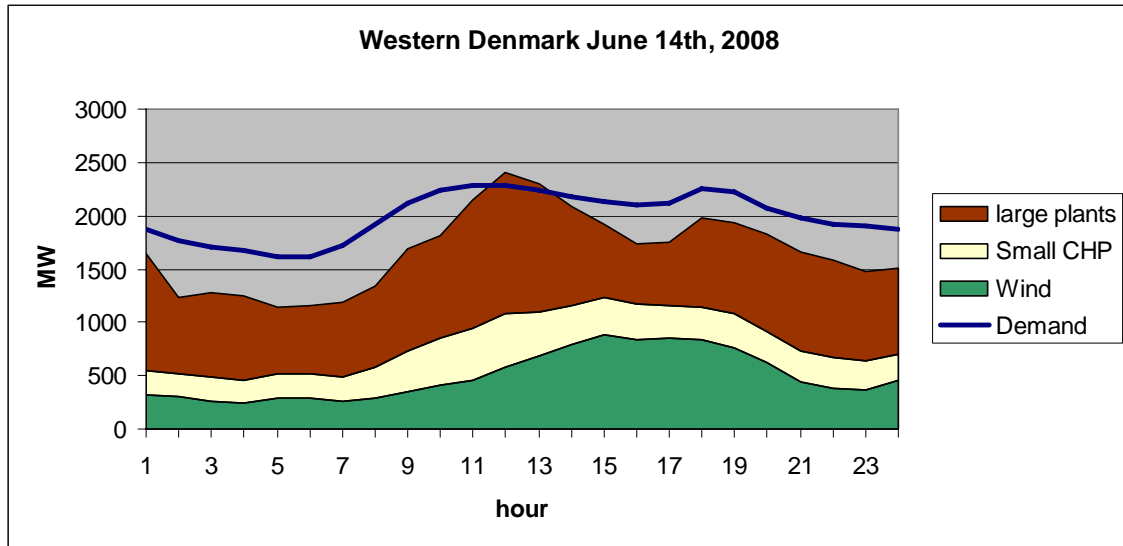


Fig. 4: Actual Danish electricity demand and production on June 14<sup>th</sup>, 2008.

As one can see, there was no export during the hours 1 to 11 and after 13 on June 14<sup>th</sup>, 2008. There was a small amount of export during the hours between 11 and 13. In the CEPOS study, this export is by default said to come from wind turbines. However, Fig. 4 shows that there is no evidence to support that.

As one can see, the coal-fired large CHP and condensing mode plants increase their production in the same period and the system ends up exporting. However, if the large plants had not increased production, there would be no export. The reason for the large plants’ production increase during such hours is the financial attractiveness to do so (the income from the Nord Pool electricity market exceeds the marginal production costs). The fact that this is a summer situation makes this even clearer as changes in electricity production are not caused by needs to produce additional heat on the CHP units.

Looking at the exact Nord Pool Prices of that day, one can see the price increases during exactly the same hours in which the large power plants increase production and peaks between 11 and 13 o’clock. Consequently, with the current price mechanism in the Nord Pool market, it is financially rational for the individual power producers to increase the production, and the aggregate effect of the increased production is that the ‘system’ starts exporting.

The point is that the reasons for export have to be found by observing the market mechanisms of international electricity markets and, as we shall see, such observation

shows a causal relation between export and large power plants but next to no causal relation between export and wind power.

## **1.2 What is correct then?**

First, we do agree with the CEPOS study that the balancing of an electricity system requires access to balancing and regulating reserves in order to make the system function, and that Denmark is well-connected to neighbouring countries with transmission lines. However, as already stated and supported above, we do not agree on the implicit presumption in the CEPOS study that this means that all export by default is wind power. Such presumption is not correct.

Denmark is part of an international collaboration in which a large number of European countries help one another in securing the balancing task e.g. within the supply of primary automatic reserves. Denmark draws upon the assistance of other countries and helps them in return. That includes the balancing of wind power in Denmark as well as in Denmark's neighbouring countries. One of these countries is Germany, and the northern region of Germany, Schleswig-Holstein, has more or less the same proportions of wind power as Denmark.

We do agree with the CEPOS study that when we increase the number of wind turbines in Denmark, we need more regulating power. However, it is not correct to say - as the CEPOS study implicitly claims - that this regulating power by default is coming from Norway and Sweden. Denmark shares a well-functioning regulating power market with Finland, Norway and Sweden which has the necessary capacity to provide all the up- and downward regulating power we need in order to operate the system. It is most cost efficient to handle the regulation in the Nordic power system via a common regulating power market, analogous to the distribution of primary (frequency) reserves among countries. However, Danish regulating power resources are used whenever it is most cost efficient, given the particular mix of energy production technologies in the system at any point in time and given the present rules for price making in the market. Moreover, all the costs of operating this regulating power market are included in the electricity price, which is on the same level as in other European countries. When regulation based on Norwegian or Swedish hydro power with storage capacity is often more cost effective than local Danish regulating resources, the hydro power will be prioritised in the merit order. Given the present institutional set-up, this solution is good business for all countries involved, but it says nothing about the possibility to regulate by use of solely local resources.

What can be said for a fact, and what would be fair to say about the present technology mix in the Danish energy system, is illustrated here for the year 2008. In 2008, wind turbines in Denmark produced 6,978 GWh equal to 19.3 percent of the electricity demand (36,105 GWh).

During a few hours, the wind power production exceeded the demand and the excess production was exported. However, this happened in only 43 hours and the total excess production being exported was as low as 5 GWh, equal to less than 0.1 percent of the wind power production (or less than 0.02 percent of the demand).

In other hours, there were *either* no export at all *or* the wind production exceeded the export. In such hours, the share of wind production which exceeded the export would have to be used domestically – no other outlet for this wind power exists. In 2008, this domestically used production was as high as 4,398 GWh equal to 63 percent of the wind power production (or approx. 12 percent of the demand). It should be noted that this number only includes the share that exceeds the export.

Consequently, one can say *for a fact* that a minimum of 0.1 percent of the Danish wind power production in 2008 was exported and a minimum of 63 percent was used in Denmark.

With regard to the remaining 36.9 percent, one cannot conclude anything from a purely technical, physical or statistical point of view as illustrated before. In all the remaining hours, the production was a combination of wind power and electricity production from large-scale CHP and power plants and small distributed CHP plants, and it is not possible from a technical, physical or statistical point of view to determine which parts of this production were exported and which were used domestically. Such question cannot be answered solely by looking at the correlation over time.

If one should identify whether export in such hours came from one type of production or another, one would have to establish a causal relation, i.e. explain why and from which units export is generated. Such causal relation can be established by observing the international electricity markets on which the import/export is determined.

Denmark is part of the Nordic electricity market Nord Pool on which the electricity production and price are found as illustrated in Fig. 5.

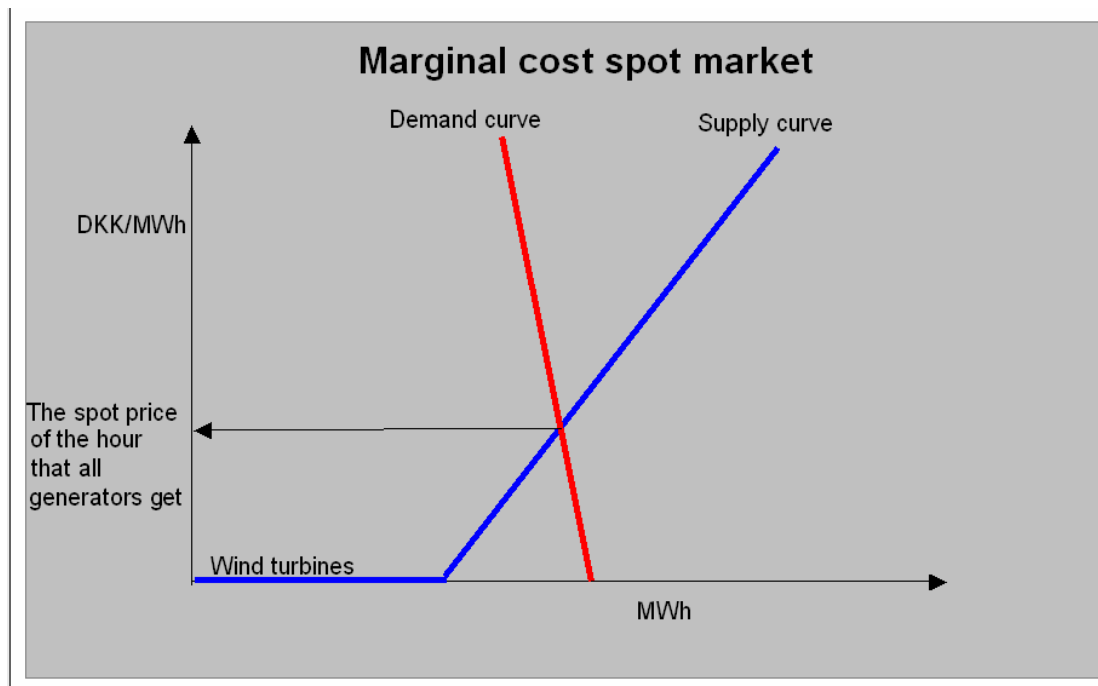


Fig. 5: Price setting in a marginal cost electricity spot market.

Wind power and other categories of electricity generation are offered at the short term marginal cost of producing electricity on the given unit. For wind turbines this is close to zero whereas power plants with a fuel use have marginal costs substantially higher. This creates a notable implication for the power market. By shifting the supply curve to the right, wind power in fact typically reduces the spot market price in a given hour. This is for the benefit of consumers but at the expense of the more expensive power units.

Fig. 6 shows the merit order of marginal production at the Nordic Nord Pool Market.

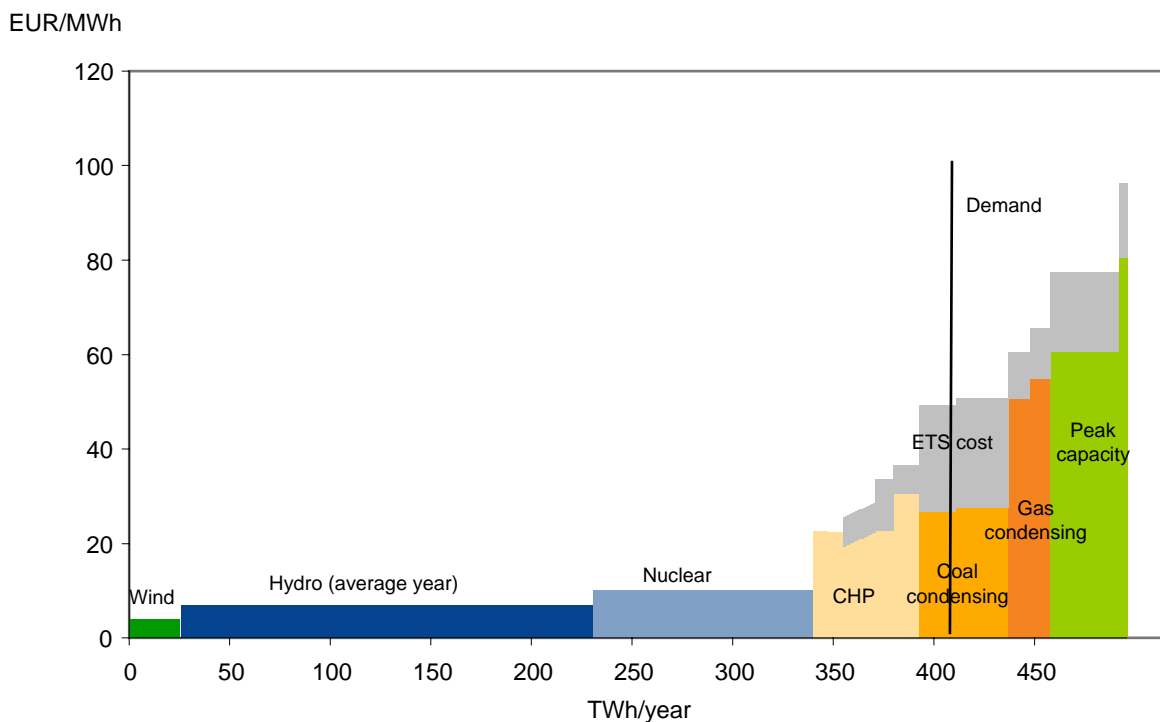


Fig 6: Merit order of marginal production at the Nordic Nord Pool Market. Source: Pöyry A/S.

Wind power has the lowest marginal production costs in the Nordic power system. Danish export is possible because Denmark has interconnectors and access to the international market as illustrated in Fig. 7. Export takes place when the price outside Denmark is higher than the short-term marginal cost of the Danish units that may increase production. From a market perspective, it is generally the most expensive production in Denmark which is exported, as any cheaper production would already have replaced more expensive production operating to cover the Danish demand. In the Danish case, these production costs are influenced by CHP production.





Fig. 7: Denmark (in box) is situated between continental Europe and the Scandinavian Peninsula. Western Denmark is connected to Germany, Sweden and Norway while eastern Denmark is connected to Sweden and Germany only. The map also indicates the price areas of the Nord Pool electricity market area (EUR/MWh). Source:[4]

How export is generated can be explained by observing the example shown in Tables 1 and 2.

In Table 1, there are no interconnectors and hence no export. In such case, the production in Price area 1 (E.g. western Denmark) will be 2,000 MWh and the price will be 200 DKK/MWh. Production and price in Price area 2 (e.g. southern Norway) will be uncorrelated with production and price in area 1. However, in Table 2 there are interconnectors and thus the possibility of import/export. In this case, the market will find a situation in which a final price of 350 DKK/MWh is established in area 2 and 275 DKK/MWh in area 1. Thus, it will pay for power plants 2 and 3 to start producing so that Price area 1 can export to Price area 2.

This example clearly illustrates the market principle that the export is produced on the unit with the highest bidding price, i.e. the unit with the highest marginal production costs which in the Danish system is not the wind turbines.

Using a market principle leads to the conclusion that in most cases the units with the lowest marginal production costs (i.e. wind) are sufficient for domestic demand (i.e. in Denmark), while the units with the highest short-term marginal production costs (i.e. thermal units) are in general the ones which enable the export of electricity. Such

principle is valid to the point at which the present stock of thermal plants cannot be decreased further due to the technical operation of the system.

NordPool Spot						
Simple example of spot trade in a certain hour tomorrow						
No connection between the two price areas						
	Price area 1			Price area 2		
		Amount [MWh]	Bidding price [DKK/MWh]		Amount [MWh]	Bidding price [DKK/MWh]
<b>Buying offer:</b>		2000	Priceindep.		2500	Priceindep.
<b>Sale offers:</b>	Wind turbines	1500	0	Power plant 5	500	50
	Power plant 1	500	200	Power plant 6	500	100
	Power plant 2	500	250	Power plant 7	500	350
	Power plant 3	500	275	Power plant 8	500	400
	Power plant 4	500	325	Power plant 9	500	435
				Power plant 10	500	450
<b>Spot price of the hour</b>			<b>200</b>			<b>435</b>

Table 1: Example of a spot trade in a certain hour tomorrow. No connection between the two price areas. The shaded area indicates the marginal price of the hour and, thus, the marginal supplier unit.

NordPool Spot						
Simple example of spot trade in a certain hour tomorrow						
1000 MW interconnector between the two price areas						
	Price area 1			Price area 2		
		Amount [MWh]	Bidding price [DKK/MWh]		Amount [MWh]	Bidding price [DKK/MWh]
<b>Buying offer:</b>		2000	Priceindep.		2500	Priceindep.
<b>Sale offers:</b>	Wind turbines	1500	0	Power plant 5	500	50
	Power plant 1	500	200	Power plant 6	500	100
	Power plant 2	500	250	Power plant 7	500	350
	Power plant 3	500	275	Power plant 8	500	400
	Power plant 4	500	325	Power plant 9	500	435
				Power plant 10	500	450
<b>Spot price of the hour</b>			<b>275</b>			<b>350</b>

Table 2: Example of a spot trade in a certain hour tomorrow. 1000 MW connection between the two price areas.

In reference to this analysis, the technical need for power plant production is expressed in terms of two requirements. It is emphasized that the requirements for operation of the electricity system are both complex and under constant development. The requirements presented here serve as illustrative examples:

- The large power units currently in the energy system cannot go below a certain technical minimum. In 2008, there were hours during which the large units in western Denmark were operated at only 415 MW and in eastern Denmark only 181 MW. Consequently, it could be argued that the system *technically* can be operated with such minimum production, and that everything above this is due to economic and market based optimisation.
- The grid requires a certain minimum ratio between power production on large central plants and wind power in order to remain stable. In 2008, hours can be found during which the grids were operated, for the western and eastern Denmark respectively, with a wind power of 3.53 and 3.03 times the production on the large power units. Consequently, it can be argued that the system can operate with such minimum shares of production on the large units, meaning that they can reduce production to this level without compromising the system stability.

By using the above principles, one can identify hours during which the wind power plus a production on large units of a minimum of 415 MW and a minimum of  $1/3.53$  of the wind power exceed the demand. Such excess production can then be defined as wind power being exported while the rest is export due to the decision to increase production on the power plants for financial reasons.

By using such principles, the wind power export in 2008 was 61 GWh equal to less than 1 percent of the wind power production (or less than 0.2 percent of the demand).

However, one modification should be mentioned. In some cases the marginal production on large CHP power plants in Denmark is very low and can even be negative, if saved start-up costs are included. In the present system however such hours are rare and the export of wind power production with this approach is with high certainty not much more than 1 percent.

### **1.3 How can more wind power be integrated in the future?**

As described above, today, Denmark demonstrates how to supply approx. 20 percent of its electricity demand by wind power. However, there are plans to increase this number substantially in the future. Denmark has a long-term objective of stopping the use of fossil fuels and expanding the share of wind power to 50 percent or even more. So what about the future? How will Denmark (and other countries) be able to utilise such a high percentage of wind power in a way so that neighbouring countries can do the same?

Various studies of researchers (university and consultancy companies) and authorities (The Danish TSO and the Danish Energy Agency) have examined how to deal with such a challenge [5-20]. From such studies the following results can be highlighted:

- a. CHP is a very efficient way to produce heat and power. Denmark has a high number of small CHP plants producing both heat for district heating and electricity. Most plants were established in the mid/late 1990s and were designed with heat storage capacity to be able to produce a lot of electricity during peak hours and less or none when the electricity consumption is low

during nights and weekends. Changing the regulation of Danish small CHP plants to take account of fluctuations in both demand and wind power instead of only demand was the first less costly step to help the integration of wind power. Such step was (for a large proportion of the small CHP plants) implemented in January 2004 and is one of the reasons why Denmark is able to integrate the present share of 20 percent wind power, while still having a fuel efficient heat and power supply.

- b. If Denmark subsequently supplements (and partly replaces) some of its CHP units with heat pumps and additional heat storage capacity, the integration of wind power can be raised from the present 20 percent to around 40 percent. The first steps of such measure are in the process of being implemented along with the increases in the share of wind power.
- c. If Denmark starts to replace fossil fuelled cars with battery or hybrid electric cars and/or hydrogen cars in a long-term perspective, calculations show that Denmark will be able to integrate a share of wind power of approx. 60 percent.
- d. Additional to these measures, a lot of other possibilities exist such as flexible demands, hydrogen and/or similar energy carriers and various storage options which are also presently being considered. Such measures would be able to further increase the share of wind power.
- e. It is very important to include the small CHP plants, heat pumps and the electrification of transportation as well as the wind turbines in the power balancing (i.e. the stabilisation of voltage and frequency) if the abovementioned measures are to be successful. Again, such steps are being taken and the small CHP plants are already participating in almost all of these tasks via their participation at the following power markets: Primary automatic control (frequency), Secondary automatic control (15 minutes), Manual regulating power (15 minutes) and spot market (day-ahead hour market).

The conclusion is not only that Denmark with its present mix of energy technologies is able to integrate 20 percent wind power in a way so that our neighbouring countries can do the same, but also that Denmark has a strategy to raise this share to 50 percent in the not so far future, and the necessary measures are in the process of being implemented.

#### **1.4 Conclusions on Wind Power and Export**

Of a Danish wind power production of 6,978 GWh in 2008, one can say for a *fact* that a minimum of 0.1 percent was exported and a minimum of 63 percent was used in Denmark. With regard to the remaining 36.9 percent, one cannot technically, physically or from statistics of correlations over time determine which parts were exported and which were used in Denmark.

One has to establish a causal relation, which can be found by observing the market mechanisms of international electricity markets. Such observation leads to the conclusion that the production of the last unit of electricity comes from the units with the highest short-term marginal production costs, and consequently the wind export in

2008 was only 61 GWh equal to approx. 1 percent of the wind power production (or less than 0.2 percent of the demand).

Consequently, it is only fair to say that the wind power production in 2008 supplied approx. 19 percent of the Danish electricity demand. Furthermore, no evidence supports the claim from CEPOS that approximately half of it was exported. In other words, by serving the local demand, the Danish wind power has made it possible for existing CHP units and condensing units to increase their export to neighbouring countries. This possibility has been exploited due to the relatively low marginal costs of these plants at the market.

Neither the hourly production statistics nor the market based argument presented in this report can claim to be an in-depth analysis of the technical challenges of integrating large amounts of wind power. However there is no doubt that the wind power in Denmark has pushed the traditional power units further up the merit order, and reduced their earning potential. Also the hydropower with storage capacity in Norway and Sweden has proved to be a cost efficient way to integrate wind on market terms.

The conclusion is that Denmark has demonstrated the ability to integrate 20 percent wind power by use of local resources and the international market in a way so that our neighbouring countries can do the same. Moreover, Denmark has a strategy to raise this share to 50 percent and the necessary measures are in the process of being implemented.

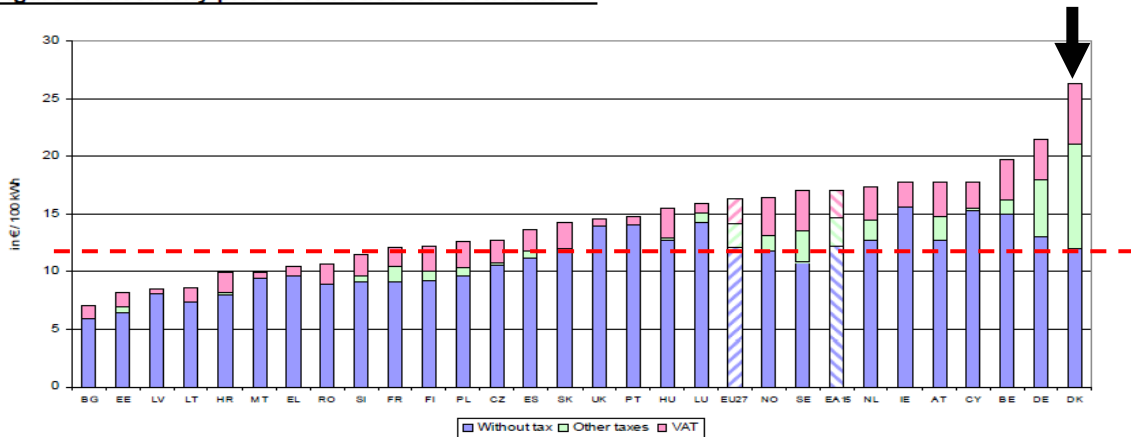
## 2. The Financing of Danish Wind Power

The CEPOS study claims on page 19 that “a significant fraction of the charges and taxes paid for by Danish domestic consumers is recycled to support ..... the feed-in tariffs that make it attractive ... to invest in wind power”. This statement is incorrect.

### 2.1 Why is the CEPOS statement on financing not correct?

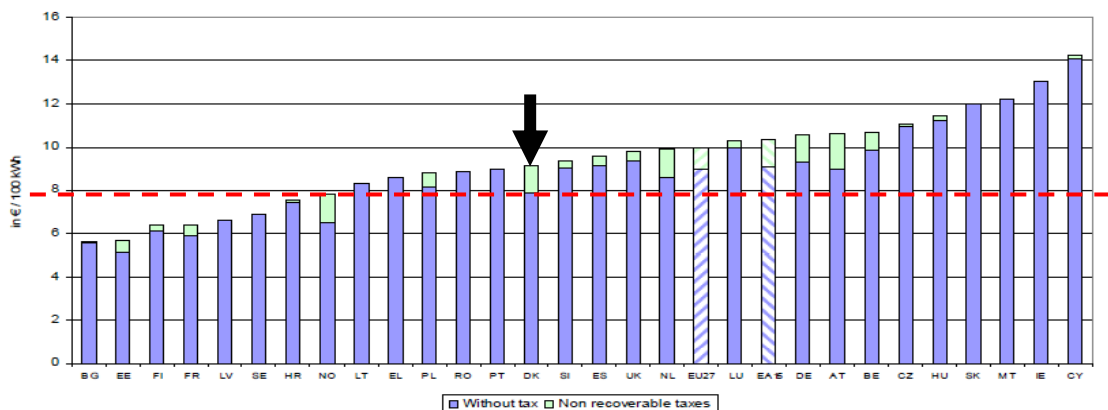
On page 18 in the CEPOS report, a section starts with the headline: “*How Denmark finances wind power*”. This section starts by showing the following Figs. 8 and 9 (see below), including the two black arrows each pointing at the electricity prices in Denmark for households and industry. We have added the two horizontal dashed red lines showing the Danish electricity production costs excl. taxes and VAT. As one can see, the Danish electricity production costs are at the level of the European average or below. For example, the Danish electricity prices for industries (excl. tax and VAT) are the 7<sup>th</sup> lowest out of 27 countries.

**Figure 8: Electricity prices for household consumers \***



\* 'Household consumers' refer to consumer band Dc (annual consumption between 2500 and 5000 kWh)

**Figure 9: Electricity prices for industrial consumers \*\***



\*\* 'Industrial consumers' refer to consumer band Ic (annual consumption between 500 and 2000 MWh)

Source: CEPOS's reproduction of EUROSTATS electricity prices for first semester 2008. (The black arrows are added by CEPOS, and the horizontal red line by the authors of this publication.)

Based upon Figs. 8 and 9, CEPOS concludes, quote page 18 and 19:

*“Taxes and charges on electricity for Danish household consumers make its household consumed electricity by far the most expensive in the European Union (EU). In contrast and in order to keep Danish Industry competitive, power to industry is hardly taxed at all. So the disparity between what householders and industry pay for their power is very wide. As the foregoing charts show, Danish householders pay 2.5 times more than Danish industry. Not all the difference goes to general expenditure. A **significant fraction of the charges and taxes paid for electricity by Danish domestic consumers is recycled to support new energy research and the feed-in tariffs that make it attractive for Danish individuals and companies to invest in wind power.** The feed-in support-for-wind-turbines tariff has been the key feature of the Danish wind power expansion from the beginning.”*

As this quote shows, the CEPOS report claims that the difference between private and industrial consumer prices in terms of taxes can be partly explained by feed-in support to wind power. The CEPOS description and conclusion are not correct. They involve two basic mistakes:

**Mistake no. 1:** The extra payment for CO<sub>2</sub> free energy to wind power is not made by the tax-payers. It is made by the transmission company Energinet.dk, and is therefore contained in the electricity price indicated by the blue pillar in Figs. 8 and 9. Taxes and VAT (the green and purple elements of the price pillar) are general taxes and have nothing to do with the cost of wind power. Thus, it is wrong when CEPOS claims that they do.

**Mistake no. 2:** The extra payment for CO<sub>2</sub> free energy to wind power is made not only by household consumers, but also by all other consumers, including industrial consumers. This payment is included in the blue element of the price pillar. Thus, the cost of wind power has nothing to do with the difference between the prices for private and industrial consumers.

## **2.2 How Denmark is really financing wind power?**

If these two mistakes are removed, the horizontal dashed red line shows the price including payment to CO<sub>2</sub> free wind energy production in comparison with electricity prices in other EU countries. The conclusion is:

- a. The price of electricity production and distribution for household consumers including payment to 20 percent wind power is the 10<sup>th</sup> highest out of the 27 EU countries. Furthermore, the Danish electricity prices for households, incl. payments to wind power, but excl. general taxes, are below the average among the old EU members, EU 15.
- b. The price of electricity production and distribution for industrial consumers including payment to wind power is the 7<sup>th</sup> lowest out of the 27 EU countries, and much below average in both EU 27 and EU 15.

Appendix 3 shows a comparison of industrial electricity prices and the share of renewable energy sources for the 19 out of the 27 EU countries, where the industrial

electricity price is higher than the Danish electricity price for industrial consumers incl. payment to wind power. Such comparison shows that for instance the UK has industrial prices that are 18 percent higher than the Danish electricity prices for industrial consumers, despite the UK using only 5 percent renewable energy and 3 percent wind power and having an energy system relatively similar to the Danish one. Out of these 20 countries, Denmark has the lowest electricity prices for industrial consumers, including the cost to wind power, and the highest share of wind power.

Therefore, we can conclude that Danish electricity prices, including extra payment for 20 percent CO<sub>2</sub> free wind power, are below the European average and among the lowest amongst the old EU members, EU 15.

Even though the Danish electricity prices including payments for wind power are among the lowest in Europe, wind power still influences consumer prices. However, when looking at the impact wind power has on consumer prices, one has to consider two effect areas, namely 1) payments from the consumers to wind power, and 2) lowered consumer prices caused by wind power at the Nord Pool market. These two elements are elaborated on in the following:

***Payments from electricity consumers to wind power for CO<sub>2</sub> free electricity.***

The payments for wind power are handled by the Danish TSO Energinet.dk and are listed in the table below which shows consumer payments to wind power based electricity. Again, it should be noted that these payments are included in the “Blue pillars” in Figs. 8 and 9, and thus paid by the power consumers and not via public taxes.

Year	Consumer payment to wind power for CO <sub>2</sub> free electricity (million DKK)	Consumer payment to wind power for CO <sub>2</sub> free electricity in million Euro
2004	1440	193.3
2005	1690	226.85
2006	1085	145.6
2007	1875	251.7
2008	720	96.6

Table 3: Extra payment for CO<sub>2</sub> free wind energy. Source: Energinet.dk

***The effect of wind power on the electricity prices at the Nord Pool power market***

Consumers’ payment to wind power is not the only influence wind power has on the consumer prices. Wind power also creates additional competition at the Nord Pool market which induces a downward price pressure on an oligopolistic market (as already illustrated by the examples in Tables 1 and 2). The effects are further explained and illustrated in Appendix 3.

The losers are the large power companies.

***The net effect of wind power on the electricity prices combining both aspects.***

By combining the two abovementioned aspects, the net effects of wind power are calculated and shown in Table 4 below.

As the table shows, in recent years, the influence of direct payments to the wind turbines has made consumer prices vary between 0.28 and 0.73 €/kWh with an average



of 0.54 €/kWh. However, this is reduced by the lowering effects of wind power on consumer prices varying between 0.10 and 0.38 €/kWh. The net price impact, column 4, is at an average of 0.27 €/kWh. This is equal to approx. 3 percent of industrial and 2 percent of private consumer prices (not including taxes and VAT). If taxes and VAT are included, the net influence of wind power is as low as 1 percent of the electricity price for private consumers.

Consequently, it is only fair to conclude that the influence of wind power on Danish consumer electricity prices is small and in general negligible.

Moreover, it should be noted that the net influence in 2008 was positive (seen from the consumers' point of view) and actually *decreased* the consumer price slightly for both industrial and private consumers. This is interesting since CEPOS in Figs. 8 and 9 uses the same year to postulate the opposite, namely that wind power causes higher electricity prices.

Year	(1) Wind power production / consumption (TWh/y)	(2) Average consumer payment per consumed electricity (€/kWh)	(3) Average reduced market price due to wind power (€/kWh)	(4)= (2)-(3) Net price impact of wind power (€/kWh)	(5) Annual net cost (M€)	(6) Tonnes CO <sub>2</sub> saved due to wind power (1000 t)	(7) Cost per tonne CO <sub>2</sub> reduction. (€/t)
2004	6.55/33.06	0.58	0.096	<b>0.48</b>	158.7	4.585	34.6
2005	6.62/33.53	0.677	0.35	<b>0.327</b>	109.6	4.634	23.7
2006	6.11/33.92	0.429	0.19	<b>0.24</b>	81.4	4.277	19.03
2007	7.17/33.73	0.73	0.38	<b>0.35</b>	118.1	5.019	23.5
2008	6.93/33.37	0.284	0.33	<b>-0.046<sup>2</sup></b>	-15.4	4.851	-3.17
Sum 2004-08	33.4/167.6				452.4	23.366	
Average 2004-08		0.54	0.27	<b>0.27</b>			19.4

Table 4: Price and CO<sub>2</sub> effects of wind power production 2004-2008. Source: Pillar (2) calculations based on data sent from Energinet.dk. Pillar (3) based on data sent from P.E. Morthorst, and [21].

The numbers in Table 4 do not take into account the fact that wind power also influences the electricity price in hours of no wind. The reason is that the wind power produced during hours with wind replaces hydropower which is then saved and put on the market in hours of no wind. As a result consumer prices decrease. Such an effect is not included in the calculations and will increase the positive influence of wind power even further.

<sup>2</sup> It should be underlined that these 2008 numbers show reduced consumer prices caused by the wind power production, and that Figs. 8 and 9 in the CEPOS report are used for saying that wind power causes higher electricity prices.

### **2.3 Conclusions on the Financing of Danish Wind Power**

The CEPOS report is based on a basically wrong understanding of how Danish wind power is financed. Thus, the statement, quote page 19, is wrong: “*A significant fraction of the charges and taxes paid for electricity by Denmark’s domestic consumers is recycled to support new energy research and the feed-in tariffs that make it attractive for Danish individuals and companies to invest in wind power.*” This wrong understanding built into the arguments of the CEPOS report leads to the report’s misleading conclusions that the high electricity prices for Danish households in 2008 are caused by wind power. The high household prices are caused by high electricity taxes and a 25 percent value-added tax. The additional subsidy payment to wind turbines is not financed by taxpayers, but entirely via the electricity charges before tax, i.e. the blue part of the pillars in Figs. 8 and 9, and therefore paid by both household and industrial consumers.

The Danish wind power programme with around 20 percent wind power on average has resulted in an annual electricity price increase of 0.27 €/kWh in the years 2004-2008. This equals a price increase of around 3 percent of the electricity price for industrial consumers, and a price increase of 1-2 percent for the household consumers depending on whether or not taxes and VAT are included in the calculation.

In 2008, wind power production even created a slight *reduction* in the Danish electricity prices. This contradicts the CEPOS report which, based on the 2008 price statistics in Figs. 8 and 9, postulates that Danish electricity prices are high due to payment to wind power.

Danish industrial electricity prices excl. taxes, but including payment to wind power, are in the lowest 30 percent amongst the 27 EU countries. In general, the 19 out of the 27 EU countries having higher industrial electricity prices than Denmark have a much lower fraction of renewable energy in general and wind power in particular.

Danish household electricity prices excl. taxes, but including payment to wind power, are slightly higher than average in EU 27, but lower than the prices in the UK, Belgium, The Netherlands, Ireland and Germany, where incomes are at the same level as in Denmark.

### 3. Can the Danish experiences regarding wind power's effects on employment be transferred to the US?

CEPOS is against the arguments of President Obama when he, by referring to the Danish example, concludes that wind power gives jobs, and that investing in wind energy is a win-win activity for the economy. CEPOS says, quote page 37 in the CEPOS report: *“The Danish experience also suggests that a strong US wind expansion would not benefit the overall economy.”*

This conclusion is based on an array of arguments of which a couple will be discussed below. CEPOS writes page 33, quote:

*“The conclusion is that there is no significant tendency for the energy technology sector to have a higher growth rate than the Danish manufacturing industry as a whole”.*

This conclusion is wrong, as illustrated by Table 5 below.

	1992	1997	2002	2006
Industry as a whole	100	156	280	328
Energy technology sector	100	175	355	515

*Table 5: Growth in industry as a whole and the energy technology industry (index with 1992=100). Source: Danish Energy Agency, Energierhvervsanalyse, 2009*

As the table shows, the Danish energy technology sector has grown by 415 percent whereas the manufacturing industry as a whole has grown by 228 percent from 1992-2006. In this period, the energy technology has had almost twice the rate of growth as the manufacturing industry as a whole. In 1992, the energy technology sector comprised 5.7 percent of the manufacturing industry as a whole, and in 2006, this had increased to 9 percent (and 11 percent in 2008). Therefore, the Danish experience shows that it is possible by means of a systematic policy to develop and implement a new and successful green industry.

CEPOS says that the Danish wind power development is based on ongoing heavy subsidies, page 35, quote:

*“Based on the total subsidies to the industry, the average subsidy per worker employed in the sector equals 60,000-90,000 DKK (\$9,000-14,000)”.*

This is incorrect:

*Firstly*, since CEPOS does not include the price reducing effects of the production of wind power on the market. This means that there was, for instance, no net subsidy to wind power in 2008. See Table 4.

*Secondly*, because during the years 2004-2008, close to 100 percent of the manufactured wind turbines in Denmark were exported.

This export has no direct links to the subsidy mentioned by CEPOS, which is the annual subsidy given to the electricity production of all wind turbines located in Denmark that were built in the period 1980-2003.

*Thirdly*, because the subsidy is given to wind turbine owners as a payment for their (public service) production of pollution free energy. The average cost per tonne of CO<sub>2</sub> reduction from this wind power production in the period 2004-2008 was 19.4 € per tonne (Table 4), which is below many estimates of socio-economic costs of CO<sub>2</sub> emissions.

Thus, it is problematic that CEPOS labels a public service payment/subsidy paid to owners of wind turbines built in the period 1980-2003 an “export subsidy” per employee for an export production taking place in the years 2004-2008.

*CEPOS states that the development of a wind turbine industry in the US will generate no extra employment.*

We believe that Obama was too modest in his statement of the potential positive effects of wind power in the US. He could have added that wind power in the future will be able to supply electricity for electrical vehicles, and in that way become an important part of a solution to the US balance of payment problem by reducing the amount of oil being imported and at the same time generating new jobs. The current economic crisis in the US is in part caused by the large and long lasting deficit on the US balance of trade. This deficit is partly caused by an increasing import of oil which means that money is sent abroad as payment for oil instead of invested in US jobs replacing oil import.

The problem of the increasing US import of oil can be illustrated by Table 6 below.

	Net import [1000 barrels per day]	Average price per barrel [US\$/barrel]	Annual net import of petroleum products [Billion US\$]	Balance of payment in [Billion US\$]	Increase in foreign debt per member of the 140 million people US workforce [US\$]
1970	-	2	-	2	
1995	7.886	16	46	-96	685
2001	10.900	21.5	86	-365	2.607
2008	11.100	95	386	-677	4.835
2001-2008				-4.732	33.800
1993-2000				-1.286	9.185

*Table 6: US oil import and the economic crisis. Source: U.S. Energy Information Administration, 2009 and U.S. Department of Commerce, Bureau of Economic Analysis, 2009*

As the table shows, the US has increased its import of oil at a considerable rate from 1995-2008. Importing such a large amount of oil transfers purchasing power and jobs out of the US. If an ambitious wind power programme is introduced in the US, they could reduce the almost 400 billion US \$ spent annually importing oil. The money saved could be used to modernise the energy system. This could be done by improving the building stock, introduce low-temperature district heating and district cooling as well as improving the vehicle stock by further developing electric cars to replace petrol

and diesel powered cars. As a result, implementing wind power in the US would generate employment and reduce their oil dependency and CO<sub>2</sub> emissions.

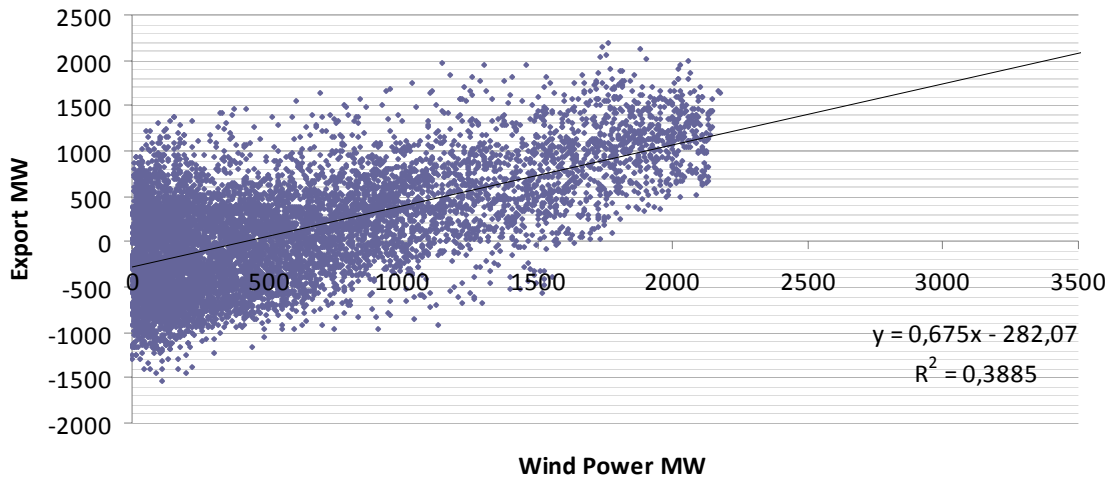
Our conclusion is that the general Danish experience of replacing energy and oil import with the development and implementation of energy- and oil-saving technologies can be transferred to most countries, and especially to the US.

## Appendix 1:

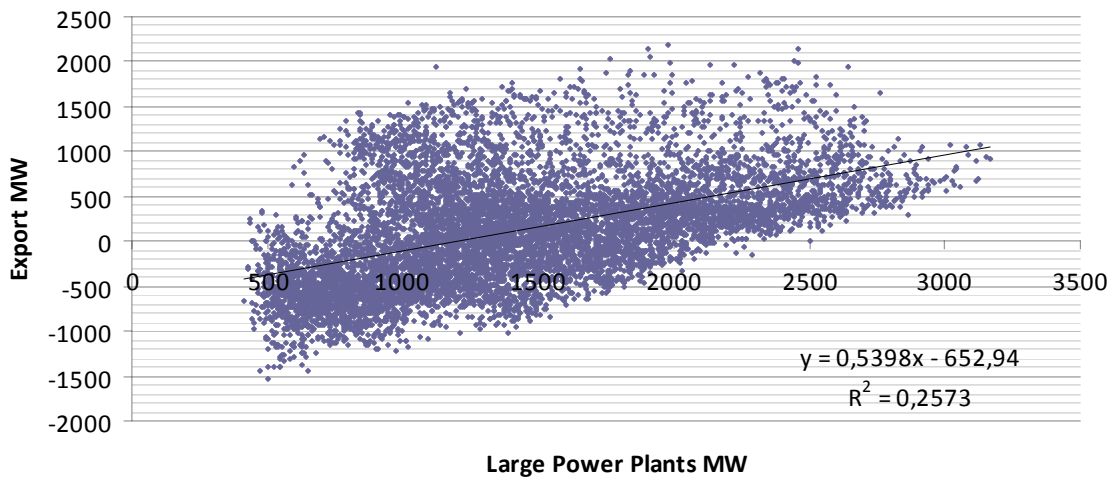
### Statistical analysis of the correlation between wind power and export

This appendix shows three diagrams illustrating the correlation over time between Danish export of electricity and electricity production from 1) wind power, 2) large power plants and 3) small CHP plants, respectively, in 2008.

#### Wind Power and Export in 2008



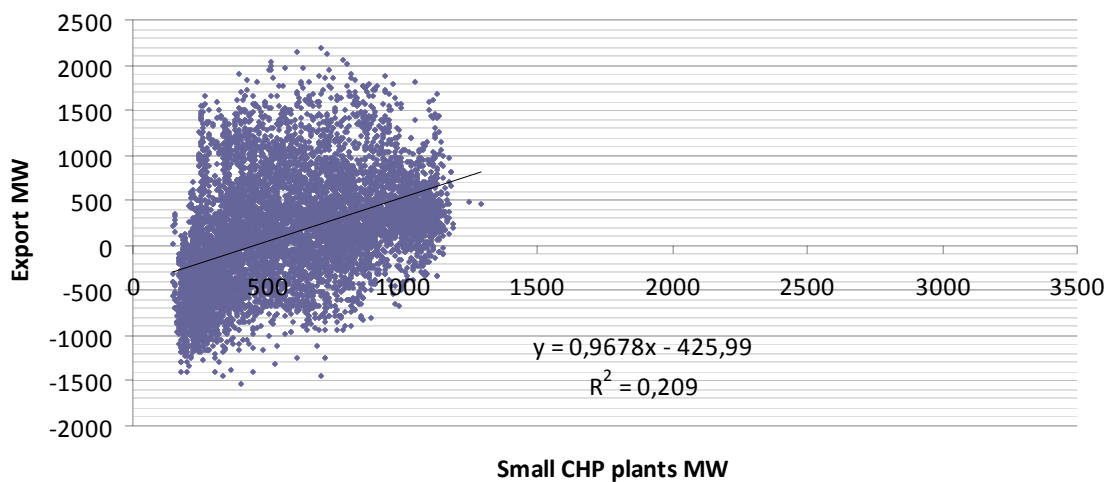
#### Large Power Plants and Export in 2008



As can be seen, wind power as well as large and small power plants seem to produce more electricity during hours of high export than during hours of low export. Normally, one would require a correlation,  $R^2$  of around 0.9 or above, to conclude that there is a strong correlation. As one can see, the correlation coefficients between export and wind power, large power plants and small CHPs are  $R=0.62$  ( $R^2=0.3885$ ),  $R=0.51$  ( $R^2=0.2573$ ) and  $R=0.46$  ( $R^2=0.209$ ), respectively. Consequently, there is a very weak correlation for all three. Even if the correlation were stronger, none of these diagrams would say anything about the causal relation, i.e. which units cause the export.

Moreover, it is not possible based on any of these diagrams to conclude (as CEPOS does) that all export by default is caused by wind power.

### Small CHP plants and Export in 2008



## Appendix 2: Statistical analysis of the correlation between changes in wind power and export

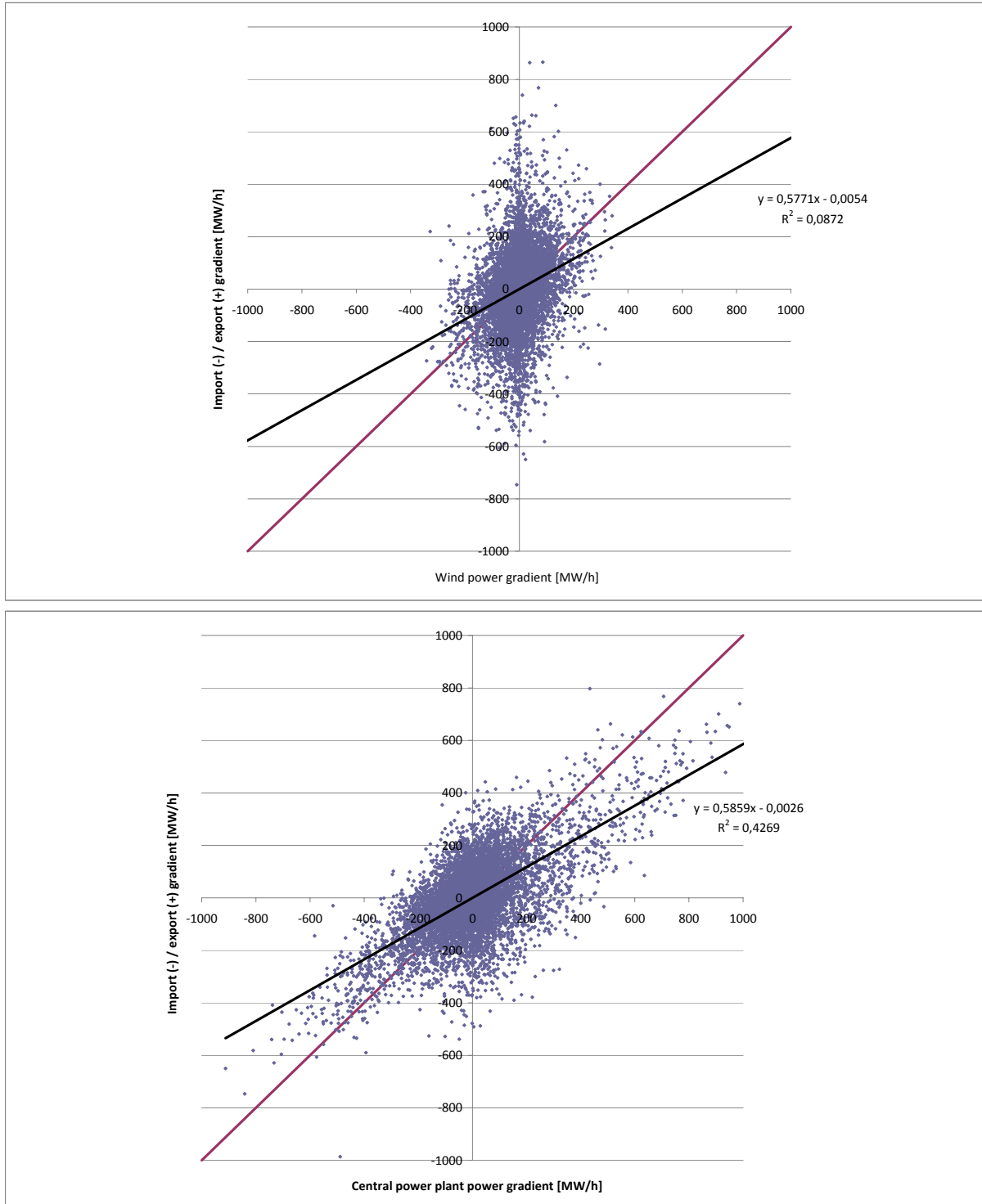


Fig A2: X,Y plots of hourly changes in export and changes in wind power (top diagram) or large power plants (bottom diagram) in western Denmark in 2008.



In Fig. A2 (Top), all dots in the upper right quadrant represent hourly changes in which both wind power and export increase. Similar dots in the lower left quadrant represent hourly changes in which they both decrease. Thus, all dots in these two quadrants represent a correlation between hourly changes in wind and changes in export. However, in the other two quadrants, the opposite takes place. In this case, export decreases as wind power increases and vice versa. If there was truth to the CEPOS study presumption that all changes in export derive from wind power, then one would expect all dots to be on the red line. However, as one can see, this is far from the case.

In the table we have identified the number of dots in each of the four quadrants.

	Increasing export and decreasing wind power	Increasing export and increasing wind power	Decreasing export and decreasing wind power	Decreasing export and increasing wind power	Increasing export and decreasing PP production	Increasing export and increasing PP production	Decreasing export and decreasing PP production	Decreasing export and increasing PP production	Positive feedback, wind	Positive feedback, PP
No. of hours	1.817	2.576	2.613	1.777	1.632	2.761	2.993	1.397	59%	66%
GWh power	993	1.597	1.705	898	1.036	1.553	1.667	936	64%	62%

Table A2: Distribution of number of annual number of hours and production viz. Fig. A2

On the basis of the table, the analysis shows that there is no special correlation between hourly changes in wind power and export. There is a high-high and low-low coincidence in approx. 60 percent of the hours. However, in the remaining 40 percent, wind power decreases when export increases and vice versa. Such correlation is not unique for wind power. The same is the case with regard to large power stations. Looking at the energy (GWh) instead of the number of hours does not change the picture.

The two correlation coefficients (R) are calculated and shown in the diagrams above. Normally, one would require an  $R^2$  of around 0.9 or above to indicate a strong correlation. As one can see, the correlation between changes in wind power and import/export is as low as  $R=0.30$  ( $R^2=0.0872$ ) while the correlation between changes in large power plants and import/export is  $R=0.65$  ( $R^2=0.4269$ ). Consequently, such analysis does not in any way suggest that changes in import/export are generated by changes in wind power. On the contrary, it points in the direction that such changes may be generated by changes in production at large power stations. As elaborated on in this report, the reason is that the causal relations are more complex and involve market mechanisms and cascading effects between power suppliers, i.e. wind power releases capacity for export on e.g. large CHPs. These are in turn competitive with e.g. German and Finnish power plants, thus leading to an export of electricity from large CHPs, in situations with high wind. High wind, thus, leads to Danish fossil power plants replacing foreign fossil power plants due to market mechanisms, and not due to wind power being exported.

### Appendix 3: Wind Power and Electricity Prices

Table A3.1 shows a comparison of industrial electricity prices and the share of renewable energy sources for the 19 out of the 27 EU countries, where the industrial electricity price is higher than the Danish electricity price for industrial consumers incl. payment to wind power.

Country	Industrial electricity price excluding taxes [€/kWh]	Share of renewable energy of electricity consumption [%]
<b>Denmark</b>	<b>7.85</b>	<b>29</b> <b>(hereof 19.6 wind power)</b>
Latvia	8.29	36
Greece	8.6	7
Romania	8.9	27
Slovakia	11.97	17
Malta	12.21	0
Ireland	13.02	9
Portugal	8.95	30
Czech republic	10.95	5
Cyprus	14.05	0
Hungary	11.24	5
Slovenia	9.04	22
Luxembourg	9.99	4
UK	9.37	5
Spain	9.15	20
Belgium	9.88	4
Poland	8.14	4
Germany	9.29	15
Netherlands	8.6	8
Austria	8.97	60

*Table A3.1: Renewable energy share and industrial electricity prices in 20 EU countries.*

On the basis of Table A3.1, it can be seen that for instance the UK has industrial prices that are 18 percent higher than the Danish electricity prices for industrial consumers, despite the UK using only 5 percent renewable energy/3 percent wind power and having an energy system relatively similar to the Danish one. Out of these 20 countries, Denmark has the lowest electricity prices for industrial consumers, including the cost of wind power, and the highest share of wind power.

Therefore, we can conclude that Danish electricity prices, including extra payment for CO<sub>2</sub> free wind power, are still below average in EU 27.

Wind power creates additional competition at the Nord Pool market which induces a downward price pressure on an oligopolistic market where additional competition is desirable.

The losers are the large energy power companies.

Fig. A3 summarises the impact of wind power production on Nord Pool electricity prices. As the figure illustrates, it is generally found that in 2004-2008 the consumer

price of power (excluding transmission and distribution tariffs, taxes and VAT) would have been approx. 3-10 percent higher in Denmark, if wind power did not contribute to power production (left part of Fig. A3). The strongest impact of wind power is estimated for western Denmark owing to the high penetration of wind power in this area. In 2007-2008, this adds up to approx. 0.3-0.4 €/kWh saved by power consumers due to wind power lowering electricity prices (right part of Fig. A3).

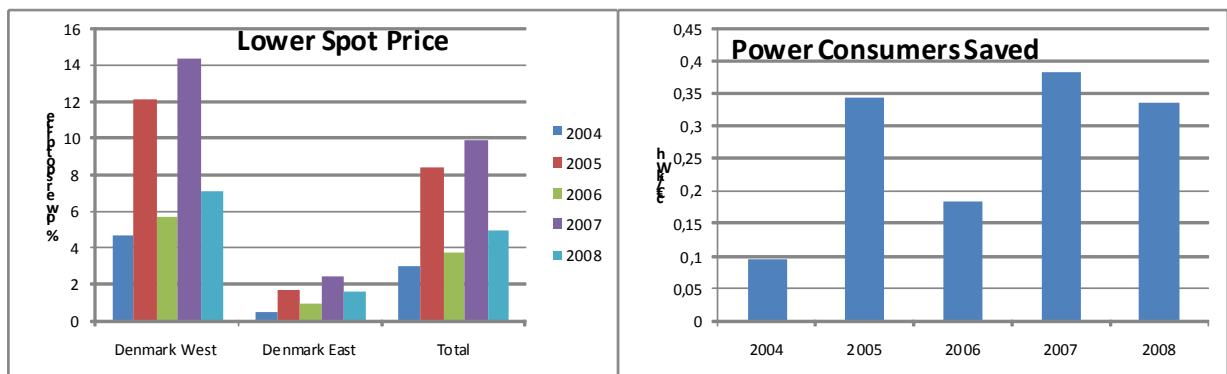


Fig. A3: Price impact of wind power at the Nordpool market, 2004-2008. Source: Poul Erik Morthorst 2009 updated with 2007 and 2008 numbers from [21,22].

## References

- [1] CEPOS. Wind Energy - the case of Denmark. Copenhagen: The Danish Think tank CEPOS, 2009.
- [2] The Heritage Foundation. See also: <http://blog.heritage.org/2009/09/14/wind-power-an-expensive-and-inefficient-way-to-reduce-co2/>
- [3] Institute for Energy Research. Press release, 14 September 2009. See also: <http://www.instituteforenergyresearch.org/2009/09/14/something-rotten-obama-says-danes-receive-20-of-their-power-via-wind-new-study-tells-the-real-story/>
- [4] NordPool Spot A/S. See also: [http://www.nordpoolspot.com/trading/The\\_Elspot\\_market/](http://www.nordpoolspot.com/trading/The_Elspot_market/)
- [5] Energinet.dk. Effektiv anvendelse af vindkraftbaseret el i Danmark, samspillet mellem vind, varmepumper og elbiler (Efficient use of wind power using heat pumps and battery electric vehicles). Fredericia, Denmark: Energinet.dk (Danish TSO), 2009.
- [6] Lund H, Salgi G. The role of compressed air energy storage (CAES) in future sustainable energy systems. *Energy Conversion and Management* 2009;50(5):1172-1179.
- [7] Henrik Lund. *Renewable Energy Systems. The Choice and Modeling of 100% Renewable Solutions*. Burlington, USA: Academic Press (Elsevier), 2010.
- [8] Lund H, Kempton W. Integration of renewable energy into the transport and electricity sectors through V2G. *Energy Policy* 2008;36(9):3578-3587.
- [9] Mathiesen BV, Lund H. Comparative analyses of seven technologies to facilitate the integration of fluctuating renewable energy sources. *IET Renewable Power Generation* 2009;3(2):190-204.
- [10] Andersen AN, Lund H. New CHP partnerships offering balancing of fluctuating renewable electricity productions. *Journal of Cleaner Production* 2007;15(3):288-293.
- [11] Lund H. Large-scale integration of optimal combinations of PV, wind and wave power into the electricity supply. *Renewable Energy* 2006;31(4):503-515.
- [12] Lund H, Munster E. Integrated energy systems and local energy markets. *Energy Policy* 2006;34(10):1152-1160.
- [13] Lund H. Excess Electricity Diagrams and the Integration of Renewable Energy. *International Journal of Sustainable Energy* 2003;23(4):149-156.
- [14] Lund H. Large-scale integration of wind power into different energy systems. *Energy* 2005;30(13):2402-2412.
- [15] Lund H, Østergaard P, Andersen AN, Hvelplund F, Mæng H, Münster E, Meyer NI. *Lokale Energi-markeder (Local Energy Markets)*: Department of Planning and Development, Aalborg University, 2004.
- [16] Danish Energy Agency. *Rapport fra arbejdsgruppen om kraftvarme- og VE-elektricitet (Report from the expertgroup on CHP- and RES-electricity)*. Copenhagen: Danish Energy Agency, 2001.
- [17] Meibom P, Kiviluoma J, Barth R, Brand H, Weber C, Larsen HV. Value of electric heat boilers and heat pumps for wind power integration. *Wind Energy* 2007;10(4):321-337.
- [18] Meibom P, Weber C, Barth R, Brand H. Operational costs induced by fluctuating wind power production in Germany and Scandinavia. *IET Renewable Power Generation* 2009;3(1):75-83.
- [19] Ea Energianalyse. 50% vindkraft i Danmark i 2025 – en teknisk-økonomisk analyse. (50 per cent wind power in Denmark year 2025 - Summary available in english). Copenhagen: Ea Energianalyse, 2007.
- [20] Mathiesen BV, Lund H, Karlsson K. *IDAs Klimaplan 2050, baggrundsrapport - Tekniske systemanalyser, brændselsforbrug, drivhusgasser, samfundsøkonomiske konsekvenser, erhvervspotentialer, beskæftigelseeffekter samt helbredsomkostninger (IDAs Climate Plan 2050, background report in Danish and English)*. Copenhagen: Danish Society of Engineers (IDA, Ingeniørforeningen Danmark), 2009.
- [21] Munksgaard J, Morthorst PE. Wind power in the Danish liberalised power market--Policy measures, price impact and investor incentives. *Energy Policy* 2008;36(10):3940-3947.
- [22] Østergaard P, Morthorst PE, Moesgaard R, Enevoldsen S. The impact of wind power on power spot prices in Denmark. (In Danish: Vindkraftens betydning for elprisen i Danmark). Aarhus: IBT-Wind, Aarhus University, 2006.