Ireland and the SuperGrid 2022

Connecting an Energy Independent Europe

WIND ENERGY IRELAND

Table of contents

1 **Executive Summary** 04
- 1.1 The SuperGrid 04
- 1.2 What can we do now to help to deliver a SuperGrid? 06

2 **Overview of the SuperGrid and Ireland's Role** 06
- 2.1 What is a SuperGrid? 06
- 2.2 Why does Europe need a SuperGrid? 07
- 2.3 Ireland's Role and Geographic Responsibility 09
- 2.4 Transmission Today 12
- 2.5 Transmission of the Future 14

3 **The Benefits a SuperGrid Can Bring** 16
- 3.1 Opportunity to decarbonise on a European scale 16
- 3.2 Help realise our Climate Ambitions 16
- 3.3 Key enabler to realising our offshore wind potential 17
- 3.4 Improved energy security through increased interconnection 17
- 3.5 Lowering dispatch down 17
- 3.6 Cost and infrastructure efficient 18
- 3.7 Address variability of renewable energy 18
- 3.8 Jobs 19

4 **Work on coordination to date** 19
- 4.1 What a SuperGrid could look like 19
- 4.2 Multi-Purpose Interconnectors and Energy Islands 25

5 **How will the SuperGrid be Funded?** 25
- 5.1 How will the SuperGrid be paid for? 26

6 **Timing and how the SuperGrid could develop** 27
- 6.1 2020 – 2030 28
- 6.2 2030 – 2040 28
- 6.3 2040 – 2050 29

7 **Challenges to realising a SuperGrid** 29

8 **Recommendations** 30
- 8.1 Maritime Spatial Planning Recommendations 30
- 8.2 Policy and Regulatory Recommendations 31
- 8.3 TYNDP Recommendations 31
- 8.4 Recommendations for Ireland 31

9 **Appendix**
- 9.1 Offshore Wind Technical Potential in Ireland 33

1. Executive Summary

Europe is at a critical crossroads in its energy systems development. Climate change is a problem not just faced by each country individually, but it is an existential crisis facing humanity. If we are to overcome the worst effects of climate change, countries must band together to drive towards a net-zero world. Decarbonising the Irish and European energy systems is an essential first step and will create not just a cleaner energy system but a more efficient and more effective one too.

The key to this decarbonisation is the electrification of our economies powered by renewable energy. In order to move away from harmful fossil fuels, a new energy system must be designed around the specific characteristics of renewables, and how to connect resource rich areas to demand centres. A SuperGrid can be this new system. A SuperGrid is a vision for a fully integrated European electricity grid unlocking the best renewable resources and connecting them to all of Europe. A SuperGrid would span far enough to alleviate the variability of local weather and connect the strongest resources to demand centres. This ensures that every European will have access to clean renewable power, whatever the local weather conditions might be.

Imagine:

- A café in Prague making hot chocolate using clean solar power from Spain.
- A farmer in Ireland powering his milking parlour with electricity from a wind farm off the coast of Denmark.
- A manufacturing plant in Milan using electricity from a Norwegian hydro plant.
- An entire continent, united and powered by clean, renewable energy.
- A Europe that is energy independent, no longer reliant on imported fossil fuels or vulnerable to spiralling oil and gas prices, where we produce our own energy and drive a truly green recovery.

This is the opportunity we have before us, a future Europe that can become our reality using a combination of innovative technology and renewable power in a SuperGrid which would span our continent.

1.1 The SuperGrid

Europe's best wind resources are in the north and its best solar resources are in the south, while the major demand is in the centre. A SuperGrid would allow Europe to install its renewable generation capacity where the resources are strongest and then move this power to where it is needed. Optimising the location of renewable generation will result in a lower cost of electricity, while a larger grid can reduce the levels of constraints and curtailment and facilitate a more stable and secure electricity system.

A SuperGrid will:

- Provide an opportunity to decarbonise our energy systems on a continental scale.
- Help to achieve the 2050 climate targets.
- Facilitate a more stable and secure future electricity system with seasonal complementarity of wind and solar.
- Develop a more interconnected system which will reduce the level of curtailment on the system.
- Help Europe gain energy independence.
- Allow Europe to build its renewable capacity where the resource is best, ensuring Ireland's offshore wind resources play a vital role in Europe's 2050 ambitions.

A SuperGrid will enable us to harness Ireland's enormous offshore wind energy potential.

"Countries with offshore wind resources have a geographical responsibility to lead Europe in this [the deployment of offshore wind]", WindEurope - Our Energy, Our Future[1].

Offshore wind is envisaged as being a vital part of Europe's fight against climate change. 2050 will see at least 400 GW of offshore wind installed in European waters. Ireland also has ambitious plans for offshore wind, with a target of 5 GW set for 2030, and the Programme for Government highlighting a potential for at least 30 GW of floating wind in the longer term.

The offshore area does not have an electricity grid yet, and how these huge capacities of offshore wind connect into the energy system is a question now being asked, particularly as we identify levels of offshore potential beyond what individual national grids could accommodate alone. The delivery of a pan-European offshore electricity network will be essential in enabling and accelerating Ireland and the EU's ability to incorporate offshore resources and meet 2050 climate targets.

A SuperGrid can radically accelerate the decarbonisation of our energy systems, offering Europe the opportunity to gain energy independence from its reliance on volatile fossil fuel markets in favour of the vast, local renewable resources. This does not mean, however, that each country should view this as a call to meet its own demand solely from within its borders. Implementing a SuperGrid should encourage international cooperation, allowing countries to work together to achieve targets, minimising the infrastructure needed and ensuring they are delivered as efficiently as possible, propelling Europe to become a true leader in the fight against Climate Change.

1.2 What can we do now to help to deliver a SuperGrid?

While the ultimate realisation of a pan-European SuperGrid is seen as a longer-term ambition, planning must begin now. Developing a SuperGrid would be one of the most significant infrastructure projects ever undertaken. It will require international coordination at a level never seen before in the context of electricity grids. Preparations cannot begin soon enough. There are several key steps that can be taken now to facilitate the planning and delivery of the SuperGrid.

1) **Marine Spatial Planning (MSP):** To support international meshed offshore grid development (Figure 1), cooperation is needed between national MSP authorities and energy authorities from bordering countries to identify optimal locations for corridors and transfer gates for interconnectors. The recent TEN-E revision aims to encourage regional cooperation in the development of offshore wind and the required infrastructure.

2) **Resources:** A vast amount of focus at present is rightly being placed on delivering Ireland's 2030 target of 5 GW offshore wind. But planning needs to start now for a post-2030 electricity grid when Ireland moves towards a more centrally planned grid delivery model. To do this, resources must be invested in the relevant Government departments, An Bord Pleanála, NPWS, EirGrid, ESB Networks and the CRU.

3) **Grid Planning:** Ireland should propose, and contribute to, a long term (2050) regional roadmap for offshore grid development with our neighbours. Now is the time to explore state-of-the-art solutions for the connection and distribution of offshore wind energy.

   A meshed grid connecting the Celtic Sea, English Channel and the Bay of Biscay would facilitate an increase in power flows and improve security of supply. Considering the long lead times of offshore wind farms and grid projects, interest in meshed grids must translate into bold policy-making and reinforced transnational cooperation soon, before the region is further locked into a suboptimal energy system.

1. https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Our-Energy-Our-Future.pdf

4) **Future Grid Implementation:** The recent Shaping our Electricity Future[2] report from EirGrid indicates a continuance of the incremental approach in grid planning. A more ambitious, transformative approach is needed. A Coordination Council should be immediately established to start investigating what post-2030 looks like and how it would operate. This would bring together industry, EirGrid, CRU, and the Department of Environment, Climate and Communications. Successful implementation will include regular engagement with EirGrid to discuss approaches to post 2030 design and implementation.

5) **International Relations:** Ireland will not realise its ambitious offshore wind targets without cooperation with neighbouring countries. Concurrently, Europe will not achieve its decarbonisation goals without full cooperation of all members. Ireland must effectively use its presidency of the North Seas Energy Cooperation in 2022[3] to take an active role in promoting the coordinated development of regional and European level grids.

2 Overview of the SuperGrid and Ireland's Role

2.1 What is a SuperGrid?

At the September 2021 Wind Energy Ireland Offshore Wind Conference, Minister for the Environment, Climate and Communications, Eamonn Ryan, told delegates that *"due to our location at the edge of the Atlantic, with a sea area of 490,000 square kilometres – almost seven times our land mass - we have considerable but as yet undeveloped offshore renewable energy potential. As technologies develop, Ireland has the resource potential to become a major contributor in a pan-European renewable energy and transmission system change".*

This pan-European system has been termed a SuperGrid. A SuperGrid is essentially a large transmission network which makes it possible to move huge volumes of electricity across great distances, using high-voltage direct current (HVDC) or ultra-high-voltage direct current (UHVDC, above 800 kV) power lines[4].

The idea of a European SuperGrid is a transmission network spanning the continent which can help to connect resource-rich areas with high renewable energy potential – such as Ireland (offshore wind) or Spain (solar) – to Europe's main demand centres, with less renewable energy potential relative to their demands. Ireland's Programme for Government outlined an ambition to make Ireland a major contributor to a pan-European renewable energy generation and transmission system, taking advantage of at least 30 GW of offshore floating wind power. A SuperGrid will be key to these goals and can bring a host of other benefits to Ireland and Europe as we aim to decarbonise our electricity systems. This paper will give an overview of the SuperGrid, explain why it is so important to both Ireland and Europe, and outline what is needed to begin implementing it across Europe.

2. https://www.eirgridgroup.com/the-grid/shaping-our-electricity-f/
3. The North Seas Energy Cooperation (NSEC) supports and facilitates the development of the offshore grid and the large renewable energy potential in the region. Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Sweden, and the European Commission are currently members of the NSEC.
4. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_SuperGrids_2019.pdf?la=en&hash=4C6639C08B1BEC582B700609C6D-3C3B2E126AE70

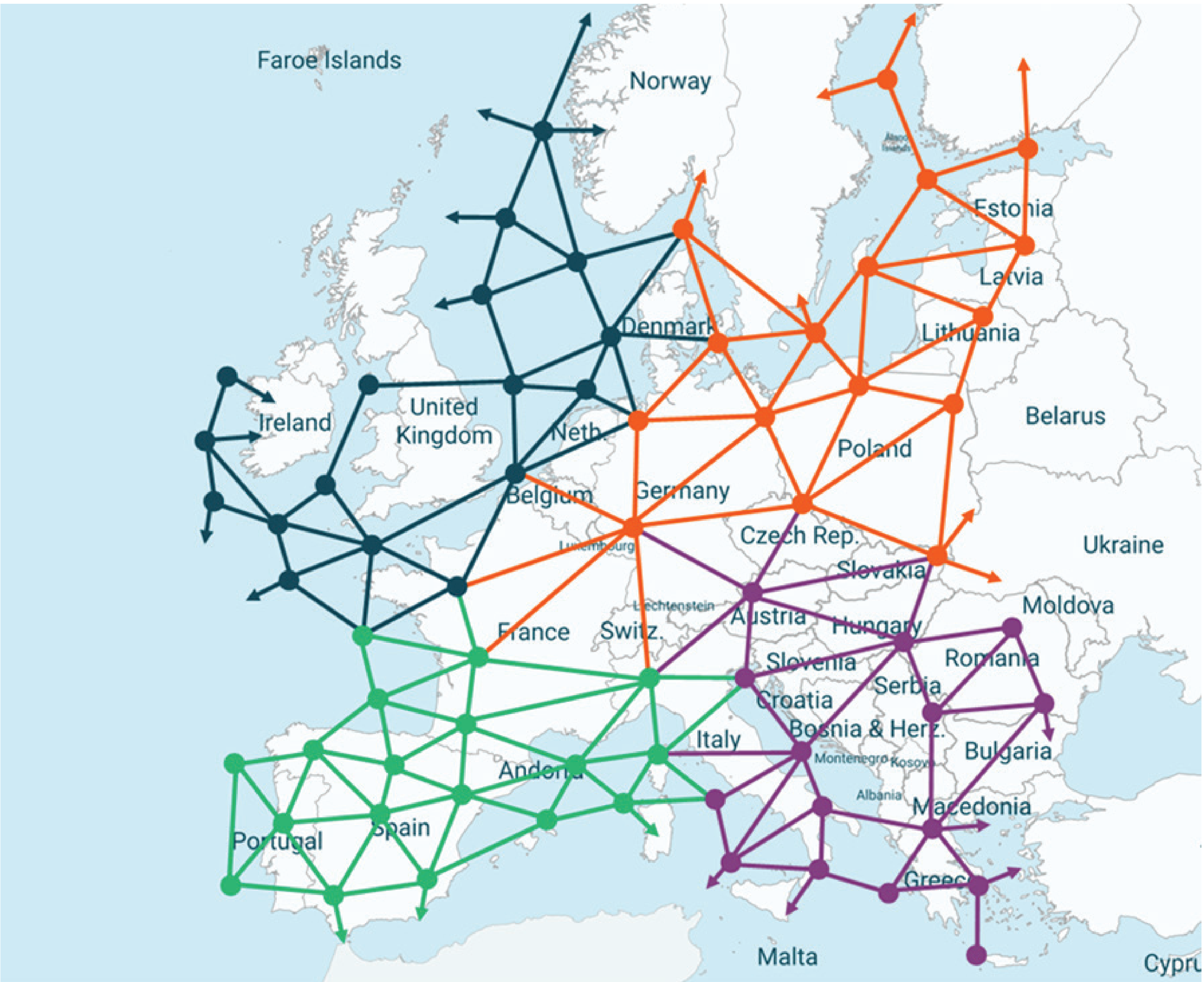

Figure 1. Representative Map of what a SuperGrid could look like

2.2 Why does Europe need a SuperGrid?

The EU has reduced its greenhouse gas emissions by a quarter over the past three decades. Over the next three, we must transition to a net-zero economy. The European Green Deal requires a transformation of Europe's energy sectors unlike anything in history in terms of scale, impact, and pace. The transition from a coal-based global energy supply in 1900 to one based on coal, gas, and oil has lasted over a century.

Energy accounts for 75 per cent of greenhouse gas emissions in the EU. A carbon-free electricity supply and the electrification of heat and transport to the greatest extent practicable are preconditions for decarbonising Europe's economies. The EU's renewable energy share increased from 9 per cent in 2005 to 21 per cent in 2021. In the same period, the share of renewables in the electricity sector increased from 15 per cent to 37 per cent and renewable electricity production has doubled from 500 TWh to over 800 TWh in 2020.

Despite this golden period of growth for renewable power in Europe, electricity's share of overall EU gross final energy consumption has remained unchanged at 24 per cent for the past 15 years. To reach our Green Deal decarbonisation objectives, electricity will likely need to cover at least 30 per cent of final energy demand by 2030 and 57 per cent by 2050[5]. Moreover, large amounts of electricity will be needed to produce hydrogen and hydrogen-derived fuels to decarbonise sectors like heavy transport and shipping.

5. https://etipwind.eu/files/reports/Flagship/fit-for-55/ETIPWind-Flagship-report-Fit-for-55-set-for-2050.pdf

Europe now has all the prerequisites to make the necessary transition towards a decarbonised economy, based on renewable electricity. We have access to capital at historically low rates; affordable renewable electricity generation technologies are available in abundance; and we can process data at unprecedented speed.

The European Commission has shown through scenario analysis ("A Clean Planet For All" 1.5TECH and 1.5LIFE scenarios) that to achieve the Paris Climate Agreements targets of limiting atmospheric temperature change to an increase of 1.5 degrees, Europe (including the UK) will require by 2050 at least:

- 700 GW of Onshore Wind – 200GW operational today
- 400 GW of Offshore Wind – 26 GW operational today
- 770 GW of Solar – 150 GW operational today

This will require a significant increase in renewable capacity, with a large proportion of this coming from the offshore space, where aside from offshore project connections, no meaningful grid infrastructure currently exists. Consideration must be given to where these renewables will be built, and how they will reach the market. In an unconstrained world, these renewables would be built where the resource is highest, with wind predominantly in the northern seas and solar in the south (Figures 2 & 3).

Building a grid which can facilitate this is the challenge and its absence will critically undermine Europe's ability to decarbonise its economies. Europe must dramatically increase power system capability and flexibility in the coming decades to accommodate renewables. This must be provided for by increased interconnection and innovative grid infrastructure, not least in the offshore space. We need a pan-European approach. This means a coordinated approach to renewable development supported by a grid that can ensure security of supply for all countries.

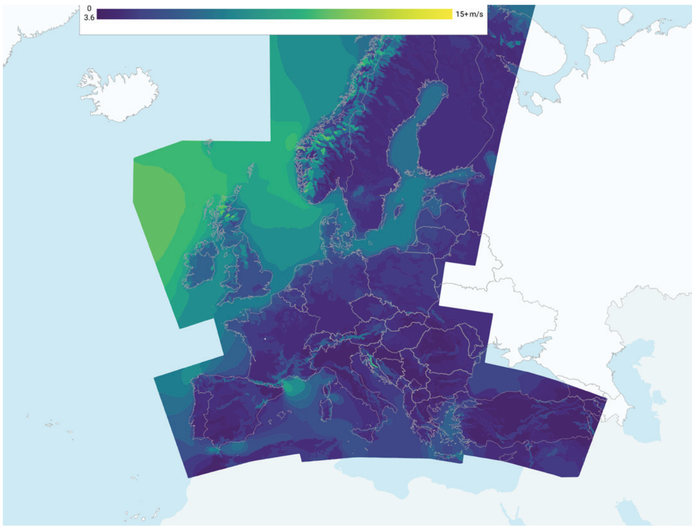

Figure 2. European Average Wind Speeds at 100m[6]

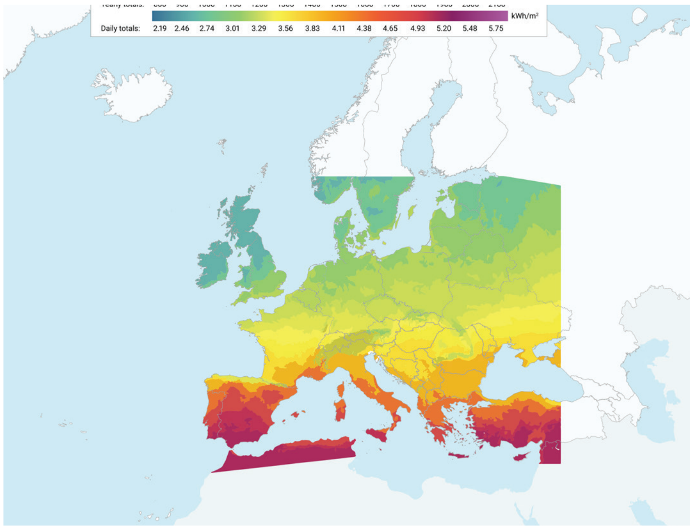

Figure 3. European Horizontal Irradiation[7]

6. https://map.neweuropeanwindatlas.eu/
7. Solar GIS

2.3 Ireland's Role and Geographic Responsibility

Ireland can play a key role in a European SuperGrid, and given our offshore wind resource, we have a responsibility to do so. WindEurope's Our Energy, Our Future[8] report states *"Scaling up from 20 GW today to 450 GW by 2050 will require a visionary approach. Governments must start setting the course for enabling higher levels of deployment. And they need to do it now.* ***Countries with offshore wind resources have a geographical responsibility to lead Europe in this"***.

Ireland has some of the highest average wind speeds in Europe as shown in Figure 2, averaging more than 12 m/s at 100m hub height on the west coast. For context, the Scottish North Sea is thought to have some of the best wind resources in Europe which have been developed to date, and average wind speeds there, at the same height, are between 9.5 – 10 m/s.

The case for developing a European SuperGrid is clear in the Irish context. Ireland is a small country with a sea area seven times larger than its land mass. Studies put the theoretical maximum potential annual energy output from Ireland's waters between 7,000[9] – 12,000 TWh, or between two and four times current European electrical demand.

The 2020 Programme for Government, Our Shared Future, identifies a target of 30 GW of offshore wind for Irish waters.

A recent piece of work performed by the Offshore Renewable Energy Action Coalition, led by the Global Wind Energy Council, found that Ireland has a technical potential of 51 GW of fixed bottom offshore wind and 553 GW of floating wind for a total technical potential of 604 GW[10]. This study does not account for environmental considerations, so it is not feasible to consider 604 GW of wind in Irish waters. However, it demonstrates the scale of our resource and puts Ireland's 30 GW target for 2050 into context. It also shows that with the right infrastructure in place, unlocking further offshore areas, Ireland can achieve more than 30 GW. The full map is shown in Appendix 7.1.

WindEurope[11] identifies 22.2 GW of offshore wind to be in Irish waters, assuming business as usual with incremental changes to national grids in Europe. This capacity would be capable of producing approximately 116 TWh annually – about four times Ireland's electricity demand today. However, Ireland would be capable of hosting much larger quantities of offshore wind if an offshore grid were to be developed facilitating the bulk export of power. The SuperGrid can enable Ireland to fully exploit its offshore wind potential, meet its own power needs, and export clean electricity to the rest of Europe.

8. https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Our-Energy-Our-Future.pdf
9. http://www.wse.ie/papers/offshore-wind-a-significant-natural-resource-of-ireland
10. https://gwec.net/oreac/
11. WIndEuropes "Our Energy, Our Future"

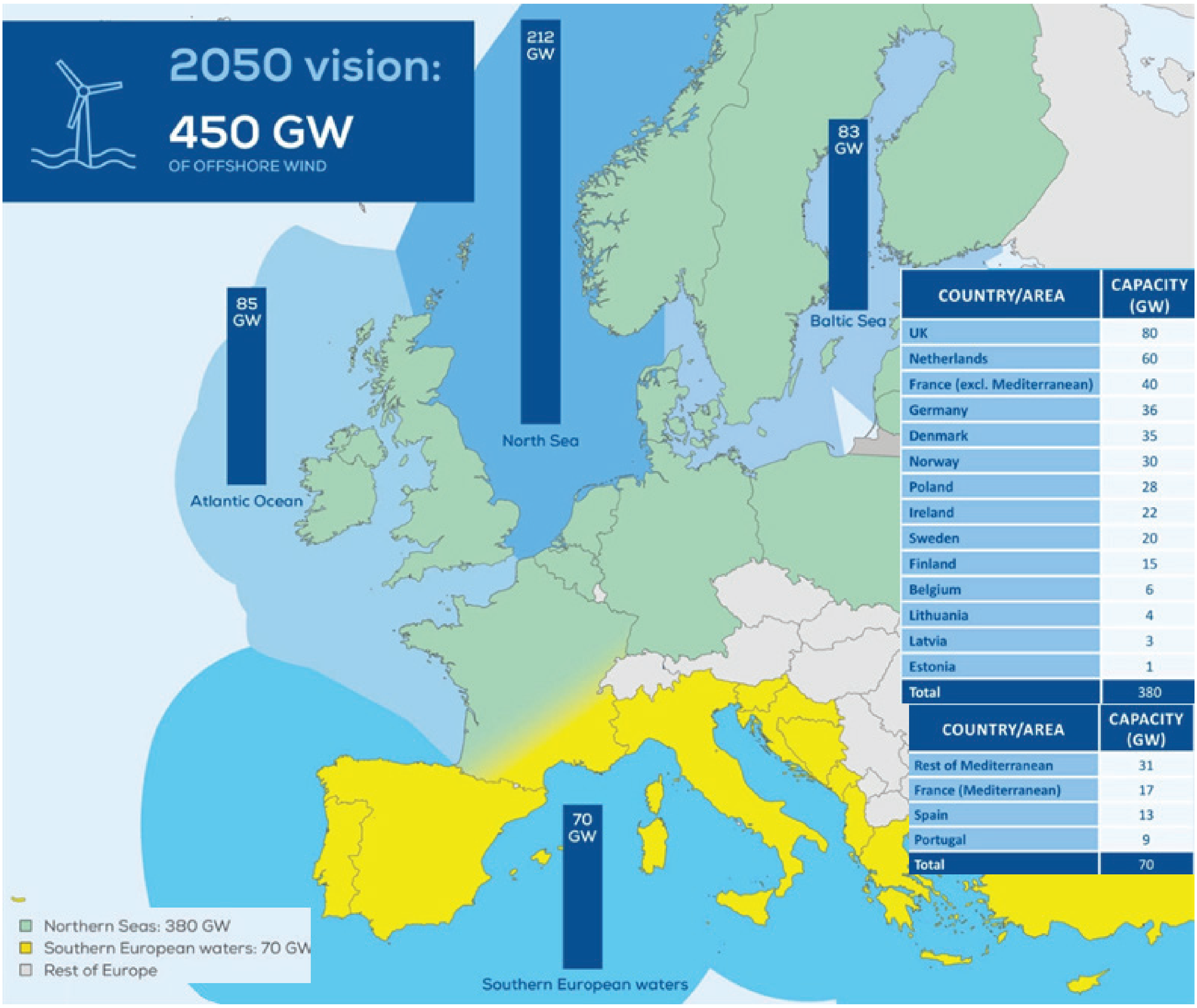

Figure 4. WindEurope "Our Energy, our Future" 2050 Offshore Wind Capacity by Sea Basin

Ireland developed its first offshore wind farm, Arklow Bank, in 2004 using the largest offshore wind turbines in the world at the time. It appeared then to be a sign of a prosperous period of development for offshore wind in Ireland. Instead, a lack of Government commitment and strategic planning meant that no offshore wind farm has been built since.

But while Ireland missed our opportunity, one of our closest neighbours made the most of theirs.

Scotland identified that it was host to 25 per cent of Europe's wind potential, and to ensure that they exploited this opportunity, published the Offshore Wind Route Map[12] in 2009. This outlined the opportunities, challenges, and the priority recommendations for action for the sector to realise Scotland's full potential in offshore wind. Today, Scotland is a world leader in offshore wind with a well-established industry, positioned to take advantage of the growing global opportunities for a leading supply chain and skilled workforce, with a Gross Value Add (GVA) worth an estimated €40 billion over the next five years[13].

12. https://www.gov.scot/publications/scotlands-offshore-wind-route-map-developing-scotlands-offshore-wind-industry/
13. https://ore.catapult.org.uk/wp-content/uploads/2018/10/PN000244-FWMS-Report_FINAL.pdf

It is worth reflecting that had the right choices been made by Government 20 years ago, this could have been an Irish, rather than a Scottish, success story.

Denmark, the birthplace of offshore wind, provides another interesting example. Since building the world's first offshore wind farm in 1991, Denmark has been slowly reinforcing its grid and further interconnecting its electricity system with neighbouring countries and it is now known worldwide as having one of the smartest grids for the integration of renewable generation. Its recently commissioned 605 MW Kriegers Flak offshore wind farm is the first hybrid project in Europe, combining grid connections to offshore wind farms with an interconnector between two countries – Germany and Denmark – via a Combined Grid Solution.

Ireland has set an ambitious target of 80 per cent renewable electricity share by 2030[14], but the reality of rapidly increasing electricity demand highlights the challenges around the plans to meet the 2030 targets set. The current Irish approach of incrementally changing the grid system to facilitate slowly increasing levels of renewables will not be sufficient as demand increases at a faster rate. Current grid planning is reactionary to renewable targets. This method of planning is not fit for purpose and will result in grid capacity remaining as one of the major roadblocks to delivering our renewable targets.

The world is on fire. This is not the time for business-as-usual.

Ireland does not currently have the grid capacity available to fully unleash its offshore wind potential. Figure 5 shows the forecast of capacity available in 2030, as stated by EirGrid in the *Shaping our Electricity Future* report[15]. The report suggests a mindset still rooted in an incremental approach to grid planning when the science tells us a much more ambitious, transformative, approach is needed. The 5 GW target is seen as a maximum, when really it is a stepping-stone and without appropriate longer-term planning, EirGrid and Ireland will find themselves in the same position with a capacity constrained grid in 2030. Beyond 2030, there is a need for Ireland to plan for achieving net-zero carbon, which EirGrid recognises as requiring the development of a strategy by 2024. Grid infrastructure takes time to plan and develop, with EirGrid suggesting that the average length of time needed to complete a single grid reinforcement project is approximately 8 years.

Ireland has the unique opportunity to lead the development of an offshore grid that integrates a high level of offshore renewables and offers us the opportunity to export vast levels of energy. For this to happen, Ireland and EirGrid need to start thinking beyond the 2030 target time horizon. Given the length of time involved in a single reinforcement project as identified by EirGrid, we must start planning for our future now, today, and not leave it until it is too late.

14. https://gridbeyond.com/ireland-targets-80-renewables/
15. https://www.eirgridgroup.com/site-files/library/EirGrid/Full-Technical-Report-on-Shaping-Our-Electricity-Future.pdf

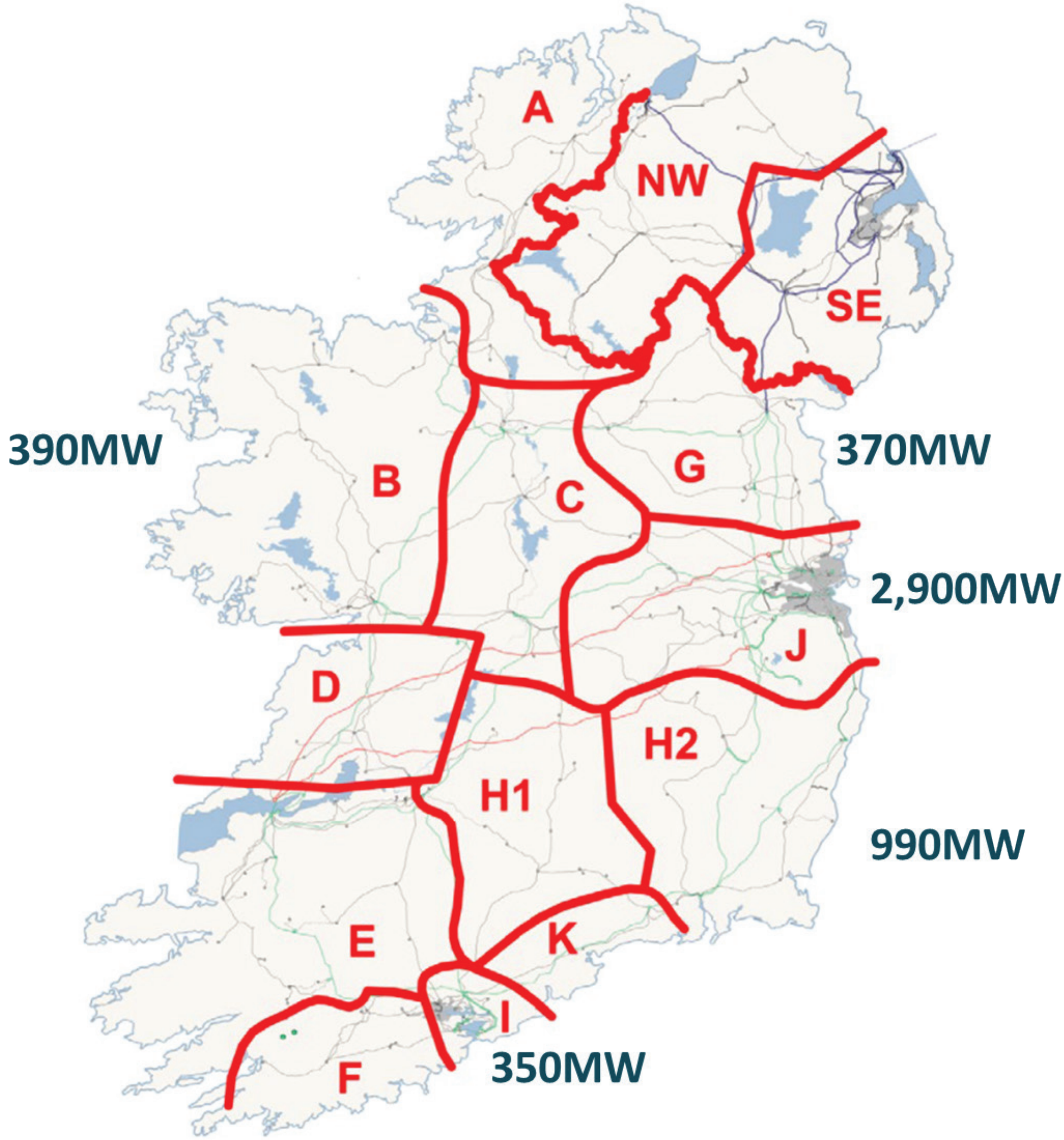

Figure 5. Forecast of Available Offshore Wind Grid Capacity in Ireland in 2030 [source: EirGrid]

2.4 Transmission Today

The existing transmission system was designed for fossil-based generation. It was designed in the knowledge that a generation station could be built where needed and the efficiency of this station would not vary greatly.

A decarbonised grid must be designed around the specific characteristics of renewable energy. The best renewable energy sources are often found in remote locations far from demand centres in places such as the North Sea and the Atlantic Ocean. Renewables are also a variable energy source, and reliance on a single area for the development of renewables will result in an inefficient energy system.

Europe's primary demand centres lie in Central Europe, which coincides with the most populous countries in Europe as shown in Figure 6. These areas will naturally see the largest electricity demand but will also struggle to meet this demand with national renewable resources. Even today, Central Europe relies on interconnection amongst countries to balance grids. Europe will need to increase the level of installed capacity significantly, which will need a complete change in how interconnection is used today.

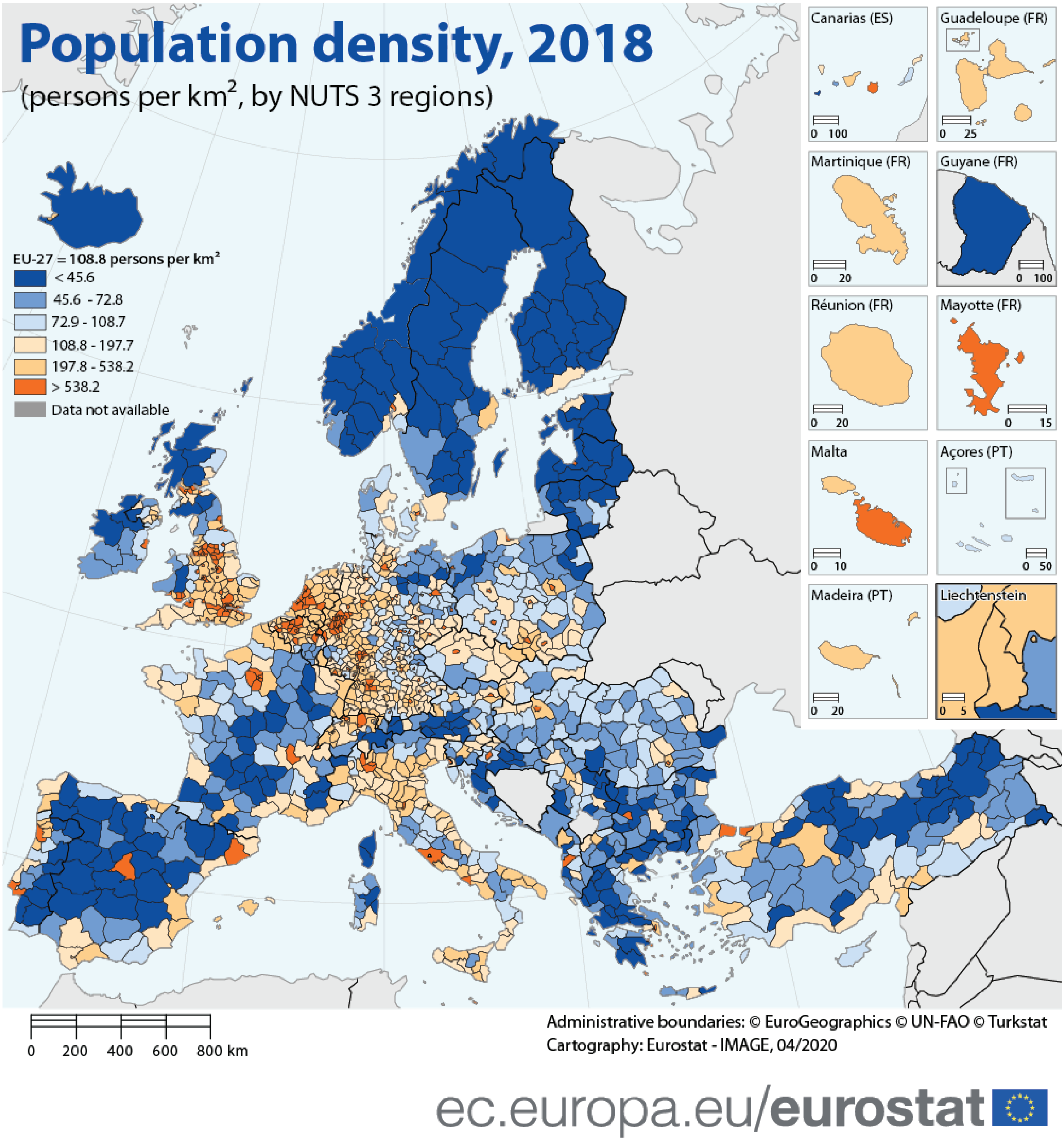

Figure 6. European Population Density per km2

Onshore wind and solar projects to date have been built in relatively small project capacities meaning that the existing grid has been capable of accepting these projects without affecting system security. However, offshore wind has been built in significantly larger capacities using a radial point to point approach which is now encountering challenges in getting power back to land in a cost-competitive manner.

Offshore wind farms have grown from 300 MW capacities to wind farms greater than 1,000 MW over the past 10 years in some areas. This has led to some countries investigating different ways of bringing power back to land and minimising the infrastructure required.

16. https://www.researchgate.net/figure/Population-density-map-2018-source-Eurostat_fig1_343628317

The UK operates with a developer-led model which puts the responsibility of developing the transmission assets on the developer. Figure 7 shows the grid planning regimes of some European countries.

Germany operates with a different system, where the grid connection point is planned and developed by the TSOs. This model led to one of the German TSOs, TenneT, to investigate the use of shared transmission systems, whereby a high capacity HVDC connection is developed offshore to which multiple wind farms can connect. The first generation of these connection schemes were in the range of 900 MW in capacity, with up to 4 wind farms connecting.

As the scale of offshore wind energy continues to rise, the connection points required change too. The next generation of connection schemes will be 2 GW in capacity. These require large offshore platforms to house all the conventional equipment that a wind farm substation would house as well as a large converter station for converting the power from AC (from the wind farm) to DC for transmission. DC is used for transmission as it is better for long distance transmission.

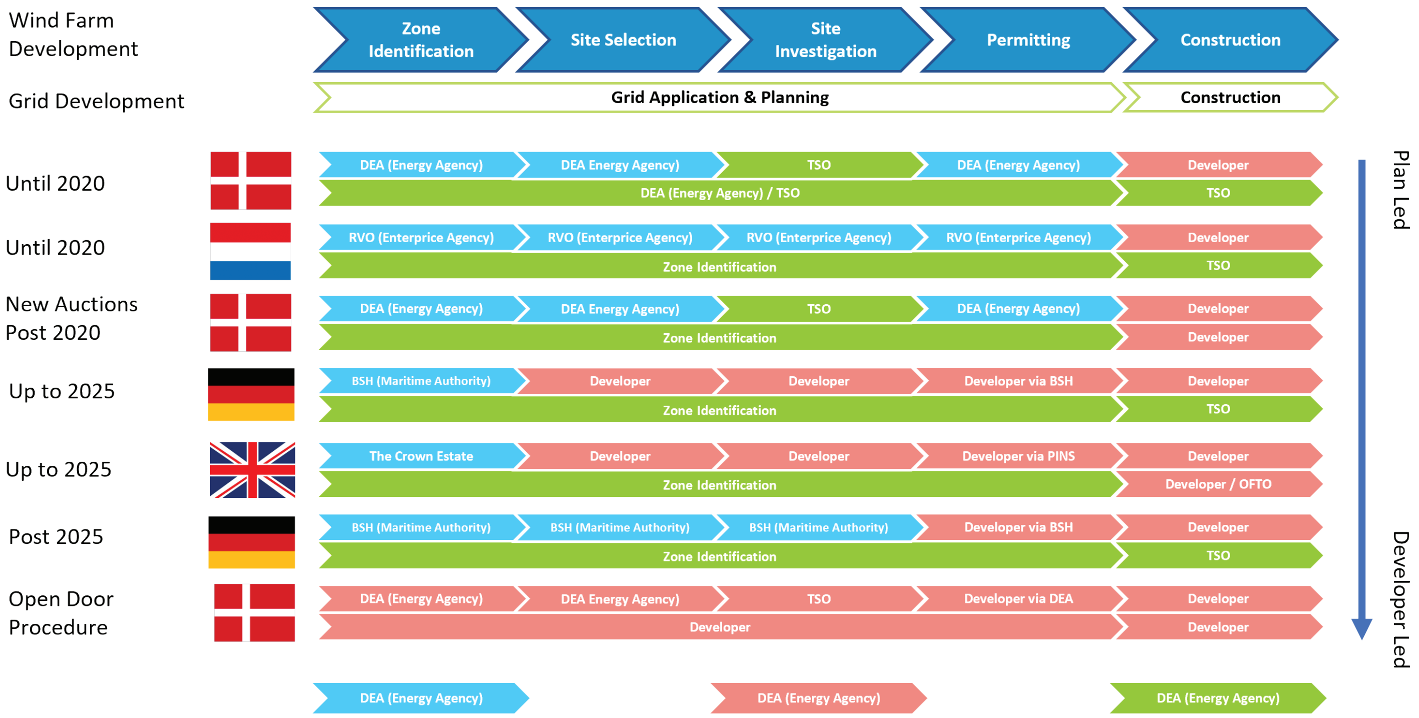

Figure 7. Different Offshore Transmission Regimes in Europe[17]

2.5 Transmission of the Future

TSOs are coming to the realisation that changes in how offshore wind is connected to the grid are required as climate and renewable energy targets increase. The problem is that changes are not happening fast enough to support the climate and energy targets required by science because transmission is a regulated, natural monopoly sector, in which cost control and security of supply are incentivised, while innovation and future decarbonised systems are not.

European TSOs have excelled in ensuring those aims are met, yet the structural setup disincentivises transformative innovation. Therefore, TSOs are not encouraged to be forward-looking, undertake anticipatory investments or introduce new, innovative, technology. Grid development continues to be evolutionary at a time when it needs to be revolutionary. Until now, the market and supply chain have not been optimised for connecting remote renewables at scale.

17. https://assets.gov.ie/75918/9659386d-7526-4ebe-8420-8854033250b6.pdf

Steps are being taken in the right direction as planning for deeper interconnection occurs. Hybrid interconnectors, an asset which acts as both the export cable for a wind farm and as an interconnector between two countries, are becoming more prevalent with more projects being planned.

Figure 8 shows a view of planned and operational offshore wind farms and interconnectors. It highlights the opportunity that shared infrastructure can bring. Europe is unique in that it has relatively shallow waters in the North Sea, with good wind resource and 10 countries in the surrounding area that need renewable power.

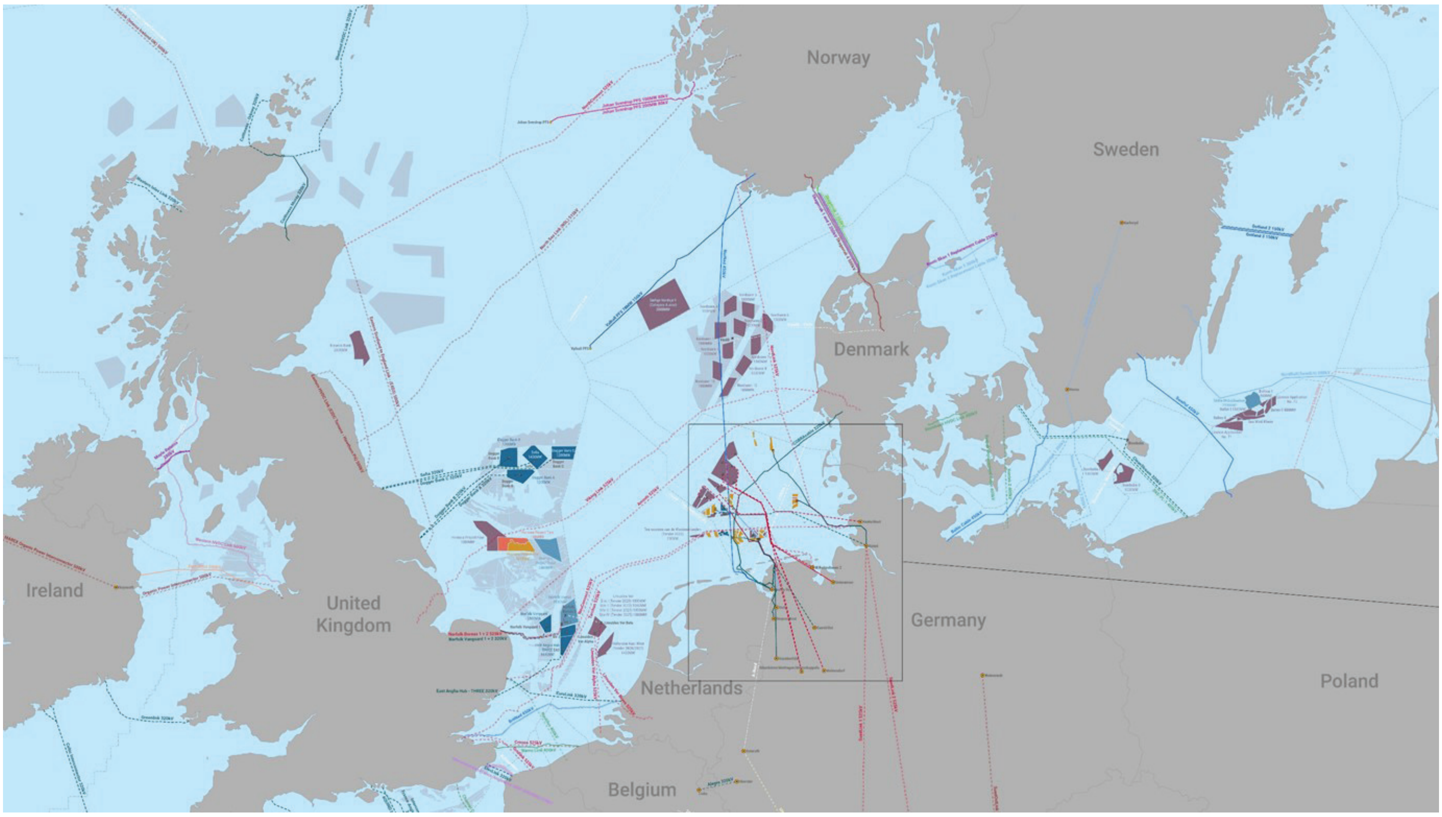

Figure 8. Planned and Operational Offshore Transmission Schemes in the North Seas

The development of a coordinated meshed grid in the North Sea is now seen as logical and inevitable, however, extending this grid to encompass the Baltic Sea, the Irish Sea, and the Atlantic would see a grid that can harness some of the best offshore wind resources in the world. The recently published European Commission strategy entitled *An EU Offshore Renewable Energy Strategy* states[18] that to step up offshore renewable energy deployment in a cost efficient and sustainable way, a more rational grid planning and the development of a meshed grid is key.

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Pair this with a grid that is developed to harness the solar resources found in southern Spain, and the result is an energy system that takes advantage of seasonal and geographical variability in wind and solar resources to achieve a fully decarbonised European economy.

Europe also experiences a unique seasonal variability which means that wind speeds are higher during winter months when solar output is weaker, and solar output is stronger in summer months when wind speeds are lower. This complimentary relationship can only be taken advantage of with a big enough grid that connects parts of Europe blessed with large volumes of wind power with parts where solar energy is more plentiful.

China is leading the deployment of high capacity UHVDC lines, which span thousands of kilometres via overhead lines. One line in particular – the Changii Guquan 1,100 kV transmission line – delivers up to 12 GW of power from the Xinjiang province in the Northeast, 3,324 km across the country to Guquan, east of Shanghai. That is more than twice Ireland's peak demand.

18. https://ec.europa.eu/energy/topics/renewable-energy/eu-strategy-offshore-renewable-energy_en

The Zhangbei HVDC power transmission project[19] in China is the world's first multi-terminal HVDC system using voltage sourced converter (VSC) technology. It is an advanced VSC-HVDC system with four interconnected converter stations in a ring network, designed to transmit up to 4.5 GW of clean energy. The four-terminal ring grid interconnects Zhangbei, Kangbao, Fengning, and Beijing.

In Europe there are numerous geographic, environmental, and political constraints to such an approach. Overhead lines can be challenging to build. To avoid potential delays a European SuperGrid should be built predominantly underground and offshore.

Overhead lines can carry significantly higher voltages than conventional underground cables today. There will be a need for new innovative grid technologies to facilitate efficient, long-range, bulk power transfer both in the onshore and offshore space that can match overhead lines' power capacity. One such solution is to use more of the lower capacity underground cables to meet required capacities.

Superconducting cables are another innovative technology. Superconductivity is a phenomenon in certain materials that when cooled to very low temperatures operate with zero resistance and as such can be used as a cable with zero electrical resistance. These cables can carry higher currents than conventional cables meaning they can operate at lower voltages while still carrying several GWs of power, using a much smaller surface area and require significantly less infrastructure, materials, and space. At higher capacities, the overall cost of installing superconductor cables will be lower than high-capacity conventional cables such as those used offshore. This is due to the need for less infrastructure, primarily smaller collector stations.

3 The Benefits a SuperGrid Can Bring

A pan-European SuperGrid can bring a host of system, environmental and commercial benefits to Ireland and Europe as a whole.

3.1 Opportunity to decarbonise on a European scale

The decarbonisation of our economies is absolutely vital in the fight against climate change but the challenges in doing so are vast. With the European Green Deal setting a target of climate neutrality by 2050, many Member States are now looking at how they can achieve this target. Wind Energy Ireland recently released two reports – *Endgame*[20] and Zero by *50*[21] - showing how Ireland can achieve a zero-carbon electricity system and a net-zero energy system.

The SuperGrid provides an opportunity to look at decarbonisation on a continental scale, rather than nationally. This should enable countries to act more effectively and efficiently in collaboration, leading to the optimal deployment of renewable and grid infrastructure, and helping Europe as a continent to reach climate neutrality as efficiently as possible.

3.2 Help realise our Climate Ambitions

A carbon-free electricity supply and the electrification of the heating and transport sectors, to the greatest extent practicable, are preconditions for decarbonising Europe's economies. To get to net-zero emissions, the IEA predicts that electricity will have to increase from around 20 per cent of global final energy consumption in 2020, to nearly 50 per cent in 2050[22]. WindEurope and ETIP Wind predict that electricity will provide 57 per cent of final energy demand in Europe directly in 2050, and a further 18 per cent through hydrogen and e-fuels[23].

The European Commission's scenario, outlined in Section 2.2, shows the vast increase in renewable capacity needed for 2050 to reach net zero. This will require a significant increase in offshore wind capacity. The grid will need to expand and evolve to accommodate increased electrification and the production of e-fuels. WindEurope and ETIP wind predict Europe needs an additional 85 GW of interconnection on top of today's 50 GW[24]. The SuperGrid provides the most efficient route to providing the scale of interconnection needed to realise our net-zero ambitions.

19. https://www.nsenergybusiness.com/projects/zhangbei-vsc-hvdc-power-transmission-project/
20. https://windenergyireland.com/images/files/20210629-baringa-endgame-final-version.pdf
21. https://www.marei.ie/wp-content/uploads/2021/03/Our-Climate-Neutral-Future-Zero-by-50-Skillnet-Report-March-2021-Final-2.pdf
22. https://iea.blob.core.windows.net/assets/20959e2e-7ab8-4f2a-b1c6-4e63387f03a1/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf
23. https://etipwind.eu/files/reports/Flagship/fit-for-55/ETIPWind-Flagship-report-Fit-for-55-set-for-2050.pdf
24. https://etipwind.eu/files/reports/Flagship/fit-for-55/ETIPWind-Flagship-report-Fit-for-55-set-for-2050.pdf

3.3 Key enabler to realising our offshore wind potential

A primary benefit of the SuperGrid, which is particularly relevant to Ireland, is its ability to provide a route to market for offshore wind. Offshore wind cannot grow sustainably without the parallel development of an interconnected offshore grid[25].

Ireland has a relatively low demand for electricity. Despite projections from EirGrid that system demand could grow by as much as 50 percent in the period 2020-2029[26], demand is still only expected to reach circa 37 – 46 TWh in 2029, up from 28 TWh in 2020. For comparison, Norway – with a similar population to Ireland – had an electricity consumption in 2020 of 122 TWh[27].

However, Ireland has access to a vast offshore wind resource which can supply much more than we can use. As such, the key to unlocking Ireland's offshore wind resource will be increased interconnection with Europe to allow Ireland to export this electricity to Europe's primary demand centres in Central Europe. The Super-Grid provides the most efficient method of achieving this.

One example of a project which is leading the way in terms of international renewable export is SunCables AAPowerLink, which is a project that will develop 17 – 20 GWp of solar capacity in Darwin, Australia, along with 36 – 42 GWh of storage. This project connects into the world's longest subsea HVDC cable from Darwin to Singapore at around 4,200km. AAPowerLink has the potential to generate up to €1.25 billion in exports for Australia annually and will meet 15 per cent of Singapore's electricity demand in 2028. The project will create more than 1,500 jobs in construction, 350 operational jobs, and 12,000 indirect jobs, and provides an example of the benefits an international renewable export project could bring to Ireland.

3.4 Improved energy security through increased interconnection

Ireland has a total electricity interconnection capacity of 1 GW, coming from the Moyle and East-West interconnectors – at 500 MW each – connecting to the UK. Following Brexit, Ireland has no direct link to the European electricity market. The addition of the Celtic Interconnector in 2026, connecting Ireland and France, will provide this link. Celtic, along with the Greenlink Interconnector to Wales in 2023, will bring Ireland's interconnection capacity up to 2.2 GW. This is a significant step forward, but there will still only be a single 700 MW connection to the European electricity market. The SuperGrid will allow Ireland to greatly increase interconnection and improve our energy security.

3.5 Lowering dispatch down

Dispatch down occurs when a TSO instructs a renewable electricity generator to produce less electricity than it can or even to shut down entirely, due to local network limitations (constraints) or broad power system limitations (curtailment). Dispatch down is a growing issue for the wind sector in Ireland. Wind Energy Ireland estimates dispatch down cost the industry almost €130 million in lost revenue in 2020 alone, with curtailment on the island reaching 5.9 per cent, and constraints 6.2 per cent[28]. Not only is dispatch down an economic issue, but it is also a problem as it results in clean energy being lost, affecting the efficiency of the system.

Dispatch down will also become more of an issue across Europe as countries increase their share of renewables on the system. Interconnection can leverage flexibility from neighbouring countries to alleviate technical constraints, thereby lowering dispatch down.

25. https://etipwind.eu/files/reports/Flagship/fit-for-55/ETIPWind-Flagship-report-Fit-for-55-set-for-2050.pdf
26. https://www.eirgridgroup.com/site-files/library/EirGrid/All-Island-Generation-Capacity-Statement-2020-2029.pdf
27. https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_e/default/table?lang=en
28. https://www.eirgridgroup.com/site-files/library/EirGrid/2020-Qtrly-Wind-Dispatch-Down-Report.pdf

3.6 Cost and infrastructure efficient

An extensive, interconnected, cross-border SuperGrid will allow renewables to be located optimally, reducing the overall amount of generation that will need to be constructed, saving time and money. Continuing our current business as usual approach will result in a less efficient and more costly grid compared to a coordinated and planned international approach.

A recent piece of work by E3G and Imperial College London, entitled *Offshore Wind in the North Seas: From Ambition to Delivery*[29], analysed how offshore renewables will develop in the Northern Seas and how grid architecture can affect system costs. The conclusion from this research was that an integrated and coordinated approach would provide several benefits over a conventional radial approach. Reducing the number of network connections to the onshore grid by moving to an approach involving co-ordinated offshore connection to hubs across the North Seas could provide £23- 45bn in costs savings in the period out to 2050.

3.7 Address variability of renewable energy

A SuperGrid would allow the transfer of power across huge swathes of land, connecting many more people across a much larger area with more diverse weather patterns and generation portfolios. This can exploit Europe's seasonal variability where the wind speeds are higher during winter months when solar output is weaker, and solar output is stronger in summer months when wind speeds are lower. This complimentary relationship can only be taken advantage of with a grid big enough to connect areas of wind and solar generation to where the power is needed. Figure 9 shows a graphical representation of data supporting this, with wind and solar having an inverse relationship with regards to peak output.

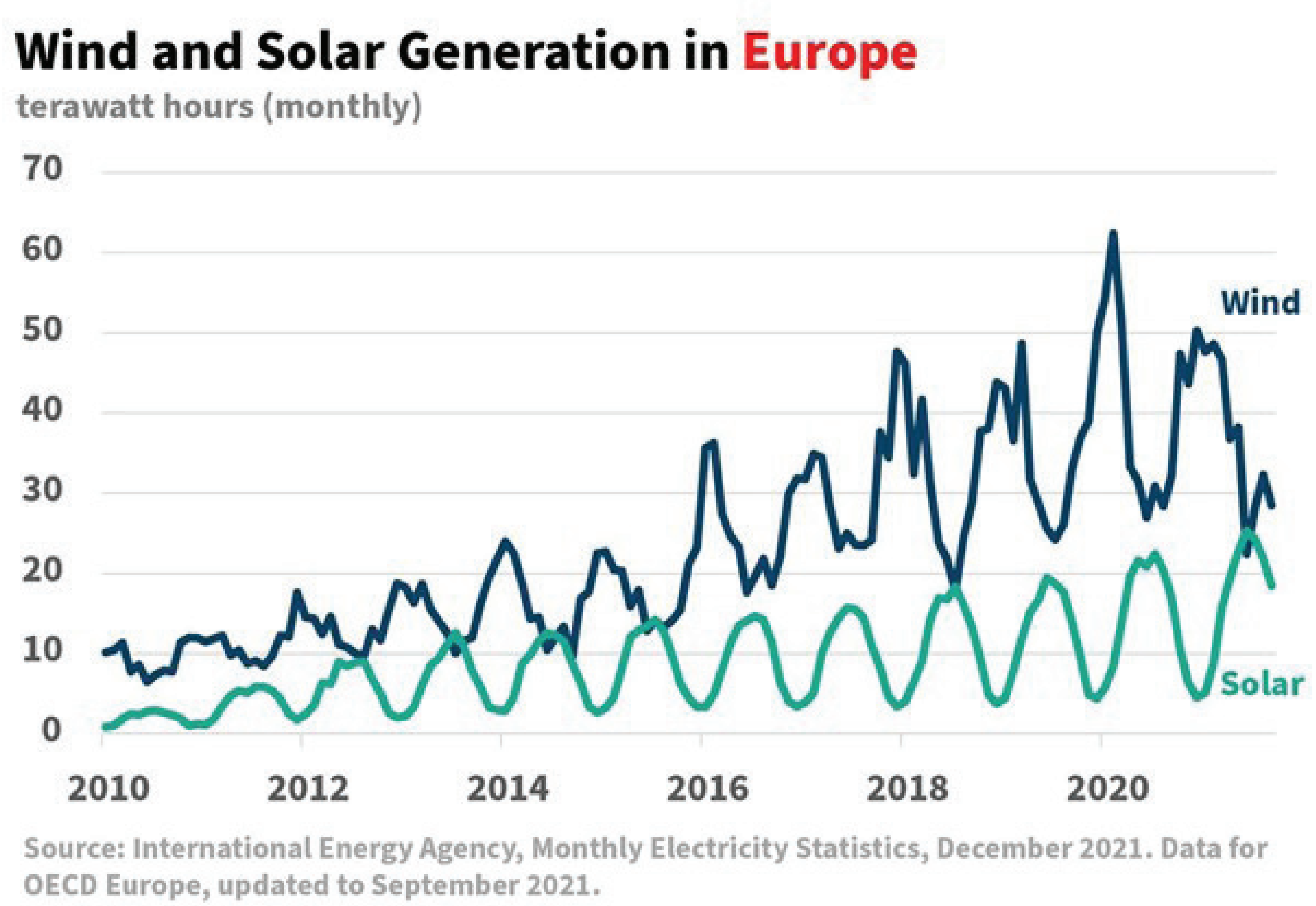


Figure 9: Seasonal Variability of Wind and Solar - The Complimentary Relationship

29. https://9tj4025ol53byww26jdkao0x-wpengine.netdna-ssl.com/wp-content/uploads/Offshore-wind-in-the-North-Seas-from-ambition-to-delivery-report.pdf

A SuperGrid can take advantage of the geographic spread of renewables and allow capacity to be located where the resource is best. This is called the portfolio effect. The Mean-Variance Portfolio (MVP) theory has been used for decades in the financial sector to identify portfolios of bonds or assets which minimise the risk for a given level of profit. The application of MVP to renewable power planning provides an analytical framework to optimise the trade-off between maximising renewable output and minimising variability of output through geographic diversification[30].

This also minimises the need to bring carbon-intensive fossil fuel units online to provide power and reduces the total installed capacity of generation needed. A report entitled Optimal Wind Power Deployment in Europe—A Portfolio Approach[31] concluded that "transmission network and wind resource limitations can reduce considerably the potential of efficiency gains through geographic portfolio optimisation by combining different wind production patterns across countries. Relieving cross-border network constraints and improving European electricity markets integration are therefore priorities to enable an optimal geographic wind power deployment across European countries".

3.8 Jobs

The construction of a European SuperGrid would offer Europe an opportunity to become a world leader in grid technology and innovation and establish itself as a clean energy technology and modern grid infrastructure manufacturing hub, creating much needed post-pandemic jobs and growth.

In Ireland, the SuperGrid will also be a key route to market for offshore wind at scale, which will bring with it associated jobs. Wind Energy Ireland and the Carbon Trust's Harnessing our Potential[32] report estimates that delivering just 3.5 GW of Irish offshore wind by 2030 will deliver 2,500 local development and construction jobs by 2030 and 700 local permanent O&M jobs. Realising our offshore wind potential and delivering the 30 GW ambition set out in the Programme for Government can deliver multiples of this in terms of jobs and associated investment.

The SuperGrid itself would create jobs in planning, installation, manufacturing etc. Europe can establish itself as a clean energy technology and modern grid infrastructure manufacturing hub. The Irish supply chain can also play a major role here in developing and growing a skillset in grid infrastructure development, installation, operation, and maintenance.

4 Work on coordination to date

4.1 What a SuperGrid could look like

The SuperGrid will need to deliver electricity over huge distances. The grid will be meshed containing many nodes which will receive and re-route power to demand centres as needed. Security of supply will be ensured by an abundance of redundant lines in case of failure.

The development of a SuperGrid would be one of the largest infrastructure projects in history. The lack of European cooperation to date makes the development of such a grid challenging, as policy and regulation will prove more difficult to change than developing the technology required.

The conversation on offshore meshed grids is growing in Europe. A European SuperGrid would not only offer Ireland a huge opportunity for exporting its domestic wind resource, but Ireland would also be an ideal starting point for the development of such a grid and leading the European project. Ireland could be a leader in the next evolution of Europe's electricity grid and, consequently, a true climate action leader.

The SuperGrid will connect electricity grids across Europe, acting like a trans-continental motorway network for electricity, capable of moving large amounts of power from one country to the next. The current grid will have a crucial role to play and will still operate at a national level. It is important to understand that a SuperGrid will not replace national grids. It will support and strengthen them.

30. https://www.sciencedirect.com/science/article/pii/S030142150900545X
31. https://www.sciencedirect.com/science/article/abs/pii/S030142150900545X
32. https://windenergyireland.com/images/files/final-harnessing-our-potential-report-may-2020.pdf

The key technology used will be DC transmission cables for bulk power transfer over long distances. For long distance, high-capacity power transmission, DC technologies are favoured over AC as DC operates with lower electrical losses and is better value for consumers. To date, HVDC cables, both underground and overhead, have been used in DC projects. While HVDC operates with lower losses than HVAC projects, it still experiences losses of 4 per cent – 6 per cent per 1,000km.

Long term storage will also play an important role in the SuperGrid in line with developing technology, further increasing reliability as well as providing important system services to national grids.

The previously cited work from E3G and Imperial College London – *Offshore Wind in the North Seas: From Ambition to Delivery*[33] – concluded that an integrated and coordinated approach to offshore wind and grid development would provide several benefits over a conventional radial approach; this highlights the benefits of a SuperGrid (Figure 10).

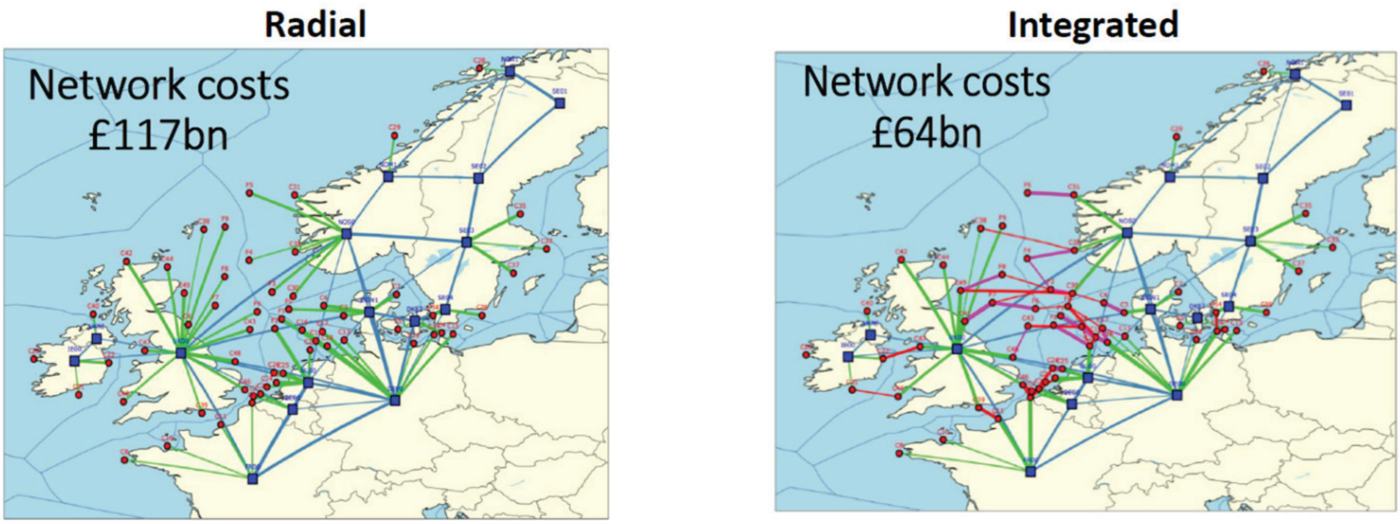


Figure 10. E3G & Imperial College: Offshore Wind in the North Seas: From Ambition to Delivery

When considering the areas of high renewable resource, there will be large power flows across Europe, largely moving from the North and South into Central Europe. There will inevitably be energy importers and exporters as some countries will have abundant renewable resources while others will have a limited supply. This has already been highlighted as one of the big gains for Ireland in developing a SuperGrid.

This is similar to the current fossil fuels-based energy system, but the result here will be a single European energy union with free movement of electrons joining freedom of movement of goods, services and capital, further deepening the unity of the EU, and ensuring security of supply. Ultimately, the SuperGrid could also look beyond Europe with interconnectors to Africa and Asia.

Decarbonisation offers both Ireland and Europe the opportunity to become energy independent, and to cut our shared reliance on imported fossil fuels . Europe has sufficient renewable resources to meet its future decarbonised energy system needs. This independence will reduce any political standoff leading to concerns in electricity prices as a result of reduced access to oil or gas.

This report has already discussed how power grids are currently designed in a reactive manner to known future requirements from network users. However, it is possible to replace this reactive and incremental approach with a strategic plan which focuses on anticipatory developments to the grid. It can simply start with the development of grid corridors to offshore hub locations where high levels of offshore resource exist in our shared waters.

There is a strong argument for a single energy market within the EU and neighbouring countries where members share renewable resources. Technical and regulatory uncertainties are the challenges to a single market being realised, especially within the North Sea region. This is an issue further complicated by the UK's exit from the European Union. It is vital that this work does not remain insular and considers our continental European neighbours which should be part of this project. Some interesting examples of coordination on grid development to date are expanded on below.

33. https://9tj4025ol53byww26jdkao0x-wpengine.netdna-ssl.com/wp-content/uploads/Offshore-wind-in-the-North-Seas-from-ambition-to-delivery-report.pdf

4.1.1 The North Seas Energy Cooperation

There have been numerous initiatives created to explore the technical, regulatory, and development aspects of such a coordinated approach. The North Seas Energy Cooperation (NSEC) is a cross-border group currently comprising nine European states (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway and Sweden) and the European Commission. The UK was also part of this group until leaving the EU. This group was established with the aim of facilitating the cost-effective deployment of offshore renewable energy, in particular wind, and promoting interconnection between the countries in the region.

The European Green Deal emphasises the importance of offshore renewable energy in meeting the EU's 2030 and 2050 climate and energy objectives, stressing the importance of regional cooperation. The NSEC has previously looked at how hybrid projects can reduce the environmental impacts from transmission through reducing the need for additional electrical infrastructure and reduce the costs of offshore developments[34]. Most recently, the work programme for 2020 – 2023[35] was released with an emphasis on exploring "more coordinated maritime spatial planning" and grid development to facilitate the increased deployment of offshore wind generation capacities in the North Sea region.

The NSEC represents an interesting opportunity for Ireland whereby the prospect for taking on the presidency of this group could allow for Ireland to emphasise the benefits that developments in Irish waters can bring to the wider energy system. Ireland must learn from the work this group is presenting and adopt learnings on how hybrid projects can be the starting point for offshore grid developments which will increase the level of connectivity between Ireland and the rest of the EU.

4.1.2 Promotion

The project 'PROgress on Meshed HVDC Offshore Transmission Networks' (PROMOTioN) applied in 2015 for funding under the EU Horizon 2020 programme call 'Competitive Low-Carbon Energy'. Within the framework of modernisation of the European electricity grid, this call focused on advancing innovation and technologies relevant to the deployment of meshed offshore HVDC grids. Its specific objective is to pursue an agreement between network operators and major equipment suppliers regarding a technical architecture and a set of multi-vendor interoperable technologies to accelerate HVDC grid development.

This project did not directly look at the benefits of coordinating the development of offshore grid but focussed on the technologies that will be required for developing a meshed grid. Work Package 7 focuses on the regulatory changes required to facilitate this cross-border development. One of the key conclusions from the project outlined how *"International collaboration and coordination is key to establishing political agreement"* for regulatory and legal compatibility, project and planning compatibility, and topological compatibility

The project highlighted the concerns around the current lack of harmonisation and standardisation issues with respect to technologies and regulations of member states as well as the urgent need for international coordination to address these issues. Work Package deliverable 1.3 concluded that "a number of regulatory and financial barriers are also hampering a large-scale deployment of meshed HVDC grids. Thus, even if progress has been made, there is not yet a definite international regulatory and financial framework for an offshore grid in the North Seas."

Deliverable 12.3 poses a view for a potential deployment plan for a coordinated meshed grid for the North Seas. With one interesting conclusion stating *"All multi-terminal and meshed solutions indicated an improvement in benefits. Meshing of the grid, where appropriate, generally leads to lower curtailment and a higher security of supply. Realising targeted benefits, however, may also require a change in the market setup around bidding zones or a new regulatory approach. Application of novel technologies will also be necessary."*

34. https://ec.europa.eu/energy/studies_main/final_studieshybrid-projects-how-reduce-costs-and-space-offshore-developments_en
35. https://ec.europa.eu/energy/sites/default/files/work-programme2020-2023.pdf

4.1.3 Trans-European Networks for Energy (TEN-E)

Energy policy is a shared competence, meaning that both the EU and Member States can adopt legally binding acts. However, Member States can only do so if the EU has not exercised its competence or ceased to do so. The Trans-European Networks for Energy (TEN-E) is a policy that is focused on linking the energy infrastructure of EU countries. As part of the policy, nine priority corridors and three priority thematic areas have been identified.

In March 2019, as part of the partial political agreement between the European Parliament and the Council on the Connecting Europe Facility (CEF) for the period 2021-2027, the co-legislators agreed on the need to evaluate the effectiveness and policy coherence of the TEN-E.

There are nine priority corridors which cover different geographic regions in the field of electricity, gas, and oil infrastructure. EU support for development in these corridors will connect regions currently isolated from European energy markets, strengthen existing cross-border interconnections, and help integrate renewable energy. The four electricity corridors include:

1. North Seas offshore grid (NSOG)
2. North-south electricity interconnections in western Europe (NSI West Electricity)
3. North-south electricity interconnections in central eastern and south-eastern Europe (NSI East Electricity)
4. Baltic Energy Market Interconnection Plan in electricity (BEMIP x` Electricity)

4.1.4 Offshore grid planning in the European Commission’s TEN-E proposal

A regional approach to offshore electricity grids was proposed by the European Commission in December 2020 as part of its revision of the EU TEN-E Guidelines. The European Parliament’s Energy Committee (ITRE) agreed its position in September 2020. A final agreement between EU Member States (Council) and the European Parliament was reached at the end of 2021.

The European Commission published its proposal, to bring the TEN-E framework in line with the increased climate ambition for 2030 (target for GHG emissions increased from 40 per cent to 55 per cent) and 2050 (carbon neutrality), established by the European Climate Law which entered into force in July 2021.

Article 14 of the Commission’s proposal for a revised TEN-E framework states that:

- Member States within the designated priority offshore grid corridors identified by the proposal, jointly define and agree to cooperate on the amount of offshore renewable generation to be deployed within each European sea basin by 2050, with intermediate steps for 2040 and 2030. This should be done before 31 July 2022.
- ENTSO-E, based on the generation proposed by Member States (point above), “Shall develop and publish integrated offshore network development plans”, starting from the 2050 objectives, with 2030 and 2040 intermediate steps. The first plan is proposed for 31 July 2023 and be updated every three years.
- If ENTSO-E fails to develop the integrated offshore network development plans for each sea basin, they shall be drawn up by the Commission.

In Article 15, the Commission proposes they develop principles for a specific cost-benefit and cost-sharing methodology for offshore renewable energy cross-border grids.

4.1.5 Baltic InteGrid/Baltic Offshore Grid Forum

The Baltic InteGrid project was implemented from 2016 to 2019 to explore the potential of meshed offshore grids in the Baltic Sea Region. It was funded and conducted under the support of the EU's Interreg Baltic Sea Region Programme 2014-2020 with the objective of contributing to the EU's energy policy, which aims to streamline and link the energy markets of the Member States while facilitating a safe and sustainable transition to renewable energy. The efforts for a meshed offshore grid in the Baltic Sea region are being further continued through the Baltic Offshore Grid Forum (BOGF).

The Baltic InteGrid project analysed legal, regulatory, technological, and planning issues affecting the design and implementation of meshed grid solutions, and conducted prefeasibility studies linked to a cost-benefit analysis. The analyses showed that a meshed offshore grid (Figure 11) is a sound configuration for ensuring that the wind power generated offshore in the Baltic Sea in the coming decades is transported to end users in an efficient and cost-effective way.

The project completed two pre-feasibility studies to measure the suitability of a meshed grid approach to the Baltic Sea in technological, market related, environmental, and economic terms. For this purpose, the studies compared a meshed-grid configuration with a radial system, considered technical designs and their costs, and provided a comparison of the costs and benefits of the various options.

The results of the studies found that a meshed approach to grid development in the region would be cost efficient in most cases as well as harbouring substantial advantages beyond cost efficiency. It would result in fewer AC and DC cables, and a resulting reduction in installation and maintenance activities.

A coordinated grid moves away from today's point to point model, and as such would drastically reduce the volume of cables coming back to land. As such, this would reduce the environmental effect of the grid infrastructure as fewer cables are needed as well as fewer cable landing points.

A meshed grid, with this reduction of cables, would also require fewer landfall points, which can improve public acceptance. The final advantage found is unique to the area whereby the meshed grid would facilitate easier transmission of power between Estonia, Latvia, and Lithuania and the other two synchronous grids of Europe.

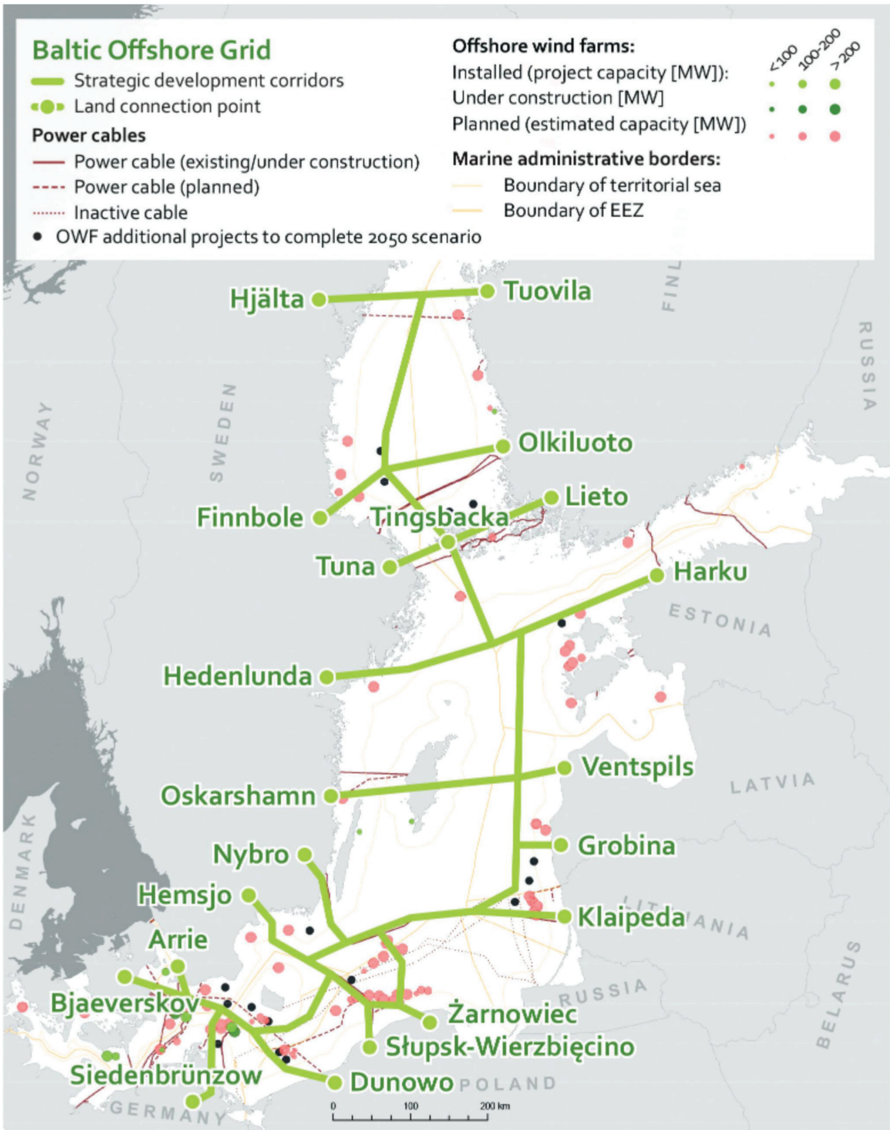


Figure 11. The Baltic Offshore Grid (BOG 2050) concept.

The final report notes that:

> *"If the expansion is not carefully managed and coordinated, there will be a risk of a needless proliferation of radial configurations and an accompanying glut of export and interconnector submarine cables. This might be inefficient, possibly leading to higher costs for end users, while also potentially causing significant conflicts with other marine and seaside uses. The deployment of new offshore wind infrastructure should therefore preferably be accompanied by meaningful coordination between the countries and stakeholders involved. It is important to consider this well in advance of the coming expansion, as the lock-in effects of an inefficient grid design could be difficult or impossible to correct in the future.[36]"*

36. http://www.baltic-integrid.eu/index.php/download.html

4.2 Multi-Purpose Interconnectors and Energy Islands

Multi-purpose interconnectors (MPIs) or hybrid interconnectors would allow clusters of offshore wind farms to connect simultaneously, plugging into the energy systems of neighbouring countries. In the future, they could allow offshore wind and interconnectors to work together as a combined asset.

MPI developments have mainly taken place in the North Sea, one such development being a project being led by TenneT in Dutch waters. This project will be the first 2 GW shared transmission scheme and will be built in the Ijmuiden Ver region. It is considered the second generation of shared transmission projects and will be one of seven to be built. The Ijmuiden Ver project will initially act as a shared transmission asset connected to the Netherlands, with early investigations for it to become an MPI with the UK (WindConnector). The platform will be designed to be multi-terminal ready which means that these projects will be capable of connecting to other projects in the future. This MPI could be the first part of a future multi-terminal grid in the region.

One of the more important aspects of this project is the consideration given to future proofing the infrastructure for further connection. More MPI projects are emerging in the market and consideration is being given to replicating the design from the Ijmuiden Ver project to allow for future connection.

One of the more aspirational concepts being considered is the use of energy islands in the North Sea. The North Sea benefits from relatively shallow waters meaning that the use of energy islands is potentially viable for large scale connection hubs. The North Sea Wind Power Hub (NSWPH) consortium was founded in March 2017 and consists of some of the leading TSOs of North Sea Countries; Energinet, Gasunie and TenneT.

The concept centres around a hub and spoke grid model. At its focal point are energy islands located in the North Sea which have the capacity to connect over 5 GW. These islands will then be connected to the member countries, meaning that each island could be connected to 4 or 5 countries. These islands could also house electrolysers to produce green hydrogen as well as conventional forms of energy storage.

In February 2021, the Danish Ministry of Climate, Energy and Utilities announced that they will initiate plans to construct the first energy hub in the North Sea by the early 2030s. This is the first actual development of an energy hub. The hub will be situated approximately 80 kilometres off the coast of Jutland, Denmark. The initial capacity will be 3 GW (with a footprint of ~120,000 m2) and the Danish plans envisage the possibility to expand this to 10 GW in later stages.

These energy islands pose their own challenges though. The solution proposed for the North Sea here will not be replicable elsewhere in Europe, with water depths proving to be a limiting factor, particularly for Ireland. Long-term plans for a coordinated approach should consider and facilitate the integration of ongoing projects involving energy islands as these are important steps forward towards a meshed grid in the North Sea.

5 How will the SuperGrid be Funded?

The funding of the infrastructure may come from a range of sources though it is likely to be paid for by a combination of both generators and/or consumers across Europe, similar to today's network as well as from EU funding sources for PCIs such as the Connecting Europe Facility.

If the competition to build various legs is structured properly it will be possible to use project finance. This would involve commercial borrowings from banks, sponsors equity, and possibly a mezzanine tranche. The markets will perceive risks to be high at the beginning of any new venture. This will be reflected in the expected rate of return. There is a role for the EIB, the EBRD, the IFC or national finance institutions or sovereign wealth funds, at least in the early stages of the rollout.

5.1 How will the SuperGrid be paid for?

The principle that the customer pays for the service provided is the operating principle underlying the payment philosophy. The tariff design for connecting offshore renewable generation assets should provide incentives for efficient network use. However, it is equally important that the tariffs also provide for the financing and cost recovery of the grid connection.

An increasing proportion of electricity will be generated outside the boundaries of the consuming state and individual generation assets will feed power into several markets with significantly different charging and tariff regimes in place e.g., 'deep', 'shallow' and 'extra shallow' charging. Therefore, the Governing Body must be tasked with aligning the different national rules and apply a harmonised tariff structure throughout the SuperGrid. The Regulator must be tasked with enforcing and monitoring the market rules.

One possible solution to further explore could be to average the price of imported electricity from all supplying countries and to charge that in the consuming state. There would have to be additional charges for the SuperGrid costs. These would be levied on the customer as a separate line item, in much the same way as Transmission Use of System charges (TUOS) are currently levied.

There would be a distinct time element in the charges associated with the SuperGrid. In the early stages of the deployment, generating plants near the shore, in shallower water, would be built. The grid costs associated with these would be less than would be the case when more remote generators and longer grid becomes the norm.

There is a case to be made for European financial support to apply to the early stages of rollout of the SuperGrid, just as is done today through the EU Trans-European Networks framework.
In supporting such subsidies, the following facts can be cited.

- The construction of the different legs of the SuperGrid should be the result of auctions, so at any point in time the cheapest one that meets technical standards would be built.
- As has been the case with wind, offshore wind, solar PV and storage, competition will reduce the price of the next and subsequent legs of the SuperGrid. There is no reason to suppose, with the huge market that will have been created in the underpinning technology, that the SuperGrid will not follow the same path.
- The lifetime of these assets, if properly protected and maintained, could be semi-infinite, just like their terrestrial counterparts, some of which are in existence for 80 to 100 years.
- The fuel that powers Europe is free and native to Europe. It is infinitely available and will remain free in perpetuity. Payments to third countries and companies for energy imports, will be a thing of the past. Added to the fact that our domestic renewable resources cause no pollution, these considerations will give competitive advantage to European industry as against countries which have been slower to make the transition to sustainability.
- The SuperGrid will integrate the two great sources of renewable generation in Europe: wind and hydro in the north and solar in the south. This alone will lead to a reduction in the cost of European electricity. Surpluses of wind in the northern climes, instead of leading to curtailment of generation, as happens currently, energy will be shipped via the SuperGrid to southern Europe. In winter there will be more generation in northern Europe, and less around the Mediterranean basin. The opposite will be the case in Summer.
- Via the SuperGrid, cheap solar will be made available to northern Europe. The cost of solar from Spain and Portugal is currently in the order of 1.5 to 2 €cents per kWh, while the cost of offshore wind is in the order of 5 €cents per kWh.
- Without the SuperGrid this cannot happen, Europe will not reap the full economic and commercial benefits of exploiting its renewable energy resources.
- Solar is variable, but it has the great benefit of contributing electricity during the daytime.
- Wind on the other hand, in northern climes, shows little correlation with time of day. It is driven by atmospheric pressure differences which happen not because of local temperature differences, but because of fronts and storms.
- A SuperGrid will future proof Europe's energy system, facilitating further integration of renewables.

6 Timing and how the SuperGrid could develop

Given the scale, a SuperGrid cannot be built all at once but should be developed gradually in stages. A form of this has already begun, albeit slowly, with some international interconnectors already in use today but a major acceleration and increased coordination are required. It is logical to begin the first stage in the offshore space where no grid exists today, and where a significant level of Europe's power generation will be.

The planning, development, and operation of a SuperGrid will require a multilateral governing body and an independent European-wide regulator. An independent technical body would develop scenarios, perform cost-benefit analysis for infrastructure and identify technology gaps. A priority should also be placed on innovation frameworks and funding, e.g. the Horizon Europe programme, as well as sandboxes and accessible trials and funding, to nurture new technologies and allow them to aid in the overall goal of decarbonisation.

The European Commission proposed the idea of an Independent System Operator (ISO) in a 2020 working paper[37] when discussing 'future offshore highly-meshed grids'. It stated:

> *"Where real-time system operation becomes increasingly complex and intricate, it could be warranted to take a more holistic approach to future system operation in offshore regions. The relevant group of TSOs could appoint one TSO to manage the entire offshore area (possibly consisting of several offshore bidding zones) or the TSOs and NRAs decide to establish an independent system operator (ISO) for this purpose, potentially as a joint venture. An ISO established for this purpose would build up significant expertise in the technical challenges associated with offshore DC infrastructure and could become a global leader in managing a variable renewables-based electricity system."*

It went on to say:

> *"An ISO could function as a system architect to develop the long-term master plan for offshore meshed grid development, map locations for offshore wind, as well as undertake the required grid investments needed for Europe-wide grid optimisation. It would provide scope for the relevant NRAs to assess in a neutral and coordinated way the best type of incentive regime and tariff design for a variable renewables-based electricity system. It would also have the advantage of solving coordination challenges and could help de-risk anticipatory investments."*

For a SuperGrid to be successfully implemented, the Independent System Operator needs to be established by 2030 and will require interaction from many different stakeholders at a European level and national level. Grid development could grow in each region, with increasing levels of interconnectivity occurring over time to realise the benefits of these larger meshed grids. These starting points can be separated into region, sea basins, or clusters throughout Europe and should see a natural growth and transition towards a European SuperGrid. Developing in different regions also facilitates the realization of some benefits earlier on in the project, such as the advantages of meshed grids in each of the regions. This is shown in the image of the SuperGrid (Figure 1) where the four colours represent the four regions in which the SuperGrid could begin its development.

The following sections outline how a SuperGrid could come to life throughout the next 3 decades, and how Ireland could play a pivotal role in developing a crucial section of the grid.

37. https://ec.europa.eu/energy/sites/ener/files/staff_working_document_on_the_offshore_renewable_energy_strategy.pdf

6.1 2020-2030

Experiences in the German North Sea have shown the scale and challenges of developing shared transmission projects but have also exhibited their benefits. These projects trialled different designs and installation methods, paving the way for the second generation of these project types which increase in scale from 900 MW up to 2,000 MW, which will also be developed using a standardised design to improve on costs.

These 2 GW schemes are being designed to be multi-terminal ready. This will allow for these schemes to become part of hybrid projects as well as seeing the development of relatively simple, multi terminal grid topologies. It is expected that further work will occur on aligning the relatively short-term focus of the Ten-Year Network Development Plan (TYNDP) process with longer term system planning, to provide longer term coordinated offshore generation planning and roll out the control and Governance mechanisms.

At present, electricity interconnectors and offshore wind farms are connected to the grid independently of each another. The next generation of interconnectors will combine the connection of offshore wind farms with cross border interconnection (MPIs). It is expected that MPIs will come online over the next decade. As discussed, there is ongoing planning for “Energy Islands” for the North Sea, to help Denmark achieve its 2030 targets.

One of the areas of concern for the timeline of the coordinated development of grid infrastructure is ensuring that the supply chain is adequately prepared for the increase in activity this decade as well as post 2030. This is where the proposals made by the commission are vital whereby a single independent system operator can provide a clear pipeline of transmission development projects to facilitate the supply chain making the required anticipatory investments.

During this period, Ireland will see the development of commercial scale offshore wind farms in its waters, with the target of installing 5 GW by 2030. This 5 GW of offshore wind will be connected using the conventional approach of radial connection schemes, however, it expected that a new connection regime will be developed and implemented for post 2030 projects to strengthen the Irish grid while facilitating an increase in capacity of offshore wind.

Other EU Member States are already evaluating and planning hybrid interconnectors for the future, and how these can be part of a future interconnected grid. Ireland must follow suit and begin analysing where these projects can be constructed and how these integrate with future grid plans. Future planning must consider neighbouring grids and the relevant TSOs for appropriate planning. The TEN-E revision emphasises the need for regional cooperation, and for Ireland this means working with the UK and France to develop the full potential of the Celtic Sea and Atlantic Ocean.

The Irish Sea is one area of great interest to both Ireland and the UK. There have been proposals presented for the development of shared backbone infrastructure to connect increasing levels of offshore wind. The development of such infrastructure with the UK would be a tremendous first step in ensuring the UK is considered in future energy system planning with the EU, but also present a vital first step in the development of a meshed grid in Irish waters. This backbone infrastructure could begin development towards the end of this decade.

6.2 2030-2040

In line with development procedures in place today, what occurs post 2030 is purely speculative. Current planning facilitates a ten-year development window for projects being considered today. By 2030 it is expected that continental Europe will have over 110 GW of offshore wind. By 2040, Europe will need 260 GW.

The North Sea will experience the largest growth and see more hybrid projects coming online as well as more complex cross-border meshing. This period of growth will be vital in establishing the correct pathway for grid development as well as establishing appropriate market measures for more interconnected energy systems. Early artificial islands will be operational and have their capacity grow throughout this period to allow a significant amount of offshore wind to be connected.

With regards to the development of a SuperGrid, the early-stage projects will begin to link up as early multi-terminal projects and begin offering benefits that come with basic meshed grids. These meshed grids could consist of three or four countries now more heavily connected, with regional grids becoming more prominent as the expansion of the grid continues.

Ireland could see the development of its first shard transmission infrastructure projects this decade, with plans for developing backbone links with the UK. The offshore wind opportunity in the southern waters of Ireland could also see the development of hybrid interconnectors with France, which towards the latter parts of the decade could evolve into a small multi-terminal grid connecting with the backbone of the Irish Sea. For Ireland, it is this decade that is crucial. Grid planning started in the 2020s needs to be realised during the 2030s to facilitate the continued growth of offshore capacity in Irish waters.

The key theme of this decade is the development of anticipatory infrastructure, which while initially may not be fully utilised, will pave the way to a more effective connection with projects in the future. The increasing level of meshing means that more countries are connected through the same network. Current market models and supports will not be as efficient and effective and will need to change to remain effective for the system.

6.3 2040-2050

The final decade of the buildout will see regional meshed grids beginning to merge, as sea basins see their grids combine and increase the levels of power flows in the energy system. All regions connect during this decade and the full benefits of the SuperGrid are realised.

This will enable the full integration of the North Sea, Irish Sea, Atlantic Ocean, and Baltic Sea. Europe will now operate under an Energy Union, with its energy needs being served from within its borders.

The installed capacity of offshore wind will reach at least 450 GW aligning with European targets, indicating another increase in the annual installation rate. For Ireland, this means achieving an installed capacity of at least 30 GW, with the vast majority serving for export to the continent.

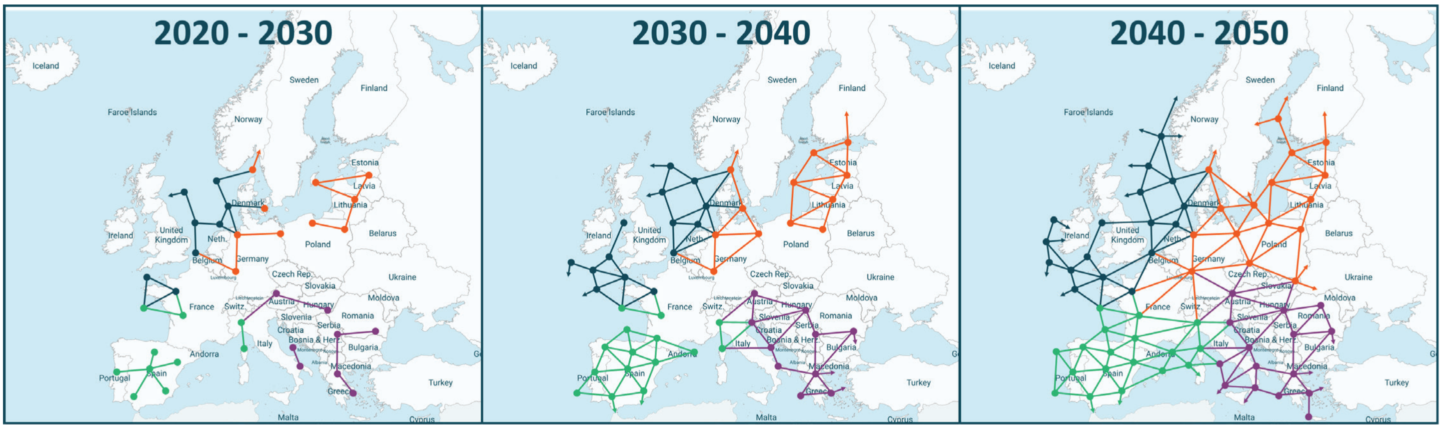


Figure 11. The Baltic Offshore Grid (BOG 2050) concept.

7 Challenges to realising a SuperGrid

The major advantages of a SuperGrid correspond with the goals of the EU's Energy Union, which aims to safeguard power supply, integrate the EU energy market, help decarbonise the economy and support breakthroughs in low-carbon and clean energy technologies. The legal, regulatory, technical, planning and acceptance challenges such a project would face would be significant, which it is important to be aware of at this stage.

There are several questions that need to be answered, but progress is being made in the right direction. The already mentioned TEN-E revisions indicate a need for deeper regional coordination. The paper already shows a quote from the European Commission proposing the idea of an Independent System Operator which would oversee the operation of such a grid.

Political opposition or a lack of political determination could delay the adoption policies which support the development of the SuperGrid. To prevent this, governments must adopt the correct policies and regulations to promote the SuperGrid and create the right market conditions for it to function. It is important that the electricity markets in participating countries are aligned to maximise the effectiveness of this interconnection. This is particularly important in the context of Great Britain's recent departure from the

European Union and the Integrated Single Electricity Market (I-SEM).

The development of the SuperGrid will also require collaboration and co-ordination between different governments and stakeholders. It is important that a framework for collaboration between different stakeholders is put in place to mitigate any risks relating to these interfaces and to keep all stakeholders aligned, from TSOs to project developers to local stakeholders. For example, it is likely that the onshore and offshore planning process across multiple jurisdictions will be a barrier during development. The recent TEN-E revision brings forward regional cooperation as a focal point for European sea basins and will reduce the potential barrier of joint development.

In Ireland, the recent policy statement on the offshore transmission network appointed EirGrid as the asset owner and system operator of offshore infrastructure. Further clarity will be required on how this decision would impact the SuperGrid. Similar hurdles may exist in other European countries which will need to be overcome.

A lack of funding for R&D at EU and national level could also slow progress on the SuperGrid. Significant public and private investment will be required to develop the project and there are many challenges to securing this investment, including uncertainty in technology costs.

There are also technical risks associated with the SuperGrid, as with any technological innovations. The network would be based on multi-terminal HVDC technology, and the operational complexity is a notable barrier. For example, fault finding on subsea DC cables could lead to prolonged outages on the network. In the case of the Moyle Interconnector in Northern Ireland, the repair of cable faults resulted in reduced power transfer capability for several years until the cables were replaced. The design of a meshed grid would present alternative routes around the area of concern, however, enabling part of the grid experiencing technical difficulties to be bypassed.

Significant transmission upgrades will likely be needed to integrate the SuperGrid with existing onshore transmission networks. The timelines and costs associated with these upgrades could delay development. Onshore grid constraints could also result in an export limit on the SuperGrid.

While there are potential barriers and risks to development of a European SuperGrid, this is not surprising given the scale of what is being proposed. Europe needs to transition to a net-zero emissions economy by 2050 and doing so will require a revolution in how our energy systems develop and function. Failure to deliver a pan-European offshore electricity network could mean putting Ireland and the EU's 2050 decarbonisation targets at risk, as well as missing out on all the benefits discussed in this paper.

8 Recommendations

From the several projects that have been conducted to date, there have been suggestions and recommendations as to what needs to be done in Europe to progress towards a SuperGrid which Ireland can learn from.

8.1 Maritime Spatial Planning Recommendations

As maritime spatial development plans formally assign marine space to specific uses, they are a crucial element in the development of offshore wind energy.

Robust frameworks should be established to ensure fruitful international cooperation. The same methodologies should be developed and applied across countries for the evaluation of the productivity of marine space, while maintaining the overriding need to protect the environment and our marine biodiversity. To support international meshed offshore grid development, there should be cooperation between national MSP authorities and energy authorities from bordering countries to locate corridors and transfer gates for interconnectors.

Ireland has done a significant amount of work on quantifying the technical resource potential that exists in our waters. It is time to move past this and begin taking advantage of this resource. Refining the resource model will only delay us in achieving our potential.

8.2 Policy and Regulatory Recommendations

Key areas of risk in the development of a SuperGrid centre around policy and regulation. Obstacles identified include issues with public acceptance, insufficient grid capacity (onshore and offshore) to accommodate offshore generation, ever-changing legislation related to support for electricity from renewable sources, and complex administrative procedures concerning the permitting of grid and generation projects.

To limit costs in network expansion and reinforcement, relevant stakeholders must be brought together including maritime spatial planners, regulatory authorities, TSOs and the energy sector at a regional or EU scale to identify the most suitable locations for offshore wind and grid development. Non-EU states like the UK and Norway should be part of all offshore grid planning proposed by the EU.
TSOs must also be incentivised to investigate, invest in, and operate offshore grids. Incentive packages for TSOs could be adopted to promote innovation. TSOs' profits could be coupled to the expected benefits of a meshed grid.

Finally, cross-border network development expenses in meshed offshore grids should be allocated between the TSOs involved using an adapted methodology in a fair, cost-efficient, and transparent way. This will require a high degree of cooperation between TSOs and the relevant authorities in the definition and implementation of jointly agreed cost allocation methods.

Once these larger grids are developed early on, there must be appropriate regulation to allow for these grids to operate properly. Focus should be put on facilitating MPIs and shared transmission assets for the early stages of a coordinated grid approach. The multilateral nature of these grids means that it is a requirement for Europe to establish a single overarching system architect by 2030 which would encourage TSO cooperation and facilitate the design of these grids in a united approach, leading towards a SuperGrid.

8.3 TYNDP Recommendations;

The TYNDP is a vital framework and should be updated to reflect Europe's longer-term targets. Offshore winds growth has resulted in new grid connection schemes being considered, and updates into longer-term grid developments should reflect this. Formal support for the integration of meshed-grid solutions with offshore wind farms should be included in the TYNDP. The removal of barriers for MPIs and hybrid projects is an area of focus that has been brought forward in the recent TYNDP revision. This should continue to be the focus as well as considering support for offshore meshed grids.

8.4 Recommendations for Ireland

Building a European SuperGrid can have great benefits for the continent and provide a secure and stable energy system for a decarbonised society. This is not a task that can be completed by a single country alone, it requires input and discussion from all involved. Ireland has an incredible offshore resource, beyond what it could ever use itself, so the benefits to the Irish economy are clear.

The Irish Government's recent decision to designate EirGrid as the transmission system operator for the offshore wind sector is timely. Under the plan EirGrid will own and operate grid assets for projects around the coast. EirGrid chief executive Mark Foley said this provides "a long-term strategic opportunity for Ireland as we seek to maximise our wind resource and, in time, may enable Ireland to become a major exporter of renewable energy."

Ireland's grid planning to date has limited itself in vision, considering only the ten-year time frame. It is time to look beyond this time frame to realise the benefits of longer-term planning for a future decarbonised energy system. Ireland currently only has an interconnection capacity of 1,000 MW installed, with a planned capacity of 2,200 MW by 2030. Further work on interconnection is urgently required. Ireland must develop its Zero Carbon Strategy which considers the necessary developments to the national grid, along with the foundations for the offshore grid which can expand and connect into a future supergrid with Europe.

Ireland should first initiate more progressive discussions with the UK and France and look at commissioning a study which could have a similar scope to the Baltic InteGrid project, which considers the 2050-time frame and what solutions offer the best result for the region. There have been several studies which have shown conceptually that meshed grids can be the most beneficial approach. It is time Ireland identifies the climate, economic and technical benefits that a coordinated approach would bring. The most important part of this work should be in developing a roadmap for the steps Ireland needs to take to achieve the development of a meshed grid in the region.

While the offshore sector is only starting in Ireland, it should not limit itself to focussing explicitly on the short term. A study looking at the longer time frame will ensure that Ireland not only meets its goals for offshore capacity but does so in the most effective and efficient manner possible. There is a need for Ireland to move beyond conversation on developing its offshore sector and consider promoting action now which can make it a leader in grid development.

8.4.1 Action Items for Ireland for the Centralised Grid Model

1) Marine Spatial Planning: To support international meshed offshore grid development. There should be cooperation between national MSP authorities and energy authorities from bordering countries to locate corridors and transfer gates for interconnectors.

2) Resources: A vast amount of focus at present is rightly being placed on delivering Ireland's 2030 target of 5 GW offshore wind. There needs to be adequate planning within the relevant Government departments, An Bord Pleanála, NPWS, EirGrid, ESB Networks and the CRU for the grid post 2030, however.

3) Grid Planning: Ireland should propose, and contribute to, a long term (2050) regional roadmap for offshore grid development to our neighbours. Now is the time to explore state-of-the-art solutions for the connection and distribution of offshore wind energy. A meshed grid connecting the Celtic Sea, English Channel, and the Bay of Biscay would facilitate an increase in power flows and improve security of supply. Considering the long lead times of offshore wind farms and grid projects, interest in meshed grids must translate into bold policy-making and reinforced transnational cooperation soon before the region is further locked into a suboptimal energy system.

4) Future Grid Implementation: It is proposed that a Coordination Council be set up for considering the grid post 2030, which can bring together industry, EirGrid, the CRU, and DECC. Successful implementation will include regular engagement with EirGrid to discuss approaches to post 2030 design and implementation.

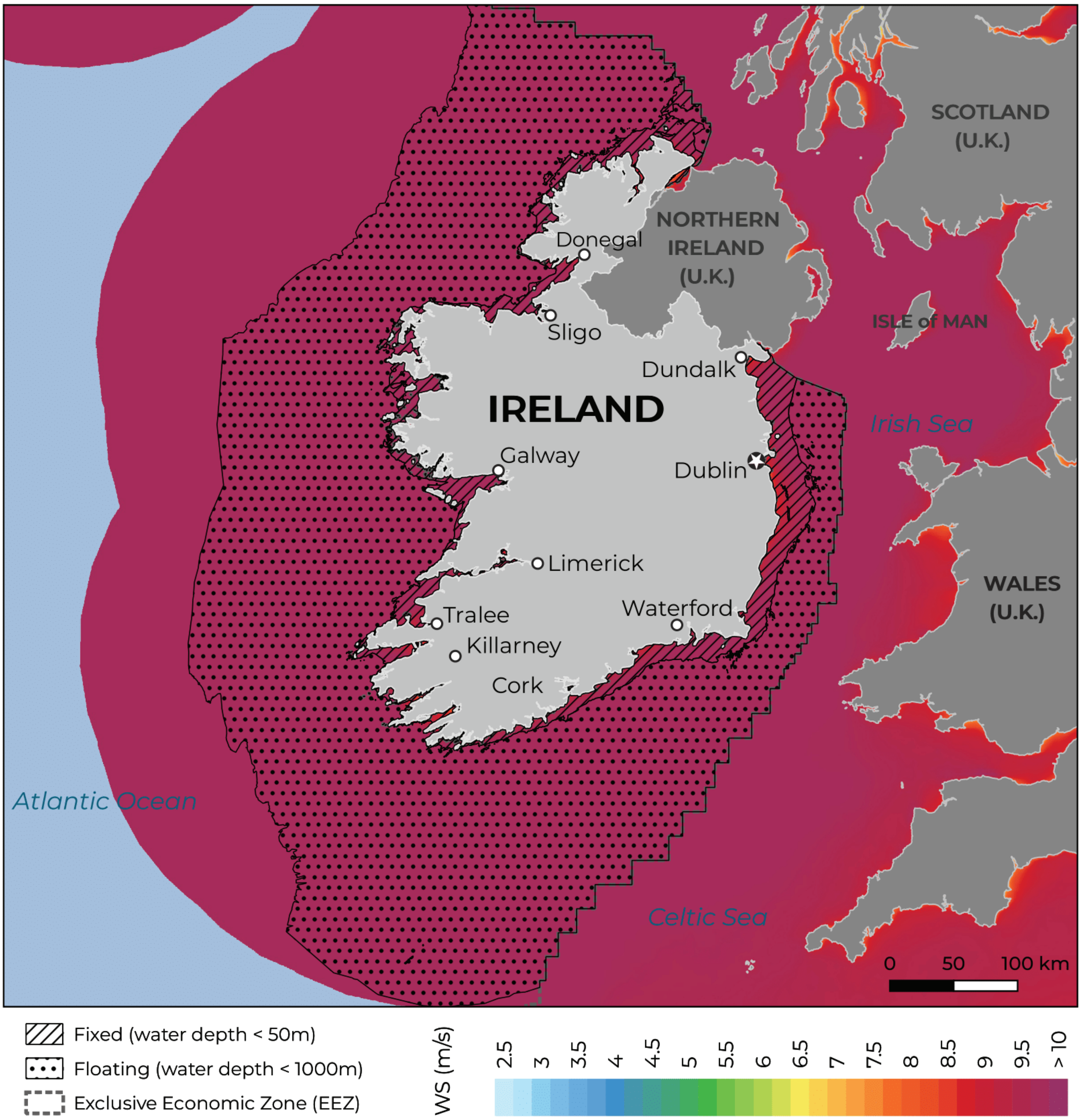
5) International Relations: Ireland will not realise its ambitious offshore wind targets without cooperation with neighbouring countries. Concurrently, Europe will not achieve its decarbonisation goals without full cooperation of all members. Ireland must take an active role in promoting the coordinated development of regional and European level grids and ensure we are active participants in the North Seas Energy Cooperation.

9 Appendix

9.1 Offshore Wind Technical Potential in Ireland

Offshore Wind Technical Potential in Ireland

RISE RE Score: 84 **Fixed: 51 GW || Floating: 553 GW || Total: 604 GW**



This map shows the estimated technical potential for fixed and floating offshore wind in Ireland in terms of installed power capacity in megawatts (MW) within 200 kilometers of the shoreline. It is provided by the Global Wind Energy Council (GWEC) with funding from the Ocean Renewable Energy Action Coalition (OREAC), to support the UN High Level Panel for a Sustainable Ocean Economy (Ocean Panel). For more information visit: ***https://gwec.net/oreac/.***
Fixed and floating foundation datasets and methodology was developed by the Energy Sector Management Assistance Program (ESMAP), a donor-trust fund administered by the World Bank Group. For more information and to obtain maps for WBG client countries please visit: ***https: //esmap.org/offshore-wind.*** The wind resource data is sourced from the Global Wind Atlas and depicts the wind resource at 100m hub height at 250m resolution based on the latest input datasets and modeling methodologies. For more information visit: ***https://globalwindatlas.info.*** For further details on the RISE RE score provided please visit: ***https://rise.esmap.org/.*** GWEC, OREAC, The World Bank Group and ESMAP do not guarantee the accuracy of this data and accept no responsibility whatsoever for any consequence of their use.

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