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Sustainable change.

Powering Net Zero 2030 in Business Region Aarhus

Assessment of the electricity grid to support the region's net zero ambition.

November 2023

Key Abbreviations

Abbreviation	Description
BRAA	Business region of Aarhus.
TSO	Transmission system operator
DSO	Distribution system operator
DH	District Heating
MWh	Energy quantity consumed/generated from a unit with rated power of 1 MW over one hour. 1 MWh = 3600 MJ.
MWh-electricity	Electrical energy quantity in MWh.
MWh-heat	Heat energy quantity in MWh.
P2X	Power to X, technology aimed to the transformation of power into a final fuel “X” (e.g. hydrogen, methanol, ammonia).
Shore to ship	Power supply for large ships while they are docked at a harbor.
Substation	Node in which power consumption and generation are located
EV	Electric Vehicle

Who is Business Region Aarhus?

Business Region Aarhus (BRAA) is situated in East Jutland, in the heart of Denmark. BRAA looks after the interests of East Jutland when it comes to framework conditions and competitiveness, ensuring that the East Jutland metropolis maintains a strong and visible profile, both nationally and internationally. BRAA speaks with one, powerful voice that provides the region with a stronger platform in a competitive, global world.

BRAA cooperation comprises the following municipalities: Favrskov, Hedensted, Horsens, Norddjurs, Odder, Randers, Samsø, Silkeborg, Skanderborg, Syddjurs, Viborg, and Aarhus.

Preface

- Denmark's ambition to achieve 70% reduction in greenhouse gas emissions by 2030 and achieve carbon neutrality by 2050 is highly dependent on massive amounts renewable energy and the electrification of certain sectors such as heat and transportation. Therefore, the electricity network plays a crucial role as an enabler of net zero.
- However, the electricity network in Denmark has been previously invested on the basis of low demand growth and upgraded reactively as projects requested a connection offer. The low demand growth experienced in the past will change significantly in the next decades as sectors electrify. Which raises the question, **will the electricity grid support Denmark's net zero ambition?**
- This report analyses the area covered by BRAA to determine the scale of new demand and production levels in the municipalities and whether or not the electricity grid (both on transmission and distribution) can accommodate these new load levels. Therefore, in this report, the above question is reformulated to **will the electricity grid in the BRAA area support their net zero plans?**
- There have been multiple studies and articles in the media where the grid companies are heavily under pressure to answer this question. This report aims to highlight the future plans of the collective area (rather than looking at individual projects) to support grid investment. Furthermore, this project aims to support the political and national efforts by BRAA to promote practices that enable the grid companies to have the tools they need to enable net zero.
- Ramboll has been commissioned by BRAA to undertake this study and support subsequent collective efforts to ensure that the policies introduced at a national level, help the grid companies in their role of providing access to the electricity highway on the road to the green transition.

Ramboll has been appointed by BRAA to perform a study on the 2030 electricity network constraints to support net zero in the region.

The electricity network has been identified as key enabler and a potential bottleneck to the net zero transition in the BRAA area. This project aims to quantify the scale of the problem and provide evidence to BRAA on where potential constraints will be located in the network.

The project investigates the following sectors, and their future consumption or production to support net zero by 2030:

- Renewable generation
- Electrification of heat supply
- Power-to-X (PtX)
- Electrification of transport
- Shore to Ship in ports
- Dairy sector electrification

The project also focuses on the potential carbon emissions savings from some sectors.

This report presents a summary of the findings and is accompanied by a confidential report where calculation methodologies are explained.

Executive summary

Business Region Aarhus' Road to Net Zero: 2030 outlook

Electricity production and consumption (demand) is set to significantly grow in BRAA's region by 2030 in line with their green transition plans. Renewable generation alone is expected to grow six times compared to current levels from 1.3 GW to 8.3 GW by 2030. Solar PV is expected to experience a 15-fold increase reaching a potential capacity of 5.9 GW in 2030. Conversely, demand growth in the region is expected to be driven by decarbonisation efforts on electrification of heat, PtX and electrification of transport. Electricity demand in the BRAA area is expected to increase from 1.3 GW to 4.4 GW (circa 3-fold increase) by 2030.

What about the electricity grid?

TSO and DSO companies (which own and operate the networks) are under rising pressure to accommodate this significant increase in production and consumption. TSO and DSOs have already identified various upgrades that are scheduled for completion by 2030 and beyond. Through the current analysis, Ramboll has identified additional assets which may experience overloading and congestion issues by 2030. This means that further investment is needed above and beyond what is currently planned.

What can BRAA do to support the continued growth of the electricity network?

Upgrading the electricity network is a costly and time-consuming endeavour. TSO and DSOs are already investing in their networks, but current regulatory and financial frameworks can be restrictive. Therefore, it is imperative to support the TSO and DSOs to enable their operating frameworks and ensure there is enough electricity capacity for the green transition. BRAA can support TSO and DSOs both nationally and locally by promoting investment "ahead-of-need" frameworks, highlighting the need for national strategic planning and working with TSO/DSOs on local energy plans as a region to increase coordination.

Rambøll er blevet udpeget af Business Region Aarhus (BRAA) til at udføre en undersøgelse af elsystemets tekniske evne til at kunne håndtere den stigende mængde vedvarende energi i området frem mod 2030.

Elsystemet vil være den centrale energibærer og potentielle flaskehals ved overgangen til *net zero* i BRAA området. Dette projekt har til formål at kvantificere problemets omfang og give indikationer på hvor de potentielle begrænsninger vil være placeret i elsystemet.

Projektet ser nærmere på følgende sektorer og deres fremtidige forbrug eller produktion for at understøtte *net zero* i 2030:

- Vedvarende energi
- Elektrificering af varmeforsyning
- Power-to-X (PtX)
- Elektrificering af vejtransport
- Elektrificering af havne
- Mejerisektorens elektrificering

Projektet fokuserer også på de potentielle CO_2-besparelser fra udvalgte sektorer.

Denne rapport præsenterer et resumé af resultaterne og er ledsaget af en fortrolig rapport, hvor beregningsmetoderne er nærmere forklaret.

Executive summary - Danish

Business Region Aarhus’ vej imod Net Zero: 2030 fremskrivning

Elproduktion og -forbrug forventes at vokse markant i BRAAs område frem imod 2030 i overensstemmelse med kommunernes VE planer. Elkapaciteten fra VE-anlæg forventes at vokse 6 gange sammenlignet med den nuværende kapacitet fra 1,3 GW til 8,3 GW i 2030. Solcelleanlæg kan opleve en 15-dobling og nå en potentiel kapacitet på 5,9 GW i 2030. Omvendt forventes det øgede elforbrug at blive drevet af elektrificering af varme, PtX og elektrificering af transport. Det maksimale elforbrug i BRAAs område forventes at stige fra 1,3 GW til 4,4 GW (ca. 3 gange stigning) i 2030.

Hvad med elnettet?

Transmissions- og distributionsselskaber (som ejer og driver elsystemerne) er under stigende pres for at imødekomme denne betydelige stigning i el-produktion og forbrug. Transmissions- og distributionsselskaberne har allerede identificeret forskellige opgraderinger, der er planlagt til at være færdige i 2030 og derefter. Men ud over de moderniseringer, der allerede er identificeret, har Rambøll med den nuværende analyse identificeret, at der er yderligere aktiver, som kan opleve problemer med overbelastning og flaskehalse i 2030. Det betyder, at der er behov for yderligere investeringer ud over det, der er i øjeblikket planlagt.

Hvad kan BRAA gøre for at understøtte elsystemets omstilling til vedvarende energi?

Opgradering af elnettet er en omkostningsfuld og tidskrævende indsats. Transmissions- og distributionsselskaber investerer allerede i deres netværk, men de nuværende lovgivningsmæssige og økonomiske rammer begrænser potentielle investeringer for at fremtidssikre elsystemet. BRAA kan støtte netværksoperatører både nationalt og lokalt for at fremme investeringsrammer "forud for behov", hvilket fremhæver behovet for national strategisk planlægning og samarbejde med transmissions- og distributionsselskaber om lokale energiplaner for atforbedre koordineringen.

Acknowledgments

This report and project results were produced by Ramboll with the support of many entities who provided information and answers to clarification questions. These include 12 of the municipalities that BRAA represents, Energinet and the DSOs that keep the lights on in this area.

Additional data was sourced from Danmarks Statistik (Statistikbanken), local ports open data and internal Ramboll experts.

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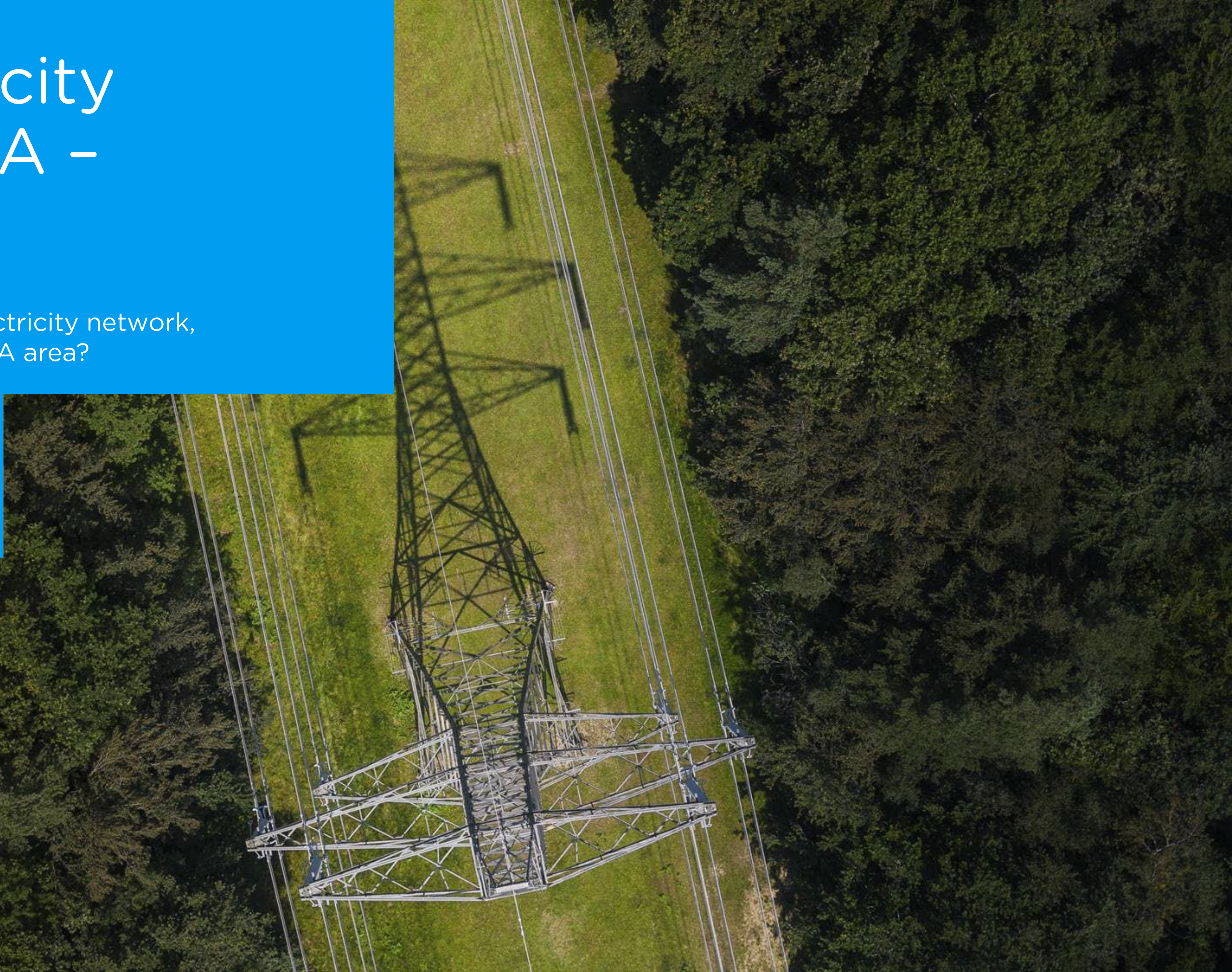
1.0 The electricity sector in BRAA – 2023

What is the current state of the electricity network, demand and generation in the BRAA area?



1.0 Key messages

Electricity networks are the gateway for electricity flow between power production plants and our homes and businesses.

Installed production capacity in the BRAA region in 2023.

2GW

The percentage of the total consumption in the area which is accounted for in Aarhus, Viborg and Horsens

50%

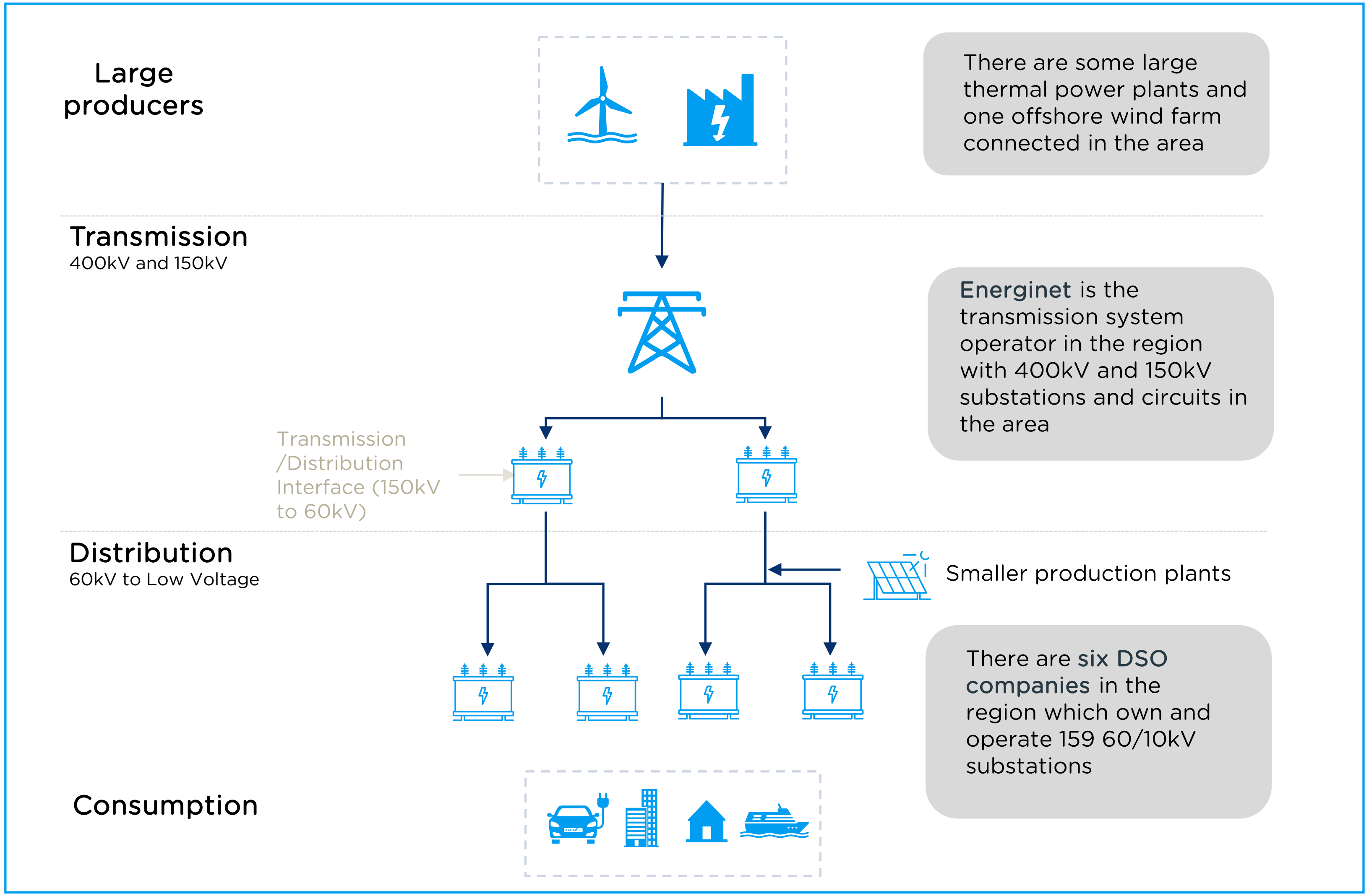
1.1 Electricity network overview

Electricity networks are the gateway for electricity flow between power production plants and our homes and businesses.

Due to the way electricity works, these networks are typically composed of two key systems: Transmission and Distribution.

Transmission networks allow for large amounts of power to be transported across long distances. They can be similar to electricity motorways where vehicles (electricity) are travelling at high speed (high voltage/current). For Denmark, the Transmission System Operator (TSO) which owns and operates the transmission network is Energinet.

The distribution network can be thought of as the local roads that connect the motorway to its final destination. They carry lower amounts of power, which can be safely used at homes and businesses. The companies responsible for the ownership and operation of the distribution network are called Distribution System Operators (DSOs).



1.2 The electricity network in BRAA - Transmission

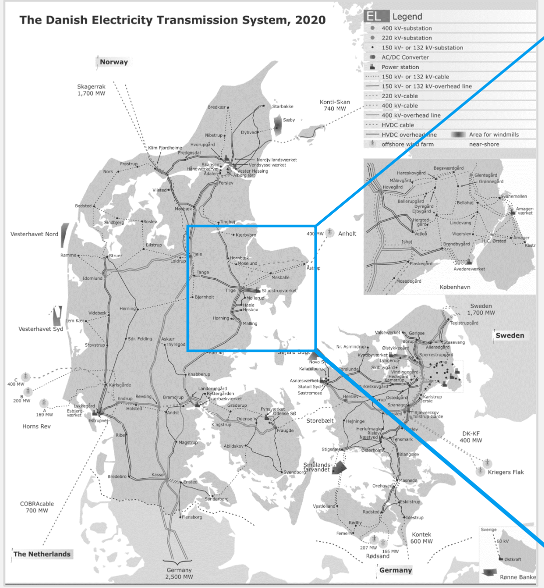


Fig 1-1 Danish Transmission System – Source: Energinet

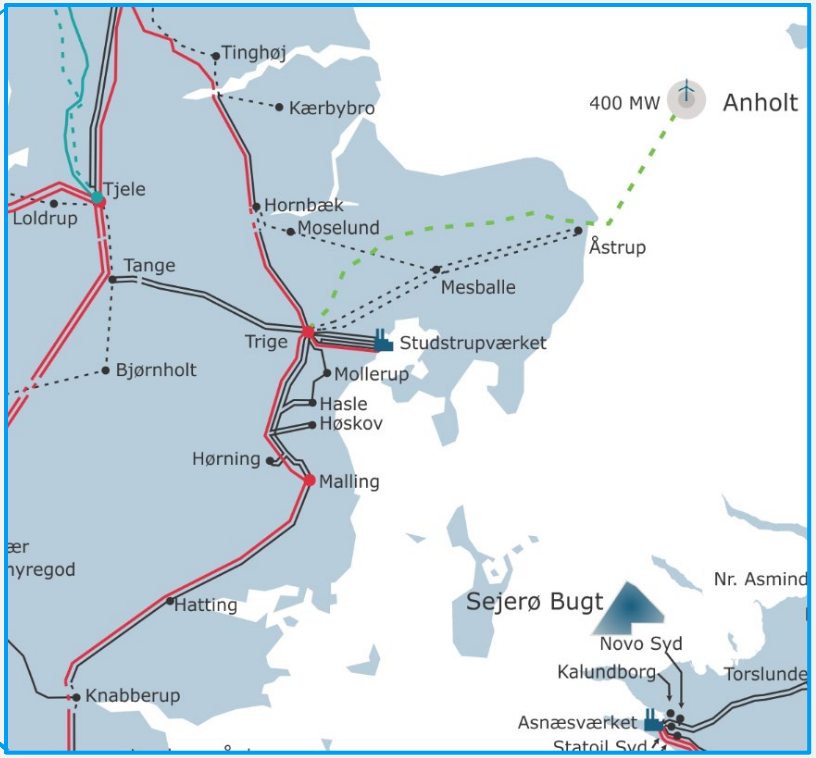


Fig 1-2 Transmission system in BRAA – Source: Energinet

The transmission network in the BRAA area connects large thermal power plants and wind farms (e.g. Studstrupværket and Anholt) to transmission substations (nodes) in the region. These substations in turn connect to smaller substations that form the Transmission-Distribution interface.

The network in the area also has a connection to Norway.

There are circa 20 substations and connection points, 426 km of cable on the transmission network in the area connecting the transmission and distribution networks.

The modelling performed in this study relates to the substations and cables within the transmission system.

1.3 The electricity network in BRAA - Distribution

Contrary to transmission where the whole network is owned and operated by one company, the distribution network in the region is split between 10 legal entities.

Figure 1-3 shows the number of DSO substations[1] in the BRAA area divided per ownership. Of the 159 substations, 45% are owned and operated by N1, followed by 33% Konstant (Nord and Syd).

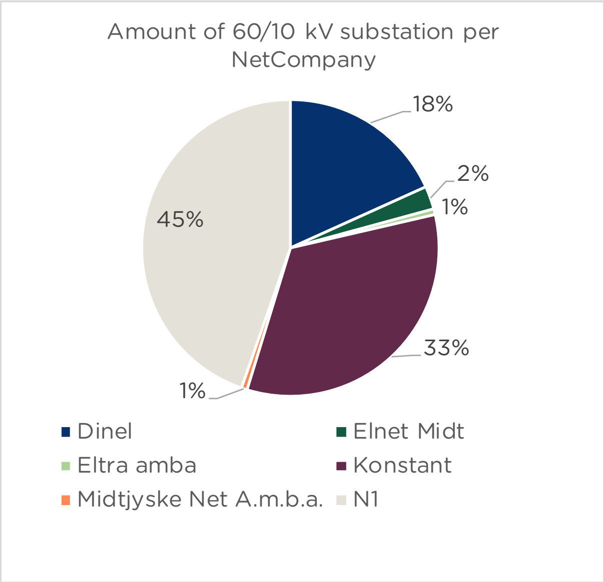


Fig 1-3 DSO Substations in BRAA– Source: Ramboll

[1] DSO substations included in this analysis are only those who have voltage level 60/10kV.

Box 1: The current network regulatory framework

In Denmark, everyone has the right to use and connect to the electricity networks. This is governed by the Electricity Supply Act. As natural monopolies (e.g. there is only one electricity network in a particular area), TSO and DSOs are governed by the financial regulations adopted by the Danish Parliament and enforced by the Danish Supply Authority (Forsyningstilsynet). These regulations are in place to protect consumers from high electricity prices due to unnecessary investments in the networks.

Network companies are incentivised to maintain their networks at a low cost. In the past, investments in the network have been forecasted using low levels of demand and generation growth, which are no longer the case.

Why is this relevant to this analysis?

By allocating funds for network investment based on past low demand/generation growth, the existing electricity grid is not prepared for the rapid increase of demand/generation during the green transition. This results in constraints (bottlenecks in the network) and the need for rapid investment – investments that the grid companies are making, but can't recover under the current regulation, which is based on limited or no growth.

1.4 The electricity network in BRAA – substation and cable locations

The figure below illustrates the 60/10kV substations in the BRAA area where we see a large concentration of substations in the Aarhus region.

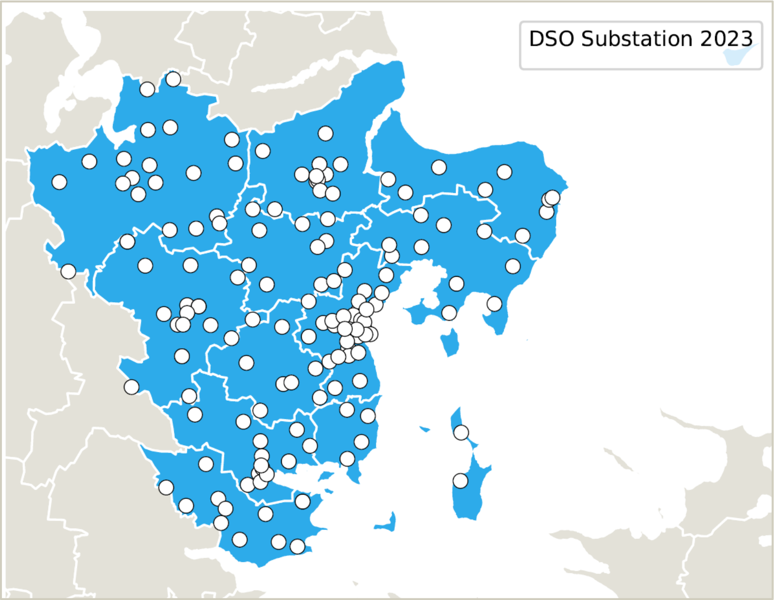


Fig 1-4 DSO Substations in BRAA per location– Source: Ramboll

For the modelling undertaken in this report, a model of the TSO network in the BRAA region was created and shown in the figure below.

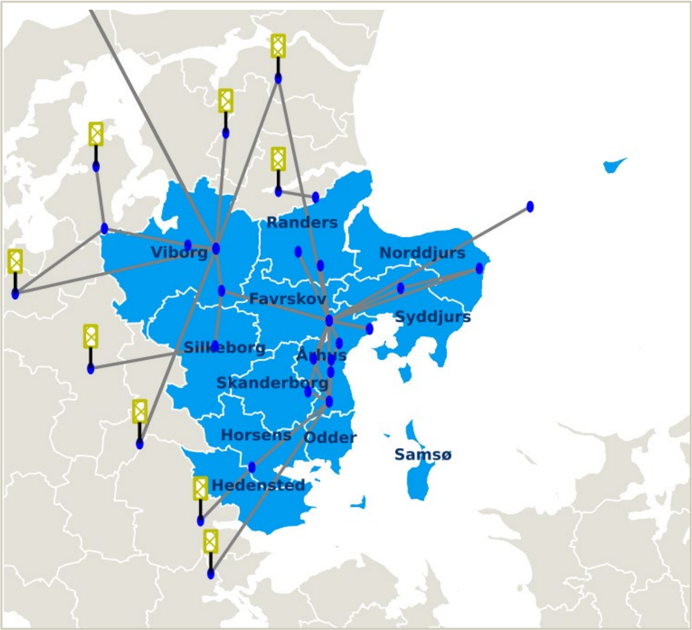


Fig 1-5 TSO Network in BRAA – Source: Ramboll

1.5 Electricity production and demand 2023

PRODUCTION

BRAA's installed capacity in 2023 is **2GW** of which **63% comes from renewable sources** (wind and solar) with 37% being generated by conventional power plants.

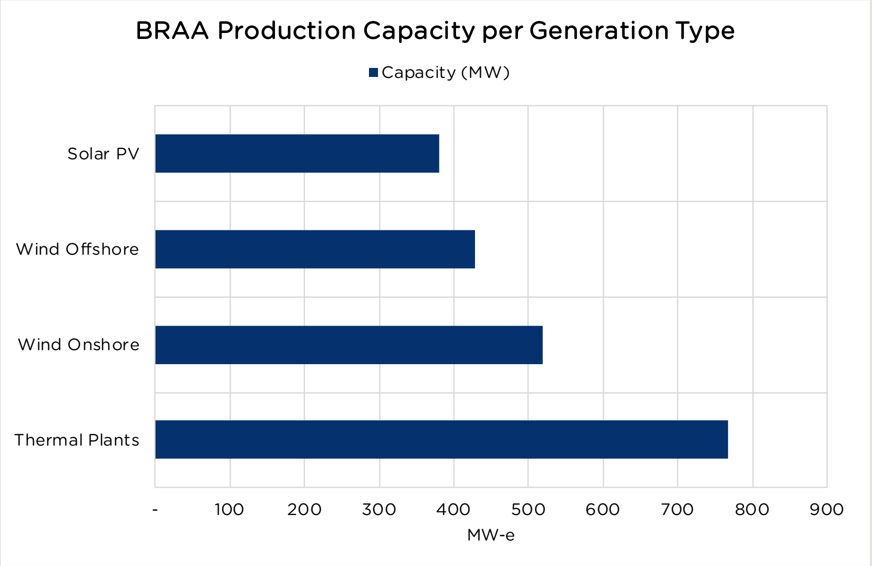


Fig 1-6 BRAA Production Capacity in 2023 – Source: Ramboll, DEA

DEMAND

Demand in the area relates to the amount of electricity that is consumed by homes and businesses in the 12 municipalities. There is a total demand of **1.3 GW** of which 24% is capacity used by electric heating (heat pumps and boilers) on the district heating networks.

Municipality	Share on total consumption
Aarhus	30%
Viborg	13%
Horsens	11%
Silkeborg	9%
Randers	8%
Hedensted	7%
Skanderborg	6%
Syddjurs	5%
Favrskov	5%
Norddjurs	5%
Odder	2%
Samsø	<1%

Aarhus, Viborg and Horsens accounts for **more than 50%** of the total consumption in BRAA.

Table 1-1 BRAA municipality consumption share. Share evaluated from 01/2021 to 07/2023.

1.6 Where are the constraints in the network?

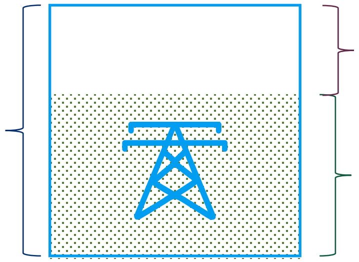
With demand and generation growing rapidly in the area, the electricity network comes under additional pressure to accommodate these new connections and electricity flows.

Why do these constraints occur?

A distribution substation in the area, HSTV in Hedensted, which is owned and operated by Konstant Syd is taken as an example. This substation has a total usable capacity of 38.4 MVA, which means this is the maximum amount of electricity the substation can safely handle. In 2023, the maximum loading was 22 MVA, meaning that the substation has 16.4 MVA spare capacity available to connect additional demand. But what happens if a large demand customer wishes to connect using up that spare capacity?

Initial Condition

This symbolises the total usable capacity in the substation



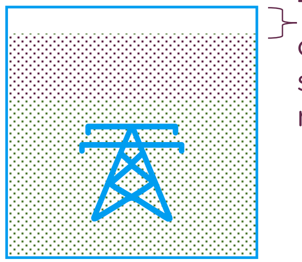
This is the spare capacity left on the substation

This symbolises the existing maximum load in the substation

Substation

Let's assume there is a new connection customer that wants to use 15MVA

Condition after new 15MVA connection

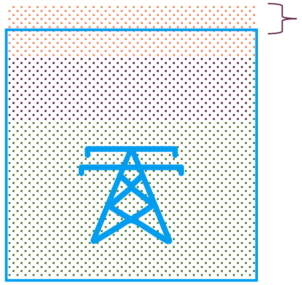


This is the spare capacity left on the substation after that new user connects

Substation

If a new eTruck charging station[1] (5MVA) wants to connect to that substation, it will exceed the maximum capacity and reinforcement will be required

Condition after new 15MVA and 5MVA eTruck connections



The substation is now overloaded, and the network company cannot take more connections until the substation is upgraded

Substation

[1] Note that the worst-case scenario is used to demonstrate this example. EV chargers might use a lower capacity depending on the day/time.

1.6 Where are the constraints in the network?

The previous example illustrates that in certain cases, all it takes is a couple of new connections or customers to take up the spare capacity of a substation. As the network companies are mandated to connect everyone that wishes to use the network (and cannot discriminate due to technology, low-carbon uses, etc.), the project that takes up the connection is not necessarily one that can contribute to the low carbon transition.

As the connection queue works on a "first come, first served" basis, the grid companies cannot prioritise low-carbon projects to take up the spare capacity in the network. So, a new fossil fuel generating plant, has the same rights to connect to the network as a solar PV plant.

There is currently an estimated[1] 2.2 GW of usable capacity in the distribution network of BRAA. In 2023 the estimated maximum loading is a total of 1.1 GW, leaving 48% of spare capacity in the area. However, this spare capacity is not evenly spread in the whole region, with some substations already experiencing overloading.

Constraints in the network are not just a 2030 problem. The below figure illustrates the indicative loading estimated by the DSOs of the substation in BRAA with already 16% of substations being loaded above 80%.

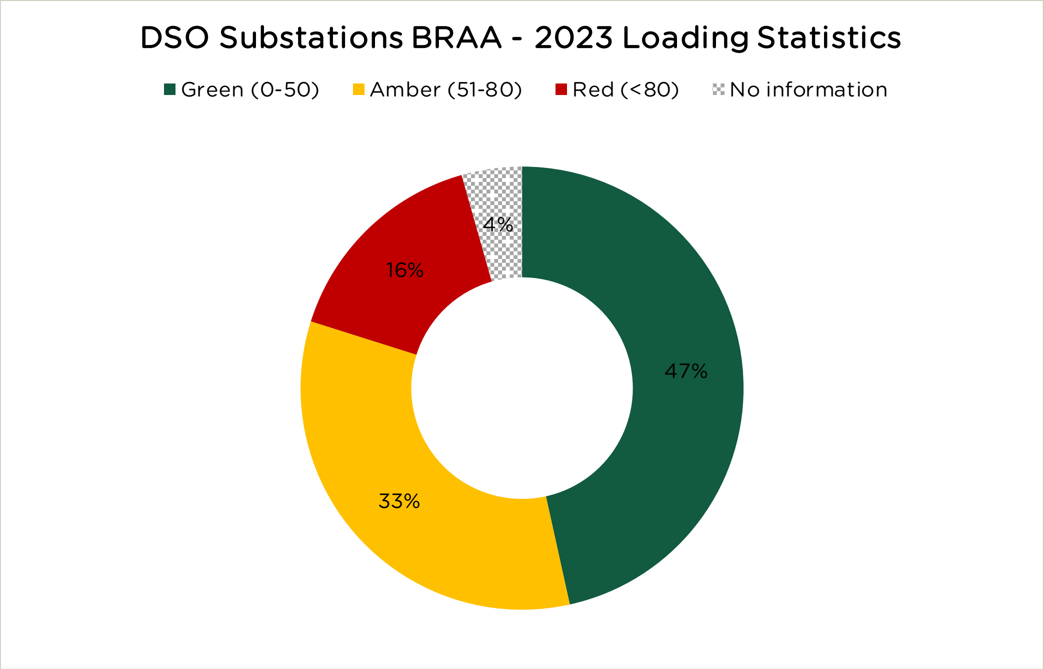


Fig 1-7 BRAA DSO Substation Loading Statistics[1]– Source: Ramboll

[1] Ramboll analysis from the information provided by DSOs and assumptions from the area.

2.0 Net zero plans 2030– Future demand and production in the area.

What is the future state of the demand and generation in the BRAA area to 2030?

2.0 Key messages

Renewable generation alone is expected to grow from 1.3 GW to 8.3 GW by 2030. That is a 6-fold growth in 7 years.

x6

Solar PV is expected to experience a 15-fold increase reaching a potential 2030 capacity of

5.9GW

By 2030, electrification of heat can account for circa 1GW of additional demand in the area.

1GW

Electricity demand in the BRAA area is expected to increase from 1.3 GW to 4.4 GW. That's a 3-fold increase in 7 years.

x3

Electrification of transport may require a total of 1.6 GW of new capacity for the substations in the system

1.6GW

New PtX electricity capacity needed in BRAA by 2030.

1GW

2.1 BRAA production – 2023 to 2030

The 2030 electricity production landscape in BRAA sees a significant increase in installed renewable energy capacity driven primarily by new installations in wind and solar PV.

Solar PV capacity in the BRAA region has experienced significant growth, being 381 MW in 2023, projected to reach 5,900 MW by 2030.

Notably, offshore wind capacity has seen remarkable growth, due to the Energistyrelsen Kattegat II tender for offshore wind farm in 2030.

The BRAA region maintains a steady conventional power plant capacity of 767 MW from 2023 to 2030.

This significant expansion in installed capacity will directly affect both transmission and distribution networks in the area.

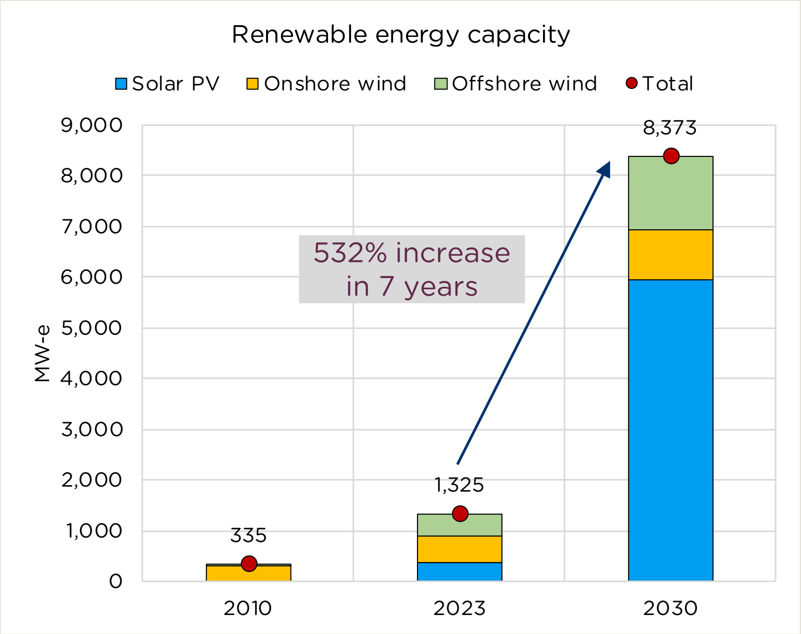


Fig 2-1 BRAA Renewable production capacity in 2030 – Source: Ramboll, Energistyrelsen

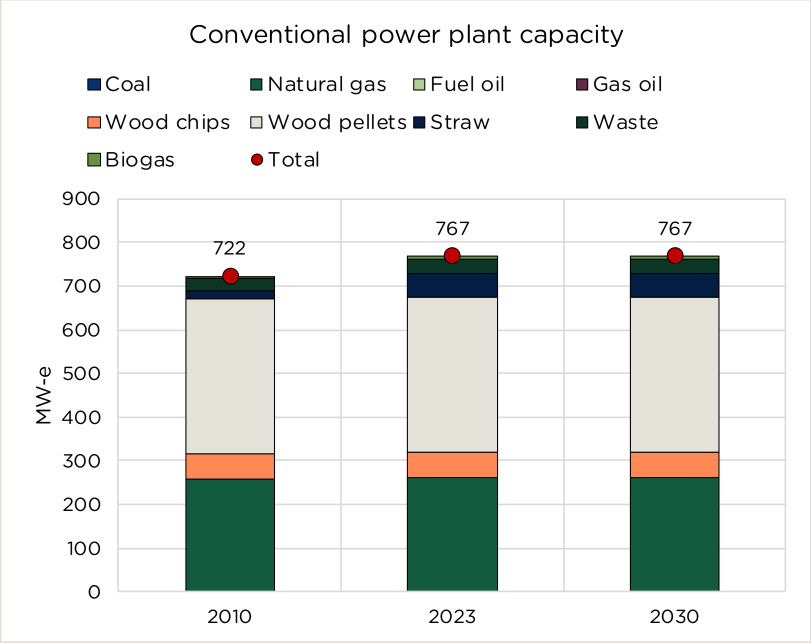


Fig 2-2 BRAA conventional production capacity in 2030 – Source: Ramboll, Energistyrelsen

2.1.1 Offshore wind – Installed capacity towards 2030 is driven by Kattegat II

KEY INSIGHTS

Kattegat II is an offshore wind project in the Danish EEZ of the Kattegat sea. It covers approximately 122 km^2 and will have a capacity between 1,000 MW and 2,460 MW.

The project aims to be fully operational by the end of 2030.

Offshore export cables from Kattegat II will likely connect to the transmission substation called Trige, where the existing offshore wind farm (Anholt) is connected.

Investment on the transmission network to accommodate this wind farm is assumed to be already included in development plans by Energinet.

Fig 2-3 Kattegat 2 – Source: Energistyrelsen

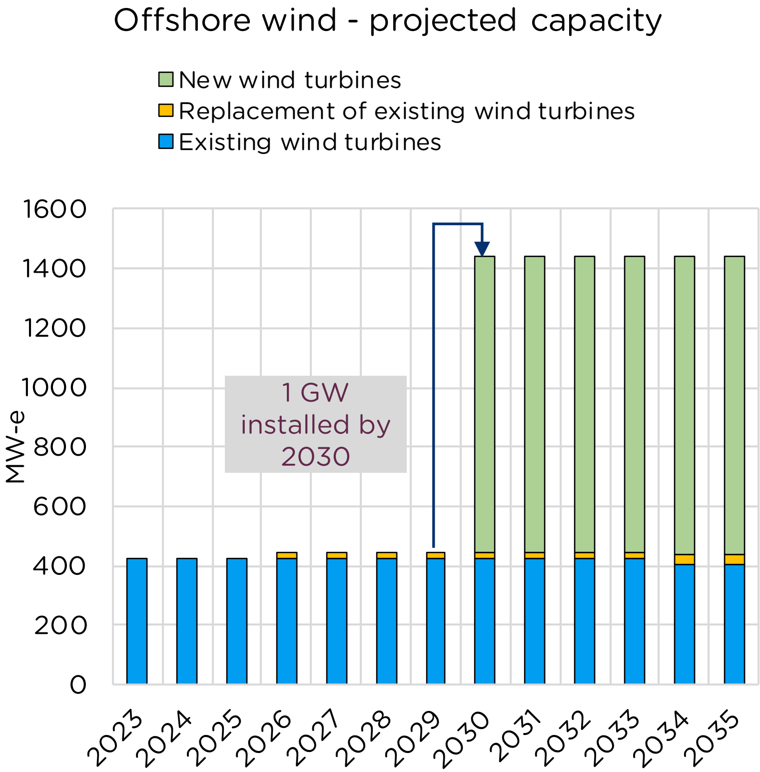


Fig 2-4 BRAA offshore wind production capacity in 2030 with assumed 1 GW installation of Kattegat II project. Source: Ramboll, Energistyrelsen

2.1.2 Solar PV - Installed capacity towards 2030

In contrast to offshore wind where growth is primarily driven by one project, solar PV in the region is expected to grow from circa 0.3 GW installed in 2023 to 5.9 GW in 2030 (a 15-fold increase).

Figure 2-5 summarises the solar PV projects planned in each municipality with information collected from the municipality's plans. There is a total of 3 GW of solar PV projects with high probability of going ahead (either approved or under approval).

The Danish Energy Agency estimated the total Danish solar PV generation capacity in 2030 will be 17.7 GW[1], meaning that if all projects go ahead, BRAA will contribute 30% of that total national goal.

Depending on the size of the project, solar PV projects can be installed either at transmission or distribution networks. However, as the transmission and distribution networks are interconnected, increased generation at a distribution level can affect the transmission network.

What does this mean?

The growth of projected solar PV in the BRAA region aggravates the future grid connection constraints. This could translate in more expensive connections in the future, which can erode the business case of PV in the area.

[1] AF22 – Danish Energy Agency.

A 15-fold increase in solar PV is expected in BRAA by 2030, with a potential capacity of 5.9 GW.

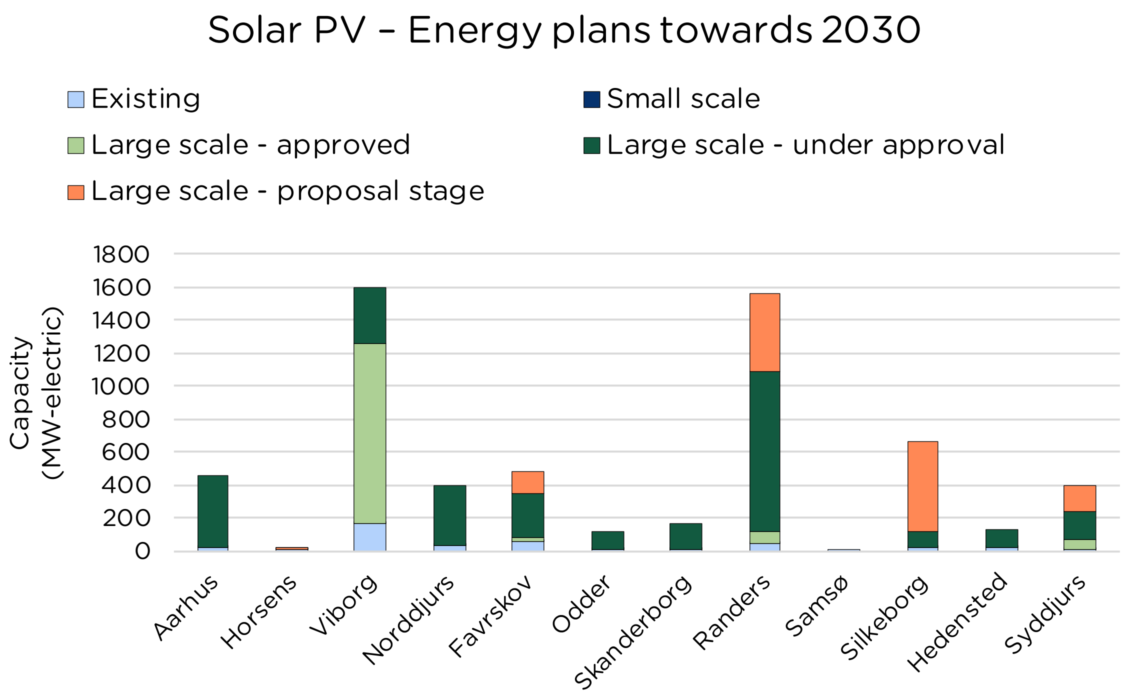


Fig 2-5 BRAA solar PV production capacity in 2030[2] – Source: Ramboll

[2] Does not include existing or speculative developments.

2.2 BRAA demand in 2030

- Electricity demand in the BRAA area is expected to increase from 1.3 GW to 4.4 GW (circa 3-fold increase) by 2030. Although a significant increase, it is important to note that not all peak demands per sector will occur simultaneously.

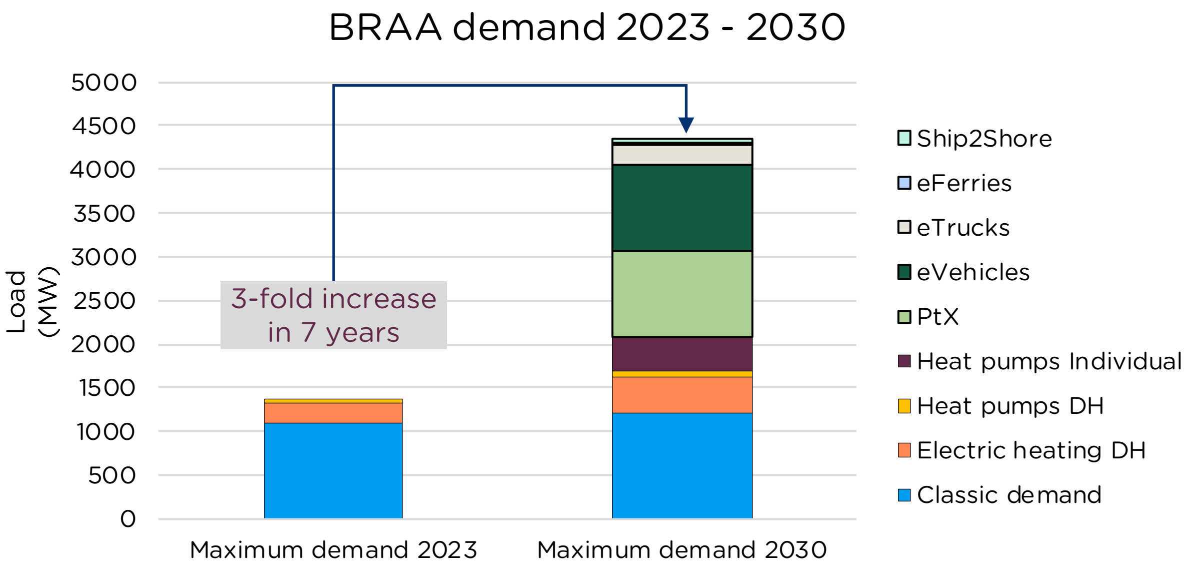


Fig 2-6 BRAA Future Demand– Source: Ramboll

What are the key sectors driving the demand growth in 2030?

The green transition relies on electrifying processes which are currently done using fossil fuels. For example, driving cars or trucks, heating our homes and businesses and ferries that connect our islands. The following summarises the key sectors that are driving the demand in the area. These sectors must be decarbonised to ensure we reach our net zero targets.

Electrification of Transport

Including:
- Electric Vehicle (EV) charging
- eTruck charging
- Shore to ship
- eFerries
- eBuses

Low Carbon Heat

Including:
- Heat pumps for individual use and district heating
- Electric boilers

Power to X

Installation of new plants for the production of efuels and/or hydrogen

2.2.1 Electrification of transport in 2030

	Forecasted Volume	Forecasted Demand
Passenger cars and vans	It is estimated that there will be 184k electric vehicles in BRAA by 2030 with 104k being fully electric (EV) and 79k using hybrid technology	These additional vehicles are estimated to require between 668 MW to 1337 MW of additional capacity in substations in the area.
Electric Trucks	It is assumed that journeys (both destination or passing through) below 300km will require electrical charging. This means that circa 3 million per year journeys will be electric.	To provide charging infrastructure for these journeys, between 116MW and 232 MW can be required in substations in the area.
Electric Buses	The current bus fleet in BRAA is 1856 vehicles. Assuming that between 60 and 100% of buses will be electric in 2030, this would translate to a volume between 1275 and 1856 electric buses	To provide charging infrastructure for these buses, between 31MW and 45 MW can be required in substations in the area
Electric Ferries	This study assumes that out of the three ferry routes in the area, only two are electrified: Ballen-Kalundborg and Hou-Sælvig	To provide charging infrastructure for these ferries, between 4MW and 12 MW can be required.
Shore to Ship	New EU law states that from January 2030, ships staying for more than two hours in a port would have to connect to on-shore power supply, unless they use another zero-emission technology.	To provide power for these vessels, circa 58MW will be required.
Trains and air transport	Very low volume expected in 2030	Not considered for 2030

2.2.2 Low carbon heating in 2030 – Key numbers

Just under **1 GW** of additional capacity in the network will be required to accommodate new heat pumps and electric boilers both for district heating and individual use in BRAA.

The average CO_2 emissions from heating supply can be reduced from **976 kTon CO_2 in 2022 to 88 kTon CO_2 in 2030**, due to the high penetration of district heating supply, electric boilers and heat pumps.

The Danish district heating system is set to be carbon neutral in 2030.

2.2.3 Electrification of transport in 2030 – Key numbers

A total of **1.6 GW** of new capacity for the substations in the system[1] will be required to electrify the transport sector by 2030. This is equivalent to the current total demand of the whole BRAA region.

Electrification of trucks and shore to ship alone can save the region upwards of **360 kTon of CO_2 a year**.

[1] Actual charger capacity might be larger.

2.2.4 Power to X in 2030 – Key numbers

Within BRAA the only announced project for P2X is Green Hydrogen Hub project in Viborg, with a **1 GW** capacity of P2X production in Viborg to be deployed over the next decade.

Box 2 - Dairy decarbonisation in BRAA

The dairy industry uses gas for the following key processes:

- Space heating to ensure indoor comfort
- Hot water for general use
- Milk treatment such as pasteurisation to ensure safe milk processing
- Milk powder production to concentrate the product intro a dry powder.

There are 6 dairies located in the BRAA region which process milk products accounting for approximately 102 GWh of gas consumption. These dairies primarily use the gas for space heating, hot water and milk treatment with the latter accounting for most of the gas consumption.

If these dairies where to electrify their processes, they would require circa 4MW of additional power to their sites saving 17.5 kTons of CO_2 per year.

Moreover, compared to the other sectors assessed, the relatively low power required will not cause severe grid bottlenecks in the region.

2.2.5 Industry electrification

Another key element of the green transition in the area is decarbonising the industries currently located in the BRAA area.

Some industries rely heavily on gas as their energy source as seen in Fig 2-7 where, for example, the food industry in Denmark contributes to 41% of the total gas consumption.

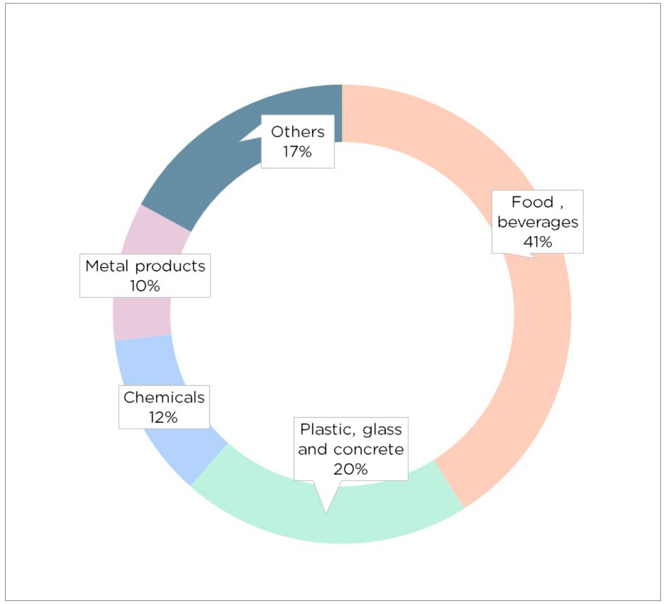


Fig. 2-7: Danish total gas consumption breakdown for manufacturing sector[1]. (Year 2020)

Why is this important?

To move away from fossil fuels such as gas, the processes that currently consume gas would need to be modified to either be electric (from renewable sources), low-carbon fuels (such as hydrogen) or capturing the carbon emissions at the source.

In some industries, the transition from gas to electricity is simpler than others. Using proven technologies such as heat pumps and electric boilers, certain industries such as dairy processing can decarbonise. However, as more sectors increasingly rely on electricity, the pressure on the grid keeps increasing.

[1] Denmarks statistics

03. Electricity network in 2030

What does the network look like in 2030?

3.0 Key messages

Overload conditions can be seen in several scenarios on both TSO and DSO networks. These can be attributed to new production and demand connections on the grid in 2030. This can result in delays to new connections.

64% of DSO substations may experience loading above 80% in 2030 under certain operating scenarios.

In addition to planned investments, it is likely that both the transmission and distribution networks will require additional expense to prepare for the rapid growth of electricity production and demand in the area.

3.1 Electricity network in 2030 - Scenarios modelling

The previous sections have highlighted the additional production and consumption/demand in the region compared to the current situation.

Using information from the TSO and DSOs in the region, Ramboll modelled the potential impact that this additional use of the grid will have on the existing and planned infrastructure.

The modelling was focused using different scenarios to perform a representative assessment of typical days of grid usage.

Investments in the grid are determined by the network companies performing studies to ensure that their assets can cope with typical operating conditions. In this analysis, we have directed our modelling efforts toward five critical grid operational scenarios, each representing possible operating conditions.

Scenario name	Description	When could this scenario happen?
High Solar	Scenario with high production of solar power. Consumption is set at 60% of peak demand, assumed to occur in the summer season.	Summer season → Low demand, high production of photovoltaic power from solar PV plants and low production from wind.
High Wind	Scenario with high production of wind from both onshore and offshore wind farms. Assumed to occur in winter season.	Winter season → High wind production, low solar and thermal plants outputs, high classical demand, high District Heating demands.
High demand – Low renewables	Scenario simulating a high consumption with low or null renewable energy production in the system, with the deficit covered by thermal power plants.	Winter season → Low renewable production, high classical demand, district heating, transport and PtX demands. High thermal power output intended to supply power deficit.
High demand – High renewables	Scenario simulating a high consumption with a high renewable energy production in the system and low thermal power supply.	Winter season → High renewable production and low thermal power output, high classical demand, district heating, transport and PtX demands.
Low demand – High renewables	Scenario simulating a low consumption with a high renewable energy production in the system. Assumed a windy summer day.	Summer season → High solar and wind production, low classical demand, district heating, transport and PtX demands.

Table 3-1 Scenarios used in the grid modelling

3.2.1 Grid investments currently planned - Distribution

Electricity companies have a regulated duty to ensure the safe operation of their network. Although their investments have been limited in the past by assumptions of low demand growth and driven by new connections, there are other factors that require network companies to upgrade their networks:

Asset condition: Has the equipment failed and needs to be replaced or repaired?

Asset age: Is the equipment past their operational age and needs to be replaced or repaired?

New connections and load growth: Are there new connections requiring upgrades to the network?

What are the network companies currently planning?

Distribution

From the information obtained from DSOs, there are currently 61 substations of 60/10kV which DSOs have identified as requiring upgrades from now until 2033. This accounts for 38% of the total substation stock (of this voltage level) that has been identified to require some upgrades due to any of the aforementioned drivers. Furthermore, the DSOs already expect that circa 40% of substations will experience loading of 80% and above on their network.

This planned expansion in the area is key to ensuring there is capacity for the additional production and demand planned to be online in 2030. However, if the network companies' plans are not aligned with those of the municipalities or other key players in the BRAA region, these planned investments will not be sufficient.

3.2.2 Grid investments currently planned - Transmission

Energinet has already observed that the electrical grid in the entire Denmark and specifically in Eastern Jutland will face a large increase in production and consumption.

In particular, within the BRAA region, there are plans for a significant number of photovoltaic projects, prompting Energinet to ready the electrical grid for voltage levels ranging from 150 to 400 kV to accommodate these requirements.

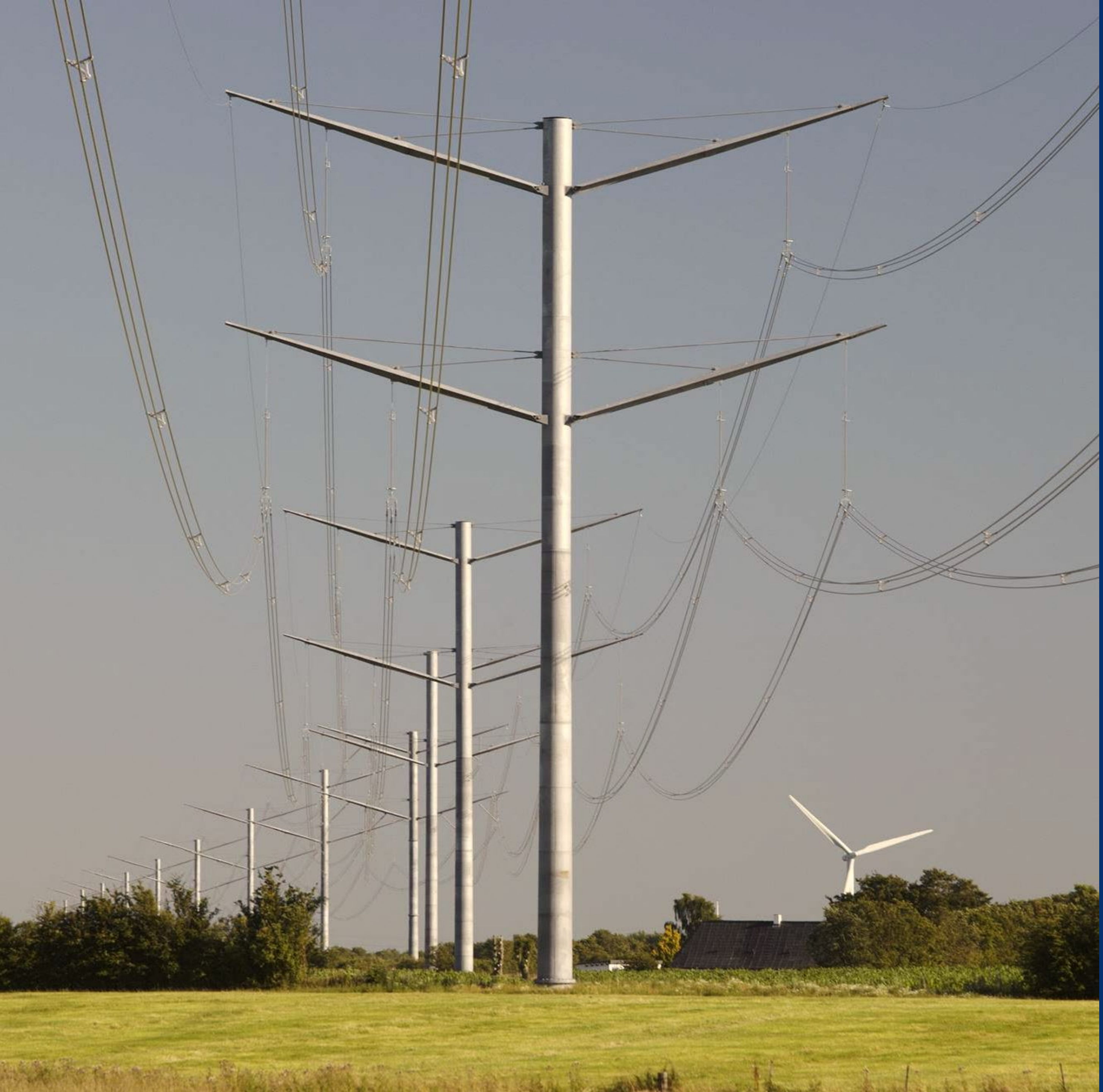
Fig. 3-1 shows the projects in the BRAA area, and these projects are divided into:

- *Projects under construction*, maturation started before 2022
- *Projects under development*, maturation started before 2022
- *Possible projects*, maturation date could be from 2030, however with larger uncertainty. The degree of probability of these projects is not provided.

The project list also offers limited details about the investment location, specifying whether it pertains to transmission lines, transformers, substations, and the associated voltage level.

In summary, Energinet has outlined various investment plans for the grid from 150 kV to 400 kV. While this analysis does not account for the 150 kV substations, Energinet is considering them for reinvestments. Additionally, there are plans for further reinvestment in the BRAA area both before and after 2030. Are these investments sufficient for the future production and demand in the area?

Fig. 3-1: Ongoing and potential projects in Central and Eastern Jutland up to 2034 – Source: Energinet.



3.3 TSO network modelling

This section highlights the key results of the TSO 2030 grid modelling. The key conclusions of this modelling are:

Overload conditions can be observed in key elements of the network. Scenarios featuring high production or high demand lead to the network experiencing more bottlenecks.

It is highly likely that the transmission network will require significant further investment. This is **in addition** to the billions of DKK already required for TSO upgrades. Certain projects might not be able to connect to the network until these reinforcements are carried out.

Although overloads are expected, this does not translate to low power quality or probability of blackouts. This will however result in delays for new production or demand connections. It's important to note that the TSO will keep the lights on by using operational mechanisms to ensure there is no detriment to consumers.

3.3.1 TSO network modelling – Selected scenario results

In the case of **High demand and Low renewables**, Fig 3-2 shows that in 2030 there could be four overloaded circuits and two substations also experiencing overloads.

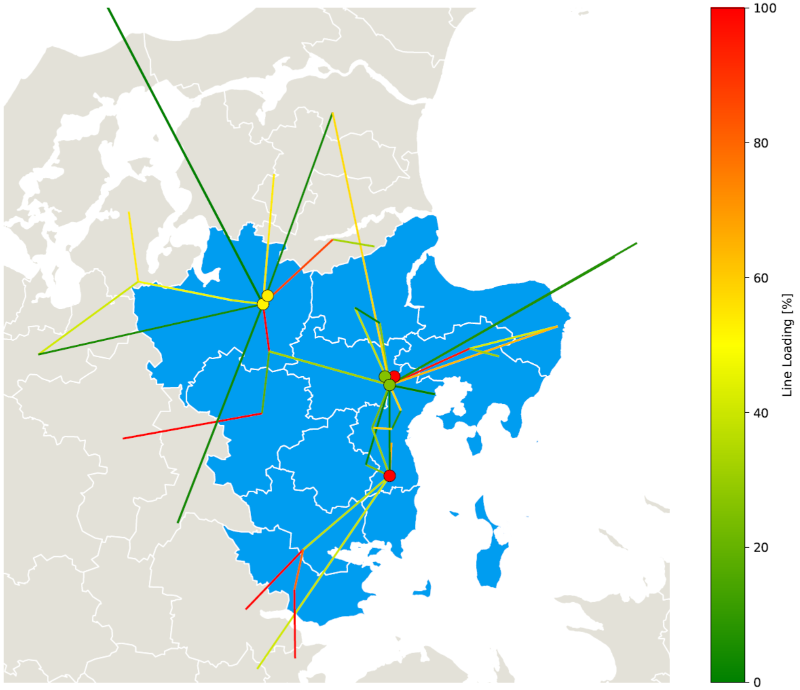


Fig. 3-2: Transmission grid High demand Low renewables scenario.

For the **Low demand and High renewables case,** Fig 3-3 shows that several circuits may experience overloading

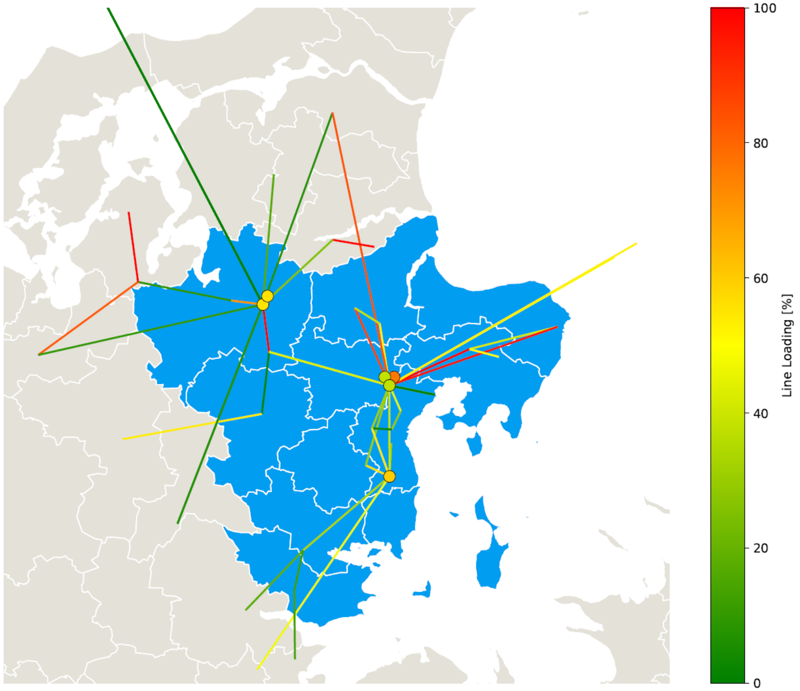


Fig. 3-3: Transmission grid Low demand High renewables scenario.

On the **High Solar scenario,** Fig 3-4 shows that several circuits may experience overloading

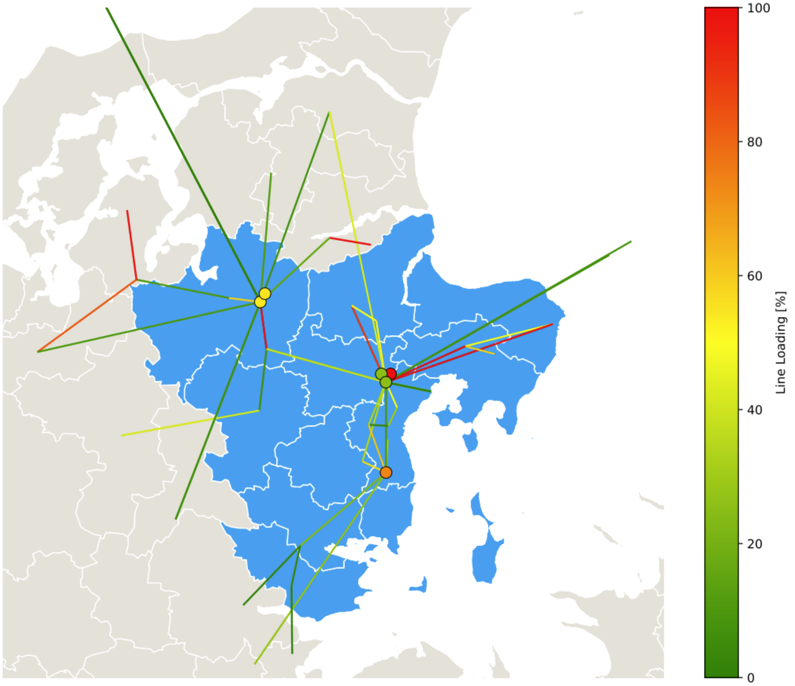


Fig. 3-4: Transmission grid Low demand High renewables scenario.

3.4 DSO network modelling

This section highlights the key results of the DSO 2030 grid modelling. The key conclusions of this modelling are:

Overload conditions can be observed in some substations. Scenarios featuring high demand conditions are more likely to result in substation overload. The worst case is observed in the High Demand/Low Renewable scenario where circa 64% of substations experience loading above 80%.

Green transition requires upgrades on both transmission and distribution. The distribution network will see a significant amount of new demand connections as a result of EV charging and heat pumps, which are typically connected at lower voltage levels.

It is highly likely that the distribution network will require significant further investment in addition to billions of DKK already planned by DSOs. Similar to the transmission network, this will translate to certain projects not being able to connect to the network until these reinforcements are carried out.

3.4.1 DSO Network modelling – Selected scenario results

In the case of High demand and Low renewables, **51% of the substations are overloaded (and 64% are above 80% load)**, and these are divided in the entire region with a major focus on Viborg, Aarhus, and Silkeborg.

High demand and High renewables is similar to the previous case with **44% of substations are overloaded**.

In the case of Low demand and High renewables, 11% of the substations are overloaded, showing a larger share in the Viborg and Aarhus areas.

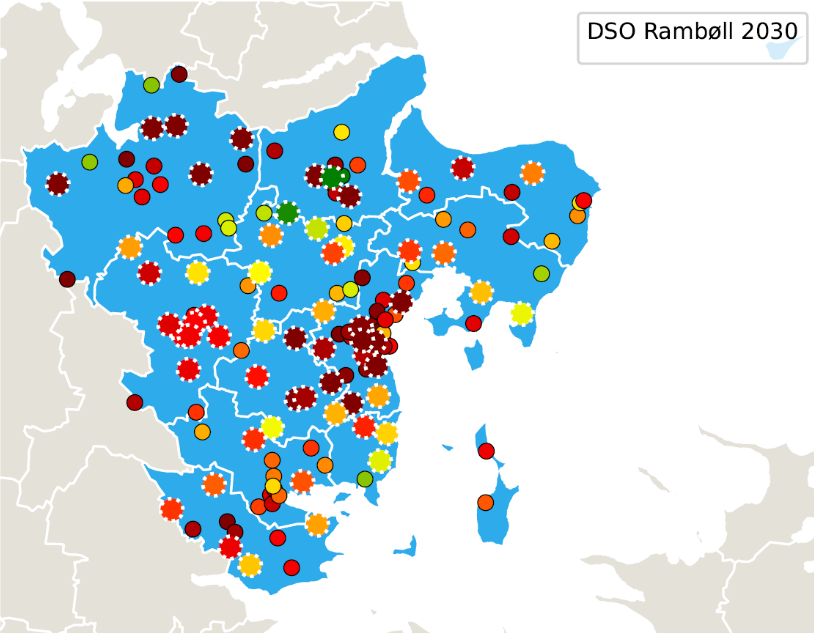


Fig. 3-5: Distribution substations High demand Low renewables scenario.

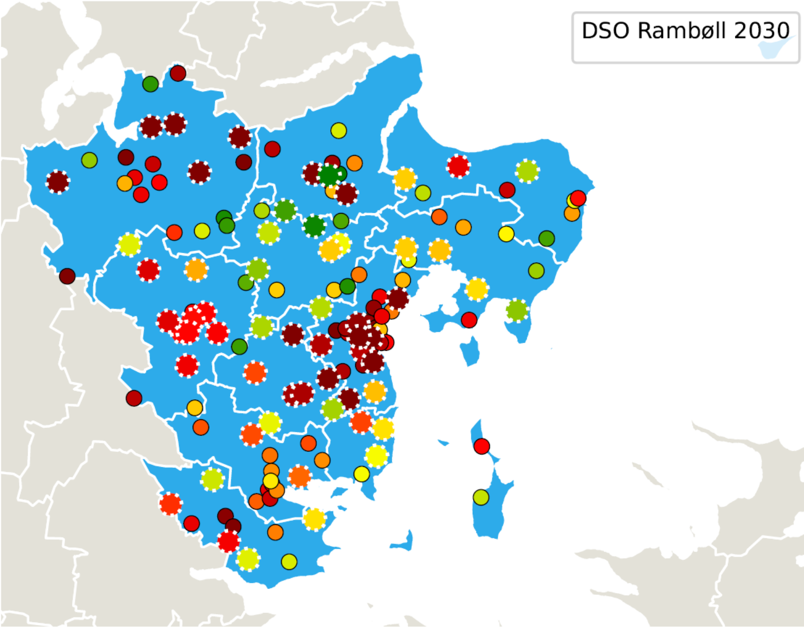


Fig. 3-6: Distribution substations High demand High renewables scenario.

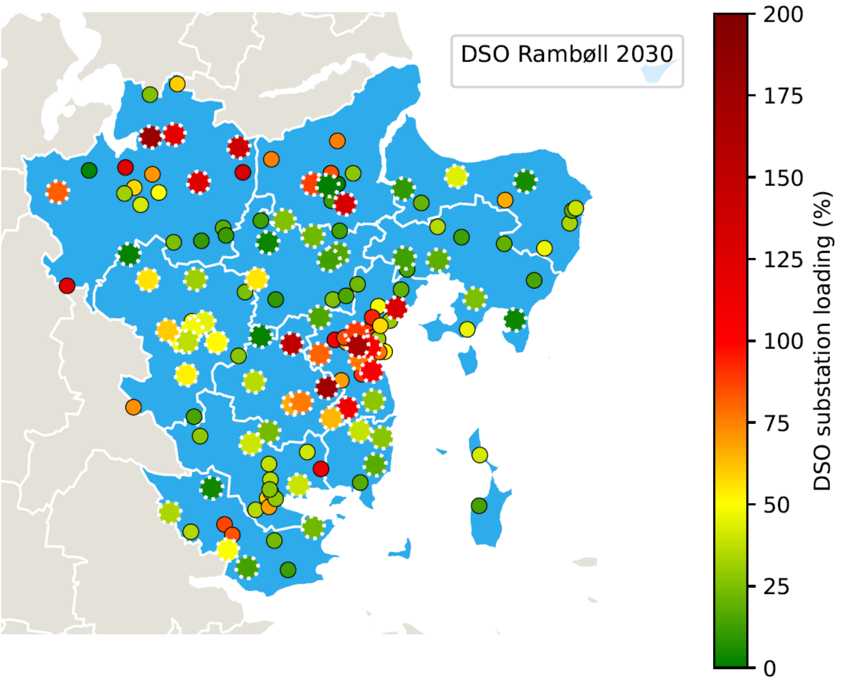


Fig. 3-7: Distribution substations Low demand High renewables scenario.

3.5 What does this mean for BRAA?

Although investments are planned in the transmission and distribution networks in the BRAA area, these might not be sufficient to enable the accelerated growth in production and demand which is required for the green transition. A new green project might find that the capacity in the network is not available for them to connect on a timely fashion as the grid operator would need to perform upgrades in the network before connecting the new project.

It must be noted that grid companies have the obligation to connect anyone that wishes to use the electricity grid (for a fee). But this obligation does not mean that this connection is necessarily a quick process. If the grid capacity is not available, the grid operator must prioritise the safe operation of the network before connecting more generation or demand. It must complete upgrades to the network or constrain other network users to enable new connections.

This means that the grid companies will enable all the connections to the network that are requested, but these connections won't necessarily occur on the timeframe needed.

This will be aggravated as new connections take up the available capacity in the grid in a cumulative fashion. One single project could potentially take up all the available capacity in the area, meaning that the next on the connection queue must wait until reinforcements are done in the network before it can be online.

4.0 Key preliminary takeaways

What can the BRAA municipalities do to enable the green transition in the region?

The green transition will rely heavily on the use of the electricity grid to power our homes, transport, industry and businesses.

In the BRAA region, this means that by 2030, production from solar PV and wind can grow almost 6 times compared to the current total production in the area. Demand could grow 3-fold in seven years to enable the electrification of land vehicles, ferries and power to x. This rapid increase of production and demand will create bottlenecks in the electricity grid both at transmission and distribution levels.

TSO and DSOs are already investing in their networks, but current regulatory and financial frameworks restrict potential investments to future-proof the network and to cater for this increased use. The current frameworks have assumed that demand will grow slowly and had not anticipated the green transition's reliance on the network.

Therefore, it is imperative to support the TSO and DSOs to enable their operating frameworks to ensure there is enough electricity network capacity for the green transition.

4.1 Powering net zero 2030 BRAA

The network operators (Energinet and DSOs) have been working to promote changes in their internal practices and proposing recommendation for regulatory framework changes (see Net til Tiden report published by Green Power Denmark). However, there are additional elements where BRAA can support network operators both nationally and regionally to enable the creation of the electricity capacity needed for the green transition. The below summarises some of the potential ways BRAA can provide this support.

National

- Promoting investment "ahead-of-need" frameworks
- Highlighting the need for national strategic planning

Local

- Working with TSO/DSOs on local energy plans as a region
- Aligning project location with available capacity.

4.2 Powering net zero 2030 BRAA – National initiatives

Promoting investment "ahead-of-need" frameworks

Current regulatory frameworks have focused on developing the network as needed. Meaning that limited load growth was assumed, and investments in the network were primarily led by low demand growth, new connections (once connection applications are made) and asset conditions.

To future-proof the grid and ensure there is capacity when it is required, the grid operators must be incentivised to invest ahead of need.

Investment ahead of need means that network operators can take a holistic view of the future and invest in the networks before a connection has materialised. Although this is allowed under the current regulation, the incentives on the networks are to lower expenditures. New incentives must be created to support the grid networks on this rapid investment need without compromising the safe operation of the network.

Highlighting the need for national strategic planning

Like highways and large infrastructure projects, electricity networks take time to develop. There are currently high lead times on key equipment needed to build new networks coupled with a skill shortage to undertake the projects.

If investment in the networks could be planned in a holistic matter taking into consideration national targets, local plans and sector constraints, this could ensure that grid investment and priorities are aligned with both Danish Energy Agency and local forecasts/ambitions.

This holistic analysis should also consider the flexibility that some of the new technologies bring. Although not specifically discussed in this report, Battery Energy Storage Systems (BESS) can support grid flexibility and constraints in the network.

4.3 Powering net zero 2030 BRAA – Local initiatives

Working with TSO/DSOs on local energy plans as a region

The solar PV production plans for each local authority, when combined, result in a 15-fold increase when compared to current levels. It is unlikely that all these projects will go ahead in the next seven years. However, if BRAA wishes for the network to be future-proof, grid operators must also have a level of confidence that the local plans for each municipality will be realised.

The case of solar PV also highlights that each municipality potentially sees solar PV as a tool to reach their goals, but as more projects connect to the grid, these might have detrimental effects on the business cases of other future projects in the area.

Therefore, it is recommended for the local plans to be aggregated, streamlined and approved prior to communicating them with the grid companies. Then the TSO/DSOs can take these plans forward to ensure there is the capacity when needed.

Aligning project location with available capacity.

There are areas of the network where there will be less congestion in the future. Wherever possible, local plans and new projects should consider prioritising those grid areas first to obtain faster connection times, but also support more even usage of the network.

We note this is not always possible as, in particular with solar and wind, the projects will be located where there is abundance of resource. However, where possible this is something municipalities and developers should consider in their plans.

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