Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Ebbe Münster, PlanEnergi, Denmark
E-mail	em@planenergi.dk
Title of dissemination	Comparison of Electricity Balancing for Large Scale Integration of Renewable Energy in six European Regions.
Type of activity	Oral presentation and article for journal
Title of forum	Dubrovnik Energy Conference 2007.
Language	English
Date of dissemination	June 3-8th , 2007
Place of dissemination	Dubrovnik, Croatia.
Brief abstract / description of dissemination activity	This paper address the question of balancing fluctuating electricity productions from renewable energy sources in Europe a) by the use of additional capacity of interregional transmission lines versus b) by increasing the balancing capacity of the regional production and distribution system. The aim has been to identify technologies and in particular mix of technologies which will enable the increase in fluctuating and unforeseeable electrical productions which will be the result of the fulfilment of the current EU energy plans. It is found that new transmission lines often cannot compete economically with measures to improve the internal balancing potential of the regions involved. Part of the reason for this is the large costs and long planning periods involved in the strengthening of the internal transmission networks which are necessary to distribute the increased exports and imports. The fundamental changes of the production and distribution systems for electricity which are mainly caused by the rapid development of the information technology and the liberalisation of the markets are shown to have a positive potential for the growing balancing requirements. The scenario analyses have been carried out for the electrical production and consumption systems in six regions in Denmark, Estonia, Germany, Great Brittan, Spain, and Poland.
Audience impact assessment	NA
Dissemination	Included after this form

Comparison of Electricity Balancing for Large Scale Integration of Renewable Energy in six European Regions.

Dr Ebbe Münster*
PlanEnergi
Jyllandsgade 1, Skoerping, DK 9520 Denmark
e–mail: em@planenergi.dk

Professor Henrik Lund
Department of Development and Planning.
Aalborg University, Fibigerstraede 13, Aalborg, DK 9220 Denmark.
e–mail: lund@plan.aau.dk

ABSTRACT

This paper address the question of balancing fluctuating electricity productions from renewable energy sources in Europe a) by the use of additional capacity of interregional transmission lines versus b) by increasing the balancing capacity of the regional production and distribution system. The aim has been to identify technologies and in particular mix of technologies which will enable the increase in fluctuating and unforeseeable electrical productions which will be the result of the fulfilment of the current EU energy plans. It is found that new transmission lines often cannot compete economically with measures to improve the internal balancing potential of the regions involved. Part of the reason for this is the large costs and long planning periods involved in the strengthening of the internal transmission networks which are necessary to distribute the increased exports and imports. The fundamental changes of the production and distribution systems for electricity which are mainly caused by the rapid development of the information technology and the liberalisation of the markets are shown to have a positive potential for the growing balancing requirements. The scenario analyses have been carried out for the electrical production and consumption systems in six regions in Denmark, Estonia, Germany, Great Brittan, Spain, and Poland.

THE DESIRE PROJECT

The DESIRE project addresses the balancing of the forecasted increased amount of fluctuating and unpredictable electricity production in Europe. [1]
It has been carried out in the framework of EU-FP6 by 10 European companies and universities headed by Aalborg University. It was concluded May, 31st 2007.
A number of technologies with balancing potentials have been investigated using six chosen regions throughout Europe as cases. The methodology has been to analyse the balance of the electrical grid of each region as a whole and to compare various mixes of production and regulating technologies with respect to the ability to assist in minimizing either the need for forced exchange of power with the neighbouring regions or the total socio economic costs of electricity production of the region.

* Corresponding author

In the scenario analyses used to identify the best technologies, optimal use of all parts of the electrical system has been assumed on an hourly basis for a whole year. This is a sound assumption to make when the purpose is to find the best solutions from a technical point of view, but it is of course an ideal, which it is difficult to achieve in practice. In parallel parts of the project the economic and bureaucratic barriers have been addressed.

THE SIX REGIONS

The following countries have been involved in the DESIRE project: Estonia, Denmark, Germany, Poland, Spain, UK.
For each country a region suitable for simulation has been selected. The criteria used are:
1. Large enough to include both fluctuating electricity production (e.g. wind turbines) and power plants with regulation capacity (Combined-Heat-and-Power plants - CHP)
2. Small enough not to have important internal bottlenecks (one price area)
3. Well defined boundaries.
4. Available data (for 2004 plus forecasts for 2020).

The results of the selection were:
- Estonia - the whole country
- Denmark - the western part (Jutland and Funen)
- Germany - the whole country
- Poland - the whole country
- Spain - the whole country (minus the islands)
- UK - the southern part of Scotland (Fig. 1)

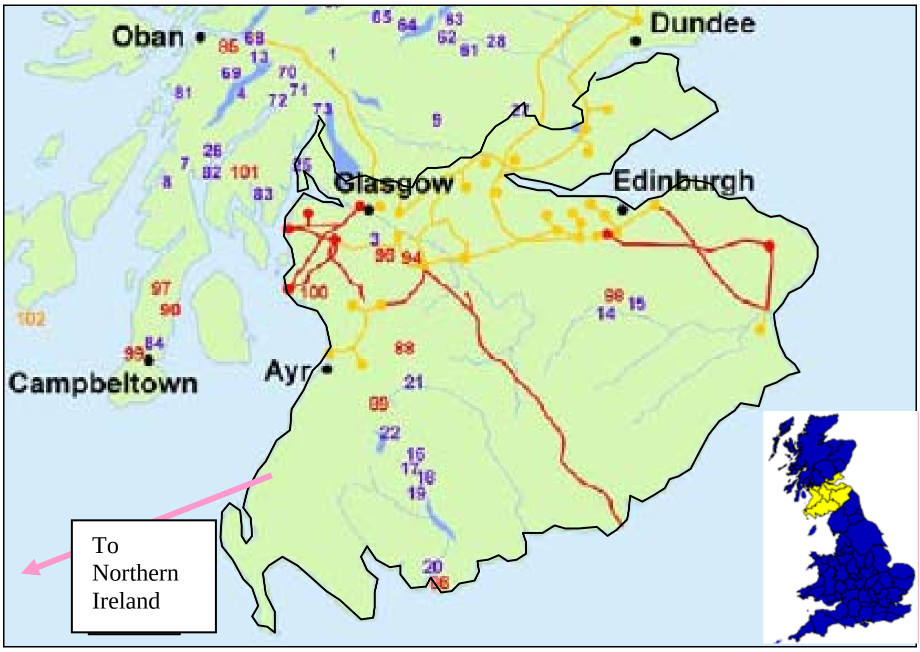


Figure 1. UK calculation region.

Reference calculations

Simulations of the energy systems in the selected regions had a number of different purposes during the project:

- Calculations of how the present and future energy systems can improve the capability of incorporating fluctuating electricity production (e.g. wind turbines) by optimising regulation strategies.
- Calculations of how changes in the flexibility of the electricity production units (e.g. by increasing heat storages at CHP plants) influence the electricity balance in scenarios with growing share of fluctuating and unpredictable electricity producers.
- Calculations of how changes in the flexibility of the electricity consumption (e.g. by the introduction of battery cars) influence the electricity balance in scenarios with growing share of fluctuating and unpredictable electricity producers.
- Calculations of various scenarios concerning the question of establishing new international transmission lines versus increasing the flexibility of the production and consumption in the electricity system.

The simulation software, EnergyPLAN, which has been developed by Aalborg University and other partners in the project, was used for the simulations.

It is an input-output model, which uses data on capacities and efficiencies of the energy conversion units of the system and availability of fuels and renewable energy inputs.

Hour by hour it calculates how the electricity and heat demands of society will be met under the given constraints and regulation strategies.

Fig. 2 gives an impression of the functioning of the model. It is seen how it concentrates on the electrical system but incorporates other parts of the system which interact with it.

The result of the calculation is a detailed knowledge on the production of the different units. From this, fuel consumption can be calculated and subsequently the socio-economic costs and CO_2 emissions caused by the of meeting the demands of the society can be found.

The model is described in detail in delivery D 1.5 of the DESIRE project [1]. It can be downloaded free of charge from [2] including a comprehensive manual.

The process of collecting the necessary data and carrying out the reference calculations for 2004 and 2020 is described in deliveries D 1.1 and D 1.3 [1].

In this process determination of fuel prices and electricity market prices for 2020 constituted a special problem. For all data official forecasts have been used when available, but the forecasts for prices depending on the oil price were too different. This can be explained by different attitudes regarding the development of the oil price. In Denmark and Spain, the official IEA forecast has been used, in which the present high level of oil prices is expected to be intermediate, while other countries have more pessimistic (realistic?) approaches. To make the calculations comparable it was decided to use two sets of standard data for oil, N-gas and electricity. A low price scenario, 2020a, corresponding to the first attitude (26 $/brl) and a high price scenario, 2020b, corresponding to the latter (100 $/brl).

Examples of the assumed prices for N-gas and electricity is shown in figure 3. As the calculations are dealing with socio economy only, the shown prices are estimates of international wholesale market prices. On top of these prices an estimate of the 2020 price of CO2-certificates is taken into account (13,3 €/t).

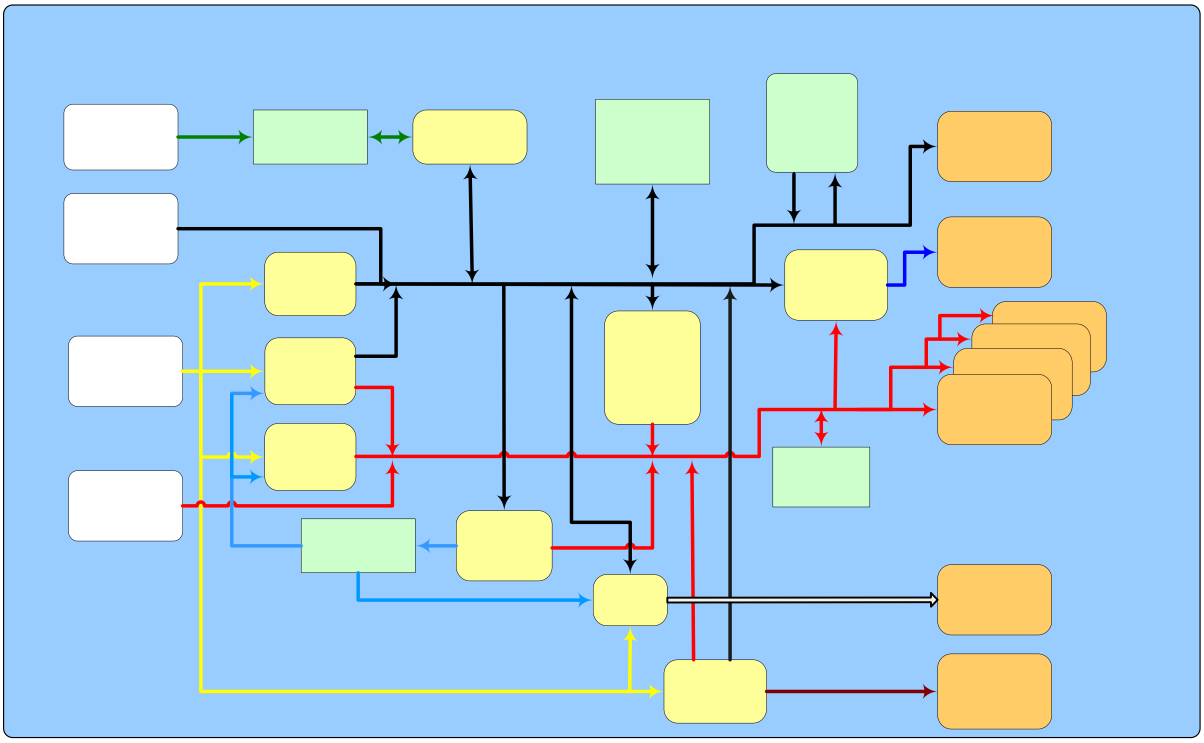


Figure 2. The EnergyPLAN model.

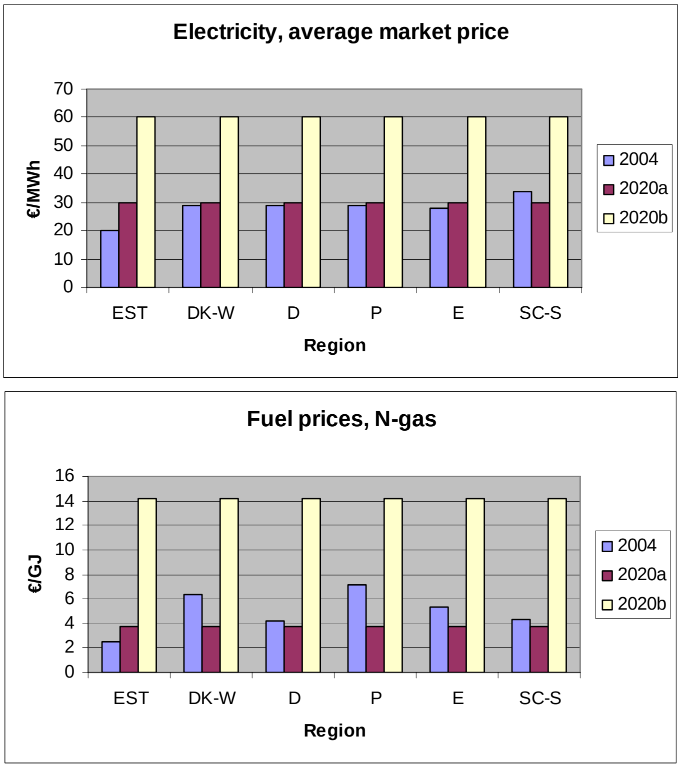


Figure 3. Assumed market prices.

IMPORTANT BALANCING TECHNOLOGIES

Electricity production technologies

The most important production technology considered is the co-production of electricity and heat at small (< 25MW) or large power plants. In particular when such plants are equipped with heat stores corresponding to the daily heat production they have a very significant balancing potential apart from a high overall efficiency. In Denmark this technology has been promoted for the last 20 years and a share of app. 60% of the total production of electricity has been achieved. The level in EU in general is much lower, but lately a specific promotion programme has been launched. The main reason for this is not the balancing potential but the fuel savings involved in the increase of overall efficiency.
The technologies used for CHP are mainly N-gas engines at the small plants and extraction steam turbines at the large plants (mainly coal fired).
In the project also micro turbines, fuel cells and stirling engines have been analysed for small plants or even households.
Hydro turbines with reservoirs and eventual reverse pumping capacity also have large balancing capacities, but they have the disadvantage of being difficult to establish. The present plants can seldom be enlarged.

Conversion and storing technologies

The use of large heat pumps (> 1 MWe) at the CHP plants will enable these to shift from electricity production to electricity consumption in a matter of minutes without loosing the heat production capacity. If the efficiency of the heat pump is sufficient the overall efficiency of the system will not decrease. The only disadvantage is the investment and operation costs of the heat pump.(see German case below).
Storing heat is simple but storing electricity is still difficult and expensive. The following technologies have been looked into: hydrogen and electrolysers, compressed air, reverse pumping, batteries (in particular in connection with battery cars – see Spanish case below).

Regulating technologies

Demand-Side-Management (DSM) has been analysed in particular in connection with heating, ventilating and cooling of houses. In this connection the use of district cooling has been considered.

Use of interconnectors

In principle imbalances in one region can be balanced by the neighbouring regions if interconnectors have sufficient capacity and commercial availability. This method is particularly relevant when the regions have different profiles regarding electricity production or consumption. The balancing of German wind power by Austrian hydro power is an example of such a situation. The economic and physical planning difficulties in establishing new power lines, however, are huge and often internal measures as described above are preferable. (see Danish case below).

THREE CASES

Increasing capacity of interconnectors (Denmark)

In order to investigate the economy in solving the balancing problem involved in a considerable increase of wind power in Denmark a situation is considered where the capacity of wind power is gradually increased from the present 20% to about 120% of the electricity demand. The economic consequence of doing this is shown below in figure 4.

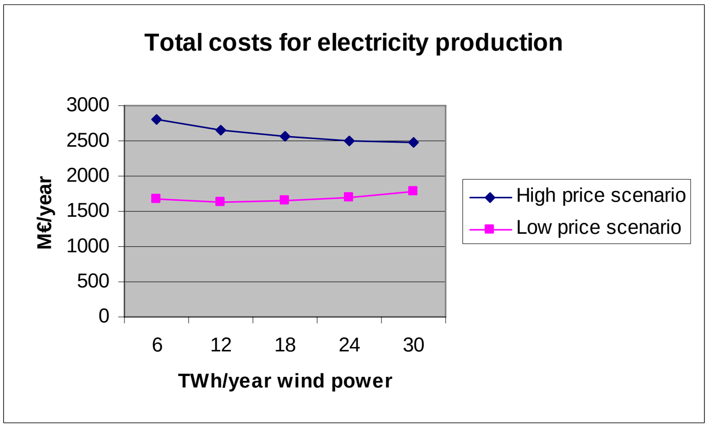


Figure 4. Costs of production at various levels of wind power.

It is seen how very high levels of wind power are profitable in the high price scenario, whereas a minimum level of costs is reached at a level of 12 TWh/year in the low price scenario. It is noted that socioeconomic costs only are considered and that a low interest rate of 3% without inflation is assumed. Often much higher rates are used for this kind of calculations causing much lower levels of renewable energy technologies to be feasible. The low rate is used for the following reasons:

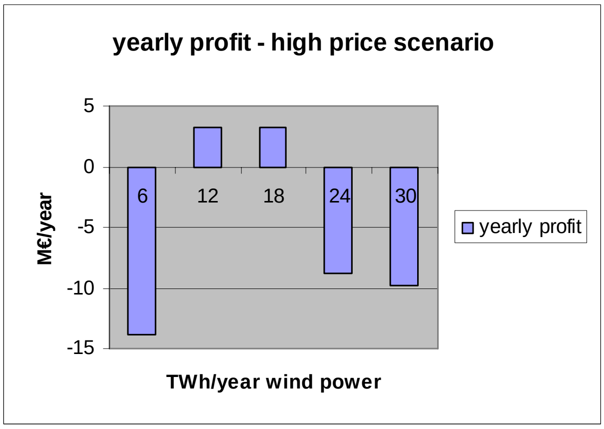
- This interest rate is close to the rate which is to day obtainable in Denmark for long term investments in e.g. insulation projects.
- It resembles the rate used when long term environmental and health effects of energy investments are assessed. (like in the ExternE project [3])
- That long term energy investments compete with other investments like in the export industry and hence should ‘pay’ the same interest rate is an argument often used but not valid. Such other investments depend on cheap and reliable supply of energy. In other words: It might be that it is more profitable to invest in trains than in rails, but sooner or later this strategy will prove unsustainable.[4]

Part of the reason for the falling marginal profit of wind power at higher levels of production is that the assumed capacity of interconnectors to Norway/Sweden and to Germany, 1700 MW, becomes unable to balance the fluctuating production despite utilisation of the CHP´s for balancing (4850 MWe with 25 GWh thermal stores). This means that Critical Excess Electricity Production (CEEP) would occur if special measures, which are economically unwanted, were not taken into use. Table 1. shows the measures used in the above calculation to maintain the balance of the Western Denmark region in the case of 30 TWh/year wind power. It is stressed that the measures shown in table 1. are used at high levels of wind power only and only after all economically sound measures like making use of the heat stores of the CHP’s have been fully exploited.

Table 1. Avoiding critical excess production at 30 TWh/year

CEEP – reduction, TWh	Low prices	High prices
Reduce CHP production, (increase boiler heat production)	5,21	2,04
Use electric boilers at CHP	4,01	4,38
Reduce wind power by stopping wind turbines	3,44	3,10

The methods shown in table 1. are used from top to bottom, which means that the actual stopping of turbines is used as the last (and most uneconomic) resort.
If an attempt is now made to solve the balancing problem at high levels of wind power by adding 1000 MW of new capacity to the interconnectors the following results are obtained.



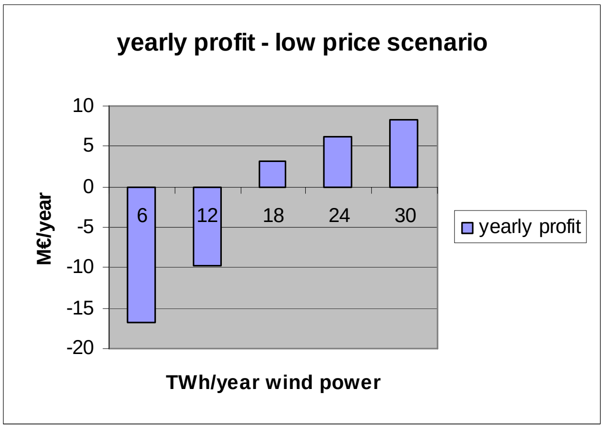


Figure 5. Profit of increasing interconnector capacity with 1000 MW.

It is seen that the additional capacity pays only in some situations. And it is noted that it does not pay in the situations where the wind power provides maximum benefit. Hence the investment is questionable.
In the above calculation the total investment for the1000 MW interconnector is assumed to be 300 M€. (lifetime 30 years, O&M 0,5% of investment). An interregional transmission line normally requires costly strengthening of the internal grid. The total cost in the actual case is based on analyses carried out by the Danish Energy Agency [5].

Adding heat pumps to combined-heat-and-power plants (Germany)

The forecasts for electricity production in Germany for 2020 call for 23 GWe of CHP capacity and 45 GWe of wind turbines. They contribute 17% and 26% respectively of the electricity production (app. 500 TWh/year).
This amount of wind power can easily be balanced. One reason for that is the strong interconnector capacity of 17 GW.
It should be noted that critical excess electricity production will start to occur if the wind power share is increased to more than 50% of the demand.
In this situation the effect of installing 5 GWe of heat pumps with a COP of 3 is investigated. The low temperature heat source could be condensing cooling of exhaust gas from N-gas engines.(e.g. 20 dg.C) stored in a low temperature heat storage.

The economic result of this calculation is shown in figure 6.

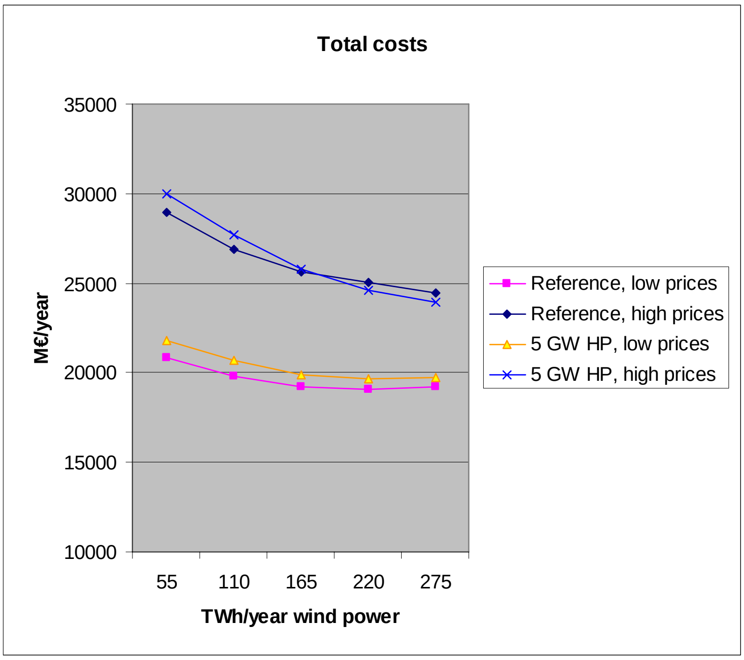


Figure 6. 5 GWe heat pumps, Germany.

Figure 6 shows that the investment in heat pumps pays in the high price scenario only. The hybrid effect of heat pumps and wind turbines,however, is seen by the way the heat pumps increase the marginal value of the wind power in the whole range of the variation (faster decrease of costs at increasing level of wind power).

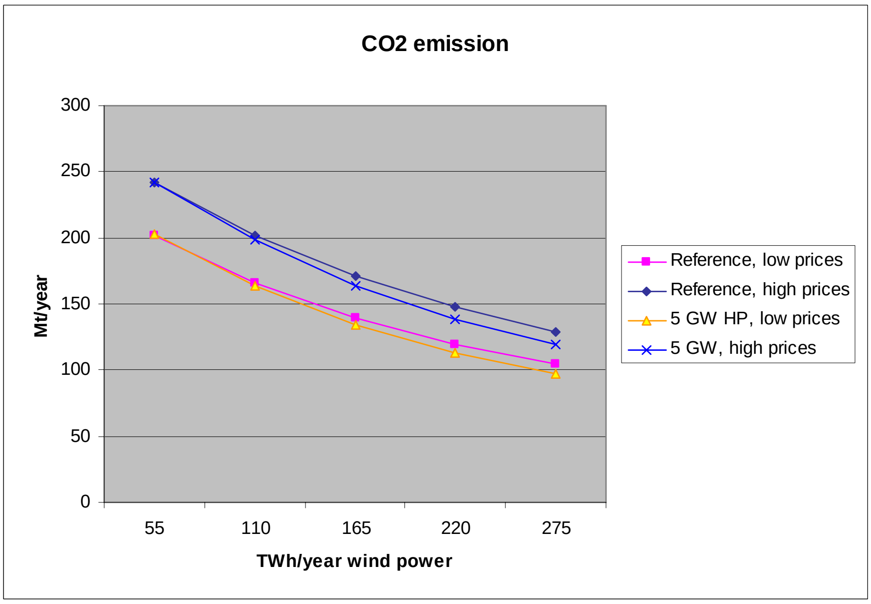
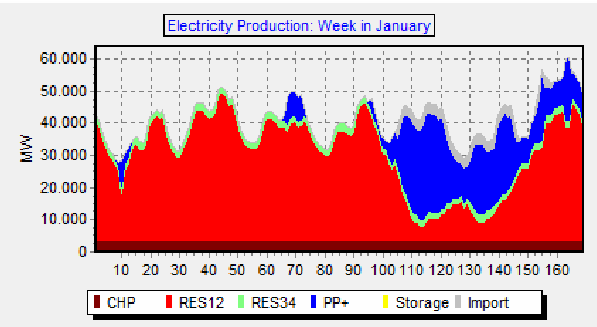


Figure 7. CO_2-effect of heat pumps.

Finally the environmental effects of the heat pumps are assessed. It can be seen from figure 7 that the heat pumps have a clear positive effect on CO_2-emissions regardless of the prices and the wind power levels. This shows that they do not lower the overall efficiency of the system.

Introducing battery cars (Spain)

The projected situation for Spain in 2020 is that 25 GWe of wind power provides 22% of the total demand (app 380 TWh/year) while hydro power provides 9%, nuclear 17% and conventional power plants 41%. CHP is negligible.
The hydro plants have some regulating capacity, but the conventional plants provide most of the balancing. The interconnectors to France, Portugal and Morocco are weak (total app. 2000 MW).
New technologies with balancing potential must be introduced if further increases in the wind power capacity are wanted. In this case the possibility of involving the transport section is investigated. The assumption is made that 20% of all cars will be changed to battery cars. The necessary electrical power to maintain the former amount of transport work is calculated to be 13 TWh/year. Because of the high efficiency of battery cars compared to petrol cars this electricity in turn substitutes 60 TWh petrol and lower CO2 emission with 15,9 Mt CO2. The cost of the investment is assumed to be 80% more than the corresponding petrol car, which is valued at 11000 € (socio economic costs). It is underlined that the estimate of the extra cost prices is based on today's technology. In 2020 they are probably much lower.
To maximise the balancing use of the batteries in this great number of cars the so-called Vehicle-to-Generator (V2G) operation is assumed. According to this method the owners of the cars are motivated to keep the cars connected to the grid whenever they are not in use. This will make it possible for the system operators to load and to unload the batteries according to the balancing needs of the system. An intelligent control system in each car ensures that sufficient energy is available for the battery when it is needed by the owner. Figure 8. below shows how this function in practice. In the shown situation the left graph shows how the electricity demand is met in a situation with a high level of wind power, i.e. 75% of total yearly demand and without the battery cars. The right graph shows how the batteries are used to lower the production of the power plants (yellow=storage). The energy for this purpose has been loaded into the batteries at times, where a surplus of power would otherwise have caused some turbines to be stopped.



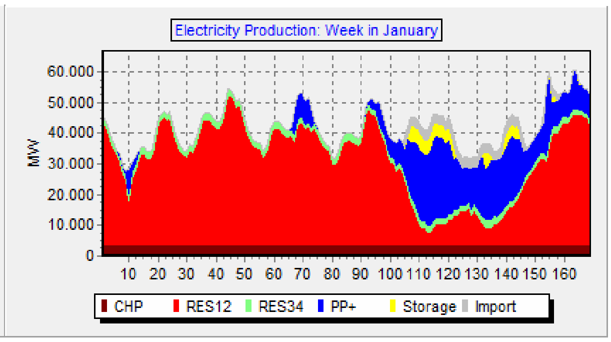


Figure 8. Production without (left) and with (right) battery cars.(RES12=wind power, RES34=hydro power and photo voltaic, PP=power plant).

The economy of the investment and the operation of the cars are shown in figure 9. It shows that the heavy investment in the battery cars is not justified in the low price scenario, but in the high price scenario they provide a profit and a clear increase of the marginal profit of wind power.

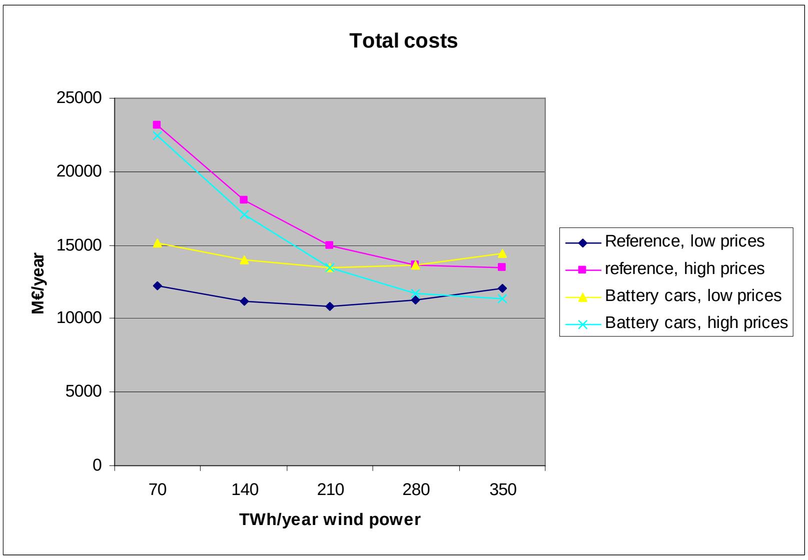


Figure 9. Economy of battery cars.

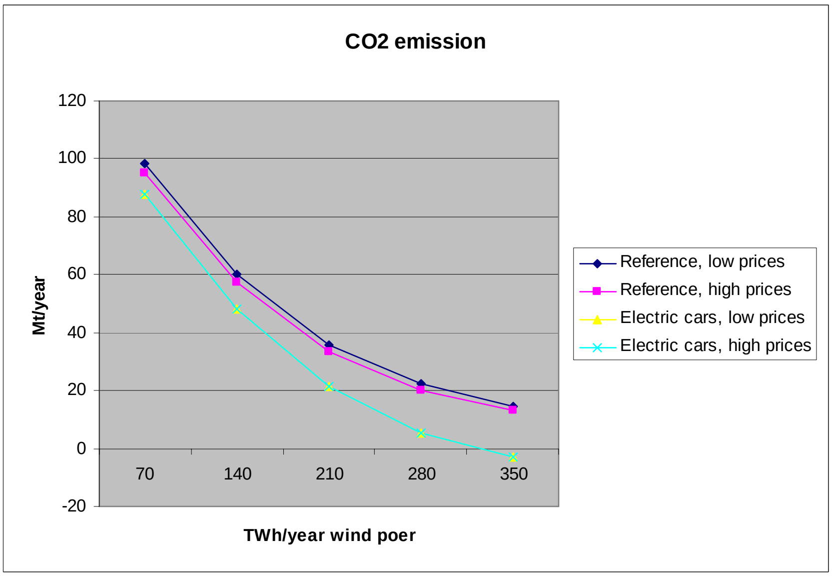


Fig 10. CO_2 emissions, battery cars.

Finally figure 10 shows the effect on CO_2 emissions of the battery cars. It can be seen that the decrease of emissions is not just due to the fuel substitution. It increases with higher levels of wind power because the regulating capacity becomes more and more important.

NECESSARY STRUCTURAL CHANGES IN THE DISTRIBUTION NETWORK

The energyPLAN scenario calculations referred to above assume that a perfect market (or a centralised control system) allocates the production capacities hour by hour in a way which ensures either minimum excess electricity production or minimum socio economic costs of production. This is a sound methodology when the aim is to compare the potential of different capacity mixes or different control strategies, but it does not give a realistic picture of the functioning of the partially liberalised electricity market today.

The reasons for this are analysed in a number of deliveries of the DESIRE project [1]. However, this situation is being improved as both the markets and the technical systems are changing at considerable speed in the direction of more intelligence and flexibility.

This process has been studied by a number of EU projects and lately in the EU SmartGrid Technology Platform, which was launched in April 2006. The text below and in Figure 11 show how the process involves many topics from microgrids to Smarter use of transmission lines.

Electricity grids of the future are Smart in several ways. Firstly, they allow the customer to take an active role in the supply of electricity. Demand management becomes an indirect source of generation and savings are rewarded. Secondly, the new system offers greater efficiency as links are set up across Europe and beyond to draw on available resources and enable an efficient exchange of energy. In addition, environmental concerns will be addressed, thanks to the exploitation of sustainable energy sources. The potential benefits are impressive, but how will they be achieved?

The platform in turn relies partly on the finding of the projects in the FP5 cluster: IRED. Among them DISPOWER and CRISP.

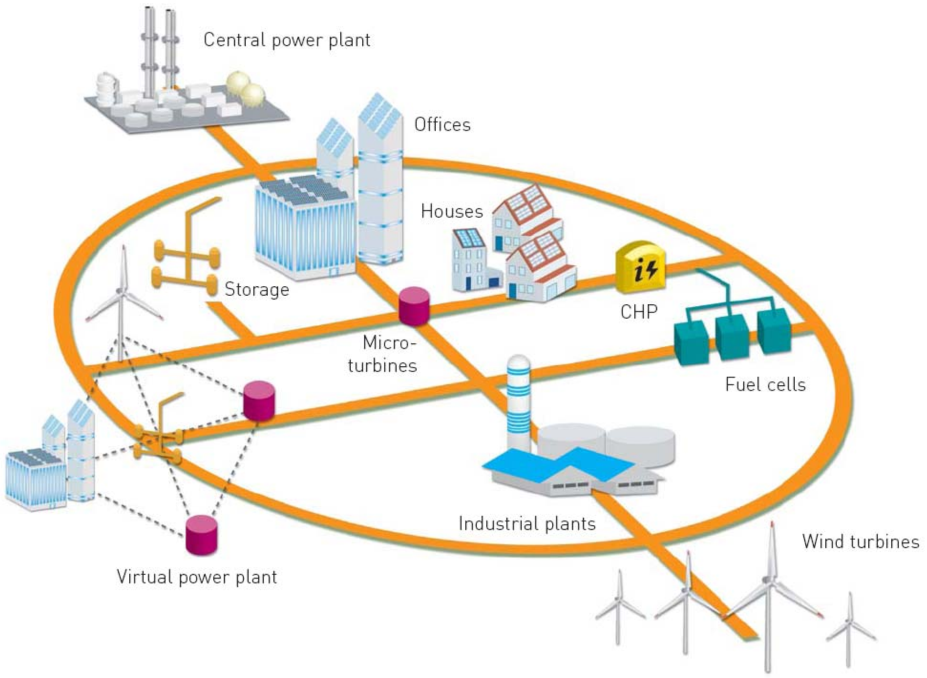


Figure 11. SmartGrids.

It is seen from these studies that the aim of the mentioned process is not just to improve the ability to incorporate fluctuating electricity sources but also to minimise the need for new costly interconnectors and – most of all – to improve the supply security in 'open' systems with many operators. There are two main headlines for this studies: a) more powerful communication networks. b) a change from AC distribution systems towards DC systems involving HVSC (high voltage semi conductors). The first can provide more flexible and efficient balancing of fluctuating electricity productions. The latter can provide cheaper and more effective transmission and distribution systems with less environmental impact (underground cables).

In Denmark, where the need for changes is big because of the high share of wind power, a large scale pilot test is ongoing with a new way of organising the distribution system – the cell system. It is described in detail in ref [6].

The idea is to equip a distribution area at the medium voltage level (60 kV) with an extensive information network connecting all producers and a number of large consumers. This will

create a semi-independent ‘cell’ where automatic balancing of as well active as reactive power can take place. In case of voltage break-downs at the higher levels of the transmission system this cell can disconnect itself and continue operation in ‘island’ mode. The cell is situated in the Holsted area in Southern Jutland and encompass as well wind turbines as CHP’s. [7]
Similar projects are under way in Australia and USA where a combination of new decentralised power plants (mainly N-gas combined cycle), high peak demands caused by air condition and a liberalised marked have caused a decreasing security of supply.[8]

CONCLUSION

A: The scenario calculations of the future electricity supply in different parts of Europe performed in the DESIRE project show that economic balancing of production and supply in the regions can only be achieved by carefully planning the combination of production units with different characteristica. A specific technology cannot be assessed alone, but only as part of a mix in a complete scenario analysis. The economy in establishing new transmission lines with the purpose of interregional balancing must also be analysed carefully as it depends strongly on the dynamic behaviour of the grids in the regions involved. Often such new transmission lines cannot compete economically with measures to improve the internal balancing potential of the regions involved. Part of the reason for this is the large costs and long planning periods involved in the strengthening of the internal transmission networks which are necessary to distribute the increased exports and imports.

B: Fundamental changes in the electricity production and distribution systems are taking place for the following main reasons:

- Development of cheaper and more effective information technology
- Development of more effective and flexible power transmission systems (DC)
- A need to incorporate larger shares of fluctuating and unpredictable electricity productions (RES) and combined-heat-and-power (CHP)
- A wish to open and liberalise the electricity markets

These developments are not in conflict. An example: The improved information systems which are needed to secure safe operation of decentralised production can also be used for advanced market functions. This can secure optimal allocation of production units and effective balancing of fluctuating productions.

REFERENCES

1. Homepage for DESIRE project, www.project-desire.org
2. Homepage for EnergyPLAN software, www.energyplan.eu
3. ExternE Externalities of Energy – Methodology annexes, Appendix V:Assessment of global Warming damages. EU commission, Brussels 2002.
4. IDA, Ingeniørforeningens Energiplan 2030, Copenhagen 2006. (The energy plan 2030 of the association of Danish engineers – in Danish.)
5. Rapport fra arbejdsgruppen om kraftvarme- og VE-elektricitet, Danish Energy Agency, Copenhagen 2001, (Report on CHP and RES electricity – in Danish).
6. Lund, P, Cherian, S and Ackermann, T, A CELL CONTROLLER FOR AUTONOMOUS OPERATION OF A 60 KV DISTRIBUTION AREA, *International Journal of Distributed Energy Resourses,* Vol. 2, No. 2, pp 83-100, 2006
7. Official planning report for 2006 for the Danish TSO, Energinet.dk
8. Platt, G, James, G P, Wall, J, West, S. The Intelligent Control of Distributed Energy Networks. *EIC2006.* CSIRO, Australia.