ESO East Anglia Network Study

March 2024

ESO

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Context

Great Britain's energy system is undergoing a generational transition. The electricity grid is critical in supporting this transition and ensuring the delivery of a reliable supply of energy to homes and businesses across Great Britain.

East Anglia is playing a vital role in this transition with a significant increase in low carbon and renewable generation, predominantly from offshore wind, interconnection and nuclear generation. In many ways, East Anglia is at a more advanced stage of its energy transition than other regions due to early seabed leasing rounds by The Crown Estate. As a result, many offshore wind farms off the East Anglian coast are either already generating or are due to connect before 2030. Due to these developments, the UK Government incentivised voluntary coordination of this offshore infrastructure through what is known as the Offshore Coordinated Support Scheme (OCSS).

As announced by the Department for Energy Security and Net Zero on 5 December 2023, three projects within this scheme: North Falls Offshore Wind Farm, Five Estuaries Offshore Wind Farm along with National Grid Electricity Transmission (NGET (Sea Link)), have proposed a coordinated network design which sees the coordination of the two offshore wind farms and Sea Link. These developers are currently exploring the feasibility of this proposal and the UK Government will shortly be deciding whether to continue funding this exploration[1].

Recognising that coordinating the connections of these two offshore wind farms may change underlying power flows in East Anglia, we, the Electricity System Operator (ESO), committed to independently assess different network configuration options that could transfer power around and across the region. For the purposes of this study, the coordination being proposed by developers via the OCSS has been used as the baseline.

This report presents ten network configuration options that transfer power around or across the region in different ways. Six of these were developed through collaboration with NGET and four of them have been proposed by community representatives.

For this study, we have utilised the same criteria as within the Holistic Network Design (HND). Requested by stakeholders, we have also stress tested these options against a range of other time-based and scenario sensitivities. The options have also been benchmarked against comparable projects within Britain and Europe.

During our three-month study period the invaluable feedback we have received is reflected where possible in the assessment below. While the assessment itself does not recommend an optimal path to take, the results show that there is no universally accepted solution that delivers the required electricity network capacity needed by the early 2030s.

Each option comes with trade-offs between costs borne on energy consumers, communities hosting this nationally significant infrastructure as well as environmental considerations. We hope that this assessment will provide stakeholders with an independent view of different on and offshore circuit options as well as currently available network infrastructure technology within Great Britain.

[1] This funding has been allocated through the Offshore Coordination Support Scheme, known as OCSS.

1. Introduction

Who is the Electricity System Operator?

As the Electricity System Operator (ESO) for Great Britain, our role is to operate Great Britain's electricity transmission system, while developing a secure, clean, and fair system for tomorrow. We transport electricity around the system to ensure electricity supply to matches demand second-by-second, 365 days a year.

We work in partnership with the Government, Devolved Governments and regional authorities, the energy regulator (Office of Gas and Electricity Markets (Ofgem)), industry and consumers to guide Great Britain on the energy resources, markets and networks required to securely accelerate the transition away from fossil fuels into new energy technologies and economies.

As the ESO, we do not generate or sell electricity, we also do not own or build the infrastructure the electricity travels through. This ensures the ESO is independent of companies with a commercial interest in generating energy or building network infrastructure.

In April 2019, the ESO, then part of National Grid became a legally separate business within the National Grid PLC group. This means that the ESO is independent from the Transmission Owners, including National Grid Electricity Transmission (NGET). This separation was to provide greater transparency in our decision making and confidence in our independence.

With the passing of the Energy Act 2023, we are transitioning into an independent public corporation named National Energy System Operator (NESO) in the summer of 2024. We will have new responsibilities for advising government across the whole energy system as it transitions to net zero, from strategic network planning across electricity and gas to new technologies such as hydrogen.

What is the electricity transmission system?

The electricity transmission network is often compared to Great Britain's motorways. It transports high voltage electricity, ensuring cities and towns are connected and supplied with electricity. This high voltage electricity is then moved through distribution networks, equivalent to the A and B roads, and turned into a lower voltage for homes and businesses to use every day.

The network spans across Great Britain and comprises a mixture of overhead cables, underground cabling and subsea cables – these assets can operate at a range of voltages such as 400 kV, 275 kV and 132 kV.

These are all linked together via substations across Great Britain to connect generators, interconnectors, large demand (such as transport links and factories), and distribution systems (that provide electricity to homes and small businesses). Distribution networks carry electricity at 132 kV and below in England and Wales, and 66 kV and below in Scotland.

As the ESO, we are responsible for operating the transmission networks in England, Wales, Scotland and in the surrounding offshore waters, ensuring that electricity is transported from where it is generated to where it is needed reliably, efficiently and economically.

Great Britain has three onshore Transmission Owners that own, maintain and develop their networks, namely National Grid Electricity Transmission (NGET), Scottish Power Energy Networks (SPEN) and Scottish and Southern Energy Networks Transmission (SSEN). The map below illustrates their boundaries. There are also several offshore developers that own the assets that connect operational offshore wind farms to the transmission or distribution network.

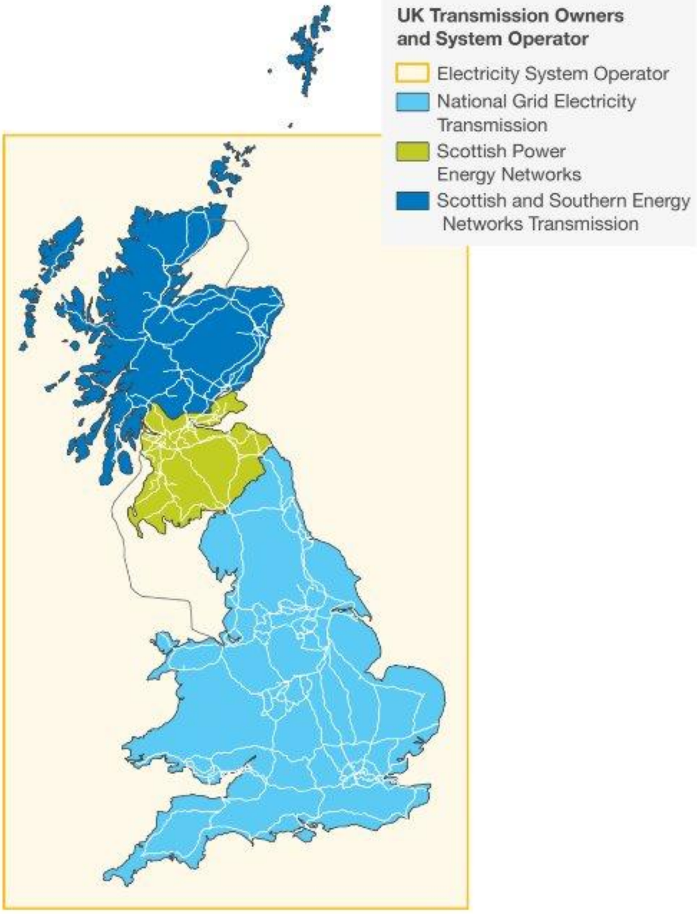

Figure 1: Map of UK Transmission Owners and System Operator

Electricity transmission network planning process

One of our key responsibilities is to model Great Britain's future energy supply and demand needs and put forward recommendations for a high-level coordinated electricity network to meet those needs in a safe, efficient and affordable way.

The process involves assessing a range of different network and non-network build options to ensure electricity can get to where it is needed, when it is needed, and we work in close collaboration with the Transmission Owners throughout this process.

Our role is to stress test network options provided to us, primarily by the Transmission Owners, against a range of different future energy scenarios and ensure that any proposed new network infrastructure is balanced against agreed design criteria. The four criteria we use for this assessment is below:

Objective	Description
Economic and efficient costs	The network design should be economic and efficient, ensuring best value for bill payers
Deliverability and operability	The network design should be deliverable, and the resulting system should be safe, reliable and operable
Environmental impact	Environmental impacts should be avoided, minimised or mitigated by the network design, and best practice environmental management incorporated in the network design
Local community impact	Local community impacts should be avoided, minimised, or mitigated by the network design

Table 1: Four Design Objectives

After we have put forward a coordinated network design recommendation, these designs are then used as an investment needs case by the Transmission Owners to take forward to the next stage of development to optimise further, refine and build.

It is the responsibility of the Transmission Owners to decide upon potential route corridors as well as decisions on types of infrastructure to use, and crucially consulting with local communities and planning authorities on these proposals.

This East Anglia Network Study is not part of the usual electricity transmission network planning process. It is a standalone study to assess different ways to transfer power around and across the region. This is as a result of the change in power flows from the voluntary offshore coordination being explored by National Grid Electricity Transmission (NGET (Sea Link)) North Falls Offshore Wind Farm and Five Estuaries Offshore Wind Farm. NGET have committed to carefully considering the study's findings.

How the electricity network planning process is evolving

To ensure the network can accommodate new types of energy technologies, along with the UK Government and the regulator, we have been evolving the way electricity networks are designed.

Previously, assets generating electricity offshore were assessed on an individual basis. Each connection application was assessed through an economic lens, with consideration of the surrounding environment and network reinforcements required by the developer and Transmission Owners. Up until 2022, onshore network reinforcements, through the ESO's *Network Option Assessment*[2], were also assessed through this economic lens.

More recently, we have moved to an approach where the electricity network is designed holistically from the very first step in the cycle, considering the impact of multiple connections in a coordinated way, and balancing different network options against the four design criteria mentioned previously.

This evolution began with the UK Government asking us to create a coordinated network design that connected 23 GW of offshore wind to the onshore electricity network, supporting the Government ambition of connecting 50 GW of offshore wind by 2030 (known as the *Pathway to 2030 – Holistic Network Design*)[3]. In

[2] https://www.nationalgrideso.com/research-and-publications/network-options-assessment-noa
[3] https://www.nationalgrideso.com/future-energy/pathway-2030-holistic-network-design
The terms of reference for the Holistic Network Design and its subsequent follow up exercises were set by the UK Government, with alternative workstreams developed by the UK Government for offshore generation deemed too later stage to be included within the HND.

March 2024, we will publish the *Transitional Centralised Strategic Network Plan* which will facilitate connection of a further 21 GW of offshore wind connection in Scotland and provide a network plan out into the 2030s.

When the ESO transitions into a new public corporation in the summer of 2024, we will be responsible for producing a Centralised Strategic Network Plan (CSNP) as well as working with government to deliver a Strategic Spatial Energy Plan (SSEP), as announced in the UK Government's *Transmission Acceleration Action Plan (TAAP)*[4]. We expect the ESO to be commissioned to undertake the SSEP in 2024.

In practice this means working closely with UK, Scottish and Welsh governments as well as regional representatives to recommend where future electricity supply and large-scale demand should be located, and then subsequently and proactively identifying and designing energy networks (across electricity, gas and hydrogen) to ensure future iterations of the network is planned holistically, onshore, offshore and across vectors.

How the grid connection process works

We, as the ESO have overall responsibility for the electricity grid transmission connections process. This process, while under reform, is a regulatory approved process.

While in the future, we may be able to recommend to government through the strategic energy planning processes where future energy generation and demand should be regionally located, for existing grid connection contracts, we have very limited powers to move a customer's grid connection location and could be subject to legal challenge if we were to look to unilaterally alter or disregard contractual agreements.

Offshore generation previously went through what is known as Connections and Infrastructure Options Note (CION)[5] process. This is where a developer applied to the ESO with a preference on where they would like to connect into the system. The Transmission Owners then put forward a range of options on where the developer could connect into the Transmission System based usually on their preferred location. These options were then considered by the ESO, Transmission Owner and developer and then the ESO conducted a cost benefit analysis (CBA) on these options and a collective decision was made trilaterally on where the developer should connect in, and the connection offer made on that basis.

Usually, securing a grid connection is one of the first steps that developers take in their project, owing to the length of time it takes to connect into the system. Following this, developers usually start to engage with regional stakeholders through planning and consenting processes. It is ultimately a decision for the Planning Inspectorate and the Secretary of State as to whether associated energy infrastructure is granted planning consent.

2. Proposed regional energy generation and transmission network

Context today

East Anglia has a diverse mix of electricity generation sources including offshore wind, onshore wind, nuclear, solar, storage, and gas-fired power, which currently generates approximately 5.67 GW for the area. In terms of electricity demand, East Anglia has a growing population and economy, which has led to an increase in overall energy consumption. Current peak demand for the region is approximately 1.31 GW. The existing network in the East Anglia region can currently export around 4.2 GW of electricity generation. Figure 2 shows maps of existing transmission network within the region, showing what is known as the EC5 boundary.

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[4] Electricity networks: transmission acceleration action plan - GOV.UK (www.gov.uk)

[5] CION is developed by parties under the CUSC connections process and under CUSC (and more generally under s105 of the utility act). The outputs are confidentiality. Any disclosure would therefore require the other parties to the CION to consent to this.

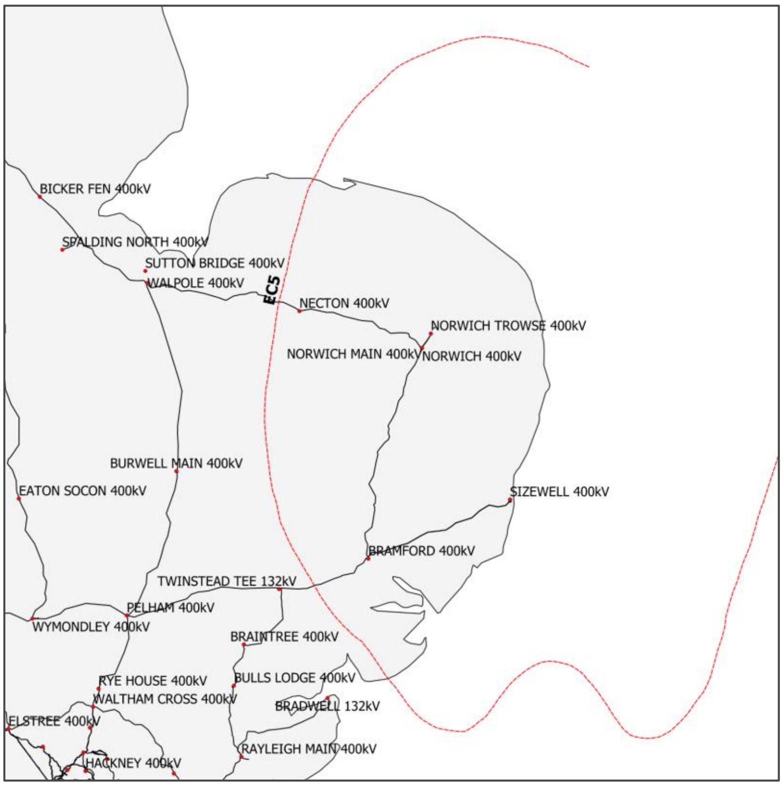

Figure 2: Map of existing transmission network in the region, showing the EC5 boundary

Boundaries such as the EC5 that includes much of East Anglia are used in our modelling to represent limitations of the existing power-flow system, as only a certain amount of power can flow out of the region based on the capacity of the existing network. As generation continues to increase within East Anglia and the behind the EC5 boundary, more export capacity from the region is required.

Proposed offshore energy generation connecting into East Anglia

Over the next decade, we will see a large growth in low-carbon renewable generation, in particular offshore wind, connecting into the East Anglia region. By 2030 we expect between 12.3 GW and 16.1 GW of new generation and interconnection into the region. As set out in *the Electricity Ten Year Statement*[6] *(ETYS)*. These are predominantly connecting behind the EC5 boundary which includes most of East Anglia. We first identified the need for this growth in export capacity in the NOA 2020/21 in January 2021.

Both the table and map below set out offshore generation projects planning to connect into the area[7]:

[6] https://www.nationalgrideso.com/research-and-publications/electricity-ten-year-statement-etys

[7] Information extracted from the ESO's TEC Register.

Project Name	Proposed onshore substation	Total capacity (MW)	Connection date	Generation type
Lion Link (Euro Link)	Friston 400 kV Substation	1600	2024	Interconnector
Vanguard	Necton 400 kV Substation	1320	2025	Wind Offshore
East Anglia Two	Friston 400 kV Substation	860	2025	Wind Offshore
East Anglia One North	Friston 400 kV Substation	860	2026	Wind Offshore
East Anglia Three	Bramford 400 kV Substation	Phased to total (1300)	Phased 2026-2028	Wind Offshore
Hornsea Power Station 3	Norwich Main 400 kV Substation	Phased to total (3000)	Phased 2026 - 2028	Wind Offshore
Nautilus	Friston 400 kV Substation *(exploring Isle of Grain as well)*	1500	2027	Interconnector
Vanguard East	Necton 400 kV Substation	Phased to total (1320)	Phase 2028 - 2030	Wind Offshore
Norfolk Boreas	Necton 400 kV Substation	Phased to total 1320	Phased 2029-2030	Wind Offshore
Scira-Dudgeon Extension	Norwich Main 400 kV Substation	Phased to total (1350)	Phased 2029 - 2034	Wind Offshore
Five Estuaries	East Anglia Connection Node	1080	2030	Wind Offshore
North Falls	East Anglia Connection Node	1000	2030	Wind Offshore
Race Bank Extension	Walpole 400 kV Substation	565	2030	Wind Offshore
Tarchon	East Anglia Connection Node	1400	2030	Interconnector

Table 2: offshore generation with a connection contract to the onshore electricity system within East Anglia.

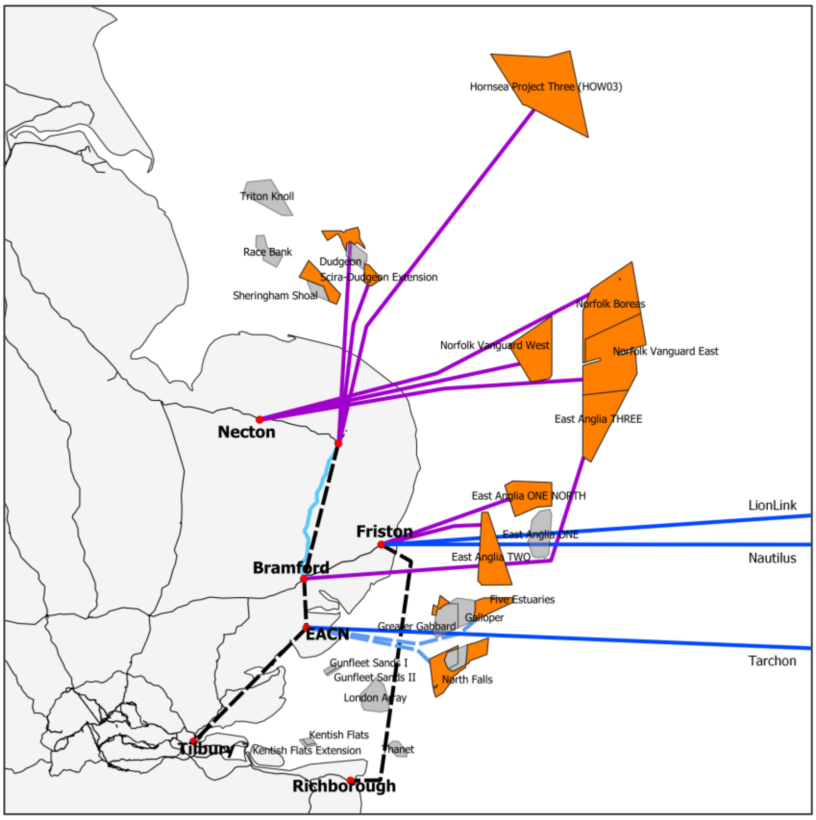

Figure 3: Map of existing and future generation in the region. Future, interconnectors are shown in dark blue. Links from future offshore windfarms are shown in purple. The light blue is the default connection arrangement for North Falls and Five Estuaries before OCSS

Our future energy scenarios are not predicting the level of regional electricity demand to increase at the same rate, meaning the region will be a net exporter of electricity. This imbalance of what is generated in the region to what is used locally means that more power will need to be transferred out of the region to the Midlands, London and the Southeast.

When there is not enough network capacity to transport power to where it is needed, bottlenecks or traffic jams ("constraints") are created on the electricity network. Because of these bottlenecks, as the system operator, we sometimes have to pay wind farms to switch off to prevent the grid becoming overloaded – wasting cheap, sustainable home-grown wind power. We do this through the Balancing Mechanism.

Solutions to network capacity constraints caused by increased energy generation

Today there are several solutions available to us to manage the increased power flows from the region predicted for the future, these include technical solutions, additional network capacity and in the future recommending where additional generation and demand should be located.

To resolve capacity issues in the short term, we have designed the Constraint Management Intertrip service (CMIS) and Local Constraint Market[8]. Once operational, this will contract with generators in the region to provide a more economical method of managing constraints than actions through the Balancing Mechanism. This follows the success of the CMIS now in operation across the boundary between England and Scotland. These schemes will provide some short-term relief on the constraint costs, but the volume of generation and benefits that these market solutions bring are not sufficient to avoid network investment.

Different types of energy generation proposed within the region can also be a solution to network capacity constraints. As there is a large amount of weather-dependent generation already connected or due to connect in the region, interconnectors provide opportunities to export energy away from the region to other countries when it is windy, negating the need for additional network capacity to transport all the electricity generation to centres of demand within England.

Network reinforcements currently proposed

To address the forecast network capacity constraints within the region, there are several proposed electricity transmission network routes currently being brought through planning and consenting by National Grid Electricity Transmission (NGET) in this region to support the wider electricity system, these are:

[8] Local Constraint Market | ESO (nationalgrideso.com)

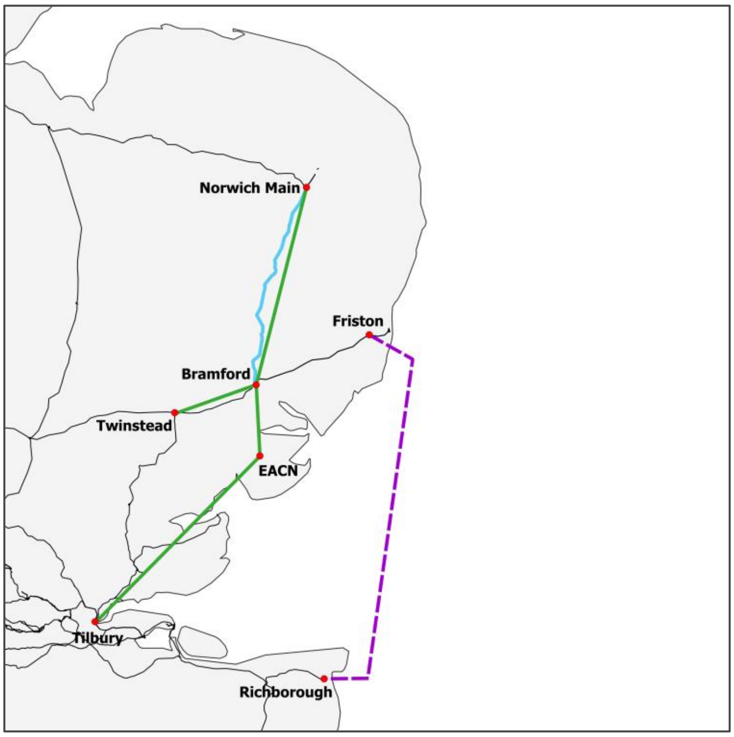

Figure 4: Map showing current reinforcements proposed by the Transmission Owner

Figure 4 Legend:

Works under construction by NGET. Bramford to Norwich refurbishment[1] – the existing 98 km route is being upgraded to bring it to modern standards and allow more energy to flow through it. Expected to be complete in Summer 2024.

Proposed new requirements by NGET. An upgrade of existing substations at Norwich and Bramford to provide more capacity at the existing sites (due to be operational in 2028).

A new transmission circuit between Bramford and Twinstead[1]. This 400 kV route is 29 km in length and is a mixture of 18 km of overhead lines and 11 km of underground cabling. This is currently with the Planning Inspectorate under the Development Consent Order (DCO) process and subject to their determination this circuit is expected to be operational by 2028. The Electricity System Operator (ESO) has provided the economic needs case for this circuit on page 13.

A new transmission circuit between Norwich to Tilbury. This 400 kV overhead route is 183 km in length and is due to be operational by 2030, subject to planning. This would include substation upgrades at Norwich, Bramford and Tilbury; and a new substation proposed in North Essex called 'East Anglia Connection Node' (EACN). This route was previously known as 'East Anglia GREEN'.

A new subsea cable named Sea Link[1] between a proposed substation at Friston in Suffolk and Richborough in Kent. This high voltage direct current (HVDC) offshore circuit is 145 km in length and due to be operational by 2030, subject to planning.

Electricity network requirements beyond the 2030s

The current electricity transmission cycle (known as the second Transitional Centralised Strategic Network Plan) is currently being finalised by us, the ESO, with an expected publication due in March 2024. This transmission planning cycle has focused on reinforcements the electricity network needs throughout the 2030s across Great Britain.

Economic needs case for Bramford to Twinstead

Bramford to Twinstead is a new 400 kV overhead Line being developed by NGET. The current capital cost of delivering the project is anticipated to be approximately £500 million. As a solution to the issue of exporting power from East Anglia, the option has been proposed for several years. Since the *Network Option Assessment* published in January 2019, we have seen a strong economic need for Bramford to Twinstead, and for this to be delivered by 2028.

The development of Bramford to Twinstead is well advanced, and NGET have submitted the Development Consent Order (DCO) to the planning inspectorate. Changing Bramford to Twinstead at this stage, would mean an alternative is unlikely to be delivered until beyond 2030. Our analysis of flows in the region, shows this would have a very significant cost to consumers - through additional constraint costs, lost low carbon energy, and wasted spend on the Bramford to Twinstead Network Optimisation (BTNO) project.

In the NOA7, BTNO received a proceed signal, and was shown to be optimal (e.g., required on its earliest in-service date) in all future energy scenarios in the economic analysis. The quantity of generation in these scenarios (based on FES 21) were notably lower than what is now expected to connect in East Anglia even before moving connections under OCSS. These higher values of generation in the region, strengthen the case for more capacity out of the region, such as that provided by Bramford to Twinstead.

In *NOA7 Refresh 2021/22*, BTNO received a ‘Holistic Network Design (HND) essential option’ signal meaning it is needed to ensure the compliance of the network.

Bramford to Twinstead, together with some other small developments provides around 3.6 GW of additional export capacity out of the region.

Figure 5 Future power flow expectations and requirements from the region

In the Transmission Works Register[1], Bramford to Twinstead is listed as transmission reinforcement schemes being carried out to facilitate generator connections. Bramford to Twinstead facilitates the connection of 9.5 GW of low-carbon and supporting technologies. This comprises of 4.3 GW of offshore wind, 3.5 GW of combined solar / battery projects, and 1.7 GW of battery storage projects. Previous studies have found that a one-year delay to delivering Bramford to Twinstead would cost consumers £25 million in constraint costs. From Figure 5, under all scenarios the existing capacity of the network is insufficient, and Bramford to Twinstead will add additional capability from later this decade onward.

3. Study introduction

Exploration of voluntary offshore coordination off the coast of East Anglia

Offshore wind farms off the coast of the region were deemed in scope of the early opportunities workstream due to their participation in early seabed leasing rounds run by The Crown Estate. This workstream led by the UK Government is part of the Offshore Transmission Network Review (OTNR). This workstream incentivised voluntary offshore coordination[9].

As announced[10] by the Department for Energy Security and Net Zero in July 2022, five projects within East Anglia agreed to commit to exploring voluntary coordinated network designs under the Government led OTNR. These projects were North Falls Offshore Wind Farm, Five Estuaries Offshore Wind Farm, National Grid Ventures (Lion Link[11] and Nautilus) along with National Grid Electricity Transmission (NGET(Sea Link)).

Overall, there were a number of design options proposed and assessed by these developers within East Anglia which consisted of offshore hybrid assets (OHAs) and sharing of onshore convertor station location and connection into Sea Link, a 2 GW high voltage direct current (HVDC) link between Suffolk and Kent designed to alleviate network constraints within East Anglia region.

The Early Opportunities workstream and the subsequent OCSS are UK Government-led workstreams, independent of the ESO. We were asked to provide constraint analysis to this workstream but were not privy to any design options created and subsequently taken forward by the relevant developers.

Offshore Coordination Support Scheme outcome

The conclusion of the analysis carried out by these developers resulted in one solution being proposed and deemed suitable for further development through the Offshore Coordination Support Scheme (OCSS).

The eligibility for schemes under the OCSS was outlined by the Government, and in particular criteria seven[12] said that the coordinated project must show the potential for a demonstrable reduction to cumulative onshore and offshore assets versus the alternative where relevant projects pursue radial or single purpose offshore transmission proposals.

As confirmed[13] by the Department for Energy Security and Net Zero on 5 December 2023, the outcome of the first exploratory stage of the OCSS has seen a proposal being put forward by North Falls Offshore Wind Farm, Five Estuaries Offshore Wind Farms and NGET (for their Sea Link project) to explore voluntary offshore coordination.

The proposal is for the two offshore wind farms to be coordinated. We have modelled this as the two wind farms connecting into an offshore platform into Sea Link (a new 2 GW HVDC circuit from the proposed Friston substation to Richborough in development by NGET). The current connection agreements have the two offshore wind farms connected to a proposed ‘East Anglia Connection Node’ (EACN) being planned in North Essex, on a new 400 kV overhead circuit from Norwich-Bramford-Tilbury.

[9] This consequently meant the offshore wind farms in development around those shores were deemed out of scope of the later stage workstream of OTNR, that enabled the creation of Holistic Network Design (HND) and its follow up exercises.
[10] Joint statement from North Falls, Five Estuaries and National Grid: Commitment to exploring coordinated network designs in East Anglia - GOV.UK (www.gov.uk)
[11] formerly named Euro Link
[12] Offshore Coordination Support Scheme guidance (publishing.service.gov.uk)
[13] Joint Statement

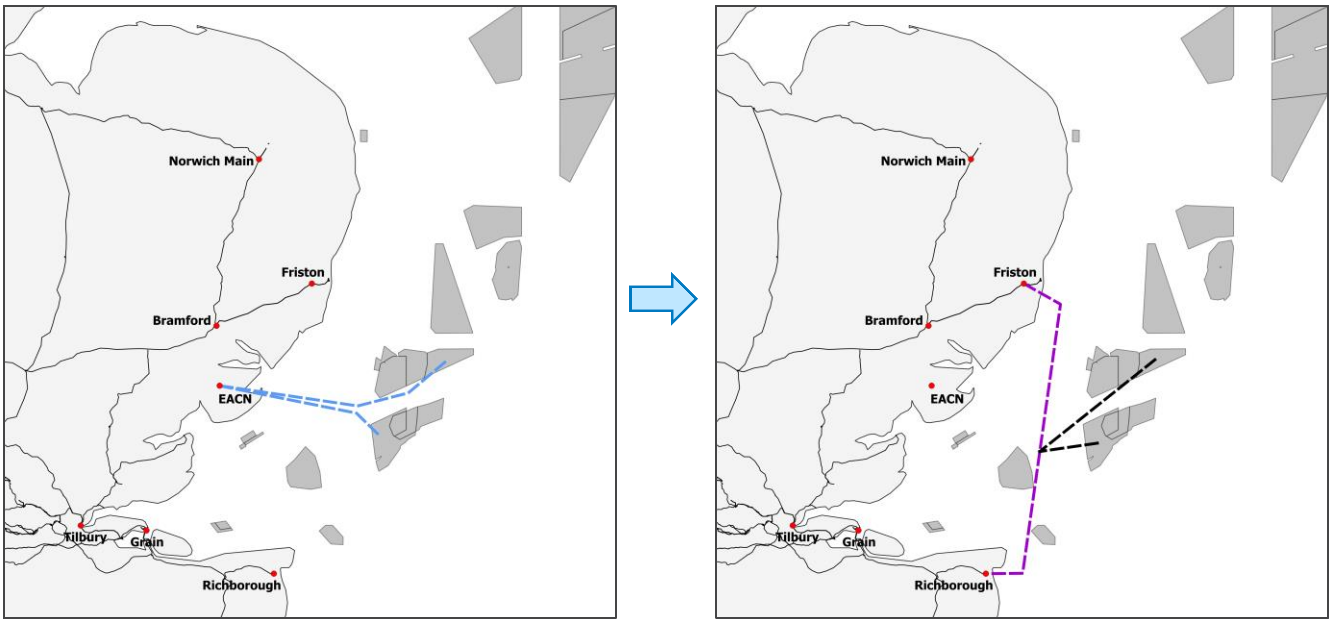

Figure 6: Map of North Falls and Five Estuaries offshore wind farms off the Suffolk/ Essex coast, and the indicative location of their contracted connection point to the transmission network prior to OCSS – the proposed substation at the East Anglia Connection Node, in North Essex

The wind farm developers and NGET are continuing to assess the feasibility of the proposed coordination over the course of 2024. UK Government will then take a view as to whether to continue to fund the exploration of this voluntary coordination.

It is important to note that a decision from government to grant OCSS funding does not result in immediate or automatic changes to existing, signed connection agreements between us and offshore wind projects. It is our understanding that all developers in scope of the OCSS are pursuing the exploration of voluntary offshore coordination alongside progressing their existing connection agreements.

Rationale for the Electricity System Operator’s (ESO’s) East Anglia network study

Separately, following the Offshore Coordination Support Scheme (OCSS) announcement, we agreed to study whether this change in connection location (due to the coordination proposed through the OCSS) changes the underlying power flows within the region.

The starting point for this study is therefore the change in power flows that have come from the changes in connection location of the North Falls and Five Estuaries offshore wind farms. Therefore, for the purposes of this assessment we have assumed that these offshore wind farms are connecting into Sea Link and not their currently contracted connection location at the proposed East Anglia Connection Node.

This study is separate from and independent of the electricity transmission network planning cycle. The ESO will not as a result of this study be making recommendations to relevant parties on which network option they should proceed with. The analysis within this report will be considered by NGET, the Transmission Owner. It will also be publicly available for consideration by other interested parties, should the OCSS coordination take place.

Study scope - What have we assessed?

The objective of this study is to provide a side-by-side holistic comparison of different electricity network configuration options that transfer power across or around the region. There are three core elements to this assessment which are as follows:

- Network technology capability assessment.
- A preliminary screening assessment of options submitted to us for consideration.
- A holistic assessment of network configuration options.

4. Network technology capability assessment

In order to get an independent view of different electricity network technologies to help aid our assessment[14], we asked DNV, an independent engineering consultancy firm, to provide their view of different network technology choices available on the market as well as next generation technologies not yet currently deployed.

Electricity network technologies used regularly in Great Britain

The three main current technologies used in Great Britain, and included within this study, are:

- Alternating current overhead line (AC OHL)
- Alternating current underground onshore cables (AC UGC)
- High voltage direct current link with offshore cables (HVDC).

The main technology used for the transmission network in Great Britain is AC overhead lines. These form the 275 kV and 400 kV supergrid built in the 1950s and 1960s to connect fossil fuel generation to areas of electricity demand. The majority of this network is overhead lines supported by lattice towers. Some elements of the network are undergrounded, typically through areas of designated landscape, or in very congested areas such as cities[15].

The 'National Policy Statement for electricity networks infrastructure' (NPS)[16] provides government planning guidance for developers of nationally significant electricity network infrastructure projects. It states that the UK Government's position is the use of overhead lines as the starting presumption for electricity network development. The NPS also explains when technologies such as underground onshore cables, or subsea offshore cables may be a viable alternative.

HVDC is a newer technology, primarily used for bulk power transfer over longer distances due to the lower losses of electricity compared to AC. HVDC can also connect 'non-synchronous' power regions – such as Great Britain to Ireland, or Great Britain to mainland Europe which can operate at slightly different frequencies.

HVDC technology is in use in Great Britain off the west coast from Hunterston to Connah's Quay (known as the Western Link) and from Spittal to Blackhillock across the Moray Firth in Northern Scotland (known as the Caithness to Moray HVDC line). New HVDC lines are planned as part of the Pathway to 2030 Holistic Network Design, including links on the east coast from Scotland to England.

Below is a table setting out DNV's key comparisons between these technologies, more detailed analysis can be found within the report's appendix.

Characteristic	AC OHL	AC UGC	HVDC (VSC[17])
Archetype Description			
Maximum continuous	>6,000 MVA	>6,000 MVA[18]	2,000 MVA

[14] Please note: this network technology capability assessment is not an assessment of how the technologies perform as part of wider solutions, it is simply a unit cost comparison that is true regardless of how it is deployed.
[15] AC network technology can also be used for short distances offshore. However as this is not a technology utilised for the purposes of this study, it is not included within DNV's assessment.
[16] National Policy Statement for electricity networks infrastructure (EN-5) - GOV.UK (www.gov.uk)
[17] Voltage Source Converter, see details on types of HVDC technology in Section 7
[18] Comprising one or more underground cables per electrical phase

Characteristic	AC OHL	AC UGC	HVDC (VSC[17])
transmission capacity (MVA)	(per 400 kV double circuit route)	(per 400 kV double circuit route)	(per +/-525 kV bipole circuit route)[19]
Maximum technically feasible route length (km):	Unrestricted - but see note[20][3]	~ 20 km - but see note[21]	Unrestricted
Lifespan (years)	> 40 years[22]	> 40 years[23]	~ 40 years[24][7]
Infrastructure operational footprint	• 50-150sqm land-take per tower, 3 spans per km • Building beneath the overhead line route permanently discouraged, though many agricultural /rural land uses can resume • Periodic vegetation management required	• Building and excavations permanently discouraged within, typically, a 25m wide cable swathe (see DNV report), though many rural/agricultural land uses above ground can resume • Periodic vegetation management may be required	• ~45,000sqm land-take per 2,000 MVA converter station (max. 2 converter stations per circuit) • Building and excavations permanently discouraged within ~10m wide onshore cable swathe, though many rural/agricultural land uses can resume
Future scalability for long-term planning	✓ Uprating (at refurbishment) ✓ Route diversion ✓ Usually less cost and disruption to connect additional generation and demand in the future	✗ Uprating ✗ Route diversion ✗ Usually more cost and disruption to connect additional generation and demand in future	✗ Uprating ✗ Route diversion ✗ Impractical to connect additional generation and demand in future
Deliverability and operability			
Planning and consents	• An application for a Development Consent Order (DCO) is required • Process complex and time-consuming, could	• Process relatively easier for underground cables • Classed as 'permitted development' • Any sealing end compounds may require planning permission	• Subject to all usual planning procedures for onshore and offshore connections • Planning consent for a converter station can vary very considerably and subject to significant delays

[20] En-route compensation stations may be required beyond about 200 km route length.

[21] Beyond around 20 km route length, a 400 kV AC underground cable circuit would need intermediate compensation so, technically, interfaces with the network become increasingly complex and costly.

[22] Major refurbishment(s) of overhead line conductor systems at around 40-year intervals are expected to extend overhead line lives to 80 or even 120 years.

[23] XLPE cable technology track record for transmission voltages is still developing, but early indications are that these cables could possibly reach 80-year lives, or more, without major refurbishment.

[24] HVDC expected to require a major refurbishment at around 20 years to achieve this design life.

Characteristic	AC OHL	AC UGC	HVDC (VSC[17])
	sometimes lead to public inquiry • Compulsory purchase authority may be used in special circumstances	• Suitable rights over land (wayleaves and easements) are needed, often granted voluntarily	• Complex consent process for offshore power cables due to requirements for ‘no disruption’ assurance to other linear services (including power, telecoms, gas, oil), other sea users, plans for the seabed and sea life • A National Competent Authority (NCA) will provide the final approval for projects in England
Reliability, availability and maintainability	• Robust operation - auto-reclose for lightning strikes • Physical damage normally repaired within hours or days (excessive damage within weeks) • Maintenance; three days pa (average)	• Reliable operation • Physical damage repaired within days (excessive damage within weeks) • Maintenance; 3 days pa (average)	• Reliable operation (however limited-service experience) • Physical damage to converter repaired within hours or days • Physical damage to cable repaired within months • Maintenance; 10 days pa (average)
Flexible circuit rating	• Up to 35% above rating for short period.	• Up to 30% above rating for short period.	• None
Environmental impacts			
Construction	• Traffic noise and dust • Access may impact vegetation/habitats • Potential impact on biodiversity (habitat loss) • Construction activities contribute to Greenhouse Gas (GHG) emissions	• Traffic noise and dust • Excavation activities may lead to soil disturbance, vegetation removal and habitat loss • Construction activities contribute to GHG emissions	• Traffic noise and dust • Potential impact on marine species and seabed disturbance • Construction activities contribute to GHG emissions and water pollution
Operational	• Acoustic noise (poor weather crackle) • Potential impact on bird species (collision risk)	• Cable access points will require vegetation clearance	• Acoustic noise and vibration impact (permanent hum) on biodiversity • Vessel traffic
Community impacts			
Construction:	• Minimal traffic disruption	• Traffic disruption • Potential land use disruptions due to cable	• Traffic disruption • Disruption to economic activities such as fishing

Characteristic	AC OHL	AC UGC	HVDC (VSC[17])
	• Land use disruptions • Less impact in rural areas, higher impact in urban due to population proximity	trenching (depending on the route selected) • Less impact in rural areas, higher impact in urban	• Low impact on both rural and urban areas, but higher impact on both with installation of new supporting infrastructure (if required)
Operational:	• Tower ground footprint occupied • Potential to depress property values • Building on route denied • Visual impact • Potential 50Hz EMF exposure • Noise propagation	• Building on cable route denied • Potential 50Hz magnetic field exposure	• Converter station ground footprint occupied • Building on cable route denied • Converter station visual impact • Potential DC magnetic field exposure
Cost magnitude comparison factors for a 75 km 6,380 MVA / 6,000 MW transmission route (per unit)[25]			
Lifetime archetype costs:	x 1	x 4.7	x 8[26]
Lifetime losses costs:	x 1	x 0.8	x 1.6[27]
Commercial and supply chain			
	• Currently, no known supply issues for overhead line – key dependencies are supplies of aluminum and steel	• Long UGC installations may suffer extended delivery lead times • Reactive compensation required for long cable installations that may suffer extended delivery lead times	• There are presently three competitive 2000MW VSC HVDC converter suppliers • As global demand rises (as expected in the near future), converter delivery lead times are expected to lengthen • Key issue for HVDC links is presently the lack of submarine cable manufacturing capacity. Delivery lead times are already extended 2-3 years beyond normal, and likely to further increase until new production comes online around 2030

Table 3: Unit comparison (AC overhead line, AC underground cable, HVDC link with offshore cables)

As the above table illustrates, there are trade-offs between the different types of network technologies and the choice to be made between them depends on where and when the infrastructure is being deployed. From a high-level perspective, the following are the summary findings for each technology.

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[25] Based on cost analysis in Section 4, for all three technologies the minimum values tend to reflect the longest route length, while the maximum costs tend to associate with the shortest route length. It should be noted that these cost comparisons are generalised; they are based upon many assumptions, and they are not associated with a specific application or location. For this reason, they should be treated as indicative only

[26] In practice this 6,000 MW capacity would probably be realised with 3 x 2MW HVDC links. This cost factor includes an allowance for mid-life refurbishment of the converter electronics.

[27] Mainly due to losses from converter station

- The lowest cost and least environmentally impactful are AC overhead lines, however they are the most visually intrusive once built.
- Underground AC circuits are more expensive solutions and more environmentally damaging during the construction phase. They are also potentially technical viable only for shorter routes (typically of less than 20 km) however they are less visually intrusive once built.
- HVDC is the most feasible technology for longer circuits where a cable solution is necessary, and it offers important operational benefits compared to AC equivalents over such distances, such as the direct control of power flow and dynamic voltage support, it is also more expensive option (per installed km) compared to an AC alternative, and it is the most inflexible to adapt if the network requirements change over the lifetime of the asset.
- The maximum ratings of present HVDC technology are lower than AC circuits, which means that to achieve the same transmission capability, multiple HVDC circuits would be required.
- All three technology types need to comply with transmission licensing, technical codes and engineering policies. The regulations apply equally.

5. Preliminary assessment of proposed options

Over the three-month study period, five alternative 'network' options were submitted to us by community representatives for our consideration. These were:

- Proposed Option: A predominantly onshore option without East Anglia Connection Node (EACN).
- Proposed Option: Two or more multi-purpose interconnectors (MPIs) with wind farms connecting into them, utilising Bradwell in Essex as an onshore interface point as well as areas in Kent.
- Proposed Option: An undergrounded high voltage direct current (HVDC) cable stretching from Norwich in Norfolk to Tilbury in Essex.
- Proposing Option: A predominantly offshore option - Utilising Bradwell in Essex as an interface point for HVDC cables.
- Proposed Option: An offshore ring main, connecting all wind farms around the coast of the region, utilising brownfield sites for onshore interface points, such as Bradwell and areas in Kent.

Preliminary assessment process

To determine whether options submitted to us should be taken forward to the next stage of holistic assessment, we have screened these options against the below criteria as outlined within the table below.

	Proposed Option	**Proposed Option**	**Proposed Option**	**Proposed Option**	**Proposed Option**
Description	**Onshore option without EACN**	**Two or more MPIs**	**Underground onshore HVDC**	**Predominantly offshore option - Utilising Bradwell as a landing point**	**An offshore ring main**
Is this proposal in scope of the study's Terms of Reference[28]?	Yes	No	Yes	Yes - if Bradwell is hosting transmission infrastructure, no if it is hosting generation infrastructure.	No
Would the proposal require a change in connection location for projects not exploring voluntary coordination through the OCSS?	Within the sensitivity range of the study	Yes	No	No – if only wider network HVDC landing points were considered.	Yes

[28] East Anglia Study – Terms of Reference - download (nationalgrideso.com)

Description	Proposed Option Onshore option without EACN	Proposed Option Two or more MPIs	Proposed Option Underground onshore HVDC	Proposed Option Predominantly offshore option - Utilising Bradwell as a landing point	Proposed Option An offshore ring main
Is the proposal technically feasible in the timescales the capacity is needed?	Yes	Yes - if regulatory regime is in place	Yes	Yes	No
Progression to next stage of assessment	Yes	No	Yes	Yes – if the proposal is only moving network transmission infrastructure to Bradwell	No

Table 4: Summary of the Gate 1 assessment of the proposals.

6. Holistic Assessment

Methodology for holistic assessment

The design criteria methodology we use helps us to balance the impacts of new infrastructure with the benefits it can bring. This methodology was originally approved by the UK Government as part of their Offshore Transmission Network Review (OTNR) and later adopted into our wider onshore network planning process. Our equally weighted design criteria for new infrastructure are:

- Criteria 1: Can be delivered and operated in a timely and practical way.
- Criteria 2: Minimise the impact, where possible, on the natural environment.
- Criteria 3: Minimise the impact, where possible, on the communities that host this infrastructure.
- Criteria 4: Can be delivered in an economic and efficient way, ensuring the best value for consumers.

As this is still the first step in the electricity transmission network planning cycle, it is important to emphasize that the holistic assessment is based on high level study areas (often using geospatial data), not route corridors. If these network options are progressed further by the relevant Transmission Owner they will undertake more detailed assessments, to help determine any potential cumulative as well as specific community impact and local environmental constraints.

The assessment used a combination of financial information about the designs e.g. capital infrastructure costs and operational costs to determine the value of each design in terms of net present value (NPV). The NPV enabled us to compare the economics across each design.

To assess and compare the deliverability and operability, environmental impact, and community impact, we used Black, Red, Amber, or Green (BRAG). Definitions of the BRAG ratings are provided below:

BRAG Ranking		
●	Black	The design is not viable in its current state from an environmental/community/deliverability and operability perspective due to environmental/community/deliverability issues.
●	Red	The design has a high level of constraints from an environmental/community/deliverability and operability perspective and is potentially viable, however will have to overcome many environmental/community/deliverability issues.
●	Amber	The design has a medium level of constraints from an environmental/community/deliverability and operability perspective and is

		likely to be viable, however may have to overcome some environmental/community/deliverability issues
●	Green	The design has a low level of constraints from an environmental/community/deliverability and operability perspective and is likely to be viable without any major environmental/community/deliverability issues.

Table 5: Definitions of BRAG ratings

The BRAG is also applied to subparts of the ratings, and the overall deliverability, environmental and community is taken as the cumulative impact of the subparts. In general, the most severe rating of a subpart applies to the rating of the whole option.

To assess and compare the economic impact, we have presented two rankings in this report. Further details and sensitivities are contained in the appendix. We have compared the capital cost of delivering each option, with the benefit it brings in reducing constraints. This is a lifetime cost measure – the cost of building an option plus the constraints remaining. We present that costs in comparison to the cheapest option, which in this assessment is Option 3. We have secondly compared the options as if they were all delivered in 2034, to assess the impact if options delivered earlier where to be delayed. As additional lifetime costs range from £0bn to over £10bn, we have divided the range in to three for the RAG status: £0-£3bn Green; £3bn-£7bn Amber; £7bn or above Red.

In the appendix, we have included further economic analysis including sensitivities to other generation and demand scenario, the impact of new strategic demand and changes in constraint and capital cost.

As the starting assumption for this study is that Offshore Coordination Support Scheme (OCSS) has happened, any costs associated with changes to Sea Link or other coordination costs (which would be common across options) are not included.

Additional assessment - community sentiment

In addition to the assessment criteria set out above, we have also assessed the community sentiment of all options, set out in the result below. This has followed from engagement we have undertaken with a range of community and elected representatives. We are, however, unable to quantify this assessment and represent the views of the whole community. We have therefore included this separately below.

Options under holistic assessment

Following the preliminary screening assessment, network configuration options have undergone holistic assessment using the above methodology.

These are set out below[29]:

1. Predominately offshore option – variation without EACN
2. Predominately offshore option – variation with EACN
3. Onshore option
4. Alternative onshore option – variation without Bramford to EACN
5. Alternative onshore option – variation without EACN
    b. Alternative onshore option – variation without EACN – sensitivity
6. Hybrid onshore and offshore option – variation with EACN
7. Hybrid onshore and offshore option – variation without EACN
8. Onshore HVDC option
9. Predominantly offshore option – Utilising Bradwell as a landing point.

These network configuration options are a variation of on and offshore circuit options that transfer power across or around the region. The options have been tested against multiple variables such as:

- Different background assumptions of supply and demand through Future Energy Scenarios

[29] Option 5, 8 and 9 correspond to Proposal P5, P3 and P4 respectively.

- Different commissioning dates for new elements of the network infrastructure
- Additional growth in large strategic demand such as data centres or hydrogen electrolysers

The options have also been benchmarked against standard costs, sliding timelines of delivery and how that impacts costs, as well as similar projects elsewhere across Great Britain and beyond. Feedback provided by stakeholders on the proposed circuit options have been accounted for within the report under the community sentiment metric.

Assumptions relating to grid connections, network requirements and delivery dates for options under holistic assessment

Offshore wind farms

In all ten circuit configuration options set out below, each offshore wind farm is assumed to connect at their current contractual location at set out in their connection agreement[30] apart from North Falls and Five Estuaries offshore wind farms. These two wind farms are modelled as connected into Sea Link in all ten network configuration options, as per their voluntary exploration of coordination through the OCSS.

All other generation and demand, nationally and locally, connects according to the locations in our Future Energy Scenarios[31] which is consistent with our overall approach to network planning.

Interconnectors

There are three proposed interconnectors with connections in the region[32]. Contractually, two interconnectors have connections[33] at Friston (Nautilius and Lionlink), and one has a connection at EACN (Tarchon). Nautilius's developer has said[34] they are also investigating changing their connection location to Isle of Grain in Kent, we have therefore modelled this interconnector at both Friston and the Isle of Grain.

As a result of the OCSS process, Tarchon interconnector is the only party left connecting at the proposed East Anglia Connection Node. The OCSS drives no other similar change we have therefore conducted sensitivity analysis as to whether the interconnector connects at that proposed node or elsewhere.

In terms of the connection locations for interconnectors:

- In most options where EACN is constructed, the three interconnectors connect at contracted position (one at EACN, and two at Friston). These are options 3,4,6 and 8.
- In options where EACN is not constructed, we assume two interconnectors at Friston (unchanged) and one at Grain). These are options 1, 5 and 7.
    - We have conducted a sensitivity analysis on option 5 to assume three interconnectors behind the EC5 electrical boundary – known as option 5b.
- In option 2, where EACN is constructed, one interconnector is connected as each of EACN, Friston and Grain. This is because otherwise, three interconnectors would be connected in proximity between Friston and Bramford which would likely trigger the need to upgrade the onshore network further.
- In option 9, as we are exploring Bradwell as a landing site, it is assumed one interconnector lands at Bradwell, one at Grain and one at Friston.

As stated previously, we, as the ESO cannot unilaterally compel Nautilus or Tarchon to move connection locations[35].

Why is a potential new circuit required from Friston to EACN in some options?

In all the options (except for option 9), a new route is shown as being required from Friston either onshore to EACN or offshore to (nominally) Sellindge in Kent. The need for one of these circuits is triggered by the

[30] https://www.nationalgrideso.com/data-portal/transmission-entry-capacity-tec-register/tec_register
[31] https://www.nationalgrideso.com/future-energy/future-energy-scenarios-fes
[32] An interconnector is an HVDC cable that connects the GB power system to the power system of another country and are developed under Ofgem's Cap and Floor regime.
[33] https://www.nationalgrideso.com/data-portal/interconnector-register
[34] About Nautilus | National Grid Group
[35] This assessment was conducted prior to Ofgem's interconnector cap and floor announcement.

changes in the location of generation proposed by OCSS, which brings further generation (North Falls and Five Estuaries) linked to the proposed Friston substation via Sea Link.

The following table summarises the existing and planned generation and interconnectors at Sizewell, Leiston and proposed Friston substations:

	Already Connected	Planned
Sizewell	• Sizewell B nuclear power station	• Sizewell C nuclear power station
Leiston	• Galloper offshore wind farm • Greater Gabbard offshore wind farm	
Friston (proposed)		• East Anglia One North offshore wind farm • East Anglia Two offshore wind farm • Nautilius interconnector[36] • Lionlink interconnector • Sea Link HVDC, which connects to North Falls and Five Estuaries offshore wind farms (under OCSS)

Table 6: Generation and Interconnection planned for existing Sizewell and Leiston substation, and proposed substation at Friston

The existing route for power out of the region is two double overhead circuits from Sizewell to Bramford, where it connects to the rest of the electricity network. In this study, Sea Link is always required to be built to provide generation connections for North Falls and Five Estuaries.

In designing the network to account for this change in generation connection, the system must be robust to faults and temporary loss of parts of the network – this is so continuity of supply is maintained. The Security and Quality of Supply Standard[37] (SQSS) provide the standard for how connections and the wider network need to be designed; and in particular under which faults on the network we cannot have a large loss of generation. For this area local to Sizewell, there are two credible faults to consider – (i) a fault of one of the double circuit overhead lines, or (ii) a fault on Sea Link which means all the power from the wind farms must flow north.

Under projection for the mid 2030s, there is around 9.4 GW of generation in the region, plus interconnectors. For the highest power flow and transmission loading case, we assume full generation output meaning around 9.4 GW of power to take out of the region[38] which includes output from North Falls and Five Estuaries which have moved to the area under OCSS. Broadly, under a fully intact (without any disconnected circuits) network (2 x double circuits, plus Sea Link) a total of 14 GW of power could be exported from the region.

However, we must secure the network under fault conditions to ensure that generation remains connected:

- Under a fault of one of the existing double circuit overhead lines out of the region the export capacity of the area reduces to around 8 GW (one double circuit plus Sea Link) which is less than the generation connected. This is not an acceptable fault condition under the SQSS and must be avoided.
- Under a fault of Sea Link, there is sufficient capacity to export the generation via the remaining double circuit overhead lines.

It also follows that if less generation were to connect then the need for an additional circuit, based on 'fault conditions', may be removed. In the situation without OCSS an additional circuit is not required.

The need for the additional circuit is the cumulative impacts of all the generation connected / connecting at Friston, Leiston and Sizewell (including North Falls and Five Estuaries under OCSS), but it is likely to be 'required' for operation only when Sizewell C Nuclear Power Station connects (as this is the last of the

[36] The developer, NGV have discussed moving the connection for *Nautilus* from Friston to the Isle of Grain, they still hold a contractual agreement to connect at Friston.
[37] Security and Quality of Supply Standard (SQSS) | ESO (nationalgrideso.com)
[38] There is minimal local demand in the region.

proposed connections to connect[39]), hence a delivery date of 2034 is acceptable for that line (see delivery dates below).

This additional circuit out of the Sizewell/Friston area can either be an onshore route to the EACN, or as a second HVDC line from Friston to (indicatively) Sellindge as in the previous options. If it were an onshore route, the default in planning is that it would be an overhead line, with some portions potentially undergrounded.

Delivery Dates

Delivery dates for each option are based on several elements. In each option Sea Link is assumed to deliver its base capability in 2030, and then take an outage in 2032 to integrate North Falls and Five Estuaries offshore wind farms. After this, Sea Link returns but provides reduced capacity, as it is now dual purpose as both a route to move power to and from the region, and a connection point for offshore wind.

The current projected timescale for the delivery of Norwich to Tilbury is 2030. This applies to parts of the route such as Norwich to Bramford, Bramford to EACN, and EACN to Tilbury.

For other new or substantially new circuits, such as the new offshore proposed lines, the Friston to EACN, or Friston to Tilbury routes, which have not been subject to any detailed engineering, consultation or consenting, these are assumed to be delivered by 2034 at the earliest.

All delivery date assumptions are based on technical assessment, a planning process which runs ‘to time’, and a supply chain which is able to deliver what is required. The risk to consenting and supply chain are captured in the deliverability assessment.

We have undertaken a sensitivity if the 2030 onshore elements were delayed. This will provide a direct comparison of if all projects were delivered in 2034 as requested by stakeholder.

[39] Sizewell C has a contractual connection date of 2029 and 2030 in the TEC register. However, the developer have said a ten to twelve year build from construction which has recently commenced edfenergy.com/sites/default/files/szc-esg-brochure.pdf

Options Assessment

1. Predominately offshore option – variation without EACN

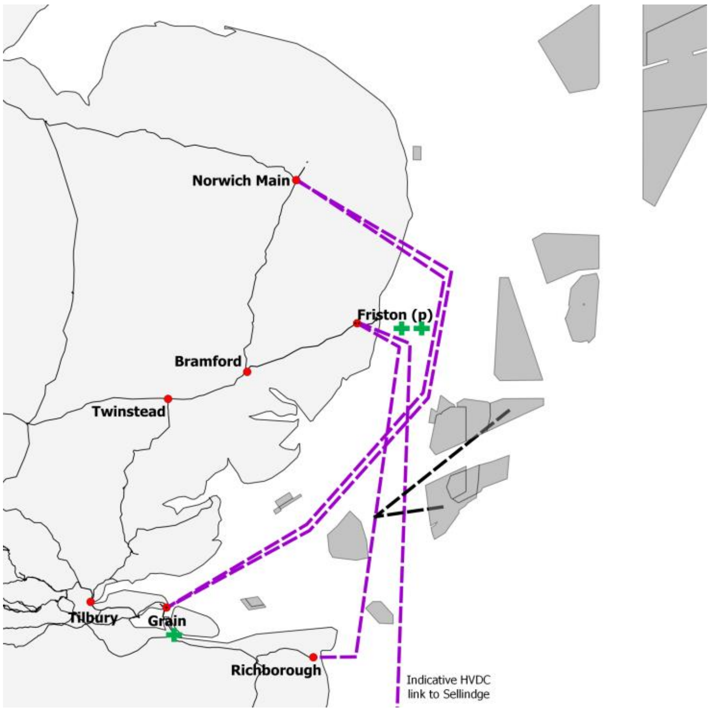


Figure 7: Map showing Option 1: Predominantly offshore option – variation without EACN

Legend
- Existing Transmission Network
- Proposed AC circuit
- Proposed HVDC circuit
- Coordination from North Falls / Five Estuaries & Sealink
- Key Substations (*p* = proposed)
- Interconnector connection points

Option Description

This network configuration has four circuits and is a predominantly offshore option, with no additional overhead lines proposed in East Anglia.

There are two proposed onshore starting points for undersea cables, beginning at Norwich and Friston that will be undergrounded to the coast and continue offshore in the sea to three onshore locations in Kent - Grain, Richborough and (nominally) Sellindge.

Technology

- Two 2 GW HVDC links from Norwich to Grain, providing 4 GW of capacity with HVDC converter stations to be built at both ends of the link.
- One 2 GW HVDC link from Friston to (nominally) Sellindge with HVDC converter stations to be built at both ends of the link.
- One 2 GW HVDC link from Friston to Richborough into which North Falls and Five Estuaries connect into Sea Link. This will also need HVDC converter stations to be built at both ends of the link.

Delivery Date	2034 (with Sea Link delivered earlier)
Capital Cost	£5.8bn

Option 1			
Design Criteria	**Ranking**	**Sub Description**	**Commentary**
Deliverability & Operability	Red	Supply chain, deliverability, and operability	Challenging delivery with multiple offshore HVDC circuits. Limited suppliers of HVDC and known supply chain delays. Complex operation to coordinate all HVDC circuit power flows. This drives the Red rating.

		Consenting	The solution is predominantly offshore, and so consenting is believed to present complexity, especially around areas with a concentration of infrastructure such as Friston.
Environmental	Red	Norwich to Grain	Norwich to Grain must first traverse underground to the shore (avoiding The Broads), and through a complex marine environment comprising of extensive and overlapping SACs, SPAs, MCZs and SSSIs, resulting in its Red rating. As the Norwich to Grain route makes up a significant proportion of this option, and considering the complexity of mitigations in the marine environment compared to on land, the overall rating is assessed to be Red. A Red rating means this option is heavily constrained, it is potentially viable, however will have to overcome many environmental issues.
		Friston to Richborough	
		Friston to nominally Sellindge	
Community	Amber	Norwich to Grain	All the routes featured in this option are predominantly offshore routes. As such, the overall community impact is moderately constrained for this option. Some significant impact is possible at the coastal interface, and avoidance of constraints may be challenging, but should still be possible at the detailed routeing stage of the design process.
		Friston to Richborough	
		Friston to nominally Sellindge	
Economic	Economic Rank	£4.2bn	The options received an Amber rating costing £4.2bn more over its lifetime compared to the cheapest option (Option 3 delivered in 2030). This option is delivered in full by 2034. It is one of the most expensive options driven by the cost of converter stations and HVDC subsea cabling. It is effective at reducing constraints but not sufficient to offset the additional CAPEX, or the delayed delivered.
	Delay Impact	£4.2bn	There is no change in the relative economic position of this option if all options are considered delivered in 2034.
Community Sentiment	Amber	This option negates the need for new overhead lines – removing visual impact; however, it has significant concentrated impact at proposed coastal nodes.	

2. Predominately offshore option – variation with EACN

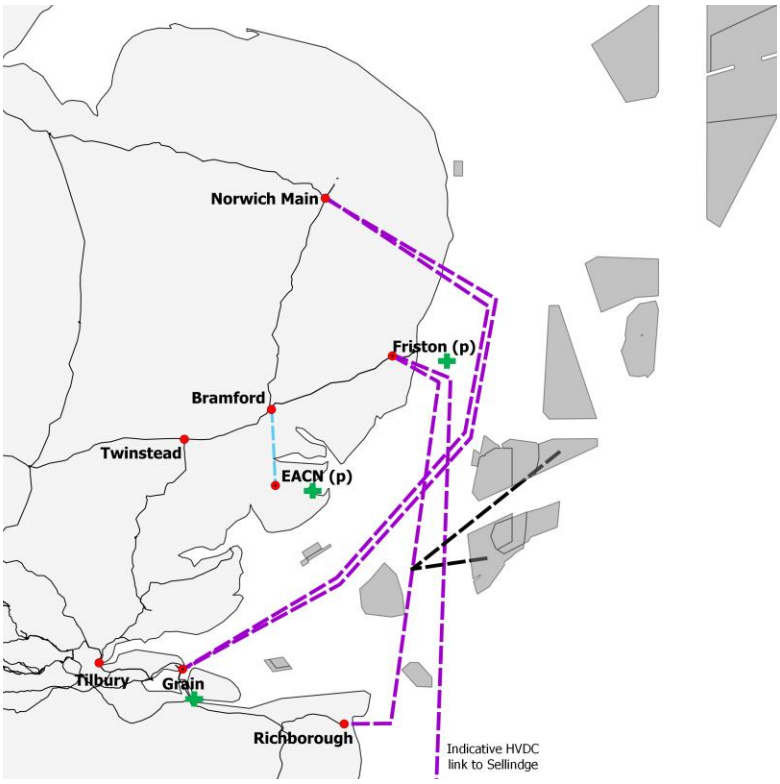
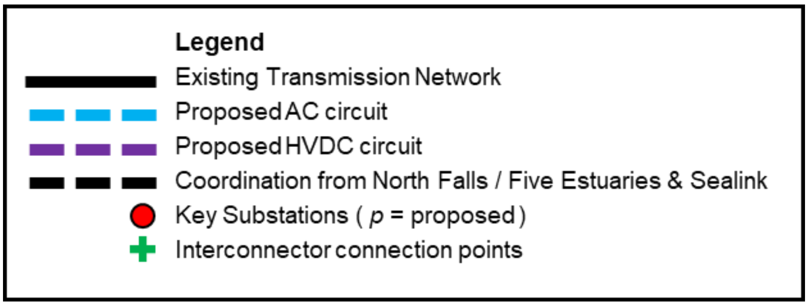


Figure 8: Map showing Option 2: Predominantly offshore option with EACN



Option Description

This network configuration has five circuits. These circuits would begin at Norwich and Friston and will be undergrounded to the coast and continue offshore in the sea to three onshore locations in Kent - Grain, Richborough and (nominally) Sellindge.

It also has an onshore circuit to connect the proposed EACN substation to Bramford substation.

Technology

- Two 2 GW HVDC links from Norwich to Grain, providing 4 GW of capacity with HVDC converter stations to be built at both ends of the link.
- One 2 GW HVDC link from Friston to (nominally) Sellindge with HVDC converter stations to be built at both ends of the link.
- One 2 GW HVDC link from Friston to Richborough into which North Falls and Five Estuaries connect, known as Sea Link. This will also need HVDC converter stations to be built at both ends of the link.
- One AC onshore route from the proposed EACN to the Bramford substation. It is likely that this circuit would be part part overhead line, and part underground through the Dedham Vale Area of Outstanding Natural Beauty (AONB)[40].

Delivery Date	2034 (with Sea Link delivered earlier)
Capital Cost	£5.9bn

[40] The ESO have made this assumption as this is similar circuit route to that be proposed by NGET as part of the existing Norwich to Tilbury circuit. Partial undergrounding has been identified through the Dedham Vale Area of Outstanding Natural Beauty (AONB) as part of this circuit.

Option 2			
Design Criteria	**Ranking**	**Sub Description**	**Commentary**
Deliverability & Operability	Red	Supply chain, deliverability, and operability	Challenging delivery with multiple offshore HVDC circuits, and an additional onshore circuit. Limited suppliers of HVDC and known supply chain delays. Complex operation to coordinate all HVDC circuit power flows. This drives the Red rating.
		Consenting	This solution is predominantly offshore, but with an onshore route from Bramford to the EACN, and the associated substation onshore. This is likely to present a level of high complexity around consenting, especially around areas with a concentration of infrastructure such as Friston, and the impact on EACN and the Dedham Vale.
Environmental	Red	Norwich to Grain	Norwich to Grain makes up a significant proportion of this option. The route must first traverse overland (avoiding The Broads), and through a complex marine environment, with the cumulative combination of designations and receptors such as SACs, MCZs and SPAs, mostly in the southern section, causing its Red rating. Because of the significance of the Norwich to Grain route to this option, and considering the complexity of mitigations in the marine environment, the overall rating is assessed to be Red. A Red rating means this option is heavily constrained, it is potentially viable however, will have to overcome many environmental issues.
		Friston to Richborough	
		Friston to nominally Sellindge	
		Bramford to EACN	
Community	Red	Norwich to Grain	Much of this design option is in the marine environment, however considering the significant constraints identified between Bramford and EACN, overall the combination of routes make this option significantly constrained. Some impact will need to be considered at the coastal interface and detailed routeing will need to be carried out to avoid where possible some of the key constraints. Additionally, undergrounding may need to be considered as a mitigation for some of these features, for example Dedham Vale National Landscape, which spans a significant part of the study area.
		Friston to Richborough	
		Friston to nominally Sellindge	
		Bramford to EACN	
Economic	Economic Rank	£4.8bn	The options received an Amber rating costing £4.8bn more over its lifetime compared to the cheapest option (Option 3 delivered in 2030). This option is delivered in full by 2034. It is the most expensive options driven by the cost of converter stations and HVDC subsea cabling, and the onshore route through the Dedham Vale. It is effective at reducing constraints but not sufficient to offset the additional CAPEX. It performs slightly worse that Option 1 as an interconnector is moved out of the region (otherwise there would be too many Interconnectors close to Bramford/Friston), which exports power when there is high wind / low prices in Great Britain.

Option 2			
	Delay Impact	£4.8bn	There is no change in the relative economic position of this option if all options are considered delivered in 2034.
Community Sentiment	Red	This option involves a short OHL/UG onshore infrastructure through an Area of Outstanding Natural Beauty.	

3. Onshore option

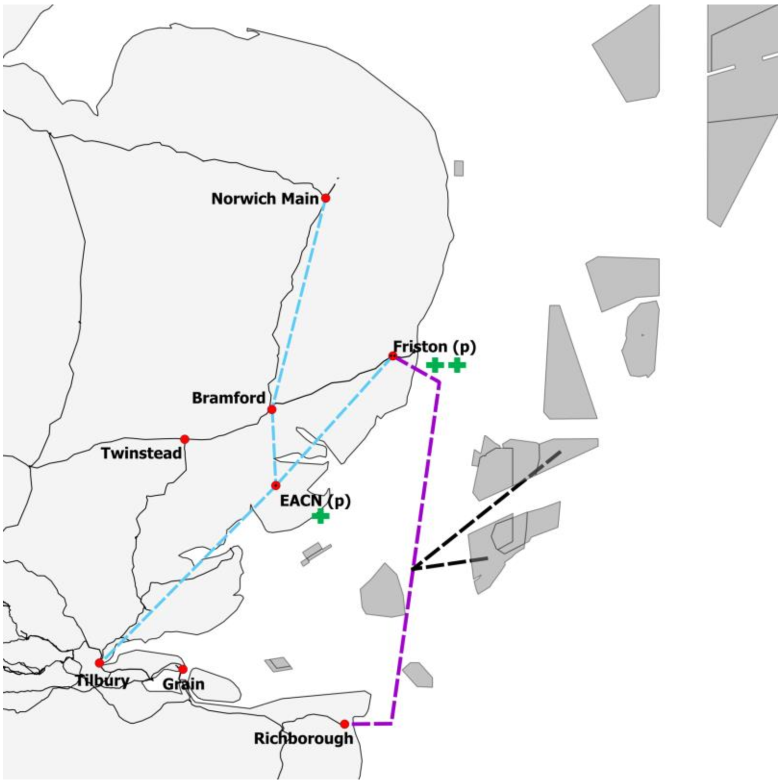


Figure 9: Map showing Option 3: Onshore option

Legend
- Existing Transmission Network
- Proposed AC circuit
- Proposed HVDC circuit
- Coordination from North Falls / Five Estuaries & Sealink
- Key Substations (*p* = proposed)
- Interconnector connection points

Option Description

This network configuration has three circuits.

This network configuration option includes currently proposed Norwich to Tilbury circuit as well as an additional circuit between Friston and EACN.

Technology

- One AC onshore circuit from Norwich to Tilbury, which is predominantly overhead line, with underground in some sensitive areas. The route goes from Norwich to Bramford, to EACN, to Tilbury substation.
- One AC onshore circuit from Friston to EACN.
- One 2 GW HVDC link from Friston to Richborough into which North Falls and Five Estuaries connect, known as Sea Link. This will also need HVDC converter stations to be built at both ends of the link.

Delivery Date	2030, with Friston to EACN delivered later and before required.
Capital Cost	£2.7bn

Option 3			
Design Criteria	**Ranking**	**Sub Description**	**Commentary**
Deliverability & Operability	Red	Supply chain, deliverability, and operability	Challenging delivery of multiple new onshore AC circuits. No additional HVDC so reduced HVDC supply difficulties. This would drive an Amber as significantly complex.
		Consenting	This option presents a highly complex consenting risk due to the large number of onshore routes required and impacts on multiple pinch points in the region such as especially around areas with a concentration of infrastructure such as Friston, and the impact on EACN and the Dedham Vale.

Option 3			
Design Criteria	**Ranking**	**Sub Description**	**Commentary**
Environmental	Amber	Friston to EACN to Tilbury (onshore)	As an onshore route, the individual components receive individual Amber or (in one case) Green BRAG ratings. The spatial extent and distribution of the onshore constraints allows for potential avoidance, whereas a number of constraints in the marine environment are unavoidable.
		Bramford to EACN (onshore)	
		Friston to Richborough (offshore)	However, mitigation such as detailed route planning, should be able to reduce the impact on many of the significant onshore environmental constraints.
		Norwich to Bramford (onshore)	An Amber rating means this option is moderately constrained; it is potentially viable however, will have to overcome some environmental issues.
Community	Red	Friston to EACN to Tilbury (onshore)	Overall, this option is significantly constrained. A combination of the onshore works, and the widespread of community impact features, combined with the significant constraints identified between Bramford and EACN, means avoidance of key constraints would be difficult.
		Bramford to EACN (onshore)	
		Friston to Richborough (offshore)	In addition, undergrounding may need to be considered as a mitigation where avoidance was not possible.
		Norwich to Bramford (onshore)	
Economic	Economic Rank	£0bn	The option received a Green rating, being the cheapest over its lifetime compared to all other options if delivered in 2030. It has a relatively low capital cost, and is efficient at mitigating constraints from 2030, and it facilitates all interconnectors at their original locations.
	Delay Impact	£1.6bn	If this option cannot be delivered until 2034, then its lifetime cost is increased, as it does not mitigate constraints from 2030 onwards. A number of other options, if everything is delivered in 2034, move to having similar lifetime costs.
Community Sentiment	Red	This option has new overhead lines – with visual impact spanning across three regions. Significant concentrated impact at proposed substations.	

4. Alternative onshore option – variation without Bramford to EACN

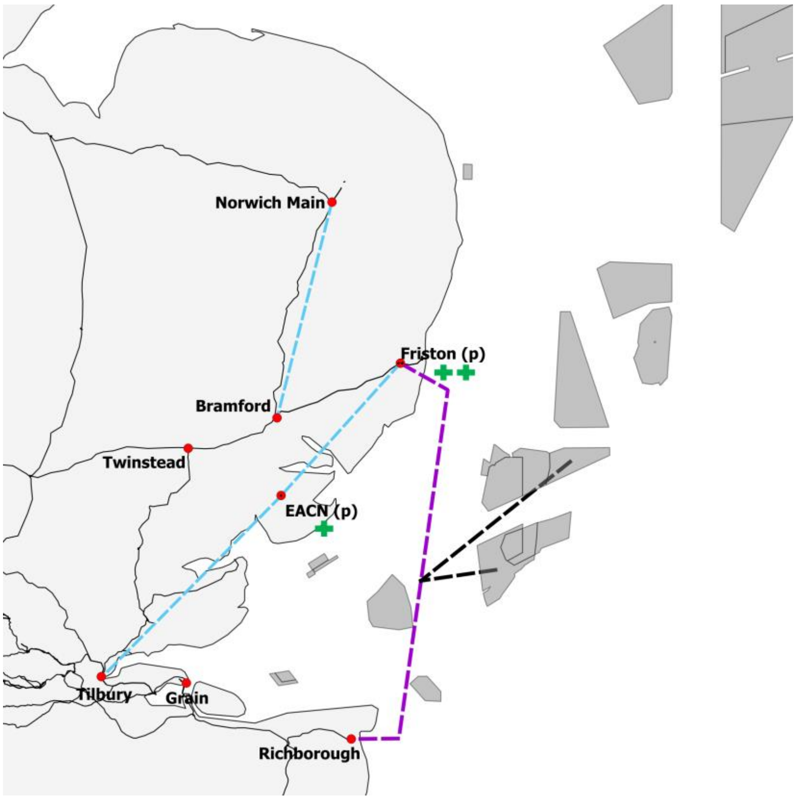


Figure 10: Map showing Option 4: Alternative onshore option - variation without Bramford to EACN

Legend

- Existing Transmission Network
- Proposed AC circuit
- Proposed HVDC circuit
- Coordination from North Falls / Five Estuaries & Sealink
- Key Substations (*p* = proposed)
- Interconnector connection points

Option Description

This network configuration has three circuits. This configuration is similar to Option 3, but with the part of the Norwich to Tilbury route between Bramford and EACN removed.

Figure 10 on the left: Map showing Option 4: Alternative onshore option – variation with EACN

Technology

- One AC onshore circuit from Norwich to Bramford
- One AC onshore circuit from Friston to Tilbury, via EACN.
- One 2 GW HVDC link from Friston to Richborough into which North Falls and Five Estuaries connect, known as Sea Link. This will also need HVDC converter stations to be built at both ends of the link.

Delivery Date	2030, with Friston to EACN delivered later and before required.
Capital Cost	£2.4bn

Option 4			
Design Criteria	**Ranking**	**Sub Description**	**Commentary**
Deliverability & Operability	Red	Supply chain, deliverability, and operability	This option has the same challenges as Option 3, but with a small section of onshore circuit through the Dedham Vale removed. This does not change the rating as remains significantly complex

Option 4			
Design Criteria	**Ranking**	**Sub Description**	**Commentary**
		Consenting	This option is assessed to have the same highly complex risk to consenting as Option 3, even with a small section of onshore circuit through the Dedham Vale removed. Overall, this is not sufficient to change the overall rating from Red.
Environmental	Amber	Friston to EACN to Tilbury (onshore)	This option is an onshore option. The individual components receive individual Amber or (in one case) Green BRAG ratings. This represents that many of the significant onshore and (where applicable) offshore environmental constraints should be avoided (or otherwise mitigated) at the detailed routeing stage.
		Friston to Richborough (offshore)	
		Norwich to Bramford (onshore)	An Amber rating means this option is moderately constrained; it is potentially viable however, will have to overcome some environmental issues.
Community	Amber	Friston to EACN to Tilbury (onshore)	This option comprises a balance of onshore and offshore study areas. Some consideration will need to be made to routeing including at the coastal interface point to avoid constraints where possible.
		Friston to Richborough (offshore)	While a number of features have been identified across study areas, these are generally distributed thinly across the areas, meaning detailed routeing could be feasible to avoid most constraints. This option is overall considered to be moderately constrained.
		Norwich to Bramford (onshore)	
Economic	Economic Rank	£2bn	The options received a Green rating costing £2bn more over its lifetime compared to the cheapest option (Option 3 delivered in 2030). It is one of the cheapest solutions, however, the removal of the circuit through the Dedham Vale reduces the effectiveness of this option at routeing power out of the region in comparison of Option 3, which increases the constraint cost.
	Delay Impact	£3.6bn	If this option cannot be delivered until 2034, then the benefits in reducing CAPEX it brings in the early years is lost, and other options move to the comparatively better.
Community Sentiment	Red	This option has new overhead lines – with visual impact spanning across three regions. Significant concentrated impact at proposed substations.	

5. Alternative onshore option – variation without EACN

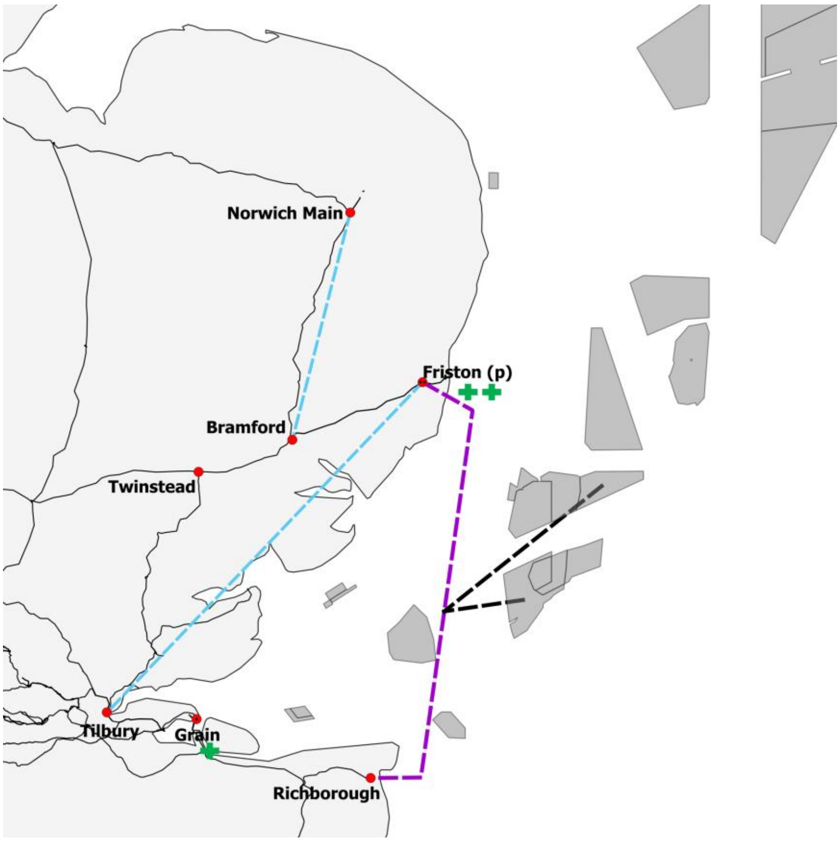


Figure 11: Map showing Option 5: Alternative onshore option – variation without EACN

Legend
- Existing Transmission Network
- Proposed AC circuit
- Proposed HVDC circuit
- Coordination from North Falls / Five Estuaries & Sealink
- Key Substations (*p* = proposed)
- Interconnector connection points

Option Description

This network configuration has three circuits. This configuration is similar to Option 4, however the proposed substation at EACN is not required.

Therefore, the line does not need to route to the EACN, and can take a different route, although detailed routeing is undertaken by National Grid Electricity Transmission (NGET) at a later stage in the design process.

Technology

- The Norwich to Bramford AC route which is predominantly overhead lines (this is the northern part of the proposed Norwich to Tilbury route).
- An AC route from Friston to Tilbury, which is predominantly overhead line (this includes the southern part of the Norwich to Tilbury route. Near the proposed EACN the route no longer needs to serve that substation so can be routed elsewhere.
- As well as Sea Link, the 2 GW HVDC link from Friston to Richborough into which North Falls and Five Estuaries connect. Converter stations will be required at both ends of Sea Link.

Delivery Date	2034 (the components such as Norwich to Bramford and Friston to Richborough could be delivered earlier)
Capital Cost	£2.3bn

Option 5			
Design Criteria	**Ranking**	**Sub Description**	**Commentary**

Deliverability & Operability	Amber	Supply chain, deliverability, and operability	Similarly to Option 3 and 4, this onshore option has the same challenges, although without the section of circuit through the Dedham Vale, and the rerouting of the circuit as it does not need to go via the Tendering peninsula for EACN. This does make it comparatively simpler as few components need to be delivered.
		Consenting	Overall, the position is similar to Options 3 and 4, but with the removal of two of the areas of high complexity of consenting at the Dedham Vale and EACN. Significant complexity remains both onshore especially at areas such the concentration of infrastructure at Friston, but overall this leads to an Amber RAG rating.
Environmental	Amber	Friston to Tilbury (onshore) Friston to Richborough (offshore) Norwich to Bramford (onshore)	This option is a variation of Option 4 comprising both onshore and offshore areas. As EACN does not feature in this option, the assessment can be considered without the impact of EACN. Overall although avoiding the Tendring Peninsula reduces the impact there, the line still needs to be routed in the vicinity, affecting other similar areas. As the overall rating is still driven by the Amber ratings of two components, this option is assessed as Amber. An Amber rating means this option is moderately constrained, it is potentially viable however, will have to overcome some environmental issues.
Community	Amber	Friston to Tilbury (onshore) Friston to Richborough (offshore) Norwich to Bramford (onshore)	This option comprises a balance of onshore and offshore study areas. Some consideration will need to be made to routeing including at the coastal interface point to avoid constraints where possible. While a number of features have been identified across study areas, these are generally thinly distributed across the areas, meaning detailed routeing could be feasible to avoid most constraints. This option is overall considered to be moderately constrained. This option does not include EACN. While its inclusion could result in some reduced localised impact it, is not considered to materially impact the cumulative rating and so the option remains moderately constrained.
Economic	Economic Rank	£10.3bn	The options received a Red rating costing £10.3bn more over its lifetime compared to the cheapest option (Option 3 delivered in 2030). Although this option is the cheapest option the removal of the circuit through the Dedham Vale, together with moving an Interconnector to Grain reduces the effectiveness of this option at routeing power. Significant constraints are caused moving power to the interconnector in Kent for power to be exported.
	Delay Impact	£10.3bn	There is no change in the relative economic position of this option if all options are considered delivered in 2034.
Community Sentiment	Red	This option has new overhead lines – with visual impact spanning across three regions. Significant concentrated impact at proposed substations.	

Option 5b. Alternative onshore option – variation without EACN – sensitivity

Following a stakeholder request, we explored the high constraint cost results in Option 5 (an alternative onshore option without Bramford to the EACN and without EACN substation) and why it compares economically worse to other options, including Option 4.

As Britain moves from being a net importer to a net exporter of electricity over the coming years and builds out more and more renewable generation, interconnectors to neighbouring countries help a region with a high level of low carbon generation compared to demand. Therefore, in a region such as East Anglia with a high volume of proposed wind generation connected, proposed interconnectors in the region export power from the region at times of high wind and low energy prices to other countries and hence this power does not need to flow across the network and out of the region. Whereas, if an interconnector is located elsewhere in Britain, the power would first need to leave East Anglia and traverse the network to reach the interconnector.

In Option 5, a scenario without Bramford to EACN, two interconnectors are modelled at Friston, and one at the Isle of Grain. Grain has been chosen as we are aware an interconnector is exploring connecting there. This means less interconnector export capability from East Anglia. This is also a common setup in other options, for the predominantly offshore (Option 1) and hybrid option (Option 7) without EACN.

Under Option 5, with an interconnector at Grain, at times of high wind / low prices, power must leave the East Anglian region and traverse the network in the southeast to Grain to be exported, rather than being exported directly, as is the case in Option 4. This means that at times the export capacity from East Anglia is not sufficient and capacity in the southeast is already limited at times. Therefore, we see this manifest as an increase in constraint costs, both to manage the power flows exiting East Anglia, as well as potentially limiting the flows of power into the Southeast.

Comparing Option 5 to other options with an interconnector at Grain

We do not see a similar magnitude in constraint costs under Options 1 and 7, which have the same interconnector configuration. This is because of the circuits which form part of Options 1 and 7 to move power out of the East Anglia region. In these two options, there is a new HVDC subsea 2 x 2GW circuit from Norwich to Grain. This moves power directly from Norwich to Grain. This means that excess power from the region can be moved 'directly' to the point of interconnection – without needing to traverse the constrained network in the southeast.

Sensitivity Analysis

The ESO hypothesised with stakeholders that to reduce the cost of constraints within option 5 there could be two primary solutions:

- Reinforce the electricity network (via overhead lines) between Tilbury in Essex and Grain in Kent, or within Kent itself. Short overhead lines could have a relatively cheaper capital costs to build compared with the system constraint costs accrued within this option (both of which are paid for by energy bill payers). However, they would result in additional onshore circuits proposed in Kent.
- Change the interconnector location from Grain to behind the EC5 electrical boundary encompassing East Anglia within the model, moving all three interconnectors back into the region – with two at Friston and one (nominally) at Bramford.

The ESO have modelled the change in interconnector location, the result of our assessment was that this sensitivity changed the economics of this option, but all other metric results stayed the same as shown below.

Economic	Economic Rank	£1.4bn	The option receives a Green rating costing £1.4bn more over its lifetime compared to the cheapest option (Option 3 delivered in 2030). Moving the interconnector to (nominally) Bramford removes the high constraint costs seen in Option 5.
	Delay Impact	£1.4bn	If other options cannot be delivered until 2034, then this option moves to having a similar lifetime cost to the cheapest options.

This sensitivity analysis also demonstrates the important role that interconnectors play in the region in exporting excess electricity and supporting in managing in constraints.

6. Hybrid onshore and offshore option

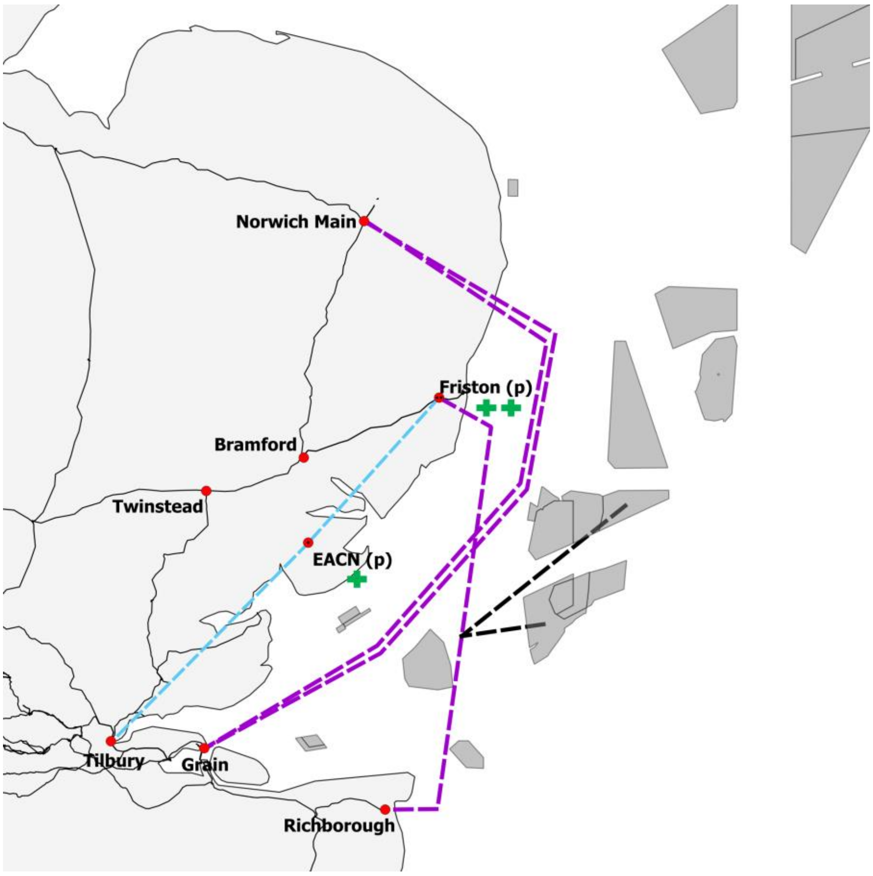


Figure 12:Map showing Option 6:Hybrid onshore and offshore option

Legend

- Existing Transmission Network
- Proposed AC circuit
- Proposed HVDC circuit
- Coordination from North Falls / Five Estuaries & Sealink
- Key Substations (*p* = proposed)
- Interconnector connection points

Option Description

This network configuration has four circuits.

This option proposes replacing the northern part of the Norwich to Tilbury route (from Norwich to Bramford to EACN) with two offshore HVDC circuits.

Technology

- Two 2 GW HVDC links from Norwich to Grain, providing 4 GW of capacity. Converter stations will be required at both ends of the links.
- The EACN to Tilbury AC route which is predominantly overhead line (this is the southern part of the proposed Norwich to Tilbury route).
- A new AC route from Friston to EACN.
- As well as Sea Link, the 2 GW HVDC link from Friston to Richborough into which North Falls and Five Estuaries connect. Converter stations will be required at both ends of Sea Link.

Delivery Date	2034 – (the EACN to Tilbury line is assumed delivered earlier in 2030)
Capital Cost	£4.4bn

Option 6			
Design Criteria	**Ranking**	**Sub Description**	**Commentary**
Deliverability & Operability	Red	Supply chain, deliverability, and operability	The single additional HVDC may add some delay but less than the options with multiple additional HVDC. Limited suppliers of HVDC and known supply chain delays.

Option 6			
Design Criteria	**Ranking**	**Sub Description**	**Commentary**
		Consenting	As a blend of onshore and offshore, this solution has a highly complex risk to consenting. The option includes a concentration of infrastructure at Friston, and the East Anglia Connection Node. The HVDC route in this option also need to pass from Norwich to the coast (in the vicinity of The Broads) which is likely to add to the complexity of consenting. This drives the Red rating.
Environmental	Red	Friston to EACN to Tilbury (onshore) Norwich to Grain (offshore) Friston to Richborough (offshore)	This option includes the heavily constrained component from Norwich to Grain, with its impact on the onshore environment in Norfolk and the complex marine environment offshore. As Norwich to Grain is a key part of this option, overall the option is assessed to be Red. A Red rating means this option is heavily constrained, it is potentially viable however, will have to overcome many environmental issues.
Community	Amber	Friston to EACN to Tilbury (onshore) Norwich to Grain (offshore) Friston to Richborough (offshore)	This option comprises two study areas in the marine environment with moderate constraint. Consideration will need to be given to coastal interface locations and routeing to avoid and minimise impact where possible. The onshore study area includes a number of constraints which are distributed across the study area, meaning with detailed routeing it could be feasible to avoid most constraints. This option is overall considered to be moderately constrained.
Economic	Economic Rank	£1.7bn	The options received a Green rating costing £1.7bn more over its lifetime compared to the cheapest option (Option 3 delivered in 2030). This option is delivered in full by 2034. It is a ‘middle cost’ options driven by the cost of converter stations and HVDC subsea cabling, and the onshore route. It is effective at reducing constraints, and the route from Norwich to Grain performs well at moving power from the region.
	Delay Impact	£2.1bn	If some of the onshore elements of this option are delivered late, then some of that initial benefit is lot. This means that it moves slightly comparative economic ranking if everything is delayed, but it still have a comparatively similar lifetime cost to the cheapest options.
Community Sentiment	Red	This option has a mixture of new overhead lines and subsea cables with visual impact spanning across three regions. Significant concentrated impact at proposed substations.	

7. Hybrid onshore and offshore option – variation without EACN

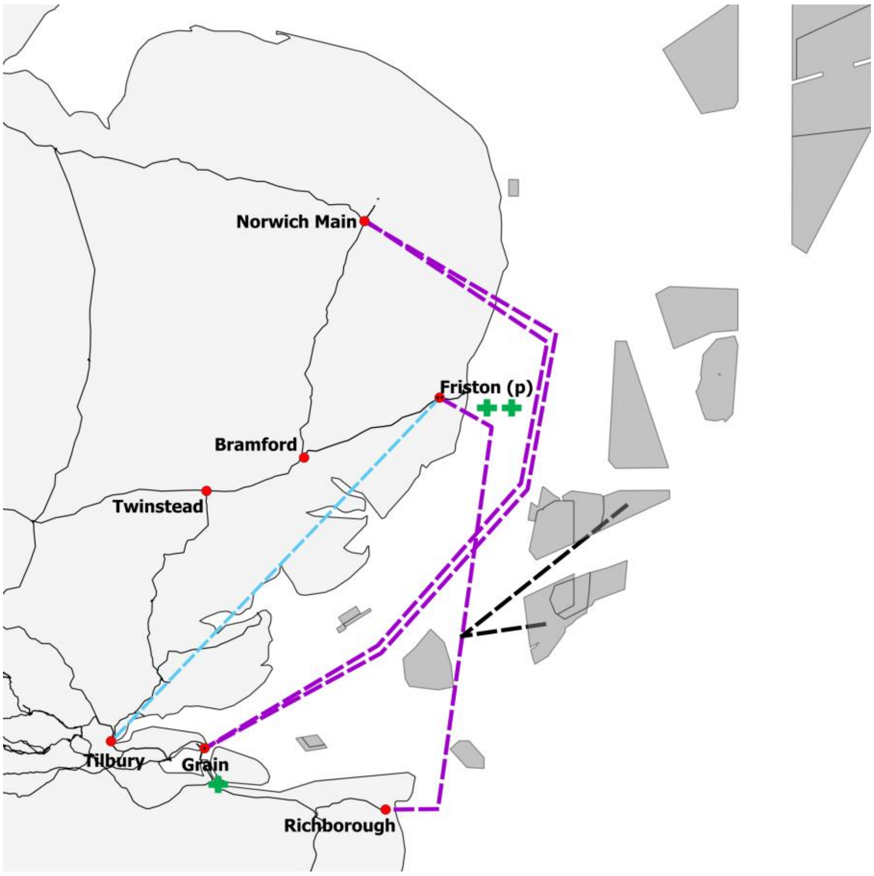


Figure 13: Map showing Option 7: Hybrid onshore and offshore option (without EACN).

Legend
- Existing Transmission Network
- Proposed AC circuit
- Proposed HVDC circuit
- Coordination from North Falls / Five Estuaries & Sealink
- Key Substations (*p* = proposed)
- Interconnector connection points

Option Description

This network configuration has four circuits. This option is a variation of Option 6 removing the proposed EACN substation.

Technology

- Two 2 GW HVDC links from Norwich to Grain, providing 4 GW of capacity. Converter stations will be required at both ends of the links.
- A new AC route from Friston to Tilbury.
- As well as Sea Link, the 2 GW HVDC link from Friston to Richborough into which North Falls and Five Estuaries connect. Converter stations will be required at both ends of Sea Link.

Delivery date	2034
Capital Cost	£4.3bn

Option 7			
Design Criteria	**Ranking**	**Sub Description**	**Commentary**
Deliverability & Operability	Amber	Supply chain, deliverability, and operability	The single additional HVDC may add some delay but less than the options with multiple additional HVDC. Limited suppliers of HVDC and known supply chain delays.
		Consenting	This option is assessed to be a significantly complex risk to consenting; although and southern onshore route and

			a Norwich to Grain offshore route remains, the option does not include the EACN or a route through the from Bramford through the Dedham Vale. There are still significant complexities in consenting this option, including concentration of infrastructure at Friston.
Environmental	Red	Friston to Richborough (offshore)	As EACN does not feature in this option, the assessment for the Friston to Tilbury component can be considered without the impact of EACN. Overall, although avoiding the Tendring Peninsula reduces the impact in that location, the line still needs to be routed in the vicinity, potentially affecting other similar areas.
		Norwich to Grain (offshore)	This option includes the heavily constrained component from Norwich to Grain, with its impact on the onshore environment in Norfolk and the complex marine environment offshore. As Norwich to Grain is a key part of this option, overall the option is assessed to be Red.
		Friston to Tilbury (onshore)	A Red rating means this option is heavily constrained, it is potentially viable however, will have to overcome many environmental issues.
Community	Amber	Friston to Richborough (offshore)	This option comprises two study areas in the marine environment with moderate constraint. Consideration will need to be given to coastal interface locations and routeing to avoid and minimise impact where possible. The onshore study area consists of several constraints which are distributed throughout. It should be feasible to avoid most constraints with detailed routeing. This option is overall considered to be moderately constrained. While this option does not include EACN - which may result in some reduced localised impact – it is not considered to materially impact the cumulative rating and so the option remains moderately constrained.
		Norwich to Grain (offshore)	
		Friston to Tilbury (onshore)	
Economic	Economic Rank	£1.8bn	The options received a Green costing £1.8bn more over its lifetime compared to the cheapest option (Option 3 delivered in 2030). This option is delivered in full by 2034. It is a middle cost expensive driven by the cost of converter stations and HVDC subsea cabling, and the onshore route. It is effective at reducing constraints, and the route from Norwich to Grain performs well at moving power from the region including to the interconnector located at Grain.
	Delay Sensitivity	£1.8bn	If all options are delayed, then this option has a comparatively similar cost of a number of the other cheapest options.
Community Sentiment	Red	This option has a mixture of new overhead lines and subsea cables with visual impact spanning across three regions. Significant concentrated impact at proposed substations.	

8. An onshore HVDC route

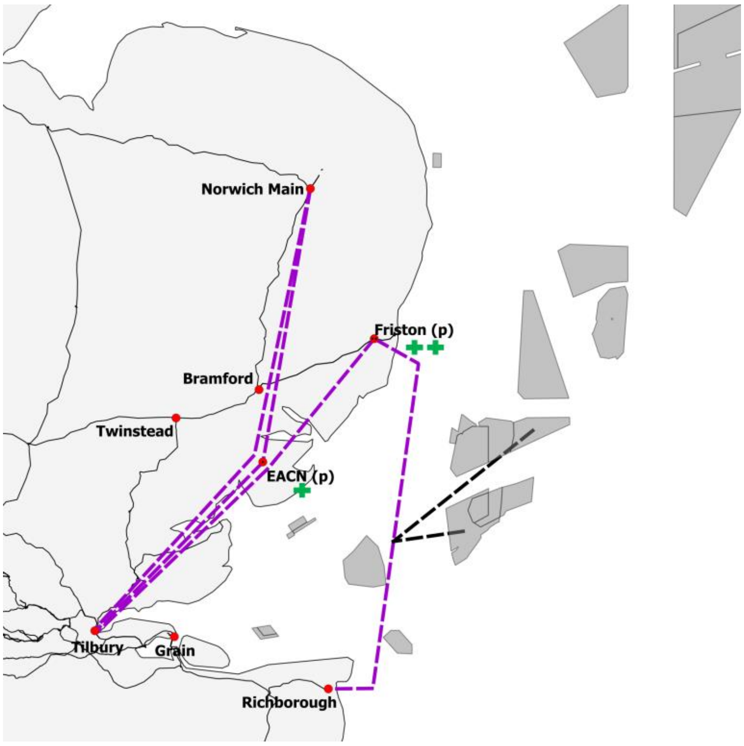


Figure 14: Map showing Option 8: Onshore HVDC option

Legend
- Existing Transmission Network
- Proposed AC circuit
- Proposed HVDC circuit
- Coordination from North Falls / Five Estuaries & Sealink
- Key Substations (*p* = proposed)
- Interconnector connection points

Option Description

This network configuration has three routes across and out of East Anglia, comprising of three circuits. This option replaces the onshore network configuration with an equivalent undergrounded HVDC route.

Technology

- A 2 GW undergrounded HVDC line from Friston to Tilbury, bypassing the EACN.
- A 2 GW undergrounded HVDC three-ended line, from Norwich to EACN to Tilbury. This would have a 'T point' to connect the interconnector at EACN, but it would not be a full substation.
- In addition to Sea Link, the 2 GW HVDC link from Friston to Richborough into which North Falls and Five Estuaries connect.
- In this region there would be two converter stations at Norwich, one at Friston, and three at Tilbury. EACN would receive a 't-point' connection the DC interconnector.

Delivery Date	2034 (with Sea Link delivered earlier)
Capital Cost	£4.9bn

Option 8			
Holistic Network Design Criteria	**Assessment Ranking**	**Sub Description**	**Commentary**
Deliverability & Operability	Red	Supply chain, deliverability, and operability	Challenging delivery with multiple HVDC circuits. Limited suppliers of HVDC and known supply chain delays. A solution of this nature and scale has never been delivered in Great Britain which increases the risk.

Option 8			
Holistic Network Design Criteria	**Assessment Ranking**	**Sub Description**	**Commentary**
		Consenting	This option, while onshore, results in an undergrounded solution so less long-term visual impact, except at the ends of the circuits with the placement of convertor station. Significant HVDC converter stations will be needed at the ends of the routes – Norwich, EACN, Friston and Tilbury. This is likely to present a significant complexity to consenting.
Environmental	Amber	Friston to Tilbury (HVDC onshore)	In this option, similar routes to Option 3 are used onshore, but all the circuits are now underground. Overall this does not affect the environmental score of the options. As whilst the potential for environmental impact for this underground route is greater during the construction phase. once complete (and with the addition of appropriate mitigation) the long term impact should be significantly reduced. This would be of particular relevance to the Dedham Vale area. Whilst offshore a number of constraints would be unavoidable due to their significant size and location. Overall, on balance, this option remains an Amber rating. An Amber rating means this option is moderately constrained, it is potentially viable however, it will have to overcome numerous environmental issues.
		Friston to Richborough (offshore)	
		Bramford to EACN (HVDC onshore)	
		Norwich to Bramford (HVDC onshore)	
Community	Amber	Friston Tilbury (onshore HVDC)	This option consists of study areas predominantly onshore with one area offshore. Despite the significant constraints identified between Bramford and EACN, combination of the options is overall considered to be moderately constrained. The other study areas have several constraints spread widely throughout these locations. This means overall detailed routeing would be needed to avoid constraints where possible. This option mitigates some of the constraints by placing the routes underground rather than overhead, and whilst this has the potential to cause significant impact during construction, the enduring impact is reduced.
		Friston to Richborough (offshore)	
		Bramford to EACN (onshore HVDC)	
		Norwich to Bramford (onshore HVDC)	
Economic	Economic Rank	£1bn	The options received a Green rating costing £1bn more over its lifetime compared to the cheapest option (Option 3 delivered in 2030). This option although at the higher cost, and delayed, performs well over its lifetime.

Option 8			
Holistic Network Design Criteria	**Assessment Ranking**	**Sub Description**	**Commentary**
	Delay Impact	£1bn	If other options are delayed until 2034, then this option comes into closer comparison to other options, showing itself overall, to be the lowest cost option in the delay situation.
Community Sentiment	Amber	Onshore routes but undergrounded are view more favourably. Still significant impact at Friston, EACN, Norwich and Tilbury for converter stations.	

9. Predominantly offshore option – utilising Bradwell as a landing point

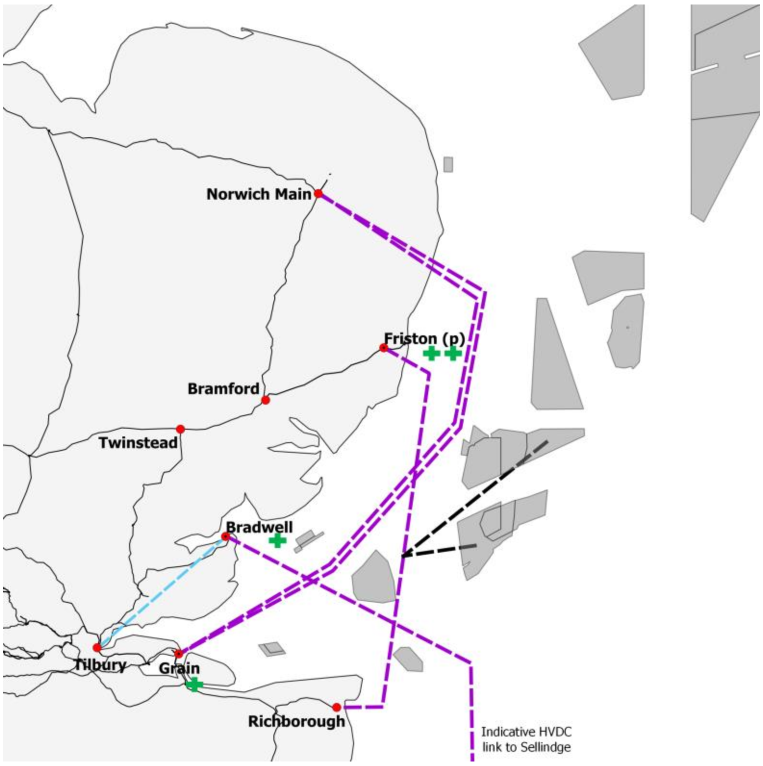
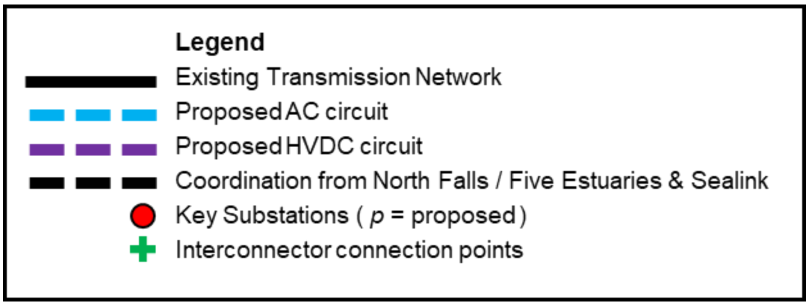


Figure 15: Map showing Option 9: Predominantly Offshore Option utilising Bradwell



Option Description

This network configuration has three routes out of East Anglia, comprising of four circuits. These circuits would begin at Norwich, Friston and Bradwell and will be undergrounded to the coast and continue offshore in the sea to three onshore locations in Kent - Grain, Richborough and (nominally) Sellindge. There is uprating required at Bradwell to Rayleigh.

This configuration is a variation of Option 1 and explores using Bradwell as a landing point for an HVDC cable, to remove power from the wider region and negate the need for additional infrastructure at Friston.

Technology

- Two 2 GW HVDC links from Norwich to Grain, providing 4 GW of capacity with HVDC converter stations to be built at both ends of the link.
- One 2 GW HVDC link from Friston to Richborough into which North Falls and Five Estuaries connect, known as Sea Link. This will also need HVDC converter stations to be built at both ends of the link.
- A 2 GW HVDC link from Bradwell to (nominally) Sellindge with HVDC converter stations to be built at both ends of the link.
- A 400 kV Overhead line replacing the existing 132 kV route from Bradwell to Rayleigh substation.

Delivery Date	2034 (with Sea Link delivered earlier)
Capital cost	£5.2m

Option 9			
Design Criteria	**Ranking**	**Sub Description**	**Commentary**
Deliverability & Operability	Black	Supply chain, deliverability, and operability	Challenging delivery with multiple HVDC circuits. Limited suppliers of HVDC and known supply chain delays. The options have a limitation on export capacity from Friston, which means either less generation or a further route of Friston is required (see below). This is driving the Black rating. This option is notable as the one option, which has a black rating for one of the metrics, specifically Deliverability. This is because the network under this option does not have sufficient capacity for export out of Friston under the fault condition as discussion in assumption on page 23, and this was a specific design choice to avoid putting additional infrastructure at Friston. This black rating for deliverability could be mitigated in two ways – either less generation connects at Friston than is expected, or additional network is built out of Friston. As an example of the additional network required, a further 2GW HVDC line from Friston to Bradwell would cost around £900m in capital costs but would reduce the total lifetime cost from £9bn to around £6.2bn.
		Consenting	The solution is predominantly offshore and removes one link out of an area with a concentration of infrastructure at Friston. Overall, it still presents a significant complexity, especially around areas with a concentration of infrastructure such as Friston.
Environmental	Red	Norwich to Grain (offshore)	This option reduces the number of HVDC lines landing at Friston, and instead uses Bradwell. It still has the heavily constrained Norwich to Grain route, and now gains a complex marine environment at Bradwell which identifies many overlapping significant constraints such as MCZs, SACs, SPAs, RAMSARs and SSSIs. The impacts of these cannot be mitigated by avoidance measures. Overall, this option is assessed as Red. A Red rating means this option is heavily constrained, it is potentially viable however, will have to overcome many environmental issues.
		Friston to Richborough (offshore)	
		Bradwell to Sellindge (offshore)	
		Bradwell to Rayleigh (onshore)	
Community	Amber	Norwich to Grain (offshore)	This option reduces the number of HVDC lines landing at Friston and instead uses Bradwell. Due to the number of coastal interface locations, consideration will need to be given to routeing and landfall locations to avoid and minimise impact where possible. The onshore study area consists of a number of constraints including National Landscapes. While further community features have been identified across the study area, these are generally thinly distributed, meaning
		Friston to Richborough (offshore)	
		Bradwell to Sellindge (offshore)	

Option 9			
Design Criteria	**Ranking**	**Sub Description**	**Commentary**
		Bradwell to Rayleigh (onshore)	detailed routeing should be feasible to avoid most constraints. This option is overall considered to be moderately constrained.
Economic	Economic Rank	£9bn	The options received a Red rating costing £9bn more over its lifetime compared to the cheapest option (Option 3 delivered in 2030). This option has one of the highest capital costs, and performs poorly at removing power from the East Anglia region, as the connection from Bradwell to Kent is outside where the majority of the power is being generated and connected.
	Delay Impact	£9bn	There is no change in the relative economic position of this option if all options are considered delivered in 2034.
Community Sentiment	Amber	This option involves an uprating of an existing overhead line which could have a visual impact; however, it has significant concentrated impact at proposed coastal nodes.	

7. Summary of results

The ratings from the options assessment tables in the previous section are summarised below. A rating is given for each option and for each of the holistic design criteria.

	Option description	Delivery date	Deliverability and operability ranking	Environmental ranking	Community ranking	Economic rating (on-time delivery)	Economic rating (2034 Delivery)
1	Predominately offshore option – variation without East Anglia Connection Node (EACN)	2034	Red	Red	Amber	£4.2 bn	£4.2 bn
2	Predominately offshore option – variation with EACN	2034	Red	Red	Red	£4.8 bn	£4.8 bn
3	Onshore option	2030	Red	Amber	Red	£0 bn	£1.6 bn
4	Alternative Onshore option – variation with EACN	2030	Red	Amber	Amber	£2.0 bn	£3.6 bn
5	Alternative Onshore option – variation without Bramford to EACN	2034	Amber	Amber	Amber	£10.3 bn	£10.3 bn
5b	Alternative Onshore option – variation without Bramford to EACN – sensitivity	2034	Amber	Amber	Amber	£1.4 bn	£1.4 bn
6	Hybrid onshore and offshore option – variation with EACN	2034[41]	Red	Red	Amber	£1.7 bn	£2.1 bn
7	Hybrid onshore and offshore option – variation without EACN	2034	Amber	Red	Amber	£1.8 bn	£1.8 bn
8	Onshore HVDC Option	2034	Red	Amber	Amber	£1.0 bn	£1.0 bn
9	Using Bradwell as a landing point	2034	Black	Red	Amber	£9.0 bn	£9.0 bn

Table 7: Summary of options assessment

Community sentiment

The community sentiment for each option is summarised below.

Option Number	Option description	Community sentiment
1	Predominately offshore option (without East Anglia Connection Node (EACN))	Amber
2	Predominately offshore option (with EACN)	Red
3	Onshore option (closest to status quo)	Red
4	Alternative Onshore option – variation with EACN	Red
5	Alternative Onshore option – variation without EACN	Red
5b	Alternative onshore option – variation without EACN – sensitivity	Red
6	Hybrid onshore and offshore option (with EACN)	Red
7	Hybrid onshore and offshore option (without EACN)	Red
8	Onshore HVDC Option	Amber

[41] *Elements of the hybrid option 6 can be delivered in 2030, although the full solution would not be delivered until 2034, so it has a variation in the delay case.

Option Number	Option description	Community sentiment
9	Using Bradwell as a landing point	Amber

Table 8: Summary of community sentiment

Conclusions

To transfer the energy being generated in the region and off its shores, there have been several network reinforcements proposed by the relevant Transmission Owner. This spans from upgrading existing circuits, reinforcing the Bramford to Twinstead onshore circuit as well as a new onshore circuit proposed from Norwich to Tilbury.

The new power flows brought on by the potential change in connection location stemming from the OCSS, has meant that new network configuration options are available for the Transmission Owner to consider should OCSS continue. However, these options assessed within this study come with critical trade-offs to be made.

The ESO have holistically assessed ten network configuration options in East Anglia using the OCSS outcome as our baseline. Six options were developed by the ESO and NGET and four were proposed by community representatives. These network configuration options range from onshore network configurations to a network configuration involving no new overhead lines within East Anglia.

What is evident is there is no single option that minimises impacts across all the metrics. Critical trade-offs will need to be made between the cost borne by consumers, communities hosting this nationally significant infrastructure as well as environmental considerations.

Economic:

Our economic analysis compares the cost of moving power around the system posed by each option compared to its capital cost. The capital cost and the cost of managing a lack of capacity in the system is borne by bill payers.

When combined with overall system impact, the onshore option ranks highest as it is deliverable earlier (in 2030), however if a later delivery of 2034 is assumed then the undergrounded HVDC option as well as hybrid onshore and offshore options are comparable in ranking.

The options under assessment have been benchmarked against European (Scottish and equivalent schemes in Great Britain). The offshore options utilising HVDC technology and onshore AC technology are within the price range that we would expect. Further information on this benchmarking and additional economic sensitivities undertaken can be found in our appendix.

Environmental:

In general, all options under assessment face environmental constraints. Some of the offshore circuits present more challenges due to the complexity of the marine environment. Bradwell is particularly environmentally challenging as a landing point for offshore cables compared with other landing points within the study. This is because Bradwell has more overlapping sites of international designation than other proposed landing points.

Community:

Typically, more communities are impacted by onshore network configurations within this assessment than offshore options. To reflect the sentiment when engaging with local elected officials, we have scored each option against community sentiment, reflecting that our community metric is high level and uses geo-spatial data.

Most of the network options result in areas with a concentration of infrastructure (substation, converter station and associated overhead lines or underground cabling) at key proposed nodes along the coast. This is likely to have significant cumulative impact in these areas.

Deliverability:

While all technology faces supply chain issues, HVDC circuits face supply chain issues due to limited suppliers and global demand for this technology. This means that options with multiple offshore HVDC circuits are more challenging to deliver.

Next steps

This assessment has set out a side-by-side comparison of different electricity network configurations that transfer electricity across or around the region. Following this publication, we expect NGET to consider the assessment findings as part of their ongoing development of the Norwich to Tilbury circuit route.

We also shortly expect the UK Government and relevant OCSS developers to decide upon their progression to the next stage of the OCSS. We hope that this study provides all stakeholders with a range of options that could meet the network capacity needs of the region.