

# Kriegers Flak Combined Grid Solution Feasibility Study

---

50HERTZ

**ENERGINET/DK**



**SVENSKA  
KRAFTNÄT**

24 February 2010

## Content

<b>1</b>	<b>Executive Summary.....</b>	<b>1</b>
<b>2</b>	<b>Introduction.....</b>	<b>3</b>
<b>3</b>	<b>Overview of costs of the different variants.....</b>	<b>5</b>
<b>4</b>	<b>Overview of revenues/benefits .....</b>	<b>6</b>
<b>5</b>	<b>Comparison of costs versus benefits .....</b>	<b>10</b>
<b>6</b>	<b>Market Rules .....</b>	<b>12</b>
<b>7</b>	<b>Permissions for the project.....</b>	<b>13</b>
<b>8</b>	<b>Project implementation .....</b>	<b>14</b>
<b>9</b>	<b>Developments after finalising the common feasibility study .....</b>	<b>15</b>

## 1 EXECUTIVE SUMMARY

The Project Partners 50Hertz Transmission, Energinet.dk, and Svenska Kraftnät have been investigating different technical concepts for connecting offshore wind farms (OWFs) at Kriegers Flak in the Baltic Sea - Kriegers Flak 1 in Germany, Kriegers Flak 2 in Sweden, and Kriegers Flak 3 in Denmark.

The reference case is a classical solution where the offshore wind farms are only connected directly to each country. This concept is compared to combined grid solutions based on DC or hybrid technology where the grid connection of the offshore wind farms would also function as an interconnector between Denmark, Germany, and Sweden. One variant of these solutions is selected and referred to in the following as the Combined Grid Solution (CGS).

The results of the feasibility study are summarised below:

### □ **The CGS is the preferred solution from a technical and cost perspective**

The CGS is the preferred technical solution since it allows for a modular, step-wise development and maximum flexibility with moderate additional costs. The CGS has a significant strategic dimension and is a pilot project as such a solution involving both AC and DC technology was never built before.

### □ **Cost benefit analysis shows a positive net benefit for a CGS compared to radial grid connections**

Concerning the benefits the basic assumption is that capacity on the interconnections not expected to be required for transporting wind energy can be made available to the spot market. The utilisation of the transmission lines to/from Kriegers Flak increases with the combined solution at Kriegers Flak when the excess capacity is given to the market. The resulting trade generates social benefits. The difference in social benefits between a situation with radial connections of the OWFs and the situation under the CGS is estimated and evaluated. The social benefits are defined as the sum of producer surplus, consumer surplus, and the value of the transported energy through congested interconnections measured with the price differences between the two sides.

In order to come to an overall evaluation of costs and benefits, the costs for the preferred technical design of the CGS was compared with three different sets of benefit estimates. Only under the least favourable combinations of cost overruns and low benefits the difference in social benefits is lower than the estimated additional cost of the CGS. At an assumed real interest rate of six percent, the pay-back period of the additional investment for the CGS is approximately 10 years. The CGS would provide additional benefits, e.g. the increase of the security of supply by providing transmission capacity, the practical expertise for developing offshore grids, etc.

### □ **The benefits generated by the CGS are more favourable than for the other technical solutions**

Given the results on cost differences and the results on differences in benefits, the CGS shows a higher socio-economic benefit than the other technical solutions. The differences in social benefits are driven by price differences between the three markets, one key driver of which are differences in the merit order cost structure of the national generation capacity.

- ❑ **The CGS would pose some challenges for the existing market rules and national regulations in the three countries.**

Different rules for balancing and scheduling exist today in the three countries for wind power. The CGS and the three interconnectors would require changes in existing market routines, i.e. rules for determination of trading capacity on the interconnector day-ahead prior to gate closure. The relevant power exchanges would have to be included when determining the necessary changes to market rules. In case of long-term outages on connections between the national grids and the CGS, the connections to other countries could be used to feed in generation from national wind farms.

- ❑ **Permission procedures for CGS are expected to take between 2 and 3 years**

There will be a strong focus of the permission authorities on the environmental impacts of CGS and potential conflicts with other marine uses or projects. However, no insurmountable obstacles were identified. Even though the permission procedures of the evaluated technical alternatives may differ, between the countries these differences are not regarded as critical and would not rule out any of the technical designs investigated.

- ❑ **The CGS is a very flexible solution and can be implemented in a step-wise manner**

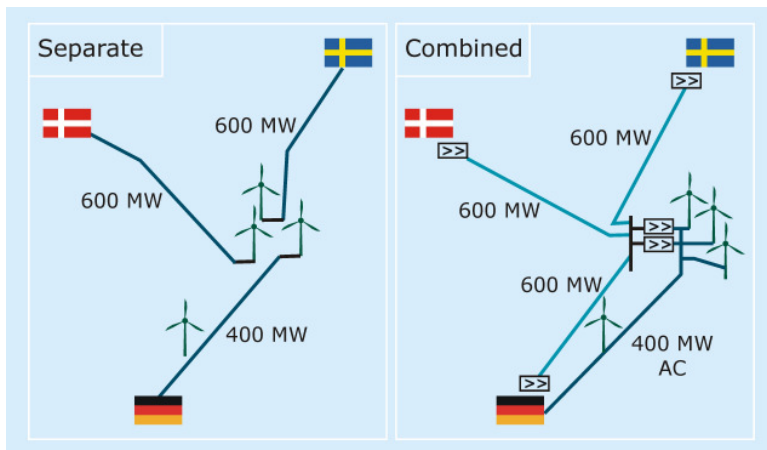
It is assumed that the wind farm KF1 in Germany will be realised between mid-2012 and 2013. The grid connection therefore needs to be ready by mid-2012. Planning for this wind farm has already started and a final decision on its realisation is expected by April 2010. A decision on KF3 in Denmark is expected to be made before summer 2010. In mid 2012 the final investment decision for realizing the Combined Solution Project is expected. At the same time it is assumed that the wind farm KF1 is (partly or fully) realised. The current technical design of the Combined Solution fully accommodates a modular build-up in case parts of the wind power developments will take place at a later stage. It is estimated that the Combined Grid Solution Project could be realised between October 2012 and June 2016 to be in operation from July 2016.

## 2 INTRODUCTION

The possibility to combine the grid connection of the offshore wind farms Kriegers Flak 1 (Germany), Kriegers Flak 2 (Sweden), and Kriegers Flak 3 (Denmark) with cross-border transmission capacity across the Baltic Sea has been investigated in a joint feasibility study by 50Hertz Transmission, Energinet.dk and Svenska Kraftnät (the Project Partners).

The feasibility study analyses different technical concepts for connecting offshore wind farms (OWFs) at Kriegers Flak in the Baltic Sea. The reference case (Variant A) is a classical AC-based solution where the OWFs are connected radially (nationally). This concept is compared to combined grid solutions where the grid connection of the OWFs would also function as an interconnector between Denmark, Germany, and Sweden (Variant D HVDC CGS). In addition, national grid connections of the OWFs together with direct bilateral interconnectors as well as a variant with offshore AC-based connection of the wind power combined with onshore located DC converters were also considered.

One variant of the feasible combined solutions is selected and referred to as the Combined Grid Solution (CGS). The Project Partners envisage constructing this Combined Grid Solution (CGS) as a High Voltage Direct Current (HVDC) connection in combination with AC connections to Germany.



**Figure 1: Schematics for separate solutions and for the selected HVDC Combined Grid Solution**

The following table provides an overview:

Variant	Description	Trading capacity (MW)	
		DE↔SE/DK	DK↔SE
A	Separate radial (national) connections of the OWFs (offshore wind farms) (Reference Case)	0 MW	0 MW
A – DE-SE	600 MW DC bilateral interconnector between Germany and Sweden combined with radial connections of OWFs	600 MW	0 MW
A – DE-DK	600 MW DC bilateral interconnector between Denmark and Germany combined with radial connections of OWFs		
B	AC-based CGS (all offshore connections based on AC technology combined with onshore located converters)	0–400 MW	0 - 600 MW
D 1 - central	HVDC-based CGS based on a central platform with two converters (2 x 600 MW)	0 – 1000 MW	0 - 600 MW
D 1 – semi-central	HVDC-based CGS based on semi-central platforms with two converters (2 x 600 MW)		
D 2 - central	HVDC-based CGS based on a central platform with three converters (2 x 600 MW, 1 x 400 MW)		

**Table 1: Overview of technical solutions analysed (In the CGS' the trading capacity is depending on wind in-feed at KF.)**

The AC-based CGS in variant B has some operational drawbacks and is therefore not fully comparable with the DC-based solutions.

The HVDC CGS may be implemented with two offshore converters<sup>1</sup> either on a central platform or on semi-central platforms. Assuming that a third converter is not required from a technical and operational perspective, the D1 semi-central solution is the preferred technical solution since it allows for a modular, step-wise development and maximum flexibility (for example, a third converter could be installed at a later stage).

This document summarises the major results of the feasibility study.

---

<sup>1</sup> Two converters are expected to be sufficient for the CGS from a technical and operational perspective. Nevertheless the D2 – central variant with three converters was also investigated in order to evaluate the marginal costs for a third converter.

### 3 OVERVIEW OF COSTS OF THE DIFFERENT VARIANTS

The costs shown are only the ones directly associated with connecting the OWF's to the national grids. They do not take into account any internal grid reinforcements that could be necessary to handle the increased trade.

The Table 2 provides an overview of the investment and operational costs.

Costs in M €	A - Reference	A - DE-SE	A - DE-DK	B	D1 - central	D1 semi-central	D2 central
Investment Costs	975	1.328	1.294	1.315	1.357	1.296	1.418
Operational Costs	39	194	173	122	180	180	224
Total costs	1.014	1.522	1.467	1.437	1.537	1.476	1.642
delta total cost versus A	0	509	453	423	524	462	629

**Table 2: Comparison of costs of the different variants**

The additional investment costs for the D1 semi-central solution in relation to the reference case are around **320 M€**. The rationale for considering only the difference is that the radial grid connections would be required in any case.

The variant A – DE-DK leads to approx. the same additional investment costs as the D1 semi-central solution, whereas the variant A – DE-SE and the AC-based variant B both lead to higher additional investment costs than the D1 semi-central solution.

The operational costs (losses and maintenance) are shown as present values. Again the D1 semi-central solution is the least costly HVDC CGS with additional operational costs estimated at around 140 M€. Variant A - DE-DK and variant B have similar total costs.

Overall the HVDC-based CGS based on semi-central platforms with two converters (2 x 600 MW) is the least costly HVDC CGS solution.

#### 4 OVERVIEW OF REVENUES/BENEFITS

Concerning the benefits the basic assumption is that capacity on the interconnections not expected to be required on the next day for the wind energy injection can be made available to the spot market via the power exchanges. The resulting trade generates social benefits. As in the case of costs discussed above, the difference in social benefits between a situation with radial connections of the OWF's and the situation under the CGS is estimated. Changes in losses in the national grids are not included in the calculation.

Two models were used to estimate these differences: Energinet.dk obtained estimates with the EMPS model and consulting firm Econ Pöyry provided an assessment based on its BID model. As in the case of costs, a range of assumptions and input parameters were considered with a view to getting a feel for the sensitivity of results.

The following table provides an overview of estimated annual benefits expressed in terms of millions of Euros<sup>2</sup>:

Variants	Yearly Social Benefits in M€				
	Year	EMPS Model		BID Model	
		2015	2030	2015	2025
A - DE-SE: Business as Usual	46	47	77	189	
A - DE-DK: Business as Usual	26	22	66	161	
B: Business as Usual	29	n.a.	n.a.	n.a.	
D - CGS: Business as Usual	58	43	96	195	
D - CGS: Green / Wind Scenario	14	64	n.a.	193*	
D - CGS: BAU & 400 MW res. (DE)	45	38	n.a.	n.a.	
D - CGS: BAU & IEA fuel prices	n.a.	50	n.a.	177*	

\* (DE+DK+SE) only, other scenarios include more countries

**Table 3: Estimated differences in yearly benefits (n.a.: not available)**

Given the earlier results on cost differences and the results on differences in benefits presented here, the CGS shows to be more favourable than the other technical solutions.

The differences in social benefits are driven by price differences (see discussion below) between the three markets, one key driver of which are differences in the cost merit order structure of the national generation capacity. Bearing this in mind, the above results can be explained as follows:

- The EMPS "green" (GREEN) scenario assumes an additional 7000 MW of installed wind capacity in 2015 relative to the business-as-usual (BAU) scenario. Additional wind capacity shifts the merit order to the right in all three markets. However, the relative effect on prices is more pronounced in Germany which is known to have a steeper merit order than the

<sup>2</sup> The base year in terms of purchasing power is 2010; i.e., all figures correspond to 2010 EUR amounts. The effect of general price inflation is thereby stripped out.

Scandinavian countries. The relative reduction in price differences leads to much lower benefits under the GREEN scenario than under BAU in 2015.

- This effect is reversed for the year 2030 as conventional thermal capacity under the GREEN scenario is assumed to be much lower than under BAU. The relative lack of conventional capacity means that price differences will more frequently be determined by peak plants with very high marginal costs. This increases gains from trade and, therefore, benefits.

The BID model generally produces higher benefit estimates because of its more granular (hourly) resolution. The finer the resolution, the more accurately differences in (peak) prices can be captured and the higher estimated benefits. By contrast, the EMPS model only uses thirty time steps per week. Further more the dataset used in the BID model is automatically reduced with respect to installed thermal capacity when wind capacity is increased, also in the short run. This is not the case in the EMPS model.

Therefore the EMPS model is regarded as conservative and likely underestimates the benefits.

The utilisation of the transmission lines to/from Kriegers Flak increases with the combined solution at Kriegers Flak when the excess capacity is given to the market – see Table 4 and Figures 2, 3 and 4. In cases with no wind production at Kriegers Flak and high prices in Germany it seems that the price in Eastern Denmark is between Southern Sweden and Germany, hence the connection from Sweden to Kriegers Flak is utilised first with 600 MW and secondly the connection from Denmark to Kriegers Flak with 400 MW. This explains why the duration curve from Denmark to Kriegers Flak appears to be capped at -400 MW (not -600 MW).

Utilisation factors						
	Reference case			CGS		
	KF to Germany	KF to Sweden	KF to Denmark	KF to Germany	KF to Sweden	KF to Denmark
2015	36 %	36 %	36 %	64 %	79 %	55 %
2030	36 %	36 %	36 %	55 %	73 %	42 %

**Table 4: Utilisation factors for the flows from Kriegers Flak to the different countries in the Business-as-usual scenario (EMPS)**

**Duration curve for flow from Kriegers Flak to Germany  
Business-as-usual 2015**

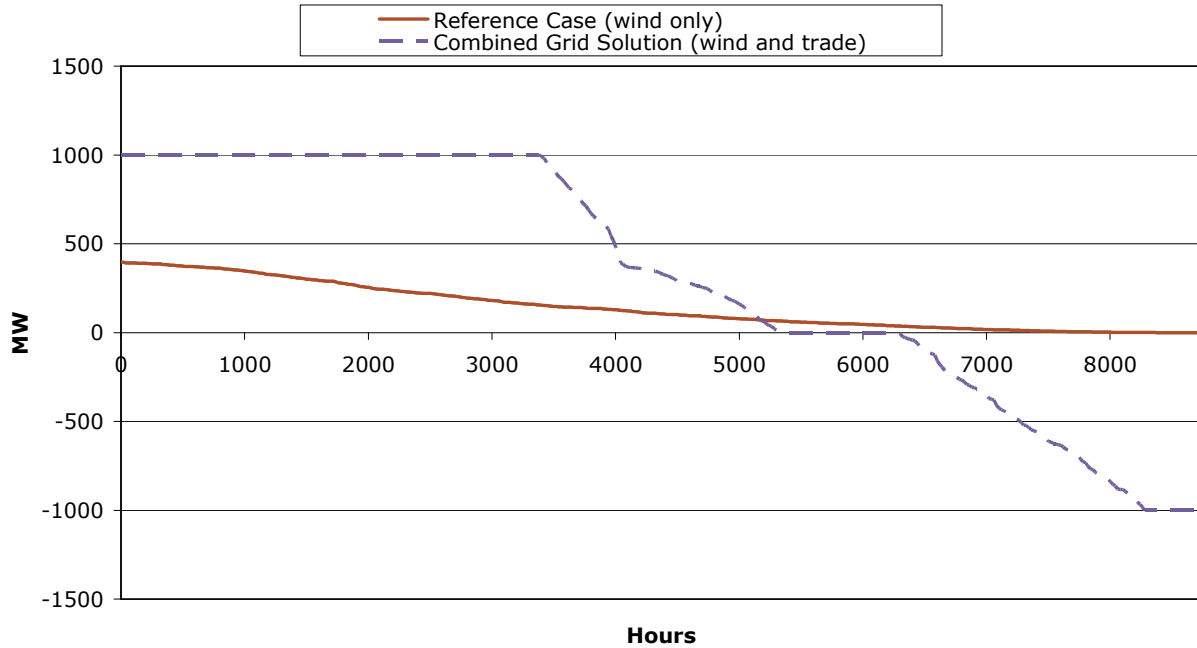


Figure 2: Duration Curve for flow from Kriegers Flak to Germany (Business-as-usual 2015)<sup>3</sup>

**Duration curve for flow from Kriegers Flak to Sweden  
Business-as-usual 2015**

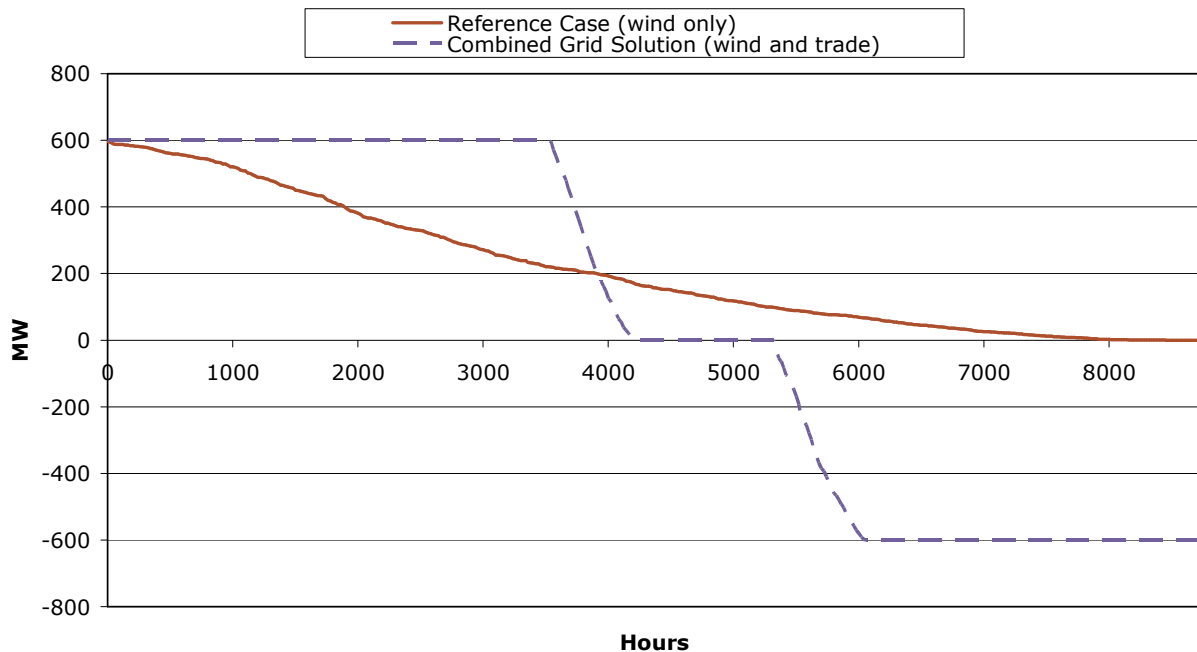
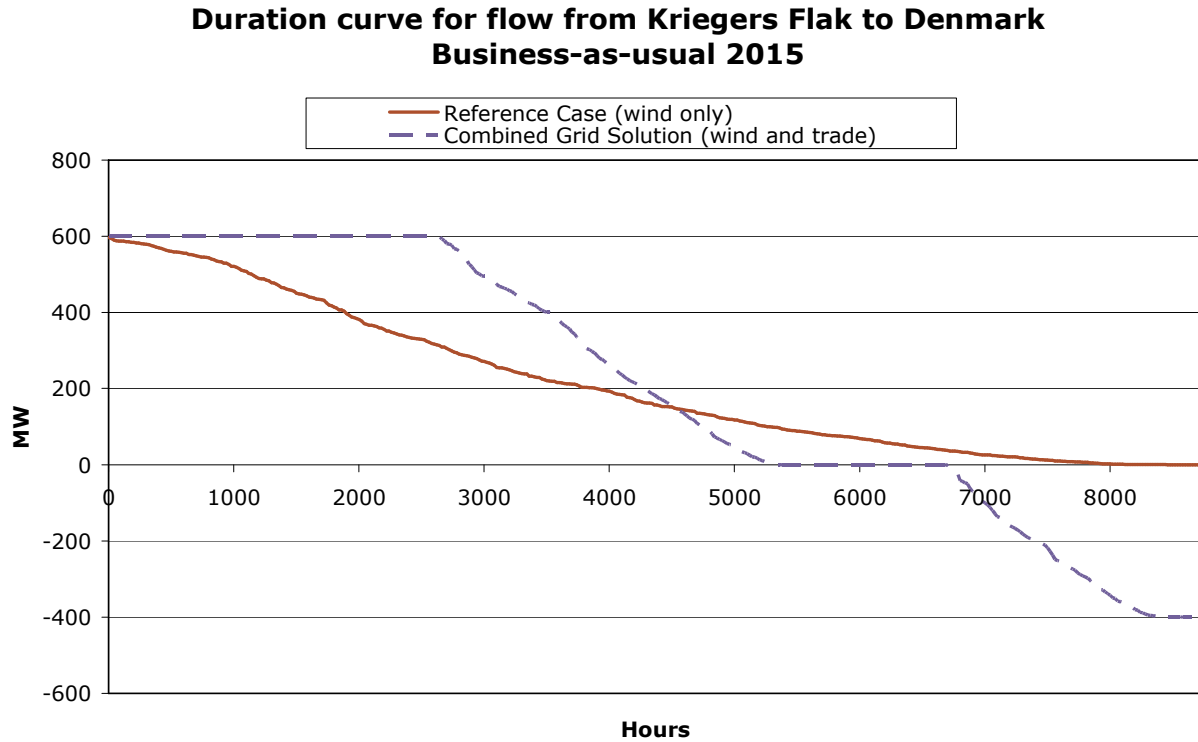


Figure 3: Duration Curve for flow from Kriegers Flak to Sweden (Business-as-usual 2015)<sup>4</sup>

<sup>3</sup> Positive algebraic sign means flow from Kriegers Flak to Germany whereas negative sign means flow from Germany to Kriegers Flak.



**Figure 4: Duration Curve for flow from Kriegers Flak to Denmark (Business-as-usual 2015)<sup>5</sup>**

The expected pattern is that the average price in Germany goes down and the average prices go up in Sweden and Denmark.

The price level increases from 2015 to 2030, due to increase in fuel prices of 10 - 14 % in real terms, 50 % increase in CO<sub>2</sub> - prices and change in generation capacity. The prices in the European thermal system and in the Nordic hydro system approach, because the expected transmission capacities between the areas increase with around 2,500 MW (Norway - Germany, Denmark West - Germany, Sweden - Lithuania).

The price level is expected to be lower in the Green scenario compared to the Business-as-usual scenario due to in feed of more wind generation at zero prices.

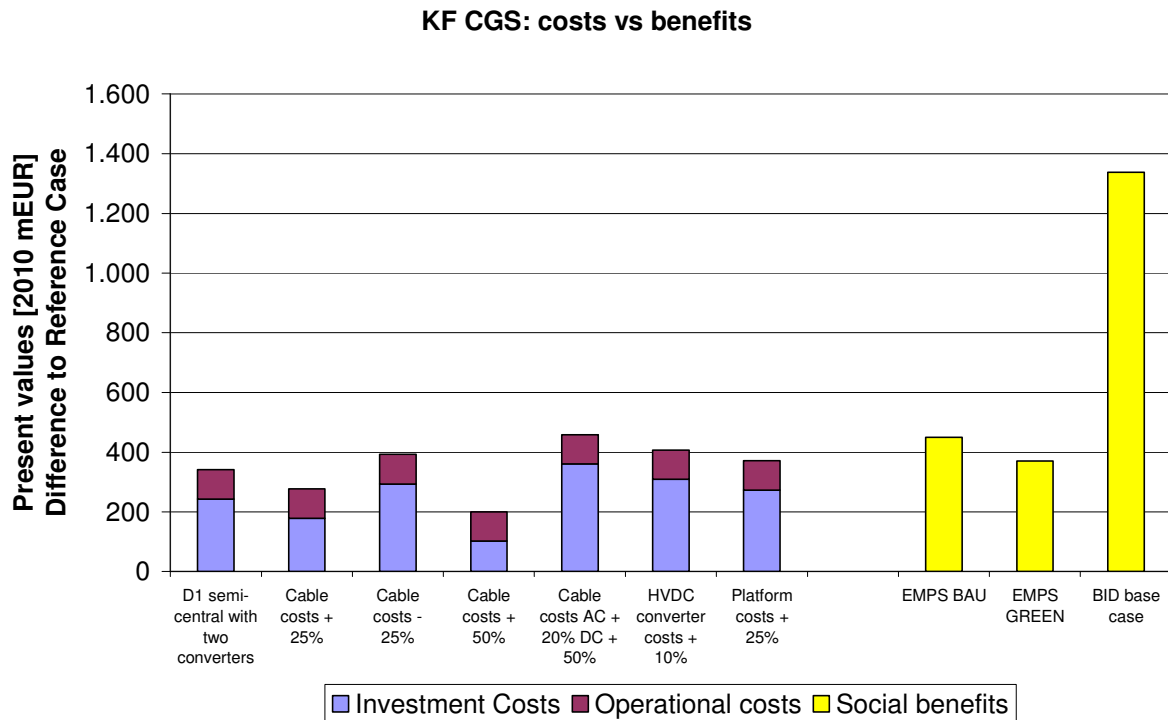
In 2030 there is an expected congestion at "cut 4" in Sweden from Sweden Mid to Sweden South in 1000 hours/year in the reference case with separated solution at Kriegers Flak. With a combined solution at Kriegers Flak it increases to 2000 hours. The congestion in Sweden implies higher prices in the southern part of Sweden especially.

<sup>4</sup> Positive algebraic sign means flow from Kriegers Flak to Sweden whereas negative sign means flow from Sweden to Kriegers Flak.

<sup>5</sup> Positive algebraic sign means flow from Kriegers Flak to Denmark whereas negative sign means flow from Denmark to Kriegers Flak.

## 5 COMPARISON OF COSTS VERSUS BENEFITS

In order to come to an overall evaluation of costs and benefits, the following chart compares the costs for the preferred technical design of the CGS with three different sets of benefit estimates and scenarios (EMPS BAU, EMPS GREEN, BID base case). Sensitivities of the cost difference with respect to changes in certain cost components (described in the chart) are also displayed. All benefits and costs are discounted at a real interest rate of six percent and stated in present value terms in 2010 Euros. The figures are thus directly comparable.



**Figure 5: Costs versus benefits (present values in terms of millions of 2010 Euros)**

Only under the least favourable combinations of cost overruns and low benefits the difference in social benefits is lower than the estimated additional cost of the D1 semi-central CGS. As noted above the EMPS model produces conservative estimates that likely underestimate the benefits.

At an assumed real interest rate of six percent, the pay-back period of the additional investment for the CGS is approximately 10 years.

The CGS would provide the following additional benefits, which were not quantified:

- Increase the security of supply by providing transmission capacity
- Develop practical expertise for developing offshore grids
- Trading Ancillary Services, e.g. “EEG Reserve (special type of slow schedule activated tertiary reserve)” could be provided partly by CGS (depending on capacity reservation)
- Compared to radial connections, the CGS provides redundant capacity to feed in wind generation to the other countries in case of outages or capacity reductions in one connection.

These synergies would be the result of optimising grid connection of offshore wind farms not just nationally but also regionally.

In summary, the CGS is expected to yield a positive net benefit compared to radial grid connections of the three offshore wind farms.

## 6 MARKET RULES

The CGS at Kriegers Flak would pose some challenges for the existing market rules and national regulations in the three countries.

Different rules for balancing and scheduling exist today in the three countries for wind turbines. This will have an impact on the socio-economic value of the CGS and make the implementation of market rules more complex but the establishment of the KF CGS will still be beneficial. Based on the Directive 2009/28 all countries have priority access to the grid for renewable energy sources. German national legislation furthermore demands that wind turbines at all times can feed-in to the national German transmission grid. However, in the event of insufficient transmission capacity the formal grid access requirements can be solved by means of counter trading or balancing market measures.

The KF CGS and the three interconnectors would also require changes in existing market routines, i.e. rules for determination of trading capacity on the interconnector day-ahead prior to gate closure. The relevant Power Exchanges would have to be included when determining the necessary changes to market rules.

Today exchange of balancing services is possible within the Nordel area, i.e. between Sweden and Denmark, but not yet between Germany and the Nordic countries.

The primary control immediately restores the balance between generation and demand within the synchronous area. Primary control is activated automatically and immediately by the deviation in the system frequency. Secondary control adjusts the frequency offset and restores the power cross-border exchange to its values agreed between the respective TSOs. Secondary control is automatically provided by selected generator sets in the control area affected by the power imbalance. Tertiary control is used to free up secondary control reserve. Tertiary control reserve also referred to as "minute reserve" is operated in the responsibility of the TSO and usually activated manually by the affected TSO. In principle it is possible to activate minute reserve located in another than the affected control area if sufficient transmission capacity is available.

One of the reasons why at present, this is not possible between Germany and the Nordic countries yet, is the fact that capacity on congested interconnectors is not being reserved for providing control reserve between the markets. From market point of view so far all transmission capacity is used for trading transactions.

At present, the balancing market in Germany is going through some major changes. For example at the end of 2008, three German TSOs, started to establish a method, where the demands of the three TSOs in secondary control power are continuously netted and only the netted demand is activated on the basis of a common merit order. There are ongoing investigations to extend this concept for exchanges between all four German TSOs and, furthermore, for international cross-border exchanges of balancing services within Central Europe. Within the next one or two years, the TSOs will introduce a common merit order for tertiary control reserve power.

Overall if the three parties are to realize all potential socio-economic gain on the KF CGS balancing market rules have to some extent to be harmonized.

In case of long-term outages on interconnectors between the national grids and the KF CGS, the connections to other countries could be used to feed in generation from national wind farms.

## 7 PERMISSIONS FOR THE PROJECT

The permission procedures for CGS (platform(s) and cable routes) are estimated to take approx. 2 years in Denmark and Germany and approx. 3 years in Sweden. There will be a strong focus of the permission authorities on the environmental impacts of CGS and potential conflicts with other marine uses or projects. However, no insurmountable obstacles were identified in the study. The main foreseeable topics of the permission procedures can be summed up as follows:

- ❑ environmental impacts of HV cables, in particular crossing of special protected areas under EU Habitats and warming of sea bed
- ❑ environmental impact of converter platform, in particular foundation and emissions
- ❑ conflicts concerning shipping routes/ navigation, in particular risk analysis concerning platform
- ❑ potential conflicts with raw material extraction/ spoil grounds, in particular on the Danish side at Kriegers Flak area

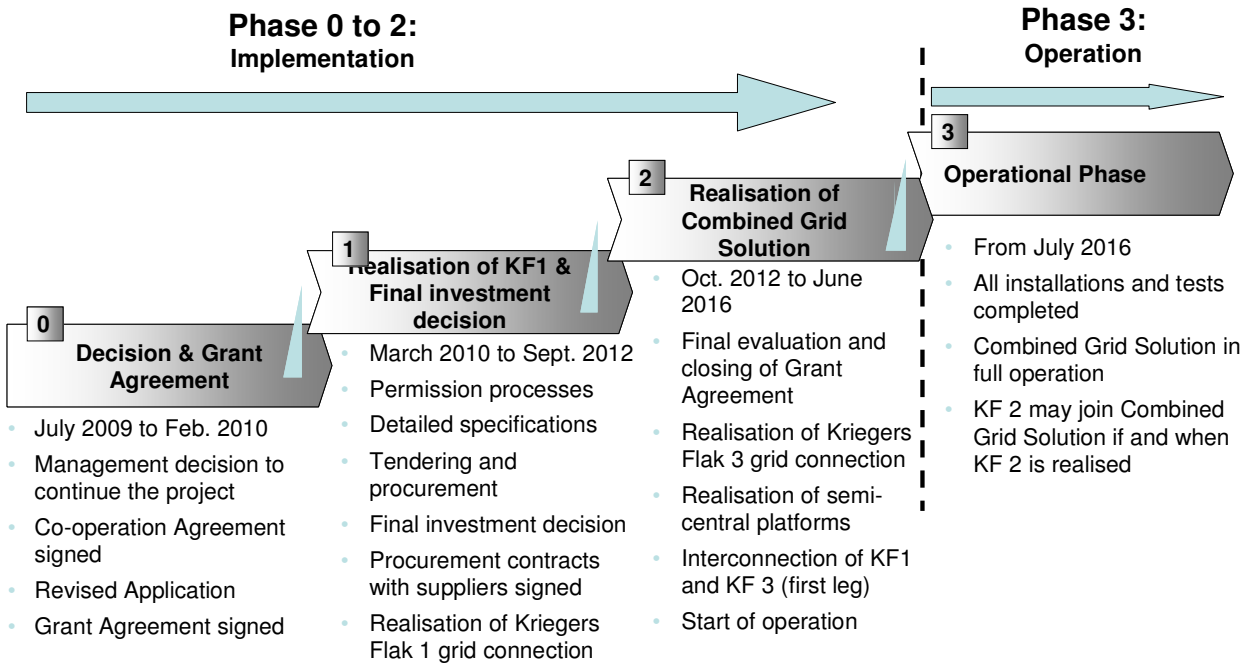
The main characteristics and technical/ constructional challenges of the prospective HV cable routes leading from the Kriegers Flak area to the transmission grids of the project partners are expected to be as follows:

- ❑ burying of sea cable to a depth of approx. 1 – 1.5 m in the seabed; elaborate completion in particular in areas with hard subsoil (clay)
- ❑ crossing/ by-passing of other electricity or telecommunication cables or pipelines
- ❑ crossing of dumping areas and ammunition clearance

Even though the permission procedures of the evaluated technical alternatives may differ, these differences are not regarded to be of such significance, that they would amount to a criterion for decision-making for or against a certain technical concept.

## 8 PROJECT IMPLEMENTATION

The semi-central CGS is a very flexible solution and can be implemented in a step-wise manner. The project can be divided into four phases - three implementation phases followed by the operational phase as illustrated in the following figure:



**Figure 6: Illustration of project phases**

It is assumed that the wind farm KF1 in Germany will be realised between mid-2012 and 2013. The grid connection therefore needs to be ready by mid-2012. Planning for this wind farm has already started and a final decision on its realisation is expected by April 2010.

A decision on Danish KF3 is expected to be made before mid 2010.

Right before mid 2012 the tender for the semi-central platform(s), the HVDC converters etc. must be started. In mid 2012 the final investment decision for realizing the Combined Solution Project need to be in place.

At the same time it is assumed that the wind farm KF1 is (partly or fully) realised.

The possibility is assessed that the Combined Solution Project can be realised gradually between October 2012 and June 2016 to be in operation from July 2016.

## **9 DEVELOPMENTS AFTER FINALISING THE COMMON FEASIBILITY STUDY**

Svenska Kraftnät informed in 2010-01-15 that it abstains from engaging now in a combined development of Kriegers Flak. Assessments of Svenska Kraftnät show that offshore wind farms are not expected to be constructed at the Swedish part of Kriegers Flak in the foreseeable future. Svenska Kraftnät is willing to technically support the further development of the Danish and German parts of the combined structure.

Energinet.dk (Denmark) and 50Hertz Transmission (Germany) continue the EU supported project to combine the connection of offshore plants at Kriegers Flak with interconnections between Denmark and Germany. The technical solution will allow future participation of Svenska Kraftnät and increased trading capacity should offshore wind power projects on the Swedish part of Kriegers Flak be constructed.

According to the latest information (received after finalising the calculations) from the wind farm developer, the size of the wind farm KF1 is expected to be less than 300 MW. The transmission capacity will be adjusted accordingly (only one AC-cable will be laid between KF1 and Baltic 1 in a first step). It must be noted that all calculations and results shown in this feasibility study are based on the 400 MW transmission capacity.

The decision on the Danish wind farm will probably be made by summer 2010 and the Swedish wind farm may join at a later stage if and when it is built.