ELINFRASTRUKTURUDVALGET

Technical report on the future expansion and undergrounding of the electricity transmission grid

Summary

April 2008

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One of the energy-political objectives is to increase the share of renewable energy to at least 30 per cent of the energy consumption in 2025.[1] The Danish government also wants to ensure that the overall objectives on security of supply, environmental protection and high competitiveness are met in a cost-effective manner.

An adequate and robust electricity transmission grid is a precondition for realising the energy-political objectives on the environment, security of supply and market development in the energy sector. The electricity transmission grid must therefore be continuously expanded and adapted concurrently with the integration of large volumes of renewable energy and the expansion of trading capacities to neighbouring areas.

In the continued development of the EU's single energy market a decisive precondition will be the ability of the infrastructure to handle the transmission of considerable energy volumes – often across national borders – and thus reduce congestion in the market. This would limit the individual players' possibilities of using their market power to influence price formation to the detriment of enterprises and households. As a part of the TEN activities (Trans European Network) the EU has pointed to a number of specific interconnections between the countries that need to be built or expanded. This includes a spectrum of tie-lines in Denmark and from Denmark to Norway and Germany.

So far, the planning of this expansion has been based on the then Danish Ministry of the Environment and Energy’s principles for the establishment and upgrading of high-voltage installations from 1995 with subsequent updates – most recently in connection with the Danish government’s Energy Strategy 2025 from June 2005. The current guidelines can be seen in Appendix 2.

In addition to the quantification and specification of the expected expansion requirement, it has also been deemed expedient to establish the basis for systematic assessment of the considerations on which the planning of the expansion of the electricity transmission grid is to be based.

On this background, the former Danish Transport and Energy Minister set up the Electricity Infrastructure Committee in the summer of 2007, which was tasked with preparing a technical report on the future expansion of the electricity transmission grid.

1.1 The Electricity Infrastructure Committee's mandate

According to its mandate, the Committee is to prepare a technical report describing and quantifying the total expansion requirement and the tasks to be solved by the electricity infrastructure when it comes to integrating renewable energy and local electricity generation, maintaining the security of supply and facilitating the electricity market at transmission level.

The technical report is also to comprise an analysis of the potential future grid structures based on various long-term grid expansion strategies. This must include various scenarios for the development of the overall Danish energy system. Furthermore, the report is to provide an analysis of the increasing use of underground cables instead of overhead lines in the Danish 400 kV grid.

[1] On 21 February 2008, the Danish government made a broad political energy agreement. In the agreement, the parties involved have, among other things, agreed to the erection of new offshore wind turbines with an installed capacity of 400 MW by 2012, which is more or less in line with the assumptions used by the Committee in its work. The Committee is of the opinion that the energy agreement does not change the Committee's results.

Against the backdrop of these analyses, the technical report is to propose a number of specific models for the future expansion of the electricity infrastructure based on various technological possibilities.

The technical report is to identify the environmental/landscape, technical, cost-related and socio-economic consequences of the individual expansion models. It must also include an assessment of the impact on electricity prices.

The aim is for the alternatives to fulfil comparable requirements as regards security of supply, market expansion and integration of large volumes of renewable energy in accordance with the objectives laid down in the government's Energy Strategy. The alternatives must also be assessed on the possibility of interaction with foreign countries. As reference, Energinet.dk's present plan for the long-term electricity infrastructure based on the existing principles for electricity infrastructure expansion is used.

1.2 Defining the report

The Electricity Infrastructure Committee has drafted a technical report on the possible future principles for the expansion and undergrounding of the electricity grid. The Committee was tasked with ensuring that the suggested grid expansion principles are sufficiently broad and robust to support the security of supply and market functioning when using various combinations of interconnections and domestic electricity generation equipment.

The report does not, however, provide a detailed analysis of the optimum solution for expanding the overall electricity system seen from a socioeconomic point of view. The specific infrastructure expansions will be analysed further when the decision basis for the individual investments is prepared. In the continued work, account must be taken of the changed framework conditions in Denmark and the neighbouring areas which are important to the Danish energy system. It is vital to stress that the integration of large volumes of wind power into the electricity system entails a considerable need for exchanging electricity with neighbouring areas. Trading via strong interconnections is a precondition for ensuring appropriate utilisation of the rest of the Danish electricity generation system, which must be maintained to a certain extent in order to safeguard the stability and security of supply in the Danish system. This report does not present any conclusions as to which specific development of the electricity generation equipment is the most likely or directly necessary in order to maintain the security of supply.

Likewise, the report does not provide any analysis of the possible lack of expansion of interconnections to neighbouring areas. As such, the calculation of the market costs related to grid congestion only includes costs resulting from congestion in the internal Danish transmission grid – ie costs of congestion in interconnections are left out.

Finally, it should be noted that the timely implementation of the expansion principles is entirely dependant on the public authorities' consideration of the project being made much more flexible. In future, steering committees and working groups should, for example, be set up in connection with the planning of electricity transmission projects. The Danish Energy Authority, the Danish Ministry of the Environment as represented by the Danish state's regional environmental centres, the municipalities affected, Energinet.dk, the regional transmission companies and other relevant authorities should have a seat on these groups so that the two approvals required under the Danish Electricity Supply Act and the Danish Spatial Planning Act are coordinated to a greater extent. The Committee has not additionally considered the procedures currently applied by public authorities in their consideration of electricity infrastructure facilities.

1.3 Main conclusions with regard to the expansion principles

The electricity grid must be expanded through coherent, long-term, controlled development, maintaining the security of supply and supporting the functioning of the electricity market in the best possible manner. The expansion must furthermore take account of the continued technological development, the environment, including landscape considerations, and the socioeconomic framework.

Today, the overall electricity grid consists of approx. 1,100 km of 400 kV power lines and 3,000 km of 132 kV and 150 kV power lines. The 400 kV grid is the backbone of the Danish electricity system and can in popular terms be described as the motorways of the electricity system. By way of comparison, the 132 kV and 150 kV grids can be considered the main roads of the electricity system.

At the 400 kV level, approx. 165 km of power lines have been placed underground, 80 of which are AC cables. At the 132 kV and 150 kV levels approx. 600 km of power lines have been placed underground.

Table 1 provides an overview of the share of cables and overhead lines in the existing grid and the estimated costs of undergrounding the remaining overhead lines.

Voltage level	Total no. of km	Km of cable	Km of overhead line	Costs of burying remaining overhead lines (DKKbn)
6-20 kV	61,566	53,428	8,138	3[2]
30-60 kV	8,465	2,760	5,705	7-8
132-150 kV	4,062	611	3,451	11.5
220-400 kV	1,478	164	1,314	37

Table 1 Distribution of cables and overhead lines in the existing grid and the costs of undergrounding. All lengths are given in system kilometres.[3]

It is highly probable that the entire distribution grid below 100 kV will be buried in the ground within the time horizon used in these analyses.

If increased undergrounding of the overall transmission grid is required, this can be done at the 132 kV and 150 kV levels without any significant technological problems. Increased undergrounding of 400 kV power lines is, however, a major technical challenge. It is also considerably cheaper to place the 132 kV and 150 kV grids underground than is the case with the 400 kV grid.

The Committee has assessed the environmental, security of delivery[4], market-related and socioeconomic aspects of six different expansion principles; two of which are not considered appropriate, being unable to support the environmental and energy political objectives to the

[2] An overall estimate, which is highly uncertain. The estimate is based on costs amounting to DKKt 350 per km. Costs derived for the rebuilding of substations are not included in the estimate.

[3] Kilometres of route indicate the length of the route. Kilometres of system indicate the length of the power line which may be longer than the route length as several systems can be placed on the same row of towers.

[4] Security of delivery can be defined as the probability of the grid being able to transmit electricity to the end consumers. Security of delivery is thus not the same as security of supply, which can be defined as the probability of electricity being available to end consumers, but it is an important element of this.

necessary extent.

For each of the six expansion principles, the Committee has conducted calculations for one or more specific expansion models as examples of each principle, see Appendix 1. The analyses focus specifically on alternative undergrounding principles. The analyses cannot be used as decision basis for specific electricity grid expansion as this would in the long-term limit the possibilities of, for example, putting a new technology into use. As such, it is primarily the expansion principle that must be determined.

Figure 1 illustrates the six expansion principles A to F for the overall electricity system at 400 kV level.

It is assumed that principles A, B and C are all combined with undergrounding of the existing 132 kV and 150 kV grids in accordance with separate criteria to be described in detail at a later stage in a specific cable action plan. For principles D and E, undergrounding of the 132 kV and 150 kV grids is optional.

Where the 400 kV grid is concerned, principles B and E can also be combined with an improvement of the visual appearance of the existing 400 kV grid. With the present technological possibilities, this will primarily be done by replacing existing lattice towers with new and lower towers (see Figure 7, page 13) as reconstruction becomes necessary. The existing 400 kV power lines can be placed underground over short and specifically chosen sections.

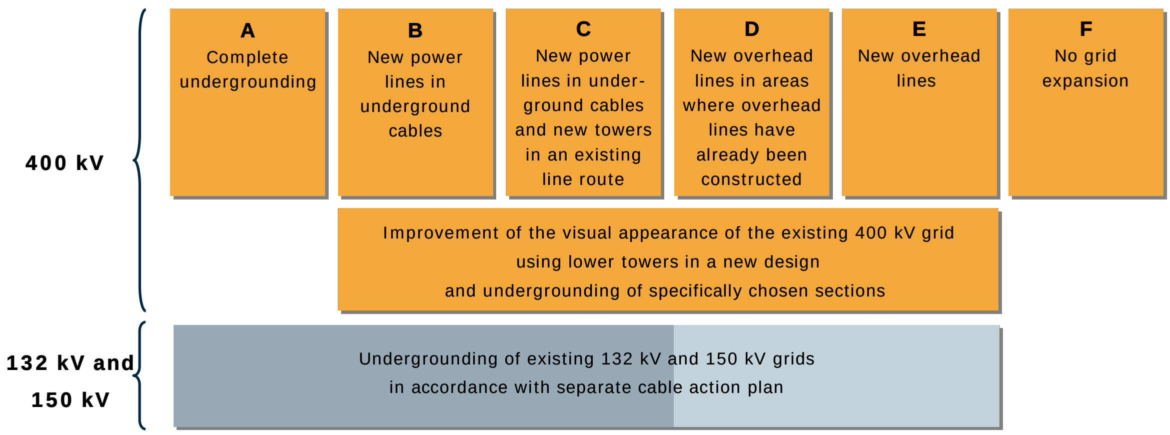

Figure 1 Expansion principles for the electricity grid.

A – Complete undergrounding of the electricity grid

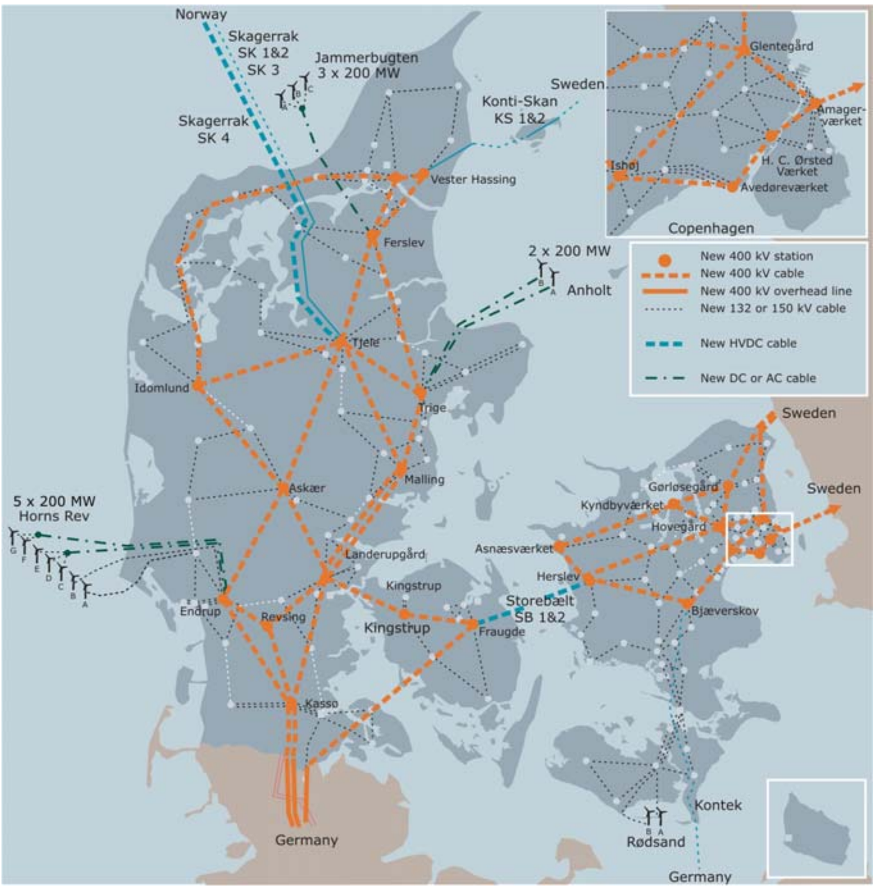

Figure 2 Expansion principle A – complete undergrounding of the electricity grid.

Complete undergrounding of the Danish 400 kV grid will be a comprehensive and technically demanding task that cannot be completed in less than 30-40 years.[5]

Because of the time horizon and the technological challenges involved, an actual decision to place the entire Danish electricity grid underground cannot be taken until these challenges have been solved. Instead, complete undergrounding of the electricity grid can be considered an overall, long-term objective irrespective of which of the other expansion principles is chosen.

If it were possible to place the entire 400 kV grid underground using today's technology, the expected costs would be around DKK 37bn[6], ie 14 times the expected costs of continuing with the expansion principles used today.

To this should be added the costs of placing the entire 132/150 kV grids underground, which will amount to about DKK 11.5bn. All in all, it would cost approx. DKK 48bn to place the Danish 400 kV, 150 kV and 132 kV grids underground.

[5] In order to compare this principle with the other expansion principles, it is assumed in the economic analyses that undergrounding will be completed in 2030.

[6] All costs related to the realisation of the principles are stated in 2008 prices.

B – New 400 kV power lines in underground cables

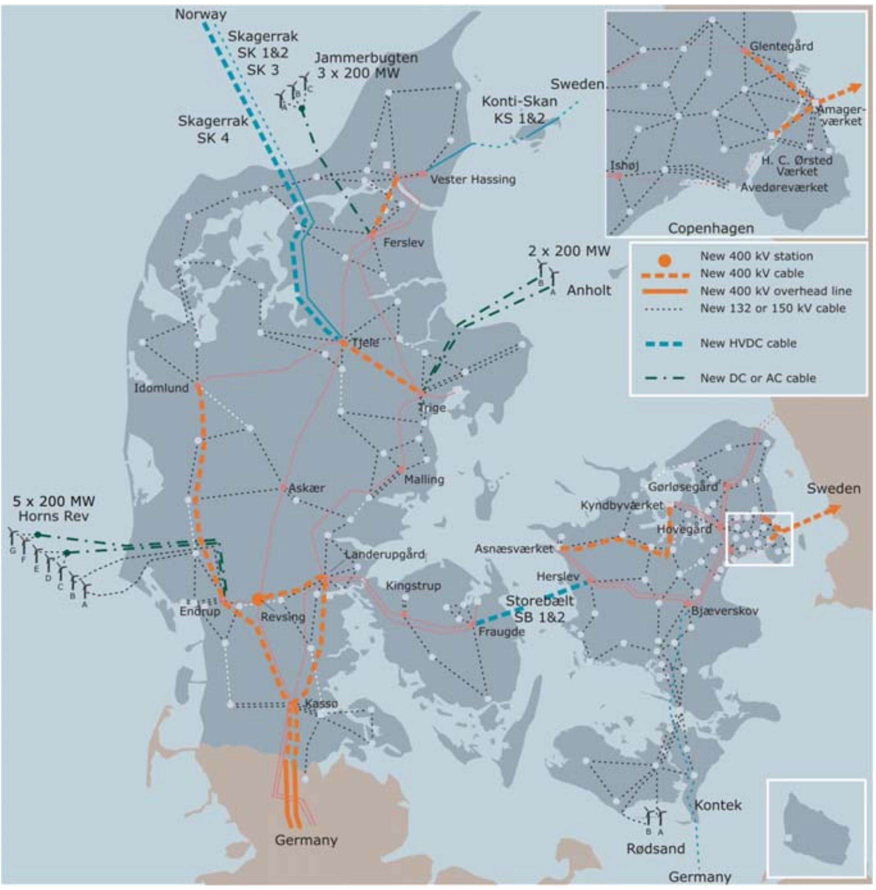

Figure 3 Expansion principle B – new 400 kV power lines in underground cables.

In expansion principle B, all new 400 kV power lines are placed underground.

The existing 400 kV overhead line network will not be removed, but the principle opens up for the implementation of projects to improve its visual appearance, involving the replacement of old tower types with new tower types, re-routing of routes and partial undergrounding just as today, giving landscape values as much consideration as possible.

This principle is expected to cost about DKK 8bn, ie three times more than the expected costs of continuing with the expansion principles used today. The first expansion projects will presumably be Endrup-Kassø-Germany (2012) and Endrup-Idomlund (2014). All 400 kV projects are expected to be completed by 2020.

This expansion principle is conditional on extensive restructuring of the existing 132 kV and 150 kV grids as a consequence of the undergrounding of the 400 kV grid. Complete undergrounding of the 132 kV and 150 kV grids can be carried out concurrently with the restructuring and will cost around DKK 11.5bn.

The total price for expansion principle B will thus be approx. DKK 20bn.

The technological solutions to be used in connection with this expansion principle have not been tested to the extent assumed. This expansion principle must therefore be regarded as considerably more risky than principles C, D and E.

So as not to jeopardise the security of delivery because of new technological solutions, the undergrounding of several new power lines over longer sections cannot be initiated until long (more than 40 km) 400 kV AC cables have been tested in the existing electricity grid with satisfactory results. If targeted efforts are made, such tests can be conducted within 6-10 years.

As the integration of markedly more renewable energy requires an expansion of the electricity grid before these cable tests can be carried out, it is to be expected that more short-term solutions, eg DC cables, will be required in a transitional period; solutions, which not in all cases support the long-term development of the electricity grid. Some of the investments involved in this expansion principle must therefore be considered as short-term.

C – New 400 kV power lines in underground cables and towers in a new design in an existing route

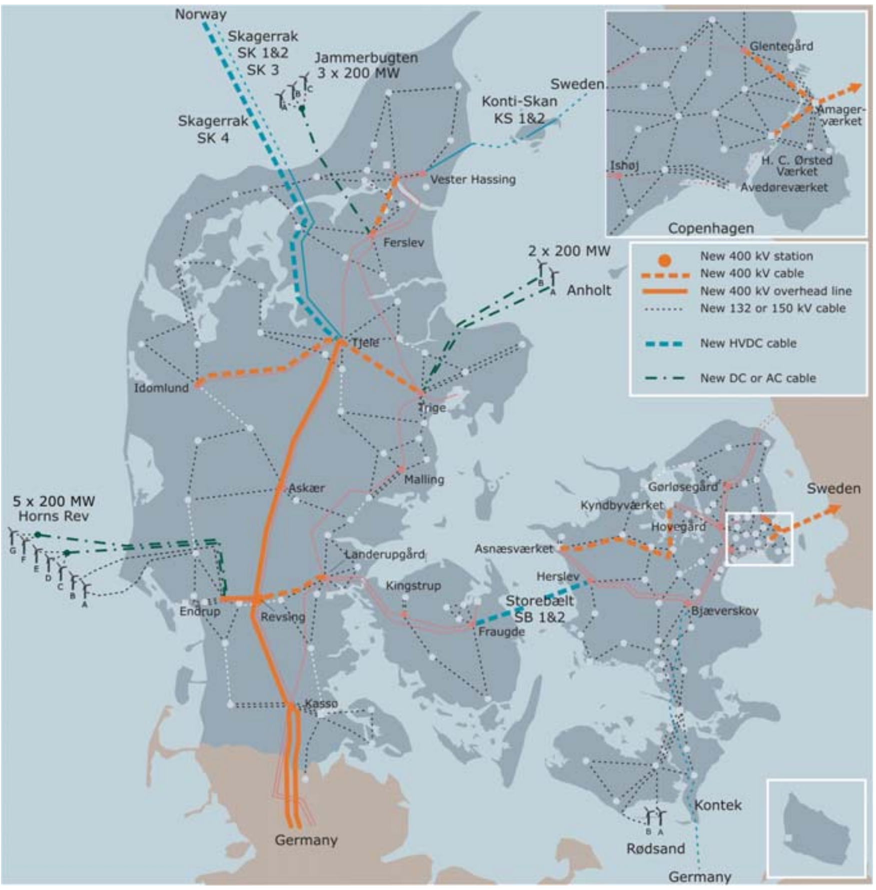

Figure 4 Expansion principle C – new 400 kV power lines in underground cables and towers in a new design in an existing route.

In expansion principle C all new 400 kV power lines are as a main rule placed underground. At the same time, the 400 kV grid's vital backbone down through Jutland will be reinforced by using a tower of a more up-to-date design.

This means that the existing row of towers between the Jutland-German border and Tjele will be removed and replaced by a new double-circuit line[7] on towers in a new design.

The remaining 400 kV overhead line network will not be removed, but the principle opens up for the implementation of projects to improve its visual appearance, involving the replacement of old tower types with new tower types, re-routing of routes and partial undergrounding just as today, giving landscape values as much consideration as possible.

This expansion principle is expected to cost around DKK 5.5bn, ie 2.5 times more than the expected costs of continuing with the expansion principles used today. The first expansion projects to be implemented in accordance with this principle will presumably be Revsing-Kassø-Germany (2012), Revsing-Tjele (2014) and Endrup-Revsing. All 400 kV projects are expected to be completed by 2020.

As is the case with principle B, this expansion principle is conditional on an extensive restructuring of the existing 132 kV and 150 kV grids as a consequence of placing the 400 kV grid underground. Complete undergrounding of the 132 kV and 150 kV grids can be carried out concurrently with the restructuring and will cost around DKK 11.5bn in 2008 prices.

The total price for expansion principle C will thus be approx. DKK 17bn.

As is the case with expansion principle B, the technological solutions to be used in connection with this expansion principle have not been tested. Due to the reinforcement of the vital 400 kV power line down through Central Jutland and staged integration of 400 kV cables into the electricity grid, this principle will, however, be a considerably safer and more robust solution than principle B. As a result of the reinforcement in Central Jutland, placing all other new 400 kV power lines underground will be considerably less risky than is the case with expansion principle B.

As is the case with expansion principle B, the undergrounding of several new 400 kV power lines over longer sections can be initiated concurrently with satisfactory results being achieved in connection with the testing of long (more than 40 km) 400 kV AC cables in the existing electricity grid. If targeted efforts are made, these tests can be implemented within 6-10 years.

7 Two 400 kV systems will be placed on the same row of towers.

D – New 400 kV overhead lines in areas where overhead lines have already been erected, but on towers in a new design

Figure 5 Expansion principle D – new 400 kV overhead lines in areas where overhead lines have already been erected, but on towers in new design.

In expansion principle D all new 400 kV power lines are constructed as overhead lines. The new power lines will be placed solely in routes where high-voltage towers have already been erected. Existing and new overhead lines are gathered on new, lower towers in a new design after which the old lattice towers will be removed.

Expansion principle D builds on the existing grid expansion principles.

To reduce the visual landscape disturbance new 400 kV overhead lines will be erected in existing routes only, using a new tower type. For example, the existing overhead line between Kassø and Tjele will be replaced with a new double-circuit overhead line.

This expansion principle is expected to cost around DKK 4bn, ie 1.4 times more than the expected costs of continuing with the expansion principles used today. The first expansion projects to be conducted in accordance with this principle will presumably be Revsing-Kassø-Germany (2012) and Revsing-Tjele (2014). All 400 kV projects are expected to be completed by 2020.

This principle can be combined with projects to improve the visual appearance of the existing 400 kV grid and the undergrounding of the electricity grid at the lower voltage levels. Here overhead lines can be placed underground without any major technological problems; a solution that is considerably cheaper than undergrounding the 400 kV grid.

This expansion principle provides maximum electricity grid capacity at the lowest possible costs and prevents the installation of new 400 kV routes.

E – New 400 kV overhead lines on lower towers in a new design

Figure 6 Expansion principle E – new 400 kV overhead lines on lower towers in a new design.

In expansion principle E new 400 kV power lines are erected as overhead lines on towers which are lower and in a more up-to-date design than the traditional lattice towers.

Expansion principle E builds on the existing grid expansion principles and is expected to cost approx. DKK 2.7bn in 2008 prices. The first expansion projects to be conducted in accordance with this principle will presumably be Revsing-Kassø-Germany (2012) and Endrup-Idomlund (2014). All 400 kV projects are expected to be completed by 2020.

This principle can be combined with projects to improve the visual appearance of the existing 400 kV grid and the undergrounding of the electricity grid at the lower voltage levels.

This expansion principle provides maximum electricity grid capacity at the lowest possible costs, but the principle also increases the visual impact on the landscape due to the new overhead lines.

F – No grid expansion

The Committee has assessed the consequences of not expanding the electricity transmission grid any further.

The principle cannot be compared to the other expansion principles due to security of supply reasons, considerations in terms of ensuring well-functioning competition on the electricity market and the desire to integrate markedly more renewable energy into the electricity system. The electricity transmission grid must be reinforced if the political objectives of integrating more wind energy into the electricity system are to be achieved.

Cabling of the 132 kV and 150 kV grids

The 132 kV and 150 kV grids are the main roads of the electricity system.

In accordance with current rules, new 132 kV and 150 kV power lines are already now being placed underground.

If the existing 132 kV and 150 kV overhead line networks are to be placed underground, this option can be combined with each of the expansion principles for the 400 kV grid. If extensive undergrounding of the transmission grid is required, it will from a socioeconomic point of view be most expedient to place the 132 kV and 150 kV grids underground according to a coherent cable action plan on the basis of environmental, technical and economic criteria and in connection with large reconstruction projects. The Danish Energy Association is currently preparing a detailed analysis of the undergrounding of the 132 kV and 150 kV grids. This analysis can form part of the basis for drafting a specific cable action plan once the future principles for the expansion of the electricity grid have been determined.

The price for placing the entire existing 132 kV and 150 kV grids (about 3,000 km) underground is expected to be in the area of DKK 11.5bn.[8]

Improvement of the visual appearance of the existing 400 kV grid

Expansion principles B-E can all be combined with an improvement of the visual appearance of the existing 400 kV overhead line network. When the existing overhead line network is to be reconstructed, the existing towers on chosen sections can be replaced with lower towers in a new design. See Figure 7. The towers will be 7-12 metres lower than a typical 42 m Danube tower. The new towers can also be integrated better into the landscape than the existing towers by planning the route in better harmony with the landscape, giving as much consideration as possible to landscape values. As is the case today, shorter sections can be placed underground – eg in dense urban areas and in areas where an overhead line will seriously impact the landscape.

All in all, the visual appearance of the landscape will be much better than is the case today.

[8] This amount includes the costs of undergrounding only. It is assessed that it will be necessary to rebuild substations to an amount of DKK 1-2bn.

Figure 7 Existing and new tower types – all intended for two 400 kV systems. The Danube tower is used in several places in Jutland. The development of the Eagle tower has been completed, and the tower can now be used in new projects. The fibre mast is currently being developed and will presumably be ready for use in approximately five years.

Improvement of the visual appearance of the existing 400 kV grid involving the replacement of approx. one third of the existing towers (with 50 km being placed underground and towers being replaced with new towers over a 350 km section) is expected to cost approx. DKK 2.3bn. It is worth noticing that part of this improvement is included in principle C, which involves the erection of new 400 kV overhead lines close to an existing route.

Summary of key figures for the expansion principles

Table 1 shows a comprehensive list of the main results for the six expansion principles.

Parameter	Year	Principle A	Principle B	Principle C	Principle D	Principle E	Principle F
Total no. of km of 400 kV overhead line	2015	1,100	1,100	1,100	1,100	1,280	1,100
	2020	740	1,100	1,100	1,100	1,360	1,100
	2025	370	1,100	1,100	1,100	1,360	1,100
	2030	0[9]	1,100	1,100	1,100	1,360	1,100
Total no. of km of 132 kV and 150 kV overhead line	2015	1,940	1,940	1,940	2,330	2,330	2,330
	2020	1,300	1,300	1,300	2,330	2,330	2,330
	2025	650	650	650	2,330	2,330	2,330
	2030	0	0	0	2,330	2,330	2,330
Investment costs 400 kV, total – DKKbn (2008 prices)[10]		36.6	8.1	5.6	3.8	2.5	0
Investment costs 132 kV and 150 kV, total – DKKbn (2008 prices)		11.5	11.5	11.5	0.2	0.2	0
Tariff impact øre/kWh[11]	2015	0.5	1.2	0.8	0.3	0.3	1.0
	2020	3.2	2.6	2.3	0.6	0.4	2.7
	2025	6.2	3.3	3.0	0.7	0.5	4.4
	2030	9.5	3.9	3.5	0.7	0.5	-
Socioeconomic costs/year[12] – DKKbn. Principle E (existing principles) has been used as reference.	2015	0.0	0.4	0.2	0.0	0.0	0.3
	2020	1.4	1.1	0.8	0.1	0.0	1.0
	2025	3.0	1.4	1.2	0.1	0.0	1.4
	2031	5.0	1.8	1.6	0.1	0.0	-
Security of delivery[13]		-	Medium	Medium	High	High	-
Technical feasibility[14]		Not possible today	Low	Medium	High	High	High

Table 2 Key figures for the six expansion and undergrounding principles.

9 Complete undergrounding at 400 kV level will not be technically possible in 2030, but it will be used as an example in order to compare the principles.

10 Costs of expanding interconnections and landing facilities for offshore wind farms are not included in the investment costs.

11 Tariff impact for the 400 kV grid and the 132 kV grids owned by Energinet.dk, is calculated as 4.3 per cent nominal interest, linear depreciation and 2 per cent inflation. The tariff impact for regional grids (132-150 kV) is, on the other hand, calculated as the benchmark long-term mortgage bond rate + 1 per cent (presently corresponding to 6.7 per cent) in pursuance of the Danish Executive Order no 1520 of 23 December 2004.

12 In the calculation of the socioeconomic costs, distortion losses of 20 per cent of the additional cost of using underground cables instead of overhead lines have been included. Distortion losses are socioeconomic losses resulting from distortion of the market balance due to the additional costs of using underground cables.

13 The level of security of delivery is primarily based on deterministic analyses of the system adequacy supplemented with a few probabalistic calculations. Differences in "energy not supplied" are relatively small and can probably be countered in a subsequent detail projection. See also chapter 7.12.

14 Technical feasibility means an overall assessment of the technical risks of the principle and the possibility of implementing the principle within the time frame provided. Risks in connection with the public authorities' consideration are not assessed under technical feasibility.

1.3.1 Robustness

Using Energinet.dk's four scenarios[15] as point of departure, an assessment has been made of the flexibility and robustness of the individual expansion principles in relation to the various developments in the surrounding factors affecting electricity grid investments towards 2030. Table 3 shows the assessment of the usability of the principles in the four scenarios.

	Grønnevang High environmental priority Predominantly national focus	**Greenville** High environmental priority Predominantly international focus	**Blåvang** Lower environmental priority Predominantly national focus	**Blueville** Lower environmental priority Predominantly international focus	**SUM**
A	-1	1	-1	2	1
B	-1	1	1	2	3
C	1	2	2	1	6
D	2	2	2	-1	5
E	2	2	2	-1	5
F	-1	-1	-1	1	-2

Table 3 Scenario-based comparison of the robustness of the principles. Score: -1 = not appropriate in the scenario; 1 = usable in the scenario; 2 = usable in the scenario and supports the scenario.

Principles B, C, D and E achieve the highest scores. Principle C scores a little lower than principles B, D and E. The reason for this is that principle C is the most flexible of the principles. Principle C is thus the only principle that is not assessed as being inappropriate in one or several scenarios.

1.4 Calculation assumptions and expansion requirement

A robust electricity transmission grid both internally in Denmark and in the interconnections to neighbouring areas yields considerable socioeconomic benefits. Good exchange possibilities mean that electricity can be produced where it is cheapest and used where the value is the highest. A strong infrastructure helps to ensure a well-functioning market, and when there are good possibilities for exchanging electricity, the market area is expanded. This sharpens competition and improves the security of supply.

Basically, the electricity transmission grid is to contribute to:

- maintaining the security of supply
- ensuring well-functioning competition on the power market
- ensuring optimum integration of renewable energy and other energy sources
- minimising the environmental impact
- creating robustness in relation to future requirements.

The political objective is that at least 30 per cent of the energy consumption must be based on renewable energy in 2025, which means that approx. 50 per cent of the electricity consumption must come from renewable energy. The incentives contained in the support system and the market will decide the future structure of the electricity generation system, ie the specific power balance and mix of offshore wind, land wind and other central and local production units. This mix is a decisive parameter when it comes to determining which expansion model is to be used.

Offshore wind turbines expansion is one of the greatest challenges to the development of the

[15] Four scenario descriptions of the surrounding world in 2030 with a varying degree of national/international focus and a higher/lower degree of environmental focus.

coherent electricity grid towards 2025.

The Committee's analyses presuppose an expansion of 1,000 MW land wind, reaching a total of 4,000 MW in 2025, which is equivalent to the assumptions in the government's Energy Strategy from January 2007.[16] Similarly, the number of offshore wind turbines is expected to be increased, bringing the total capacity up to 2,500 MW. In the Wind Turbine Committee's report "Future locations for offshore wind turbines – 2025" from April 2007 the possible locations for offshore wind turbines have been prioritised, and these prioritisations have been used in the Committee's analyses (basic calculation).

In the basic calculation, offshore wind turbine expansion will - after the completion of the planned Rødsand 2 offshore wind farm - thus take place in Western Denmark only. To assess the robustness of the expansion principles the Committee has also analysed the impact of moving three offshore wind farms from Horns Rev in the North Sea to Kriegers Flak in the Baltic.

In the basic calculation, the remaining production facilities are assumed to be as indicated in the basic projection prepared by the Danish Energy Authority in January 2007. The expansion principles have also been analysed in relation to an expansion model where the central production capacity is increased by 1,000 MW in both Eastern and Western Denmark.[17]

The analyses are based on an electricity consumption projection equivalent to an overall electricity consumption of 35.6 TWh in 2025.

The Committee has analysed the grid load and thus the grid expansion requirement on the basis of two different framework conditions; ie one with and one without an expansion of the interconnections to other countries and between Eastern and Western Denmark.

	Year 2015	**Year 2025**
Framework condition 0	Existing grid and interconnections 2007 and Great Belt Power Link 1	Existing grid and interconnections 2007 and Great Belt Power Link 1
Framework condition 1	As above + Skagerrak 4 (600 MW) + DKWest-Germany (2,000 MW)	As above + Skagerrak 4 (600 MW) + Great Belt Power Link 2 (600 MW) + DKWest-Germany (2,500 MW)

Table 4 Two assumptions about interconnections.

1.4.1 Expansion requirement

With these assumptions concerning the need for integrating wind power etc. it is possible to calculate the load on the existing transmission grid. The electricity transmission grid is designed and operated in accordance with the so-called *n-1* (n minus one) *principle*, which means that electricity system operation must be maintainable in the event of an outage of any grid component (line, transformer or generator). The figure below illustrates which grid sections will be overloaded in case of a grid defect (n-1). This would typically be in situations when a 400 kV, 132 kV or 150 kV power line or a transformer is out of operation, necessitating the transmission

[16] On 21 February 2008, the Danish government made a broad political energy agreement. In the agreement, the parties involved have, among other things, agreed to the erection of new offshore wind turbines generating 400 MW by 2012, which is more or less in line with the assumptions used by the Committee in its work.

[17] The Danish Energy Authority has subsequently published an updated basis projection in mid-January 2008. It has not been possible within the given time frame to update the analyses in accordance with this basis projection.
It should also be noted that this report does not present any conclusions as to which specific development of the electricity generation equipment is the most likely or directly necessary in order to maintain the security of supply.

of a large quantity of electrical energy in the rest of the electricity grid. These situations must be dealt with at all times, and the electricity transmission grid must therefore be designed in a way that makes it possible to handle these situations.[18]

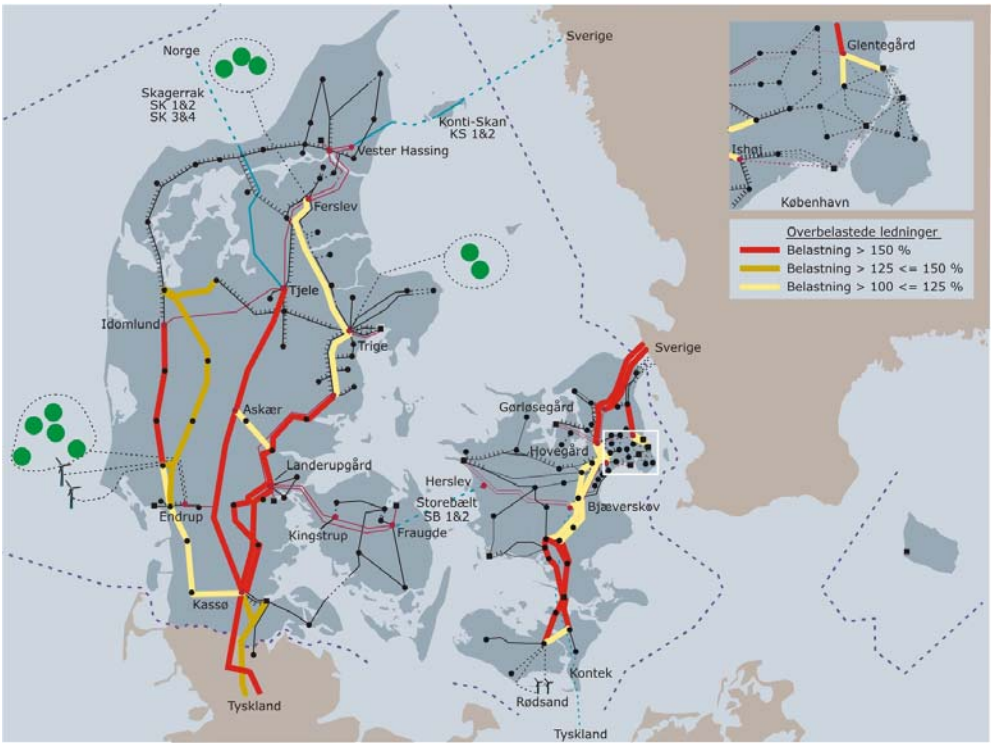

Figure 8 Overloads in the existing grid at n-1 with expansion of interconnections (framework condition 1).

The analyses show that in the scenario involving expansion of the interconnections Skagerrak 4, the interconnection between Jutland and Germany (2,500 MW) and Great Belt Power Link 2 – equivalent to framework condition 1 – there will be a risk of the transmission grid in Central Jutland being overloaded for approx. 94 per cent of the hours of the year if key grid components are out of operation. These overloads must be avoided in practice as there is a high risk of system breakdown and damage to power lines and other installations.

On Zealand it will primarily be the 132 kV grid in Southern Zealand that will be overloaded in situations with high wind power production. This will often exceed the local electricity consumption. These overloads can be eliminated by implementing minor reinforcements and upgrading of the existing 132 kV overhead lines, the erection of which is planned to take place when Rødsand 2 offshore wind farm is connected to the grid.

Thus, the analyses show that it will be necessary to reinforce the existing electricity transmission grid if the political objectives of integrating more wind power into the electricity system are to be met without jeopardising the security of supply. The wind energy cannot be utilised in full without an expansion of the electricity grid.

It can also be concluded from the analyses that the expansion of the interconnections to neighbouring areas has a significant impact on the load on the domestic grid. If one or more of

[18] In these years work is under way to develop models taking account of the probability of these calculated overload situations actually occurring, but the calculations in this report are based on the n-1 principle without an assessment being performed as to whether the probability of overload is high or low.

the expansions assumed are not realised, this could affect how the electricity transmission grid can be optimised.

1.4.2 Other means

Expanding the electricity transmission grid is just one of the means that can be used to solve the future challenges in the electricity transmission grid. This could, for example, be the installation of large consumption units providing high sales of electricity in specific consumption points or the establishment of compressed air storages or electrolysis installations for the production of hydrogen which use the electricity generation close to the offshore wind farms. The consumption scenario in Western Jutland will, for example, be changed markedly if a 600 MW electrolysis facility is located near Endrup where much power is fed in from offshore wind farms in the North Sea. As a large part of the consumption will thus take place close to the infeed point, internal grid congestion in the Western Jutland grid will be reduced correspondingly.

Other means of increasing the overall electricity consumption, eg electric cars and heating pumps, will be able to support the increased need for control options in an electricity system integrating a great deal of wind power, but they do not change the conclusions about the expansion requirement and thus the choice between the expansion principles analysed to any material extent.

It lies outside the Electricity Infrastructure Committee's mandate to perform a detailed assessment of the means mentioned, including their profitability and technological maturity. It should only be noted that the alternative means may potentially affect the need for electricity infrastructure expansion. As such, it is necessary to further analyse the potential and possibilities of these means irrespective of which principle is chosen for the future expansion of the electricity infrastructure.

1.5 The technologies and the technological challenges

There are two basic technologies for transmitting current – direct current (DC) and alternating current (AC).

1.5.1 Alternating current

In Denmark and the rest of the world, by far the greatest part of the transmission grid is based on alternating current in overhead lines. In normal circumstances, this solution is technically the most simple and also the cheapest when it comes to transmitting large volumes of electrical energy. The advantage of alternating current is that as opposed to direct current it is relatively simple to transform up and down between different voltage levels. This means that current in a manner of speaking can be fed into and drawn from anywhere in the grid, right from the transmission level (400 kV, 132 kV and 150 kV), over the distribution level (60-10 kV) to the supply level (230/400 V (households and enterprises)).

Alternating current and direct current can be transmitted in overhead lines and underground cables. Alternating current presents, however, various technical challenges when it comes to placing high-voltage power lines (400 kV) underground.

AC cables

400-500 kV AC cables for transmission are only used to a relatively modest extent worldwide. They are particularly used in short sections in urban areas and only rarely in open country.

There is only 250 km of AC XLPE cable at the 400-500 kV level in the world today. Of this, about one third has been laid in Denmark. As such, Denmark is in the leading group when it comes to the length of AC XLPE cable that has been placed underground at this voltage level. The longest cable in Denmark is found in Copenhagen. It is 20 km long but consists of two sections as a substation has been added halfway.

The longest cable at the 400-500 kV level in the world is found in the city of Tokyo where a 40 km long 500 kV cable transmits current to downtown Tokyo from an overhead line network encircling the city. In addition, the city of Tokyo has an extensive 275 kV cable grid.

Overvoltages and resonance – risk of power failure
When a 400 kV cable is disconnected, the large energy volumes stored in the cable and the cable substations will oscillate and cause overvoltage.

The installation of long cables or a large number of short 400 kV cables increases the risk of such phenomena becoming a serious problem. The overvoltages may become very large with the ensuing risk of other components being disconnected. This increases the risk of power failures.

In theory, overvoltages can be minimised by installing suitable equipment in substations. There is, however, no practical experience of using such equipment in 400 kV cables longer than 40 km.

In addition, the system-related challenges of using long AC cables in overhead line systems are linked to the fact that AC cables at high voltage levels reduce the so-called natural frequency of the electricity system considerably. This increases the risk of resonance oscillations occurring in the system.

Resonance oscillations are critical because even a frequently occurring incident – such as the disconnection of a circuit breaker – may initiate the resonance oscillation, which in turn may result in other components being damaged or cutting out due to high and oscillating voltages. When several power lines and generators are disconnected from the grid in an uncontrolled manner, system security is reduced, and the risk of power failures is high.

The phenomena with natural frequency and resonance oscillations in the electricity system is physically completely identical to the phenomena that may occur in connection with, for example, bridges and machinery which suddenly and without warning start "shaking" or oscillating.

The risk of resonance oscillations is more critical at the 400 kV level than at lower voltage levels as the 400 kV grid is the backbone of the electricity system. It ties together the entire European electricity system and ensures the electricity consumer a strong, stable voltage. Incidents at lower voltage levels are "resolved" by the 400 kV system. If the 400 kV system becomes unstable, the strength necessary to regain stability must be provided by the 400 kV system itself.

It will presumably take many years before a large number of long 400 kV AC cables can be integrated into the Danish electricity system. Very long AC cables have never been tested anywhere in the world, and a possible test involving one long cable section in the Danish electricity grid (60-100 km) will be the world's largest cable test. A well analysed and calculated project which fits into the landscape and has been considered in detail as well as a long period of collecting operational experience are therefore a decisive precondition for using more AC cables in the electricity grid at a later stage.

1.5.2 Direct current

Transmission of high-voltage direct current (HVDC) is normally used in situations where for technical or other reasons alternating current cannot be used to, for example, connect AC systems that are not synchronous, ie do not oscillate at the same frequency, and in connection with long sub-sea interconnections. The transmission grid in Jutland is, for example, connected to the Norwegian and Swedish transmission grids via several DC interconnections, while the Eastern

Danish system is connected to Germany via a DC interconnection. The new Great Belt Power Link will also be a DC connection as the electricity systems in Eastern and Western Denmark are not synchronous.

HVDC connections are point-to-point connections transferring power between converter substations installed in the terminal points of the connection. These converter substations are large and expensive.

The converter substations convert alternating current to direct current and vice versa. Today, two different conversion technologies are used: classic HVDC, which converts the current by means of so-called thyristors, and new HVDC (so-called VSC), which is based on so-called power transistors.

The new HVDC technology has a number of advantages over the classic technology but its energy loss is higher than that of the converter substations.

Today, the classic HVDC technology is used for transmission capacities up to 3,000 MW, while the VSC technology is used for transmission capacities of 50 to 1,000 MW. At this point in time, new HVDC connections have not been established for transmission capacities higher than 350 MW. However, in January 2008, Svenska Kraftnät decided to establish a 1,000 MW HVDC connection in Southern Sweden, the so-called SydVästlänken. The connection is expected to be commissioned in 2012/2013.

1.5.3 Construction costs of the various technologies

At voltage levels higher than 100 kV overhead lines are generally cheaper than underground cables. The higher the voltage level, the higher the price difference between overhead lines and underground cables.

AC overhead lines also have a significantly higher "in-born" transmission capacity than underground cables. As such, the transmission capacity provided by an AC grid with overhead lines is considerably higher than the one offered by a similar grid based on underground cables.

DC cables are cheaper than AC cables at the same transmission capacity. On the other hand, the necessary converter substations are considerably more expensive than AC substations.

In Figure 5 examples are shown of the estimated construction costs of building a transmission line of approx. 600 MW when using the various technologies. Note that the capacity is 2,000 MW for the overhead line as this is the normal capacity of a single 400 kV overhead line network.

Technology	**400 kV alternating current**		**400 kV direct current**	
	Overhead line	**Cable**	**Classic (cable)**	**New VSC (cable)**
Capacity	2,000 MW	600 MW	600 MW	550 MW
50 km	DKK 290m	DKK 515m	DKK 1,500m	DKK 1,400m
100 km	DKK 550m	DKK 990m	DKK 1,900m	DKK 1,675m
200 km	DKK 1,050m	DKK 1,940m	DKK 2,600m	DKK 2,250m

Table 5 Comparison of prices for typical sizes of 400 kV AC overhead lines and underground cables as well as DC installations based on the classic and new technologies. The prices apply to a complete installation (substation and power line). Note that the transmission capacity differs greatly between the various technologies.

In general, it should be noted that there is a high degree of uncertainty about the future development in cable prices. The supply of cables and the number of cable suppliers is very limited, and the costs of cable-based technologies therefore vary considerably depending on current world market demand. There are, for example, only three suppliers of HVDC substations worldwide. Due to the normal market mechanisms, it is to be expected, however, that a globally increasing demand will increase the production capacity in the long term.

1.6 Environmental impact of the expansion principles

The environmental impact of an electricity generating facility varies in nature and extent. The environmental parameters discussed in this report include the visual impact, noise problems and magnetic fields in connection with overhead lines and underground cables. In addition, the properties, landscapes, natural resorts and cultural-historic sites have been analysed by means of electronic maps.

The Committee's report on environmental impacts consists of:

- a count of the area which the routes in the existing grid pass through
- a quantification of the positive environmental impact of removing overhead lines and the negative environmental impact of placing the existing overhead line routes underground
- a report on the noise and visual impact of the facilities
- an assessment of the landscape impact following the expansion of the electricity transmission facility
- an account of the impact on nature, animals and plants
- a description of the problems in connection with magnetic fields.

Detailed descriptions of this work can be seen in Chapter 5 of the report.

A normal planning procedure for a route includes detailed environmental analyses, environmental assessments and possibly also environmental impact assessments. The specific environmental impacts of the various expansion principles are difficult to describe as the various route sections are preliminary. The environmental problems can therefore only be assessed at a general level.

The charts below are primarily to be used for comparing the various principles. The absolute figures in the figure are estimates and thus relatively uncertain.

Figure 9 shows the number of properties affected by 400 kV overhead lines in each expansion principle. The affected properties included in the count are the ones that are located up to 290 m from 400 kV routes and up to 190 m from 132 kV and 150-kV routes[19]. Where underground cables are concerned, properties located up to 50 m from 132 kV and 150 kV routes and up to 100 m from 400 kV cable routes are included.

[19] Corresponding to the current compensation zone.

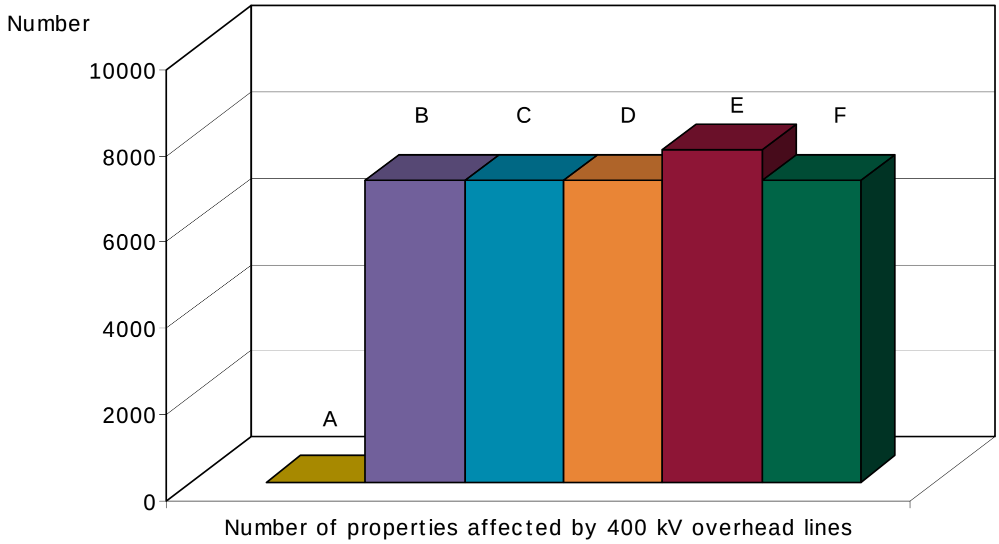

Figure 9 Number of properties affected by 400 kV overhead lines.

The number of properties affected by 400 kV overhead lines in each individual principle shows that virtually no properties are affected by complete undergrounding as contemplated in Principle A. Principle E entails that new 400 kV power lines are constructed as overhead lines, which will affect approximately 700 properties more than is the case with principles B, C, D and F. The number of properties affected by the existing 132 kV and 150 kV overhead lines has been computed to about 11,500.

An estimate of the number of kilometres of route passing through various landscape and natural areas in connection with each expansion principle can be seen from Figure 10 below. The column charts show for each expansion principle how much of the route that passes through an area.

The "landscape" columns show how many kilometres of route that lie within the various protection lines stipulated by the Danish Nature Conservation Act. This may, among other things, include church protection lines, forest building lines, lake and creek protection lines, etc. Often the areas overlap, but in the analysis they have only been included once.

The "nature" columns indicate how many kilometres of route that lie in areas that can be characterised as EU habitat and bird protection areas, section 3 areas (types of nature protected in section 3 of the Danish Nature Conservation Act) and potential wetlands. As is the case with the "landscape" columns, data have been accumulated in a manner preventing overlap.

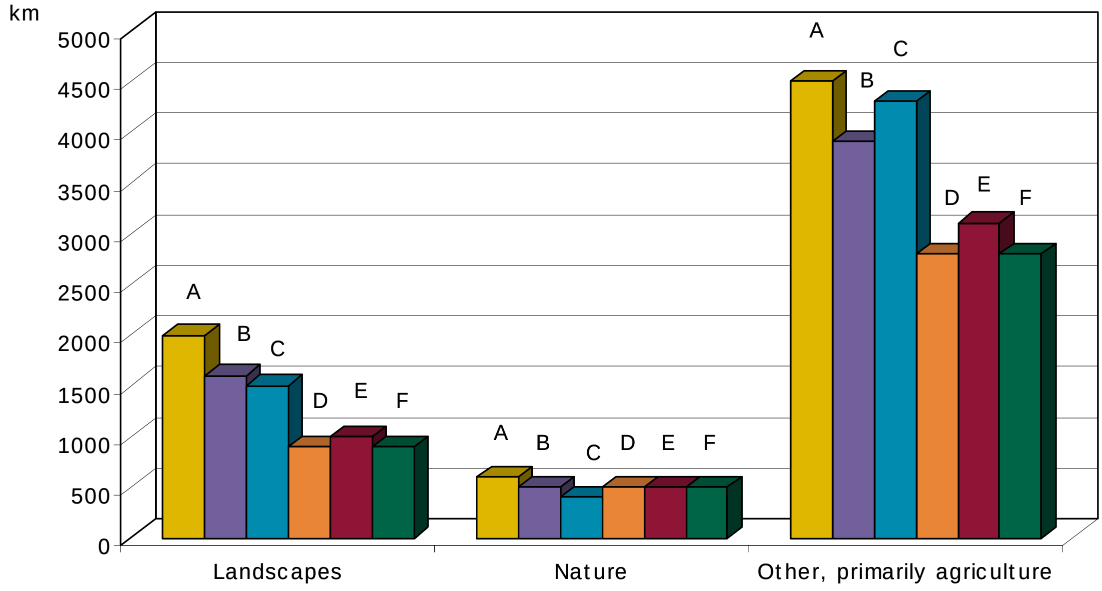

Figure 10 Kilometres of 132, 150 and 400 kV routes passing through various area types.

Figure 10 shows a general trend towards an increasingly larger area of land being required for establishing routes from Principle F up to Principle A, which requires the largest area of all. Other areas, primarily agricultural areas, will in particular be affected by new installations.

1.7 Economic summary of the expansion principles

The expansion and cable undergrounding principles described are very different in terms of the investments required. Furthermore, the choice of expansion principle has a fairly significant impact on the operating expenses of the electricity transmission system.

In the following sections, the most important financial key figures for the six expansion principles are summarised and compared.

Even though the actual analyses only cover the period until 2025, the financial key figures are calculated up to 2030/2031. This is due to the fact that the full effect of several of the principles will not be seen until that time[20]. Expansion principle E, which corresponds to the expansion plan for the electricity grid contemplated until today in pursuance of the current guidelines for the expansion and upgrading of high-voltage power lines, has been used as reference.

For all principles, the economic key figures are indicated on the basis of framework condition 1 in terms of expansion with interconnections as an expansion is regarded as considerably more likely than framework condition 0, which does not involve any additional expansion of interconnections up until 2025.

1.7.1 Investment costs of expansion principles

The table below shows the expected accumulated investment costs involved in realising each expansion principle. As can be seen from the table, the investment required in connection with principles A, B and C will not be completed until 2030 at the earliest.

	Principle A Complete under-grounding	Principle B New 400 kV power lines in cables + 132/150 kV power lines in cables	Principle C New 400 kV power lines in cables and new towers in an existing route + 132/150 kV power lines in cables	Principle D New 400 kV overhead power lines in areas where there are already overhead lines	Principle E New 400 kV overhead lines	Principle F No electricity grid expansion
Overall investment until 2025	DKKbn	DKKbn	DKKbn	DKKbn	DKKbn	DKKbn
Investment 400 kV	24.4	8.1	5.6	3.8	2.5	0
Investment 132/150 kV	8.3	8.3	8.3	0.2	0.2	0
Total until 2025	**32.7**	**16.4**	**13.9**	**4.0**	**2.7**	**0**
Overall investment until 2030						
Investment 400 kV	36.6	8.1	5.5	3.8	2.5	0
Investment 132/150 kV	11.5	11.5	11.5	0.2	0.2	0
Total until 2030	**48.1**	**19.6**	**17.0**	**4.0**	**2.7**	**0**

Table 6 Investment costs 2010-2030 in DKKbn (2008 prices). Costs of interconnections and offshore wind farm landing facilities are not included in the prices.

20 Where principle A is concerned, complete undergrounding of the 400 kV grid cannot be implemented in less than 30-40 years. To enable comparison with the other principles, it is assumed in the economic analyses that principle A has also been implemented by 2030.

The costs of completely undergrounding the existing 132 kV and 150 kV grids are included for principles A to C, but this can also be chosen for the other principles. It can be seen from the table that the price of undergrounding the entire 400 kV grid (1,100 km) is approx. DKK 29bn (DKK 36.6bn – DKK 8.1bn). The price of placing the entire 132 kV and 150 kV grids (approx. 3,000 km) underground is approx. DKK 11.5bn.

The costs given for principle A are clearly the largest. This figure is uncertain and must be considered as a minimum as it is not yet clear what additional investments are required to operate a 400 kV electricity transmission system solely based on underground cables with a satisfactory security of supply. In the calculations it is assumed that the undergrounding of the electricity grid will be completed by 2030, which - with the knowledge available today - is not considered realistic.

1.7.2 Tariff impact for electricity consumers

The table below shows the expected tariff impact of the various expansion models.

Year	**Tariff impact of principles deflated to fixed prices (øre/kWh) (investment and operation)**					
	Principle A Complete under-grounding	Principle B New 400 kV power lines in cables + 132/150 kV power lines in cables	Principle C New 400 kV power lines in cables and new towers in an existing route + 132/150 kV power lines in cables	Principle D New 400 kV overhead power lines in areas where there are already overhead lines	Principle E New 400 kV overhead lines	Principle F No electricity grid expansion
2015	0.5	1.2	0.8	0.3	0.3	1.0
2020	3.2	2.6	2.3	0.6	0.4	2.7
2025	6.2	3.3	3.0	0.7	0.5	4.4
2030	9.0	3.8	3.5	0.7	0.5	n.a.
2031	9.5	3.9	3.5	0.7	0.5	n.a.

Table 7 Expected tariff impact for electricity consumers (2008 prices).[21]

Where principles A to E are concerned, the tariff impact is primarily attributable to depreciation of new investments in the electricity transmission grid. If a principle is chosen which is based on underground cables only, it can as mentioned previously become relevant to use DC solutions on chosen sections of the internal electricity transmission grid. These solutions will result in extra costs for covering the transmission losses of such connections. This may increase costs to more than what is indicated in Table 7.

Where principle F is concerned, the tariff impact for electricity consumers is primarily attributable to market losses due to the inadequate, internal grid. These will in practice – in accordance with the operating principles used – manifest themselves as costs incurred by the TSO in connection with implementing ordered changes of consumption and generation in the electricity system through so-called countertrade as a result of internal grid congestion. Such market losses do not occur to any appreciable extent in the other principles.

[21] For the 400 kV grid and any 132 kV grids owned by the TSO the usual depreciation profile for the TSO's non-current assets (serial loans) and assumptions concerning expected cost of capital (4.3% and 2% inflation) are used. For 132 kV and 150 kV grids owned by the transmission companies the benchmark long-term mortgage bond rate + 1% (presently corresponding to 6.7%) is used.

1.7.3 Socioeconomic costs

The section above provides an assessment of the likely price effects of the individual expansion principles for the consumers. The following tables show the socioeconomic costs calculated in accordance with common socioeconomic analysis principles.

The most significant difference is that the investments here are repaid on the basis of an annuity principle and that a socioeconomic discount rate of 6 per cent is used.

Year	Socioeconomic annual costs of principles with reference to existing guidelines – principle E (DKKbn per year) incl. distortion losses					
	Principle A Complete under-grounding	Principle B New 400 kV power lines in cables + 132/150 kV power lines in cables	Principle C New 400 kV power lines in cables and new towers in an existing route + 132/150 kV power lines in cables	Principle D New 400 kV overhead power lines in areas where there are already overhead lines	Principle E New 400 kV overhead lines	Principle F No electricity grid expansion
2015	0.0	0.4	0.2	0.0	0.0	0.3
2020	1.4	1.1	0.8	0.1	0.0	1.0
2025	3.0	1.4	1.2	0.1	0.0	1.4
2030	4.7	1.8	1.5	0.1	0.0	n.a.
2031	5.0	1.8	1.6	0.1	0.0	n.a.

Table 8 Expected annual socioeconomic costs.

Total finances for the period 2010-2025 (discounted to year 2010)	Principle A	Principle B	Principle C	Principle D	Principle E	Principle F
Investment and residual value 400 kV	**DKKbn**	**DKKbn**	**DKKbn**	**DKKbn**	**DKKbn**	**DKKbn**
New 400 kV transmission line	15.8	7.1	4.5	3.2	2.2	0
Value of remaining life in 2025	-10.8	-2.9	-2.1	-1.6	-1.1	0
Investment and residual value 132 kV and 150 kV grids						
Investment and residual value 132 kV and 150 kV	6.0	6.0	6.0	0.2	0.2	0
Remaining life of cables in 2025	-3.5	-3.5	-3.5	-0.1	-0.1	0
Operation and maintenance	-0.06	-0.04	-0.02	0.02	0.02	0.00
Market losses due to internal grid congestion	0.1	0	0	0	0	5.6[22]
Total costs (DKKbn) for the period, excl. distortion losses	**7.6**	**6.7**	**4.9**	**1.7**	**1.2**	**5.6**
Effect of distortion losses	1.3	1.1	0.7	0.1	0.0	0.0
Total socioeconomic costs for the period	8.8	7.8	5.7	1.8	1.2	5.6
Total investment 2025	**32.7**	**16.4**	**13.9**	**4.0**	**2.7**	**0.0**

Table 9 Total socioeconomic costs for the period 2010-2025. Market losses due to congestion in the internal transmission grid have for principles A-E been calculated to be insignificant.

It should be noted that environmental impacts, eg landscape/visual environment, have not been calculated and are therefore not included in the figures above on equal terms with other gains and costs. Instead, generalising power objectives (cost effectiveness analysis) were used to quantify the environmental impacts.

[22] The market losses calculated are fairly uncertain and may be lower. The figure depends significantly on the assumptions used regarding price differences between the Nordic countries and Continental Europe.

1.7.4 Sensitivities and variants

An assessment has been made of the sensitivity to investment prices and discount rate.

Sensitivity element	Principle A Complete under-grounding	Principle B New 400 kV power lines in cables + 132/150 kV power lines in cables	Principle C New 400 kV power lines in cables and new towers in an existing route + 132/150 kV power lines in cables	Principle D New 400 kV overhead power lines in areas where there are already overhead lines	Principle E New 400 kV overhead lines	Principle F No electricity grid expansion
4% discount rate	79%	79%	79%	74%	74%	100%
8 % discount rate	122%	122%	122%	128%	128%	100%
+25 % construction price	125%	125%	125%	123%	121%	100%

Table 10 Assessment of sensitivities to future transmission grid requirements.

In addition, in order to ensure the necessary robustness to uncertainties in the development of the overall electricity system in connection with an analysis of the expansion models listed, analyses with variations of the development of the assumptions defined. In particular, focus has been on the establishment of alternative interconnections to neighbouring areas and an expansion of the domestic central production facilities. Finally, the consequences for the electricity grid of expanding the offshore wind farm at Kriegers Flak instead of the one at Horns Rev have been examined.

The following overall conclusions can be drawn from these analyses:

- The possible construction of a 600 MW DC interconnection between Jutland and the Netherlands does not give rise to changing the expansion requirement of the principles.

- In general it is not possible to establish an increased requirement for expanding the 400 kV grid when establishing new central production capacity at existing power station sites. For principles A-E market losses resulting from possible congestion in the internal transmission grid have been calculated to be insignificant. Any market losses in connection with congestion in interconnections have not been analysed.
  For expansion principle F it can be ascertained, however, that market losses increase markedly as a result of an inadequate domestic grid if the central production capacity is increased by 1,000 MW in Eastern and Western Denmark in relation to the assumptions used in the basic calculation.

- The establishment of offshore wind farms at Kriegers Flak (3 x 200 MW) as an alternative to Horns Rev will not reduce the expansion of the 400 kV grid in Jutland. The establishment of offshore wind farms in the Baltic places additional demands on the 400 kV grid expansion in Zealand. This requirement can be met by establishing a northern 400 kV ring structure between Asnæs Power Station and Kyndby Power Station.