January 2022

Network Options Assessment

nationalgridESO

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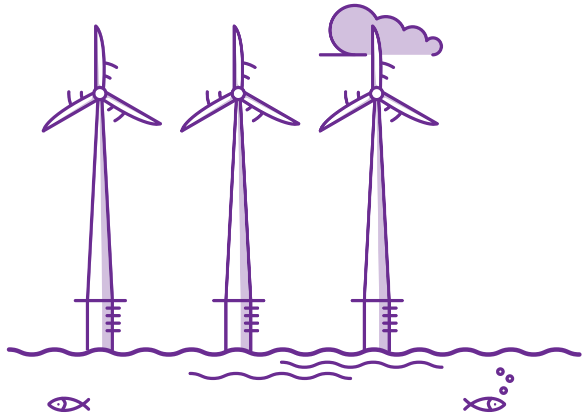

Introduction

NOA introduction

Network Options Assessment 2021/22 Explanatory Note

The Network Options Assessment (*NOA*) for 2021/22 is different in format and content than in previous years. That's because the ESO needs to factor in outputs from the ongoing Offshore Transmission Network Review (OTNR), a project led by the Department for Business, Energy and Industrial Strategy.

As part of the OTNR, the ESO will produce a Holistic Network Design (HND), later this year, recommending how offshore wind farm projects within its scope could be connected to the transmission network. While the *NOA* already factors in the system impact of 40 GW of offshore wind by 2030, the HND may lead to changes to allow for coordination.

The *NOA* assesses the reinforcements required to the electricity transmission networks owned by the three onshore Transmission Owners (TOs). It takes the connection point of assets owned by other customers as inputs. If the HND makes changes to these customer connection locations and offshore network configurations, this may drive changes in the requirements of the TOs' networks.

The full impact of the HND on the *NOA* recommendations is unknown at this stage and may not impact some reinforcements at all. However, we do know that our net zero future will require network reinforcements to enable the electricity generated by offshore wind to reach all parts of the country. Some of the projects in the *NOA* are needed in all our scenarios; the need for these is likely to be reinforced by the HND.

The HND cannot remove the need for all onshore reinforcements, although it aims to result in a more efficient outcome by considering the onshore and offshore parts of the network holistically, as well as factoring in community impact and environmental factors.

When the HND is finalised, the *NOA* will be reviewed and updated. This refreshed *NOA* will be published alongside the HND in June 2022.

Why is the ESO publishing a *NOA* in January in advance of the HND?

The *NOA* is published annually every January and the onshore Transmission Owners (TOs) use the information contained in it to help decide which transmission projects to proceed with.

If we delayed the *NOA* until June, it could adversely impact timely and cost-effective delivery of transmission projects. Failure to deliver these transmission projects in a timely manner will lead to rising constraint costs, i.e. the costs we pay generation when network capacity is not sufficient to transport the electricity they are producing. The impact of delaying the *NOA* publication until June could therefore be costly to consumers.

On this basis, we have decided to publish a *NOA* to help the TOs to proceed with the development of their projects between January and June 2022. Then in June 2022, a refreshed *NOA* will outline the projects required to reinforce the network, incorporating the HND as a key input.

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NOA introduction

Differences between this *NOA* and previous ones

This *NOA* is to enable progress with transmission projects while we finalise the HND and assess the impact it has on onshore reinforcements. It provides only what is necessary to help the TOs to make progress with projects.

Supporting narrative and detail has been removed from this *NOA*, to reflect the fact that it is a bridging document between last year's *NOA* (*NOA* 2020/21) position and the *NOA* that will be published in June 2022.

Despite the document being shorter, the outputs are as robust as in previous years and the full *NOA* methodology has been followed. When the refreshed *NOA* is published in June, the ESO will provide full context, narrative, and explanation for the *NOA* recommendations.

ScotWind

The *NOA* analysis was completed prior to the announcement of the ScotWind leasing round. We will work through the impact of the ScotWind announcement and incorporate it into future *NOA*s.

Enabling works

Some customer connection agreements have major reinforcements as they're required enabling works for connection. If the *NOA* recommends a change to the delivery of these works, we will work with these customers to identify if any updates are required to their agreement and minimise the impact as much as possible.

NOA for interconnectors

The document includes a full *NOA* for interconnectors section. Unlike the onshore *NOA* which assesses proposed projects, the *NOA* for interconnectors assesses the potential for interconnection between GB and neighbouring countries. As such, the projects are notional rather than real proposals. Therefore, the HND will have less impact on the *NOA* for interconnectors, and the ESO is publishing the *NOA* for interconnectors in full.

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What's new this year?

NOA methodology

As a result of stakeholder feedback, we've moved the methodology and other content from the publication to our website. This has made the *NOA* shorter and easier to access.

ESO-led commercial solutions

Commercial solutions represent ESO-led commercial arrangements with market participants to relieve constraints. Currently they are modelled as intertrips in the *NOA*. We have improved and revised our assumptions around the cost of commercial solutions this year for the options in the 'North' region, based on the Constraint Management Pathfinder tender in the Anglo-Scottish region. This allows us to model their economic benefit more accurately.

Least Worst Weighted Regret (LWWR)

Last year an innovation project, called 'Advanced Modelling for Network Planning Under Uncertainty', was undertaken with the University of Melbourne. The project developed a new method for exploring how varying the probability of each future energy scenario occurring impacts recommendations. Their new technique was called Least Worst Weighted Regret (LWWR). During last year's *NOA*, we trialled the LWWR technique to see its effect on the analysis and saw its potential to aid in the decision-making.

This year we extended the innovation project to build a tool to perform our analysis whilst providing more insight on the method. The University of Melbourne further improved the technique for use in this year's *NOA* as well as other cost-benefit analyses conducted throughout the year. In particular we have a better understanding of the LWWR technique and its output, as well as new metrics to interpret the data quickly.

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Constraints and option types

We make economic recommendations balancing the costs of managing constraints and the cost of reinforcing the network. This is done by evaluating different reinforcement options that increase the capacity of the network.

We use boundaries to study the power flows on the electricity transmission network. A boundary splits the system into two parts, crossing critical circuit paths that carry power between the areas where power flow limitations may be encountered. A boundary becomes constrained if more electricity is planned to cross the boundary than its technical capacity can handle. How constrained the boundaries are varies from hour to hour throughout the year. Power flow across the system is significantly impacted by changing demand and generation. For more information visit our *ETYS web page*.

Thermal constraints are the most common type of constraints. These occur when a fault happens leading to overloads on the weakest component on the boundary. As the generation mix changes, the overload can move from one area to another within a single day. The size of the overload and how much it moves influences the choice of investment in an option.

There are several types of options the TOs can propose to reduce constraints. We follow the *NOA* methodology to assess these options. We consult on the methodology and seek approval from Ofgem each year. Our latest *NOA* report methodology is published on our website.

Options fall under the following categories: Hover over for the following icons for more information

Developing new circuits	Control power flow	New or reconfigured substation	Upgrading circuits	Voltage and stability constraints	Alternative options	ESO-led commercial solutions
Total 33	**Total 26**	**Total 7**	**Total 44**	**Total 23**	**Total 3**	**Total 8**

Developing new circuits:

This can include high voltage direct current links or new onshore circuits. It often means re-using existing assets.

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Investment recommendations

NOA outcomes

This section presents the investment recommendations for submitted *NOA* options and eligible onshore competition assessments by regions. The investment recommendations are the most economic strategies for each future energy scenario. Full details on the analysis and steps we take towards recommendations for proposed options can be found on the *NOA* Methodology web page. For each region we will focus on the following:

- Number of options in the optimal path
- 'Critical' options which are recommended "Proceed" and "Delay" using the single year least worst regret or otherwise as suggested by the *NOA* 2021/22 committee.

This year *FES* scenarios have seen an increase in generation capacity compared to the previous year, driven by a large increase in renewable generation to meet the net zero 2050 government targets. To achieve the net zero 2050 target, the electricity transmission network requires large reinforcements to be delivered within the next 20 years to manage the growing cost of balancing actions associated with the quantity of new renewable energy sources. The four future energy scenarios, **Leading the Way**, **Consumer Transformation**, **System Transformation** and **Steady Progression**, outline four different, credible pathways for the future of energy between now and 2050.

Consumer Transformation and **System Transformation** represent two different ways to achieve net zero by 2050 – either by changing the way we use energy or by changing the way in which we generate and supply it. In **Leading the Way**, a combination of high consumer engagement and world-leading technology and investment has the UK reaching net zero in 2047. Decarbonisation happens slowest in **Steady Progression**, which does not meet the net zero target. For more information on the scenarios and the future electricity demand, please visit our *FES* web page.

This year we have assessed 136 options submitted to us by TOs. Of these, 112 options are 'optimal' in at least one scenario and 24 of these options are not 'optimal' in any scenario. The initial recommendation for the 24 'non-optimal' options were "Stop" or "Do not start". The recommendations were put forward to the *NOA* 2021/22 committee for further scrutiny and to get a final recommendation. It is important to note that options that receive a "Delay" or a "Hold" recommendation are still 'optimal' and we see benefit in these being delivered in at least one scenario for this reinforcement, just not on the earliest in service date (EISD). We would expect the TOs to undertake some work on these options in the next year if they believe it is required to do so to keep the option open on its 'optimal' date.

The next section of this chapter will present recommendations for the 112 asset-based options and eight ESO-led commercial solutions in the optimal path by region and highlight some key investments in each region.

A number of established schemes were approved to continue by Ofgem without the need for detailed analysis in this year's *NOA*. These options had "Proceed" recommendations in previous *NOA*s and form part of the TOs' baseline funding. These options are all in the North region:

- ECU2 – East coast onshore 275 kV upgrade
- ECUP - East coast onshore 400 kV incremental reinforcement
- ECVC – Eccles hybrid synchronous compensators and real-time rating system
- HNNO – Hunterston East – Neilston 400 kV reinforcement
- WLTI – Windyhill – Lambhill – Longannet 275 kV circuit turn-in to Denny North 275 kV substation.

Next in Table 2.1 we present the 'optimal' dates for options in each region in ascending order by scenarios 'critical' dates.

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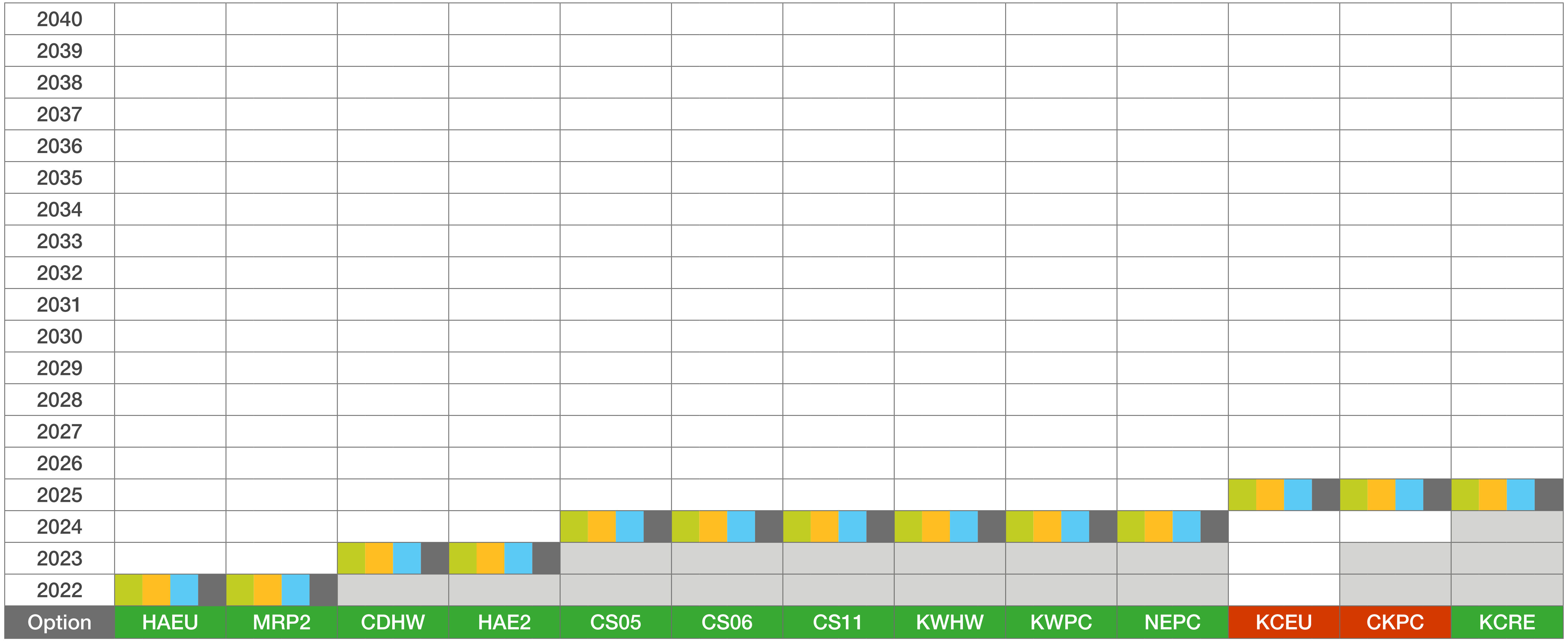
Scotland and North of England region

Table 2.1 Optimal path visualisation in Scotland and North of England region

Key

- Leading the Way
- Consumer Transformation
- System Transformation
- Steady Progression
- Years before EISD
- 'Critical' option to "Proceed"
- 'Critical' option to "Delay"
- Not 'critical' option to "Hold"



Hover over the option codes at the bottom of the table for further information

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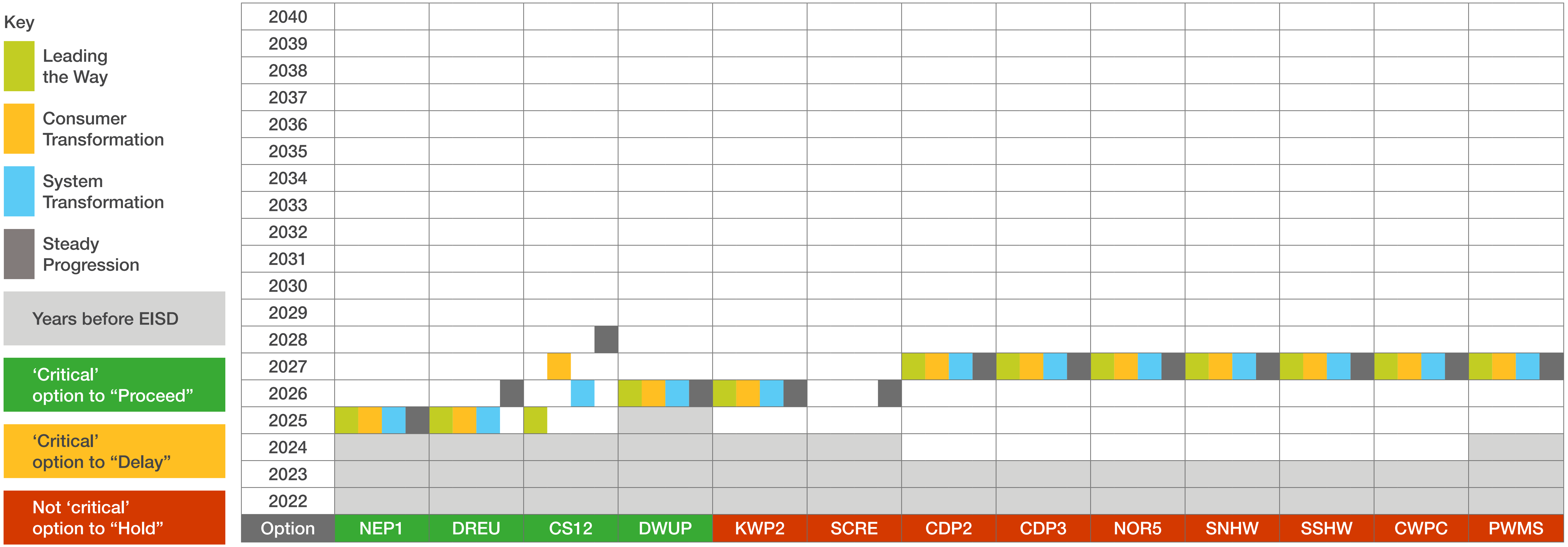
Scotland and North of England region (continued)



Hover over the option codes at the bottom of the table for further information

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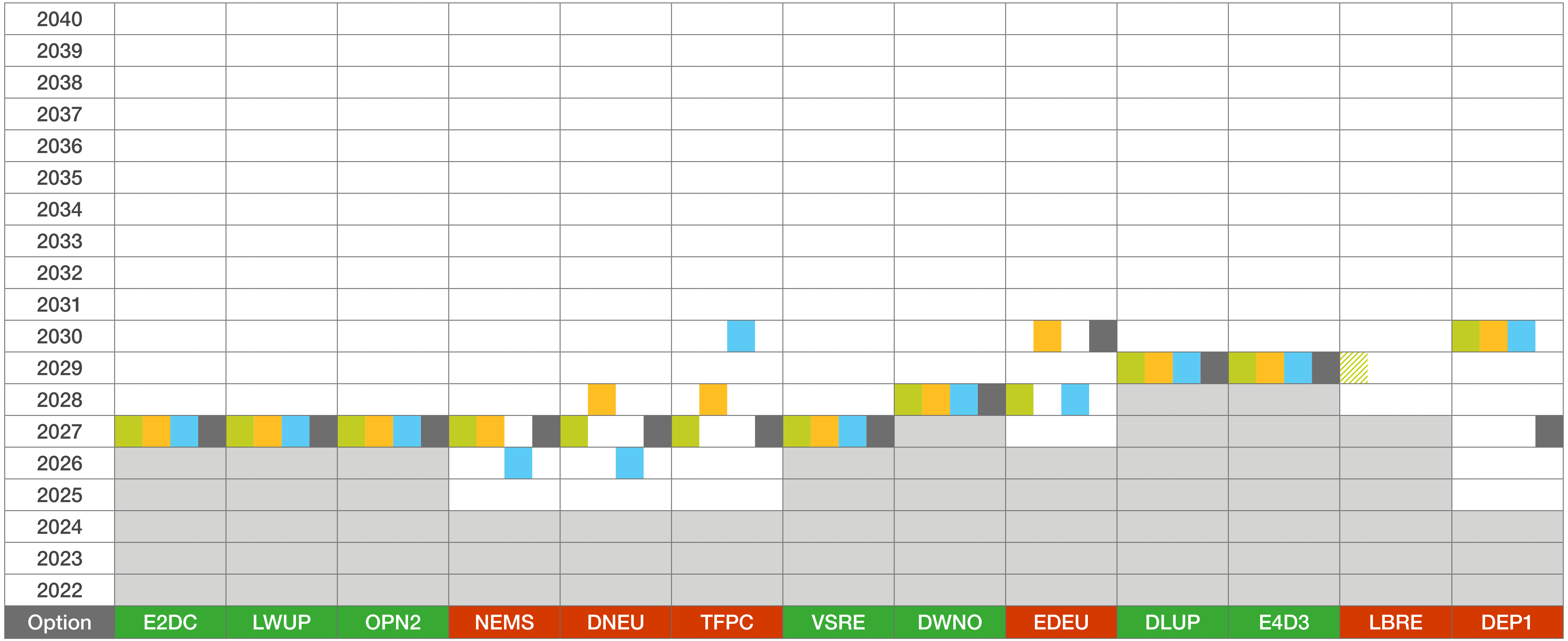
Scotland and North of England region (continued)

Key

- Leading the Way
- Consumer Transformation
- System Transformation
- Steady Progression
- Years before EISD
- 'Critical' option to "Proceed"
- 'Critical' option to "Delay"
- Not 'critical' option to "Hold"

The cross-hatched **Leading the Way** blocks in the table denote that they may be required by HND and therefore have been given a recommendation by the *NOA* Committee.



Hover over the option codes at the bottom of the table for further information

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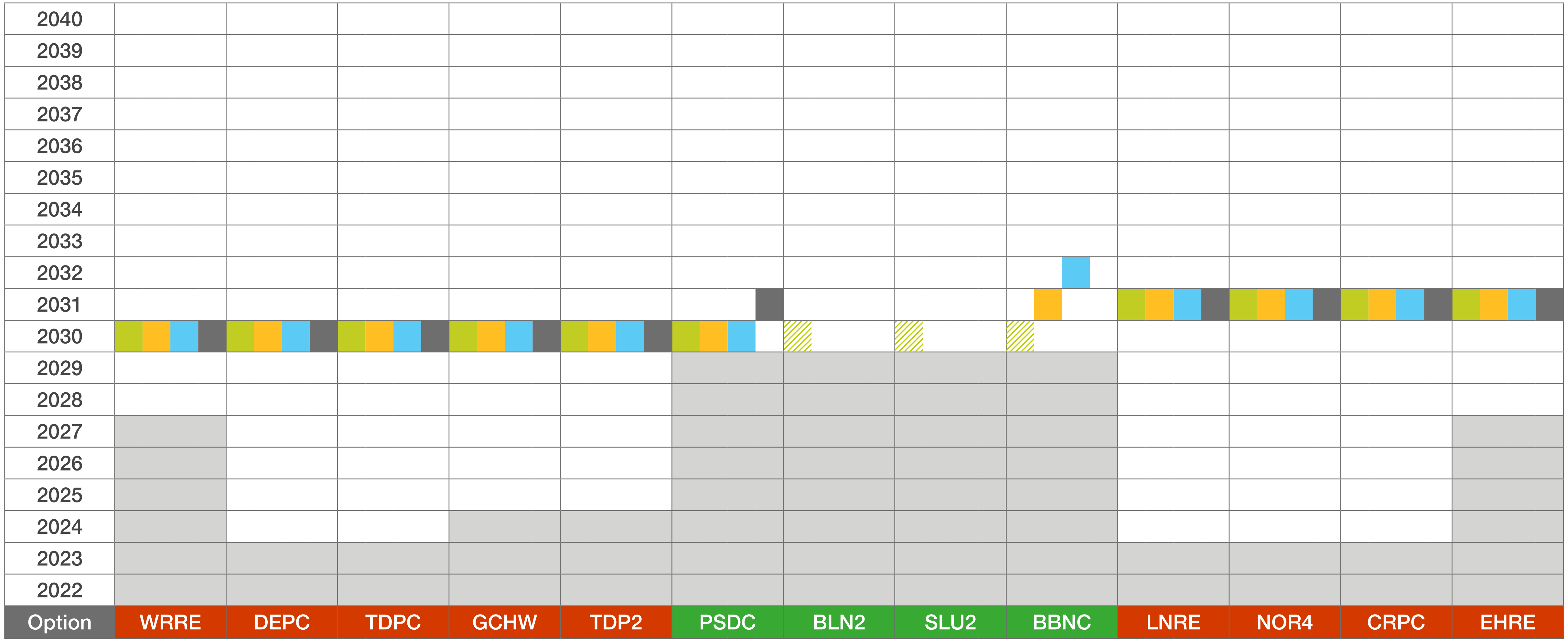
Scotland and North of England region (continued)

Key

- Leading the Way
- Consumer Transformation
- System Transformation
- Steady Progression
- Years before EISD
- ‘Critical’ option to “Proceed”
- ‘Critical’ option to “Delay”
- Not ‘critical’ option to “Hold”

The cross-hatched **Leading the Way** blocks in the table denote that they may be required by HND and therefore have been given a recommendation by the *NOA* Committee.



Hover over the option codes at the bottom of the table for further information

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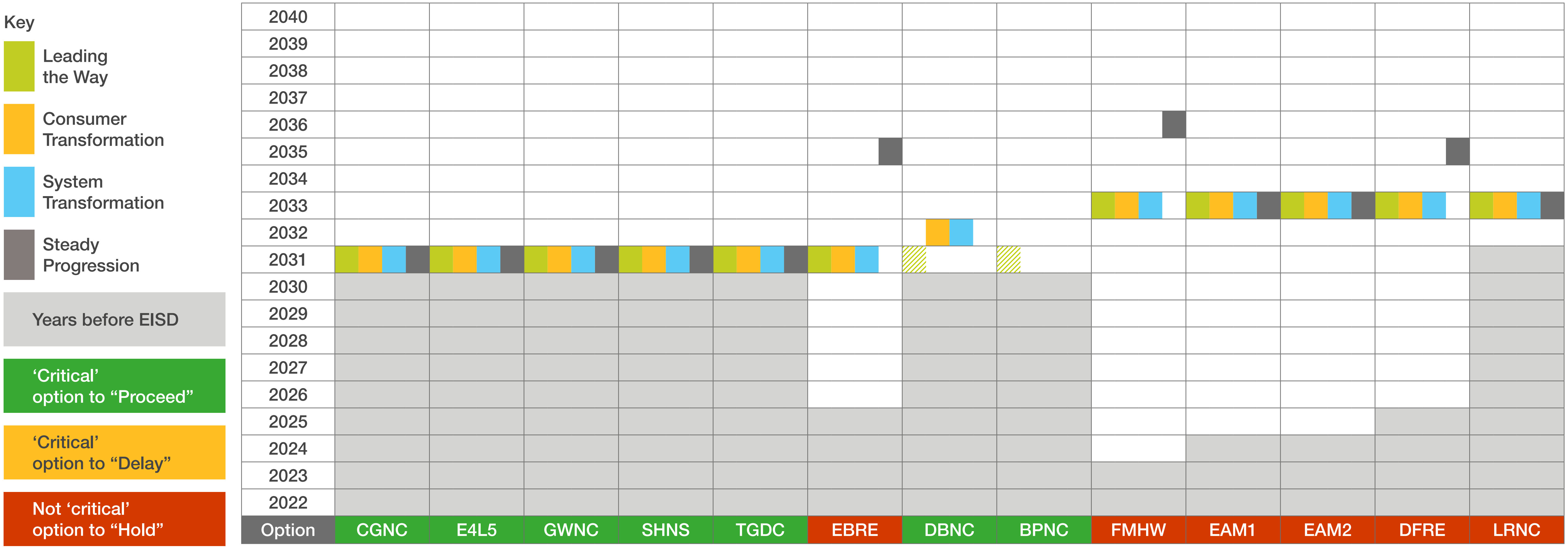
Scotland and North of England region (continued)



The cross-hatched **Leading the Way** blocks in the table denote that they may be required by HND and therefore have been given a recommendation by the *NOA* Committee.

Hover over the option codes at the bottom of the table for further information

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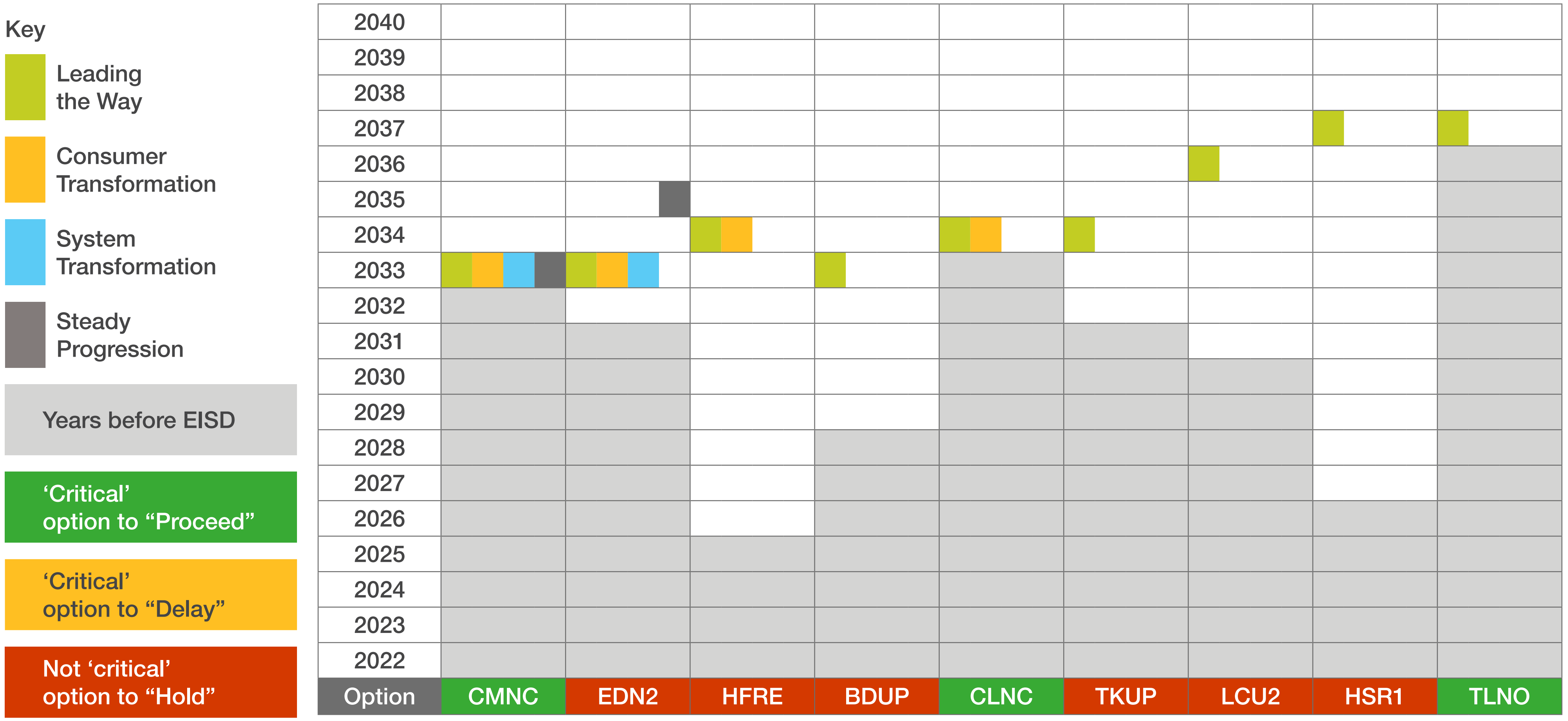
Scotland and North of England region (continued)



Hover over the option codes at the bottom of the table for further information

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Scotland and North of England region (continued)

The following tables present a list of the options that have received a “Proceed” recommendation for this year’s *NOA* alongside last year’s *NOA* recommendation for comparison. The EISD for each option is also noted.

Table 2.2 “Proceed” options to progress in Scotland and North of England region

Code	Option description	EISD	Recommendation (*NOA* 2020/21)	Recommendation (*NOA* 2021/22)
HAEU	Harker supergrid transformer 5 and supergrid transformer 9A banking arrangement	2022	“Proceed”	**“Proceed”**
MRP2	Additional power control devices at both Harker and Penwortham	2022	“Proceed”	**“Proceed”**
CDHW	Cellarhead to Drakelow circuits thermal uprating	2023	“Proceed”	**“Proceed”**
HAE2	Harker supergrid transformer 6 replacement	2023	“Proceed”	**“Proceed”**
CS05	ESO-led commercial solution for Scotland and the North of England - stage 1	2024	“Proceed”	**“Proceed”**
CS06	ESO-led commercial solution for Scotland and the North of England - stage 2	2024	“Proceed”	**“Proceed”**
CS11	ESO-led commercial solution for the North of England - stage 1	2024	“Proceed”	**“Proceed”**
CS12	ESO-led commercial solution for the North of England - stage 2	2025	“Proceed”	**“Proceed”**
KWHW	Keadby to West Burton circuits thermal uprating	2024	“Hold”	**“Proceed”**
KWPC	Power control device along Keadby to West Burton	2024	“Hold”	**“Proceed”**
NEPC	Power control device along Blyth to Tynemouth and Blyth to South Shields	2024	“Hold”	**“Proceed”**
DREU	Generator circuit breaker replacement to allow Thornton to run a two-way split	2025	“Do not start”	**“Proceed”**
KCRE	Reconductor Cottam to Keadby 400 kV double circuit	2025	Not featured	**“Proceed”**
NEP1	Power control device along Blyth to Tynemouth and Blyth to South Shields	2025	“Hold”	**“Proceed”**
DWUP	Kincardine - Wishaw 400 kV reinforcement	2026	“Proceed”	**“Proceed”**
E2DC	Eastern subsea HVDC link from Torness to Hawthorn Pit	2027	“Proceed”	**“Proceed”**

NOA / Investment recommendations / Scotland and North of England region 17

Scotland and North of England region (continued)

Code	Option description	EISD	Recommendation (*NOA 2020/21*)	Recommendation (*NOA 2021/22*)
LWUP	Kincardine 400 kV reinforcement	2027	"Do not start"	**"Proceed"**
OPN2	A new 400 kV double circuit between the existing Norton to Osbaldwick circuit and Poppleton and relevant 275 kV upgrades	2027	"Proceed"	**"Proceed"**
VSRE	Strathaven to Smeaton OHL conductor replacement	2027	Not featured	**"Proceed"**
DWNO	Denny to Wishaw 400 kV reinforcement	2028	"Proceed"	**"Proceed"**
DLUP	Windyhill-Lambhill-Denny North 400 kV reinforcement	2029	"Hold"	**"Proceed"**
E4D3	Eastern Scotland to England link: Peterhead to Drax offshore HVDC	2029	"Proceed"	**"Proceed"**
PSDC	Spittal - Peterhead HVDC reinforcement	2030	"Do not start"	**"Proceed"**
BLN2	Beauly to Loch Buidhe 275 kV reinforcement	2030	"Proceed"	**"Proceed"**
SLU2	Loch Buidhe to Spittal 275 kV reinforcement	2030	"Do not start"	**"Proceed"**
BBNC	Beauly to Blackhillock 400 kV double circuit addition	2030	"Proceed"	**"Proceed"**
CGNC	A new 400 kV double circuit from North Humber to South Humber	2031	"Proceed"	**"Proceed"**
E4L5	Eastern Scotland to England 3rd link: Peterhead to South Humber offshore HVDC	2031	"Proceed"	**"Proceed"**
GWNC	A new 400 kV double circuit between the South Humber and South Lincolnshire	2031	"Proceed"	**"Proceed"**
SHNS	Upgrade substation in South Humber	2031	"Proceed"	**"Proceed"**
TGDC	Eastern subsea HVDC link from south east Scotland to South Humber	2031	"Proceed"	**"Proceed"**
DBNC	Beauly to Dounreay 400 kV double circuit addition	2031	Not featured	**"Proceed"**
BPNC	Blackhillock to Peterhead 400 kV double circuit addition	2031	"Hold"	**"Proceed"**
CMNC	South east Scotland to north west England AC onshore reinforcement	2033	"Proceed"	**"Proceed"**
CLNC	New Cumbria to Lancashire reinforcement	2034	"Do not start"	**"Proceed"**
TLNO	Torness to north east England AC onshore reinforcement	2037	"Stop"	**"Proceed"**

NOA / Investment recommendations / Scotland and North of England region 18

Scotland and North of England region (continued)

Competition Assessment (Scotland and North of England)

We conducted the eligibility assessments for the options recommended to "Proceed" and the following options meet the eligibility criteria proposed by Ofgem.

Beauly to Dounreay 400 kV double circuit addition (DBNC)
Spittal to Peterhead HVDC reinforcement (PSDC)
Loch Buidhe to Spittal 275 kV reinforcement (SLU2)
Beauly to Loch Buidhe 275 kV reinforcement (BLN2)
Beauly to Blackhillock 400 kV double circuit addition (BBNC)
Blackhillock to Peterhead 400 kV double circuit addition (BPNC)
Eastern Scotland to England link: Peterhead to Drax offshore HVDC (E4D3)
Eastern Scotland to England 3rd link: Peterhead to the South Humber offshore HVDC (E4L5)
South east Scotland to north west England AC onshore reinforcement (CMNC)
Eastern subsea HVDC link from Torness to Hawthorn Pit (E2DC)
Eastern subsea HVDC link from south east Scotland to South Humber (TGDC)
Torness to north east England AC onshore reinforcement (TLNO)
New Cumbria to Lancashire reinforcement (CLNC)
A new 400 kV double circuit between the existing Norton to Osbaldwick circuit and Poppleton and relevant 275 kV upgrades (OPN2)
A new 400 kV double circuit from North Humber to South Humber (CGNC)
A new 400 kV double circuit between South Humber and South Lincolnshire (GWNC)

The option OPN2 would have to be split to meet the competition criterion for separability.

We also assessed all new or modified contracted connection projects in this region. We identified the following projects which meet the competition criteria proposed by Ofgem:

Dounreay to Orkney 220 kV HVAC link 1
Western Isles to Beauly HVDC link
Skye 132 kV 2nd circuit reinforcement
North Argyll substation
North Argyll to Craig Murrail 275 kV Operation
Glenmuckloch to ZV Route reinforcements

Visit Ofgem's website for more information and updates on these projects.

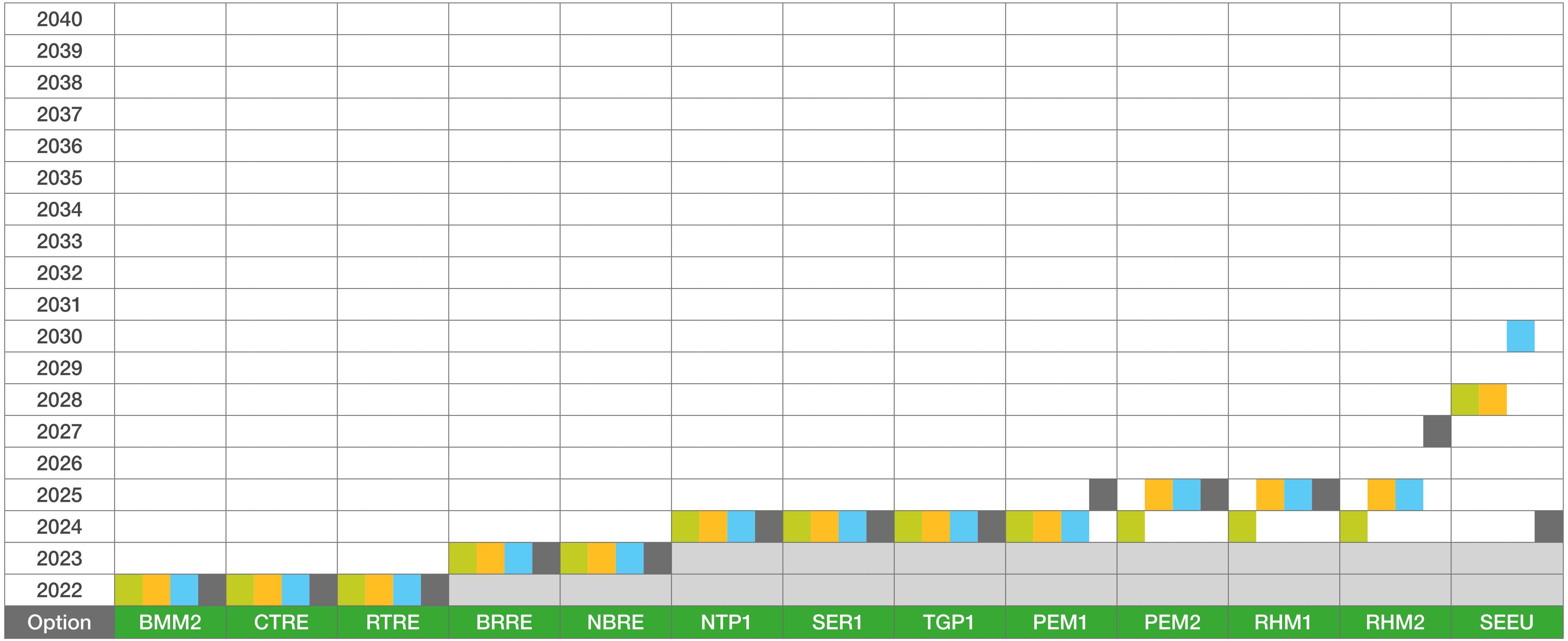
NOA / Investment recommendations / Scotland and North of England region 19

South England region

Table 2.3 Optimal path visualisation in South England region

Key

- Leading the Way
- Consumer Transformation
- System Transformation
- Steady Progression
- Years before EISD
- ‘Critical’ option to “Proceed”
- ‘Critical’ option to “Delay”
- Not ‘critical’ option to “Hold”



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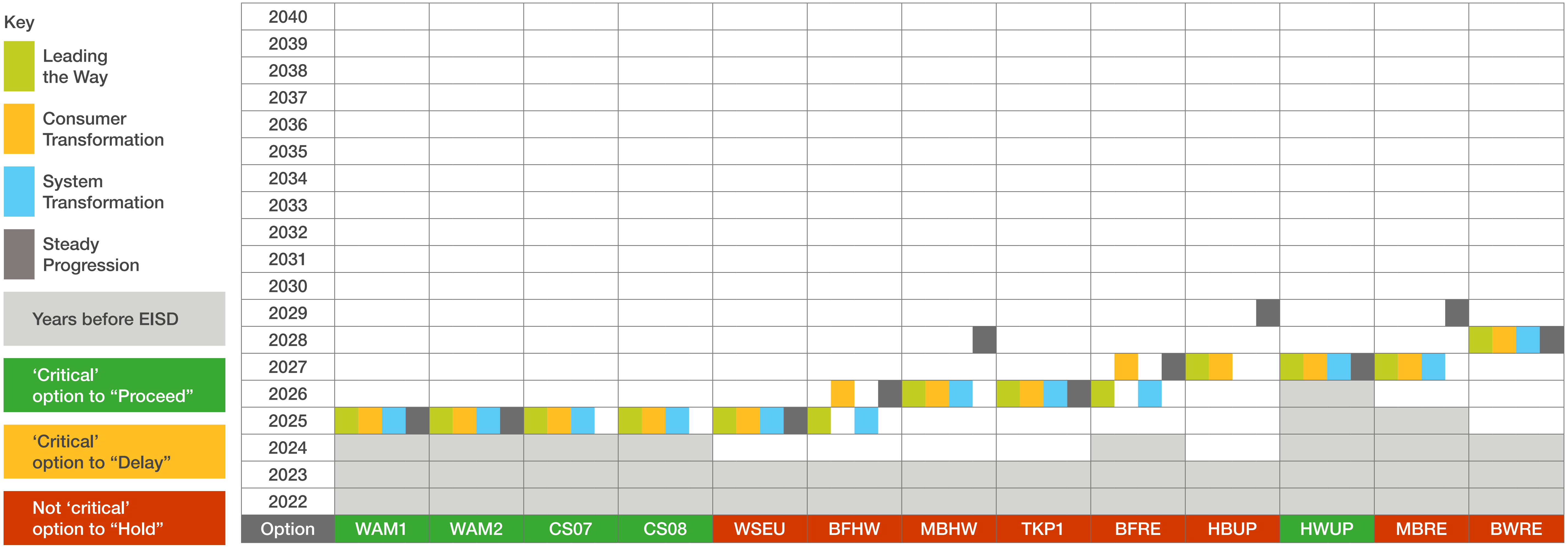
South England region (continued)



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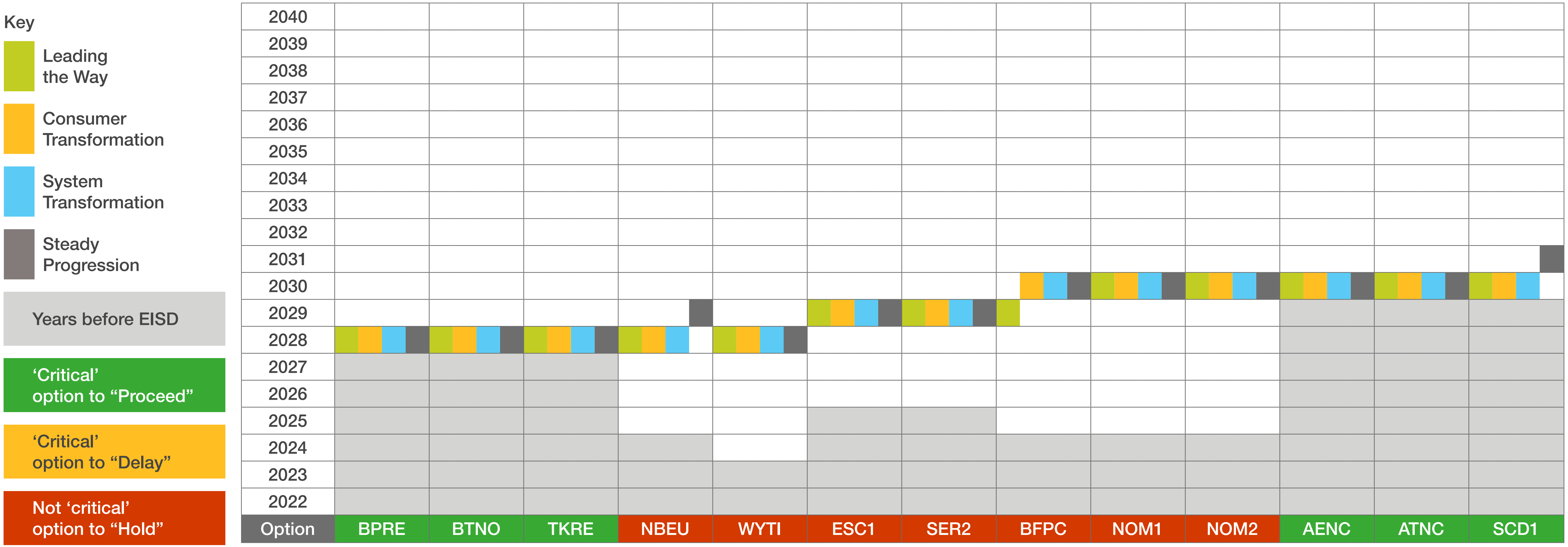
South England region (continued)



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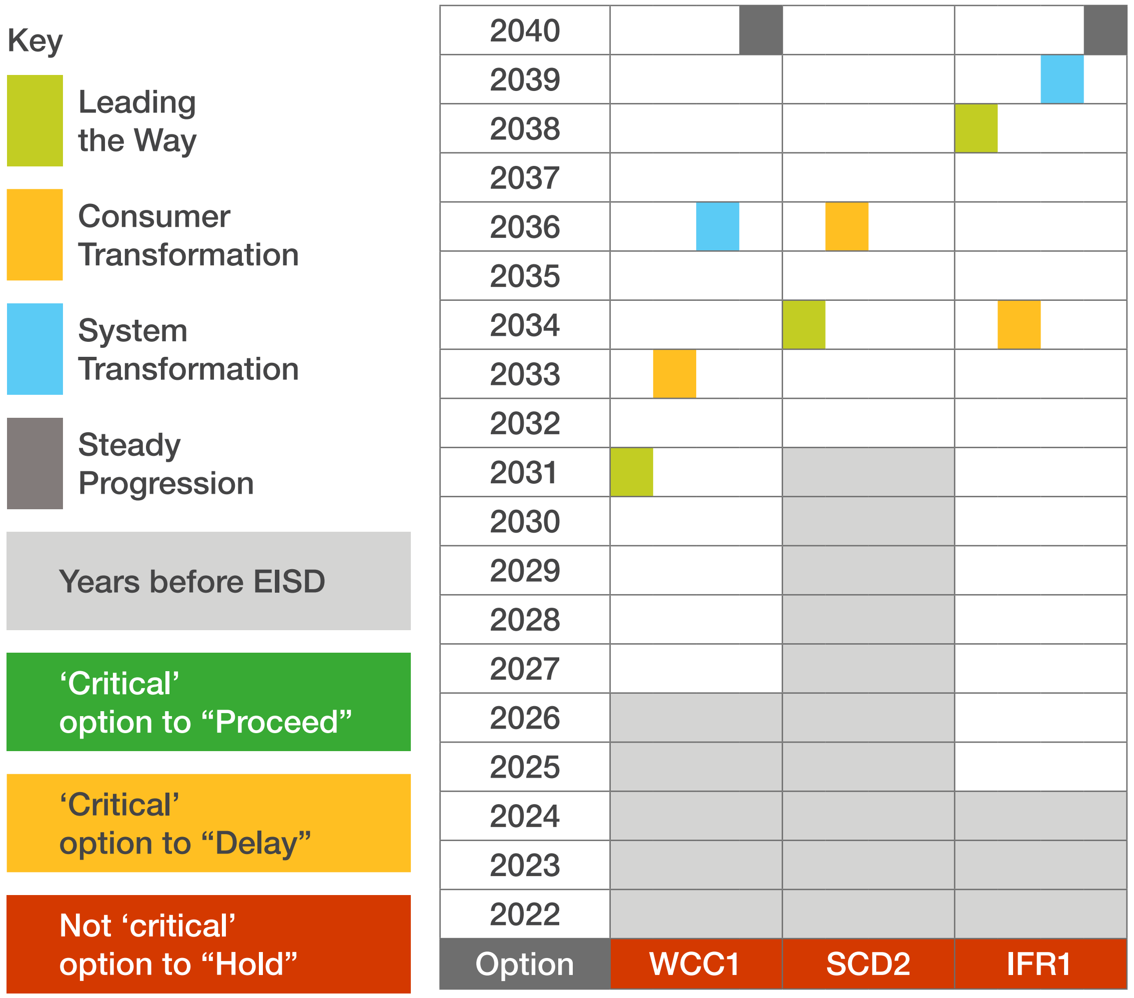
NOA / Investment recommendations / South England region 23

South England region (continued)



Hover over the option codes at the bottom of the table for further information

South England region (continued)

The following tables present a list of the options that have received a "Proceed" recommendation for this year's *NOA* alongside last year's *NOA* recommendation for comparison. The EISD for each option is also noted.

Table 2.4 "Proceed" options to progress in South England region

Code	Option description	EISD	Recommendation (*NOA 2020/21*)	Recommendation (*NOA 2021/22*)
BMM2	225 MVAr MSCs at Burwell Main	2022	"Proceed"	**"Proceed"**
CTRE	Reconductor remainder of Coryton South to Tilbury circuit	2022	"Proceed"	**"Proceed"**
RTRE	Reconductor remainder of Rayleigh to Tilbury circuit	2022	"Proceed"	**"Proceed"**
BRRE	Reconductor remainder of Bramford to Braintree to Rayleigh route	2023	"Hold"	**"Proceed"**
NBRE	Reconductor Bramford to Norwich double circuit	2023	"Hold"	**"Proceed"**
NTP1	Power control device north of Tilbury 400 kV	2024	"Hold"	**"Proceed"**
PEM1	225 MVAr MSCs at Pelham	2024	"Proceed"	**"Proceed"**
PEM2	225 MVAr MSCs at Pelham	2024	"Proceed"	**"Proceed"**
RHM1	225 MVAr MSCs at Rye House	2024	"Proceed"	**"Proceed"**
RHM2	225 MVAr MSCs at Rye House	2024	"Proceed"	**"Proceed"**
SEEU	Reactive compensation protective switching scheme	2024	"Hold"	**"Proceed"**
SER1	Elstree to Sundon reconductoring	2024	"Proceed"	**"Proceed"**
TGP1	Power control device along Tilbury to Grain	2024	"Hold"	**"Proceed"**
CS07	ESO-led commercial solution for East Anglia - stage 1	2025	"Proceed"	**"Proceed"**
CS08	ESO-led commercial solution for East Anglia - stage 2	2025	"Proceed"	**"Proceed"**

NOA / Investment recommendations / South England region 24

South England region (continued)

Code	Option description	EISD	Recommendation (*NOA 2020/21*)	Recommendation (*NOA 2021/22*)
WAM1	225 MVAr MSCs at Walpole	2025	“Hold”	**“Proceed”**
WAM2	225 MVAr MSCs at Walpole	2025	“Hold”	**“Proceed”**
HWUP	Uprate Hackney, Tottenham and Waltham Cross 275 kV to 400 kV	2027	“Proceed”	**“Proceed”**
BPRE	Reconductor the newly formed second Bramford to Braintree to Rayleigh Main circuit	2028	“Proceed”	**“Proceed”**
BTNO	A new 400 kV double circuit between Bramford and Twinstead	2028	“Proceed”	**“Proceed”**
TKRE	Tilbury to Grain and Tilbury to Kingsnorth upgrade	2028	“Hold”	**“Proceed”**
AENC	A new 400 kV double circuit in north East Anglia	2030	“Proceed”	**“Proceed”**
ATNC	A new 400 kV double circuit in south East Anglia	2030	“Proceed”	**“Proceed”**
SCD1	New offshore HVDC link between Suffolk and Kent option 1	2030	“Proceed”	**“Proceed”**

NOA / Investment recommendations / South England region 25

South England region (continued)

Competition Assessment (South England)

For this region we conducted the eligibility assessments for the options recommended to "Proceed" and the following options meet the eligibility criteria proposed by Ofgem.

A new 400 kV double circuit between Bramford and Twinstead (BTNO)
A new 400 kV double circuit in north East Anglia (AENC)
A new 400 kV double circuit in south East Anglia (ATNC)
New offshore HVDC link between Suffolk and Kent option 1 (SCD1)

We also assessed all new or modified contracted connection projects in this region.
We identified the following projects which meet the competition criteria proposed by Ofgem:

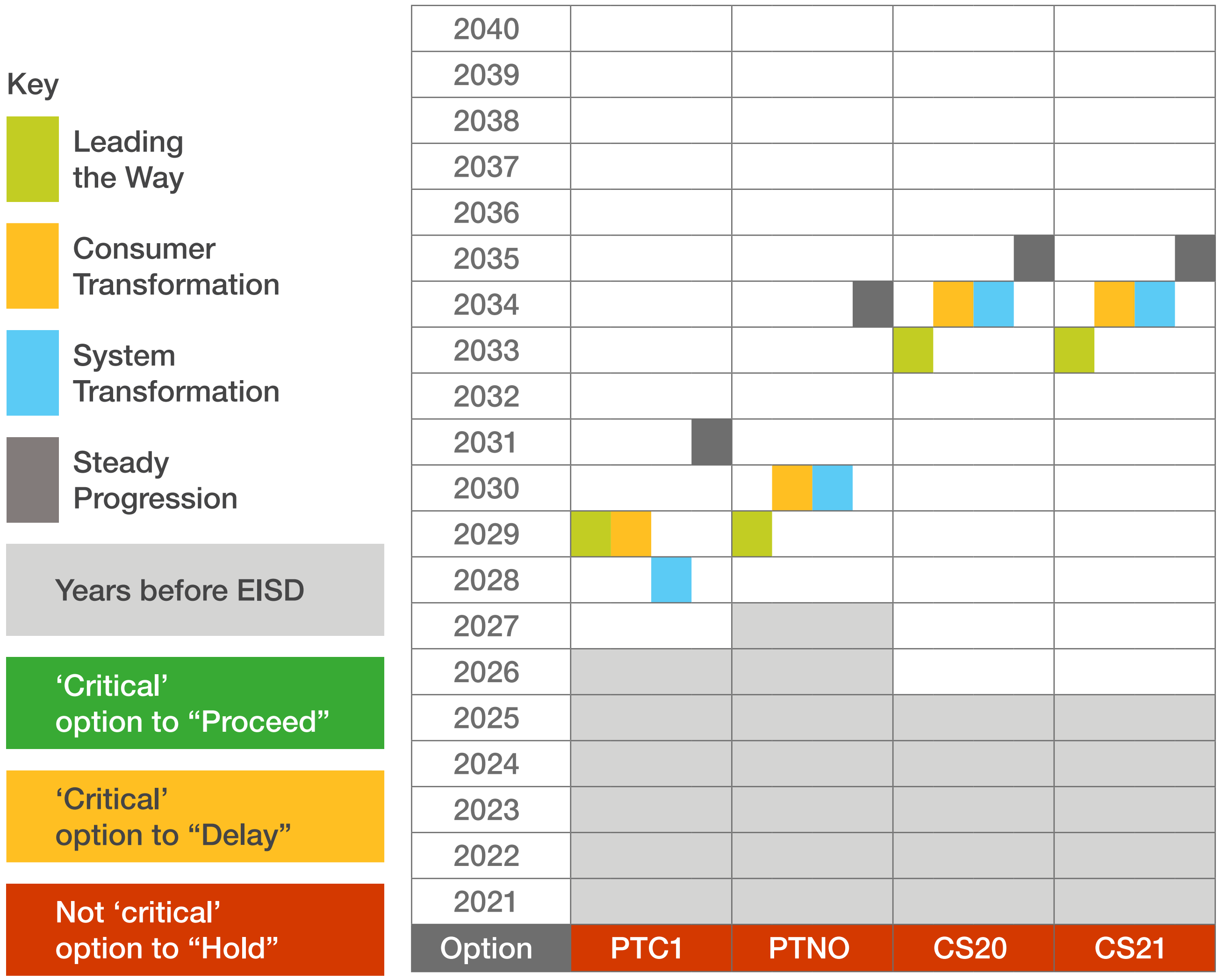
Sizewell 400 kV works

Visit Ofgem's website for more information and updates on these projects.

NOA / Investment recommendations / South England region 26

Wales

Table 2.5 Optimal path visualisation in Wales



Hover over the option codes at the bottom of the table for further information

The *NOA* doesn't see any current driver for wider reinforcements in South Wales within its economic methodology. However, it is acknowledged that there can be drivers for reinforcement works outside of the *NOA*. We are aware there are connections in the region that may need wider reinforcement due to Security and Quality of Supply Standard compliance. Drivers outside the *NOA* can, if required, be reviewed separately to this document for the whole of GB.

Interconnector analysis

Introduction

***NOA* for interconnectors (*NOA* IC) identifies how much interconnection would benefit consumers and other interested parties. It highlights the potential benefits of efficient levels of interconnection capacity between GB and other markets.**

The purpose of this analysis

The analysis outlines the socio-economic benefits of interconnection for consumers, generators and interconnector developers under a range of scenarios.

How it relates to the main *NOA*

The *NOA* for interconnectors is different from the main *NOA*. Rather than assessing proposed projects it evaluates the benefit from hypothetical interconnections. This means it is less impacted by the HND and the ESO is publishing the *NOA* for interconnectors in full at this stage.

Ofgem's Interconnector Policy Review

Following the publication of this year's *NOA*, we will commence new interconnector analysis to support Ofgem's Cap and Floor Window 3[1]. This will build upon *NOA* IC and consider system operability benefits of new interconnectors.

What *NOA* IC can do:

Provide a market and network assessment of the optimal mix of interconnection capacity.

Evaluate the overall benefit to society, by considering social economic welfare, as well as constraint costs and capital expenditure.

What *NOA* IC can't do:

Assess the viability of current or future interconnector projects; the final insights are based on assessing a range of theoretical interconnector options.

Provide project-specific information.

1 For further information on Ofgem's Interconnector Policy Review, please visit: ofgem.gov.uk/sites/default/files/2021-12/ICPR%20Decision%20Paper.pdf

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Introduction

Summary of results

Value

Additional GB interconnection can provide economic and environmental benefit for GB and Europe and is important to achieving net zero by 2050. The high levels of variable renewable generation like offshore wind that are an important component of meeting net zero often exceed demand and excess power is exported to the continent.

Benefits

Increased levels of interconnection benefit GB and the countries we connect to in a range of ways, including greater renewable generation exports, lower wholesale prices and increased access to imported energy when domestic production cannot meet demand.

18.2 to 29.5 GW

Our analysis shows that interconnection of 18.2 GW to 29.5 GW between GB and European markets by 2041 would provide the maximum benefit to GB and connecting country economies.

Location

Both the connecting country and the GB connection zones are critical in maximising value to the GB economy.

Renewable energy

Higher levels of intermittent, renewable generation in the *FES* lead to increased arbitrage opportunities between GB and Europe, particularly in the three scenarios that achieve net zero greenhouse gas emissions by 2050. There are large exports of excess renewable generation and significant imports that help maintain the supply demand balance.

GB social economic welfare

Analysis shows that GB can benefit from more interconnection projects than those included in Cap and Floor Window 2. This year's analysis shows that many of the optimal interconnector options are being driven by high levels of welfare.

Interconnector options

While the analysis results in four optimal interconnector paths based on *FES* 2021, other combinations of interconnectors will also add value.

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Methodology

NOA IC analysis uses the baseline reinforcement assumptions from *NOA*; this provides greater consistency between the *NOA* and *NOA* IC analysis. We have focused on identifying the optimal level of interconnection by examining social economic welfare, capital costs and reinforcement costs. The analysis does not consider the impact of interconnectors on system operability. The method differs from last year; we still use a step-by-step process, but this year we have tested the levels of interconnection within each *FES* by comparing the value each generates with the value from a range of study case interconnectors. We have only tested interconnectors in *FES* that are not operational or under construction.

Interconnectors provide a range of benefits to both industry and consumers, including greater security of supply, greater access to renewable energy and increased competition. Social economic welfare (SEW) is a common cost-benefit indicator when analysing projects of public interest. It captures the overall benefit, in monetary terms, to society from a given course of action and is made up of consumer welfare, producer welfare and interconnector welfare. It is an aggregate of multiple parties' benefits – so some groups in society may lose money from a particular option. In this year's analysis the optimal paths are based on SEW for GB and the connecting country, not for all of Europe. Figure 3.1 highlights the study cases considered in this year's analysis, which are made up of GB connection zones and connecting countries[2].

View study case options

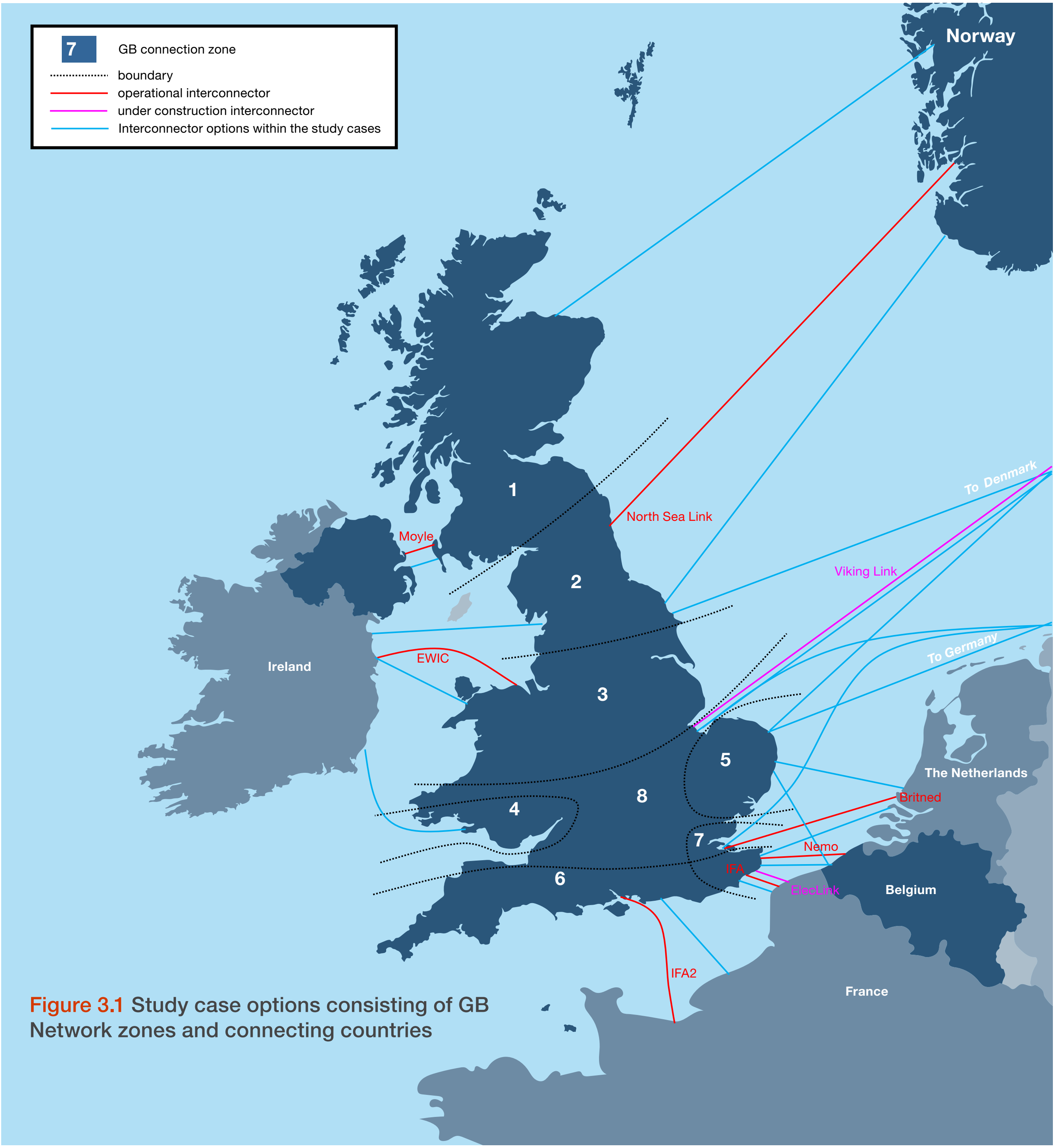

Figure 3.1 Study case options consisting of GB Network zones and connecting countries

2 For a complete explanation of the methodology used for this year's *NOA* IC, please visit: nationalgrideso.com/research-publications/network-options-assessment-noa/methodology

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Outcome

The market and network studies identified the interconnector options that resulted in the highest net present value. These options provide the most benefit to GB and the connecting country.

The output is in three parts:

1. Optimal interconnection range

2. Social economic welfare

3. Import and export flows

Optimal interconnection range

The *NOA* IC methodology only considers SEW, GB constraint costs and interconnector capital expenditure costs. It excludes any analysis of the impact of additional interconnection on operating the transmission system. We have limited the levels of interconnection modelled within *NOA* IC to broadly the levels within the original *FES* scenarios.

The methodology identifies which study cases provide the highest NPV by considering SEW, interconnection capital cost and associated constraint costs. The levels of SEW using *FES* 2021 are high and would have resulted in unrealistically large levels of interconnection to GB if we had continued beyond the levels of interconnection initially included within *FES*. The results would not have reflected the impact on system operability. So the total levels of interconnection seen within this year's *NOA* IC are broadly in line with the levels of interconnection reported in *FES* 2021. Figure 3.2 shows the total level of interconnection for each *FES*.

Consumer Transformation	Leading the Way
28.1 GW	**29.5 GW**
Steady Progression	**System Transformation**
18.2 GW	**21.1 GW**

Figure 3.2 Optimal interconnection for each *FES*

The range of total interconnection across the scenarios is between 18.2 GW to 29.5 GW. The results show there is value for additional interconnection capacity above that included within Ofgem's Cap and Floor Window 2. Currently, the total capacity for current and future electricity interconnectors with GB regulatory approval is 15.9 GW[3].

3 For a complete listing of all existing and future electricity interconnectors with GB regulatory approval see ofgem.gov.uk/energy-policy-and-regulation/policy-and-regulatory-programmes/interconnectors

Outcome

Figure 3.3 shows current GB operational interconnection and total interconnection for each scenario, broken down by country.

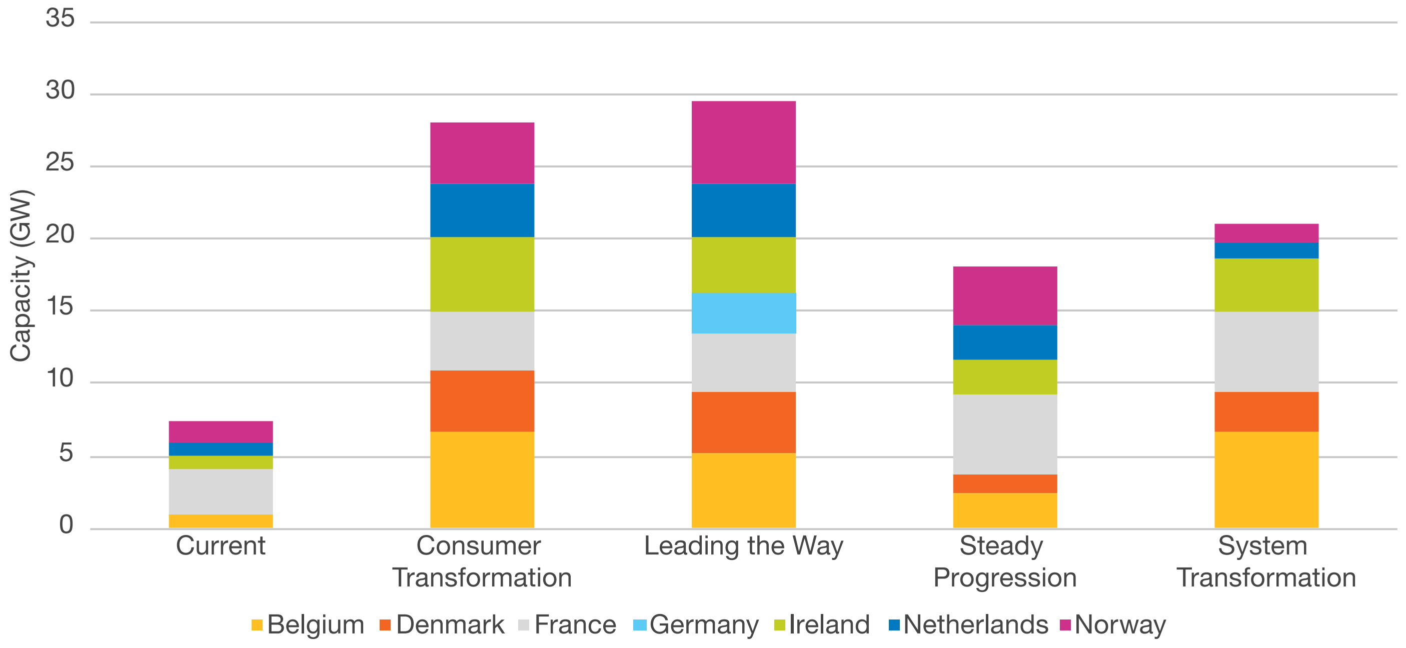

Figure 3.3 Total interconnection capacity by country for each *FES* and current GB interconnection capacity

Figure 3.3 shows a wide distribution of capacity across connecting countries within the four scenarios. Interconnection to Germany is limited to **Leading the Way**. **Consumer Transformation**, **Leading the Way** and **System Transformation** all see many more interconnectors to Belgium and Ireland, and **Consumer Transformation**, **Leading the Way** and **Steady Progression** all have more interconnectors to Norway.

Figure 3.4 shows how interconnection capacity is distributed by connecting country across the four scenarios.

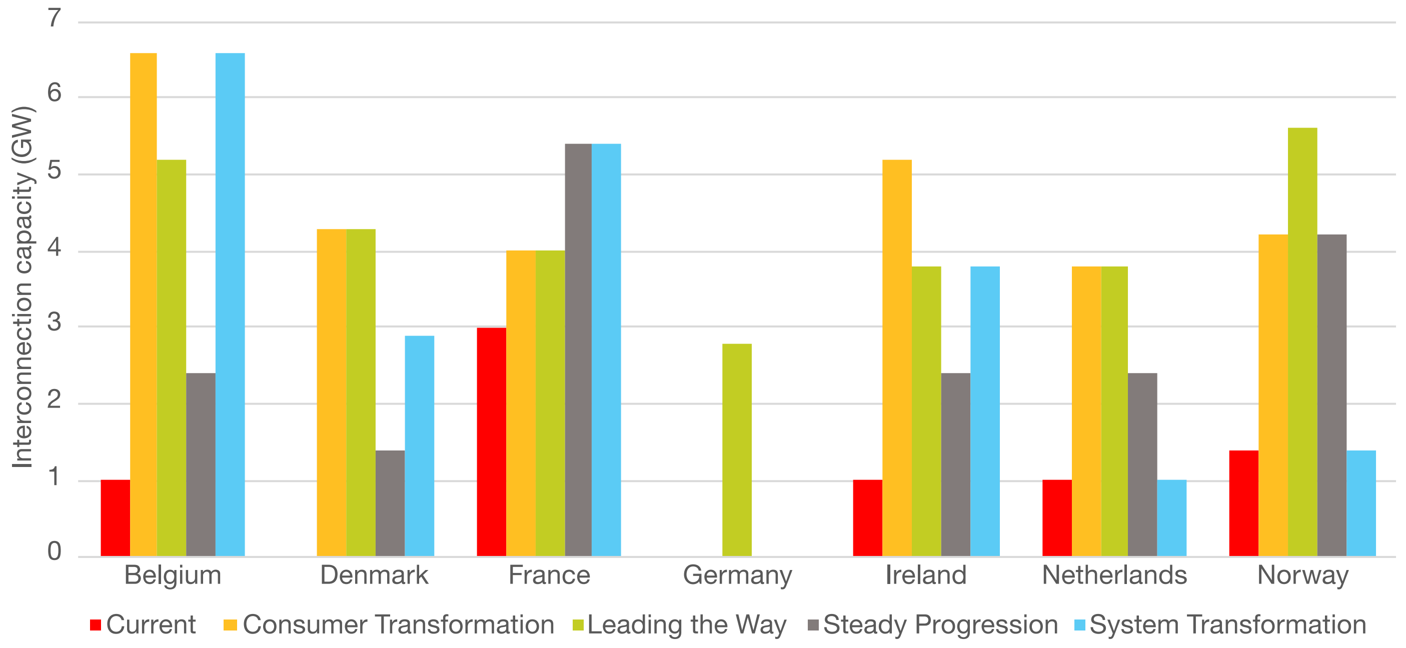

Figure 3.4 Total interconnection capacity for each *FES* by connecting country

Figure 3.4 shows that Belgium, Denmark and France all have more interconnection than current operational levels in all four scenarios. This is also the case for Netherlands and Norway in three of the four scenarios.

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Outcome

Figure 3.5 shows the number of times that each study case is optimal across the four scenarios. Four study cases are optimal in roughly three quarters of iterations, with half of the 20 study cases never being optimal. This shows that both the connecting country and the GB connection zone are critical in deciding which study case will provide the highest NPV. However, many of the study cases that are not optimal in any of the iterations also provide significant levels of NPV.

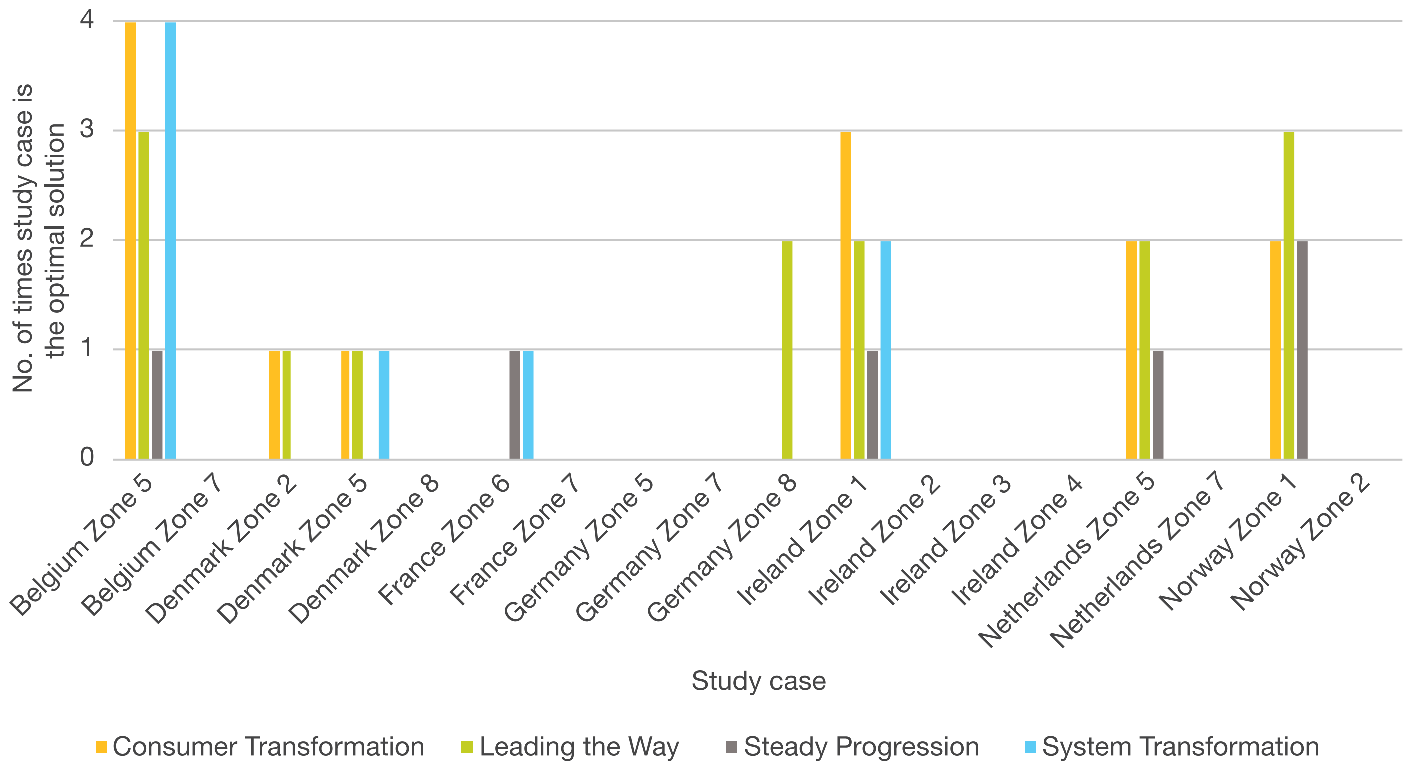

Figure 3.5 Number of times a study case is the optimal solution

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Social economic welfare

Figure 3.6 shows the optimal study cases for the optimal paths for the four *FES*.

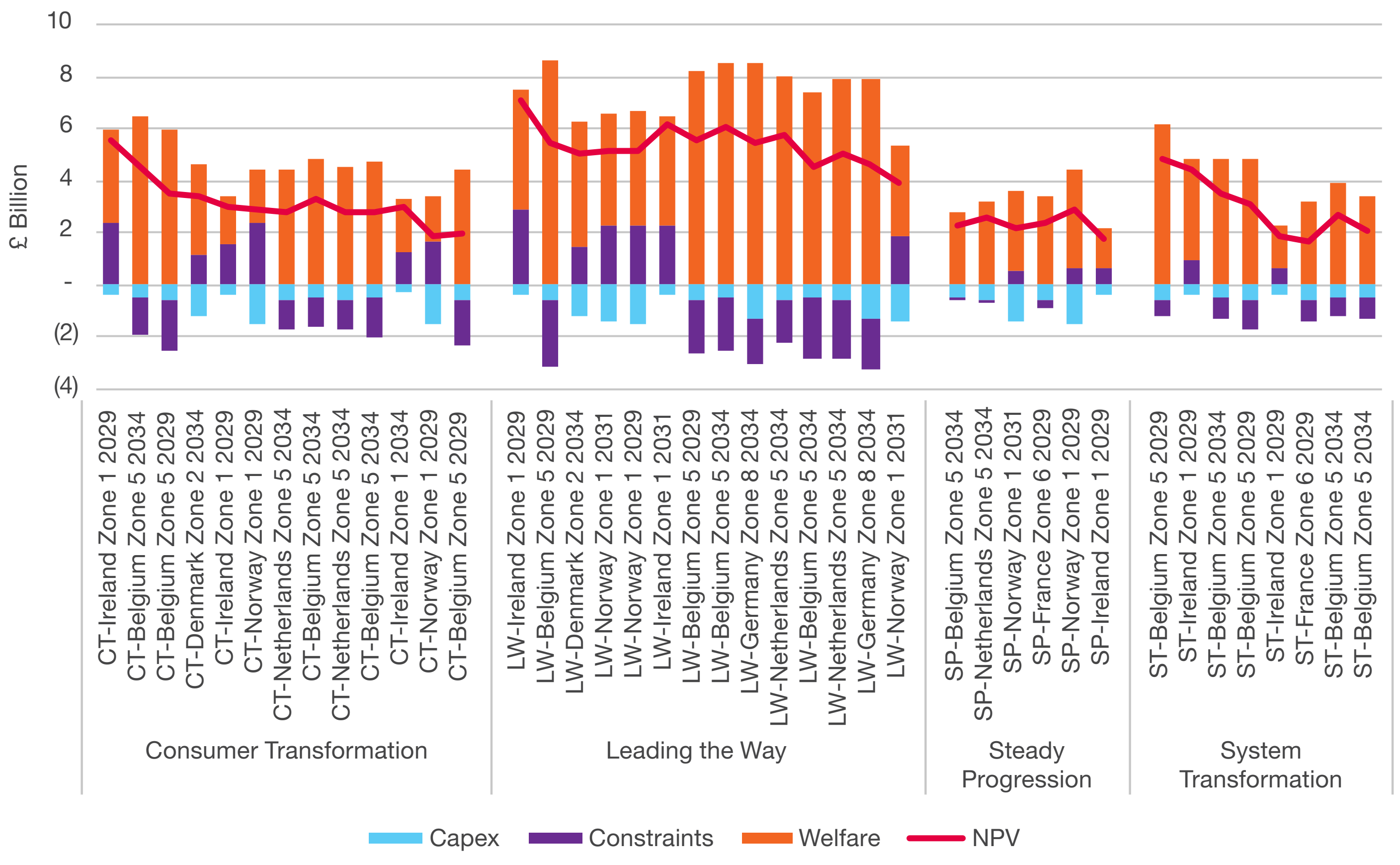

Figure 3.6 Net Present Value of each optimal study case for the optimal path for each *FES*

Figure 3.6 shows the variation in length of optimal paths across the four scenarios and the variations in net present value (NPV) relative to the base case for each iteration. It also gives a breakdown for each NPV by welfare, CAPEX and constraint costs. CAPEX is always negative relative to the base case. As the additional interconnector may result in constraint savings or additional costs relative to the base case, the chart shows constraints as both positive and negative.

The lengths of paths vary across the four future energy scenarios as the number of iterations equalled the number of interconnectors in each future energy scenario.

Figure 3.6 shows that for both **Consumer Transformation** and **Leading the Way**, study cases with interconnectors to Ireland and Norway result in significant constraint savings. However, the dominant factor to NPV in virtually every optimal study case is welfare. This is noticeably higher in **Leading the Way**, with **Steady Progression** showing the lowest levels. In iterations seven to 13 in **Leading the Way**, the high levels of welfare more than offset the increased constraint costs.

Many of the study cases that did not win - they do not feature on the optimal paths - also provide positive NPV, primarily driven by welfare.

The methodology for this year's *NOA* IC only considered SEW for GB and the connecting country. Considering SEW for all of Europe may have given different results.

Figure 3.6 shows that there were still high levels of NPV by iteration 14 for **Leading the Way**. In theory, the process could have continued until NPV declined to zero, but this would have resulted in unrealistically high levels of interconnection, with no account of the impact on system operability.

Import and export flows

Figure 3.7 shows annual imports and exports as vertical bars and net flows as horizontal lines for each of the optimal interconnection paths.

Steady Progression shows net imports up to 2034, then switches to low levels of net exports in 2038 which increase in 2041. The other three scenarios all show net exports across the study years, with **Consumer Transformation** and **System Transformation** showing increases across the study years, and with **Leading the Way**'s net exports peaking in 2034.

Figure 3.7 shows that exports are often significantly larger than imports. Export volumes reflect the high levels of GB renewable generation, particularly in **Leading the Way**, **Consumer Transformation** and **System Transformation**, with the interconnectors allowing excess generation to be exported to neighbouring markets. Imports remain relatively flat across the study years, indicating there is a sustained requirement for imports at certain times to achieve a supply demand match in GB.

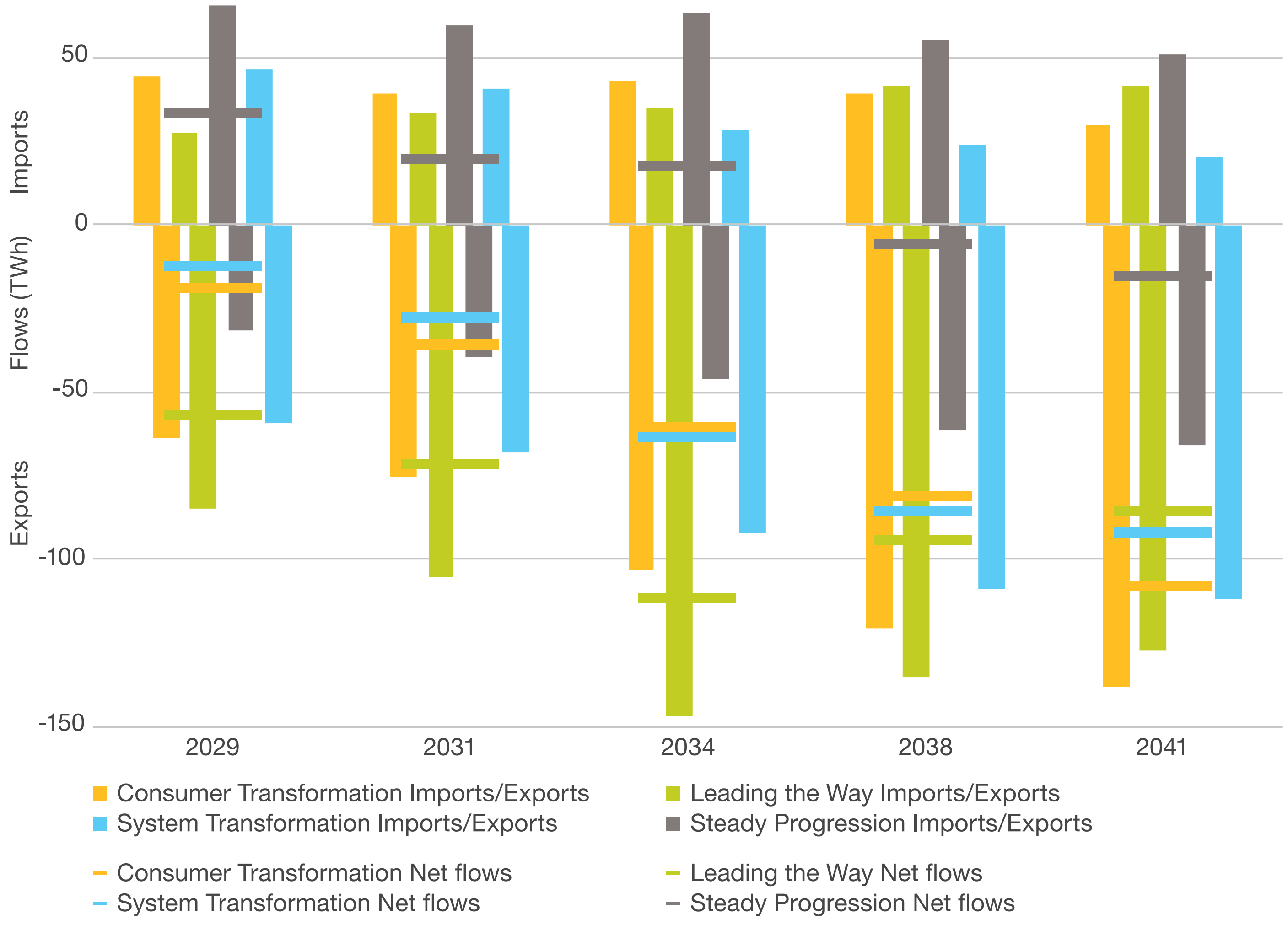

Figure 3.7 Annual interconnector imports, exports and net flows

Outcome

Figure 3.8 to Figure 3.11 show import and export flows for the four scenarios, broken down by connecting country.

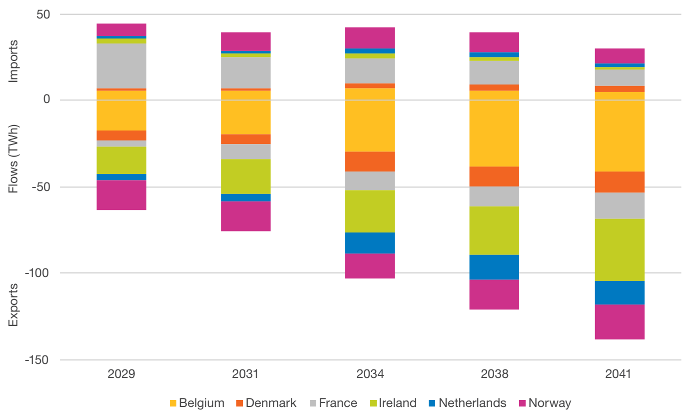

Figure 3.8 Electricity import and export flows for the optimal path for Consumer Transformation

Figure 3.8 shows that for **Consumer Transformation**, imports remain relatively flat. Exports steadily increase, as additional renewable generation is connected in GB, with exports reaching nearly 140 TWh by 2041. Belgium, Ireland and Norway show the highest levels of exports.

Jump to enlarged diagram

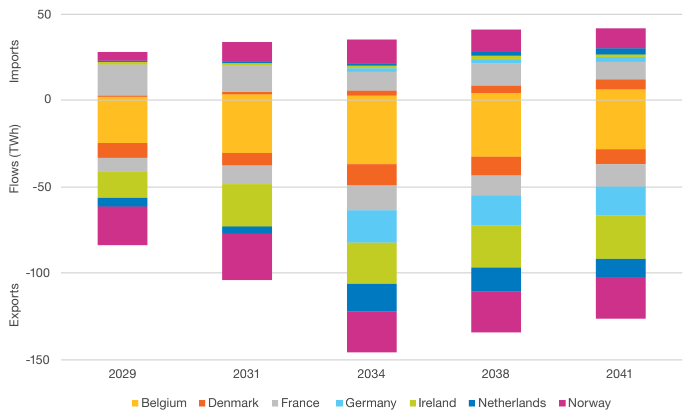

Figure 3.9 Electricity import and export flows for the optimal path for Leading the Way

Figure 3.9 shows that for **Leading the Way** imports increase slightly, with France and Norway providing the majority. Exports rise rapidly to nearly 150 TWh in 2034, then fall off slightly. Belgium, Ireland, Norway and Germany receive the highest levels of exports.

Jump to enlarged diagram

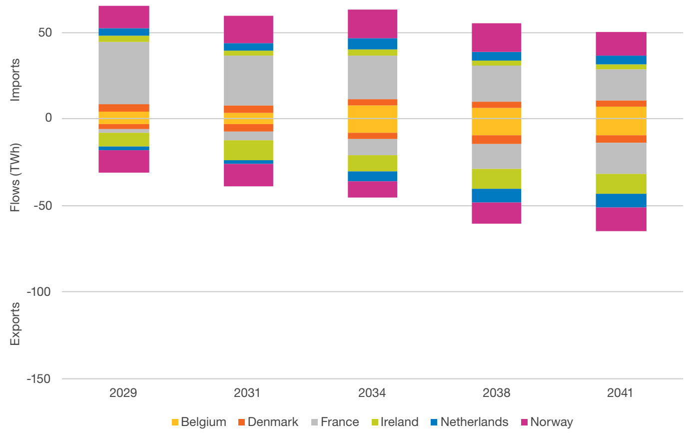

Figure 3.10 Electricity import and export flows for the optimal path for Steady Progression

Figure 3.10 shows that **Steady Progression** imports are the highest of the four scenarios, and exports the lowest, reflecting the lower levels of interconnection capacity and renewable generation in GB. Imports are mainly from France and Norway, with exports primarily to France, Ireland and Norway.

Jump to enlarged diagram

Figure 3.11 Electricity import and export flows for the optimal path for System Transformation

Figure 3.11 shows that for **System Transformation** imports decline significantly over the study years, while exports increase steadily. Imports are dominated by flows from France, with the bulk of exports going to Belgium, France and Ireland.

Jump to enlarged diagram

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Glossary

Boundary

A boundary splits the system into two parts, crossing critical circuit paths that carry power between the areas where power flow limitations may be encountered.

Cost-benefit analysis (CBA)

A method of assessing the benefits of a given project in comparison to the costs. This tool can help to provide a comparative base for all projects to be considered.

Critical

The option is 'optimal' on its earliest in service date (EISD) in at least one scenario.

Earliest in service date (EISD)

The earliest date when the project could be delivered and put into service, if investment in the project was started immediately.

Electricity System Operator (ESO)

An entity entrusted with transporting electric energy on regional or national levels, using fixed infrastructure. Unlike a Transmission Operator (TO), the ESO may not necessarily own the assets concerned. For example, National Grid ESO operates the electricity transmission system in Scotland, which is owned by Scottish Hydro Electricity Transmission and Scottish Power.

Future Energy Scenarios (*FES*)

The *FES* is a range of credible futures which has been developed in conjunction with the energy industry. They are a set of scenarios covering the period from now to 2050 and are used to frame discussions and perform stress tests. They form the starting point for all transmission network and investment planning and are used to identify future operability challenges and potential solutions.

Great Britain (GB)

A geographical, social and economic grouping of countries that contains England, Scotland and Wales.

Holistic Network Design (HND)

The Holistic Network Design is a major output of the OTNR and will deliver an economic, efficient, operable, sustainable and coordinated National Electricity Transmission System (NETS) to facilitate the pace and certainty required to deliver the 2030 offshore wind targets and the 2045 and 2050 net zero targets.

Interconnector

Electricity interconnectors are transmission assets that connect the GB market to Europe and allow suppliers to trade electricity between markets.

Investment Recommendations

As defined in the *NOA* methodology, the outcome of the *NOA* process for each option is one of five investment recommendations:

"Proceed": An option is critical to our future planning. Investment should be made in the next financial year to ensure the option's earliest in service date remains on course.

"Delay": At this time, it is not economically viable to proceed with this option. The option's delivery should be delayed by one year.

"Hold": An option is important and required in the future, however due to the lead time in delivering this option, no investment is required this year. Therefore, this option can be delayed by at least one year.

"Stop": An option is not currently required in our future plan, delivery should be stopped and not be continued.

"Do not start": An option is not currently required in our future plan, delivery work should not begin.

Offshore

This term means wholly or partly in offshore waters.

Offshore transmission circuit

Part of an offshore transmission system between two or more circuit breakers which includes, for example, transformers, reactors, cables, overhead lines and DC converters but excludes busbars and onshore transmission circuits.

Onshore

This term refers to assets that are wholly on land.

Onshore transmission circuit

Part of the onshore transmission system between two or more circuit breakers which includes, for example, transformers, reactors, cables and overhead lines but excludes busbars, generation circuits and offshore transmission circuits.

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Optimal

The option is economically justified in at least one scenario.

Offshore Transmission Network Review (OTNR)

The OTNR is being led by the Department of Business, Energy and Industrial Strategy with ESO support. It is looking into the way that the offshore transmission network is designed and delivered, consistent with Scottish and UK Government ambitions to deliver net zero emissions by 2045 and 2050.

Social economic welfare (SEW)

Social economic welfare (SEW) is a common cost-benefit indicator when analysing projects of public interest. It captures the overall benefit, in monetary terms, to society from a given course of action.

System operability

The ability to maintain system stability and all the asset ratings and operational parameters within pre-defined limits safely, economically and sustainably.

System stability

With reduced power demand and a tendency for higher system voltages during the summer months, fewer generators will operate and those that do run could be at reduced power factor output. This condition tends to reduce the dynamic stability of the NETS. Therefore, network stability analysis is usually performed for summer minimum demand conditions as this represents the limiting period.

Transmission circuit

This is either an onshore transmission circuit or an offshore transmission circuit.

Transmission Owners (TO)

A collective term used to describe the three transmission asset owners within Great Britain, namely National Grid Electricity Transmission, Scottish and Southern Electricity Networks and Scottish Power Transmission Limited.

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