ENERGINET

SYSTEM PERSPECTIVE 2035

Long-term perspectives for efficient use of renewable energy in the Danish energy system

March 2018

CONTENTS

SYSTEM PERSPECTIVE 2035

System Perspective 2035 is an analysis which focuses on the long-term opportunities and challenges related to the transition of the Danish energy systems. The analysis is based on European energy scenarios due to the highly cross-border and international nature of the Danish energy systems.

The System Perspective 2035 report is made up of several parts:

The present document is the **main report**, which affords a relatively brief insight into the approach, main findings and perspectives of the analysis.

The **background report** begins with a summary that presents a comprehensive view of the scope, findings and messages of the analysis as a whole. The rest of the background report delves deeper into the analysis and its findings and is primarily aimed at energy analysis professionals.

In addition, there is an **appendix** in English to the above reports on the specific modelling used in the analysis as well as **data appendices**.

All material used to compile System Perspective 2035 is available at Energinet's website:

www.en.energinet.dk/systemperspective2035

LONG-TERM ANALYSES ARE KEY TO ENERGINET'S PLANNING

Energinet regularly analyses scenarios predicting how the transition to renewable energy in the Danish energy systems might develop. These long-term, holistic analyses across the entire Danish energy system are key to ensuring reliable and efficient design and operation of the electricity and gas transmission grids in Denmark.

In Denmark, we have a proven track record of integrating different energy systems, such as electricity, gas and heat, in order to achieve more efficient energy systems overall. Denmark has thus successfully built efficient CHP plants that use surplus heat from electricity generation to supply the district heating network.

Going forward, the most efficient and green energy systems are obtained by integrating the systems in new ways to efficiently utilise the growing volume of renewable energy entering the Danish – and European – energy systems.

Investments in energy systems, production plants and infrastructure are often long-term, large-scale investments. It is therefore important to carry out long-term, holistic analyses that can help to identify needs and solutions across energy sectors – known as 'sector coupling' – in order to minimise the risk of making bad investments in long-term energy infrastructure.

Energinet's long-term analyses may thus be regarded as a significant supplement and input to Energinet's more detailed and sector-specific network development plans for electricity and gas infrastructure, which are prepared at the national and regional level. The analyses are also used in Energinet's development of market design and operating methods devised to underpin efficient and high security of supply in the long term.

As a public enterprise, Energinet wants to share its long-term, holistic analyses with a broad audience, partly to contribute to a long-term perspective for industry players and partly to provide academic input for a discussion of the opportunities and challenges related to the transformation of the energy sector going forward. The open academic debate will provide valuable feedback for the further development and qualification of Energinet's analyses and planning.

Platform for future long-term analyses

System Perspective 2035 is based on extensive scenarios and modelling of the entire European energy system. In the course of 2018 and 2019, this scenario and modelling complex is expected to form the basis for detailed analyses that further explore issues from System Perspective 2035, and for new long-term analyses that examine the possibilities of further market coupling of different energy sectors and its derived effects on the future energy infrastructure.

Long-term scenario analyses across energy systems

National, Nordic and European Network Development Plans for Electricity Transmission

National and European Network Development Plans for Gas Transmission

WIND AND SOLAR POWER CAN BE USED THROUGHOUT THE ENERGY SYSTEM

Over the coming decades, the European scenarios on which the analysis is based predict a massive expansion of wind and solar power across Europe – not least in Denmark's electrically connected neighbouring countries around the North Sea. An effective transition with large amounts of wind and solar power will, in addition to a strong electricity integration between countries, require flexible conversion to other in-demand energy products.

The boxes on the right show the overall measures available for the integration of large amounts of wind and solar-generated electricity in the North Sea region and hence also Denmark.

The first general category is electricity integration where end consumption is still electricity. Here, power can either be directed to the point in the grid with the strongest demand at the time of generation, or electricity consumption can be staggered using different types of power-to-power storage.

The second category involves the conversion of affordable and green electricity to other requested energy services such as heat and transport, or energy products such as fuel. These measures are often collectively referred to as electrification.

System Perspective 2035 has a particular focus on items 3 to 6, i.e. electricity storage and the conversion of electricity to other energy services. Specifically, the analysis examines the possibilities and potential of Power-to-Gas/Power-to-X (PtG/PtX) in Denmark and the derived effects and possibilities for system operation and energy infrastructure. PtG/PtX has previously only been included in system analyses of an integrated Danish energy system at a more general level. Items 1 and 2, which deal with grid expansion, will, as described on the previous page, be discussed in detail in various network development plans.

Electricity integration – electricity as end consumption

Electricity integration over distances: Grid expansion

1. **Electricity integration with Nordic hydroelectric power**
   Strong electricity integration with Nordic hydroelectric power plants are an effective and important measure. The hydroelectric power reservoirs can function as 'green batteries' for the fluctuating electricity generation. However, in case of a significant expansion of wind and solar power in the North Sea region, this measure cannot stand alone.

2. **Electricity integration between North-Western Europe and Eastern Europe**
   The expansion of solar and wind power in large parts of Eastern Europe towards 2040 is expected to be more moderate than in Western Europe. In the medium term, better grid connections to these regions may be an option. In the long term, however, expansion in these countries is also expected to include cheap solar and wind power.

Electricity integration over time: Power-to-power storage

3. **Power storage (e.g. battery storages, compressed air energy storages and pumped storage power)**
   Power storage is relatively expensive per unit of energy, with the exception of pumped storage power which is geographically limited. However, power storage may be financially viable as short-term storage for handling hourly and daily variations which may also help to significantly increase the grid utilisation rate.

Conversion of electricity for other purposes – electrification

4. **Electricity to heat and thermal storages**
   Today, it often makes financial sense to convert electricity to heat/cooling using heat pumps. Thermal energy storage, for example in district heating, provides a very flexible electricity consumption, and energy can be profitably stored for long periods of time.

5. **Electricity for transport**
   Electrical engines are emission-free and far more efficient than internal combustion engines. Electricity for transport may find widespread use not only in light transport, but also in heavy transport, ferry services and perhaps aviation. Electricity for transport will often require a mobile storage unit such as a battery. Smart charging may enable flexible use of electricity with a time offset of up to several hours.

6. **Electricity for high-value products (electrolysis/PtG/PtX)**
   In the medium term, it may be a very powerful tool with the establishment of Power-to-Gas (PtG) where electrolysis is used to convert electricity into gas which can be used immediately, released into the natural gas system or converted into liquid fuels, ammonia, plastics etc. (PtX). Such energy plants can be combined with a 'working storage' of hydrogen in large caverns and turbines that allow them to generate electricity at peak loads, ensuring a very high degree of flexibility.

METHOD: EUROPEAN ENERGY SCENARIOS SET THE SCENE

What is the expected value of different energy technologies and system solutions in Denmark in 15-20 years? Due to the cross-border energy markets and energy infrastructure, this should be analysed on the basis of scenarios for European energy development.

Electricity prices in Denmark are determined in our electrically connected neighbouring countries

With regard to electricity, gas and fuels, Denmark is a small, open energy market where prices are very much determined by the large electricity markets in our neighbouring countries, the European gas market and the global fuel market.

In Denmark, even the electricity price, which varies from hour to hour and is typically determined locally, is in the case of Denmark often settled by neighbouring countries, Due to strong interconnections to other countries, for approx. 90% of the hours in a year Denmark is price taker of the electricity spot price in at least one of our large neighbouring electricity markets (Germany, Norway, Sweden).

The three European TYNDP 2018 scenarios

Any analyses of the future Danish energy system should therefore be based on the development in the entire region around Denmark. The starting point for the analysis is three new and comprehensive European energy scenarios for 2030 and 2040 called TYNDP 2018 (Ten Year Network Development Plan), which are the result of extensive cooperation under the European Network of Transmission System Operators for Electricity (ENTSO-E) and the European Network of Transmission System Operators for Gas (ENTSOG).

The TYNDP 2018 scenarios are one of the best platforms for a comprehensive European energy scenario available to us today and the scenarios are assessed to present a likely outcome for the overall development of the European energy system.

The content of the scenarios are described in more detail on the next page, but the main scenarios are as follows:

Global Climate Action (GCA): An ambitious green scenario with strong cooperation across Europe, both in terms of infrastructure and regulation.

Distributed Generation (DG): Also an ambitious green scenario; however, the transition is chiefly facilitated by national, local and individual solutions.

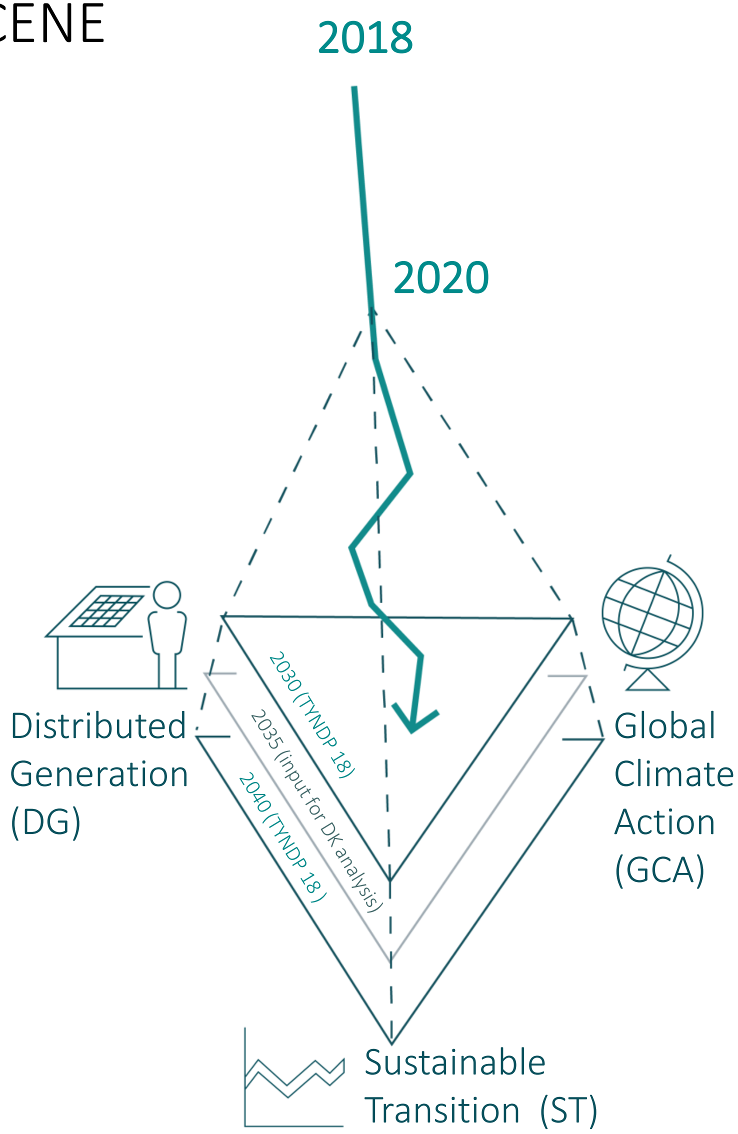
Sustainable Transition (ST): The least ambitious scenario, but still with much higher levels of wind and solar power than is the case today due to continuously declining prices.

From European scenarios to modelling of Denmark in 2035

The European scenarios in 2030 and 2040 result in three European scenarios for 2035. This makes it possible to include the development path expected after 2030, while staying within a foreseeable time frame.

With the European 2035 scenarios, electricity prices, electricity generation, electricity consumption and hourly flows are calculated for all price areas under a European electricity system model. This provides an hourly based electricity price boundary around Denmark which serves as input for a more detailed Danish energy system model.

Using input from the hourly based electricity price line to neighbouring countries, the Danish energy system model can give an indication of how a socio-economic Danish energy system might look in the year under analysis. Such modelling results should, as always, be examined thoroughly and interpreted with caution, as the results are largely determined by the inputs, opportunities and limitations of the model.



MUCH MORE WIND AND SOLAR POWER IN ALL THREE EUROPEAN SCENARIOS

The three TYNDP 2018 scenarios present a likely outcome for the overall development of the European energy systems. There are considerable differences between fuel and CO_2 prices – and whether the transition is coordinated locally or internationally. However, a common factor shared by all scenarios is the expectation of increasingly fluctuating electricity generation from wind and solar resources in Europe.

Contents of the three European TYNDP 2018 scenarios

<u>GCA scenario (Global Climate Action)</u>
- On track with EU climate targets
- Strong international scenario, green cooperation and regulation
- Moderate oil price and very high CO_2 price (IEA 450 PPM)
- Approx. 50% electricity from wind and solar sources in Europe by 2040

<u>DG scenario (Distributed Generation)</u>
- On track with EU climate targets
- Widespread local prosumer solutions (solar resources/batteries)
- High oil price (IEA New Policy) and high CO_2 price
- Approx. 50% electricity from wind and solar sources in Europe by 2040

<u>ST scenario (Sustainable Transition)</u>
- Almost on track with EU climate targets
- Low oil and natural gas prices
- Moderate CO_2 price (IEA Low Oil price scenario)

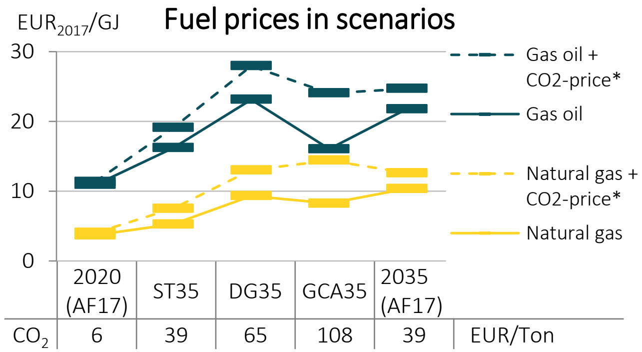
Higher levels of wind and solar power generation in Europe in all scenarios

As appears from the figure at the top right, all three scenarios have much higher levels of electricity generation from wind and solar resources than is the case today. This is essentially because the greenest and cheapest energy is expected to be generated by wind and solar resources – in so far as it can be effectively integrated and utilised.

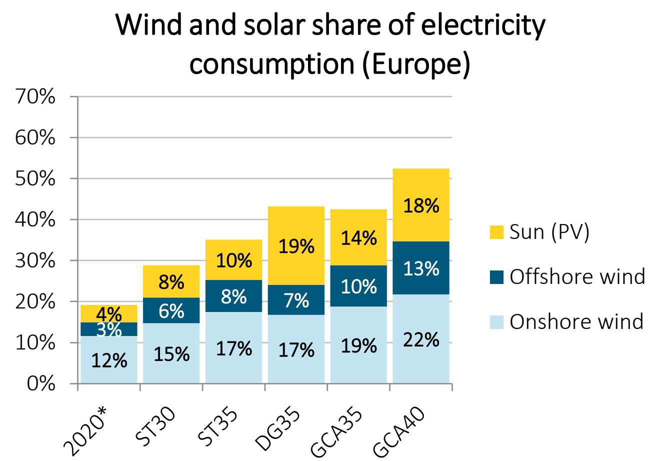
Electricity consumption between the scenarios is almost constant. The significant electrification with electricity for heat and transport expected in all three scenarios is offset by the efficiency of classic electricity consumption. The TYNDP 2018 scenarios do not include electrolysis forecasts, however.

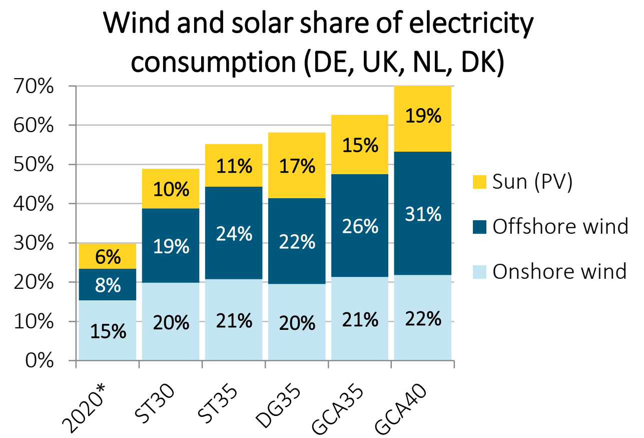
Development in the North Sea region around Denmark

As appears from the figure below, the share of electricity from wind and solar resources is considerably higher in the North Sea countries with which Denmark is expected to be electrically connected by 2030. This is especially true in the internationally co-ordinated GCA scenario where the North Sea's plentiful offshore wind resources are expected to be harnessed and distributed to Western and Central European consumption centres.



'Gas oil + CO_2 cost' and 'Natural gas + CO_2 cost' indicate the minimum price for liquid biofuel and biomethane, as this is the market price for the corresponding fossil fuel. The prices are used as the selling price for RE fuels in the analysis' investment model.





** All expectations for 2020 indicated in the tables and figures of this report are derived from Energinet's Analysis Assumptions 2017* (AA17)

BEYOND 2030 – MORE HOURS OF LOW AND HIGH ELECTRICITY PRICES

The scenarios show that a higher share of power generated by wind and solar resources in the region around Denmark is likely to lead to greater variations in electricity prices compared to today. In the scenarios with the highest levels of wind and solar, the price of electricity in Denmark is relatively low for many hours. In the long term, this could present a challenge in terms of securing funding for the further expansion of wind and solar resources, but also an opportunity for further electrification.

More hours with low electricity prices in Denmark

The figure at the top right shows the duration curves for the electricity price in Western Denmark (DK1) in the different scenarios. The duration curves show the electricity price for the 8,760 hours of the year, ranked from the highest to the lowest price. The general picture is that the higher the share of wind and solar power in the scenarios, the higher the number of hours with very low electricity prices but also with high electricity prices. The price level for the flat part of the duration curve is primarily determined by the scenario's fuel and CO_2 prices.

In the ambitious 2040 GCA scenario (light green), the electricity price drops significantly, with very low electricity prices for more than half of the hours of the year. In this scenario, the share of wind and solar power in electricity consumption in the North Sea region is approx. 70% compared to around 20% today. The scenario illustrates the risk of a significant price decline.

Varying prices make flexible electricity consumption attractive

The lower electricity prices compared to other energy prices, the more attractive electrification becomes. Particularly, flexible electricity consumption becomes interesting with more varying electricity prices. Heat pumps and PtG will typically have a flexible consumption pattern with many operating hours when electricity prices are low to medium high. Conversely, they will shut down when electricity prices are high.

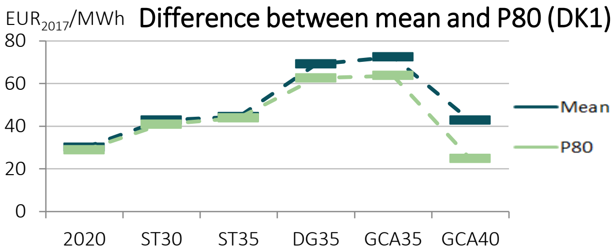
P80 mean price as a key figure

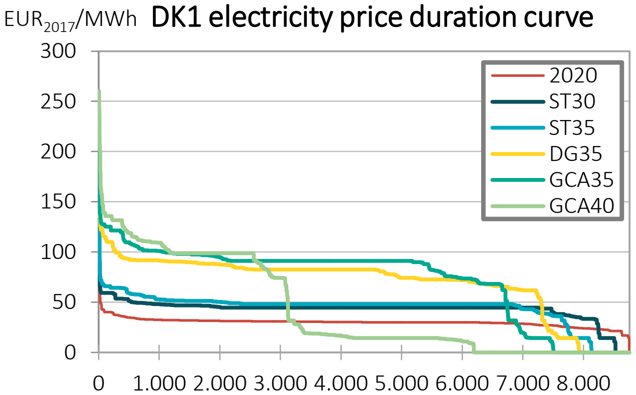
In order to easily compare the attractiveness of the electricity price for flexible electricity consumption, the P80 mean price can be specified. This is the mean price for the 80% cheapest hours over a period of one year. The P80 mean price thus better reflects the electricity price for flexible electricity consumption with relatively many operation hours. The figure below shows the difference between P80 and the normal mean price in DK1. Only DK1 is shown here, as the difference between DK1 (West) and DK2 (East) is negligible in all scenarios.

Heat pumps and PtG can provide widespread electrification

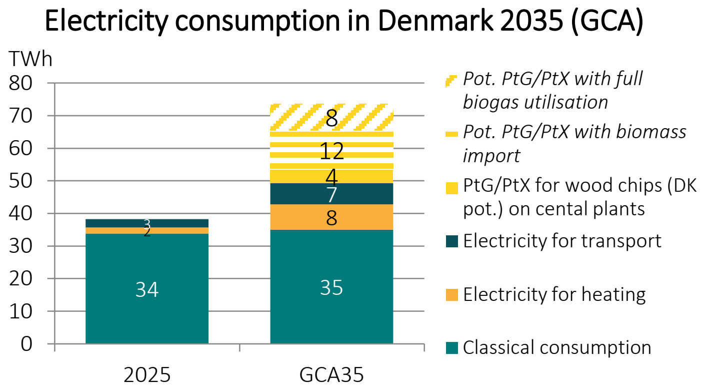
The figure at the bottom right illustrates the new electricity consumption for heat (heat pumps), transport and PtG (electrolysis) at a modelled socio-economic capacity investment in Denmark in the GCA 2035 scenario. The first column in the figure shows Energinet's expectations for 2025 for comparison.

In GCA35, there is a large and flexible electricity consumption for heat (heat pumps) and transport. However, a considerable electricity consumption for PtG/PtX (approx. 4 TWh) is also profitable in GCA35. Potentially, profitability can be sustained up to 12 TWh PtG/PtX provided that biomass is imported. Full utilisation of the Danish biogas potential of PtG does not seem feasible on pure market terms unless there is a willingness to pay for green gas on top of the energy and CO_2 prices.





Note: The duration curves do not fall below zero, as negative prices are not used in the model. Duration curves for scenarios many years into the future should be interpreted with caution. The modelling assumes optimum delivery patterns and regulation and, consequently, the number of hours with very high prices and zero prices is probably underestimated.



Note: Electricity consumption for 2025 is derived from Energinet's Analysis Assumptions 2017. The electricity consumption of large data centres is not included, neither in 2025 nor in GCA35. This is primarily because focus is on the conversion of electricity for other energy purposes.

DANISH ELECTRICITY PRICES REMAIN COMPETITIVE IN THE LONG TERM

For some years now, Denmark has had competitive electricity prices. This, combined with a high level of security of supply and a large share of RE in electricity consumption, is the main reason for the budding interest in Denmark from large data centres. The scenarios also show that Denmark's electricity prices will remain competitive in the long term. In addition, surplus heat from electricity-intensive processes in Denmark can often be utilised in the district heating network.

Denmark has stable, competitive electricity prices

The map at the top shows the electricity price level in various European countries. This map of the GCA scenario in 2035 shows the P80 mean price which is more relevant in relation to new flexible energy consumption, but the overall picture of the differences in electricity price levels is repeated across the scenarios and at the normal mean price as well.

Generally, as expected, there is only a small difference in the mean price between Denmark and its neighbouring countries in the different scenarios. Denmark has strong connections to the large North-Western European electricity markets. Its central location means that Denmark can be expected to have a stable, competitive electricity price – even if the electricity price in some periods is very high or very low in one of Denmark's neighbouring electricity price areas due to, for example, weather conditions, outages or maintenance.

As can be seen on the map, the overall trend is that electricity prices are lowest in Western Europe, where the share of electricity from wind and solar power is greatest.

Value of surplus heat for district heating provides added benefit

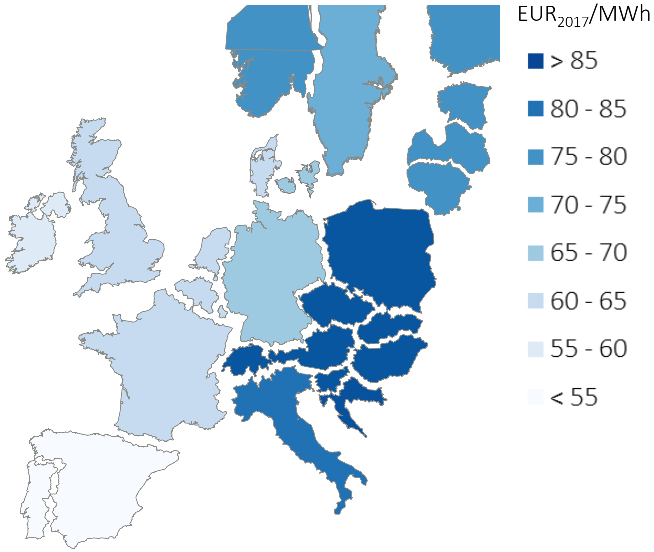
Denmark is one of few countries in Western Europe that has a well-developed district heating network which enables efficient utilisation of surplus heat from different energy intensive processes. Historically, this has given Danish CHP plants an advantage as they have been able to utilise the surplus heat from thermal electricity generation. With an ever greater share of fossil-free electricity generation from wind and solar resources, surplus heat from electricity-intensive processes, as large data centres and PtG/PtX, can be an effective heat source to be utilised in district heating.

Flexibel electricity consumption can help integrate wind and sun

With regard to long-term planning of the electricity infrastructure, it is important to continuously assess both the amount and the degree of flexibility of potential electricity-intensive companies/processes which may be introduced in Denmark. If the new electricity-intensive consumption is fully flexible like, for example, electrolysis, it may be able to exploit periods with low electricity prices and thereby contribute to the integration of wind and solar power.

At the same time, a fully flexible electricity consumption that never takes place in periods with high electricity prices might be able to increase the degree of utilisation of the electricity infrastructure and thereby potentially reduce the need for grid expansion.

P80 mean prices in Europe – GCA35



POTENTIAL OF ENERGY PLANTS AND PTG/PTX IN DENMARK

System Perspective 2035 goes into greater depth than previous analyses in its examination of the potential and the system-related perspectives of integrating PtG/PtX into the Danish energy system. The analysis suggests that Denmark can become an attractive country for refining biomass and electricity from wind and solar resources via PtG/PtX to produce high-value RE products which are traditionally based on fossil oil and gas.

Electrolysis can be used to refine RE electricity from wind and solar resources to produce high-value products which are traditionally based on fossil gas and oil (fuel, artificial fertilisers, plastics etc.). In the analysis' investment model, these RE products have a settlement price corresponding to the price of fossil fuel oil + CO_2 in the scenarios.

International market for RE-based high-value products

However, there is a growing international demand for RE-based alternatives to fossil-based products. Consequently, the market price of, for example, RE fuel, RE plastics and RE methanol is typically significantly higher than the price of the corresponding fossil fuel. The willingness to pay more for RE alternatives means that RE-based alternatives for the international market will have to be produced somewhere – also before the PtG/PtX technology can compete directly with fossil energy products.

Competitive opportunities for PtG/PtX in Denmark

The analysis indicates that Denmark has a number of competitive opportunities with respect to such an initial PtX production, specifically:

- Competitive electricity prices for electrolysis.
- Surplus heat from PtG/PtX processes can be used in the district heating network.

To this should be added a number of non-quantified advantages, which are also expected to be of significance.

- Denmark has a very large share of renewable energy in the electricity system, a strong green brand and brand credibility which have played a key role in the large data centres' choice of Denmark.
- Denmark has a well-developed gas system, with a growing share of RE gas. The gas sector also has the expertise necessary to handle other gases (such as hydrogen and CO_2), and much of the Danish geology is highly suitable for possible underground buffer stocks of new types of gas.
- The Danish energy sector has extensive experience with the handling of biomass.
- Denmark has considerable experience and energy-political focus on integration and cooperation across energy systems.

If such electricity and biomass-refining production is introduced in Denmark, it may result in a new, significant and very flexible electricity consumption which can be further combined with peak-load electricity generation. These energy plants will thus be able to effectively integrate large volumes of wind and solar power into the total Danish energy system, considerably reducing the need for traditional thermal power stations in the long run.

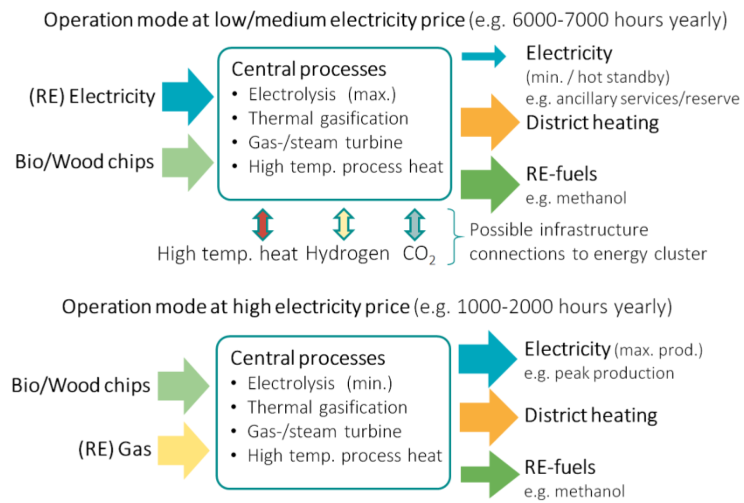
The figure on the right illustrates an input/output model for a central energy plant. Depending on the electricity price, the energy plant will be able to quickly and flexibly switch between consuming electricity and generating electricity.

ENERGY PLANTS

Conventional CHP plants convert fuel (such as coal, gas, biomass) to electricity and heat. In this analysis, energy plants are used as a generic term for an industrial complex that can convert more types of energy. The term is especially used to refer to units that can also convert electricity to gas or liquid fuels (PtG/PtX).

Energy plants may have significant synergies with other types of industry when sharing intermediate or end products such as high-temperature heat, hydrogen, CO_2 or oxygen. In the figure below, this is referred to as an energy cluster.

Outline of central energy plant



EFFICIENT RELATION BETWEEN LARGE AND SMALL PROSUMERS

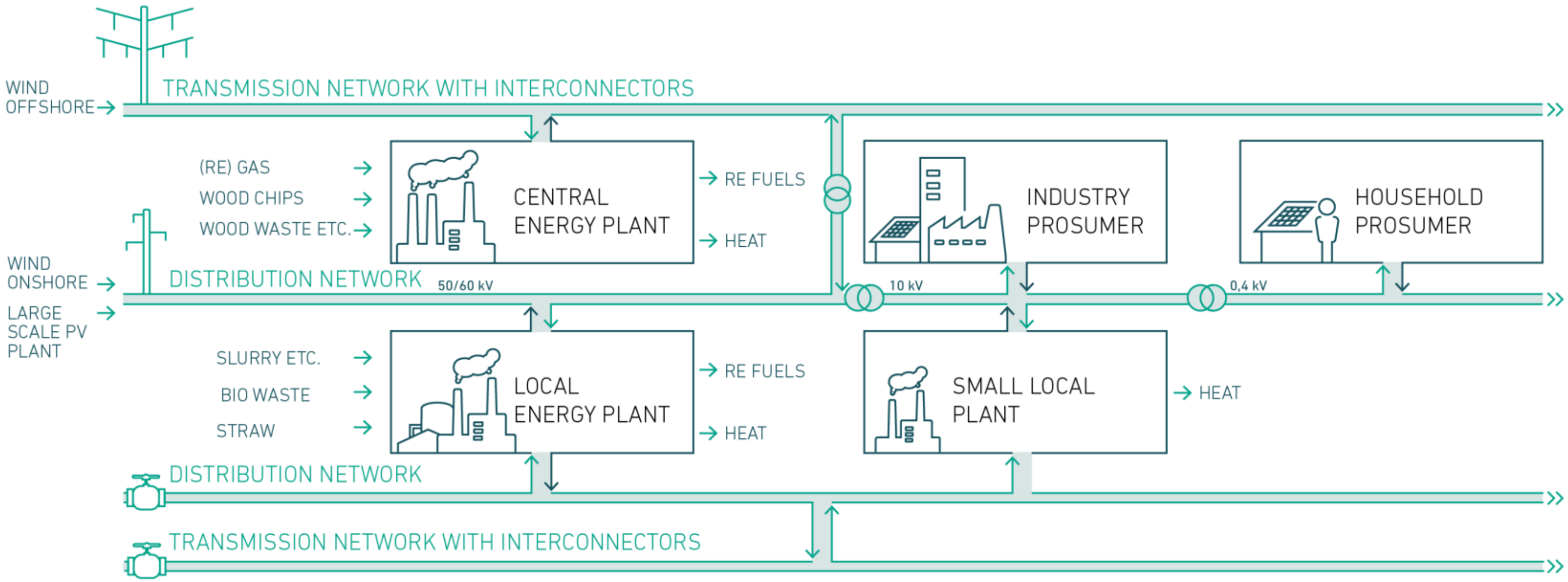
In order to secure new potential investment opportunities for Energinet's Danish energy system model, Energinet has worked with a number of industry experts to develop a range of plausible configurations of different energy consumption and energy generation technologies which could form part of the future Danish energy system.

Central energy plants are described in more detail in the figure on the previous page. Different configurations of these energy plants could be introduced at central power stations in Denmark. The basic elements are electrolysis and thermal gasification of biomass, which together can generate different types of RE fuels/products. The plants can be effectively combined with turbines, allowing them to flexibly switch to electricity generation mode at times of high electricity prices.

Local energy plants can be large local plants, where electrolysis is combined with classic biogas to produce gaseous or liquid RE fuels. By adding a gas engine, a local energy plant will also be able to switch from electricity consumption to electricity generation.

Small local plants are typically small conventional CHP plants where a gas engine and a peak-load gas boiler are combined with a large heat pump. This type of plant will also be able to switch flexibly between electricity consumption and electricity generation mode.

For both the **industrial** and the **residential prosumer,** electricity will typically be generated by a rooftop PV system. There will typically be a significant internal consumption of electricity for heat pumps, processes (industry) and electric vehicles (residential). Internal consumption may be increased in combination with battery storage. The analysis shows that connecting these prosumers to the electricity grid will also generate great socio-economic value going forward. In addition to the high level of security of electricity supply, network connection makes it possible to utilise surplus electricity generation from photovoltaic cells in the summer months and pull electricity from the grid in the winter months when solar production is at its lowest. The modelling actually shows that the substantial decline in consumption from the grid by 'residential prosumers' with PV systems is more than balanced by energy exports to the grid over a year.



OPPORTUNITIES OF PTG/PTX AND ENERGY PLANTS IN RELATION TO THE ELECTRICITY SYSTEM

A major advantage of PtG/PtX in terms of the transition of the energy systems is that an inexhaustible and increasingly cheaper RE resource such as electricity from wind and solar resources is refined, enabling it to replace fossil oil and gas in other energy sectors. A valuable added benefit of PtG/PtX is, however, also the potential for effective and flexible integration of fluctuating wind and solar power into the electricity system.

The electrolysis element of PtG/PtX has a very flexible electricity consumption. As appears from the figure on page 8, electricity consumption is the major cost associated with electrolysis. Consequently, electrolysis will not run in a commercial plant when the electricity price rises above a certain level. The electrolysis process will run almost uninterrupted at lower electricity prices; conversely, it will never run when the electricity system is under pressure and the electricity price (including tariff) is high.

If the electrolysis is part of an energy plant that can quickly and flexibly switch to electricity generation when the electricity price is high, electricity generation will also be fully flexible. An energy plant with such 'double flexibility' will be highly capable of integrating large quantities of inflexible electricity generation from wind and solar resources.

The figure at the top right shows how a central energy plant in Western Denmark (DK1) will switch flexibly between electricity consumption and electricity generation relative to the electricity price during a week in 2035 (GCA). The yellow and light blue areas show the simultaneous electricity generation from a large offshore wind farm and a large solar power plant in DK1.

Integration of high levels of wind and solar power in North-Western Europe

The figure at the bottom right shows the duration curve for the electricity price in DK1 in the ambitious GCA scenario in 2040 (GCA40). The light green line shows the GCA40 curve from the figure on page 7 which indicates that the electricity prices in many hours of the year have been very low due to large volumes of wind and solar power in North-Western Europe.

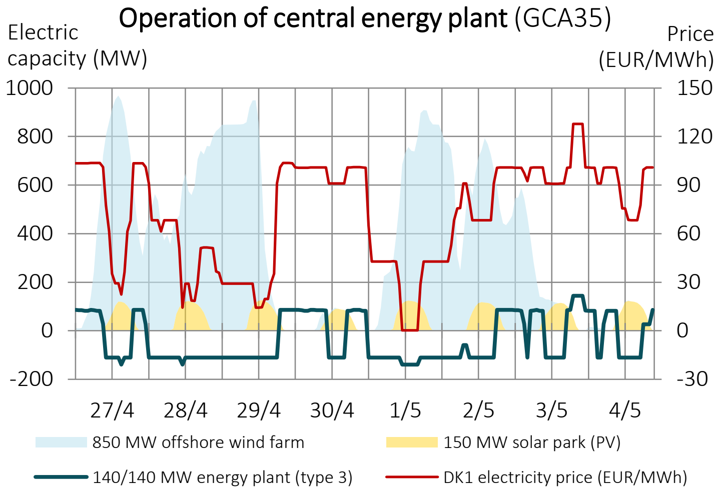
The blue curve is a modelled variation of GCA40 which includes a potential amount of PtG in North-Western Europe as a whole (as a general rule, there is virtually no PtG in the European TYNDP18 scenarios).

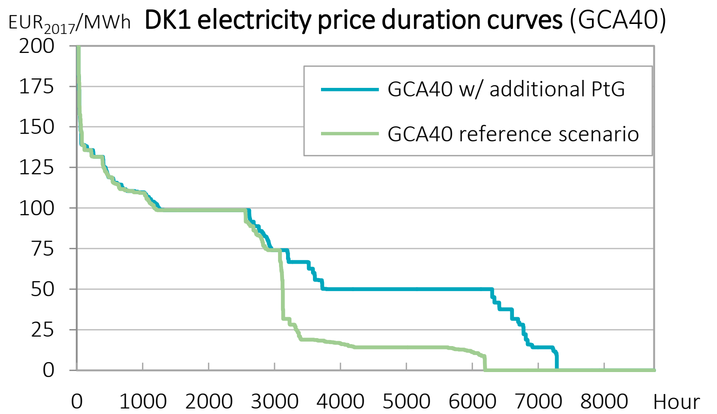
This has a significant effect on the duration curve where the electricity price is raised considerably for many hours, and the number of zero-price hours is significantly reduced. This indicates that PtG/PtX may be a powerful tool for the integration of very high levels of wind and solar power in the interconnected North-Western European electricity system.

Perspectives for efficient operation and utilisation of infrastructure

As mentioned earlier, electrolysis has a fully flexible electricity consumption. All else being equal, it means that the energy plant's significant additional electricity consumption can be integrated without reinforcing the electricity grid. The electrolysis process only has to consume electricity whenever there is available space in the grid, leading to an increased 'occupancy rate' in the grid and thereby increased efficiency.

An additional potential of especially the central energy plants is that high-temperature heat (steam) is also produced in consumption mode which can flexibly be used in both the PtG process and in steam turbines. Thus, the hot steam turbine can deliver properties required to maintain electricity system stability and regulating power as needed at any time. This may help to reduce the need to have conventional power plants on 'standby' and/or reduce the need for setting aside capacity in the electricity grid to deal with sudden outages and breakdowns.





EPILOGUE: BATTERIES ARE COMING – BUT PROBABLY NOT FOR LONG-TERM ENERGY STORAGE

Sharp falls in the price of photovoltaic cells and batteries may eventually prompt many small consumption sites to strive for a high degree of electricity self-sufficiency. Does this conflict with large-scale solutions such as offshore wind farms, a strong international electricity grid and PtG/PtX?

Energy-converting plants (including PtG/PtX) which would be capable of processing the considerable potential renewable energy volumes in the North Sea region tend to be large plants with an output of 10-1,000 MW. The current trend of sharp falls in the price of photovoltaic cells and batteries also paves the way for a higher degree of local/individual electricity generation using small household size units (1-10 kW).

This naturally begs the question whether these two development trends – 'Big scale' vs. 'Small scale' – complement or conflict with one another?

Homes and properties with rooftop PV systems and own batteries

The analysis shows that the expected price falls of batteries and photovoltaic cells may make a dramatic increase in photovoltaic cells and batteries in end consumption both economically and financially viable leading up to 2035.

A future standard solution for single-family homes could be a 10-15 kW rooftop PV system (covering the entire roof) and a 10-30 kWh battery (equivalent to approx. 1-3 Tesla Powerwalls).

In round figures, in 2035 a single-family home could have a classic electricity consumption of 5,000 kWh per year, 5,000 kWh per year for an electric vehicle and an additional 5,000 kWh per year if the home is individually heated by a heat pump. Such annual consumption corresponds to a daily electricity consumption of 30-50 kWh.

Full solar and battery self-sufficiency is too expensive

On a sunny summer's day, the rooftop PV system could generate 60-100 kWh of electricity with an annual production that could roughly cover the household's annual electricity consumption. In Denmark, however, photovoltaic power production varies throughout the year. The figure shows a typical Danish annual pattern for photovoltaic cells and electricity consumption (house without a heat pump). If the household was to rely exclusively on photovoltaic cells for electricity, it would require seasonal storage of photovoltaic energy from summer to winter corresponding to hundreds of Tesla Powerwalls or a huge surplus capacity of photovoltaic cells combined with 50-100 Tesla Powerwalls.

Even if, after 2030, photovoltaic cells and batteries were to become substantially cheaper than even the most optimistic projections, it would be a very expensive solution.

Balancing daily variations in electricity consumption

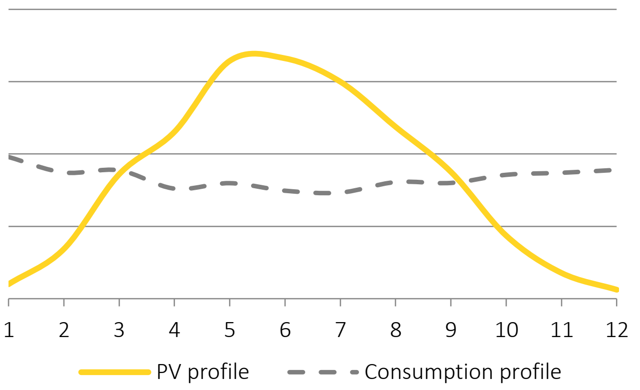
The 10-30 kWh batteries suggested by the analysis could be profitable in a single-family home with a PV system, enabling a significant balancing of daily variations in the household. In the summer months, the battery will especially be used to store much of the daily photovoltaic power production to cover the household's electricity consumption and possibly export it to the grid, up to and including the next morning. In the summer months when the household on most days will be a net producer, the rest of the photovoltaic power production will be exported and utilised via 'the big electricity grid'. In the winter months, the local battery storage will ensure a highly flexible electricity consumption in the large, integrated electricity system.

Even with battery prices which, after 2030, are lower than the expectations by a factor of 10, the analysis shows that it would not be worthwhile to maintain battery capacity in the households corresponding to more than a few days' electricity consumption.

Local batteries create value for local grids

Battery capacity in the household itself or at street level which can handle considerable daily balancing, also has the potential to significantly increase the degree of utilisation of the local electricity grid, despite a significant increase in electricity consumption in the households and the potential need for quick charging of the household's electric vehicles. Optimum use of the flexible, local batteries and capacity in the local grid is likely to require stronger cooperation between local and national grid operators to develop a market model that reflects the congestion in the local grid.

As appears from this page, there is no conflict between large-scale, international development of an integrated energy system and a growing number of local/decentralised prosumers, quite the contrary. The interaction between the two systems is examined in further detail in the background analysis.



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