METHODOLOGY FOR ENERGINET'S SOCIO-ECONOMIC ASSESSMENTS OF ELECTRICITY TRANSMISSION PROJECTS

Investment Planning, November 2022

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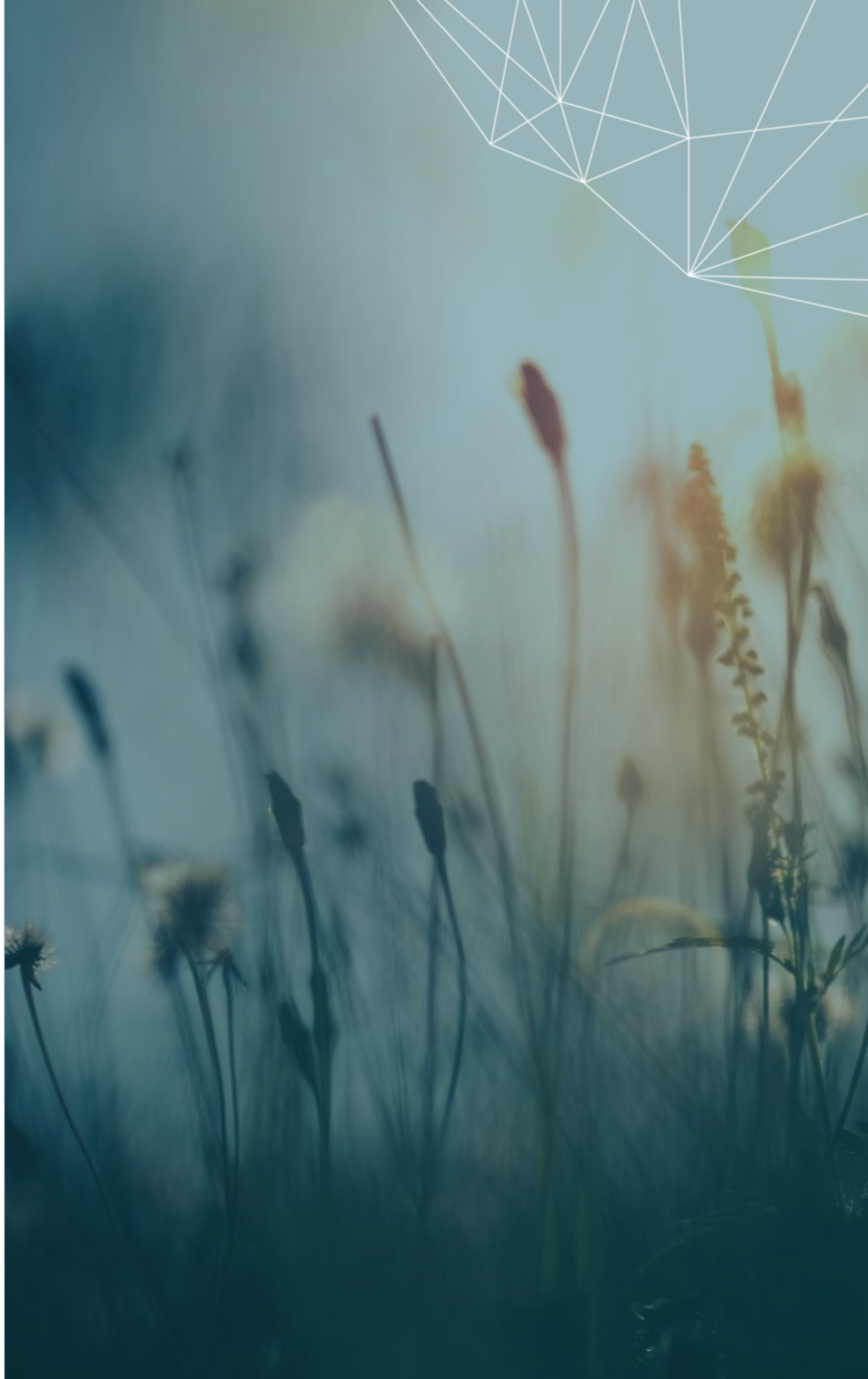
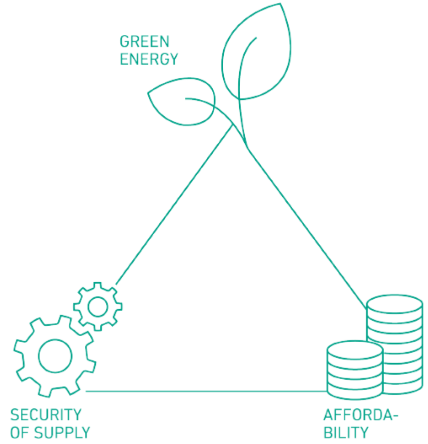


THE ROLE OF ENERGINET

Energinet's purpose is to own, operate and expand general energy infrastructure, manage related tasks and thereby contribute to the development of a climate-neutral energy supply. Energinet must consider security of supply, climate and the environment, and ensure open and equal access for all users of the transmission networks and efficiency in its operation.



Legal basis for Energinet's investments

Danish Act on Energinet

§ 4. *New electricity transmission grids and gas transmission systems may be constructed and material changes to existing grids and systems may be implemented if there is a* ***sufficient need for such expansion****, including that the aim of the expansion is to* ***increase security of supply, safeguard preparedness, create well-functioning competitive markets or to integrate renewable energy****, or if the project is necessary for compliance with statutory orders pursuant to subsection 6.*

If a project has regional significance across national borders, this must be included in the needs assessment. In special cases, changes to existing electricity transmission grids may only be made for the purpose of improving the visual appearance of the grid.

The Danish Electricity Supply Act

§ 1. *The purpose of the act is to ensure that the electricity supply in Denmark* ***is organised and implemented in accordance with the requirements for security of supply, socio-economics, the environment and consumer protection***

This act must ensure consumers access to cheap electricity and continue to influence the administration of the electricity sector's values.

METHODICAL ANALYSIS APPROACH

This memorandum forms the basis of Energinet's work with socio-economic impact assessments of potential electricity transmission projects.

The method is based on the socio-economic analysis framework laid down by the Danish Ministry of Finance[1] and the Danish Energy Agency[2].

The socio-economic impact assessment is to provide qualified decision support for Energinet's investment decisions and will form part of the overall decision basis in a business case. Furthermore, the analysis will be included as documentation in cases where a project, depending on size and complexity, requires approval by the Danish Energy Agency, the ministry or the minister; a so-called § 4 application.

Energinet always endeavours to work within a long-term planning framework in order to accommodate the broad trends in the need for development of the energy system.

The methodology is relevant for all large-scale projects initiated by Energinet. These may be both new investment projects and reinvestments.

Energinet always makes investments based on a socio-economic assessment. For certain projects, the advantages of a project are found to be disproportionately large relative to the costs of implementing the project. In these cases, a valuation of the benefits is considered superfluous. In these types of projects, the assessment of the benefits of the project will be included as a description of the rationale for the project. Therefore, only a cost-effectiveness analysis will be carried out. These may be projects such as reinvestments in central transmission lines. There may also be legislative aspects which may lead to the implementation of certain projects. Here, a cost-effectiveness analysis is also carried out.

1 Guidelines on socio-economic impact assessments (fm.dk)

2 Socio-economic analysis methodology | Danish Energy Agency (ens.dk)

GENERAL ANALYSIS FRAMEWORK FOR TRANSMISSION PROJECTS IN ENERGINET

Once a need has been identified in Energinet's needs analyses, Energinet examines how a potential investment affects the economy in Denmark, either in the form of a cost-benefit analysis or a cost-effectiveness analysis, depending on the specific problem. For transmission projects arising from a need identified by Energinet in the form of new investments or reinvestments, a cost-benefit analysis is used which compares the investment costs and benefits to establish whether the investment has a positive socio-economic effect. Transmission projects originating from Energinet's statutory obligations (3rd party projects or political orders), a cost-effectiveness analysis is generally used with the aim of finding the most cost-effective initiative for meeting a statutory target.

DELIMITATION

Socio-economics and business economy

Energinet’s transmission projects entail direct costs for Energinet, but also affects the economy in Denmark and potentially in neighbouring countries with adjacent energy systems. Energinet will make the investment decision based on the effect on the overall Danish socio-economy.

Regional effects

If a project has regional significance across national borders, this will be included in the assessment.

Scaling the analysis

Socio-economic analyses are prepared for all Energinet’s transmission projects where there is a need for a socio-economic assessment. The scope of the individual analysis is scaled to match the size and nature of the project.

ALTERNATIVES

Alternatives

Once a need has been identified in the electricity transmission system, possible alternatives to meet the demand are determined. The alternatives may be in the form of fixed asset investments, market initiatives or operational solutions.

The socio-economic advantages and disadvantages of each of the relevant alternatives are identified, quantified and valued relatively to the null alternative situation.

Null alternative

Energinet always evaluates the socio-economic consequences of a given alternative relative to the null alternative. The null alternative is the scenario in which the initiative is not initiated. This is not a status quo situation, but a description of the expected development in the absence of the specific alternatives. The null alternative also considers Energinet's statutory obligations to ensure supply, connect third parties, etc.

SOCIO-ECONOMIC EFFECT

Calculation of effects

All effects are calculated in market prices and reported in constant prices in a given basic year, typically the year in which the analysis is carried out. Effects determined on factor prices are converted into market prices by the current net tax factor determined by the Danish Ministry of Finance.

The socio-economics of the project are evaluated by calculating the net present value for the selected alternatives. I.e., all costs and benefits are discounted to a given year based on the socio-economic discount rate determined by the Danish Ministry of Finance. The time horizon of the analysis is often determined on the service life of the investment.

Derived macroeconomic effects, e.g., in the form of changed foreign trade or employment effects are not included in Energinet’s analyses according to the Danish Ministry of Finance.

Investment decision

The final investment decision will be made based on an overall assessment of the advantages and disadvantages of the alternatives, including effects which cannot be quantified or assessed.

ASSUMPTIONS

Energinet has several assumptions forming the basis of the analysis framework for socio-economic impact assessments of potential projects. However, some assumptions may vary across projects. If it is assessed that there are special reasons for deviating from the below basis as regards developments in Denmark and internationally, this will be explicitly stated in the individual analysis. These may be political agreements concluded after the publication of the latest analysis assumptions or information collected through Energinet's and the Danish Energy Agency's pipeline list which is based on updated knowledge about new installations in the Danish energy system.

ANALYSIS ASSUMPTIONS

Denmark

Assumptions about the development in the Danish energy system are based on the Danish Energy Agency's "Analysis assumptions for Energinet"[3]. This indicates today's (2022) likely development process for the Danish electricity and gas system towards 2050.

Internationally

Assumptions about developments in foreign energy systems are based on scenarios from the ENTSO-E's releases TYNDP[4] (Ten-Year Network Development Plan) and ERAA[5] (European Resource Adequacy Assessment).

Climate year

Depending on the type of project, analyses are made based on one or more climate years (Appendix B).

SIMULATION MODELS[6]

BID3

BID3 (Better Investment Decisions) simulates the electricity spot market (also called the day-ahead market) in the European electricity system as a whole and performs resource adequacy analyses.

SIFRE

SIFRE (Simulation of Flexible and Renewable Energy systems) simulates the electricity spot market in Denmark but is not limited neither geographically nor in relation to the energy type. SIFRE has been developed with focus on supporting simulations of an increasingly flexible and integrated energy system.

PowerFactory

PowerFactory is an electricity grid model that uses input from SIFRE for simulating the energy flow in the Danish electricity system.

SENSITIVITY ANALYSES

Several assumptions will be subject to considerable uncertainty. Therefore, several partial sensitivity analyses are often performed to shed light on possible consequences of the uncertainty.

Relevant sensitivities will be identified within the individual project. The following sensitivity categories will often be analyzed:

- Electricity consumption
- Expansion of renewable energy
- CO_2 and fuel prices.

Sensitivity analyses can also be performed as scenarios, or Monte Carlo simulations can be performed to shed light on the total outcome of the identified uncertainties.

3 Annual edition: Analyseforudsætninger til Energinet | Energistyrelsen (ens.dk)
4 TYNDP: https://tyndp.entsoe.eu/
5 ERAA: https://www.entsoe.eu/outlooks/eraa/
6 Energinet's simulation models: https://energinet.dk/Analyse-og-Forskning/Beregningsmodeller

SOCIO-ECONOMICS AND EFFECTS IN THE ANALYSES

PROJECT TYPES

The electricity spot market across Europe is divided into different price areas (or bidding zones) to reflect physical limitations in the electricity system.

The electricity spot price within one price area is the same, while the electricity spot price may differ between two price areas. Denmark is currently (2022) divided into two price areas, DK1 (Jutland and Funen) and DK2 (Zealand and the islands).

The project type has an impact on the analysed effects

Energinet includes several effects when investigating expansions of the electricity transmission system in a socio-economic analysis. The effects to be clarified will be determined by whether the project lies within one price area in the electricity market or connects price areas. This is because connections between different price areas and connections within one price area will affect the electricity system in different ways. The typically analysed effects are listed on the next page and explained in more detail on the following pages. However, identification of relevant effects will always depend on a specific assessment of the individual project.

PROJECTS BETWEEN PRICE AREAS

Projects between different price areas are referred to as interconnectors or international transmission lines.

Trade benefits and/or improved resource adequacy are typically the driving effects of investments between price areas. Better connected price areas make it possible to benefit from differences between, for example, the Danish and foreign electricity systems for the benefit of the participants in the two markets.

PROJECTS WITHIN ONE PRICE AREA

Investments in the electricity transmission system within one of the Danish price areas are referred to as internal projects. Please note that internal projects in some cases affect connections between price areas and therefore overlap with this project type.

The integration of renewable energy and/or improvement of security of supply most often drive investments in the internal Danish electricity transmission system.

ANALYSED EFFECTS

Item	Effect	Project between price areas	Project within one price area
Market effects	Trade benefits	X	
	Transit compensation	X	
Security of supply	Resource adequacy	X	
	Grid adequacy	X	X
	System security	X	X
Costs for ancillary services[7]	Reserves	X	X
	Emergency start-up	X	X
	Properties required to maintain power system stability	X	X
Costs in relation to assets	Construction costs (CAPEX)	X	X
	Operation and maintenance (OPEX)	X	X
	Reestablishment obligation (ABEX)	X	X
	Grid loss	X	X
	Outage	X	
Other effects	Climate impact	X	X
	Integration of renewable energy	X	X

OTHER EFFECTS

There may also be other relevant and more project-specific effects that should be included in the socio-economic analysis depending on the specific project.

Energinet's socio-economic analyses therefore also include effects other than the effects described in this memorandum.

Examples of such effects from previous projects include EU funding, the SK4 agreement (concerns correction of Danish congestion rents on the border between Jutland and Germany) and capacity market (interconnectors can in some cases participate in actual capacity markets abroad).

NON-QUANTIFIED EFFECTS

Energinet's projects may also have consequences which cannot be immediately quantified or valued. This is often seen in situations where the effect has not been converted into a market, and it is therefore not possible to derive a market price. Therefore, these effects cannot be directly included in the quantified socio-economic result. However, the effects will still be identified, and a qualitative assessment will be made of the importance of the effects and consequences for the overall analysis results.

Examples of such effects may be certain environmental factors.

Methods for quantifying the advantages and disadvantages of Energinet's projects are continuously being developed.

7 Ancillary services are tools which can be used for maintaining the security of supply. Therefore, "Costs of ancillary services" cover the costs of maintaining the security of supply.

MARKET EFFECTS

TRADE BENEFITS

A difference in electricity spot prices between price areas is a result of physical constraints in the exchange of electricity between the areas. This is because the two price areas are not connected, or that capacity on the existing interconnector is limited in relation to the trade capacity demanded by the market.

When two price areas are connected, or when capacity on the existing interconnectors is changed, the market equilibrium is affected in both price areas.

Prices in the two areas will converge, and production and consumption in the two areas will adapt to the new market equilibrium. Overall, welfare in both areas will increase as the market increases. This effect is typically referred to as trade benefits and can be divided into changes for producers and consumers as well as congestion rents[8].

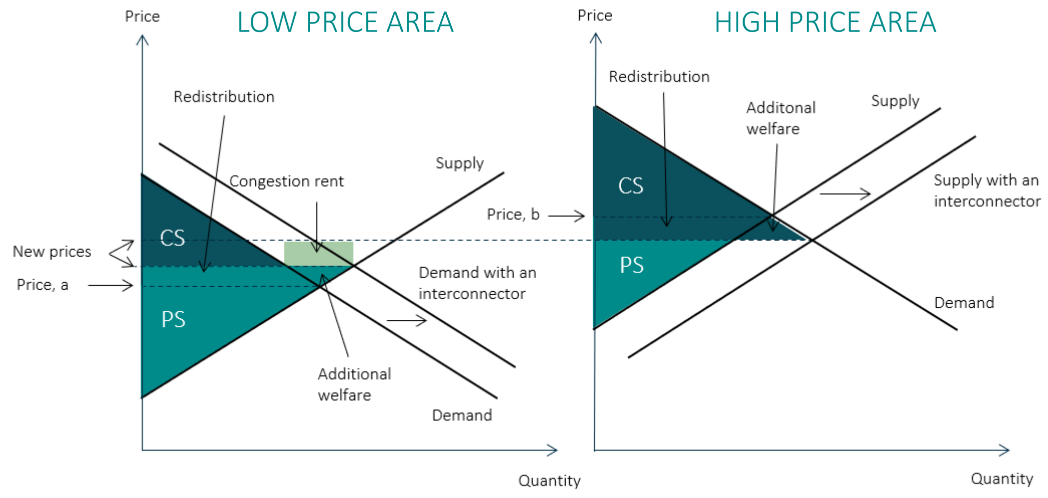
The trade benefits are typically one of the most important elements when an interconnector is established. On the other hand, there will be no trade benefits from projects affecting only one price area. The trade benefits are estimated in Energinet's electricity spot market model BID3.

8 Read more on next page

TRADE BENEFITS

Socio-economic elements

The figure on the right shows the market and welfare effects in the electricity spot market within a given hour. An interconnector from a relatively low-priced area to a relatively high-priced area will increase the demand in the low-price area and the supply in the high-price area. This will lead to a new market equilibrium with changed electricity spot prices. The total socio-economic effect is measured in *changes in consumer surpluses* and *producer surpluses* as well as changes in *congestion rents*. Energinet's analyses focus on the Danish changes in the three elements. Please note that it is the net change in congestion rents on all Danish interconnectors that is included and not only on the specific interconnection examined.



CONSUMER SURPLUS

Consumers in the low-price area will experience a price increase. This will lead to a fall in the consumer surplus. The lost consumer surplus in the low-price area will, however, be redistributed to a producer surplus.

Consumers in the high-price area will, on the other hand, experience a price drop due to the increased supply. This will lead to an increase in the consumer surplus.

Part of the increase of the consumer surplus in the high-price area will be redistribution from producers, but the new equilibrium will also result in a general welfare increase.

PRODUCER SURPLUS

Producers in the low-price area will experience an increased demand and thus increased price and volume equilibrium. This will lead to an increase of the producer surplus. Part of this will come from redistribution from consumers, but there will also be a general welfare increase.

Existing producers in the high-price area will experience a reduced producer surplus as a result of lower prices and volumes. However, this will be a redistribution among the consumers in the area.

CONGESTION RENTS

When net transfer capacity between two price areas is limited, congestion occurs. The owner of the connection will receive congestion rent when the connection is used corresponding to the transported volume multiplied by the price difference between the two price areas. The congestion rent is shared between the high-price and low-price areas.

The congestion rent is used to reduce the tariff and thus, the effect accrues to consumers of the electricity transmission grid.

Please note that increased capacity between two price areas can result in both an increase and a fall in congestion rents.

TRANSIT COMPENSATION

Some of the energy transported in the Danish electricity transmission grid is in transit through the Danish electricity grid from one neighbouring country to another. Seen in a regional perspective, the socio-economic impact of transit is positive as it allows equalisation of electricity spot prices across price areas. However, it requires investments in the Danish electricity transmission grid and leads to costs in the form of transmission loss.

The European TSOs participate in a scheme which compensates for grid losses in national transmission grids due to cross-border flows (transit) and for infrastructure related costs that facilitate cross-border flows. This scheme is called 'Inter-TSO Compensation (ITC) Mechanism' [9].

The ITC scheme ensures that costs are redistributed among the European TSOs so that the costs accrue to the countries benefiting from the transit. Historically, Denmark has been a recipient of compensation under the scheme, as we have considerable transit of electricity from abroad through the electricity system.

The investment analysis includes the change in the Danish transit compensation, as this has a direct impact in a Danish socio-economic context.

Determination of transit compensation

Calculating the actual transit compensation is complicated. The method used to determine the development of transit compensation in the socio-economic analysis is therefore a simplified method of reality.

The development in the Danish transit compensation is adjusted on the basis of changes in the relationship between transit through the Danish electricity system and the sum of net imports and exports for Denmark. Transit as well as net imports and exports are determined in Energinet's electricity spot market model BID3.

In the actual calculation of transit compensation for the countries under the ITC scheme, transit is one of the factors affecting the compensation from the ITC scheme, while the contribution to the scheme depends on net imports and exports.

A weakness in the method used to calculate transit compensation is that only changes through Denmark are considered. As the scheme covers all of Europe and transit, net imports and exports will also change in other countries through the establishment of new interconnectors, the distribution between the countries will therefore also change. This effect is not included in the simplified method, where only the pure Danish gross effect is estimated.

9 Read more about the ITC scheme here

HOW TO CALCULATE TRANSIT COMPENSATION?

Transit compensation for year *x* is estimated by:

$$\text{Transit compensation for year } x = \text{historic transit compensation} \cdot \frac{\text{Transit formular for alternative a}}{\text{Transit formular for reference}}$$

where:

$$\text{Transit formular for alternative a} = \frac{\sum_{1}^{8760} \text{Transit DK(i)}_{\text{Alt.a}}^{\text{X}}}{\sum_{1}^{8760}\left[\left(\text{Net import(i)}_{\text{Alt.a}}^{\text{X}} > 0\right) + \left(\text{Net export(i)}_{\text{Alt.a}}^{\text{X}} > 0\right)\right]}$$

$$\text{Transit formular for reference} = \frac{\sum_{1}^{8760} \text{Transit DK(i)}_{\text{Ref}}^{\text{Y}}}{\sum_{1}^{8760}\left[\left(\text{Net import(i)}_{\text{Ref}}^{\text{Y}} > 0\right) + \left(\text{Net export(i)}_{\text{Ref}}^{\text{Y}} > 0\right)\right]}$$

Y is the first simulation year, Ref. is reference/null alternative[10], Alt. a is alternative a. Please note transit, net import and net export are determined as the sum of the 8,760 hours of the year.

10 In some cases, it is not the null alternative that resembles the current grid most. This occurs, for example, in connection with reinvestments. In these cases, the calculation is based on the alternative most similar to the current grid, such as reinvestment without capacity changes.

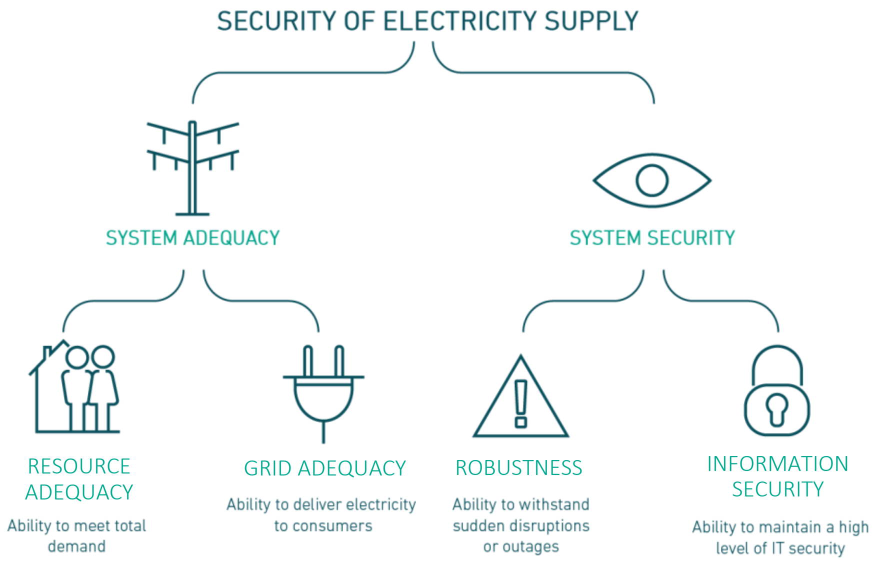
SECURITY OF SUPPLY

SECURITY OF SUPPLY

One of Energinet's main responsibilities is to ensure the security of supply.

Security of electricity supply is not just about the size and number of power lines, power plants and volumes of renewable energy. The security of electricity supply also depends on the extent to which electricity consumption and production can be balanced and on whether the power grid can transport the necessary amount of electrical energy and handle faults.

If changes are seen in the security of supply when establishing a project, this must be included when the project is evaluated.



RESOURCE ADEQUACY

Resource adequacy is defined as the electricity system's ability to meet the electricity consumers' total demand for electricity.

Resource adequacy is closely linked to the electricity spot market, where situations with lack of resource adequacy lead to high electricity spot prices.

Resource adequacy analyses are included in impact assessments for projects which may impair/increase resource adequacy. It will typically be relevant when establishing connections between price areas.

GRID ADEQUACY

Grid adequacy is defined as the electricity grid's ability to transport electricity from the place of generation to the place of consumption. Grid adequacy therefore relates to the internal electricity grid in a given price area.

If there are limitations in the internal grid that affect grid adequacy, it must be included in the project. Typically, this will be relevant in projects where internal grid expansions must be carried out due to lack of capacity.

ROBUSTNESS

Robustness is the electricity system's ability to handle sudden system disturbances without these affecting the electricity supply or resulting in disconnection of electricity consumers.

Operational disturbances can, for example, be caused by electrical short circuits or outages of production units.

The socio-economic consequences of outages due to faults and costs of increasing grid robustness are included in the business case for a project.

INFORMATION SECURITY

Information security is, among other things, the ability to maintain high uptimes on critical IT systems and to withstand cyberattacks without the electricity system and its participants being affected.

Information security is not normally an element included in Energinet's projects covered by this methodology memo but is included if relevant.

RESOURCE ADEQUACY

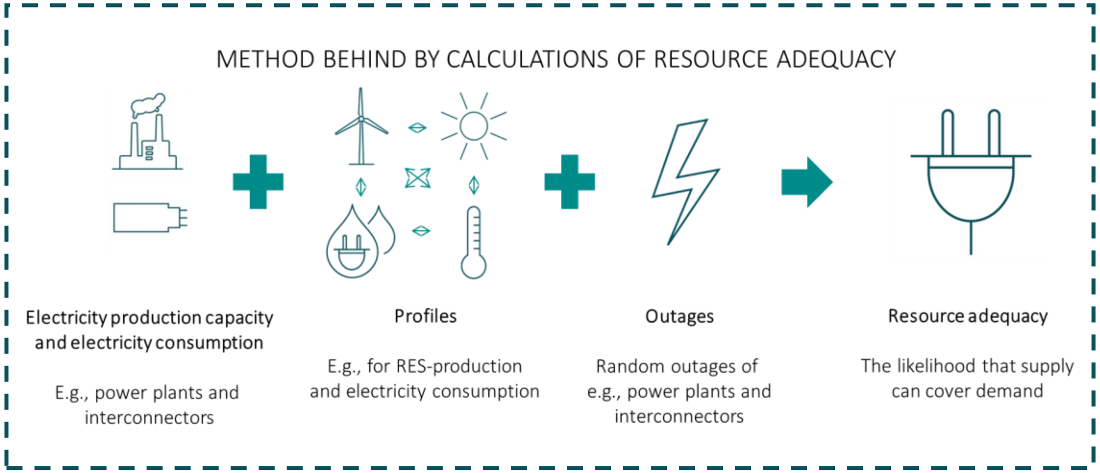
METHOD FOR CALCULATING RESOURCE ADEQUACY

The socio-economic impact of changed resource adequacy level due to a given investment in the electricity transmission system is determined by:

$$\Delta EUE \ x \ VoLL$$

Expected Unserved Energy (EUE) and Value of Lost Load (VoLL) are described in the following sections.

Investments in electricity transmission capacity between price areas, will typically affect resource adequacy. Conversely, investments in the internal electricity transmission system within the two Danish price areas will typically not affect resource adequacy.



EXPECTED UNSERVED ENERGY (EUE)

In assessing resource adequacy, Energinet uses probability-based modelling, typically the BID3 electricity spot market model. The BID3 model simulates electricity generation and electricity consumption at hourly levels with climate profiles for different historical climate years, combining this with stochastic outages on power plants and interconnectors. The simulation is carried out for the entire European electricity system, and the possibilities of imports on interconnectors are reflected sufficiently in the modelling

The output from resource adequacy calculations is various indicators for resource adequacy.

One of these indicators indicates the estimated level of unserved energy to electricity consumers due to a lack of resource adequacy. The indicator for unserved energy is referred to as EUE (Expected Unserved Energy).

Changes in the level of unserved energy are included in socio-economic impact assessments of investments in the electricity transmission system.

VALUE OF LOST LOAD (VOLL)

For the valuation of unserved energy from a socio-economic perspective, estimates of 'Value of Lost Load' (VoLL) are used.

VoLL is an economic indicator that expresses the costs of an interrupted electricity supply. VoLL is not one single value, but depends on a number of factors, e.g. who is disconnected (industry, service, households, etc.) and the characteristics of outages (duration; time of day, week, year; forewarned or not, etc.).

The current estimate is based on the DAMVAD report from 2015[11]. The report investigated how VoLL varies on the basis of four different consumption groups. The consumer groups vary in VoLL, ranging from 22 DKK/kWh for households to 276 DKK/kWh for service sectors in the event of a four-hour outage. To value the costs of interrupted electricity supply, the consumer-weighted average cost of a four-hour outage is used.

Estimates of VoLL are associated with considerable uncertainty, but the starting point for VoLL is 150 DKK/kWh in 2017 prices.

11 https://ens.dk/ansvarsomraader/el/elforsyningssikkerhed

GRID ADEQUACY

Grid adequacy is defined as the electricity grid's ability to transport electricity from the place of electricity generation to the place of consumption.

When an equilibrium exists between production and consumption in the electricity spot market, restrictions, if any, in the electricity system within the individual price areas are not taken into account (often referred to as internal congestions). If such limitations exist, it may create challenges in the form of overloads, when the market equilibrium must be handled physically in the electricity system. They say that the market and physics do not match.

When the electricity grid is insufficient, it may lead to overloading in the electricity system, when the electricity is to be transported between the production and consumption sites. The consequences of the above issues may be as follows:

- *A need for downward regulation of production*
- *A need to reduce load from consumers*

If the electricity grid is insufficient, it will be necessary to reduce the electricity generation as it is not possible to transport the electricity to where it is demanded.

Thereby, two things may happen:

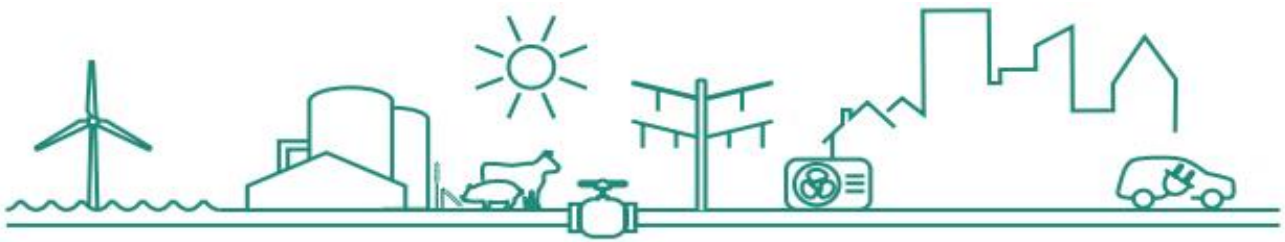
1. If it is possible to meet consumption by generating electricity from other production units not limited by internal congestions, these are activated. This is referred to as special regulation or countertrade if this takes place via interconnectors.
2. If there are no production units in the area which can be activated and supply the consumption area due to internal congestions, there will be a need to reduce load from consumers. This means that it will not be possible to supply all consumers in this case.

Expansions of the electricity transmission system can relieve grid adequacy challenges in the two cases. Thus, the value of this is relevant to be included in Energinet's investment analysis.

Estimation of grid adequacy

Typically, grid adequacy challenges will lead to a need for reducing electricity generation alone as there will be other supply routes to consumers.

Energinet's method for valuing this can be seen on the next page. If it is not possible to supply all consumers due to grid adequacy challenges, the volume of unserved energy is valued using VoLL.



GRID ADEQUACY - CHANGED TRANSMISSION CAPACITY AND GENERATION VALUE ASSESSMENT

Often, generation of renewable energy is connected far from large consumption centres, which can potentially lead to overloads in the electricity system when the electricity is transported between production and consumption sites as there is not enough capacity in the power grid. This is also referred to as limited/challenged grid adequacy.

Expansions of the electricity transmission system will be able to relieve such overloads, and the value of this is therefore relevant to include in Energinet's investment analysis.

If the issue of a challenged grid adequacy is not addressed, it will be necessary to adjust the distribution of production/ consumption of the electricity spot market in the electricity system.

Here an illustration of where generation cannot meet consumption due to Internal congestions in the Western Danish market

This will be achieved through subsequent regulation via the regulating power market, where, for example, electricity generation is reduced (downward regulation) on one side of the constraint in the electricity transmission system, and electricity generation is increased (upward regulation) on the other.

This form of regulation within one price area is called special regulation. The regulation can also take place from abroad via interconnectors, referred to as countertrade.

Special regulation/countertrade

Special regulation or countertrade means that the most efficient generators are not allowed to produce electricity due to physical capacity restrictions in the grid. This results in a socio-economic loss compared to a situation without the need for special regulation or countertrade.

Value assessment of benefits of increased transmission capacity

The benefit of increasing transmission capacity in the electricity system and thus reducing the amount of expected overloads is determined by the product of changes in energy overload and the relevant price.

The change in energy overload is estimated in Energinet's power grid model PowerFactory based on the electricity spot market equilibrium determined in Energinet's electricity spot market model SIFRE. The energy overloads are determined at an hourly level.

The price used is an estimate of the difference in marginal production costs for the units regulated upwards and downwards, respectively.

Typically, the expected overloads in the electricity system will be caused by renewable energy from wind and solar power. This means that wind or solar power generation often have to be regulated downwards. Electricity generation from both wind and solar sources is assumed to have a marginal production cost of zero.

On the contrary, electricity generation which must be regulated upwards on the other side of the overload, is assumed to be a producer that has not been activated in the electricity spot market. Based on this, upward-regulated electricity production is assumed to have marginal production costs corresponding to the electricity spot price.

Based on the above assumptions, pricing of energy overload will correspond to the estimated electricity spot prices from SIFRE when wind or solar power are regulated downwards, as this reflects the difference in marginal production costs for the two producers.

If production does not come from renewable energy sources

In some cases, it is not clear that it is renewable energy production from wind and solar power that needs to be regulated downwards in order to handle expected overloads. In such cases, it cannot be assumed that the production unit regulated downward has marginal production costs of zero. Instead, the historical difference between upward and downward regulation prices will be the starting point for the pricing of overload energies.

The difference between upward and downward regulation prices is assumed to approximate the difference in marginal production costs for the units regulated upward and downward.

The difference between upward and downward regulation prices is set relatively to the electricity spot prices as Energinet does not have a projection model for projecting future prices in the regulating power market. These are therefore projected on the basis of electricity spot price projections.

In a future with large-scale RES (Renewable Energy Sources) and large-scale consumers such as PtX plants, it is likely that these will replace thermal generation and put in bids for a balancing market. Energinet is thus working on a method for valuing production, which takes into account a future with RES providers and consumption contributing to a balancing market.

SYSTEM SECURITY

The part of system security that deals with robustness is examined in Energinet's impact assessments for electricity transmission projects when an investment affects the robustness of the electricity grid. Power system robustness involves the power system's ability to withstand sudden system disturbances.

Often system security assessments will be of a qualitative nature, unless the impact on unserved energy is estimated.

In cases where it is possible to estimate the effect of unserved energy, a risk-based approach is often used to determine the value of increased grid robustness. To determine the change in the risk of sudden system disturbances, the probability of system disturbances occurring is estimated - the time that passes before the power system returns to normal operation, and the amount of unserved energy during the period is determined. Estimates for VoLL are used to value the amount of unserved energy.

The other part of system security, information security, is not included in projects covered by this methodology memo.

COSTS FOR ANCILLARY SERVICES

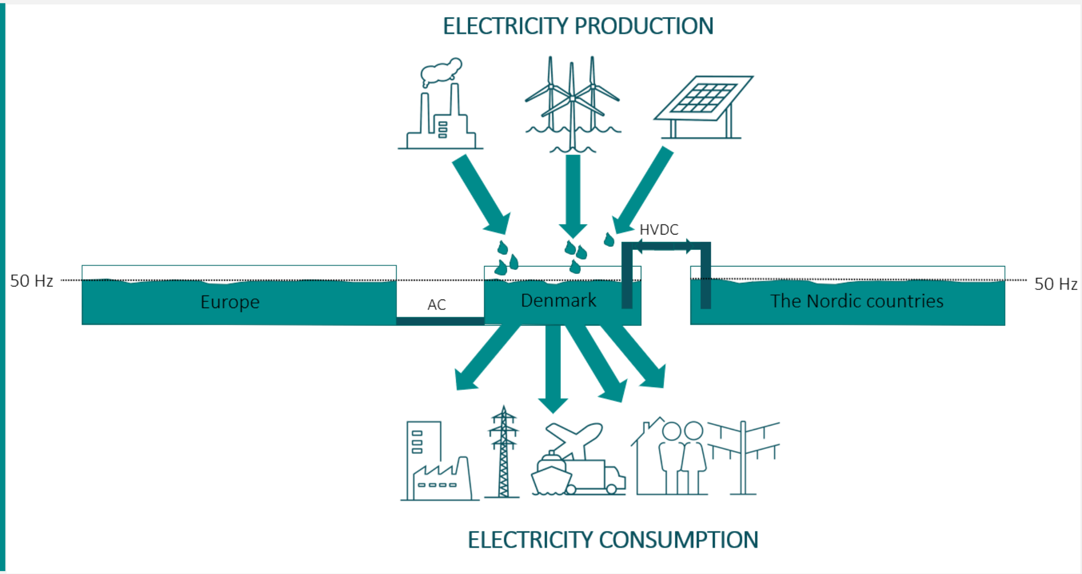
ANCILLARY SERVICES

In the electricity system, consumption and production must always balance in order to ensure reliable and stable operation of the system. Ancillary services are thus tools that can be used to maintain a high level of security of supply. As system operator, Energinet needs a number of special products – called ancillary services – in order to maintain this balance. Ancillary services is a general term for the electricity generation and consumption resources used for maintaining balance and stability in the electricity system.

Energinet procures ancillary services which can be available, and which can be activated automatically or upon request from Energinet when needed. The portfolio of ancillary services is large, and their use is relatively complex. The vast majority of Energinet's ancillary services consist of reserves. To this should be added a need for properties required to maintain power system stability and other ancillary services such as black start. [12]

Major changes in the electricity transmission system may affect the electricity system's need for ancillary services, and it is therefore an important element to analyse in relation to an investment decision.

12 Read more about the different ancillary services, including types of reserves here.



RESERVES

Balancing is important to maintain a certain level of security of supply in an electricity system with an increasing amount of fluctuating renewable energy. For this purpose, for example reserves are used. When Energinet integrates more renewable energy or builds large facilities, the need for reserves changes.

Investments in the electricity transmission system can affect both the need and the price for the various types of reserves. This could be a socio-economic benefit or cost, and it is relevant to include them in the investment analysis.

EMERGENCY START-UP

After a blackout, the electricity system needs an emergency start-up/black start, i.e. start-up from dead network. Historically, the service in Denmark is supplied by power plants, where Energinet pays these to be available for black start of the system.

In addition, it is also possible to use interconnectors for emergency start-up. However, having a new interconnector will typically not have any socio-economic impact, as emergency start-up agreements have already been concluded via some of the existing interconnectors.

PROPERTIES REQUIRED TO MAINTAIN POWER SYSTEM STABILITY

Properties required to maintain power system stability comprise a number of technical properties (inertia, short-circuit power, continuous voltage control and dynamic voltage support during faults), which are necessary to ensure the stability of the electricity system. These services can primarily be provided by large power plants, Energinet's synchronous compensators or HVDC connections.

Investments in the electricity transmission system will potentially be able to deliver certain properties required to maintain power system stability, thus affecting the socio-economic costs of supplying the necessary properties required to maintain power system stability.

RESERVES

Energinet purchases various types of reserves with different functions. The different types of reserves are referred to as FFR, FCR, FCR-N, FCR-D, aFRR and mFRR.[13]

For all types of reserves, these are procured in a capacity market so that the reserves are available if/when needed. For all types of reserves, a project may lead to more or less costs for reserves. However, the effect will often be zero.

Investments in the electricity transmission grid can affect reserve costs through changes in the three categories below.

13 Read about the different types of reserves in the vocabulary on the last page or more here

RESERVE CAPACITY REQUIREMENT

Two factors may change the need for reserve capacity:

1) A project (typically new interconnectors) can change the capacity of the dimensioning unit in the Danish electricity system. If the dimensioning requirement is increased, it means that more reserve capacity (mFRR) must be purchased in order to maintain the same level of security of electricity supply, which will have a socio-economic effect.

2) Establishment and connection of renewable energy creates more imbalances in the electricity system. This may increase the need for reserve capacity in order to maintain the same level of security of electricity supply. The methodology and calculation of this effect on the reserve requirement in Energinet's investment analyses are undergoing continued development.

Technology-based costs for the construction of new reserve units[14] and historical reserve prices have been used to estimate price changes in reserve requirements.

For example, a price of approx. 300,000 DKK/MW/year is typically used as an approximation for establishing new gas turbines as peak-load/reserve capacity.

14 https://ens.dk/service/fremskrivninger-analyser-modeller/teknologikataloger

THE PRICE OF RESERVE CAPACITY

By establishing an interconnector, it may be possible to connect two separate reserve markets, which means that the most efficient reserve suppliers across the two price areas potentially can be purchased in one single market.

Reserve sharing between interconnected price areas/countries requires a specific agreement. For example, since the establishment of the Great Belt Power Link there has been an agreement on sharing 300 MW reserves (mFRR) from DK2 to DK1.

Potentially, a reserve sharing agreement may also affect the procured amount of reserve capacity and thus have a socio-economic effect.

So far, the historical price difference for reserves in the relevant price areas has been used to estimate the price impact.

If capacity is not reserved on the interconnector specifically for reserve exchange, it will only be possible to exchange reserves when there is available capacity after the electricity spot market exchange. The available capacity for reserve exchange is estimated in the BID3 electricity spot market model.

COSTS OF ACTIVATING RESERVES

The activation costs of reserves can be affected in the same way by investments in the electricity transmission grid. Changes in this will typically be caught by other socio-economic effects described in this memo.

For example, some grid expansions could reduce/eliminate the need for downward and upward regulation of production to avoid potential overloads. This will reduce reserve activation costs; see the section 'Grid adequacy – changed transmission capacity and generation value assessment'.

Similarly, the need for reserve activation can be reduced when reinvestments are made, where older components with a greater risk of outages are replaced. In these cases, a qualitative assessment is often made focussing on security of supply, which is included in the business case, see sections on “Grid adequacy” and “System security”.

EMERGENCY START-UP AND PROPERTIES REQUIRED TO MAINTAIN POWER SYSTEM STABILITY

Emergency start-up

The technical design of interconnectors has an impact on whether a connection can contribute to emergency start-up of the power grid in the connected price areas. If an interconnector can contribute to emergency start-up and thus prevent investments that would have been made in the null alternative, this must be included as a benefit of establishing the connection.

Investments in the internal electricity transmission system in the two Danish price areas will typically not affect the emergency start-up need or price in Denmark.

Historical prices for procuring emergency start-up reserves in the Danish electricity system will typically be used as the basis for the valuation. The current costs of emergency start-up reserves are stated on Energinet's website (Long-term agreements). Alternatively, a technology-based approach to valuation may be applied[15]

15 https://ens.dk/service/fremskrivninger-analyser-modeller/teknologikataloger

Properties required to maintain power system stability

The technical design of interconnectors has an impact on whether a connection can contribute with properties required to maintain power system stability in the connected price areas.

Historically, investments in the internal electricity transmission grid in the two Danish price areas have typically not affected the need for properties required to maintain power system stability in Denmark. A future energy system will, however, see an increasing need for properties required to maintain power system stability. Energinet therefore foresees that it will be relevant to perform socio-economic analyses of investments in properties required to maintain power system stability, also within a price area. This could, for example, be investments in synchronous compensators in the electricity system, which will typically be driven by the need for properties required to maintain power system stability. Work is being done to develop the methodology for including properties required to maintain power system stability in investment analyses.

Historical prices for ordering/forced operation of Danish power plants have typically been the basis for the valuation. Alternatively, a technology-based approach to valuation may be applied.

COSTS RELATED TO ASSETS

COSTS RELATED TO ASSETS DURING SERVICE LIFE

Costs relating to the construction and operation of assets as well as the reestablishment of areas after expiry of service life are included in the socio-economic analysis. The costs are calculated using factor prices and converted into market prices in the socio-economic analysis using the net tax factor. [16]

Construction costs

Energinet estimates budgets for investments in the electricity transmission system primarily based on historical prices in Energinet possibly supplemented with knowledge from dialogues with suppliers in the market.

The total construction budget (P85) consists of a) a physics estimate, b) an uncertainty analysis and c) a risk analysis. The physics estimate forms the basis of the basic budget and is the expected value/price of the individual items. For the uncertainty analysis Energinet uses the successive calculation method, which specifies a worst case (max) and best case (minimum) in addition to the most likely value (expected price). The weighted mean value is used to calculate the statistical expected value (P50), which is the control target. The dispersion is used to calculate the budget uncertainty allowance corresponding to a standard deviation. The risk pool has been determined on the basis of a risk analysis. A financial estimate is used from the risk analysis, which is calculated on the basis of the product of the probability and financial consequence.

In some analyses, it may be relevant to include a scrap/residual value of certain components with a longer service life than the analysis period. The residual value is placed in the last year of the analysis period and is determined on the basis of a principle of straight-line depreciation.

There may be cases in which Energinet accepts higher investment costs to ensure that a solution is chosen which is optimal from a socio-economic point of view. Here, costs for e.g. third parties are included in the socio-economic assessment.

Derived grid reinforcements

The establishment of interconnectors, connection of energy production or other expansions of the electricity system may result in a derived need for grid expansions elsewhere in the electricity system in order to be able to include the full benefits. Typically, the derived grid reinforcements will be quantified and integrated into the construction budget or in a separate item in the investment analysis.

In some cases, a separate project will handle the derived grid reinforcement. In this case, it is ensured that the full benefit estimate is not included twice.

Typically, Energinet handles grid connections separately. These are handled solely as cost-effectiveness analyses as third-party grid connections to the electricity transmission grid are statutory requirements. The benefit estimate is therefore only included in projects where derived grid reinforcements are made.

16 See guidelines from The Danish Ministry of Finance - in Danish only: Vejledning om samfundsøkonomiske konsekvensvurderinger (fm.dk) ,

COSTS OF OPERATION, MAINTENANCE AND REESTABLISHMENT

Operation and maintenance costs

Operation and maintenance include the expected ongoing costs of keeping the assets in operation during the service life.

Costs related to faults may be included if specific assumptions have been made concerning a certain number of faults during the asset's service life.

Costs of replacing large individual components with a shorter expected service life than the analysis period will typically not be included under cost related to operation and maintenance.

Operating and maintenance costs are calculated based on historical prices. Operating and maintenance costs are calculated as the annual costs in constant prices.

Reestablishment obligations

Energinet is obliged to set aside resources for the reestablishment of the physical areas when parts of the electricity system are decommissioned.

These resources are included in the costs at the expected end-of-life and will typically be a small cost item compared to construction costs.

Preventive investments

Preventive investments in the electricity grid can be realised if the investment eliminates another investment which had to be made in the null alternative.

This could, for example, be a planned reinvestment resulting from a worn-out electricity grid or a reinvestment in an interconnector.

If it is possible to prevent an investment under the alternative, the costs of the preventive investment must be included in the investment’s benefit estimate. The gain estimate can be calculated by using the expected costs to establish the planned project.

HOW ARE THE COSTS APPLIED IN ENERGINET'S ANALYSES?

When Energinet makes an investment decision, the project costs are stated under different sections in the business case

- *Construction budget and derived operating expenses*
- *Socio-economics*
- *Economic impact and tariff effect*

Construction budget - 2022 prices	Mio. DKK
Project management	
Plan and environment	
AC stations	
Automation	
Constructions	
Land cable	
Sea cable	
HVDC converter (converter facilities)	
Basic budget (excl. construction loan interest)	
Construction loan interest	
Basic budget	
Expected supplement (project manager reserve)	
Steering target	
Risk pool	
Budget uncertainty (steering committee reserve)	
Construction budget	

The construction budget must state the total construction costs. The total budget constitutes the basic budget, construction loan interests, an expected supplement, risk pool and budget uncertainty. The construction budget is presented in constant prices as indicated in the table. The total construction budget is also reported in current prices.

The socio-economic analysis uses the total construction budget excluding construction loan interest and budget uncertainty (steering committee reserve).

At the time of analysis, this is assessed to be the most likely estimate of the actual construction costs. Calculated interest is not included as construction costs are distributed over the construction period and discounted; the discount factor then incorporates the costs of bringing forward the use of resources. The operating and maintenance costs are presented relative to the null alternative and thus a delta consideration.

The economic impact and tariff effect are to account for the additions to the cost cap coming from the recommended investment, which must be recommended for approval to the Danish Utility Regulator and for the derived tariff effect of the investment. Depending on whether it is a new investment, reinvestment with change of capacity or 1:1 reinvestment, either the total financial effect of depreciation, amortisation and derived operating and maintenance costs, or just the net effect, is set up as a basis for an addition to the cost cap.

Sections	Constant prices/ Current prices	Factor prices/ Market prices	Present value	Construction loan interest and budget uncertainty
Socio-economics	Constant	Market prices	Yes	Exclusive
Construction budget and derived operating expenses	Constant and current	Factor prices	No	Inclusive
Economic impact and tariff effect	Current	Factor prices	No	Inclusive

GRID LOSS

When electricity is transmitted, there is a loss of energy (electricity) due to resistance in the electricity system. The energy loss is called grid loss and will be released as heat in the electricity system's components and surroundings.

The flow of energy in the electricity system is changed by investing in the electricity transmission system, which affects the total grid loss in the system.

Value assessment of grid loss:
The value of changed grid loss is determined by estimates for the future electricity spot price:

$$\Delta \text{ grid loss } x \text{ electricity spot price}$$

Changes in grid loss and the future electricity spot price are based on simulations from Energinet's models. The grid loss is typically divided into grid loss internally in Danish price areas and grid loss on interconnectors, including the Great Belt Power Link.

Loss in Danish price areas

Grid loss internally in the two Danish price areas can be affected by investments in interconnectors as well as in the internal Danish electricity system.

The grid loss is determined in Energinet’s electricity grid model “PowerFactory” or estimated on the basis of transit flow through the Danish electricity system based on Energinet’s electricity spot market models. Typically, this part of the grid loss is determined on an annual basis and valued at an average annual electricity spot price based on Energinet’s electricity spot market models BID3 and SIFRE.

Internal grid loss is not calculated in projects where it is assessed that the selected alternative will lead to increased grid loss somewhere in the internal grid, but at the same time leads to lower grid loss elsewhere in the grid.

The changes in grid loss due to changed transit through the Danish electricity grid should generally be balanced by a similar change in transit compensation as described earlier.

Loss on connections between price areas

For all Danish interconnectors including the Great Belt Power Link, Energinet has prepared a loss formula in which the grid loss of the individual connection is determined as a function of the energy flow on the connection. For the existing connections, the loss formula is based on historically observed grid losses, while the loss formula for new connections is based on expected grid losses given the technology of the connection.

Based on the loss formulas, grid losses on the individual connections are determined on the basis of Energinet’s electricity spot market model BID3 and the estimated flow on the connections. The value of the grid loss is determined by the price of electricity in the price area in which it has been agreed that the loss is purchased. The electricity spot price is also estimated in Energinet’s electricity spot market model BID3. The calculation is made on an hourly basis. The summed annual values across all Danish connections are included in the investment analysis.

Grid losses on electricity transmission connections between price areas can either be handled implicitly or explicitly. In connection with implicit handling, grid loss on the connection is included as part of the market optimisation in the electricity spot market model. The optimisation takes into account that loss occurs along the way on the connection, so that the amount of energy coming out of the cable differs from the amount coming in. This method means that electricity does not flow if the congestion rents cannot pay for the electrical loss in the connection. The grid loss on connections with implicit grid loss handling is therefore included in the trade benefits and thus not included in the grid loss item.

Today (2022), the grid losses for the Skagerrak connections and Viking Link are implicitly handled in the market calculations. Losses on the remaining interconnectors are handled explicitly and determined as described above by applying loss formulas. Thus, only the grid loss on connections with explicit grid loss handling is included in the grid loss item in Energinet’s investment analyses.

In connection with projects within a price area, the grid loss on will not be included.

OUTAGE

All parts of the electricity system have outages, from either maintenance or faults. For example, a new interconnector is expected to be out of operation due to faults or maintenance for a certain part of the service life of the connection. During outages benefits or costs related to the connection's operating time are not realized.

Internal grid

Outage during the service life is generally not included in investment analyses for internal grid expansions. However, outage is often assessed in relation to design and will typically be relevant to include if it is relevant to compare outages for several alternatives

Interconnectors

Energinet's electricity spot market simulations assume that interconnectors are available at all times. Therefore, corrections must subsequently be made for outages which will occur during the service life. The outage item comprises benefits (typically trade benefits and transit compensation) as well as costs (typically grid loss) not realized due to outages. [17]

Assumptions about the outage percentage during the service life of interconnectors have either been based on historical data for similar connections or on expected outages based on the technical design of the connection.

Historical outages for the Danish interconnectors are calculated differently depending on whether they are HVDC or AC connections. For the HVDC connections, we have chosen to use identical outage percentage. For the HVDC connections, outage is based on the historical outage time for all Danish HVDC connections. At present (2022), the calculation is based on the 2012-2020 period. This method has the advantage that the present connections are at different stages of their service life.

The Danish AC connections are built up differently, and an outage based on the individual systems has therefore been calculated. This makes the figure more dependent on system age and thus not as accurate as for the entire service life of the system. However, this is our best estimate. At present (2022), the calculation is based on the 2013-2021 period.

17 See the latest security of electricity supply report for more information - in Danish only: https://energinet.dk/Om-publikationer/Publikationer/Redegoerelse-for-elforsyningssikkerhed-2022

OTHER EFFECTS

CLIMATE IMPACT

CO_2 impact

The CO_2 impact of an alternative is calculated as the direct effect on CO_2 emissions from the Danish electricity sector.

Projects with expected climate effect must account for:

- Change in CO_2 emissions during the service life of the project
- Present value of the change in CO_2 emissions
- CO_2 shadow price.

The effect is reported separately in the section on climate impact, either on an annual basis or over the service life of the project and is used as a basis for calculating present value and shadow price.

Shadow price of CO_2

The shadow price of CO_2 indicates the socio-economic costs per reduced tonne of CO_2. The shadow price of a reduction in CO_2 emissions is calculated by adding up the socio-economic benefits and costs (DKK), with the exception of the benefits of reducing CO_2, and dividing the result by the CO_2 reduction. It is thus possible to compare shadow prices across projects and in relation to the current political objective. In cases where the shadow price is negative, there will be a socio-economic surplus in connection with implementing the measure, irrespective of the effect on CO_2.

In connection with projects between different price areas in the electricity market, both the direct impact on CO_2 emissions from the Danish electricity sector as well as the direct impact on CO_2 emissions from the European electricity sector are calculated. However, the Danish impact is used as the basis for calculating present value and shadow price.

Internal grid expansions

The change in CO_2 emissions due to internal investments in the Danish electricity transmission system is based on:

- The change in grid overload in relation to the null alternative
- The Danish Energy Agency's projection of CO_2 emissions from Danish electricity consumption
- Under the assumption that production, which will be regulated downwards, is 100 % renewable energy, and the production that will be ramped up equals the average production mix in Denmark, the change in CO_2 emissions is calculated as: the change in grid overloads multiplied by the average CO_2 emission from Danish electricity consumption.

This method does not take into account the cross-border exchange of energy and is generally subject to considerable uncertainty.

Connections between price areas

The change in CO_2 emissions due to, the establishment of an interconnector is based on electricity spot market modelling in Energinet's BID3 model. The socio-economic value of changes in CO_2 emissions from the electricity sector is embedded in the calculation of trade benefits for interconnectors.

CO_2 price uncertainties

The CO_2 effect is assessed using the current fixed key ratio value for CO_2 from the Danish Ministry of Finance. As the CO_2 price is subject to considerable uncertainty, sensitivity calculations are performed with alternative CO_2 prices based on the calculation assumptions from the Danish Energy Agency.

INTEGRATION OF RENEWABLE ENERGY

The integration of renewable energy is one of the investment criteria when Energinet prepares a investment analysis.

In some cases, only a qualitative description of the possibility of integrating a certain amount of renewable energy will be included.

In other cases, the benefit is valued either by the change in the curtailment of renewable energy or a prevented downward regulation of renewable energy with the weighted spot prices; however, not as an independent item in the investment analysis. The value is reflected indirectly when calculating the trade benefits in the case of the establishment of an interconnector or, when the value of increased transmission capacity is calculated, in the case of internal grid reinforcements. Here, the value assessment is thus included under the socio-economics investment analysis.

If the analysis involves the establishment of an interconnector, the change in curtailment of renewable energy and the weighted electricity spot prices will be used for valuation via a BID3 model run.

In case of internal grid reinforcements, the preventive downward regulation volume in PowerFactory is calculated and priced using the weighted electricity spot prices estimated in SIFRE.

ELEMENTS IN THE SOCIO-ECONOMIC ANALYSIS
SUMMARY

	Concept	Description	Quantification	Valuation
Market effects	**Trade benefits**			
	- Producer surplus	Benefits to producers who obtain a settlement price higher than their production costs	Production volume. Model run in BID3.	The price difference between production cost and electricity spot price in BID3.
	- Consumer surplus	Benefits for consumers settled at a price lower than their willingness to pay.	Consumption volume. Model run in BID3.	Price difference between willingness to pay and electricity spot price in BID3.
	- Congestion rents	Benefit to the TSO through flow on interconnectors with price differences between price areas.	Flow on interconnectors. Model run in BID3.	Price difference between the connected price areas in BID3.
	Transit compensation	Compensation for grid loss in the national transmission grid due to transit and infrastructure costs enabling flows across borders.	Change in flow through Denmark. Model run in BID3.	Historical transit compensation.
Security of supply	**Resource adequacy**	Resource adequacy is defined as the electricity system's ability to meet the electricity consumers' total demand for electricity.	Expected unserved energy. Model run in BID3.	Price that consumers are willing to pay to avoid power cuts. Value of Lost Load (VoLL).
	Grid adequacy	The capacity of the power grid to transport electricity from the place of generation to the place of consumption.	Expected unserved energy. Model run in PowerFactory.	Price that consumers are willing to pay to avoid power cuts. Value of Lost Load (VoLL).
	- Increased transmission capacity	Benefits of avoided upward and downward regulation as overload in the internal grid is reduced.	Flow on the relevant connections. Model run in PowerFactory.	Electricity spot price in SIFRE.
	System security	The electricity system's ability to handle sudden system disturbances.	Expected unserved energy. Model run in SIFRE or PowerFactory.	Price that consumers are willing to pay to avoid power cuts. Value of Lost Load (VoLL).

ELEMENTS IN THE SOCIO-ECONOMIC ANALYSIS
SUMMARY

Concept		Description	Quantification	Valuation
Costs of ancillary services	Reserves	Available power that can be activated in case of unforeseen imbalances in the electricity system.	Change in reserve need procured to balance the electricity market. Energinet's analyses and expert assessments.	Historical prices and/or technology-based prices.
	Emergency start-up	Property for the start-up of the electricity system after a blackout.	Change in need for purchase of emergency start-up service from participants in the Danish electricity system. Energinet's analyses and expert assessments.	Historical prices for procuring emergency start-up reserves in the Danish electricity system.
	Properties required to maintain power system stability	Properties to ensure stability in the electricity system.	Changes in the need to purchase the properties from participants in the Danish electricity system. Model run in PowerFactory or Energinet's analyses and expert assessments.	Historical prices for ordering/forced operation of Danish power plants.
Costs related to assets	Costs for assets during service life	Costs of constructing, operating and re-establishing assets.	Based on components forming part of the asset design.	Based on experience prices and uncertainty for these.
	Grid loss	Electrical loss due to resistance in the electricity system.	Interconnectors between price areas: Loss formula determined by Energinet as well as flow on connection from model run in BID3. Internal grid: Model run in PowerFactory or assessment based on model run in BID3/SIFRE.	Electrical spot price in BID3/SIFRE.
	Outage	Periods (planned and unplanned) during which the facility is out of operation.	Historical outage or technically expected outage for assets above service life.	Value of any benefits and costs not achieved in the period.
Other effects	Climate impact	CO_2 emissions over the service life of the project.	The change in CO_2 emissions from power generation. Interconnectors between price areas: Model run in BID3. Internal grid: Based on assumptions about special regulation and average energy production in Denmark.	Valued at CO_2 prices from the analysis assumptions.
	Integration of renewable energy	Either curtailment or avoided downward regulation of renewable energy and weighted electricity spot prices. May be supplemented with the potential for further renewable energy.	Interconnectors between price areas: Change in curtailment of renewable energy and weighted electricity spot prices. Model run in BID3. Internal grid: Avoided downward regulation of renewable energy. Model run in PowerFactory.	Will not be valued directly, but the value is captured partially indirectly in the items ”trade benefits” or ”increased transmission capacity”.

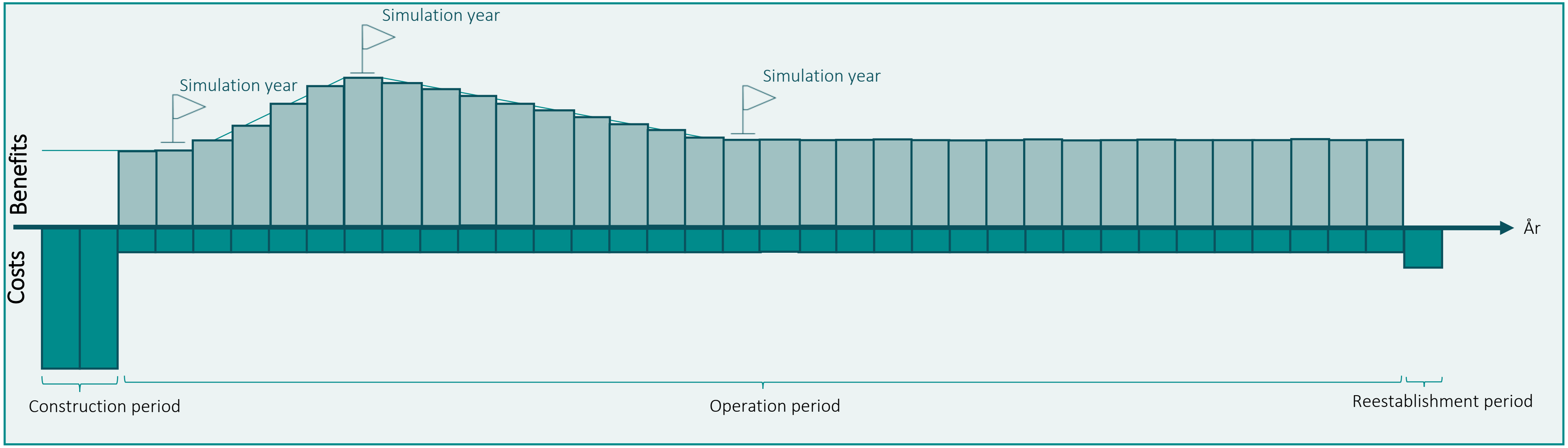
APPENDICES

APPENDIX A – COMPARISON OF EFFECTS

The investment analysis compares all relevant effects over the service life of the project.

All effects, both benefits and costs, are discounted by the socio-economic discount rate to a given year (typically the analysis year). All effects are thus calculated as present values. This allows the benefits and costs falling at different times over the service life of the project to be compared in a true and fair manner. For example, a benefit at the end of the service life will be valued less than a similar benefit at the beginning of the service life.

More effects are typically based on calculations of simulation years, which are described in the boxes below.



SIMULATION YEARS

Energinet's analyses are largely based on model simulations of the electricity market/power grid/energy system for future years. In this way, a number of the effects described in this memo are estimated here.

Energinet does not carry out simulations for each individual year over the service life of the specific project. Instead, selected years are simulated and referred to as simulation years or impact years.

The above is, among other things, founded on the fact that Energinet's model tools have not always incorporated assumptions for all future years (as is the case of simulations in BID3) over the typical service life of Energinet's assets. Furthermore, the additional information from simulating all relevant future years will not match with the resource consumption related to this.

SIMULATION YEARS IN ENERGINET'S MODELS

The simulation years in Energinet's electricity spot market model BID3 are based on the international data available from ENTSO-E's TYNDP and ERAA. At present (in 2022), Energinet has incorporated international data for the years 2025, 2030 and 2040, which can therefore be simulated.

In Energinet's energy system model SIFRE, which simulates the Danish energy system only, each year until 2040 can be simulated. SIFRE requires, among other things, assumptions about electricity spot prices in other countries, and these assumptions originate from BID3. For years between the simulation years in BID3, a linear development for electricity spot prices in other countries is assumed, which is multiplied by a price profile and used in SIFRE. In projects with input from SIFRE, Energinet does not carry out simulations for each individual year up until 2040, as the extra knowledge and insight do not match the resource consumption.

SIMULATION YEARS AND USE IN ENERGINET'S ANALYSES

For an investment analysis, the simulation years relevant to the investment time horizon must be used.

Energinet assumes linear development between the simulated years.

If the investment horizon starts before the first simulation year or continues after the last simulation year, Energinet assumes that the development is constant before the first/after the last simulation year. For example, the result in 2045 will be the same as in 2040. See figure above.

APPENDIX B – CLIMATE YEAR

Different climate years are used in Energinet's market models to take into account the fact that the weather varies from one year to the next. The climate years Energinet uses are based on the historical years 1982-2016 and their weather conditions with regard to variations in wind, sun, precipitation, temperature, etc.

Depending on the climate year used in the analysis, this will affect the results from Energinet's simulation tools BID3 and SIFRE. For example, the energy production and flow in the electricity system will vary depending on the year you are using (e.g. less precipitation than another year etc.).

Data for the climate years used in Energinet's analysis come from the Pan-European Climate Database (PECD) and are available through the cooperation with ENTSO-E.

Analyses in Energinet's simulation tools BID3 and SIFRE make assumptions about climate years.

All 35 available climate years from ENTSO-E have been implemented in the BID3 model. When calculations in BID3 are based on analyses where not all 35 available climate years are used, three climate years have been selected which are representative for a larger group of climate years with different characteristics. These have been selected on the basis of the TYNDP22 cluster analysis and are the climate years 1995, 2008 and 2009.

For projects that make calculations in BID3 for all 35 climate years, a simple arithmetic average of the results across the 35 years is used.

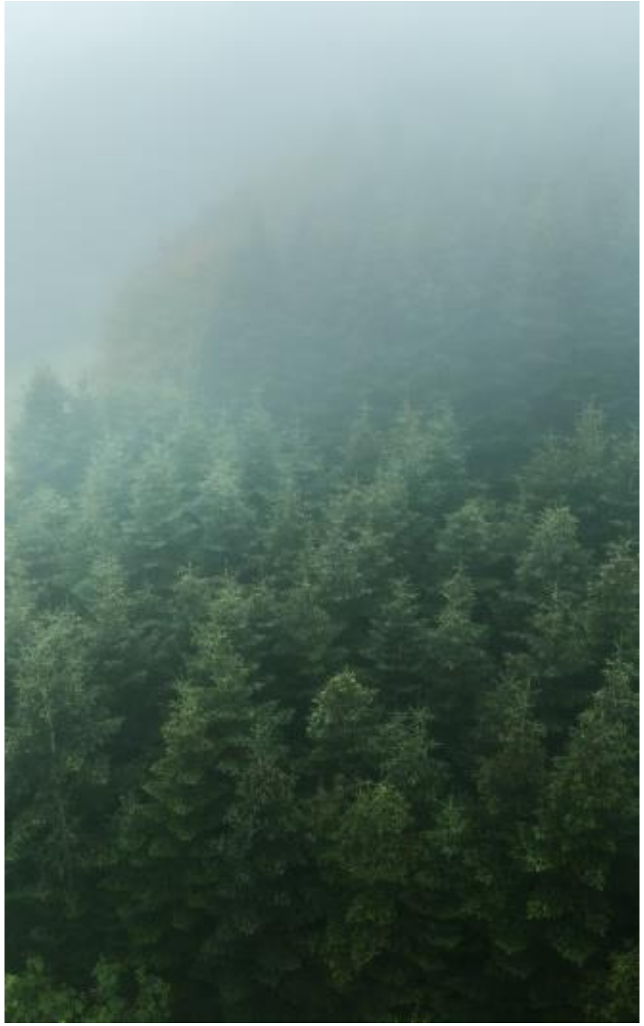
When BID3 uses only a few selected climate years, the results for the individual climate years are weighted based on weights prepared in the TYNDP22 cluster analysis. The weighting of the three currently selected climate years is shown in the table below:

Year	1995	2008	2009
Weighting	23 %	37 %	40 %

In the SIFRE model, three climate years will be used for future calculations (from 2023). In this context, the 2008 climate year is used as a normal year. The year 2008 has been applied as it is currently (in 2022) the most representative of an average Danish climate year. In addition, the years 1990 and 2010 are used as a high-price and low-price years. As the SIFRE model provides input to the PowerFactory power grid model, electricity grid analyses are based on the same climate year.

WHEN ARE WE USING MORE CLIMATE YEARS?

- *35 climate years:* All 35 climate years are typically used in large-scale investment analyses. This could be e.g., in connection with the establishment of a new interconnector.
- *3 climate years*: In investment analyses, where it is considered too time-consuming to use all 35 climate years, three different climate years have been selected instead to represent variations over different climate years.
- *1 climate year:* Typically, analyses are only conducted for a climate year when investment analyses are made for projects in the internal Danish power system. Here, 2008 is used as a normal year.



GLOSSARY

Balance in the electricity system - Electricity generation and consumption must always balance in order to maintain the frequency of approx. 50 Hz in the power system.

Basic analysis - The central analysis, based on the best estimate of the future and the consequences of the alternatives examined. The starting point for sensitivity analyses.

Business case - A description of the reasons for a project and the justification for initiating it, based on a cost-benefit analysis.

Climate year – different years in terms of climate, which are used to simulate a given future year under different historical weather conditions.

CO_2 emission prices - Market price (EU ETS) for CO_2 emissions.

Congestion rent - Benefit from the sale of electricity from a bidding zone with a low price in a price area with higher price.

Consumer surplus – the area between the demand curve and the price in the electricity spot market model.

Dimensioning unit - This principle is used for planning and operating the electricity system. It states that the general functions of the electricity transmission grid must remain intact in the event of an outage on any component in the power system.

Electricity infrastructure - All the components that enable the generation, transmission and distribution of electricity.

Electricity spot market – The market for buying and selling electricity. Also called the day-ahead market.

Emergency start-up – Energinet pays participants to be able to start up the electricity system from a dead grid in the event of a blackout. Also referred to as black start.

ENTSO-E – European association for the cooperation of transmission system operators for electricity.

ERAA - European Resource Adequacy Assessment.

Fast Frequency Reserve (FFR) – Used to ensure frequency stability in situations with low inertia in the electricity system. The reserve is activated automatically at frequency drops below 49.7/49.6/49.5 Hz, and remains active until FCR-D has been fully activated.

Frequency-controlled disturbance reserve (FCR-D) – Frequency Containment Reserves, also known as primary reserves. Used to stabilise the frequency in the emergency operation range below 49.9 Hz.

Frequency-controlled normal operation reserve (FCR-N) – Frequency Containment Reserves, also known as primary reserves. Used to stabilise the frequency in the emergency operation range below 49.9-50.1 Hz.

Frequency restoration (aFRR) – Frequency Restoration Reserve, also known as secondary reserve. Used for frequency restoration.

Grid loss - Electricity lost during transport from A to B through lines, cables and substations.

Manual reserves (mFRR) – Manual Frequency Restoration Reserves, also known as tertiary reserves. Used for balance equalisation. The term covers the capacity, that participants make available by agreement with Energinet.

Net tax factor – Used to convert factor prices (prices excluding indirect taxes, taxes and subsidies) to market prices.

Null alternative – Describes the expected situation without implementation of the measure analysed.

Outage - A period during which part of the electricity grid is not in operation due to breakdowns or maintenance.

Price area – The largest geographical area where market participants can trade electricity without limitations due to internal congestions. Denmark is divided into the DK1 and DK2 price areas. A price area is also called a bidding zone.

Producer surplus – the area between the supply curve and the price in the market equilibrium in the electricity spot market model.

Properties required to maintain power system stability– Services that cannot immediately be provided in the reserve markets for active power and which are necessary to ensure stable operation of the overall electricity system. These services may include short-circuit power, continuous voltage and MVAr regulation, dynamic voltage support during faults and possibly inertia.

Reserves - Purchased electricity capacity made available by market participants in the event of outage of the largest production unit or exchange capacity. General term for the ancillary services in the form of energy activation and capacity that Energinet purchases to maintain a secure and stable operation of the power system.

Resource adequacy – Is also called “Generation adequacy”. The probability that enough electricity is available for consumers on demand.

Socio-economics - Economic analysis of the advantages and disadvantages to society of a given investment project.

Transit compensation – Compensation for grid losses in the electricity grid in a given country caused by increased transit of electricity between neighbouring countries

Transmission grid – the overall supply grid for electricity, natural gas and district heating, which can lead large energy volumes over long distances

TYNDP – Ten-Year Network Development Plan.

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