2022 Annual Innovation Report

May 2023

EirGrid SONI

1. Foreword

We are delighted to publish our report on the innovation we have carried out across EirGrid and SONI in 2022 as well as our future ambition.

Innovation and research are essential in changing our behaviours and increasing our knowledge to help us to get to where we need to be, that as an organisation we can unlock solutions and initiatives to realise sustainable energy benefits. EirGrid and SONI have strategically innovated to deliver key projects, such as Shaping Our Electricity Future Roadmap[1] and coordinated a European wide EU-SysFlex project that will enhance the way we plan and operate the power system.

We are continuously working on realising our Innovation and Research Strategy[2] to focus on the necessary support structures, frameworks, and a change in mindset that fosters a culture of innovation, so that people are empowered to enhance our innovation and research capability. Our innovation and research strategy complements recent publications from EirGrid and SONI on the Shaping Our Electricity Future Roadmap, by focusing our collective research and innovation strategies to deliver on Ireland's and Northern Ireland's respective ambitions to 2030, while enabling and supporting the innovation and research in the wider power system ecosystem to deliver on longer term net zero carbon commitments.

Collaboration and knowledge sharing with our partners is a fundamental part of how we as organisations seek to deliver on our current commitments to our innovation programmes. Looking forward, we are seeking to strengthen existing relationships, as well as building new ones as we know partnership and relationships within the power system ecosystem are vital as we strive to enable further innovation as part of our strategic programmes of work.

As part of the reporting process, we seek to consult on our multi-year innovation and research programmes. The proposed strategic innovation programmes are EirGrid and SONI's view of the important areas of innovation to be investigated. A focused innovation and research strategy will ensure we can deliver effective solutions to a wide range of technical, economic and social challenges that have been identified by Shaping Our Electricity Future.

It is vital we begin our journey of discovery now and introduce disruptive innovation into our planning and operational practices as soon as we can. We need to understand what options and solutions are best for the island of Ireland, to ensure we are on the right path to deliver on a reliable and cleaner energy future.

Alan Campbell,
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Liam Ryan,
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[1] EirGrid and SONI, Shaping Our Electricity Future Roadmap, 2021 EirGrid | SONI
[2] EirGrid and SONI, Innovation & Research Strategy, 2021 EirGrid | SONI

2. Change Log

Version	Publication Date	Changes
1.0	20^{th} Feb 2023	Version published for public consultation
1.1	31^{st} Mar 2023	Version published after public consultation
1.2	19^{th} May 2023	Version published including public consultation response

Contents

List of Abbreviations

Abbreviation	Definition
BESS	Battery Energy Storage System
CEER	Council of European Energy Regulation
CIGRE	International Council on Large Electric Systems
CRU	Commission for Regulation of Utilities
DAC	Designated Activity Company
DAERA	Department of Agriculture, Environment and Rural Affairs of Northern Ireland
DC	Direct Current
DECC	Department of the Environment, Climate and Communications
DER	Distributed Energy Resource
DLR	Dynamic Line Rating
DPFC	Dynamic Power Flow Controller
EMT	Electromagnetic Transients
ENTSO-E	European Network of Transmission System Operators - Electricity
EWIC	East West Interconnector
FASS	Future Arrangements for System Services
FFR	Fast Frequency Response
GHG	Green House Gas
GSAT	Grid Strength Assessment Tool
GW	Gigawatt
HV	High Voltage
HVDC	High Voltage Direct Current
IBR	Inverter Based Resource
LCIS	Low Carbon Inertia Services
LSAT	Look-Ahead Security Assessment Tool
MEC	Maximum Export Capacity
MW	Megawatt
PFC	Power Flow Controller
PQQ	Pre Qualification Questionnaire
PSSE	Power System Simulator for Engineering
PST	Phase Shift Transformers
PV	Photo Voltaic
QTP	Qualification Trial Process

RES-E	Renewable Energy Sources - Electricity
RMS	Root Mean Square
RMT	Ramping Margin Tool
RoCoF	Rate of Change of Frequency
SEM	Single Electricity Market
SEMO	Single Electricity Market Operator
SNSP	System Non-Synchronous Penetration
SOEF	Shaping our Electricity Future
TRL	Technology Readiness Level
TSAT	Transformational Satellite Communications System
UR	Utility Regulator
VRES	Variable Renewable Energy Source
VTT	Voltage Trajectory Tool
WECC	Western Electricity Coordinating Council

3. Introduction

EirGrid Group is made up of EirGrid plc (the Transmission System Operator for Ireland), SONI Ltd (the Transmission System Operator for Northern Ireland), SEMO (the Single Electricity Market Operator), EirGrid Interconnector DAC and EirGrid Telecoms DAC.

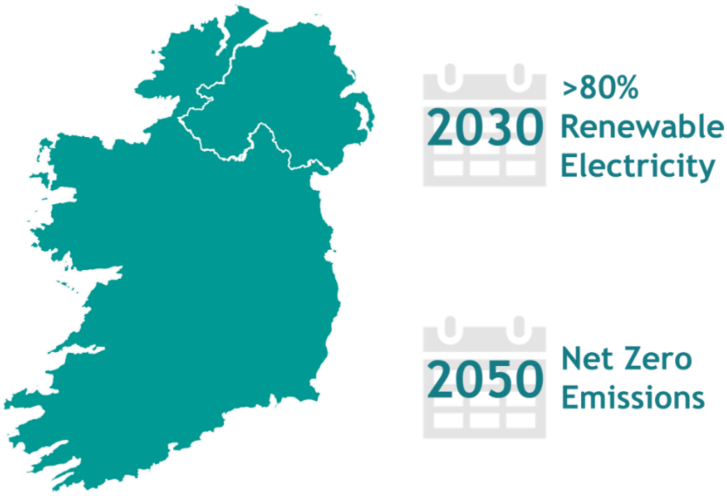
EirGrid plc (the Transmission System Operator for Ireland) and SONI Ltd (the Transmission System Operator for Northern Ireland) operate the electricity transmission grid in Ireland and Northern Ireland respectively. We also plan the future of the grid on the island of Ireland, operate the grid every minute of every day, link with neighbouring grids in countries such as Scotland and Wales (interconnection), and run the wholesale electricity market (where electricity is bought and sold by generators and suppliers). Our task is to deliver a safe, secure and reliable supply of electricity – now, and in the future.

We operate, develop and enhance the wholesale electricity market on the island of Ireland. We also develop and operate interconnections with neighbouring grids and enable third-party interconnectors.

EirGrid and SONI as Transmission System Operators (TSOs) have a critical role to play on the Island of Ireland helping to deliver on climate ambition targets in Ireland and Northern Ireland respectively. We are world leading TSOs in variable renewable energy integration. Through the successful delivery of strategic innovation programmes, we have developed solutions that allow us to currently operate the two systems with up to 75% non-synchronous generation at any given moment, primarily from wind generation. Electrification of different sectors for example heat and transport will be a key part of reducing carbon emissions. Therefore, to enable electrification to play its part in the broader decarbonisation of the economy there is a need for a transformed energy system. Key to this transformational journey is our ability to innovate and address ever more complex system, market, and infrastructure challenges.

One emerging key focus area for EirGrid and SONI is offshore wind. Ireland's Climate Action Plan 2023[3] targets at least 5 GW of offshore wind by 2030 and in Northern Ireland the Energy Strategy[4] targets 1 GW of offshore wind from 2030. Consequently, offshore wind is of great importance in our Innovation & Research activities.

[3] Department of the Environment, Climate and Communications, Climate Action Plan 2023, 2022
[4] Department for the Economy, Energy Strategy - The Path to Net Zero Energy - Action Plan, 2021



In Ireland, Climate Action Plan 2023 targets 80% of electricity to come from renewable energy sources by 2030. It also specifies carbon sectoral emissions ceilings for the electricity sector as 40 $MtCO_2eq$ for 2021 to 2025 and 20 $MtCO_2eq$ for 2026 to 2030. It also targets to reach a climate neutral economy no later than 2050.

In Northern Ireland, Climate Change Act[5] targets 80% of electricity to be generated from renewable energy sources by 2030 and the UK Net Zero Strategy[6] targets carbon net zero by 2050 as well. Currently, DAERA are developing the climate action plan for Northern Ireland which will include carbon budgets for the period of 2023-2027.

In our current Shaping Our Electricity Future Roadmaps for Ireland and Northern Ireland we provide an outline of the key developments from a networks, engagement, operations and market perspective needed to support a secure transition to at least 70% renewables on the electricity grid by 2030 – an important step on the journey to 80%. For the Shaping Our Electricity Future Roadmaps we hosted extensive consultation events across all parts of society; and carried out studies spanning across transmission networks, stakeholder engagement, power system operation and electricity markets. The current roadmaps not only give us an integrated vision of the 2030 power system and electricity markets but identifies key areas of innovation and how to implement them; to allow delivery of ambitious government targets for Ireland and Northern Ireland. EirGrid and SONI are currently undertaking the analysis to ensure Shaping Our Electricity Future reflects the updated climate and energy targets adopted for Ireland and Northern Ireland respectively.

The Annual Innovation Report is a key deliverable for EirGrid detailed in the CRU's PR5 Regulatory Framework Incentives and Reporting, CRU/20/154[7]. The Annual Innovation Report is also a key deliverable forming part of Role 2 Independent Expert within SONI's Forward Work Plan[8] for 2022 – 2023 under project ID FWP019. Through this project we will consult with industry on the multi-year innovation programmes, consider all responses provided and use this to inform our decision-making process and publish a final version of the Annual Innovation Report.

This Annual Innovation Report documents progress of EirGrid and SONI on innovative programmes throughout 2022 and points out our ambition for future developments of programmes and new initiatives to begin. The innovation programmes mentioned here reflect the ambitions of our Innovation and Research Strategy. We welcome feedback on this report to enable us to gather the views of our stakeholders, and ensure the projects are deemed appropriate by all.

[5] Climate Change Act (Northern Ireland) 2022
[6] Department for Business, Energy & Industrial Strategy, UK Net Zero Strategy 2021
[7] CRU, PR5 Regulatory Framework Incentives and Reporting, 2020
[8] SONI, SONI Forward Work Plan for 2022/23, 2022

4. Innovation in 2022

EirGrid and SONI have a proven track record in the delivery of transformational innovation in support of the energy transition and we are currently delivering a portfolio of innovative projects to achieve the government targets. These targets now necessitate enhancing and accelerating EirGrid and SONI's approach to overcome the identified limitations of many established technological, operational and market practices. We need to act now to encourage an even greater innovation culture across the companies so that we have the capability to create novel solutions to address whole system challenges.

Our Innovation and Research Strategy is aimed at enhancing our innovation and research capability. It is designed to help us become more innovative by putting in place the necessary support structures, frameworks, and a change in mindset that fosters a culture of innovation, so that people are empowered to enhance our innovation and research capability.

The strategic innovation programmes identified as part of the strategy are EirGrid and SONI's view of the crucial areas of innovation that we need to investigate across a now, next and beyond lens to ensure we can respond effectively to the challenges ahead.

- Now: Programmes aiding us to deliver on the 2030 targets
- Next: Programmes aimed at pushing the boundary even further
- Beyond: Programmes laying the foundations to enable net zero carbon

Now

- Flexible Network Strategy
- Champion the emergence of the energy citizen
- Lead the island's electricity sector on sustainability

Next

- Enhance data-driven decision-making
- Grow EirGrid TSO capabilities as it develops and operates the new offshore grid

Beyond

- Prepare for a multi-purpose offshore HVDC grid
- Understanding pathways to 100% SNSP
- Plan a net zero carbon, customer focused, export capable system

This report documents progress on innovative programmes throughout 2022. The picture below illustrates a selection of EirGrid's commitments between 2021 and 2025 and gives an idea how innovation projects in 2022 fit in the longer-term plan.

EPRI

- Advanced power flow control, HVDC planning, and contingency analysis methods and tools
- Modeling and analytics, transmission planning aspects / modeling and analytics, protection aspects

Memberships

- ESIG (Energy Systems Integration Group)
- IRDG (Industry Research and Development Group)

NexSys - 5 years

- Extended low renewable energy source periods
- Impact of the integration of green hydrogen onto the power system
- Enhanced utilisation of power system network infrastructure

2021 → 2022 → 2023 → 2024 → 2025

MaREI Public Engagement

- Public engagement with energy transitions in an era of climate crisis

HyLIGHT

- Provide the knowledge, data and the necessary tools to guide the cost-effective decarbonisation and roadmaps for sustainable large-scale implementation of hydrogen technologies.

READY4DC

- Technical and legal aspects of designing and building an interoperable multi-vendor DC grid.
- Prepare the ground for the development of the first multi-terminal, multi-vendor HVDC project in Europe.

Now – Flexible Network Strategy

Objective

Understand and utilise the benefits of flexible network technologies to maximise the use of the transmission grid while minimising the requirement for new network build.

Benefit

To meet our carbon emission targets, flexible network technologies, such as Dynamic Line Ratings and Dynamic Power Flow Controllers, need to be investigated and trialled. These technologies can provide a means to reduce network congestion, act as an alternative to extensive new network build, provide system services/operational flexibility, maximise utilisation of existing network assets, enable greater output from RES-E generation hubs and create potential economic/reliability benefits.

Projects

- Initiated:
  - **NexSys – Enhanced utilisation of power system network infrastructure**
    Investigate the benefits of existing and future technologies that could improve the real-time utilisation of existing networks and push operational (stability) limits higher
- In progress:
  - **Dynamic Power Flow Control**
    Procurement and installation of modular, easy to re-deploy devices to maximise existing network capacity
  - **Dynamic Line Rating**
    Trial and investigation of DLR devices to enable usage of real-time thermal loading limits to increase existing network capacity
- Completed:
  - **Hybrid Technology Enablement**
    Investigate the opportunities for effective use of new and existing technologies to meet the needs of the future power system

Now - Champion the emergence of the energy citizen

Objective

Understand and facilitate consumers' changing interaction with power system technologies and Services.

Benefit

Enhance EirGrid's understanding of the disparate energy citizen segments, their behaviours and what drives their choices. Prepare EirGrid to play our role in facilitating the relevant national policies with respect to community participation and best practice pre-application community consultation programmes. Trial and iterate solutions to gain deeper understanding of the technologies and the scale at which consumers are investing in and how these can support EirGrid transform the power system for future generations. Support our public engagement strategies by disseminating best practice research on community engagement and participation.

Projects

- In progress:
  - **Public Engagement with Energy Transitions in an Era of Climate Crisis**
    Impartial analysis of EirGrid's evolving public engagement processes, based on a mapping of actors, and a framework to codify different elements of existing strategies

Now - Lead the island's electricity sector on sustainability

Objective

Increase the visibility of the impact our collective actions have on the environment and assist in reducing this impact.

Benefit

Enhance EirGrid's, SONI's and society's understanding of the impact the power sector has on the environment and the natural ecosystem of the island. Enhance EirGrid and SONI's understanding of how to leverage its capabilities to champion sustainability and biodiversity on the island. Prepare EirGrid and SONI to innovate alongside our partners and society in the pursuit of a fully sustainable and circular power system with minimal impact on our environment over every timeframe.

Projects

- In progress:
  - **Nature Inclusive Design including Biodiversity Enhancement**
    Series of nature restoration projects exploring planting shallow-rooted native shrubs, building back better at passing bays and retrofitting certain overhead line uprate projects with bird diverters

Next - Enhance data-driven decision-making leveraging artificial intelligence capability

Objective

Support the development of EirGrid and SONI's next generation artificial intelligence capability to enhance data driven decision making and transparency.

Benefit

Enhance EirGrid and SONI's understanding of next generation artificial intelligence and machine learning technologies and use cases. Prepare EirGrid and SONI to lead multi party collaborations on whole system open data initiatives to drive the digitisation, decentralisation, and decarbonisation of the energy system. Build EirGrid and SONI's capability in explainable artificial intelligence and data transparency to bring society, decision-makers and industry on the machine-enabled decision-making journey.

Projects

- In progress:
  - **Real-time Contingency Analysis & Network Optimization Control Centre Tools**
    Development and validation of decision support tools to capitalise on network flexibility introduced with the use of innovative Power Flow Control technology
  - **Control Centre Tools Implementation**
    Implementation of Look-Ahead Security Assessment, Voltage Trajectory and Ramping Margin Tools to increase levels of instantaneous renewable generation

Next - Grow EirGrid TSO capabilities for developing and operating the new offshore grid

Objective

Support EirGrid TSO to develop scalable processes and solutions to manage the development of an offshore network in Ireland. In May 2021, as part of the Government's policy for Ireland's Offshore electricity transmission system it was announced that EirGrid would be appointed as the transmission system operator and asset owner of offshore transmission assets.

Benefit

Enhance EirGrid's understanding of best practice and next generation capabilities and solutions for the new Offshore grid. Prepare EirGrid to fulfil its role in the planning, development, operation, and maintenance of an offshore transmission system throughout the three phases of the network development model. Enhance ways of engaging with communities and developers through novel solutions, processes, and data. Reduce the cost and risk of working offshore through digital solutions.

Projects

We are working in this area with a focus on determining future actions and currently working in a planning stage and will be engaging in standalone research projects in the near future.

Beyond - Prepare for a multi-purpose offshore HVDC grid

Objective

Understand the capabilities and dependencies to delivering a multi-purpose, multi-terminal, multivendor high voltage direct current (HVDC) grid.

Benefit

Enhance EirGrid and SONI's understanding of HVDC technologies and their development roadmap. Prepare EirGrid and SONI to embrace and develop HVDC assets considering the asset lifecycle from technology qualification to asset management. Prepare EirGrid and SONI to support the development of multi-purpose HVDC grids by understanding the implications for infrastructure development, multijurisdictional grid operation and multi-purpose, multi-jurisdictional markets.

Projects

- In progress:
  - **READY4DC**
    Community of experts that assess and give recommendations on the major technical and legal aspects of designing and building an interoperable multi-vendor DC grid
  - **Advanced Power Flow Control**
    Investigate established and new HVDC and storage technologies to evaluate cost-effective design solutions for transmission reinforcement

Beyond - Understanding pathways to 100% SNSP

Objective

Translate net zero carbon pathway research into real-world trials of next generation technologies and routes to integration.

Benefit

Enhance EirGrid and SONI's understanding of pathways to 100% SNSP assessing the impact and real-world performance of mass integration of emerging technologies such as inverter-based resources, grid forming control, electrolysers, and distributed energy resources. Prepare EirGrid and SONI to operate at 100% SNSP by delivering minimum viable products (MVPs) and trials to further inform EirGrid and SONI's understanding of the solutions required and routes to integration.

Projects

- Initiated:
  - **NexSys - Mitigation of Extreme Weather Events on High RES Dependent Network**
    Analyse temporal and spatial resolution data to consider the role of HVDC links and the spatial correlation of low-RES events across Europe
- In progress
  - **MIN 7**
    study on relaxing the minimum number of conventional generation units that must be dispatched on the all-island system to identify potential insecurities and instabilities
  - **Modelling and Analytics of Emerging Technologies**
    Investigate the need for improved inverter-based resource (IBR) models & tools to enable planners to accurately simulate and assess power systems with high IBR penetration levels, as well the refining and verifying aggregated distributed energy resource (DER) models
- Completed:
  - **EU-SysFlex**
    Enhance EirGrid and SONI's collaboration with other sectoral participants as well as sharing knowledge to enhance the understanding and ability to solve future challenges
  - **Fast Frequency Response Interim Solution**
    Study to determine sufficiency of the Fast Frequency Response service required when operating the transmission system with a minimum of seven sets and 20 GWs system inertia
  - **SNSP75 Study**
    Investigate different aspects of power system security and stability in order to increase SNSP greater than the previous limit of 70%, thus enabling more renewable generation and reducing curtailment
  - **Low Carbon Inertia Services**
    Investigation of the dynamic and steady state security of the All-Island Power System for different scenarios of deployment of Low Carbon Inertia Services
  - **Weak Grid Analysis**
    Use EPRI's Grid Strength Assessment Tool (GSAT) to carry out a case study on the all-island power system to investigate the capability of newly developed inverter models
  - **Rate of Change of Frequency (RoCoF) Trial**
    Technical studies and tests at generator sites as well as through simulations to identify potential RoCoF-related vulnerabilities in the system

Beyond - Plan for a net zero carbon, customer focused, export capable power system

Objective

Facilitate a plan-led, whole-system approach to scheduling and exporting large volumes of generation via emerging technologies such as hydrogen.

Benefit

Enhance EirGrid and SONI's understanding of the opportunities and challenges resulting from a range of novel technologies that are quickly becoming technological and economically feasible at scale for example electrolysis or power to X. Understand possible synthetic production and demand scenarios to access impacts on generation and transmission development. Prepare EirGrid and SONI to facilitate and capture benefits arising from the mass deployment of these new technologies for the benefit of the power system and its customers.

Projects

- Initiated:
  - **NexSys - Impact of Green Hydrogen Integration onto the Power System**
    Investigate optimal location, scheduling and dispatch of electrolysers as well as the impact of large-scale hydrogen production from offshore wind on the SEM
  - **Importing Emissions to the Electricity Sector**
    Irish Government targets to decarbonise some sectors. This involves an increased level of electrification of these sectors. This study aims to understand the impact this will have on the electricity systems carbon emissions.
  - **Emissions from Dispatch Balancing**
    Emissions from Dispatch Balancing services make up the vast majority of the GHG emissions. We want to gain a better understanding and modelling of these emissions to help us achieve our target of 35% reduction by 2030, over 2019 levels.
- In progress:
  - **HyLIGHT**
    3-year programme to provide the knowledge, data and the necessary tools to guide decarbonisation and roadmaps for large-scale implementation of hydrogen technologies in Ireland

5. Strategic Outlook

This section of the report documents two programmes of work which were introduced in 2021 Annual Innovation Report. These are both critical programmes that EirGrid and SONI believe we need to progress now in order to position ourselves to achieve our future ambition effectively. The section includes progress so far and the next steps identified for the programmes.

5.1. Hydrogen

Context

Hydrogen is enjoying a period of renewed attention in Europe and around the world. Yet, hydrogen currently represents only a modest fraction of the global and EU energy mix and is still largely produced from fossil fuels, notably natural gas and coal. For hydrogen to contribute to climate neutrality its production needs to expand to a much larger scale, become fully decarbonised and find a cost-effective place in the electricity system.

Ireland and Northern Ireland have one of the best wind resources in Europe which can provide enough energy to meet our domestic needs as well as providing a huge potential for supporting new industries and also for the export of energy. However, with increasing levels of renewable electricity we would expect to see increasing levels of constraint and curtailment. The production of hydrogen through electrolysis is an area that provides significant opportunity. The synergy of reducing renewable energy curtailment and providing alternative energy sources for cases where electrification is not technically or economically feasible points to hydrogen as having the potential to play a key role in reaching renewable energy and emissions targets in Ireland and Northern Ireland. As large demand sources, the location and behaviour of electrolysers will have an important impact on the electricity network and market that it is important for EirGrid and SONI to understand fully.

In Ireland's Climate Action Plan 2023 (CAP23), green hydrogen has been identified as having the potential to support decarbonisation across several sectors, and in high-temperature heat for industry and in electricity generation. Among the measures in the 2031-2035 timeframe in CAP23 is the delivery of 2GW of offshore wind generation dedicated for green hydrogen production. The Department of the Environment, Climate and Communications (DECC) released a consultation on developing a hydrogen strategy for Ireland in July 2022 and the Climate Action Plan 2023 committee to its publication. Northern Ireland has launched an ambitious new energy strategy in 2022 - The Path to Net Zero Energy strategy that includes plans to place hydrogen as a key energy carrier for the future.

For Ireland and Northern Ireland to address the challenges associated with decarbonising our entire energy system, it is essential that we examine the role that green hydrogen[9] can play. A coordinated approach will ensure that this continues to be an important area of research focus, enabling increased capacity to be developed and maintained to support the decarbonisation of our energy future.

Need

Green hydrogen has the potential to play an important role in the decarbonisation of the economy. Our future energy needs will be met increasingly by renewable electricity; however, some energy end uses are hard to electrify via the grid or with batteries, especially Heavy Duty Vehicles (HDV's), air and marine transport and high temperature heat. In many sectors, direct electrification is, and likely will remain, technologically challenging or uneconomical.

As well as providing a potential solution for hard to abate sectors, hydrogen also represents a possible overall solution for long-term, carbon-free seasonal storage. While batteries, super-capacitors and other technologies can support short-term within day balancing of the power system, they currently lack either

[9] Hydrogen that is produced with renewable energy sources such as solar and wind

the energy capacity or the storage timespan needed to address longer imbalances of days or weeks between renewable energy generation and demand. As we transition towards net zero emissions, the requirement for zero carbon technologies that can fill this gap will need to be reviewed and hydrogen could play a key role here.

There are already some hydrogen projects in development on the island of Ireland; and we expect that there will be a significant increase in the amount of indigenous hydrogen produced over the next five years. There are many companies that are examining the potential for large-scale hydrogen production in Ireland and Northern Ireland and showing interest in installing MW or even GW scale electrolysers for this purpose. EirGrid and SONI have identified a need to be involved in hydrogen research to understand the wider power system operation and market impacts, so that we are ready for the future. It is key to consider potential electrolyser locations for green hydrogen production over the years and their impact on the all-island power system.

Benefit

Ireland and Northern Ireland are committed to tackling climate change by reducing emissions to net zero by 2050. Overcoming this challenge will require a monumental shift throughout society in how we source and use our energy. Fortunately, solutions based on existing technologies are already commercially available and research is continuing on emerging technologies that over the longer term could be deployed at scale. Renewables such as wind and solar are the primary tools available to decarbonise our power system. However, the intermittent nature of weather-based renewables means their generation pattern over the course of an hour, day or week is not a perfect match for the demand for electricity over that same period. During periods of high wind and solar generation there will be a greater supply of renewable electricity than there is demand for that electricity. Flexible electrolysers that can increase their demand during these periods will therefore help to reduce the curtailment of renewable energy. If this hydrogen can be stored in sufficient quantities, then it can also be used to provide zero carbon flexibility to the system during periods where wind and solar generation is not sufficient to meet demand. During periods of low wind and solar production there will be a gap between supply and demand. Complementary technologies are therefore required to act as a buffer to fill this gap. Green hydrogen is a leading candidate for addressing this, thereby unlocking the deeper integration of renewables.

Northern Ireland is uniquely positioned in the United Kingdom (UK) to become a leader in hydrogen deployment and technology. Northern Ireland has abundant, and in many cases untapped, resources of onshore, and offshore renewables, it has modern gas and electricity networks, complimented by interconnection to both Ireland and Great Britain. Northern Ireland is a relatively small geographic area, but has the availability of salt cavern storage useful for storing gases, and it has an internationally recognised track record of innovative engineering and manufacturing capabilities giving Northern Ireland a competitive edge to become a world leader in the new hydrogen economy.

Ireland and Northern Ireland's ambitions on hydrogen are clearly articulated and the development of a hydrogen economy would provide real benefits in decarbonisation and energy security but also in economic growth and jobs across the island.

Current state

EirGrid and SONI have already built up a solid knowledge base by actively participating in several hydrogen initiatives such as:

- **CIGRE C1.48 - Role of green hydrogen in energy transition:**
  A working group which commenced in 2021 investigating opportunities and challenges from technical and economic perspectives
- **HyLIGHT:**
  An all-island research project which commenced in 2021, with academia, industry, and state bodies to look at the islands green hydrogen transition

- **NexSys:**
  A partnership which commenced in 2022, bringing together a multidisciplinary research team to tackle some of the fundamental research questions to be addressed as part of the transition to net Zero incl. potential of green hydrogen
- **Department of the Environment, Climate and Communications (DECC) Hydrogen Working Group:**
  Working group ran by DECC involving multiple government departments and state organisations in the energy sector.
- **Department for the Economy:**
  In Northern Ireland, we note the plans to commence delivery of a to Hydrogen Centre of Excellence in 2023 as detailed in the 2022 Action Plan Report.[10]

Proposed actions

The proposed programme will further examine the role of hydrogen in the all-island energy system as a whole and specifically its potential to enable deep energy system sector integration. In 2023 it will especially focus on continuing to collaborate with both academia and industry to understand the impact of hydrogen and electrolysis on both the demand for power and supply of power – particularly post 2030. This work will be included as part of the next iteration of Tomorrow's Energy Scenarios.

Impact of Power to Hydrogen on the All-Island power system

Some modern electrolyser technologies can support fast reaction time and ramping making them a possible candidate for providing fast frequency response and operating reserve. Scaling up electrolyser plants from a few MWs to hundreds of MWs may require a dedicated connection to the high voltage transmission grid. Grid code compliance at plant level will be one of the key aspects to address. Provision of new flexible system services, such as congestion management are already established as a source of revenue stream for the plant owners while simultaneously deferring investment in grid expansion.

Impact on Grid Planning

The challenges relating to electrolysis in grid operation and in system operation are also reflected in grid planning and system development. Indeed, in the planning stage the complexity of a sector-integrated system is multiplied by the large uncertainty of most of its fundamental variables: There exists uncertainty around the capacity and speed of RES deployment, uncertainty around future load projections in particular from Large Energy Users (LEU's) and from the electrification of heat and transport. There is also a large element of uncertainty in how electrolysers themselves may operate on the system. This requires updating of scenario building framework and an important advancement in methodologies, modelling tools and simulation schemes for traditional grid planning, for adequacy resource assessment, and for resilience analysis. EirGrid and SONI will also be required to work more closely with the Gas Transmission System Operators to ensure a whole system approach is adopted.

Impact on Market

The most important operational cost factors of hydrogen produced by electrolysers are electricity price and, load factor. For analysing operational cost different operational modes like spot operation mode, baseload operation mode, market-based operation mode, or any dedicated or co-located operation mode will be considered by project developers. All these various modes of operation would interact differently with both the network and market. The time frame of development of both the existing electricity market and a new hydrogen market must be analysed and predicted to understand when and how the technology will begin to emerge at scale.

[10] Department for the Economy, Energy Strategy – Path to Net Zero Energy – 2022 Action Plan Report, 2023

5.2. Flexible Network Strategy

Context

The Flexible Network Strategy is included in our Innovation & Research Strategy and has been identified as a new project in the 2021 Annual Innovation Report. It is focused on the investigation and utilisation of flexible network technologies to maximise the use of the transmission grid while minimising the requirement for new network build and includes the facilitation of trials to accelerate the widespread integration of suitable flexible network technology.

There are two technologies ready for immediate deployment as identified through Shaping our Electricity Future. The two technologies are Dynamic Line Ratings (DLR) and Distributed Power Flow Controllers (DPFC) and are crucial for Ireland and Northern Ireland to achieve their respective 2030 climate action targets.

- There is a limit to the power that can flow through transmission circuits, called its rating. The value of the maximum circuit rating changes with external weather conditions and has traditionally been set as a fixed value on a per season basis taking into account seasonal differences in weather conditions. The ambient temperature has a significant influence on the rating of a circuit, and the colder the ambient temperature is the more power that could be allowed to flow. Similarly, wind speed has a strong influence on circuit rating, the windier it is, the more cooling effect the wind has on the circuit and consequently more power could be allowed to flow. DLR installations enable the use of real-time rating limits determined from the live environmental conditions. Research shows that on average it is possible to achieve 30% more rating on existing circuits; and
- Power along circuits generally flows along the path of least resistance and this can cause congestion in certain parts of the network. DPFC allows system operators to manage power flows through the network by encouraging power flow along alternative circuits that are complimentary, or under-utilised, pathways therefore easing congested areas of the network.

The aim of this research area is to:

- Investigate and scope out what is required for the wide scale roll out of these technologies to support the respective 2030 objectives;
- Complete a cost benefit analysis for the implementation of the Flexible Network Strategy to support investment decision-making for the deployment of flexible network technologies;
- We will develop a roll-out strategy & identification of candidate circuits for the integration of flexible network technologies in Ireland and Northern Ireland;
- Lead New Trials & Support Existing Trials:
  - Progress with a demonstration project in Ireland for DLR, in conjunction with Transmission Asset Owner for Ireland, ESBN;
  - Investigate a demonstration project in Northern Ireland for DLR, in conjunction with NIE Networks;
  - Progress DPFC demonstration project & investigations for both Ireland and Northern Ireland;
  - Trial to develop optimal operation of multiple DLR applications and DPFC devices for both Ireland and Northern Ireland.

To support the detailed scope to develop a readiness plan to support a pathway for DLR/DPFC to successfully become business as usual technologies. This includes items such as integrating the devices to control room tools, communications with devices, cyber security, etc.

Need

Flexible network technologies such as DLR & DPFC maximise the utilisation of existing assets, thus reducing network congestion. This may allow for the deferment of infrastructure developments for which delivery may be challenging and support reduced dispatch down for variable renewable energy source (VRES) generation.

Both maximising usage of existing assets and enabling fuller output of VRES generation will be valuable in reaching our 2030 RES-E targets.

Benefit

Flexible network technologies, such as Dynamic Line Ratings and Distributed Power Flow Controllers, provide a means to reduce network congestion, act as an alternative to challenging network builds/uprate, provide operational flexibility, maximise utilisation of existing network assets, enable better integration of RES, and create potential economic/reliability benefits.

As power system generation moves towards greater volumes of VRES and progression continues to be made towards our 2030 targets and beyond, the anticipated value gained from flexible network technologies will continue to increase.

Current state

Since publication of the Shaping Our Electricity Future reports, and the associated Roadmaps, key elements of the readiness plan for wider scale employment of Flexible Network devices have been completed. Modelling techniques for the technologies in the various analysis tools used by EirGrid and SONI has been reviewed, with recommendations provided to network planners. Cost benefit analysis has been undertaken to get a clearer understanding of the savings these technologies will bring in terms of reduced transmission constraints. A decision-making logic has been developed to aid network planners when considering flexible network technology as a candidate solution for network needs.

Crucially, the roll-out of Flexible Network components has progressed. A demonstrator project in Ireland is currently under way to implement Dynamic Line Rating technology on the Lisheen – Thurles 110 kV circuit. This project is part of the connection method of a new windfarm at Lisheen 110 kV station in Co. Tipperary. By implementing DLR investment in additional network capacity between Lisheen and Thurles 110 kV stations for the connection of the new windfarm has been avoided.

This project is a key demonstrator of the benefits of Dynamic Line Rating. It has helped the Transmission Asset Owner for Ireland, ESBN, develop a clearer understanding of the installation techniques which will help minimise outage requirements for future applications. Both EirGrid and ESBN have developed their understanding of the IT system requirements to allow integration of Dynamic Line Rating into asset management systems. Work is ongoing to integrate the live dynamic line rating information into the Energy Management Systems used in the National Control Room which will allow constraint minimisation on the windfarms at Lisheen.

Furthermore, EirGrid and SONI are progressing capital approvals for the Dynamic Line Rating candidate reinforcements identified in the Shaping Our Electricity Future roadmaps and seeking other opportunities for deployment. In Ireland the procurement of Dynamic Power Flow Controllers is currently underway, with pre-qualification questionnaires issued to prospective suppliers of the technology. EirGrid has capital approval for an initial demonstrator project at Binbane 110 kV station in Co. Donegal which was identified as a candidate reinforcement in the Shaping Our Electricity Future Roadmap. Similar to the Dynamic Line Rating project at Lisheen, this project will develop the EirGrid and ESBN understanding of the requirements for implementing this technology and integrating it into IT systems and real-time operations. In Northern Ireland, SONI will commence a feasibility study to determine the requirements and benefits related to adding dynamic line rating to the Magherakeel - Omagh 110 kV circuit. This circuit was identified in the SONI Shaping Our Electricity Future roadmap as potentially benefitting from DLR.

Proposed actions

We are continuing with progress on integration of DLR and DPFC onto the system and as part of our "technology toolbox".

Key to this is integration into the IT systems that support asset management, and that are used to operate the power system. The demonstration projects underway for DLR and DPFC will determine those requirements and provide a framework for the addition of further flexible network devices to the network.

As further flexible network devices are added to the network analysis will continue related to the co-optimisation of DLR and DPFC to maximise utilisation of existing transmission assets.

In conjunction with this analysis a review of international good practice on, and novel use of, overhead line and underground cable circuit ratings will be carried out to ensure the utilisation of existing circuits is maximised ensuring network constraint is minimised.

We will work to improve network related locational signals for new generation, demand, and storage to allow these developments to contribute to maximising utilisation of the existing network, minimise new network build, and mitigate or avoid constraint.

We will continuously carry out Flexible Network technology horizon scans, report learnings from other TSOs and collaboration with research hubs, to capture emerging technologies such as DLR, DPFC, Virtual Power Lines etc.

6. Innovation Trials Sandbox

EirGrid and SONI already have some mechanisms to test new energy products and services such as the Qualification Trial Process (QTP) for new System Service technologies. However, EirGrid and SONI believe that there is a potential for the power system ecosystem to provide new solutions to solve emerging problems; an Innovation Trials Sandbox is one mechanism by which we can support novel and emerging technologies by: facilitating innovation trials or bring to market new technologies, products, services, or business models. Some of the new technologies require new approaches to trials and demonstrations. We want to unleash the potential of customers to solve problems by exploring an Innovation Trials Sandbox. This means enhancing the ambition and scope of innovation trials, securing mechanisms to enable new technologies, products and services in support of innovators, assessing lower technology readiness level (TRL) solutions and quantifying benefits so that we learn more about these before their wider deployment. Therefore, we will continue to explore this concept with the regulatory authorities and with our stakeholders.

This was mentioned in the 2021 Annual Innovation Report and we received positive feedback from the consultation. During 2022, Council of European Energy Regulators (CEER) published a Paper on Regulatory Sandboxes in Incentive Regulation[11]. The document communicates a message to encourage innovation through regulation. In 2022, ENTSO-E published Innovation Uptake through Regulation[12] and shares a similar message on importance of a properly designed regulatory framework and the incentivising of innovative solutions.

As EirGrid and SONI are regulated businesses, therefore we need to explore this concept with the regulatory authorities and will do so based on feedback received as part of 2021 consultation, this consultation and published papers mentioned above.

[11] CEER, CEER Paper on Regulatory Sandboxes in Incentive Regulation, 2022

[12] ENTSO-E, Position on Innovation update through Regulation, 2022

Annex 1 - In-depth insight into projects

Now – Flexible Network Strategy

NexSys – Enhanced utilisation of power system network infrastructure	***Initiated***
Scope	The NexSys programme aims to determine how energy systems should evolve to have more renewable electricity towards 2030 and subsequently get to the net zero carbon goal by 2050. To develop an understanding of enhanced utilisation of power system network Infrastructure is one of three key targets within the NexSys programme, covering the following scope: • Quantify the benefits of existing and future technologies that could improve the real-time utilisation of existing networks and enable operational (stability) limits to be pushed higher • Development of a multi-year, stochastic planning optimisation tool that selects passive and active measures to minimise investment costs, renewables curtailment, etc. Sections of the grid will be used to demonstrate the optimisation approach on timescales from 2030 towards 2050, with the impact on capital investment, network loading, renewables curtailment, etc. • High wind conditions or post-disturbance network overloads will be investigated, supported by system service product designs to encourage provision of congestion-relieving capability
Rationale	The transition to a net Zero carbon energy system is one of the major challenges facing the world and is a crucial required action to mitigate climate change. Energy sources are converted, transported, and delivered to the end users through distinct energy systems with unique physical, commercial, and regulatory characteristics. The energy system encompasses technical, financial, and societal dimensions and this is reflected directly in NexSys.
Expected Impact	• Greater understanding on network planning to incorporate static and dynamic technology options • Greater understanding on operational coordination of dynamic technology options
Further Planning	This project is at the initial state and the next steps are to proceed with identifying suitable researchers and identify data needed for the kick-off of the project.

Dynamic Power Flow Control	*In progress*
Scope	Dynamic Power Flow Control devices are modular devices suitable for installation on 110 kV, 220 kV, 275 kV and 400 kV circuits that will be installed on an as-required basis in the most beneficial locations on the transmission network. The candidate lines are as follows: • Flagford – Sliabh Bawn – Lanesboro (110 kV) • Sligo – Srananagh – Corderry (110 kV) • Letterkenny – Tievebrack - Binbane (110kV) • Letterkenny – Cathaleen's or Letterkenny – Clogher (110 kV) • Killonan – Knockraha (220kV) • Clashavoon – Knockraha or Cullenagh – Knockraha (220 kV)
Rationale	The energy system is in a transition that leads to a changing load flow pattern. As a result, transmission grids are operated closer to their thermal and dynamic stability limits. Since building new transmission lines to relieve the congested lines is both expensive and challenging from a consenting perspective, the market for alternative technologies is growing. Usually Phase Shift Transformers (PST) are used to perform power flow control. These are devices that allow active power flow to be controlled, thereby reducing power flow on congested lines while diverting power flow to lines with spare capacity. The disadvantages of PSTs are their reactive power consumption and their limited control speed. In addition, they are large and heavy devices requiring extensive civil works infrastructure to be in place at installation sites. Solutions like Dynamic Power Flow Controllers (DPFC) promise to be modular and relatively easy to re-deploy. This way it will be possible to move them around the network to where they have the biggest impact and improve system stability and transfer capacity.
Expected Impact	• The deployment of dynamic power flow control devices will have an important role to play in network congestion management and maximising the existing network capacity • These devices will also assist in minimising the need for network reinforcement projects and mitigating the challenges associated with building new overhead lines or underground cables such as societal acceptance and prolonged outages of key infrastructure
Further Planning	• The Dynamic Power Flow Controllers are currently in procurement by the Transmission Asset Owner in Ireland (ESBN). There will be a period of tender issue, evaluation, and award before procurement can take place. The first install, to act as a trial for full-scale deployment on the gird, following the lead from Shaping Our Electricity Future, is planned at Binbane 110 kV substation in Donegal. • ESBN drafted a procurement specification. In September 2022 they issued the draft to EirGrid and to the market for comment. EirGrid and two potential suppliers responded with comments. ESBN will now finalise the specification and expect to issue it to EirGrid for final review and acceptance in early 2023.

	• In November 2022 ESBN Procurement issued a pre-qualification questionnaire (PQQ) to the market. The deadline for receipt of responses was end of January 2023. Based on the responses ESBN will draw up a short-list of suppliers who will in due course be invited to submit tenders. • The issuing of the PQQ is the first step in the procurement process. The next step will be the issuing of invitations to tender and specifications to the selected invitees. It is expected that the procurement process will take at least twelve months to complete.
Dynamic Line Rating	***In progress***
Scope	• Trial and investigate Dynamic Line Rating (DLR) implementations in Ireland • Trial of 'Direct Measurement' DLR technology • Consideration of the 'Indirect' DLR technology • Studies on the wider roll-out of this flexible network solution
Rationale	DLR installations enable the usage of real-time thermal loading limits which increase transmission capacity of lines safely without high cost burden or extensive outages. The dynamic ratings are determined from the live environmental conditions, while seasonal static ratings assume conservative limits. DLR offers the potential to facilitate the connection of greater volumes of variable renewable generation with less infrastructure upgrades and provides a medium-term solution for congested lines. The technology also offers the capability to forecast line ratings based on weather forecasting.
Expected Impact	• Increase the capability for variable renewable generators to export power onto the grid without the requirement of building/upgrading network infrastructure • Ease congestion problems experienced on the grid as well the future potential to use forecast dynamic line ratings within our processes.
Further Planning	• In Ireland in June 2022 ESBN appointed three companies under a framework contract to supply DLR schemes. • The sensors for the first scheme were installed on the Lisheen - Thurles 110 kV overhead line during an outage in September. • Communications between the line mounted sensors and the supplier's server was established and data collection commenced. • It is anticipated that the scheme will be available for use by Q2 of 2023 however this is dependent on certain enabling works being completed on the overhead line in advance, which is dependent on the availability of a suitable outage. • Further candidate overhead lines for a more extensive roll-out of this technology across the transmission network up to 2030 are being identified.

	• In Northern Ireland SONI will commence a feasibility study to determine the requirements and benefits related to adding dynamic line rating to the Magherakeel - Omagh 110 kV circuit. This circuit was identified in Shaping Our Electricity Future as potentially benefitting from DLR.
Hybrid Technology Enablement	***Completed***
Scope	• Scope work package for trading of Maximum Export Capacity (MEC) • Issue System Operators recommendations to Regulators on proposed changes to Over Install policy • Make a technical assessment of options for trading of MEC behind a single connection point
Rationale	Hybrid Technology presents an opportunity for both System Operators and industry in maximising the use of existing network assets, increasing diversity factors, and improving security of supply. This may help to maximise the use of transmission infrastructure and work towards delivering our 2030 targets and beyond. To unlock the full potential for these developments and optimise generation output and use of transmission infrastructure, we are working with stakeholders to consider mechanisms that would enable an increase in the capacity factor of hybrid connections through the installation of hybrid technology.
Expected Impact	The introduction of hybrid technology to the all-island power system presents opportunities for both market participants and system operators to increase the capacity factor and technical capabilities behind a single connection point, which will aid in increasing renewable energy contribution on the system.
Further Planning	EirGrid has now completed the actions set out under Action 125 of the Irish Government’s Climate Action Plan and reports have been submitted to CRU for consideration. Following engagement with CRU and UR, we will develop next steps and consult with industry stakeholders in 2023.

Now - Champion the emergence of the energy citizen

Public Engagement with Energy Transitions in an Era of Climate Crisis	***In progress***
Scope	• Transition based assessment of actors, roles and agency in energy grid system change • Assess the impact of community benefit funding using comparative analysis of three different case studies • Situate EirGrid’s innovative engagement practice within the national and international context to enhance proficiencies on a cross-organisational level informed by international state-of-the-art case studies
Rationale	EirGrid has a long history of engagement with local communities. Understanding this from the context of transforming the power system for future generations requires some careful consideration. EirGrid’s evolving public engagement promotes a more vibrant engagement strategy seeking to connect people, problems and solutions in a more inclusive manner. As a recognised pillar for transformation understanding how best to leverage public engagement in different forms is crucial. The project entails an impartial analysis of EirGrid’s evolving public engagement, based on a mapping of actors, and a framework to evaluate different engagement processes and programmes. This approach will simultaneously offer guidance and develop suggestions throughout the consultation and engagement lifecycle, seeking to capture learnings from both engagement processes and outcomes.
Expected Impact	• Be able to use community benefit funding collaboratively to work alongside a community in receipt of the funding to investigate the process using an engaged research approach • Gather learnings from international good practices, adopt an international collaborative approach to engagement and apply lessons learned to other emerging projects and schemes
Further Planning	Results to date include the mapping of public roles in energy system change and the synthesis of engagement in electricity grid system change. Researchers are actively engaged with a range of EirGrid Community Forum stakeholders which shall continue and expand. In 2023, the project expects to deliver a discussion paper on EirGrid’s multi-step and deliberative engagement processes.

Now - Lead the island's electricity sector on sustainability

Nature Inclusive Design including Biodiversity Enhancement	*In progress*
Scope	• A summary of this initiative was published in late 2022[13] • In 2019, EirGrid commenced a series of nature restoration projects starting with the East West Interconnector (EWIC) Biodiversity Project, in collaboration with Hitachi Energy. • In 2022, EirGrid established a new requirement for consultants to implement 'Nature Inclusive Design' proposals across capital projects, in collaboration with ESBN, landowners and other parties where appropriate. • Examples include: - Exploring planting shallow-rooted native shrubs over off-road cables. - 'Building back better at passing bays' (where road boundaries are temporarily removed during underground cable construction), by re--instating road boundaries 'better than before' using high diversity locally sourced native species; and - Retrofitting certain overhead line uprate projects with bird diverters.
Rationale	The Irish Government declared a biodiversity emergency in 2019. In 2021, the European Parliament adopted a resolution on the EU Biodiversity Strategy 2030 establishing the policy basis for an EU nature restoration plan. In 2022, the European Commission adopted a proposal for an EU-Wide Nature Restoration Law
Expected Impact	In addition to the benefits for wildlife, enhancing natural habitats will promote nature-based carbon removal and improve the resilience of ecosystems to climate change
Further Planning	• Summary of work to date published January 2023[14] • Next steps include continued rollout of existing initiatives across new projects and integrating marine biodiversity enhancement into offshore cable/substation design. Monitoring of select pilots by EirGrid, ESBN, and/or appointed contractors will be carried out to assess effectiveness of pilots to date.

[13] EirGrid, Nature Inclusive Design Pilots, 2022
[14] EirGrid, EWIC, 2023

Next - Enhance data-driven decision-making leveraging artificial intelligence capability

Real-time Contingency Analysis and Network Optimization Control Centre Tools	***In progress***
Scope	• Develop and validate open-source software tools that will enable Transmission System Operators to capitalise on network flexibility introduced with the use of innovative Power Flow Control (PFC) technology • Provide enhanced situational awareness and an optimised decision support tool in relation to PFC devices
Rationale	One key challenge of the integration of high levels of energy coming from renewable sources is managing grid congestion in a cost-effective and efficient manner. The use of Dynamic Power Flow Control (PFC) technology promises to provide a solution for this. The technology assists in dynamically controlling power flows on the system to alleviate overloads and mitigate congestion. It is anticipated that the co-ordinated control of multiple PFC devices strategically located throughout the power system will maximise use of existing infrastructure, aid in the management of network congestion and contribute to the integration of increased levels of renewable generation in real time. To maximise the benefits offered by this technology, new tools are required to support real time operation and day-ahead operational planning. Such control and scheduling capabilities are not currently available in any Control Room in the world and the open-source outcomes of this project will aim to bridge that gap.
Expected Impact	• Provide significant benefits in terms of controlling power flow on grids, minimising congestion, and deferring investment in new transmission assets • Get the maximum benefit offered by these devices • Enable the control centres to optimise the use of this technology to maximise the amount of renewable energy that can be transported on the grid
Further Planning	The outcomes of this project will support enhanced operation of the Ireland and Northern Ireland Transmission Networks and will develop understanding of how to operate and manage the Transmission System with high levels of dynamic network control devices. The project will apply international class energy R&D carried out through close collaboration with Smart Wire Grid Europe, industry experts and the demonstration of software tools. This project has the potential to improve the resiliency and efficiency of the grid through supporting a reduction in generation constraints, transmission outage management, enhancing reliability and decreasing the costs of connecting renewable and demand customers.

Control Centre Tools Implementation	*In progress*
Scope	• Implement a Look-Ahead Security Assessment Tool (LSAT) to enable Grid Controllers to analyse the stability of the power system in the near future facilitating optimal system operation with higher levels of wind and solar integration • Implement Voltage Trajectory Tool (VTT) to enable Grid Controllers to assess the impact of varying sources of reactive power across the power system to ensure that local voltage management issues are managed • Implement Ramping Margin Tool (RMT) to enable Grid Controllers to accurately schedule and dispatch the Ramping Margin services, and manage changing demand and generation profiles, with increased wind and solar integration
Rationale	A core objective of EirGrid, SONI and the DS3 Programme is facilitating levels of SNSP up to 75% to meet public policy. To increase the levels of instantaneous renewable generation on the system it is necessary to deliver a suite of Control Centre Tools to enhance the stability analysis, voltage control and frequency management capability of the control centre. E.g. voltage management in Ireland and Northern Ireland is becoming more challenging due to the reduction of available reactive power resources and the disperse location of wind farms, combined with increasing installation of HV underground cables. Enhanced voltage control management capability in the control centre is critical to facilitate increased levels of SNSP.
Expected Impact	• Enable operation of the All Island power system with world leading levels of variable renewable generation in a safe and secure manner while minimising the level of constraint and curtailment of wind and solar through LSAT • Determine optimal reactive targets for different types of device, delivering voltage trajectory plans secure against contingency events for a near time horizon through VTT • Enable operation with reduced number of conventional plan on-line and, thus, will facilitate increased levels of SNSP in the All Island system. • Enable grid controllers to accurately schedule and monitor the ramping margin reserve services through RMT, thereby enabling more effective management of changing demand and generation profiles with increased wind and solar integration
Further Planning	• The Look-Ahead Security Assessment Tool went live in the control rooms of Belfast and Dublin in December 2020. • Enhancements to Look Ahead functionality have been developed and tested during 2021 and were deployed to the control rooms in early 2022. • The Voltage Trajectory Tool has been scoped and developed throughout 2021. It was deployed to the IT production environment in Q4 2022. Operational go-live of the tool is expected in Q2 2023.

	• An enduring Ramping Margin Tool went live in the control centres in SONI and EirGrid in October 2021 EirGrid and SONI are developing a Control Centre of the Future Implementation in Q1 2023. This plan will consider the development of control centre capability out to 2030.

Beyond - Prepare for a multi-purpose offshore HVDC grid

READY4DC - Horizon Europe	***In progress***
Scope	• Working group 1: Modelling, simulation framework and data sharing for multi-vendor HVDC interaction studies and large-scale EMT simulation • Working group 2: Legal Framework for the Realization of a Multi-vendor HVDC Network • Working group 3: Multi-vendor Interoperability Process and Demonstration Definition • Working group 4: Framing the future European Energy System
Rationale	Create and engage a community of experts that will assess and give recommendations on the major technical and legal aspects of designing and building an interoperable multi-vendor DC grid. One major objective will be to prepare the ground for the development of the first multi-terminal, multi-vendor HVDC project in Europe.
Expected Impact	Developed white papers will consolidate the perspectives and views of all relevant sectors on the various technical, long-term planning and legal aspects. The results will target both the offshore and onshore use cases, overall, the application of power electronics-driven grids at every voltage level and will set the steppingstone towards a futuristic grid infrastructure with DC grids playing a central role at every voltage level.
Further Planning	We are continuing by supporting working group 4 throughout 2023. The plan is that three white papers will be published during 2023. • Whitepaper 1: How to unlock investments • Whitepaper 2: Long-term view for HVDC technology • Whitepaper 3: Framing the European energy system / role of DC + barriers

Advanced Power Flow Control	***In progress***
Scope	• Investigate established & new HVDC technologies in planning, as well as frameworks on how advanced transmission technologies and energy storage can be considered in evaluating and designing cost-effective solutions for transmission reinforcement, alongside more conventional infrastructure solutions. • Use machine learning methods to screen critical power flow cases out of large datasets to accelerate studies.
Rationale	The project considers the need for advancement in terms of tools, methodologies, and analytics, primarily in evaluating and designing solutions for transmission reinforcement, alongside more conventional infrastructure solutions.
Expected Impact	• Understanding system strength • Identification of limitations of conventional stability analysis tools and guidelines for when EMT analysis is required • Identification of when/where/how much Grid Forming capability is needed in the system
Further Planning	Involvement in the project will continue as the 2023 phase progresses to improve understanding/availability of the capabilities of new technologies, tools, and methods.

Beyond - Understanding pathways to 100% SNSP

NexSys - Mitigation of Extreme Weather Events on High RES Dependent Network	***Initiated***
Scope	The NexSys programme aims to determine how energy systems should evolve to have more renewable electricity towards 2030 and subsequently get to the net zero carbon goal by 2050. To develop understanding of impact and mitigation of extreme weather events on high renewable energy source (RES) dependent network is one of three key targets within the programme, covering the following scope: • Document actual cases of weather-related extreme RES ramping events worldwide. • Examine actual high wind speed shut-down events in Ireland and Northern Ireland, what was forecast, what happened? • Document the power output characteristics of different wind turbine types in response to high wind-speeds, and different PV types in response to cloud cover • Analyse the probability and impact (magnitude and rate of change in power output) of high speed shut-down events on windfarms in Ireland and Northern Ireland • Analyse probability and impact (magnitude and rate of change in

	• power output) of rapid shut-down (and start-up) of PV caused by cloud cover or a solar eclipse in Ireland and Northern Ireland. • Answer the question 'can such events be reasonably forecast?' • Focus on 2030+ levels of RES so significant levels of solar PV (grid scale and roof-top) and large/concentrated off-shore wind farms.
Rationale	The transition to a net Zero carbon energy system is one of the major challenges facing the world and is a crucial required action to mitigate climate change. Energy sources are converted, transported, and delivered to the end users through distinct energy systems with unique physical, commercial, and regulatory characteristics. The energy system encompasses technical, financial, and societal dimensions and this is reflected directly in NexSys.
Expected Impact	• Greater understanding of low RES periods for current & future generation portfolio 2030 timescale • Greater understanding of on interconnection & the portfolio effect for low RES periods in Europe 2050 timescale • Greater understanding of operational strategies for extended low RES periods (2030 to 2050 timescales)
Further Planning	This project is at the initial state and the next steps are to proceed with identifying suitable researchers and identify data needed for the kick-off of the project.
MIN 7	***In progress***
Scope	• Relax the minimum number of conventional units on to allow for having the minimum of all-island units set to seven, with SNSP up to up to 85% (RoCoF constraint of 1 Hz/s and inertia constraint of 20 GWs) to enable more renewable energy onto the All-Island power system • Evaluate security and stability of the future snapshots (2022 and beyond) where operational system constraints related to the minimum number of units are relaxed. • Identify potential insecurities and instabilities when operating with less than eight large units on through voltage & frequency stability and dynamic studies.
Rationale	To enable the efficient and secure operation of the power system, EirGrid and SONI schedule and dispatch units to adhere to their respective Operating Security Standards. These standards ensure that the All-Island transmission system is operated in a secure and reliable manner. The minimum number of conventional units that must be dispatched on the all-island system is currently set to eight. This limits the amount of non-synchronous renewable energy that can be accommodated on the system. The objective is therefore to relax this constraint to enable operation of the system with seven units and the associated higher levels of renewable generation in a safe and secure way. The reduction in synchronous generation on the system leads to reduction in system inertia, reserve and ramping capabilities, system strength, and synchronising torque. Different technical scarcities might

	arise when operating our system with seven units and increased need for the system requirements in frequency, voltage, rotor angle stability and system strength domains. In order to securely operate the system with a minimum of seven convention units this study evaluates in detail and identifies the technical scarcities of the all island system (2022 and beyond), identifies any mitigations and will recommend whether a trial to relax this important Operational System Constraint can commence.
Expected Impact	• The developed tools and automations significantly improve study efficiency and enable us to further explore a vast space of study scenarios, fast but comprehensive identification of issues, and efficient identification of potential mitigations • Information about whether it is prudent to start an operational trial with a reduced number of minimum units, thus enabling higher levels of renewables to be facilitated onto the all-island system, contributing towards the 2030 RES-E targets
Further Planning	• This project is ongoing into 2023 • Innovative tools such as Plexos2LSAT, DPS Extension Tool, Ramping assessment tool that calculates ramping capability, ramping requirement and ramping margin from Plexos schedules were developed as part of this project • Modified approaches are currently being progressed for pre and post contingency RoCoF calculations. • A number of automations have been developed to carry out different modelling changes and efficiently extract useful knowledge from the output results • The developed tools and automations and learning from the study will be informative and re-used in many other studies that explore the impact of the relaxation of our operational system constraints to accommodate more renewable generation to our system
Rate of Change of Frequency Interim Solution	***Completed***
Scope	This trial was carried out in two phases, with Phase I running from June 2020 until October 2020. Phase II has been ongoing since November 2020. Technical studies as part of the RoCoF trial closure analysis started in December 2021 and are continuing to be performed. The current plan is to perform 8760 hourly frequency stability simulations using snapshots over the course of a year to get a better picture of the frequency of potential RoCoF insecurities on the system over the past year. Some key innovations carried out as part of the ±1 Hz/s RoCoF trial closure project are as follows: • Development of PSS dynamic models for some thermal generation units followed by extensive testing both under simulated as well as actual trip events. The developed PSS models were successfully integrated in LSAT in August 2022. • Development of an end-to-end Python automation for extracting zipped system snapshots from LSAT, unzipping them, modifying related elements (e.g., replacing interruptible load BESS models with their WECC 2nd generation counterpart) and performing frequency

	stability simulations. • Upgrading the Python-based binanalyser script by adding filters (e.g., moving average, voltage block and delay) for smoothening of raw frequency traces from TSAT. • Development of a contingency duplication mechanism whereby fault-induced contingencies are duplicated without the actual fault but with all fault-induced equipment disconnections (e.g., data centres) included
Rationale	The DS3 Programme was envisaged for facilitating the implementation of projects to enable higher penetration of non-synchronous resources in the system. Ensuring safe, secure and reliable operation of the all-island power system at high SNSP levels was critical for achieving some of the major goals of the DS3 Programme. Given that previous technical studies conducted by EirGrid and SONI established that ensuring stable system operation at high SNSP levels would be difficult without increasing the (currently applicable) ±0.5 Hz/s threshold of RoCoF relays, undertaking detailed technical studies for successful closure of the ±1 Hz/s RoCoF trial is therefore imperative to successful conclusion of the DS3 Programme. Several RoCoF insecurities have been observed from technical studies performed as part of the ±1 Hz/s RoCoF trial closure. Rapid changes in the frequency trajectory during high positive/negative RoCoF events can lead to oscillations in synchronous generator outputs, in which case the ability of Power System Stabilisers (PSS) to damp out those oscillations is critical. Given that PSSs of some large units were not modelled in LSAT as of March 2022, it was essential to develop corresponding models and test them for simulated disturbances as well as actual trip events before successful integration with LSAT. Development of the Python automation was extremely critical to running the large (8760) number of simulations efficiently and as quickly as possible. Additionally, given that most observed RoCoF insecurities are associated with fault-induced contingencies, it was imperative to interact with relevant stakeholders (other TSOs, universities and research bodies) and develop robust tools in alignment with industry best practices for calculating RoCoF and interpreting resulting insecurities around the fault duration.
Expected Impact	The RoCoF trial and analyses are still ongoing, but some of the sub-tasks completed as part of this exercise have already had a positive impact on system operations. As an example, the PSS dynamic models developed as part of the trial closure have been successfully integrated with LSAT, thereby producing a more realistic picture of the units' responses following the simulation of relevant contingencies. The Python automation developed will be hugely influential in reducing manual intervention in running batch simulations, thereby making the process much more efficient and less time consuming. Once a final position on calculating RoCoF and interpreting corresponding insecurities is mutually agreed upon, it'll align this process with industry best practices and produce a more realistic representation of potential insecurities in the control room.

Further Planning	EirGrid and SONI are already on the right track in relation to implementing studies and projects for facilitating realisation of key governmental RES-E targets, and these recent publications make it even more critical to conclude the RoCoF trial and the DS3 Programme in a timely manner (without compromising on operational security) and progress other projects in the pipeline (e.g., MIN7 trial) under the aegis of Shaping Our Electricity Future. Development of the PSS dynamic models as well as Python automations as part of the RoCoF trial closure study are being reused in other projects as well as in LSAT, thereby increasing the efficiency of future studies. A final position on the RoCoF calculation and insecurity interpretation methodology would significantly contribute to aligning these processes with industry best practices and lead to the production of more reliable (potential) insecurity warnings for the control room.
Modelling and Analytics for Emerging Technologies	***In progress***
Scope	• Investigate the need for improved inverter-based resource (IBR) models & tools to enable planners to accurately simulate and assess power systems with high IBR penetration levels, as well the refining and verifying aggregated DER models • Investigate how this scenario impacts legacy protection schemes is also considered to enable protection engineers to conduct relay setting.
Rationale	The project considers the need for advancement in terms of tools, methodologies, and analytics, primarily in transmission planning and protection, as we transition from legacy transmission into a high IBR system with distributed energy resources (DER).
Expected Impact	• Understanding system strength • Identification of limitations of conventional stability analysis tools and guidelines for when EMT analysis is required • Modelling of IBRs in low short circuit grids • Modelling of emerging technologies (eg Grid Forming controls) • Identification of when/where/how much Grid Forming capability is needed in the system • Improved understanding of the impact of high penetration of IBRs on performance of system protection schemes.
Further Planning	EirGrid and SONI's involvement in the project will continue as the 2023 phase progresses. It is expected that the outcomes of this project will help EirGrid and SONI in the identification, analysis and mitigation of technical challenges associated with operation of the All Island power system with up to 100% SNSP.

EU-SysFlex - Horizon Europe	*Completed*
Scope	• Characterising the technical scarcities in the EU power system for ambitious RES-E scenarios aligned with EU and national renewable targets • Identification of mitigations options to address the identified scarcities as well as financial and economic analysis of the simulated results to assess the value of the system services required • Identify market enhancements required to incentivise investment in the identified system services • The consortium is conducting seven demonstration projects and qualification trials across Ireland, France, Portugal, Estonia, Italy, Germany, and Finland exploring flexibility capability of technology to provide services to grid • Assessing operator protocols and tools required to operator in a high RES-E scenario as well are data management and data exchange aspects
Rationale	The rationale for participating in EU-SysFlex is to enhance our collaboration with other sectoral participants in addressing system wide challenges as well as sharing knowledge to enhance our understanding and ability to solve future challenges. From a technical perspective, participation has funded the technical analysis and studies associated with future operations aspect of 'Shaping our Electricity Future'.
Expected Impact	From an Ireland and Northern Ireland perspective, the results of this work have directly fed into 'Shaping our Electricity Future' and our plans to meet our renewable ambition of 80% renewables and 95% SNSP
Further Planning	• The four-year project has identified the needs of the future power system by charactering the technical scarcities of the future power system with a high share of renewables across three synchronous areas of Ireland and Northern Ireland, Continental Europe and the Nordics • Through financial and economic analysis of the simulated results, the project team has identified associated financial gaps and market enhancements required to incentivise investment in system services • Flexibility for Europe[15] roadmap has been published • Potential mitigations for addressing the major technical challenges identified for Ireland and Northern Ireland are summarised in Technical Assessment of 2030 Study Outcomes report[16]

Fast Frequency Response Interim Solution	*Completed*
Scope	Complete a study to determine sufficiency of the Fast Frequency Response (FFR) service required when operating the transmission system with a minimum of seven sets and 20 GWs system inertia.

[15] EU-SysFlex, Flexibility for Europe Roadmap, 2022
[16] EirGrid and SONI, Technical Assessment of 2030 Study Outcomes, 2021 EirGrid | SONI

Rationale	EirGrid and SONI have procured FFR from diverse service providers since 2018. It is expected that new contracted capability will be procured in Gate 8 and Gate 9 under the current Volume Uncapped commercial arrangements (which are currently scheduled to terminate at the end of April 2024). It was needed to understand whether the All-island power system has enough FFR to operate the system with minimum seven units on and 20 GWs system inertia, following a system disturbance such as generator/load tripping. Hence, a study was initiated to address it.
Expected Impact	• The study was conducted for the year 2022. The sources providing FFR are 526 MW of batteries distributed over the entire island, two interconnectors between Ireland and GB, Demand side units and conventional synchronous generators. The contingencies considered in the study focusing on electromechanical phenomena and active power imbalance following generator and interconnector trips, and system separation of Ireland and Northern Ireland systems. • The main conclusions drawn from the study are: – The system has enough FFR to withstand any power imbalance event occurring in the system. – The only potential vulnerability found is for a system separation event in presence of high South to North flows exceeding 250 MW with Northern Ireland having a particular combination of NI triplet of units on: and only 100 MW of installed batteries in NI. Hence, in such cases, pragmatic preventive actions need to be in place. • In order to ensure system security, operators would have needed to carry out system simulations whenever LSAT identifies one of these potential vulnerabilities as mentioned above. • In order to mitigate the need for these repetitive time-consuming real-time studies, we developed a pictorial presentation of the safe system operating boundary of the NI system. • This boundary helps the control room operator to assess the maximum allowable flow from South to North through the tie-line for a particular system synchronous inertia in NI, without the requirement to perform any simulations up-front. The concept of such a boundary did not exist prior to this analysis and innovation.
Further Planning	Further studies to determine specific FFR requirements are planned in 2023 as part of the review of System Service products and the development of the Future Arrangements for System Services (FASS).

SNSP75	***Completed***
Scope	This trial was carried out over 11 months (concluding in March 2022), during which time 232 hours of system operation with SNSP greater than 70% were logged (with the highest SNSP achieved on 05 February 2022, 14:44 hours). Technical analyses investigated whether operating the all-island power system at SNSP levels greater than 70% (and up to 75%) had any adverse

	impacts on applicable operational security thresholds and standards. For the purposes of the main trial analyses, 5423 system snapshots associated with SNSP levels greater than 70% were extracted for further analyses. Ten timestamps with specific system attributes were finally selected from the snapshots for detailed technical studies in the following domains: frequency, voltage and rotor angle stability. Some key innovations carried out as part of the 75% SNSP trial closure project are as follows: • Sensitivity studies were carried out on the selected timestamps to get some 'preliminary' understanding of the impacts of reducing the number of conventional units online on voltage and angular stability. • With respect to the interruptible load battery models used in the (earlier) 70% SNSP trial closure, these were all replaced by (more conservative) WECC 2nd generation BESS models to get a more realistic picture on the extent to which batteries can provide support in improving frequency stability. Similarly, to produce a more conservative outcome in terms of data centre support, e.g., for frequency stability, their disconnections corresponding to over/under-voltage as well as under-frequency scenarios were disabled. • Python automation scripts were written for extracting relevant snapshots (with SNSP > 70%) from the hundreds of thousands of timestamps (at 1-minute resolution) over the trial period, as well as for onward filtering of snapshots for detailed technical studies
Rationale	The DS3 Programme was envisaged for facilitating the implementation of projects to enable higher penetration of non-synchronous resources in the system. Ensuring safe, secure and reliable operation of the all-island power system at SNSP levels of up to 75% was one of the critical milestones that had to be reached to enable successful completion of the DS3 Programme. Undertaking detailed technical studies for successful closure of the 75% SNSP trial therefore contributed to reaching this critical DS3 Programme milestone. This was also in line with achieving major governmental RES-E ambitions for tackling climate change. Sensitivity studies undertaken as part of the 75% trial closure study offered some preliminary understanding of the impacts of reducing the number of conventional units online (in Ireland and Northern Ireland) on voltage and angular stability. Besides, Python automations that were developed as part of the HIS data analyses phase of the project significantly helped reduce the time spent on filtering relevant snapshots for further studies.
Expected Impact	Thorough analysis of the results obtained from the technical studies established that all insecurities observed pertained to either local (and known) system conditions/settings or pessimistic operational sensitivity scenarios. There were no global/system-wide issues observed for the selected study snapshots, and as such, none of the insecurities were deemed to be a direct consequence of operating the system at SNSP levels greater than 70%. Following internal governance, the SNSP Operational Limit was increased from 70% to 75%. and implemented on 31 March 2022.

	The successful closure of the 75% SNSP trial and the adoption of the operational policy facilitated realisation of a critical DS3 Programme milestone. For the small and relatively less interconnected all-island power system, this was a very significant and world-leading technical achievement. The adoption of the 75% SNSP operational policy directly contributed to a higher proportion of the all-island demand being met by non-synchronous (renewable) resources, and therefore, facilitated realisation of key governmental RES-E ambitions for tackling climate change. Finally, the Python automations developed as part of this project are now being reused for future projects, thereby potentially saving significant time and increasing efficiency.
Further Planning	Successful closure of the 75% SNSP trial and adoption of the corresponding operational policy has paved the way towards commencement of more ambitious projects and technical studies. These projects will significantly help in further decarbonisation of the all-island power system without compromising on operational safety, security and reliability. The Python automations developed as part of this project have already been used for data filtering in the ±1 Hz/s RoCoF trial closure work and have helped in reducing analyses time as well as increasing efficiency.

Low Carbon Inertia Services	***Completed***
Scope	• Investigate the dynamic and steady state security of the All-Island Power System for different scenarios of deployment of Low Carbon Inertia Services (LCIS), for example Synchronous Condensers with/without Flywheels (with STATCOM) • Supports the integration of technologies which can facilitate a reduction in the quantity of carbon intensive conventional generation required on the all-island power system • Develop innovative tools to interface Plexos with LSAT and evaluate the system strength
Rationale	The operation of the power system will evolve in the coming years with the relaxation of minimum number of online units and the introduction of further interconnectors, along with substantial renewables and battery capacity. Contingencies larger than today's worst-case scenarios will emerge while inertia, short circuit level and reactive power capability will reduce. In order to ensure secure and stable operation of the all-island power system with an 85% SNSP in 2026, the needs for LCIS and their placement needs to be identified to provide sufficient kinetic energy (inertia), reactive power support, additional system strength (short circuit contribution) and synchronising and damping torque.
Expected Impact	• Pave the path towards the 2030 goal of 95% SNSP by determining optimum LCIS placement, sizing and procurement • Improve study capabilities significantly by developing new innovative tools and methodologies that allow us to carry out investigations on more realistic/accurate future operation condition of the power system

	• Reveal and mitigate bottlenecks, ensuring the continuity of a secure, stable, and reliable power system with ever increasing levels of RES-E
Further Planning	The LCIS study is a pioneer of its kind. It investigated different aspects of power system steady state and dynamic security for the procurement of LCIS power system which is very different to today's network and it set the standard for future studies. Innovative tools such as Plexos2LSAT (a Python based tool which links Plexos to SMTNET and LSAT), DPS Extension (a set of Python scripts which sit between SMTNET and LSAT and enable injecting future network developments to a snapshot of today's network), System Strength Evaluation Tool (which is a Python tool developed for PSSE that efficiently crawls through the input network and calculates short circuit level for N, N-1 and N-1-1 conditions), dynamic models (which represent equipment that currently don't exist in the network), LCIS efficiency metric (which assesses the benefit of LCIS in tackling ROCOF issues over a set of various contingencies) and allocation algorithm (which gradually deploys LCIS while considering the locational sterilization of the network with regard to further LCIS deployment) and also the methodologies that bring these together were developed as part of this project. None of these existed previously and required substantial effort to research and develop. Many of these are and will be reused in current and future projects. Particularly the learnings and developed tools and dynamic models are going to play an important role in Phase 2 LCIS. The final results facilitated the delivery of the first LCIS consultation and recommendation papers, providing signals for procurement of LCIS. Workshops to stakeholders was delivered to support the LCIS consultation. A SEMC decision[17] on the TSOs' recommendation paper was made in January 2023. This allows the next stage of the LCIS procurement process (a consultation on the contractual arrangements) to proceed.
Weak Grid Analysis	***Completed***
Scope	• Use EPRI's Grid Strength Assessment Tool (GSAT) to carry out a case study on the Irish power system, across several scenarios, for weak grid issues • Investigate the capability of newly developed inverter models to assess dynamic stability of Irish network compared to existing state of the art root mean square (RMS) dynamic models
Rationale	To reach our objectives of 80% RES-E in 2030 and net zero carbon emissions in 2050, it is inevitable to integrate renewable energy sources in remote areas of the grid and retire most of conventional power plants. This will have a negative effect on the system strength both due to limited available short circuit current and absence of system inertia. As a result, the system planners and operators face a series of new technical challenges related to the operation of a power system consisting primarily of inverter-based resources. To address these challenges, it is necessary to use robust models and tools that help

[17] SEM Committee, SEM-23-002 Procurement of Low Carbon Inertia Services Decision Paper, 2023

	identifying potential stability risks in operating systems with low system strength.
Expected Impact	• The project outcomes provide the ability to quickly assess areas on the all-island grid where inverter-based resources (IBRs) are likely to experience stability issues due to the weak grid conditions. The GSAT toolset can efficiently identify risk of instabilities at high SNSP levels. • Improved computation effort in carrying out studies in weak grid scenarios. • More accurate system planning and interconnection studies.
Further Planning	• This project has provided valuable insights into the limitations of state-of-the art dynamic models (eg REGC_A) and illustrated the capabilities of the new REGC_C model to predict converter instabilities in weak grid conditions. This new model can bridge the gap between traditional positive sequence "phasor domain" simulations (computationally efficient) and detailed EMT simulations (computationally intensive). • Next steps are aimed to (i) better understand and parametrise REGC_C (and make it available for DSATools), (ii) develop practical guidelines to identify scenarios that need to be assessed with REGC_C and those scenarios that require full EMT analysis and (iii) develop a roadmap for implementing EMT modelling & analysis capabilities in EirGrid and SONI.

Beyond - Plan for a net zero carbon, customer focused, export capable power system

HyLIGHT	***In progress***
Scope	The HyLIGHT programme looks at the future outlook for hydrogen in Ireland under five work packages. The programme also addresses a roadmap for hydrogen to determine a plan for the hydrogen industry in Ireland. WP1 – Hydrogen Production • Techno Economic Analysis & Optimisation • Identification of New Economic Opportunities for H2 Production WP2 – Hydrogen Storage and Delivery • TWh Hydrogen Storage • The evolution of the Gas Grid / Interconnection / tankers / on site storage WP3 – Hydrogen Demand • Large Industry Heat & Power Users • Hydrogen use in gas turbines

	• Outlook for E-fuels and H2-enriched Biofuels • Development of Hydrogen Markets in Ireland WP4 – Hydrogen in the Irish Energy System • Energy System Modelling WP5 – Hydrogen Policies, Social and Economic Aspects • EU & Ireland & UK hydrogen policy & GHG emission reduction • Determine the policy environment necessary to enable decarbonisation of the Irish energy system • Public perception of hydrogen • Assess socio & economic costs and benefits of large-scale hydrogen roll out
Rationale	The overall aim of HyLIGHT is to provide the knowledge, data and the necessary tools to guide the cost-effective decarbonisation and roadmaps for sustainable large-scale implementation of hydrogen technologies in Ireland to enable sector integration for a zero-carbon, secure, resilient energy system. HyLIGHT will achieve its aim by collaborating with the leading national and international companies, universities and stakeholders working to facilitate the delivery of hydrogen to all energy sectors; heat, transport and electricity; but also to where it is needed in industry, in a safe and cost effective manner for energy consumers and industry. Over its 3-year timeline, HyLIGHT has four objectives Vision, Roadmap, Plan, Partnership. The first three each contribute a project milestone. The fourth facilitates collaboration in optional investment opportunities, facilitated by the network and knowledge gained that may build into independent projects outside this project.
Expected Impact	• Roadmap for the hydrogen industry in Ireland • Report on electrolyser project at Galway Port for green electricity production. • Report on onshore hydrogen storage methods • Reports on the socioeconomic effects, techno-economic and new economic opportunities of large-scale hydrogen roll out and public perception of hydrogen. • Report on the development of the hydrogen market in Ireland • Report on hydrogen policy in Ireland and the UK in addition to reducing carbon dioxide emissions. • Report for e-fuels and hydrogen enriched biogas. • Report on modelling hydrogen integration onto the All-Island system. • Report on using hydrogen in current gas turbines.
Further Planning	Export of hydrogen should be discussed if possible. Learnings will be reviewed and assessed for applicability for Northern Ireland.

Impact of electrification on the electricity sector carbon emissions	*Initiated*
Scope	• Currently focused on Ireland only as only Ireland has definitive carbon emission targets. These targets are not available yet for Northern Ireland. • Look at historic, current, and future out to 2030 • Assess both the buildings (heating) and transport electrification
Rationale	Irish Government targets to decarbonise some sectors. This involves an increased level of electrification of these sectors. This study aims to understand the impact this will have on the electricity systems carbon emissions.
Expected Impact	• An informed position regarding the impact of electrification on the country's carbon emissions as well as the electricity sector in isolation: • Gain an understanding of the emissions avoided in each sector through electrification (note not all target reduction would come from electrification) • Estimate the increase in emissions from the Electricity sector as a result of this electrification in various different scenarios. • Gain an understanding of the accountability for emissions across sectors (e.g. electricity emissions to charge EV) • Assess the opportunities for demand flexibility in the electrification of these sectors
Further Planning	This project is just being initiated; therefore, the next steps are to move to more detailed planning stage of the project.

Emissions from Dispatch Balancing	*Initiated*
Scope	• To develop the modelling of carbon emissions in the Dispatch Balancing Plexos model. • Liaise with 'Strategy and Sustainability' team on what figures and timetable are most useful for the Annual Report.
Rationale	We are committed to Science-Based Targets to measure and to reduce our GHG emissions. Emissions from Dispatch Balancing services make up the vast majority of these emissions. Better understanding and modelling of these emissions will help us to achieve our target of 35% reduction by 2030, over 2019 levels.
Expected Impact	• Methodology for extracting the best estimate of these emissions. • Output from 2021-22 backcast model, and analysis of what particular constraints are causing most emissions.
Further Planning	This project is just being initiated; therefore, the next steps are to move to more detailed planning stage of the project.

NexSys – Impact of Green Hydrogen Integration onto the Power System	*Initiated*
Scope	The NexSys programme aims to determine how energy systems should evolve to have more renewable electricity towards 2030 and subsequently get to the net zero carbon goal by 2050. • To develop understanding of impact of the integration of Green Hydrogen onto the Power System is one of three key targets within the programme, covering the following scope: • Modelling and techno-economic analysis for the all-island power system for a multi energy vector system including electricity and gas systems • Identify optimal location, planning and scheduling of electrolysers operation under dynamic conditions in all island power system • Investigate the technical capability of green hydrogen system for providing system services and system operation • Investigate what happens when there is low RES, e.g. for producing hydrogen, for availability of hydrogen for power generation • Investigate way of scheduling and dispatching electrolysers i.e. self-dispatch • Evaluate the effect on the electricity market for green hydrogen integration considering the offshore wind potential of Ireland. • Investigate the possibility to provide system services
Rationale	The transition to a net Zero carbon energy system is one of the major challenges facing the world and is a crucial required action to mitigate climate change. Energy sources are converted, transported, and delivered to the end users through distinct energy systems with unique physical, commercial, and regulatory characteristics. The energy system encompasses technical, financial, and societal dimensions and this is reflected directly in NexSys.
Expected Impact	• Greater understanding of optimum location, scheduling and dispatch of electrolysers considering all-island power system and gas network • Greater understanding of impact of large scale hydrogen production from offshore wind on the SEM • Greater understanding of benefits and challenges of using hydrogen for power generation in Ireland
Further Planning	This project is at the initial state and the next steps are to proceed with identifying suitable researchers and identify data needed for the kick-off of the project.

Annex 2 - Consultation Response

Introduction and Purpose

On the 20th of February 2023, EirGrid and SONI published the Annual Innovation Report for consultation[18,19].

The consultation enabled EirGrid and SONI to capture feedback from stakeholders on the planned next steps for ongoing projects, as well as understanding the level of support for the future innovation projects, and any suggestions as to how they could be enhanced.

Within this annex, EirGrid and SONI summarise the responses and the proposed actions to best deliver on our stakeholders' recommendations.

Responses

This consultation utilised the new consultation portal, and for transparency, the full submissions are available for viewing on the respective portals[18,19]. There was a total of four responses to the consultation, three through the EirGrid portal, one through the SONI portal, zero submissions to both portals, and zero sent directly to the team via email. One of the respondents did not permit the sharing of their name. However, the other three respondents are listed below:

- Wind Energy Ireland,
- EDF Renewables, and
- Northern Ireland Electricity Networks

EirGrid and SONI would like to thank all contributors for their time and consideration in reviewing the report and providing carefully considered answers to the questions asked.

Completed & Ongoing Innovation Projects

Overall

Responses

Overall, there was support for the projects shared in Section 4 of the report (Innovation in 2022) and expanded on in Annex 1. Agreement was indicated with the next steps proposed. Many respondents also suggested and offered the opportunity for further discussions and collaborations.

In addition to being in broad agreement, some respondents raised valuable points and concerns regarding Completed and Ongoing Innovation Projects. These are discussed below, arranged by project.

Conclusions / Actions

This aligns closely with EirGrid and SONI's view that innovation is critical to deliver on climate ambition targets in Ireland and Northern Ireland respectively and as outlined in our Innovation and Research Strategy.

[18] EirGrid, Draft: EirGrid 2022 Annual Innovation Report, 2022
[19] SONI, Draft: SONI 2022 Annual Innovation Report, 2023

Onshore & Offshore RES Projects

Responses

Some respondents were concerned with the document's apparent focus on offshore wind. They stress the importance of onshore wind and suggest EirGrid & SONI's ability to facilitate such projects needs to be reflected in the projects. Furthermore, these respondents emphasised that the *Grow EirGrid TSO capabilities for developing and operating the new offshore grid* programme is important enough to be included within the *NOW*-timeframe.

Conclusions / Actions

We acknowledge that offshore wind is a necessary key focus area for EirGrid and SONI due to Ireland's Climate Action Plan ambitions for 5 GW offshore wind by 2030 as well as Northern Ireland's Energy Strategy targets for 1 GW offshore wind. Offshore wind presents a significant number of new challenges, and thus requires particular focus. In addition, the inclusion of Offshore wind in the innovation report also accounts for EirGrid's expanded role in terms of developing, maintaining, operating, and owning transmission assets for the Offshore grid. We will, however, simultaneously continue to support the roll-out of onshore wind. Opportunities for research and innovation continue to exist within the onshore wind space, but the technology is now largely considered mature.

EirGrid and SONI will consider the recommendation of moving the *Grow EirGrid TSO capabilities for developing and operating the new offshore grid* programme to the *NOW*-timeframe during the strategy refresh.

While we acknowledge that Grow EirGrid TSO capabilities for developing and operating the new offshore grid programme is not an innovative project in its own right, we are of the opinion that is it through our involvement in innovative projects in the offshore space that we will be growing our capabilities.

Grid Reinforcements

Responses

While grid reinforcement measures were generally welcomed, some respondents expressed their opinion that projects should consider expanding the means of accomplishing such reinforcements. For instance, research into underground networks is suggested.

Conclusions / Actions

We thank the respondents for the suggestions regarding underground cable networks and other reinforcement methods and projects. In line with EirGrid's Grid Development Strategy[20] we will consider all practical technology options when assessing potential solution options for grid reinforcement. Furthermore, as per SONI's Strategy 2020-25[21] we will make sure that grid infrastructure is prepared for the future by optimising existing assets, and by developing new infrastructure.

Hybrid Grid Connections

Responses

Some respondents offered the point that if ORESS Phase 1 struggles to deliver on the expected supply, Phase 2 will need the usage of hybrid connections to achieve the 2030 5 GW target. Therefore, to utilise hybrid connections (sharing MEC) progress must be fast tracked as the current approach will not deliver the facility on time to maximise the benefits. Respondents believe that the removal of the barriers to dynamic sharing of MEC (hybrid connections) may need to be delivered in advance of the Phase 2 auctions

[20] EirGrid, Grid Development Strategy, 2017
[21] SONI, Strategy 2020-25, 2019

in 2024. They stress that current approach to using hybrid interconnections is not sufficient. More hurdles need to be removed and the process facilitated before the start of phase 2 of ORESS in 2024.

Conclusions / Actions

EirGrid and SONI thank the respondents for their feedback. Currently we are not considering offshore wind-thermal hybrid grid connections within our scope. In the recent Department of the Environment, Climate and Communications (DECC) Phase 2 Policy Statement[22], the Irish government has committed to developing policy to enable hybrid grid connections, comprising a single connection point for both onshore thermal generation plants and offshore wind farms to the onshore transmission system. Until this policy is in place, EirGrid are not in a position to engage on such connections. We will, however, use the respondent suggestions to inform further research and considerations within the technology.

MIN7

Responses

As before, respondents broadly supported this project. However, there were instances where concerns were raised regarding the next steps in MIN7, and to review what is required as we advance through the implementation of all the other innovation projects.

Furthermore, there was a request for clarity regarding overlap between MIN7 and the current study into Low Carbon Inertia Services.

Conclusions / Actions

We thank the respondents for this feedback regarding MIN7. It is the intention of EirGrid and SONI to proceed with the MIN7 trial this year. This trial is considering a reduction in the minimum number of large conventional generators on the power system.

We would like to clarify that this MIN7 trial is not linked to our Low Carbon Inertia Services (LCIS) procurement process. The latter is aimed at delivering LCIS in 2026, with the potential for earlier delivery.

Hydrogen

Overall

Responses

Overall, the respondents were supporting that hydrogen should be seen as a focus area of EirGrid and SONI. They confirm that hydrogen plays a vital role in the decarbonisation of the economy and that EirGrid and SONI's role is facilitating the integration of projects as well as removing system and market barriers. The respondents agree that further research on the role for hydrogen in the power system as well as its impact on the infrastructure is required and needs to be assessed in an integrated way, taking account of the overarching policy objectives for the future All-Island energy system.

To complement the considered scope of further research, the following guiding questions were proposed by the respondents:

[22] Department of the Environment, Climate and Communications, Accelerating Ireland's Offshore Energy Programme, 2023

- What does the transmission system for net zero look like in 2050 where the primary energy is variable renewable, there are no fossil fuels, the geographical distribution of the power generation evolves as offshore wind ramps up and the electricity demand is 90 TWh annually?
- Given the serious consequences and costs of power cuts to an electrified net-zero economy, how can resilience of the power system be increased?
- What is the optimal combination of renewable capacity, electrolyser capacity, dispatchable generation capacity and seasonal storage capacity in secure, resilient, net zero energy system?
- What is the optimal balance of grid connected and non-grid connected electrolysers in net zero energy system?
- Based on 2050 requirements, what interim 'no regret' milestones in development of the transmission system should be achieved by 2040?
- What capacity of renewables, zero carbon dispatchable generation and seasonal storage is required to achieve secure, resilient, net zero electricity system by 2040?
- In light of 2050 and 2040 scenarios what are the 'no regret' for 2030 to ensure net zero electricity and net zero energy ambitions are delivered?

Conclusions / Actions

EirGrid and SONI are pleased that the respondents consider the topic of hydrogen to be of the same importance and will continue research in this area. All recommendations will be taken into account in the further consideration of the research area and will be fed back to the teams working on the respective projects for their consideration and potential implementation.

In this context, it should be noted that some of the questions listed above are already the subject of the Tomorrow's Energy Scenario (TES) studies. Further information regarding TES will be shared for public consultation in the summer of 2023. Furthermore, the impact on the transmission system will be assessed by subsequent analysis through the Tomorrow's Energy Scenarios Needs Assessment (TESNA).

Reflection on Proposed Actions

Responses

In their feedback, some respondents were specific about the areas of research outlined in chapter 5.1 under the section "Proposed Actions". There were two responses to the action "Impact of Power to Hydrogen on the All-Island power system" and one response each to "Impact on Grid Planning" and "Impact on Market". In addition, further complementary actions were proposed.

With regard to "Impact of Power to Hydrogen on the All-Island power system", there is agreement on the importance of hydrogen as an enabler for storage of electricity oversupply and for providing flexible system services, which will provide additional revenue streams to plant operators. EirGrid and SONI are encouraged to pay particular attention to grid conditions and Grid Code compliance considerations. It is also suggested to focus more on system services and how they can be provided.

On "Impact on Grid Planning" the challenges of grid planning and the necessary modelling were acknowledged and the role of hydrogen was also emphasised.

In "Impact on Market", the importance of the competitiveness of hydrogen was highlighted, which can be significantly enhanced in combination with offshore wind power. Furthermore, it is confirmed that the time frame of development of both the existing electricity market and a new hydrogen market must be analysed and predicted to understand when and how the technology will begin to emerge at scale.

Additional proposed actions and recommendations include:

- Assessment of the potential of hybrid connections[23] in the immediate future in order to optimise the use of existing infrastructure to ensure value for the Irish electricity consumer (also consider existing, out-of-support windfarms to produce renewable hydrogen)
- Focussing on facilitating projects and removing system and market barriers instead of investigating on optimal locations for electrolysers in the "NexSys – Impact of Green Hydrogen Integration onto the Power System" project

Conclusions / Actions

EirGrid and SONI will follow up on their proposed actions, as the consultation shows great support. Doing so, all recommendations will be taken into consideration as part of our project planning for 2023. This includes the consideration of grid conditions and grid code compliance considerations as well as investigations on system services and how they can be provided. Hybrid connections involving electrolysers are not currently a focus of EirGrid and SONI's ongoing work on hybrid connections but will be considered in the future. Furthermore, we will consider broadening the focus of future projects to include the facilitation of projects and removal of system and market barriers.

Flexible Network Strategy

Overall

Responses

Respondents broadly supported the development of a Flexible Network Strategy. This strengthens claims that pursuing such technologies will provide a means of maximising the utilisation of existing assets, and therefore network connection. The respondents welcome further study within related areas. Emphasis is placed on grid connection, in the form of the proposed hybrid grid connections, as well as the targeted addressing of transmission capacity within the context of facilitating new offshore wind projects. Multiple respondents mention the importance of addressing policy and ensuring regulatory barriers are addressed.

To complement the considered scope of further research, the following points are raised:

- Further study on how flexible networks can be implemented in regions of operational wind energy projects with existing Associated Transmission Reinforcements (ATRs) to ensure optimal use of renewable generation and minimise constraint levels.
- Consider policy:
    - Permanent Non-Firm Access and policy to avoid transformer and network upgrades.
    - Contra-flow connection policy to increase capacity and facilitates long-duration storage.
- Engage with industry on more complex international tools and solutions to allow for flexible grid connections such as dynamic Maximum Import Capacity.
- Include the use of composite pole sets to make it more feasible to carry out voltage uprating along existing corridors.
- A review of international good practice on, and novel use of, overhead line and underground cable circuit ratings to ensure the utilisation of existing circuits is maximised ensuring network constraint minimisation.

[23] Generation and electrolysers on the same connection point.

- Improvement of network related locational signals for new generation, demand, and storage to allow these developments to contribute to maximising utilisation of the existing network, minimise new network build, and mitigate or avoid constraint.

Hybrid Grid Connections within the scope of Flexible Network Strategy

As mentioned above, some consultation responses considered hybrid grid connections within the context of Flexible Network Strategy. Despite such proposals, the current scope of this project does not explicitly include the technology. The accommodation of such connections depends largely on changes in contractual and grid code and trading and settlement code, as opposed to network-related changes or new technologies.

The respondent in question recommended the following as further research actions:

- Consult with stakeholders on offshore wind-thermal hybrid connections, keeping emphasis on meeting national target policies.
- Ensure that hybrid technology grid connections are facilitated, and existing barriers removed by considering CAP EL/23/14 (CRU, EirGrid and ESB Networks), expanded on below.

Conclusions / Actions

EirGrid and SONI are pleased that the respondents consider the topic of Flexible Network Strategy to be of the same importance and will continue research in this area. All recommendations will be considered in the further consideration of the research area and will be fed back to the teams working on the respective projects for their consideration and potential implementation.

EirGrid and SONI are of the opinion that, at present, hybrid grid connections are distinct, and lie outside the scope of Flexible Network Strategy as presented here. We will consider the possibility of incorporating these technologies within the Flexible Network Strategy going forward.

Reflection on Proposed Actions

Responses

There were no notable exact responses to the *Context* section in chapter 5.2. The proposed order of trials to investigate Dynamic Line Rating and Dynamic Power Flow Controller were not critiqued in detail. When addressing the *Need* section, the overall need for these technologies was not disputed and respondents were in general agreements as to the importance of the required outcomes.

Considering the proposed technologies, respondents recommend the following steps:

- Integration of DLR and DPFC into IT systems that support asset management, and that are used to operate the power system.
- Continued analysis related to co-optimisation of DLR and DPFC when used in combination with other flexible network devices.

Regarding the *Proposed Actions* section there was, again, a general acceptance as to the existing strategy. Additional points raised by respondents are as follows:

- Using the Flexible Network Strategy to address the lack of transmission capacity required to meet 2030 renewable capacities.
- Investigating and addressing relevant policy and regulatory conditions, as above.

- Continued emphasis on hybrid connections within the scope of Flexible Network Strategy (discussed above).

Conclusions / Actions

Ultimately, there is general support for Flexible Network Strategy, with respondents largely suggesting additional points rather than critiquing those presented in the document. Therefore, EirGrid and SONI will follow up on the three stated proposed actions. Doing so, all recommendations will be considered in the future planning process.

Innovation Trials Sandbox

Overall

Responses

Of the four respondents, three expressed support for Innovation Trials Sandbox schemes, while the fourth did not comment. The necessary removal of the significant requirements placed on such technologies from Grid Code, connection policies etc. was stressed.

Conclusions / Actions

EirGrid and SONI are pleased that the respondents are broadly in support of Innovation Trials Sandbox and will continue developments in this area. The Innovation Trials Sandbox is still in the inception phase and there is plenty more work required to establish a pathway forward. The concept must be explored and discussed with Regulatory Authorities. We also intend to engage with industry to help shape the direction of the proposal and we look forward to further discussions.

Reflection on Proposed Actions

To complement the considered scope of further research, the following points are raised as considerations as we proceed with the development of Innovation Trials Sandbox procedures:

Responses

- Requires removal of the significant requirements placed on such technologies from Grid Code, connection policies etc.
- The removal of barriers to novel technologies (Grid Code and connection agreement requirements) needs to be performed in advance to technologies being deployed.
- Current rules suggest that such a pilot would require a wind farm to be fully compliant with latest Grid Code.

Conclusions / Actions

We thank the respondents for supporting the concept of Innovation Trials Sandbox. As noted previously, the Sandbox is still a concept that needs to be explored with the Regulatory Authorities. We will consider the respondents suggestions regarding the requirements that may be relaxed as we engage with the Regulatory Authorities in developing and planning the Sandbox. EirGrid and SONI agree with respondent feedback that future innovation projects should be identified by EirGrid and SONI to help facilitate the delivery of new technologies in advance of the deployment of the technologies, and the Innovation Trials Sandbox presents a means towards this.

Proposed Sandbox Projects

Responses

As requested, some respondents provided specific projects they believed were appropriate for an Innovation Regulation Sandbox. These are as follows:

- Co-location of electrolyser, hydrogen storage and fuel cell at wind farm, with export of power from fuel cell when there is no wind.
- Demonstrate at small scale what a future hybrid connection of renewables and zero carbon dispatchable generation providing 24/7 green electricity could look like.
- Deployment of wave energy technologies to grid connected sites.
- Request projects/plans on demand side strategy and TSO/DSO whole system innovation workstreams.

Conclusions / Actions

Strong insights and some guidance were provided regarding industry trends which we will take onboard for consideration and for discussion with our subject matter experts within the business. Suggested projects will be considered further by both EirGrid and SONI and then shared with the Regulatory Authorities as examples of projects that could benefit from an Innovation Trials Sandbox, where appropriate.

Other Feedback

Responses

This section outlines further points raised by respondents that fall outside of the categories associated with sections from the original report. These suggestions are as below:

- Greater clarity on project partners and their roles within each project may assist stakeholders in appreciating the impact that such projects may have on delivering longer term net zero carbon commitments.
- Provide more information on how all innovation projects will contribute to achieve the longer-term net zero carbon commitments.
- An overview of how the projects support the Net-Zero goals.
- Projects, technologies and solutions must be tested and proven within a Northern Irish context.

Conclusions / Actions

We appreciate these additional points as provided by the respondents. Suggestions will be considered in planning our future projects. We will also engage with all relevant subject matter experts across EirGrid and SONI to encourage collaboration, and knowledge sharing and to ensure there is communication and understanding of the context and scope of the various projects. EirGrid and SONI will consider adding additional details as requested above, while also clarifying points related to project partners and stakeholders.

Conclusions

It is EirGrid and SONI's view that only very minor changes to the initial report were required on the basis of the consultation responses. Feedback will be utilised by teams across EirGrid and SONI to help shape the future of the innovative programmes in question. For the strategies proposed to be developed, feedback will be incorporated into the business plans as part of the submission to the Regulatory Authorities. Publication of the outcome of these strategies, and engagement with key stakeholders through their development will provide transparency.