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

Investment Analysis, April 2025

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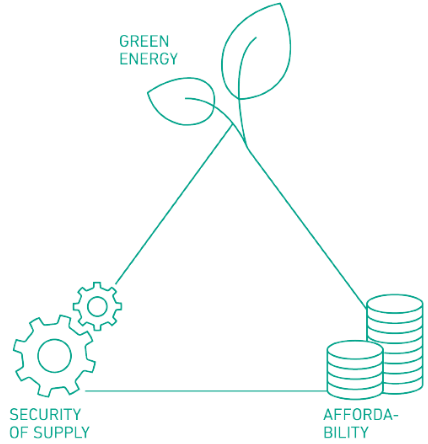
CONTENTS

THE ROLE OF ENERGINET

Energinet's purpose is to own, operate and develop the overall energy infrastructure and manage related tasks, thus contributing to the development of a climate-neutral energy supply. Energinet must account for security of supply, climate and environmental considerations, as well as ensure open and equal access for all users of the transmission networks, and efficiency in its operation.



Legal framework on 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.

SOCIO-ECONOMIC IMPACTS ASSESSMENT

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

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

The socio-economic impact assessment provides decision support for Energinet's investments and forms part of the overall decision-making material 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 needs assessment to support energy system development.

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 with departure in the socio-economic impact assessment.

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

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

GENERAL FRAMEWORK FOR SOCIO-ECONOMIC IMPACT ASSESSMENT OF TRANSMISSION PROJECTS IN ENERGINET

DELIMITATION

Socio-economics and corporate economics

Energinet's transmission projects entail direct costs for Energinet, but they also affect the broader economy in Denmark and potentially in neighbouring countries with adjacent energy systems. Energinet will make the investment decision based on the socio-economic impact in Denmark.

Regional effects

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

Scaling of the analysis

Socio-economic impact assessments are prepared for transmission projects where relevant. The scope of the individual analysis is scaled to match the size and nature of the project.

ALTERNATIVES

Alternatives

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

The socio-economic advantages and disadvantages of each relevant alternative are then identified, quantified and valued relatively to the reference scenario.

Reference scenario

Energinet always evaluates the socio-economic consequences of a given alternative relative to the reference scenario.

In the reference scenario the proposed measure is not initiated. It is, however, not a status quo situation but a description of the expected development in the absence of concrete alternatives. In addition, the reference scenario accounts for Energinet's regulatory obligations to ensure security of supply, connecting third parties etc.

SOCIO-ECONOMIC IMPACT

Quantification

All effects are estimated in market prices and reported in constant prices for a given basic year; typically, the year in which the analysis is carried out. Effects measured in basic prices are converted into market prices using the current standard conversion factor determined by the Danish Ministry of Finance.

The socio-economic value of the project will be evaluated by calculating the net present value of the selected alternatives. That is; all costs and profits are discounted to the time of the decision using the socio-economic discount rate determined by the Ministry of Finance. The time horizon of the analysis is usually determined by the investment’s expected lifespan.

Secondary macroeconomic effects, e.g., changed foreign trade or employment impacts are not included in the analyses in line with recommendations from the Danish Ministry of Finance.

Investment decision

The final investment decision is based on an overall assessment of the advantages and disadvantages of each alternative, including impacts that 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. Potential deviation from the assumptions outlined below, regarding developments in Denmark and internationally, will be explicitly stated in the individual analysis. Deviations might be due to political agreements concluded after 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 developments in the Danish energy system are based on the Danish Energy Agency's "Analysis Assumptions for Energinet"[3]. This outlines a probable development path for the Danish electricity and gas system towards 2050.

Internationally

Assumptions about developments in foreign energy systems are based on scenarios from 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 using one or more climate years (Appendix B).

SIMULATION MODELS[6]

BID3

BID3 (Better Investment Decisions) simulates the electricity spot market (also known as the day-ahead market) and the hydrogen market in the overall European energy system. The model does not account for potential internal grid congestion. It also performs resource adequacy analyses.

SIFRE

SIFRE (Simulation of Flexible and Renewable Energy systems) simulates the hydrogen and electricity spot market and the heating system in Denmark at a more detailed level than BID3. SIFRE maintains the external impact from abroad based on the results from BID3.

PowerFactory

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

SENSITIVITY ANALYSES

A number of assumptions and prerequisites will be associated with significant uncertainty. Thus, various partial sensitivity analyses can be performed to shed light on possible implications of the uncertainty.

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

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

Sensitivity analyses can also be carried out as development scenarios, or Monte Carlo simulations to shed light on interactions between identified uncertainties.

3 Annual edition : Analysis assumptions for Energinet | Danish Energy Agency (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

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ANALYSIS APPROACHES

ANALYSIS APPROACH DEPENDS ON THE TRIGGERING FACTOR

Energinet applies either cost-benefit analysis or a cost-effectiveness analysis to evaluate the socio-economic impact of potential investments depending on the specific problem. The cost-benefit analysis compares the costs and benefits of the investment to evaluate the net socio-economic impact of the investment. The cost-effectiveness analysis seeks to minimize the cost of a specific objective. The need may, among other things, stem from increased security of supply, contingency preparedness, creation of well-functioning competitive markets, or integration of renewable energy, as stated in § 4 of the Danish Act on Energinet (see also page 3).

TRIGGERS FOR INVESTMENT NEED

- Political requirements
- General development of the energy system
- Third-party connections
- Ageing electricity grid

Projects where the net socio-economic benefits are to be examined → COST-BENEFIT ANALYSIS

Projects resulting from statutory requirements etc., or projects whose socio-economic benefits significantly exceed their costs → COST-MINIMISING ANALYSIS

ANALYSIS APPROACH

COST-BENEFIT ANALYSIS

Examples:

- Interconnectors
- Megaprojects
- Often brand-new investments or combined reinvestment and new investment projects (e.g. grid reinforcements with new cables, overhead lines, transformers or synchronous condensers to ensure integration of wind and solar energy, among other things).

COST-MINIMISING ANALYSIS

Examples:

- Political requirements (e.g., connection of offshore wind power (tender parks), projects covered by the cable action plans or aesthetic improvements)
- Statutory investments (e.g. connection of third-parties)
- 1:1 reinvestment projects within the internal grid based on statutory requirements, grid dimensioning criteria, or with benefits that are assessed to significantly exceed their costs (e.g. when supplying larger areas)
- Projects involving compliance with Energinet's rules on facility and personnel safety, as well as grid dimensioning criteria (e.g. upgrading of substations due to increased short-circuit level, or reinvestments/new investments to supply a consumption area).

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TWO APPROACHES TO SOCIO-ECONOMIC IMPACT ASSESSMENT

DOES THE INVESTMENT PROJECT AFFECT THE EXPECTED DEVELOPMENT OF THE ENERGY SYSTEM?

Basically, Energinet must analyse two types of investment projects, which differ as to how far they will affect the development of the energy system. An investment project is marginal when it can be seen as an extension of the existing system, whereas an investment project is systemic when it affects the development of the energy system.

Each project type requires its own socio-economic approach to accurately evaluate the socio-economic impacts. Therefore, Energinet works with two approaches when analysing socio-economic impacts: The marginal approach and the systemic approach.

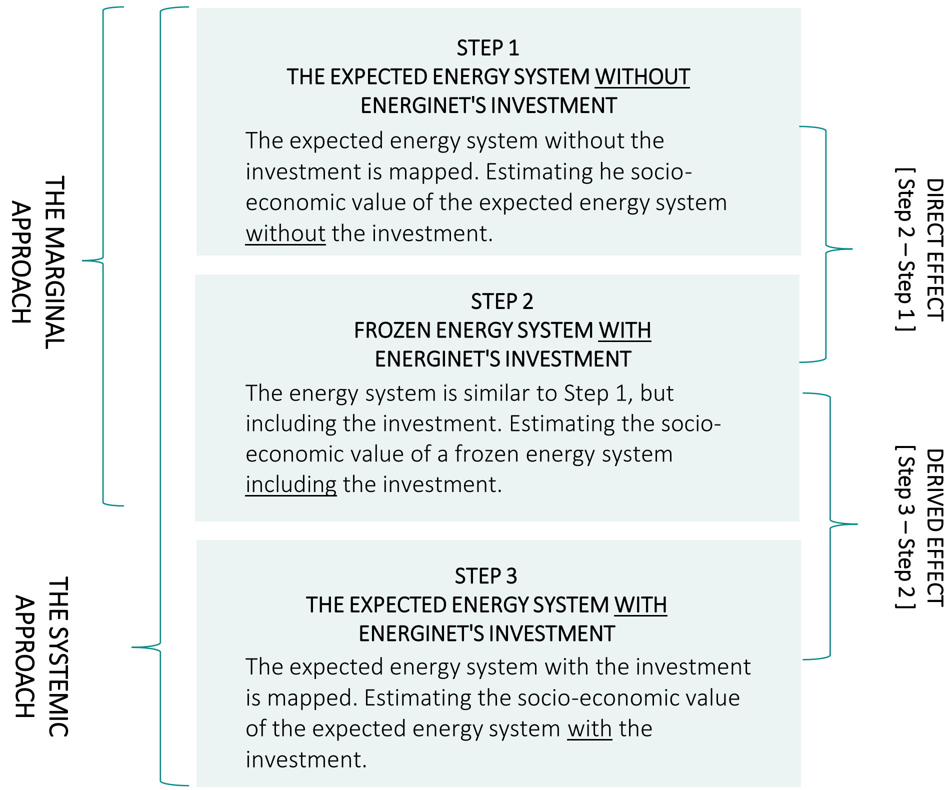
For the vast majority of Energinet's investment projects, it is reasonable to assume that the remaining energy system would be the same with and without the investment. Energinet's investment therefore only affects the operation of units within the energy system. The marginal approach is applied for these investments, and the approach will provide a sufficiently accurate assessment of the socio-economic impact.

However, certain investments are of such nature that the investment in the project in question can be expected to significantly affect future development of the energy system. In such cases, it is no longer reasonable to assume that the energy system remains the same with and without the investment.

In cases where development of the energy system is affected by Energinet's investment, there is a need to extend the marginal approach to account for the derived effects generated from the investment. Within Energinet, this approach is referred to as the systemic approach. If the marginal approach is applied to a systemic project, the socio-economic assessment would be incomplete. Conversely, the systemic approach will provide complete results for the marginal project, but it would require significant additional resources to execute without adding extra value.

To obtain a reliable picture of the socio-economic impacts for systemic investment projects, it is necessary to describe the development in the energy system, both with and without the investment, since the energy system is expected to differ depending on whether the investment in question is made.

These two approaches are described in the figure on the right.



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INVESTMENT UNDER UNCERTAINTY

To a significant extent, appropriate transmission system development depends on the development of energy generation and consumption as well as on the speed and geographical distribution of these.

Planning and establishing electricity transmission is time-consuming. For Energinet to ensure timely capacity and the right spatial distribution of the transmission grid, investments often need to be made before an actual need.

Potential-based needs assessment

Needs uncertainty is an inherent condition for energy infrastructure investments and strategic planning. To account for uncertain investment needs, Energinet considers both immediate and potential needs in the needs assessment and evaluates investments across several potential development paths.

A potential-based needs assessment is always triggered by a immediate investment need (where the triggering factors might be third-party connections, an ageing grids, political requirements, or general developments in the electricity system).

The various development paths are identified based on long-term political objectives and/or Energinet's knowledge of potential electricity generation and consumption facilities and their geographic location. This may be through the work with the long-term development plan or inquiries to Energinet, DSOs, or municipalities.

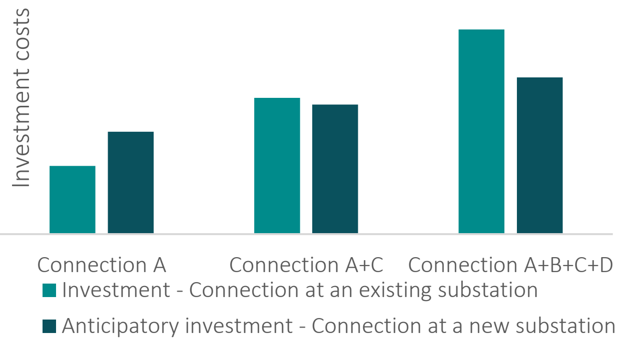
When investments are made under uncertainties, probability distributions cannot be assigned to specific development scenario. Instead, a qualitative assessment of the probability of realisation is made based on the maturity of the potential needs.

Anticipatory investments

An *anticipatory investment* is characterised by the fact that it is based on the potential-based needs assessment.

An example of an anticipatory investment would be establishing a new electricity transmission substation to integrate future renewable energy generation, where there is uncertainty about how many electricity generation facilities will connect and on what timeline.

Depending on the number of renewable energy facilities to be connected, it is possible to optimise the total connection costs and ensure faster integration of renewables.

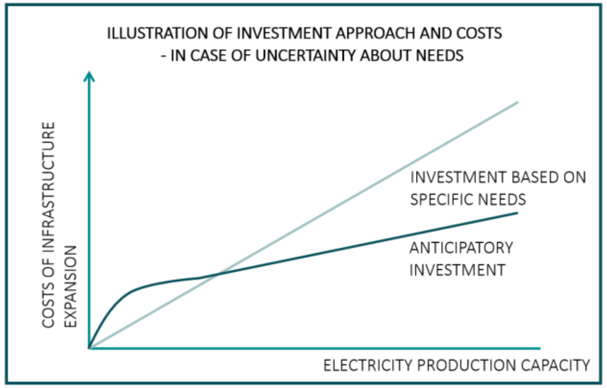


From potential-based needs assessment to anticipatory investment

The potential-based needs assessment can result in an anticipatory investment leveraging the available investment window to accelerate, merge, or expand projects. An anticipatory investment is only recommended for approval if the potential-based needs assessment is socio-economically beneficial and provided that a sufficiently likely need is identified. When evaluating this, the risk of investing too little too late is balanced against the risk of investing too much or too soon.

Potential impacts of anticipatory investments

- ✓ Increased construction costs in the short term.
- ✓ Reduced construction costs in the long term due to economies of scale by preventing later expansion and capacity adjustment.
- ✓ Reduced neighbouring nuisances and environmental impact, as the amount of activity in an area is reduced by carrying out one construction project instead of several.
- ✓ Avoided costs of upward and downward re-dispath of energy generation and consumption due to inadequate grid.
- ✓ Increased speed of connections for future generation and consumption.[7]
- ✓ Avoided costs in connection with outage of existing electricity infrastructure in connection with planned or unplanned construction activities.



7 The triggering project will not necessarily experience faster connection, but future connections will.

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SOCIO-ECONOMIC EFFECTS

PROJECT TYPES

The electricity spot market across Europe is divided into different price ares (or bidding zones) to reflect physical limitations in the electricity transmission 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 divided into two price areas, DK1 (Jutland and Funen) and DK2 (Zealand and the islands).

Impact evaluation is determined by project type

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, identifying 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 main drivers for investments between price areas. Better connectivity between price areas enables stakeholders, for example, in the Danish and neighbouring energy systems, to benefit from any differences in these two markets.

PROJECTS WITHIN A SINGLE 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.

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RISK OF OUTAGES OF KEY COMPONENTS IN THE SYSTEM

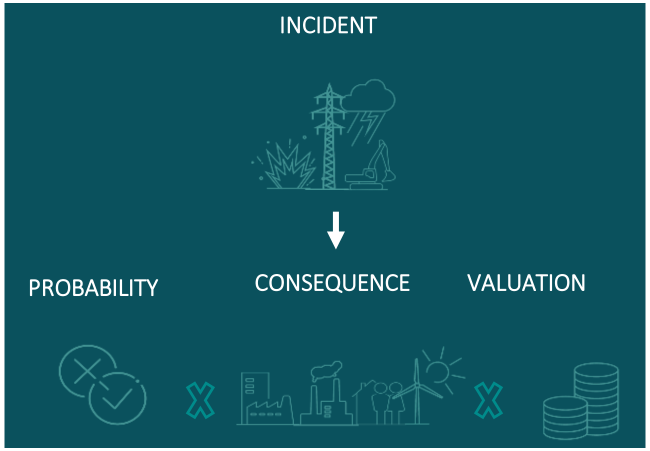
When operating an electricity system, there is a risk of outages of key components. This can lead to socio-economic losses such as limited possibilities of integrating generated electricity, reduced utilisation of interconnectors or challenges in delivering the demanded energy to the consumers.

Method

The socio-economic impacts of the risk of outages of key components can be incorporated into specific investment decisions, when it is possible to:

1) Estimate the probability of the specific incident,
2) Determine the consequence of the specific incident, and
3) Value the identified consequence.

This makes it possible to use known probabilities to make probability-weighted socio-economic assessments.

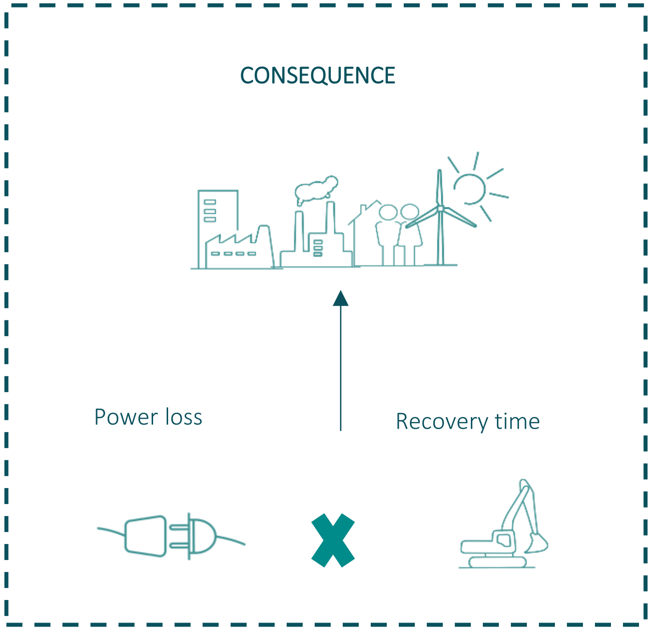


(1) Probability

Probability refers to the likelihood that an incident occurs. Typically, this likelihood is estimated based on historical incidents. If sufficient data are not available, the probability must be determined according to a qualified assessment.

(2) Consequence

Consequence usually describes the duration and scope of the incident.



The consequence of an incident is measured in terms of the total amount of power that cannot be consumed, or delivered, to the end user and is determined from the following inputs:

- Amount of power that cannot be supplied hour by hour due to outages
- Restoration time required until the system returns to normal operation.

The restoration time is determined for the relevant electricity system component(s) associated with the calculated probability. It is important that the restoration time matches the incident rendered probable.

(3) Valuation

Valuation assigns a socio-economic value to the probability-weighted consequence.

The method for valuation depends on the consequence and generally follows the valuation methods described in this document.

Impact assessment when using a risk-based approach

To estimate the benefit of making the investment, the impact of the investment on the probability and/or consequence of the incident must be assessed. A reference scenario and alternatives are prepared, after which the impact is assessed. Different conditions may trigger or influence the impact.

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REINVESTMENTS IN THE INTERNAL DANISH ELECTRICITY TRANSMISSION GRID

To maintain an acceptable level of security of supply and an efficient operation of the electricity system, there is an ongoing need to reinvest in the electricity transmission grid. Like other investments in Energinet, these reinvestments are made based on a socio-economic impact assessments.

Reinvestments in the internal Danish electricity transmission system are special because in many cases avoided re-investment will challenge security of supply and result in either load shedding or limited possibilities of collecting the generation. Many reinvestments are therefore made based on rationale elements on legal requirements, ensuring sufficient redundancy in the operation of the electricity system, or a socio-economic benefit that often significantly outweighs the investment. The same applies when Energinet makes a lifetime extension.

In these cases, a valuation of the benefits is considered redundant, as it the needs must be satisfied. 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.

An assessment is always made of whether the need for the affected assets in the electricity system remains, and whether an alternative solution would be more cost efficient.

Reinvestment in electricity transmission lines and substations

Electricity transmission lines are central parts of the transmission grid, serving as energy highways. The connections ensure that electricity can be transported from electricity producers to electricity consumers.

Energinet's electricity transmission substations ensure that electricity can be transformed up to the electricity transmission grid or down to the electricity consumers. In addition, Energinet's electricity transmission substations allow consumption and generation facilities to connect directly to the electricity grid, serving as electricity hubs where electricity connections converge from across the country.

Socio-economic impact

Supplying consumers

Provided that no reinvestments are made, it may result in a deterioration of security of supply. According to the Danish Consolidated Act on Energinet, open and equal access for all users of the power grid must be ensured. Reducing the security of supply for electricity consumers will imply a high socio-economic cost. Disconnected electricity supply has a high socio-economic cost, and reinvestments in electricity transmission connections that ensure security of supply for electricity consumers will be of great value.

Offtake of generation

If no reinvestment is made, it may also cause challenges in terms of collecting the electricity produced, as other components in the power system may become significantly overloaded. To manage the challenge, there is a need for redispatch of energy generation, which entails socio-economic costs as a less efficient generator must be activated to meet the demand.

External trade

Some internal Danish electricity transmission lines are essential for preserving capacity across Denmark’s cross-border connections. Not reinvesting in them would affect the Danish trading benefits in form of a reduced producer surplus, consumer surplus and/or reduced congestion rents.

Connection of consumption and generation facilities to the transmission grid

If a substation is not reinvested in, the generation and consumption connected to this substation must be connected to another substation. Connection to another substation may result in an increase in the total connection costs for both Energinet and the third-party. Energinet is obliged to designate and determine the point of connection with the lowest total grid connection costs.

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TYPICALLY EXAMINED EFFECTS

Different types of projects address different needs, which means varied effects may be relevant in each individual project. The choice of which effects to be assessed and analysed further is always based on a specific assessment for each project. The table below provides an overview of the typical socio-economic effects that can be examined. Furthermore, the crosses indicate the effects which are most often relevant for projects between price areas and projects within one price area, respectively.

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
	System security		
Costs for ancillary services[8]	Reserves	X	
	Emergency start-up	X	
	System-balancing capabilities	X	
Costs in relation to assets	Construction costs (CAPEX)	X	X
	Operation and maintenance (OPEX)	X	X
	Decommissioning liability (ABEX)	X	X
	Grid loss	X	
	Outage	X	
Other effects	Climate impact	X	X

8 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.

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 assessments 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 (involving adjustments to Danish congestion rent 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 that 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 their importance and impact on the overall analysis.

Examples of such effects may be certain environmental considerations.

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

MARKET EFFECTS

TRADE BENEFITS

A difference in electricity spot prices between price areas is a result of physical constraints on the exchange of electricity between the areas. This is because the two price areas are not connected, or because capacity on an existing interconnector is limited relative to the market's demand for trade capacity.

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

Prices in the two areas will converge, and generation 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.

The trade benefits are typically one of the most important elements when an interconnector is established which directly affects the transmission capacity between two price areas. Projects which do not affect the transmission capacity between price areas will not generate trade benefits. The trade benefits are estimated in Energinet's energy market model BID3.

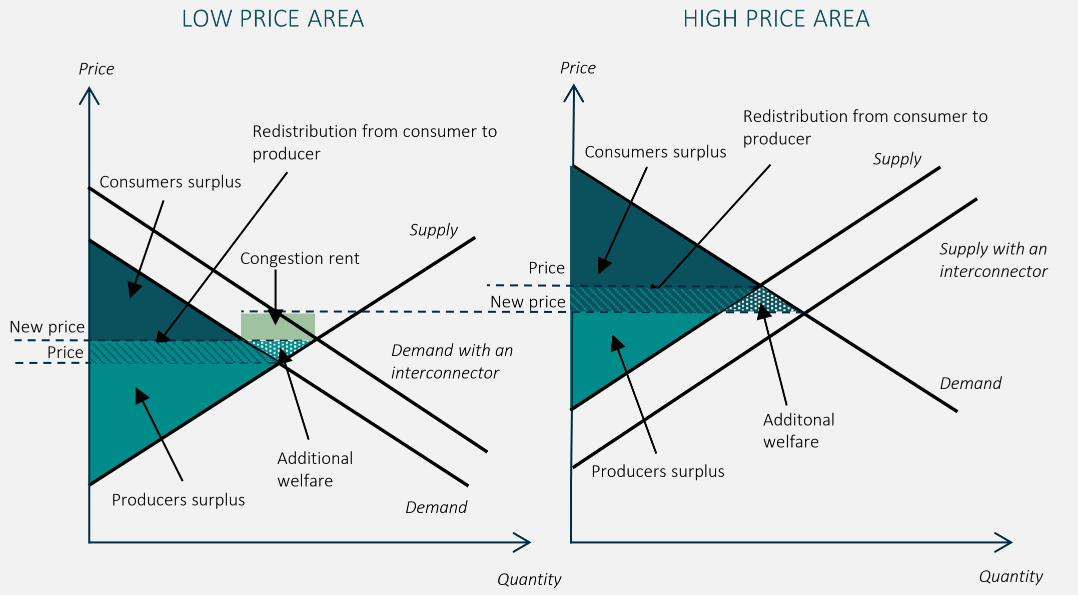
TRADE BENEFITS

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 as *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.

In both the high-price and low-price areas, there will be a redistribution between consumers and producers. Furthermore, there will be a general welfare increase ("gain") as generation and consumption in the overall system across the two price areas can be utilised more efficiently.

Please note that it is the net change in congestion rents for all Danish international connections that is included and not only the congestion rents from the connection 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.

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 rents when the connection is used corresponding to the transported volume multiplied by the price difference between the two price areas. The congestion rents are shared between the high-price and low-price areas.

The congestion rents are 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.

TRADE BENEFITS IN A SECTOR-COUPLED ENERGY SYSTEM

In the long term, the electricity and hydrogen systems are expected to be closely connected. This is because electricity from renewable energy sources is expected to be an important input in the hydrogen generation at PtX plants, and that hydrogen potentially can be used in power stations to produce electricity in the hours with high electricity consumption and when electricity generation from wind and solar power is limited.

The electricity and hydrogen markets will therefore be able to influence one another significantly, which is important to consider when assessing trade benefits in Energinet's analyses.

Joint optimisation of electricity and hydrogen

Today, this is done by endogenously modelling and optimising generation and consumption in both the electricity and hydrogen systems by means of Energinet’s energy market model BID3. Therefore, the various trading effects as depicted and explained on the previous page in both the electricity and hydrogen markets are estimated by making a change in one of the systems. For example, changes in consumer surplus, producer surplus and congestion rents in both the electricity and hydrogen markets are estimated by changing the transmission capacity between two price areas in the electricity system.

At present, effects for PtX plants generating hydrogen through electricity consumption are calculated under the producer surplus in the hydrogen market. Similarly, effects for power stations generating electricity through hydrogen are calculated under the consumer surplus in the hydrogen market.

Please note that the division into price areas in the electricity market typically reflects the actual division into electricity price areas whereas in Energinet's energy market model, each country often constitutes one individual price area in the hydrogen market.

Furthermore, it is worth noting that there is great uncertainty as to how a hydrogen system and hydrogen market will develop in Europe, as an actual hydrogen system is still under construction.

Handling of heating systems

In Denmark, the heating system is also modelled endogenously, like the electricity and hydrogen systems. The heating system and its effects are marginal compared to electricity and hydrogen effects from changes in either the electricity or hydrogen systems. Energinet cannot make changes to the heating system but only to the electricity and hydrogen systems. Effects in the heating system are typically included in the electricity market trade benefits.

Today, heating systems in countries other than Denmark are not modelled endogenously. The coupling between the electricity and heating systems is therefore typically represented with explicit assumptions about this in the energy market modelling. In the long term, it is possible that foreign heating systems will be modelled endogenously. This depends on how foreign data is represented in ENTSO-E, which is where Energinet's assumptions on foreign countries origin from.

CALCULATION OF TRADING PROFITS

The total trading profits can be calculated as follows:

$$\text{Trade benefits}_{\text{Totally}}$$

$$= \text{Trade benefits}_{\text{Electricity}} + \text{Trade benefits}_{\text{Hydrogen}}$$

$$= (\text{CS+PS+FI})_{\text{Electricity}} + (\text{CS+PS+FI})_{\text{Hydrogen}}$$

where CS = consumer surplus, PS = producer surplus and FI = congestion rents.

See detailed description of CS, PS and FI on the previous page.

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TRANSIT COMPENSATION

Some of the electricity 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 that compensates for the 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 net recipient of compensation under this 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 representation 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 net exports in Denmark. Transit as well as net imports and net 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 net 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, transit, net imports and net exports will also change in other countries through the establishment of new interconnectors and thus, distribution between the countries will change as well. This effect is not included in the simplified method, where only the pure Danish gross effect is estimated. Furthermore, the calculation is based on historical compensation, which does not necessarily reflect the development of the future price.

9 Read more about the ITC scheme here

10 In some cases, the null alternative will not be the closest alternative to the current grid. For example, this is the case with reinvestments. In these cases, the calculation is made in relation to the alternative which most closely resembles the present grid, e.g. reinvestment without changing capacity.

HOW TO CALCULATE TRANSIT COMPENSATION?

Transit compensation for year *x* is estimated by:

$$Transit\ compensation\ for\ Year\ x = Historic\ transit\ compensation \cdot \frac{Transit\ formular\ for\ alternative\ a}{Transit\ formular\ for\ reference}$$

where:

$$Transit\ formula\ for\ alternative\ a = \frac{\sum_1^{8760} Transit\ DK(in)^X_{Alt.a}}{\sum_1^{8760}[(Net\ import(in)^X_{Alt.a} > 0) + (Net\ export(in)^X_{Alt.a} > 0)]}$$

$$Transit\ formula\ for\ reference = \frac{\sum_1^{8760} Transit\ DK(in)^Y_{Ref}}{\sum_1^{8760}\left[\left(Net\ import(in)^Y_{Ref} > 0\right) + \left(Net\ export(in)^Y_{Ref} > 0\right)\right]}$$

Here:

- Y is the first simulation year,
- Ref. is reference/null alternative[10],
- Alt. a is alternative a.

Please note that transit, net imports and net exports are determined as the sum of the hours of the year (i, 1-8760).

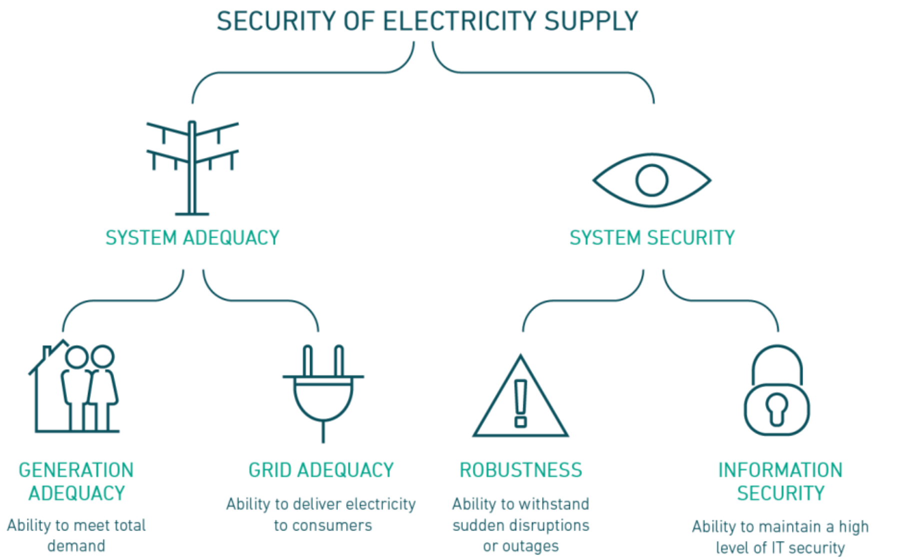
SECURITY OF SUPPLY

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. It also depends on how effectively electricity consumption and electricity generation can be balanced, and on whether the grid can transport the necessary volume of electrical energy and handle possible faults.

If changes are seen in the security of supply when establishing a project, these must be included when evaluating the project.



RESOURCE ADEQUACY

Resource adequacy refers to 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 can lead to higher electricity spot prices.

Resource adequacy analyses will typically be included in impact assessments for projects that affect the transmission capacity between price areas.

GRID ADEQUACY

Grid adequacy describes 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, these 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 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 generation units.

Often, the assessment of robustness will be of a qualitative nature, unless the impact on non-supplied energy or downward and upward redisptach is estimated.

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 will be included if relevant.

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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 the electricity transmission grid that affect the transmission capacity between price areas, such as interconnectors, typically affect resource adequacy. Conversely, investments in the internal electricity transmission system within the two Danish price areas will typically not affect the resource adequacy. Assessments of various market initiatives (e.g. a capacity mechanism) and any impact on resource adequacy resulting from this will follow the same method.

METHOD BEHIND BY CALCULATIONS OF RESOURCE ADEQUACY

Electricity production capacity and electricity consumption

E.g., power plants and interconnectors

Profiles

E.g., for RES-production and electricity consumption

Outages

Random outages of e.g., power plants and interconnectors

Resource adequacy

The likelihood that supply can cover demand

EXPECTED UNSERVED ENERGY (EUE)

When assessing resource adequacy, Energinet uses probability-based modelling, typically the energy market model BID3. This 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 stations and interconnectors. The simulations cover the entire European energy system to account for import and export possibilities in the modelling.

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

One of these 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.

For a more detailed description of Energinet's resource adequacy calculations, please see Energinet's annual report on security of electricity supply.[11]

VALUE OF LOST LOAD (VOLL)

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

VoLL is an economic indicator that expresses the costs of an interrupted electricity supply. VoLL is not one single value but depends on several 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.).

Estimates from VoLL are subject to considerable uncertainty. Energinet's basis for VoLL is DKK 174/kWh in 2020 prices, corresponding to the central estimate from the Danish Energy Agency's VoLL report from 2023[12].

The current VoLL estimate is determined by the Danish Energy Agency by examining what amount different consumer groups are willing to pay to avoid power outages of different durations at different times of day. The central VoLL estimate is a consumption-weighted average based on one hour of unannounced power outage on a weekday (daytime/evening) in the winter months. The central estimate thus reflects when the risk of outage due to lack of resource adequacy is assessed to be the highest. There is a considerable variation between the consumer groups' willingness to pay and when the power outage occurs (time of the year/day). If these matters are known in detail in an analysis, it might be considered to take them into account.

11 See appendix 2 in the latest Security of Electricity Supply Report: https://energinet.dk/om-publikationer/publikationer/redegorelse-for-elforsyningssikkerhed-2023/

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

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GRID ADEQUACY – ASSESSED AS AVOIDED REDISPATCH

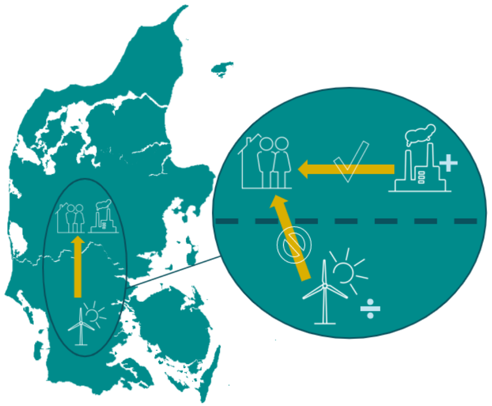
Grid adequacy is defined as the electricity grid's ability to transport electricity from the place of electricity generation to the place of consumption.

When an equilibrium exists between supply and demand in the electricity spot market, it does not factor in physical constraints within each price area (often referred to as internal congestion).

Grid inadequacy arises if such constraints 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 the physics do not match”.

In case of insufficient grid, it will be necessary to adjust the electricity spot market distribution of generation/ consumption in the electricity system. This will be achieved through subsequent redispatch of consumption and generation.

If generation is ramped down on one side of an internal congestion, the same volume must be regulated upward on the other side of the congestion to meet demand.



Here is an illustration of how generation cannot meet consumption due to internal congestion in the Western Danish electricity system. The problem is handled by downward redispatch of renewable energy and upward redispatch of a power station.

Alternatively, there will be a need to downward regulate or disconnect electricity consumers. This means that in this case, it will not be possible to supply the electricity consumers.

Remedy of grid inadequacy

Grid adequacy can be supported by ensuring an increased degree of consistency between physics and the market. This can be achieved through grid expansion or through market adjustments. In some cases, adaptations to the operation of the electricity system may relieve parts of the grid adequacy challenge.

Redispatch of generation means that it is not the most cost-effective generators which supply the market. There would be a socio-economic loss compared to a situation without the need for subsequent redispatch.

Need for redispatch

Grid inadequacy is estimated as the need redispatch on each side of the internal grid constraint.

The change in the need for redispatch is estimated in Energinet's power grid model PowerFactory.

Valuation of avoided redispatch

Changes in grid adequacy are valued as the avoided redispatch cost. This is estimated as the difference in marginal costs for the units regulated upwards and downwards, respectively.

of renewable energy is connected far away from the large consumption centres.

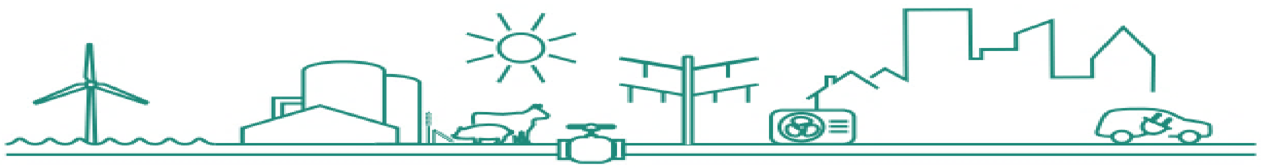
Renewable energy is assumed to have a marginal cost of zero. If generation other than renewable energy is regulated downwards, the marginal generation cost is larger than zero, and an assessment is made in relation to the generation in the area and the price to be applied for redispatch.

The redispatch is based on the units (both consumption and generation) which are available during the hours of overload.

Upward redispatch is valued by estimating a supply curve based on marginal costs for the individual plants participating in the regulating power market based on data from market simulations.

Redispatch internally in Denmark is first prioritised, along with countertrade on interconnectors for which Energinet has countertrade agreements (including the Great Belt).

When the above possibilities for redispatch are exhausted, the remaining interconnectors are used if import capacity is available. In both prioritisation steps, the cheapest way to ensure sufficient redispatch is always chosen. For the volume of energy countertraded via interconnectors, the electricity spot price in the surrounding bidding zones is used for valuation.



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COSTS RELATED TO ANCILLARY SERVICES

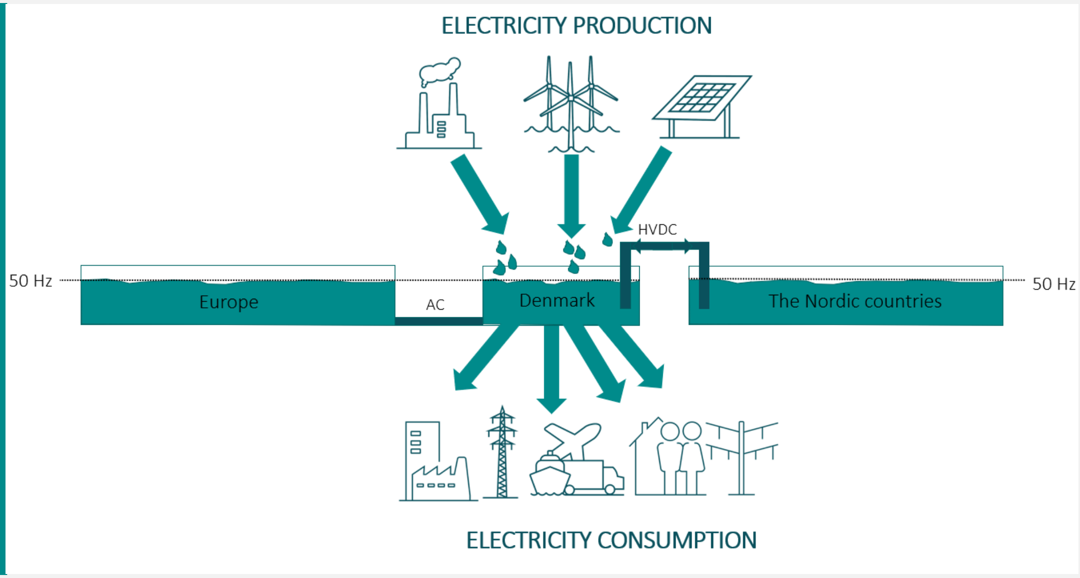
ANCILLARY SERVICES

In the electricity system, consumption and generation must always balance 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 a system operator, Energinet needs a number of special products – called ancillary services – 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. Ancillary services are thus tools used to maintain a high level of security of supply.

Energinet procures ancillary services that are available and 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 consists of reserves, although smaller shares cover properties required to maintain power system stability and additional ancillary services such as black start from a total shutdown. [13]

Major changes to 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.

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



RESERVES

When Energinet integrates additional renewable energy or builds large plants (e.g. interconnectors), the need for reserves to ensure balance in the electricity system may change.

Investments in the electricity transmission system can affect both the need (volume) or the price of the various types of reserves.

EMERGENCY START-UP

After a blackout, the electricity system requires an emergency start-up in order to start up from dead grid (black start). Historically, the service in Denmark is supplied by power plants, where Energinet pays these to be available in case black start of the system is needed.

It is also possible to use interconnectors for emergency start-up. However, a new international connection will typically not have any socio-economic impact, as Energinet already has emergency start-up agreements via existing interconnectors.

PROPERTIES REQUIRED TO MAINTAIN POWER SYSTEM STABILITY

Properties required to maintain power system stability comprise various 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.[14] For all types of reserves except FFR, these are acquired on a capacity market so that the reserves are available if/when needed.

Any of these reserve types may see an increase or decrease in costs as a consequence of a project

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

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

RESERVE CAPACITY REQUIREMENTS

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 (sum of aFFR and mFRR) must be purchased 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 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 continuous development.

Technology-based costs of establishing new reserve plants [15] and historical reserve prices have been used for pricing the changes in the reserve requirements. It will also be possible to use an estimate for the CONE (Cost Of New Entry) value.

15 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.

The market trend in ancillary services is moving towards enabling reserves to be exchanged across price areas and countries as an integrated part of the markets

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 RELATED TO ACTIVATING RESERVES

The activation costs of reserves can be affected in the same way by investments in the electricity transmission grid. Both the need for activation of reserves and the activation price for reserves can be affected. 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 redispatch of generation to avoid potential overloads. This will reduce reserve activation costs, see section *'Grid adequacy – assessed as avoided redispatch'*.

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[16]

16 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 single 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.

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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 impact assessment. The costs are estimated using factor prices and converted into market prices in the socio-economic impact assessment using the current standard conversion factor. [17.]

Construction costs

Energinet estimates budgets for investments in the electricity transmission system primarily based on historical prices in Energinet and 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. See page 32 for a typical presentation of a construction budget.

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 steering target. The dispersion is used to calculate the budget uncertainty allowance corresponding to a standard deviation.

The risk pool is determined based on a risk analysis. A financial estimate is used from the risk analysis, which is calculated based on the product of the probability and economic consequence of the risks identified. The risk pool thus indicates the expected value of the identified risks.

In analyses, where the service life of different investment alternatives varies, reinvestment is introduced as an annuity to harmonise the analysis periods. This is done by adding annuity costs to the alternative that expires first, thereby ensuring comparable conditions across alternatives with differencing lifespans.

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 generation or other expansions of the electricity system may result in a derived need for grid expansions elsewhere in the electricity system 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.

17 See guidelines from The Danish Ministry of Finance - in Danish only: Guidelines on socio-economic impact assessments (fm.dk) ,

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COSTS OF OPERATION, MAINTENANCE AND REESTABLISHMENT

Operation and maintenance costs

Operation and maintenance include the expected ongoing costs of keeping the asset 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 costs related to operation and maintenance.

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

Decommissioning provisions

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 gain estimate. The gain estimate can be calculated by using the expected costs for establishing the planned project.

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HOW ARE THE COSTS APPLIED IN ENERGINET'S ECONOMIC IMPACT ASSESSMENTS?

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

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

Construction budget – 2022-prices	Mio. DKK
Project management	
Plan and environment	
AC-substations	
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 account for 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 interest and Budget uncertainty (steering committee reserve) corresponding to the budget's steering target (excluding construction loan interest) plus risk pool. At the time of analysis, this amount is assessed to be the most likely estimate of the actual construction costs. The budget uncertainty of the budget (steering committee reserve) is thus not expected to be used based on the budgetary method.

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 operation and maintenance costs are presented relative to the null-alternative and thus a delta consideration.

The economic impact and tariff effect is to account for the additions to the cost framework 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 framework.

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 costs	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 in the electricity system is determined by estimating the future electricity spot price:

$$\Delta \text{ Grid loss} \times \text{Elspot price}$$

Changes in grid loss and the future electricity spot price are based on simulations from Energinet's models. The electricity spot price is used as it indicates the price of electricity and thus also of the grid loss. The grid loss change and the electricity spot price (Elspot price) can be estimated on an hourly basis and added up to an annual value.

The transmission loss is typically divided into transmission 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 result in lower grid loss elsewhere in the grid. It is difficult to price the effective power in a meshed grid precisely, but as the orders of magnitude are relatively small compared to other effects, this is left out of the analyses. 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, 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 interconnectors and the Great Belt Power Link will not be included.

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OUTAGE

All parts of the electricity system have outages due to 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 its service life. During outages, profits or costs related to the connection's operating time are not realized.

Internal grid

Outage during 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

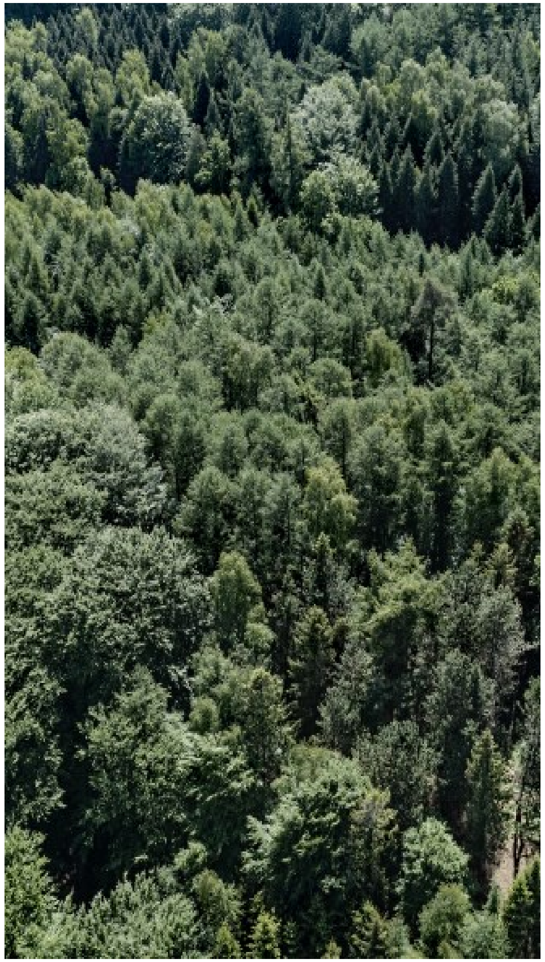
Energinet's electricity spot market simulations assume that interconnectors are available at all times. Therefore, corrections must subsequently be made for outages which will occur during the service life. Only the connection is examined in the case in question and corrections are made for outage time. No corrections are made for outage time on other connections, as the effects of the analysed connection are expected to be underestimated.

Outage time comprises a correction of gains (typically trade benefits and transit compensation) as well as costs (typically grid losses) not realised due to outage time. Outage time thus does not appear directly as a calculated effect in the business case but is implicitly included in the calculation of the items mentioned.

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. [18]

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 an identical outage percentage. So, outage is based on the historical outage time for all Danish HVDC connections. This method has the advantage that the present connections are at different stages of their service lives.

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.



18 Read more in the latest Security of Electricity Supply Report here: https://energinet.dk/Om-publikationer/Publikationer/Redegoerelse-for-elforsyningssikkerhed-2022

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OTHER IMPACTS

CLIMATE IMPACT

According to the instructions of the Danish Ministry of Finance, the CO_2e shadow price is calculated for projects with climate impacts.

CO_2e shadow price indicates the socio-economic cost per reduced tonne of CO_2e. The shadow price makes it possible to compare shadow prices across projects and in relation to the current political objective.

In cases where the shadow price is negative, implementing the measure will generate a socio-economic profit, regardless of the effect on CO_2e. In these cases, the shadow price is not presented.

Method

The CO_2e impact of an alternative is calculated as the direct impact on CO_2e emission from the Danish electricity sector[19].

Calculation of CO_2e shadow price:

$$\frac{\begin{array}{c}\textit{Socio-economic value of climate impact}\\ \textit{calculated in one present dayvalue}\\ \textit{during the project's service life}\end{array}}{\textit{Climate impact calculated in tonnes } CO_2e}$$

The shadow price of a reduction in CO_2e emissions is calculated by summarizing the socio-economic profits and costs (DKK), excluding the profit of CO_2e reduction, and divide the result by the discounted CO_2e reduction.

Internal grid expansions

When the change in CO_2e emissions is calculated in projects for internal investments in the Danish electricity transmission system, it is done under the assumption that the generation, which will be regulated downwards, is 100% renewable energy, and the generation, which is regulated upwards, equals the average generation mix in Denmark.

Calculation of the change in CO_2e emissions

$$\textit{The change in overload of the grid compared to the null-alternative} \times \textit{the average } CO_2e \textit{ emission from Danish electricity consumption.}$$

The average $CO_2e\ emissions\ from\ Danish\ electricity\ consumption$ are based on the Danish Energy Agency's projections.

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

Connections between price areas

In connection with projects between different price areas in the electricity market (e.g. interconnectors), both the direct impact on CO_2e emissions from the Danish electricity sector and the direct impact on CO_2e emissions from the European electricity sector are calculated. However, the Danish impact is used as a basis for calculating present value and shadow price.

The change in CO_2e emissions due to, for example, 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_2e emissions from the electricity sector is embedded in the calculation of trade benefits for interconnectors.

CO_2e emissions from construction activities

The calculation of the social climate impact does not take into account the climate impact of production, establishment and operation of the plants. Energinet has adopted objectives for reducing climate impacts in its own operations and value chain. During implementation, it is ensured that the project contributes to meeting these objectives.

Sensitivity analyses

According to the guidelines of the Danish Ministry of Finance, sensitivity calculations for CO_2e prices must be made for projects with climate impacts.

The CO_2e impact is valued with the current fixed key rate value for CO_2 from the Danish Ministry of Finance. As the CO_2 price is subject to considerable uncertainty, sensitivity calculations will be carried out using alternative CO_2 prices based on Calculation assumptions from the Danish Energy Agency and the Key figures catalogue from the Danish Ministry of Finance. In some projects it may be relevant to calculate sensitivities based on Social Cost of Carbon (SCC) from ENTSO-E.

19 Please note that CO_2 emissions from electricity generation are covered by the European CO_2 emission allowance trading system (EU ETS). Therefore, in theory, the combined European level of CO_2 emissions should not be affected given the functioning of the emissions trading market. It is assumed that real CO_2 reductions will take place on the basis of the estimated impact in the electricity sector. This is based on the assumption that no CO_2 allowances from the electricity sector will not be resold.

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ELEMENTS IN THE SOCIO-ECONOMIC ANALYSIS
SUMMARY

Concept		Description	Quantification	Valuation
Market effects	**Trade benefits**			
	- Producer surplus	Profit for 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	Profit 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	Profit for 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 ability of the electricity grid to transport electricity from the place of electricity generation to the place of consumption. Benefit of avoided upward and downward redispatch as internal grid overload is reduced or by avoiding consumer disconnection.	Expected unserved energy. Model run in PowerFactory.	Marginal price for facilities capable of supplying redispatch. The price which consumers are willing to pay to avoid power outage. Value of Lost Load (VoLL)
	System security	The electricity system's ability to handle sudden system disturbances.	Model run in PowerFactory.	Marginal price for facilities capable of supplying upward redispatch. The price which consumers are willing to pay to avoid power outage. Value of Lost Load (VoLL)

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ELEMENTS IN THE SOCIO-ECONOMIC ANALYSIS

SUMMARY

Concept		Description	Quantification	Valuation
Costs of ancillary services	Reserves	Available power that can be activated if an unforeseen imbalance or grid adequacy problems arise 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 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 for purchasing 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 that are part of the asset design.	Based on experience prices and uncertainty of 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.
	Outages	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 impacts	Climate impact	CO_2 emissions during 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 redispatch and average energy generation in Denmark.	Valued at CO_2 prices from the analysis assumptions.
	Curtailment of renewable energy	Either curtailment or avoided redispatch of renewable energy, along with weighted electricity spot prices. May be supplemented by the potential for additional renewable energy.	Interconnectors between price areas: Change in the curtailment of renewable energy as well as weighted spot prices. Model run in BID3 Internal grid: Avoided redispatch of renewable energy. Model run in PowerFactory.	It is not valued directly as an independent measure, but its value is partly captured indirectly in the items “trade benefits” and “increased transmission capacity”.

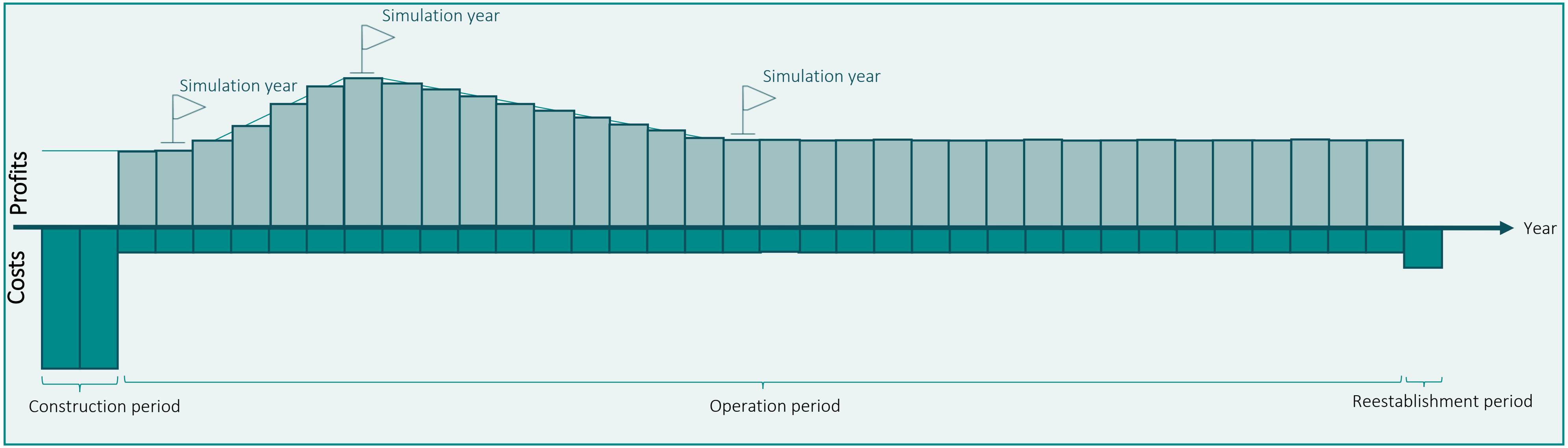
APPENDICES

APPENDIX A – COMPARISON OF EFFECTS

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

All effects, both profits 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 profits 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 profit at the end of the service life will be valued less than a similar profit 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 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, Energinet's international data for long-term analyses centres on the years 2030, 2040 and 2050, which can be simulated.

In Energinet's energy system model SIFRE, which simulates the Danish energy system only, until 2050 each year 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 2050, 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 a 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 2055 will be the same as in 2050. See figure above.

APPENDIX B – CLIMATE YEARS

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 that Energinet uses are based on the historical years 1982-2016 and their weather conditions regarding 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 generation 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 is 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 of 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.

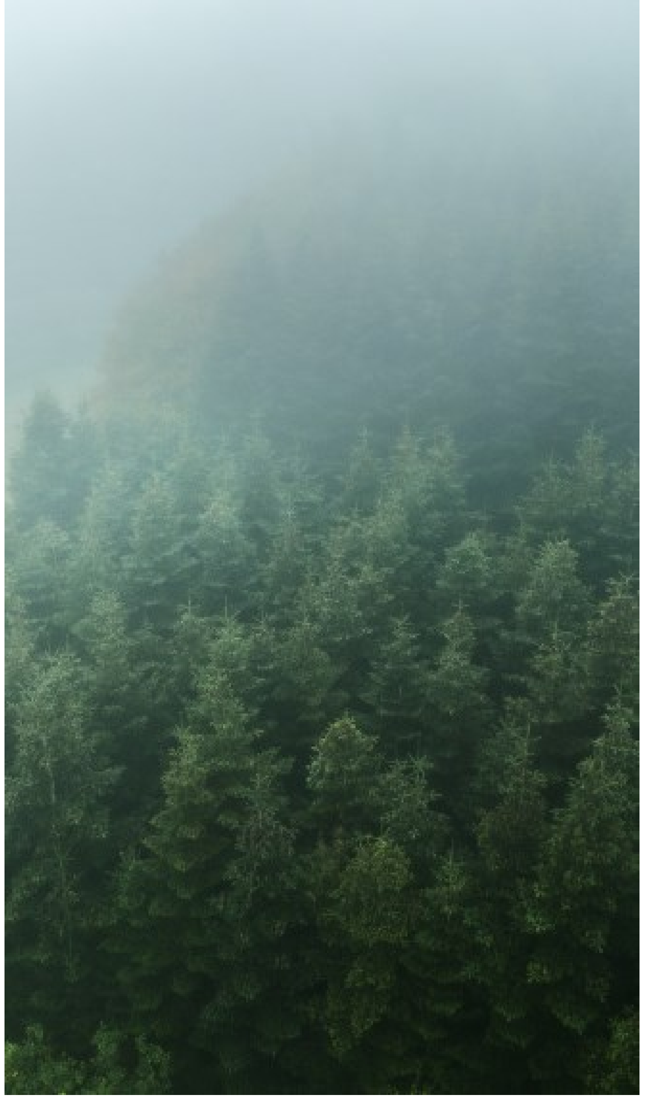
When BID3 uses only a few selected climate years, the results for the individual climate years are weighted based on weights prepared in the TYNDP22 cluster analysis. The weighting of the three currently selected climate years is shown in the table below:

Year	1995	2008	2009
Weighting	23 %	37 %	40 %

In the SIFRE model, three climate years are used for calculations. In this context, the 2008 climate year is used as a normal year. The year 2008 has been applied as it is currently regarded as the most representative of an average Danish climate year. In addition, the years 1995 and 2009 are used as high-price and low-price years, respectively. As the SIFRE model provides input to the power grid model PowerFactory, electricity grid analyses are based on the same climate year.

WHEN DO WE USE MULTIPLE CLIMATE YEARS?

- *35 climate years:* All 35 climate years have previously been used in large investment analyses for e.g. interconnectors or energy islands. Due to increased calculation time, investment analyses based on 35 climate years will be limited in future. However, 35 climate years are used in Energinet's resource adequacy analyses (See page 20).
- *Three climate years:* In investment analyses for e.g. interconnectors and energy islands, three different climate years will typically be used to represent the variation in climate years.
- *One climate year:* Investment analyses for projects in the internal Danish electricity system are typically only conducted for one climate year. In this context, 2008 is used as a normal year.



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Appendix C – Price projection

All profits and costs are reported in fixed market prices in a given base year. If any costs or profits in the project are calculated in a different year than the base year, the Ministry of Finance recommends that these be projected to the base year in question. If values are calculated in factor prices (i.e. prices excluding taxes and duties), the net tax factor is used to convert to market prices (i.e. prices inclusive of taxes and duties) as prescribed by the Ministry of Finance.

PROJECTION OF PRICE ESTIMATES FOR PLANTS AND COMPONENTS

Based on the recommendation of the Danish Ministry of Finance, Energinet uses the net price index to project historical costs not calculated for the base year.

The net price index illustrates consumer price developments exempt from changes in taxes and subsidies. Thus, the general price development in factor prices is reflected in the actual cost level used in business cases.

The Ministry of Finance also recommends using another price index if project-specific costs and profits differ from the nominal price development like the net price index.

PROJECTION OF VOLL

Where consumers' willingness to pay for the cost/profit considered depends on the evolution of their real income, the calculation price of that cost/profit should be adjusted over the considered project period. Therefore, real growth in GNP per capita is used as a starting point when projecting VoLL to the base year of the analysis.

VoLL is a shadow price at which consumers' willingness to pay is not assessed to follow the general development in consumption, but rather the general income level.

It is assumed that in general, VoLL estimates are determined in market prices.

LINK TO PRICE INDICES

The starting point is the price indices from the Danish Ministry of Transport's spreadsheet model for socio-economic analysis for the transport area: TERESA and Transport Economic Unit Prices (dtu.dk).

More specifically, the net price index and the development of GNP per capita are contained in the Excel file "Transport Economic Unit Prices 2.0" under the tab "Economic conditions".

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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 - Profit from the sale of electricity from a bidding zone with a low price to 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 - The principle 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.

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 congestion. 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 generation 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 – 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.

Standard conversion factor **-** Used to convert factor prices (prices excluding indirect taxes, taxes and subsidies) to market prices.

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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