Electricity System Operator

Innovation Strategy

2021/22

nationalgridESO

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Introduction

As Great Britain's Electricity System Operator (ESO) we are at the heart of the nation's energy system. We make sure that the electricity network operates safely and efficiently around the clock, so that homes, businesses and industry always have the power they need.

We're also helping to tackle one of the biggest challenges facing society: how to create a sustainable, low-carbon electricity system for the future that will help the UK meet its net-zero commitments. Innovation plays a vital role in this effort, which is why we're working with partners from the energy industry and beyond to harness new technologies, markets and ways of working to support the energy transition.

This refresh of our ESO Innovation Strategy sets out our innovation priorities for the first year of our RIIO-2 regulatory period.

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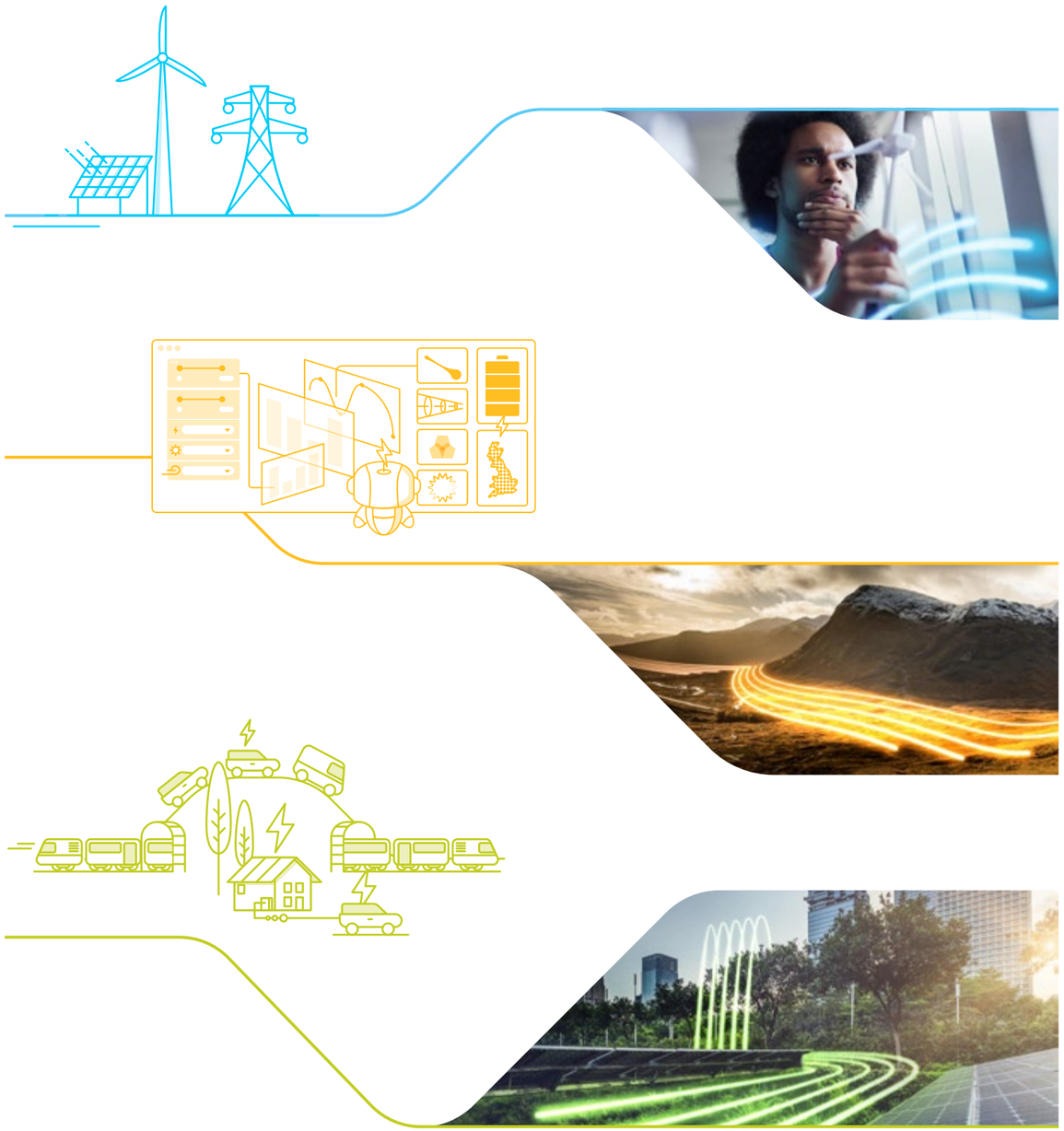

Foreword

I am delighted to introduce the 2021/22 ESO Innovation Strategy.

Carolina Tortora
Head of Innovation Strategy

Looking back at a year like no other

As we enter the first year of our new regulatory period, we are naturally filled with excitement about what comes ahead. However, we must take a breath and look back at a year that none of us will ever forget – a very difficult year, not just for the electricity system, but for all of us. When we published last year's Innovation Strategy, we had just entered the first national lockdown. A year later, we have what seems like an end in sight, with a roadmap to lifting restrictions and the rolling out of vaccinations globally. I would like to take this opportunity to give a HUGE thanks to all of the key workers, both in ESO and across the industry, that have gone above and beyond the call of duty to keep the lights on for Great Britain (GB). I am immensely proud of how we have dealt with adversity this year.

Beyond our personal lives, the impact of COVID-19 on the electricity system has been stark. Exceptionally low levels of demand (at times, 20% below expected levels) have brought on system conditions that we did not expect to see for several more years. Whilst it has been challenging, we have seen a fantastic acceleration in decarbonisation. 2020 was the greenest year on record for Britain's electricity system, with average carbon intensity reaching a new low of 181 gCO2/kWh. May 2020 saw both the greenest month on record (average carbon intensity 143 gCO2/kWh) and the lowest carbon intensity ever seen on the system – 46 gCO2/kWh on May 24. Our recent Operability Strategy report includes a fascinating case study of a day during this period – the conditions we faced and the actions we needed to take.

The resulting operability issues have given us a taste of what the future will look like, and we have had to innovate more quickly than ever before. For example, to help manage frequency during periods of extremely low demand, we rapidly created a new temporary downward flexibility service called ODFM (Optional Downward Flexibility Management).

It goes without saying that innovation is needed now more than ever, to make sure that we manage the safe transition to zero-carbon operation at the lowest possible cost to consumers, now and in the future.

Highlights of the year

There are many highlights from this year, but to name a few:

- We embraced digital and virtual ways of working, not just to run projects, but to run workshops, engage with stakeholders, and we even held our first 100% virtual conference – the Energy Networks Innovation Conference, held in December 2020.
- We worked closely with our Distribution Network Operator (DNO) colleagues to find market solutions to whole system operability issues: real-world trials started in both our Power Potential and Distributed Restart projects with UK Power Networks (UKPN) and SP Energy Networks (SPEN) respectively; we worked with Western Power Distribution (WPD) to explore optimal design of Active Network Management; and we trialled coordinated procurement of flexibility services with WPD in Centrica's Local Energy Market.
- We started to look more seriously at novel ways to manage rising constraint costs: in 4D Heat we explored the use of electric heat to absorb excess wind in Scotland with Scottish and Southern Electricity Networks (SSEN), and we worked with Form Energy to assess the potential of long-term energy storage solutions to solve transmission constraints. Expect much more work on this topic in the coming year.
- We took great strides in progressing our journey towards our digital transformation. Control REACT is mapping and quantifying the impacts of uncertainty as it permeates through our Control Room systems; we have worked with the University of Melbourne to develop advanced models for system planning under uncertainty. Have a look at our Digitalisation Strategy and Action Plan for more information.

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Looking ahead to RIIO-2

April 2021 sees us enter our new regulatory period, RIIO-2. This price control will bring us to 2025, the year when we have committed to be able to operate a zero-carbon electricity system. This is an ambitious commitment, especially following a 2020 which gave us an early taste of some of the operability challenges we expect to face. It is crucial that we capitalise on these learning experiences, and forge ahead with the right type and level of innovation that we know is required.

Ofgem recognises the scale of the challenge to be faced by ourselves and the broader industry – they have shown this by raising our Network Innovation Allowance to £23m for the RIIO-2 period, with an option to further increase this after 2 years. We welcome this recognition and have been spending the last few months getting ready to meet this challenge.

It is not just the fact that we are about to enter RIIO-2 that makes this moment feel like a starting point for the next stage to net-zero. The publication of the Government's White Paper and the Prime Minister's Ten Point Plan has given the industry its north star – an overarching strategy that aims to transform the energy system, that supports green recovery and creates a fair deal for consumers.

Ultimately, we aim to be an enabler of innovation across the whole energy system. While we have a unique position at the centre of the electricity system, we realise that it will be the innovators outside our organisation who will lead the effort to solve the toughest problems we face as an industry. This is why our focus on open innovation will increase this year. We will soon be launching our first Open Innovation call, to focus on our top innovation priorities. Make sure you sign up to our mailing list to be informed when this launch happens.

This document is our 'call to arms' across all sectors. We have worked closely with stakeholders to identify our collective priorities for innovation. We have agreed that our top four priorities for this year are:

1. **Digital Transformation**
2. **Future Markets**
3. **Constraint Management**
4. **Whole Energy Systems**

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Looking ahead: the drivers of change

The evolution of the energy system continues at pace, driven by the four macro trends of Decarbonisation, Decentralisation, Digitalisation and Democratisation.

Achieving a net-zero economy by 2050 is ultimately what is driving the energy system transition.

The 2020 Future Energy Scenarios (FES) shows that, in all net-zero scenarios, net emissions from the power sector are negative by 2033. The implications of this are huge – at least 40GW of new low-carbon capacity has to connect in the next 10 years. This largely non-synchronous capacity brings with it a host of operability issues for the power system – the resulting drop in system inertia means we must procure stability from elsewhere, and our Stability Pathfinders have been exploring how to do this. Markets are also seeing a huge impact, with negative wholesale power prices occurring during times of high renewable output. And power is just the first step – decarbonising the heat and transport sectors is going to require a complete revolution in technology, markets and consumer behaviour. The knock-on impact on the power system is going to be huge.

Did you know: Annual UK electricity generation has fallen by 13.8% since 2000 from 377 TWh to 324.8 TWh. As other sectors decarbonise and electrify this trend is expected to reverse, with BEIS analysis showing electricity demand could double between now and 2050.

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Looking ahead: the drivers of change

A huge amount of the system transition will be driven from the distribution network.

Up to 42% of GB generation capacity will be decentralised by 2050 – the number of individual units this represents will be vast. We will also see a transformation in how energy is consumed, or used, as we see large swathes of the heat and transport sector electrified, and consumers becoming much more actively engaged with the system.

We are already seeing an emergence of Distribution System Operators (DSOs), and we need to fundamentally rethink the various roles and responsibilities in the market if we are to deliver a safe and economic system transition.

Did you know: BEIS have reported that as of Q1 2020 there was 6.35 GW cumulative capacity of distribution-connected generation assets under 5 MW.

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Looking ahead: the drivers of change

The exponential rise in the number of market participants and players brings with it an explosion in the amount of market and system data.

There is also a proportional increase in the underlying complexity of the energy system, and the markets that underpin it. Different layers of the power system, as well as other energy and non-energy sectors, have increased levels of interdependence. Open data and digitalisation are key to the whole system thinking required to achieve net-zero.

There is an urgent need to:

a) gain a much deeper understanding of the whole energy system, through advanced models and analytics

b) drive coordination and co-optimisation across the system through standardisation and shared platforming of data, and

c) transforming our ways of working and culture. The rapid emergence of Machine Learning (ML) and advanced system modelling have the potential to drive a step-change in the evolution to a truly digitally-driven ESO, to unlock the full value of the vast amount of data that will be produced and collected across the energy system.

Did you know: There are over 18 million smart and advanced meters operating in homes and businesses in Great Britain.

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Looking ahead: the drivers of change

DEMOCRATISATION

Last year, ESO Innovation added Democratisation as the 4th macro trend driving the energy system transition.

What we mean by Democratisation is a move towards communities and consumers playing a much more central role in energy system operation. Since then, we have seen lots of evidence of this, including:

- Electric Vehicle (EV) drivers on Octopus Energy's Agile tariff (a time of use tariff that tracks the wholesale electricity price) took advantage of aforementioned negative wholesale power prices to get paid to charge their vehicles.
- Ofgem consulted on how and when to implement Mandatory Half-Hourly (MHH) settlement, which will be an enabler of innovations such as peer-to-peer energy trading, vehicle-to-grid, time-of-use tariffs and demand side response.
- Ripple Energy launched the first 'consumer-owned' wind farm in the UK, partnering with Co-Op Energy and Octopus Energy to get the electricity from the wind farm to the owners' homes.

This important trend means that we will continue putting the consumer at the heart of its innovation going forward, not just ensuring delivery of robust consumer benefits from projects, but looking closely at how to facilitate consumer participation in energy markets.

Did you know: 5.95 millions customers switched supplier in 2020 this is down (by 6.5%) from switching levels in 2019.

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Stakeholder engagement

We recognise our key position in the market, and that open innovation is essential for the GB electricity system to decarbonise. The wider industry depends on our innovation to unlock opportunities through access to our markets, our data, our systems and our expertise. We also understand that we do not have all the answers, and that many of the most disruptive innovations will come from third parties.

Stakeholder engagement is fundamental to what we do. We are always talking to innovators, both existing partners and potential new ones. We want to understand what it is that the industry needs us to focus on, what ideas are out there to solve system challenges, and importantly to understand how we are doing and what we can improve on.

Stakeholder engagement this year was more challenging, we had to put in additional effort just to maintain our close connection with stakeholders. In previous years, you would see ESO Innovation team members at dozens of industry events throughout the year. This year, we embraced the virtual meeting, and we ran our first every 100% virtual conference - the Energy Networks Innovation Conference. We consulted widely to inform this strategy refresh, and undertook some in-depth stakeholder interviews, some of these views are provided here.

> I would like to see more investment in **digital transformation** and… to improve the data infrastructure at ESO to make it easier to extract data and use it to inform day-to-day operations….
>
> I would also say **whole energy system** is a top priority and in particular work around how systems interact…"
>
> *- Alexi Reynolds, Smith Institute*

> My top priorities for investment would be **digital transformation, forecasting** and **future markets**. As we move towards more decentralised generation and consumption, these areas will be absolutely crucial, particularly for potential market participation from domestic customers.
>
> When it comes to wind and solar generation, **curtailment** must be the last resort."
>
> *- Alex Schoch, Octopus Energy*

Stakeholder engagement

I agree with the priorities. I think **digital transformation** would benefit from further investment as it's also a high priority for the TOs and DNOs. ESO could be doing more in this area currently and is really only at the beginning of the journey.

I'd like to see more emphasis in **future markets** on bringing more small generation and residential participants into the market. Currently, there is limited incentive to participate."

- Anna Ferguson, WSP

I think the priorities are not independent but interwoven, and this needs to be considered when making decisions. For example, **digital transformation** is key to solving all the other problems, so perhaps should not be considered in isolation."

- Jamie Taylor and Alastair Buckley, Sheffield University

Digital transformation sounds great on paper, but ESO needs software which can make that a reality. The current IT structure is slower and less agile than it needs to be, and it can't handle Big Data so further investment in IT and software would assist digital transformation considerably. It would also improve ESO's interactions with external agencies and researchers as it makes the exchange of data much easier."

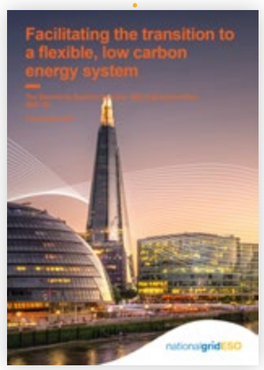
- Jack Kelly, Open Climate Fix

Building on existing work across ESO and the wider industry

As well as being driven by our conversations with industry stakeholders and ESO experts, much of this strategy refresh is driven by work being done across ESO and by strategic recommendations from BEIS, Ofgem and the Climate Change Committee. Some of the key examples of this work are signposted below:

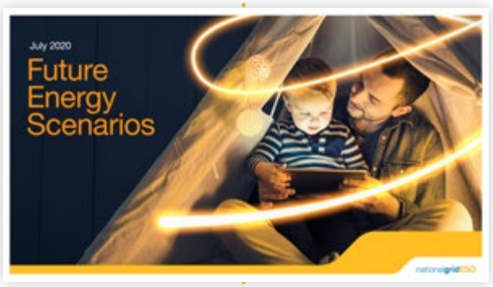
Operability Strategy

Insight into the challenges we face in maintaining an operable electricity system, and how we are addressing them.



RIIO-2 Business Plan

Detailing our activities for the RIIO-2 period and how we plan to evolve to meet the challenges of the changing energy landscape whilst maximising benefits for consumers.



Future Energy Scenarios (FES)

Presenting a range of different, credible ways to decarbonise our energy system as we strive towards the 2050 net-zero target.

Digitalisation Strategy

Setting out our ambitious plans for digitalisation and how we will prepare for increasingly digital and data driven network operation.

Continued

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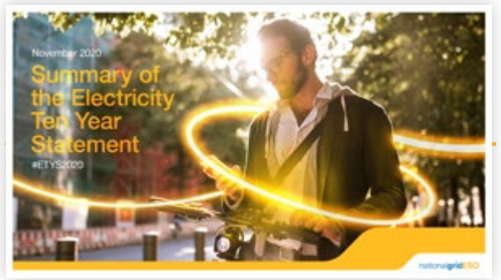
Building on existing work across ESO and the wider industry

FES: Bridging the gap to net-zero

An ongoing programme taking a closer look at what needs to be done to reach the UK's 2050 net-zero target bringing together a wide range of stakeholders.

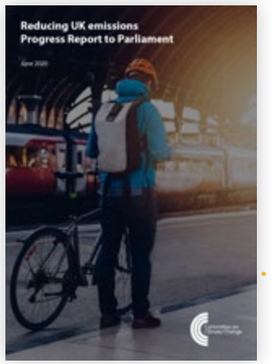


Electricity Ten Year Statement (ETYS)

Share our latest assessment of the future requirements of GB's electricity transmission system, highlighting uncertainties in future power flows and areas where network reinforcements are needed.

Ofgem's Forward Work Programme 20/21

Laying out the practical steps Ofgem will take to enable competition and innovation in the sector, protect consumers, and contribute to delivering a net-zero economy at the lowest cost to consumers by 2050.



Reducing UK Emissions: Progress Report to Parliament

The Climate Change Committee's 2020 report on the UK's progress to meeting net-zero by 2050.

Energy White Paper

BEIS setting out how the UK will clean up its energy system and reach net-zero emissions by 2050.

Ten Point Plan for a Green Industrial Revolution

Sets out the UK Government's approach to build back better, support green jobs, and accelerate our path to net-zero.

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ESO Innovation Priorities for 2021/22

Based on our extensive consultations with stakeholders, recommendations from Government and Ofgem, and our evolved understanding of issues based on our work over the past year, we have refreshed our innovation priorities for 2021/22.

Our top four priorities for this year are:

1. **Digital Transformation:** given the huge amount of feedback we have received from our stakeholders as well as our internal subject matter experts, we decided to make this our top priority this year due to the critical dependency many of the other priorities have on this transformation. Almost everything we do is driven by data and modelling. If we are to be able to operate a zero-carbon system by 2025, we need to significantly step up our capabilities in this space, as well as facilitate the digital transformation of the wider energy industry with open data and collaborative innovation.

2. **Future Markets:** it is becoming increasingly clear that current market structures are not yet fully fit for purpose in a net-zero world. Low demand due to COVID-19 has given us a glimpse into the future, and this year we have seen worrying levels of volatility and high costs in wholesale, balancing and ancillary services markets. We need to work with stakeholders to design the optimal market reforms for net-zero, while continuing to evolve current markets to level the playing field for new players.

3. **Constraint Management:** this issue has increased considerably in priority this year. The volume of generation we had to turn down to resolve constraints in summer 2020 was 50% higher than the same period in 2019. We want to explore ways over the next regulatory period that we can start to introduce new mechanisms, markets or approaches that aim to reduce the congestion costs ahead of the new boundary reinforcements.

4. **Whole Energy System:** the UK has committed to a net-zero economy by 2050. This goes way beyond the electricity sector, which is arguably the easiest step on the journey. If we are to get to net-zero, taking a whole system approach is crucial. However, there has been limited whole system innovation in the energy industry, despite strong signals from Ofgem and BEIS that this should be a focus. The Ten Point Plan has clearly stated an ambitious target for hydrogen, and the decarbonisation of heat and transport needs to accelerate.

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ESO Innovation Priorities for 2021/22

This table summaries our strategic innovation priorities for 2021/22, where you can expect to see us concentrating our innovation focus this year. A more detailed rationale for this prioritisation is given in the following pages, where we dive a bit deeper into each priority, as well as illustrating some of the work done last year with case studies.

No	2021/22 Priority (v last year)		Rationale for relative priority
1	**Digital Transformation**	↑	Critical enabler for other innovation, huge amount of progress needed in areas of Digital Twin, Artificial Intelligence (AI) & Machine Learning (ML), and data & analytics capability.
2	**Future Markets**	↑	Huge amount of work to do to facilitate 'competition everywhere', and enable net-zero. Urgent need to deliver full chain flexibility – a priority in Ofgem's Forward Plan.
3	**Constraint Management**	↑	Low demand from COVID-19 gave us a glimpse into the future where large amounts of excess generation needs to be constrained. Urgent need to find market-led solutions.
4	**Whole Energy System**	↓	Remains one of our core ambitions, lots of work to do across hydrogen, transport, heating, Carbon Capture Use and Storage (CCUS) and smart home technologies.
5	**System Stability**	↓	Still work to do in understanding and modelling system stability, but lots being done through pathfinders and existing innovation.
6	**Forecasting of Supply and Demand**	↓	Slight decrease in priority, lots of ongoing work here but need to develop our digital tools/capabilities to realise the full value of this work.
7	**Whole Electricity System**	↓	Work needs to focus on how products / markets can be co-optimised across Transmission and Distribution (T&D).
8	**System Restoration**	—	Distributed Restart is tackling the critical innovation required in Black Start.

Key:

- ↑ Increase in priority
- ↓ Decrease in priority
- — Priority level unchanged

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Digital Transformation

Digital Transformation underpins the success of us tackling almost all of our ambitions while leading the energy transition. The scale of the challenge, both internally and across the industry, is great. We know that our stakeholders are relying on us to lead the way, which is why this will be our top priority in 2021/22.

Drivers

- The energy sector is moving away from being siloed, becoming more integrated and the number of new players is rapidly increasing. The democratisation of data, through greater transparency and presumed open access is crucial and is driving digitalisation across the whole system.
- With the number of energy participants rapidly increasing, the complexity of energy network design decisions is also increasing which will result in a greater need for data to ensure that efficient choices are made as the system progresses towards net-zero.
- Consumer choices today and in the future will influence decarbonisation pathways and options for efficient whole system operation. Consumers will have an expanding role in achieving net-zero through changing behaviours in which case they will be looking to the energy industry for data and insights that support their decision making and will demand systems that are simple to interact with.
- Flexibility is seen as a key component for delivering value for consumers in a net-zero economy. Cost effectiveness will require large volumes of open data to both extract the most value from flexibility, and to create confidence that the system can rely on this flexibility in order to overcome the peaks and troughs created by a renewables-dominated generation mix.
- As the electricity networks become more reliant on data and aging technologies, the risk of cyber-attacks and the need for a faster response to such attacks becomes greater.
- A more complex, faster-moving electricity system needs much faster decision-making. Machine learning is needed to process the amount of data required to make the most economic decisions quickly enough.

Key Developments – External

- The Energy Data Taskforce made clear recommendations that the energy industry needs to work together to improve data openness and visibility.
- Ofgem issued an early draft of Digitalisation Strategy and Action Plan guidance to help ensure that there is transparency about the digital services that are available on the energy system and that upcoming service improvements are well planned and best meet the needs of consumers.

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Digital Transformation

Key Developments – within the ESO

- We have published our new Digitalisation Strategy and Action Plan.
- ESO Innovation invested heavily in this space, largely in advanced modelling projects to better understand system characteristics, or to be better prepared to deal with uncertainty in forecasts (see case study).
- We set the foundations to start building a central Data and Analytics Platform, which will allow real-time access to all our operational data, allowing us to automate data publishing and to add new datasets quickly and efficiently.
- We continued to develop our Data Portal, a centralised repository for all published data.
- We finalised our RecorDER project, which created a blockchain-based register for flexibility assets across T&D. The learnings are now being fed into our Data & Analytics Platform programme.

Opportunities for Innovation

- Our ultimate goal is to build a Digital Twin of both the power system, as well as markets. This will be a large programme of work, researching and testing different elements before starting to pull together the enduring system.
- Where can the application of AI and machine learning techniques contribute across all of our activities, from long-term network planning, to market operation, to real-time decision-making in the Control Room?
- How can we continue to enhance our power system modelling capabilities, as system characteristics continue to get increasingly complex?
- We will work on the Control Room of the Future – how can we provide our control engineers with all the information they need in an efficient manner?
- How can we utilise self-cleaning data techniques to help us manage the increasing volumes of data which drives our work?

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Case study: Control REACT

Control REACT is a project exploring how advanced data analytics and insights can be used by our control room to identify forecast errors and uncertainties, understand their cost impacts, and ultimately make informed decisions to improve the operational efficiency of the electricity system.

Control REACT is focused on the priority area of '**Digital Transformation**' and how Big Data can be used to develop decision-making tools for the control room.

These tools are increasingly important as the GB network moves towards a low carbon future. Weather uncertainties and poor visibility of embedded generation can create errors in forecasting and planning, making it harder to accurately predict supply and demand.

The Control REACT project team are developing a tool that utilises large amounts of operational data from the control room. This historic information is extracted into a programme that can visualise, query and analyse forecasting errors to help engineers improve future forecasting and planning to balance the system more effectively.

The next step in the project is to add associated costs to forecasting errors, so control room operators can ensure the decisions they make are the most cost efficient, benefiting both ourselves and consumers.

Once the project completes, the learnings from Control REACT will feed into the development of an advanced probabilistic forecasting tool, allowing engineers to see and react to uncertainties in real time.

> **By analysing control room information, we can create fine, granular data sets for use across ESO to inform the running of the network."**
>
> *- Gabriel Griffin-Booth,*
> *Senior Analyst, Commercial Development.*
> *National Grid ESO*

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Future Markets

Designing markets that are fit for purpose underpins our ambitions of 'competition everywhere' and zero-carbon operation. Again, system conditions in 2020, as well as stakeholder feedback, showed us that current market designs are not always optimal for net-zero – not just our markets but the wider energy and capacity markets that we interact with. We must understand the long-term options for market design, and work with our customers and stakeholders to find the optimal whole system solutions.

Drivers

Everything is changing: the technologies and stakeholders that generate and use electricity; the characteristics of the transmission system; the number and makeup of market participants; the business models of the companies that distribute electricity; our relationship with the EU. All of these changes have a deep impact on how markets function, and we need to understand and test the different market reforms that will facilitate this change as we strive for net-zero.

In addition, smart technologies mean many consumers won't just passively use power – they can become active players of the system too. It is important that we identify how we can best facilitate their participation in our markets; increasing consumer participation and engagement with their energy network is critical to achieving GB's net-zero ambitions.

Key Developments – External

- Low demand and high renewable generation resulted in very volatile wholesale and balancing markets, with negative prices and high bid offer spreads.
- Burst of activity and innovation happening in distributed flexibility markets.
- Lower inertia system means things happen faster – need to keep pushing for closer-to-real-time markets.
- The UK left the EU and entered a new Trade and Cooperation Agreement, with many details on cross-border electricity trade to be determined.

Future Markets

Key Developments – within the ESO

- Successful soft launch of Dynamic Containment for day-ahead procurement of frequency response services.
- ESO Innovation is investigating the design of a stability market.
- Continued investment in closer-to-real-time markets through Frequency Response Auction Trial.

Opportunities for Innovation

- How could a stability market be structured and developed?
- How to remove barriers to new and existing markets for smaller participants and new technology types?
- What are the potential impacts of locational marginal pricing on the network, market, and consumers?
- To what extent can highly distributed small assets participate in our markets and how we can further enable this?
- What effective new market modelling tools and capabilities can we use to assess future market designs and interactions?
- What new potential consumer markets are out there? What are their technical characteristics and entry conditions?

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Case study: Frequency Response Auction Trial

This project is trialling an innovative weekly format for the procurement of frequency balancing services, which will lay the groundwork for us to move to real time procurement in the future.

Addressing the priority area of ‘future markets’, the Frequency Response Auction trial explores the feasibility of moving our procurement of balancing services from a monthly tender process to a more inclusive and competitive weekly format, using an online auction platform.

Open to energy providers and consumers of all sizes, the weekly format encourages new supply and demand-side participation. Services are required for shorter term periods so more demand-side and renewable energy providers can participate.

The Frequency Response Auction trial also explores how to make pricing consistent and competitive – trialling ‘pay as bid’ and ‘pay as clear’ methods – to reduce the cost of operating the system, to benefit both ourselves and the consumer.

To date, the project has explored and tested solutions for various user requirements from an auction platform. It has also learned about participant bidding strategies and behaviours, as well as what internal systems and tools we must develop to transition from the weekly auction platform to a daily procurement option.

The weekly auction trial has given us confidence that with the right internal systems in place, we can move to day-ahead (real time) procurement by 2023 for even greater cost efficiencies and market participation.”

- Yingyi Wang,
Balancing Markets Development Officer,
Electricity Market Change Delivery, National Grid ESO

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Constraint Management

The costs to manage transmission system constraints have a large impact on consumers, and these costs are expected to increase significantly as GB's offshore wind and interconnection capacity grows. Building new transmission and distribution network capacity to meet peak flows on the system is not always the most economic solution for consumers, or the best for the environment, so we are looking to test a variety of innovative market-led solutions and technologies in this area.

Drivers

2020 gave us a unique insight into some of the challenges of operating the transmission system with lower levels of demand and higher North to South power flows; something we didn't expect to see until the mid 2020's. The volume of generation we had to turn down to resolve constraints in summer 2020 was 50% higher than the same period in 2019.

Key Developments – External

- Greater renewable generation causing more constraints, this is set to continue with the Government's plans for 40GW offshore wind by 2030.
- Low demand resulted in much higher levels of constraints in 2020 than previous years.
- Planned interconnectors will impact constraints onshore.

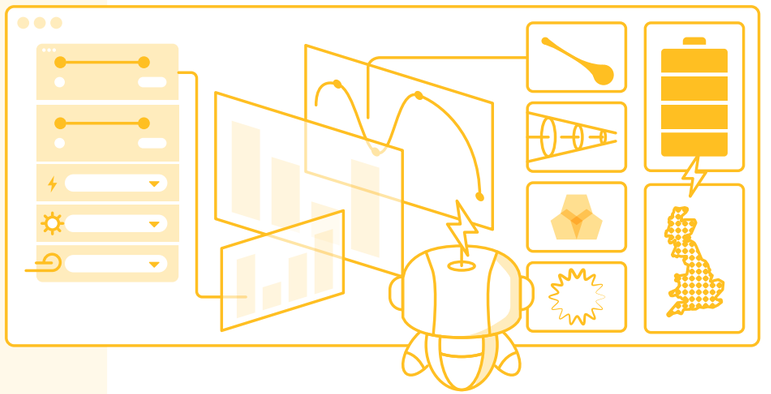
Constraint Management

Key Developments – within the ESO

- ETYS showed that constraint costs are expected to increase significantly due to high flows across the transmission boundaries.
- 4D Heat innovation project completed, looking at a novel solution for reducing constraints via domestic heating demand response in Scotland.
- Launched Constraints Pathfinders to seek solutions for managing constraints in the Mersey and Pennines areas.
- Invested in innovation looking at improving forecasting of voltage and thermal constraints.
- We are looking at aggressively tackling the constraint management issue by creating an internal task force fully dedicated to it.
- We have published a 5-point constraint management plan which focuses initially on the issues with the north to south transfer of power as they are the biggest and rising the fastest.

Opportunities for Innovation

- How can long-term energy storage (electrochemical, thermal, or mechanical) reduce year-round constraints?
- Can low-carbon hydrogen production be appropriately sited at advantageous locations to reduce constraints?
- How can we use data and new technologies to either increase transfer initially, or provide fast acting, automated response to a system condition to increase boundaries?



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Whole Energy System

We are committed to taking a leading role in delivering a holistic, whole-system approach to the energy transition. We recognise our unique position in the industry, and will invest significant effort in this space in our next regulatory period, particularly in the areas of hydrogen, transport, heating, and smart-home technologies.

Drivers

The ongoing conversation around the decarbonisation of heat and transport, combined with electricity systems' reliance on gas for flexibility (particularly on the distribution networks), present us with a crucial opportunity to consider the energy system as a whole, across multiple vectors (i.e. electricity and the multiple gas types) and the sectors this supports (e.g. heat, power, transport, industry).

Key Developments – External

- Strong signals from the Department for BEIS and Ofgem that energy transition needs holistic and collaborative approach.
- Hydrogen is a key priority in the Prime Minister's 10-Point Plan with an ambition for 5GW of H_2 capacity by 2030.
- Electrification of heat and transport also played an important role in the 10-Point Plan, with a target of 600,000 heat pump installations annually by 2028, and a ban on new petrol/diesel vehicle sales by 2030.

Key Developments – Internal

- Bridging the gap work programme working on its second report, looking at how the whole energy system must evolve to manage uncertain demand.
- We have launched an innovation project with National Grid Gas System Operator looking at modelling the future of heat decarbonisation.
- Completed the 4D Heat project, looking at how electric heating could solve whole system network constraints.

Opportunities for Innovation

- How can we model the whole energy system across all sectors and incorporate this into our work with FES, Network Operability Assessment (NOA), and Early Competition?
- Hydrogen impacts assessment, feasibility studies, and modelling.
- What flexibility services can be created for the electricity network as other sectors decarbonise?

Case study: 4D Heat

The 4D Heat project has delivered a feasibility study to explore how off-mains gas homes in Scotland could use wind power for domestic heating to ease constraint and congestion issues on the network.

4D Heat looks at the priority of **Constraint Management**, specifically in Scotland where there are notable transmission constraints as well as issues relating to the cost and inefficiency of wind generation curtailment.

The team's analysis also used a **Whole Energy System** approach, looking at how to use residential heating to solve a transmission constraint issue, without increasing costs for ourselves, DSOs or end users.

Using an off-gas grid area in Skye and extrapolating it to analyse the potential for 50-100k off-gas households in Scotland, the 4D Heat project team looked at whether residential heating demand could be used to absorb excess power generated by wind turbines, rather than paying providers to stop producing electricity.

The 4D Heat project concluded that with a collaborative approach to market reform, the installation of smart controls and the introduction of new market tariffs, residential demand could become a potential market participant to ease constraint issues in Scotland and help us move to a decarbonised electricity system.

As part of a wider combination of activities, residential heating demand can be used as a tool to manage constraints on the transmission network in Scotland and help ESO to use more of the power generated from wind turbines while lowering energy costs for consumers."

- Sean Williams and Thomas Petty, Economics Engineers, Network Development. National Grid ESO

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System Stability

System Stability has been our top priority for the past two years and we feel that significant progress has been made in this area across ESO, but there is more to be done still and it will remain a significant area of investment as we transform to a zero-carbon electricity system.

Drivers

Synchronous generation supports the stability of the system. As we transform to a zero-carbon electricity system, synchronous generation capacity is decreasing, and the system is becoming less stable. This results in faster system frequency changes, less voltage and fault ride-through stability, and makes it more difficult for both synchronous and non-synchronous generators to operate safely.

Key Developments – External

- The low demands experienced this year have given us a unique insight into some of the challenges of operating the network with a higher proportion of non-synchronous generation.
- GB system has continued to rapidly decarbonise with new renewable generation records broken.

Opportunities for Innovation

- How can we best model stability in an increasingly non-synchronous system?
- What tools can we develop to support our systems in a decarbonised network?
- How can we speed up some of our processes, or automate them in order to keep up with a lower inertia system?
- What kind of data, or metadata can further support system operation?

Key Developments – Internal

- The Accelerated Loss of Mains Change Programme has approved applications for works on a combined capacity of 10,700MW of distributed generation.
- Building on the launch of the Stability Pathfinder with the development of phase two which will open the service to a broader range of providers.
- Power Potential project's live trials were launched; an eight-week technical trial and a 12-week trial of the live commercial reactive power markets.
- Currently in the process of developing the first real-time inertia monitoring systems.
- Continued heavy investment in innovation into understanding complex system behaviour and ability of innovative technologies, e.g. Virtual Synchronous Machines, to provide stability solutions.

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Case study: DETECTS & Totem

The DETECTS & Totem projects are investigating how we can identify and understand the stability risks associated with low carbon generators being connected to the transmission network.

Addressing the priority area of ‘System Stability’, DETECTS is helping us to understand the risk to the network of a sudden drop in frequency caused by converter-based equipment such as wind turbines, interconnectors, etc. interacting and tripping offline.

To analyse the likelihood of such an event, DETECTS will be running EMT (electromagnetic transients) studies on a test area of the network (SE England). In parallel, TOTEM is developing a complete GB network model, giving ourselves and Transmission Operators (TOs) the capability to run EMT studies for all areas in the future.

EMT studies require the collation of detailed models from third-parties that fully represent the behaviour and operational performance of their equipment as well as the detailed modelling of every asset on the electricity system, from cables to generators. As these studies are complex and time-consuming to run, DETECTS is also exploring alternative techniques that could simplify the analyses.

As more asset data is secured from third parties, DETECTS will start running phased EMT analysis and experimenting with generic models where specific data isn’t available. The project will also be devising guidance notes on how and when to run analysis for optimum results.

> **By better understanding the risks that converters present, we can proactively plan ways to keep the system stable while pushing forward with our strategy to get more renewable generation onto the network.”**
>
> *- Djaved Rostom,*
> *Balancing Markets Development Officer,*
> *Electricity Market Change Delivery, National Grid ESO*

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Forecasting Supply and Demand

Forecasting of Supply and Demand is an area where we are making big progress with our ongoing work to incorporate AI, ML, and big data techniques into our processes. Balancing the system in real-time is based on our ability to accurately forecast supply and demand, with the rise in variable, renewable generation our capabilities in this area must be stepped up to ensure that we can operate the system reliably.

Drivers

This priority considers both short-term as well as long-term forecasting. The lack of visibility of intermittent, embedded generation on electricity networks, combined with more complex usage patterns, makes short-term forecasting of electricity supply and demand increasingly difficult. Long-term supply and demand forecasting are becoming harder to carry out as new technologies and business models emerge. These could lead to dramatically different end-user behaviours.

Key Developments – External

- Renewable generation records continue to be broken – forecasting wind and solar becomes more important.
- Increasing urgency for the electrification of heat and transport sectors outlined in the Energy White Paper means we must understand this new type of demand and how it will impact on system operation.

Key Developments – Internal

- We published the Platform for Energy Forecasting Strategic Roadmap.
- Improvements in short-term renewable generation forecasting, particularly solar, realised through a suite of innovation projects incorporating AI, ML, and big data techniques.
- Completed a project to understand EV charging profiles and the impacts that Vehicle to Grid (V2G) may have on supply and demand.

Opportunities for Innovation

- How do new types of consumer demand (EVs, electric heat) actually behave during normal operation? What do their demand profiles look like for different demographics?.
- How can we better understand the impact of forecast error on control room actions?
- How can we bring now-casting of weather-dependent generation sources, such as wind and solar, into our capabilities?
- How can we further integrate AI, ML, and big data techniques into our forecasting processes?

Whole Electricity System

Whole Electricity System focuses on how products, markets, and best practice can be aligned across transmission and distribution, an area which has seen significant investment and collaborative efforts from us over the past year.

Drivers

New decentralised energy resources are connecting to distribution networks, turning them into active networks and transforming the role of Distribution Network Operators. Many of these new resources can provide valuable services to us, increasing competition in our markets as well as to those of emerging Distribution System Operators (DSOs).

Key Developments – External

- ENA's Open Networks project continues to develop frameworks for DSOs, as well as for whole electricity system operation and planning.
- Ofgem published its Review of GB Energy System Operation – this sets out a potentially greater role for us in whole system coordination.

Key Developments – Internal

- Widespread activity across ESO to support delivery of whole electricity system outcomes (see WES Development paper).
- Significant investment in whole electricity system innovation e.g. Power Potential, RecorDER, Co-ordinated ESO-DSO procurement and dispatch, participation in DNO-led demonstration projects.
- Continued work on Regional Development Programmes with DNO partners around GB to solve location-specific issues.
- Collaboration with BEIS FleX Competition winners (TraDER, Piclo Flex Exchange).

Opportunities for Innovation

- Joint innovation projects to solve issues affecting both transmission and distribution networks though Regional Development Programmes.
- Can we build more complex whole system models which incorporate both ESO and DSO data?

System Restoration

System Restoration remains a vital responsibility for us and our ongoing innovation project Distributed Restart has shown that there are no insurmountable barriers for black start from distributed energy resources (DER).

Drivers

The availability of conventional Black Start service providers will decrease as part of the shift away from conventional thermal generation. New solutions are needed to ensure that we can maintain, and improve on our capability to restore the system.

Key Developments – External

- Increasing focus on the climate agenda accelerates the need to find low-carbon alternatives to provide Black Start services.

Key Developments – Internal

- We awarded six contracts for SW England and the Midlands, following a competitive procurement process.
- Distributed Restart's first successful live trial taken place, where an 11kV generator re-energised part of the 132kV/33kV network.

Opportunities for Innovation

- Distributed Restart trials may uncover further issues to be addressed.
- Testing automated controllers and end-to-end telecoms on the live power system.

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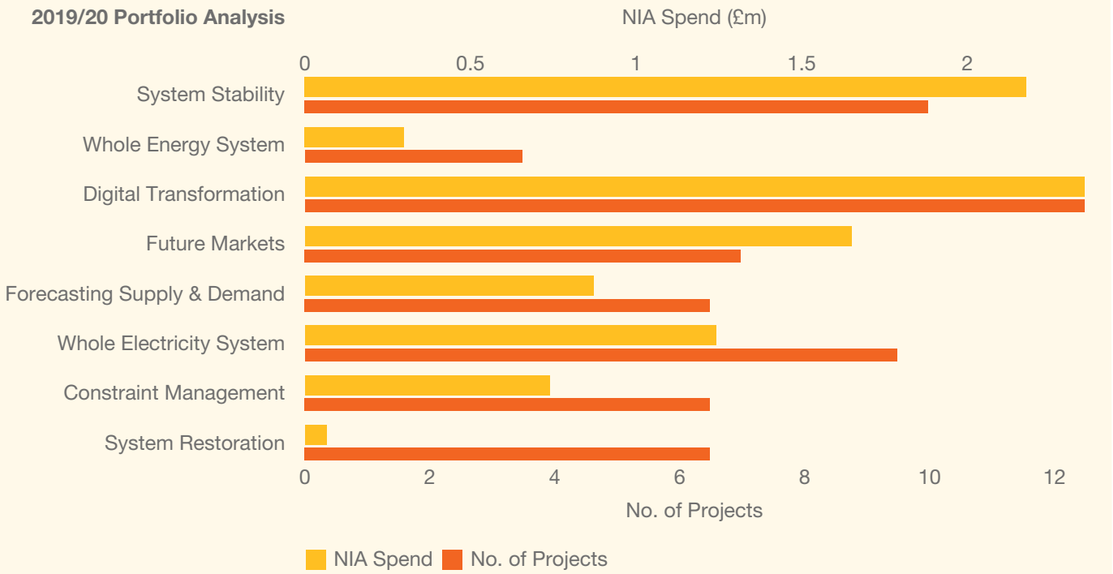
Portfolio Analysis

In the 12 months, from April 2020 to March 2021, we have once again committed our full Network Innovation Allowance (NIA) funding to tackling our strategic priorities. We've engaged with a wider range of partners and delivered a balanced portfolio of projects from early-stage research through to demonstration.

Our investment this year saw the completion of 10 projects, continued delivery of 20 and the start of 9 new projects that align to our innovation priorities.

All of our projects address more than one priority area. Figure 1.1 indicates the level of effort and funding we are allocating against our priorities and shows that we are broadly following the prioritisation that we set out at the beginning of 2020/21. System Stability, our top priority for last year, and Digital Transformation both received the most direct attention. One significant outlier is that we are investing less heavily than we anticipated last year on Whole Energy System projects. This is something we aim to address in the next regulatory period.

Figure 1.1



Innovation in RIIO-2

The scale of the challenge to achieve zero-carbon operation by 2025 is clear. We have worked in partnership with Ofgem to deliver an efficient structure for ESO Innovation in RIIO-2 to make sure we are set up to deliver what is needed. Put simply, we must be capable of supporting more innovation projects, in collaboration with a wider range of suppliers and industry stakeholders than we have been able to in the past to truly unlock the potential of our power system.

We agreed with Ofgem that our level of NIA funding should increase initially to £23m over the five-year period of RIIO-2. We will then revisit this amount in 2 years, together with Ofgem, to evaluate the work and to trigger the option to request additional funding in April 2023.

This increased funding level will allow us to support much more innovation across the industry, delivering the best outcome for consumers while increasing the number of solutions that can be implemented into ongoing activities. Allowing these funds to be used flexibly throughout the price control will create more certainty in investment and allow us to collaborate with third parties on larger, higher risk, and higher impact projects.

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Working together: meet the team

If you'd like to find out more about the way our innovation process works, the ESO Innovation team would be happy to speak to you and share details of our current innovation portfolio.

We're always on the look-out for new ideas and opportunities to partner on innovation projects too. Our publication 'Innovating with the System Operator' provides more information on how we lead innovation projects and support third party ones. All these projects share a common goal: to solve the increasingly complex challenges facing the energy industry and society.

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