Irish decarbonisation and consumer benefits of Grid-Interactive UPS

Baringa

Version History

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Contact

Baringa

Alec Granville-Willett
Senior Consultant

m +44 (0)7948 687 254
e alec.granville-willett@baringa.com

Baringa

Dr Mark Turner
Partner

m +44 (0)7584 290 310
e mark.turner@baringa.com

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Executive summary

In this study, Baringa has modelled the contribution that data centres can make towards power sector decarbonisation in Ireland using an advanced backup power supply technology known as Grid-Interactive UPS. This 'G-UPS' technology can provide services to the Irish grid historically provided by power plants that use fossil fuels.

Key findings – what have we learned?

- Grid-Interactive UPS systems deployed in Irish data centres would actively contribute towards **power sector decarbonisation**, both in the **Republic of Ireland (ROI) and Northern Ireland (NI)**.
- Displacement of fossil fuel-fired power plants providing **DS3[1] services** would **reduce costs for end consumers**.
- **Renewable generators** would benefit from **reduced curtailment** as the displacement of fossil fuel-fired power plants offers more space on the grid.

The role of G-UPS in Ireland's decarbonisation journey

Over the last two decades, power sector CO_2 emissions in Ireland have decreased, with zero-carbon, renewable wind generation increasing rapidly. However, the Irish grid remains dependent on fossil fuels. Several rules keep the grid from being able to rely on only renewable generation. In addition, some backup power plants must be ready to increase their output in emergencies.

Ireland has historically relied on fossil fuel-fired power plants to serve this backup, or 'DS3 service' requirement, resulting in increased emissions of CO_2 and costs to end consumers. G-UPS systems installed in Irish data centres could offer these services without the need for fossil fuels.

We have modelled the potential benefits of G-UPS systems by comparing the results of two simulations of our in-house power system model:

- One run with DS3 services being provided by fossil fuel-fired power plants, as has been the case historically; and
- A second run with DS3 service requirements met by G-UPS systems.

By using G-UPS systems to provide DS3 services rather than power plants that rely on fossil fuels, around **1.5 million tonnes of CO_2 could be saved from the ROI power sector in 2025**, and a further 0.5 million tonnes of CO_2 saved in NI as shown in Figure 1 below. The **carbon savings would continue in the long-term**, with almost **1.5 million tonnes of CO_2 saved across ROI and NI** in both 2030 and 2040.

Without the need to burn fossil fuels to provide DS3 services, the **cost passed on to end consumers for electricity is also decreased**. Figure 2 below shows the reduction in costs achieved; around **€270**

[1] DS3 stands for *'Delivering a Secure, Sustainable Electricity System'* and is a multi-year programme run by EirGrid and SONI, the system operators (SOs) across the island of Ireland, to increase the amount of renewable energy on the power system in a safe and secure manner. It is used as an umbrella term for system and flexibility services on the Irish power grid.

million in ROI and €70 million in NI in 2025. As with the carbon savings, **cost savings continue in the long-term**, with €250 million saved in ROI and €60 million saved in NI in 2040.

Figure 1: Potential CO_2 emission savings in ROI and NI from G-UPS systems

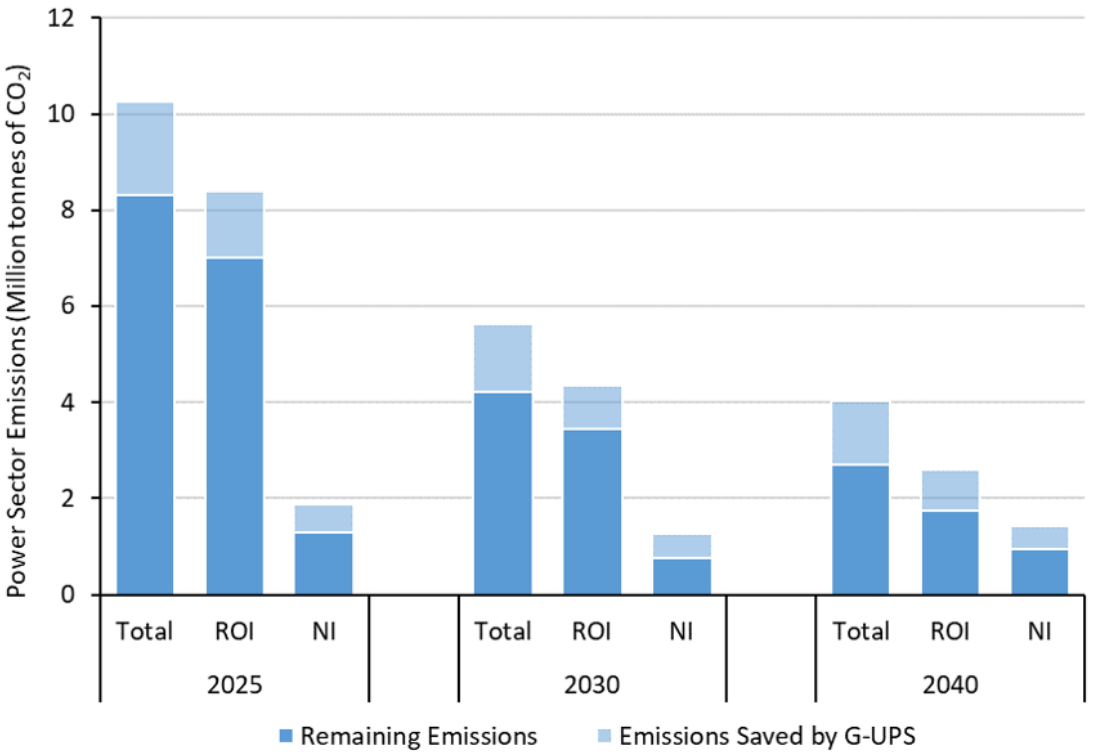
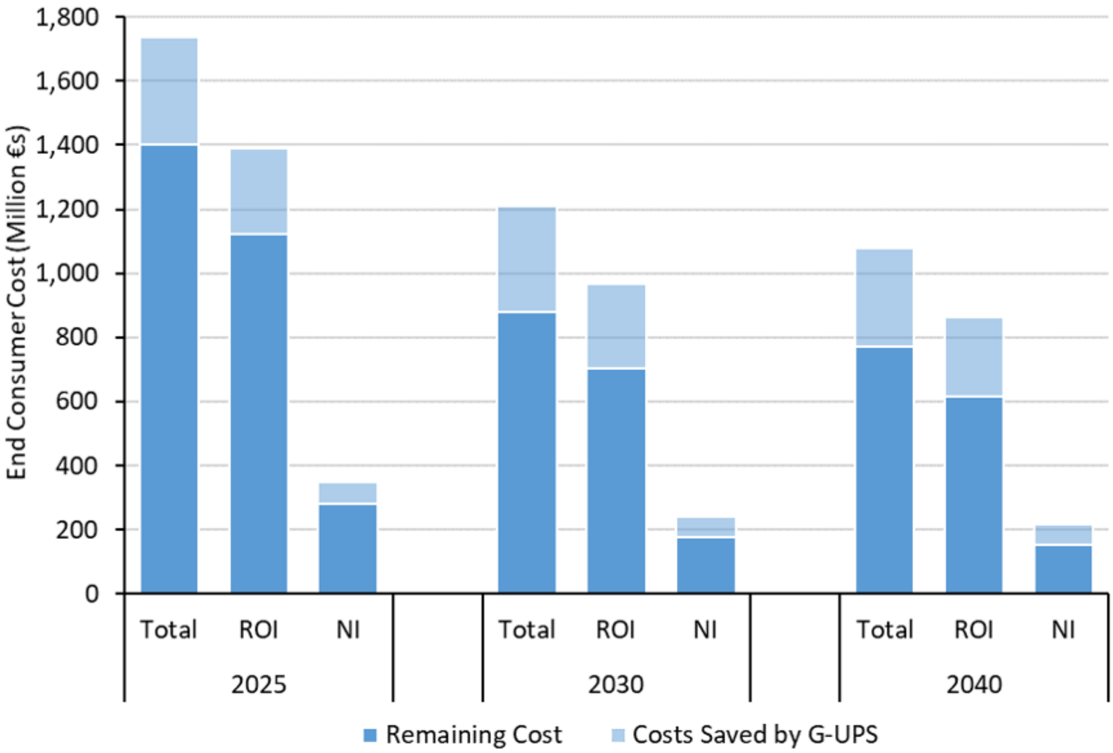


Figure 2: Potential end consumer cost savings in ROI and NI from G-UPS systems



1 Power sector decarbonisation in Ireland

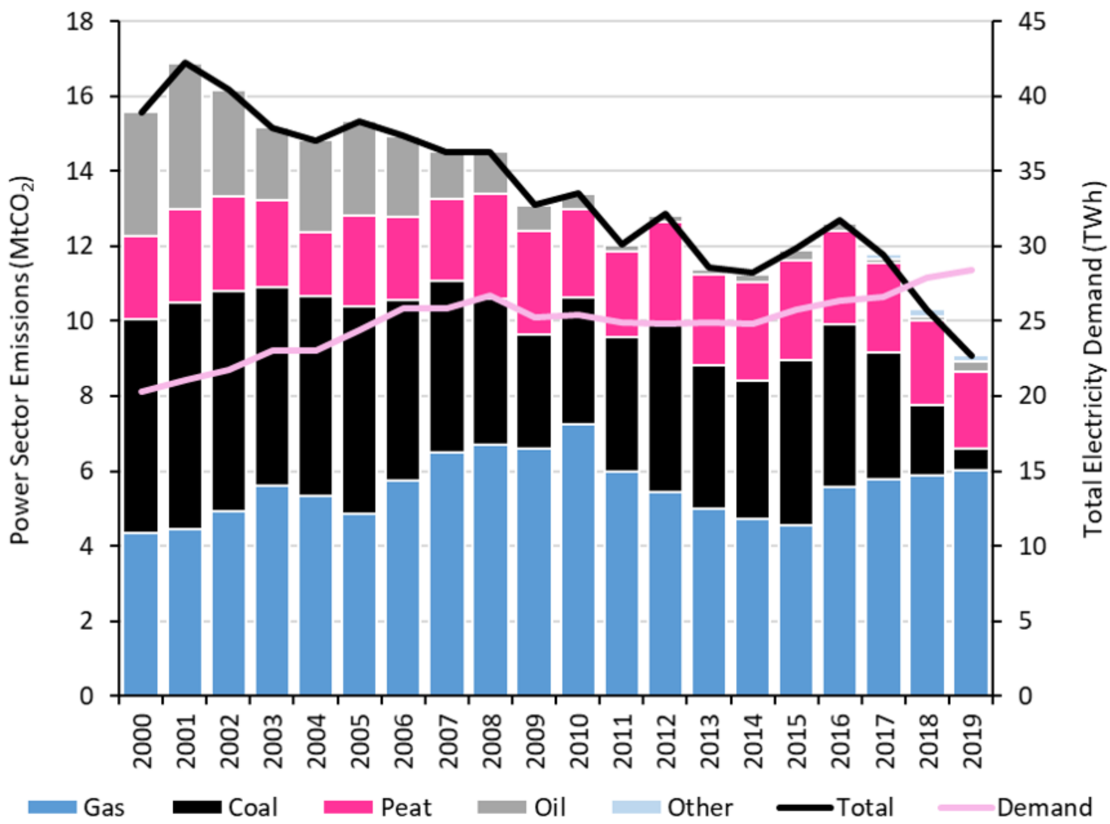
1.1 Ireland's journey to date

1.1.1 A continual decline in carbon emissions

As with many European countries, Ireland has historically relied on fossil fuels to generate electricity, primarily coal, oil, and natural gas. Ireland has also looked towards its domestic reserves of peat as a fuel for electricity generation. At the turn of the millennium, 95% of Ireland's electricity generation was provided by the burning of these four fuels[2].

Over the last two decades the Irish power sector has undergone a shift away from the burning of fossil fuels, and towards generation using renewable technologies. Figure 3 below shows the total power sector emissions of carbon dioxide (CO_2), the primary greenhouse gas emitted by electricity generation, in Ireland since 2000 along with the total electricity demand. Emissions peaked in 2001 at almost 17 million tonnes of CO_2 ($MtCO_2$) but have decreased in years since, hitting a record low of 9 $MtCO_2$ in 2019. **This trend has not been caused by a decrease in the need for electricity in Ireland, but a change in the fuels used for generation**; in 2001, an average of 800 grams of CO_2 were emitted per kilowatt-hour (kWh) of electricity generated, falling to around 320 grams by 2019.

Figure 3: Historical power sector CO_2 emissions and electricity demand in Ireland



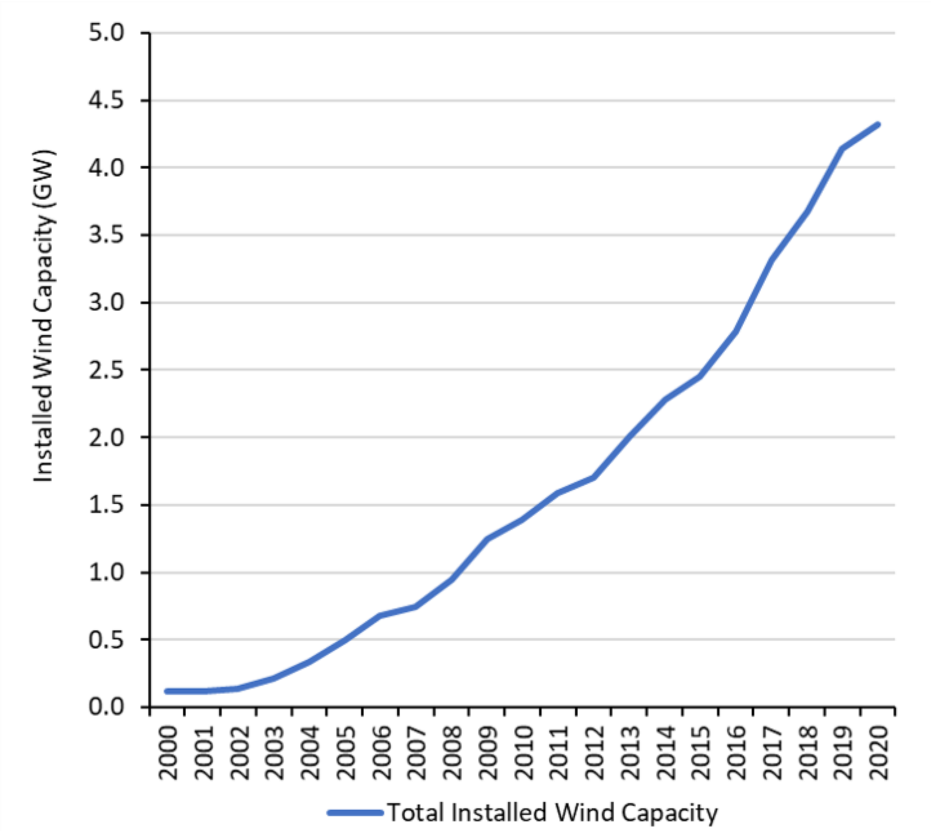
[2] https://www.seai.ie/publications/Energy-in-Ireland-2020.pdf

1.1.2 The rise of wind power

In 1992, the first wind farm in Ireland was opened in Bellacorrick, County Mayo. Since these first turbines began to spin, the installed capacity of wind power in Ireland has continually grown. Figure 4 below presents the growth in the installed wind capacity (in GW[3]) in Ireland since 2000.

As of the close of 2020, over 4.3 GW of wind capacity was installed in Ireland[4]. Wind farms have not only been built on land: the 25 MW Arklow Bank offshore wind farm was commissioned in 2004, the first and so far only example of its kind in Irish waters.

Figure 4: Historical installed wind generation capacity in Ireland



The rapid uptake of wind power has been the key driver behind decreasing power sector emissions in Ireland. **In 2020, a record 43% of electricity demand was met by generation from renewable sources**[5], with around 38% being delivered by wind farms[6]. Since 2000, the proportion of electricity met by renewable sources has increased every year, a trend presented in Figure 5 below.

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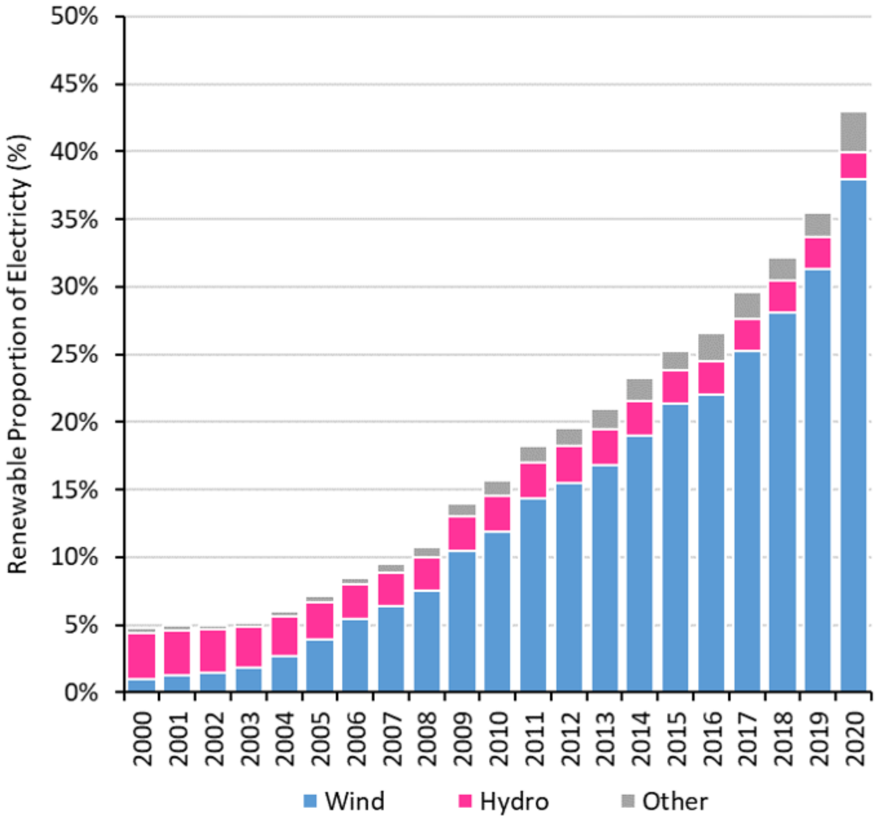
[3] Gigawatts, a unit of electrical power equal to 1,000 megawatts (MW), or 1,000,000 killowatts (kW).

[4] https://www.eirgridgroup.com/site-files/library/EirGrid/All-Island-Generation-Capacity-Statement-2020-2029.pdf

[5] https://www.eirgridgroup.com/newsroom/electricity-consumption-f/

[6] Based on Baringa analysis.

Figure 5: Proportion of Irish electricity demand met by domestic renewable generation



1.2 A green future for the Irish power sector

1.2.1 Current targets for renewables

Having achieved the target of 40% renewable electricity by 2020, the Irish Government has set out a series of longer-term targets to continue the growth in renewable electricity, and decrease power sector emissions further.

Climate Action Plan 2019 – a '70 by 30' ambition

On the 17th of June 2019, the Department of the Environment, Climate and Communications (DECC) of the Government of Ireland released the *Climate Action Plan 2019*[7], with the aim of setting out a series of decarbonisation targets for 2030 across Ireland, including the power sector, to steer the country towards an ambition of zero net carbon emissions ('net-zero') by 2050.

Within the power sector, the ambition was focussed on deployment of renewable generation capacity, including onshore wind, offshore wind, and solar photovoltaics (PV). The cornerstone of this ambition was a legally binding target of 70% of electricity demand to be met by renewable sources;

[7] https://assets.gov.ie/25419/c97cdecddf8c49ab976e773d4e11e515.pdf

widely referred to as ‘70 by 30’. This target had been shown to be achievable at minimal cost to the end consumer in the Baringa *70 by 30* report[8], released in October 2018.

The 70% renewable electricity was proposed to be achieved through two means:

- 55% supported by the Renewable Energy Support Scheme (RESS), a new government-backed subsidy scheme for renewables; and
- 15% backed by corporate power purchase agreements (CPPAs), direct contracts with large energy users in Ireland.

This target was accompanied by a projected uptake of renewable generation capacity required to meet it, consisting of:

- 8.2 GW of onshore wind capacity;
- 3.5 GW of offshore wind capacity; and
- 0.4 GW of solar PV capacity.

Programme for Government – a focus on offshore potential

On the 29th of October 2020, the Department for the Taoiseach, an advisory department to the prime minister of Ireland, released the *Programme for Government*[9]. This document set out the new Government’s vision for public policy going forward, including a broad focus on decarbonisation.

Included in the document was a reference to Ireland’s offshore wind capability, going beyond the 3.5 GW targeted in the *Climate Action Plan 2019*:

- A plan to deploy 5 GW of offshore wind capacity off the southern and eastern coasts of Ireland by 2030 was announced; as well as
- A longer-term plan to take advantage of a potential 30 GW of floating offshore wind capacity in sites of deeper water in the Atlantic.

1.2.2 An increasing drive for decarbonisation

The *Climate Action Plan 2021* is expected to be released later this year, potentially bringing with it more ambitious targets for decarbonisation in the power sector.

The Baringa *Endgame* report[10], released in June 2021, demonstrated that power sector emissions below 2 million tonnes of CO_2 per year could be achieved by 2030. This result can be achieved without a deviation from the approach currently underway to achieve a ‘70 by 30’ target, and reduces consumer costs relative to the less ambitious target.

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[8] https://windenergyireland.com/images/files/70by30-report-final.pdf
[9] https://www.gov.ie/en/publication/7e05d-programme-for-government-our-shared-future/
[10] https://windenergyireland.com/images/files/20210629-baringa-endgame-final-version.pdf

2 Benefits of zero-carbon system services

2.1 DS3 limits

2.1.1 Why does the Irish grid need limits?

The electricity system in the Republic of Ireland (ROI) is unified with that of Northern Ireland (NI) in a single electricity grid known as the Integrated Single Electricity Market (I-SEM). The I-SEM is run by EirGrid and System Operator Northern Ireland (SONI), the 'system operators' (SOs) in ROI and NI respectively.

In an ideal world the hourly electricity generation mix in I-SEM would depend only on the demand requirement, and how windy it happens to be. In each hour, EirGrid and SONI would consider how expensive each generator is to run, and stack them from least to most expensive. Wind farms have zero running cost and so, if the wind is blowing and there is sufficient demand, they should always be generating. Coal and natural gas-fired power plants have fuel and carbon costs that make them more expensive to generate than wind, and so they should only be required to generate if the electricity demand in I-SEM exceeds to total available wind generation.

This ideal situation is considered by the SOs, and every day they will order the power plants in I-SEM from least to most expensive for each hour of the following day. This is known as the day-ahead schedule. Unfortunately there are conditions that the I-SEM generation mix must follow that force the SOs to deviate from the day-ahead schedule.

The electrical grid in I-SEM, and in most grids throughout the world, uses a form of electricity called alternating current (AC), in which the direction of the flow of power alternates in both directions through the grid. In Ireland, the frequency of this oscillation is designed to remain at 50 cycles per second (50 Hz). If this frequency deviates by more than 0.5 Hz, i.e. falls to 49.5 Hz or rises to 50.5 Hz, the grid and equipment connected to it will become damaged, and blackouts can occur. The frequency should also not change at a rate of more than 1 Hz per second[11], or similar damage may occur.

To prevent either of these situations from happening, EirGrid has defined a set of rules known as DS3 limits[12], or operational constraints, that must be followed.

2.1.2 Two key limits on decarbonisation

These DS3 limits prevent the SOs from following the day-ahead schedule. Wind generation, one of the least expensive and so highest priority generation types in the day-ahead schedule, can end up having to be reduced. This reduction in output to account for DS3 limits is known as curtailment. Two of the DS3 limits have direct impacts on the output of renewables, and increase the difficulty of power sector decarbonisation:

[11] This condition is a DS3 limit, and is known as the 'Rate of Change of Frequency' (RoCoF) limit. The current official limit is set at 0.5 Hz per second, with a limit of 1 Hz per second under trial since 17th June 2020. Further detail is given in Appendix A.1.

[12] https://www.sem-o.com/documents/general-publications/Wk31_2021_Weekly_Operational_Constraints_Update.pdf

SNSP – a limit on renewables

One limit applies a direct cap onto the level of renewable generation at any one time – the 'System Non-Synchronous Penetration' (SNSP) limit. This limit states that the ratio of renewable generation from wind or solar farms (plus the volume of electricity imported into I-SEM from other countries) to the total electricity demand, must not exceed a certain value. If the day-ahead schedule includes wind and solar generation greater than this limit then some of this renewable, and zero-cost, generation must be curtailed.

The SNSP limit is currently set at an official level of 70%, with a 75% limit under trial by EirGrid and SONI since 22nd April 2021.

Min Gen – a reliance on fossil fuels

The 'Minimum Generator Units for System Stability' (Min Gen) limits state that a certain number of large coal or natural gas-fired units must be generating at all times to maintain grid reliability. These limits are necessary because large fossil fuel-fired power plants produce electricity that is synchronised with the frequency of the grid, whereas wind and solar farms do not. Being synchronised to the grid frequency gives the generated electricity a property known as inertia[13]. The more inertia in the electricity grid, the less likely the frequency is to change.

If these large power plants are not due to be generating in the day-ahead schedule, then other generators must be curtailed to make room for them on the grid. Typically wind and solar farms are curtailed.

The Min Gen limits in I-SEM are currently set at 5 units in ROI, and 3 units in NI[14].

2.2 DS3 services

2.2.1 Insurance in the event of an outage

Even with the DS3 limits in effect, sudden drops in frequency can occur. If a large power plant disconnects from the grid unexpectedly, either because a fault causes it to go offline, or because the plant is cut off from the network, then the grid frequency will fall. Inertia provided by other power plants acts to slow down the rate of the drop, but without other generation coming online to replace the lost plant, a blackout could occur as the frequency falls below 49.5 Hz, or falls faster than 1 Hz per second. The same effect can occur if there is an unexpected increase in electricity demand. The frequency of the grid must also be returned to 50 Hz to ensure stability during future events.

To reduce this risk, and ensure that the grid operates effectively at all times, EirGrid and SONI pay for a suite of 14 additional 'DS3 services' to prevent frequency movements in an event of this type, as well as changes in grid voltage. In the event of a frequency drop, generators with DS3 service contracts will increase their output to compensate, at varying times.

[13] The level of inertia produced is itself subject to a DS3 limit, known as the 'Minimum Inertia' limit. The value of this limit is currently set at 23,000 MWs. Further detail is given in Appendix A.1.
[14] A second Min Gen limit is active in NI, and states that 2 of the units running must be either Coolkeeragh, Kilroot 1 or Kilroot 2.

2.2.2 A cascade of response

Inertial response – slowing the fall in frequency

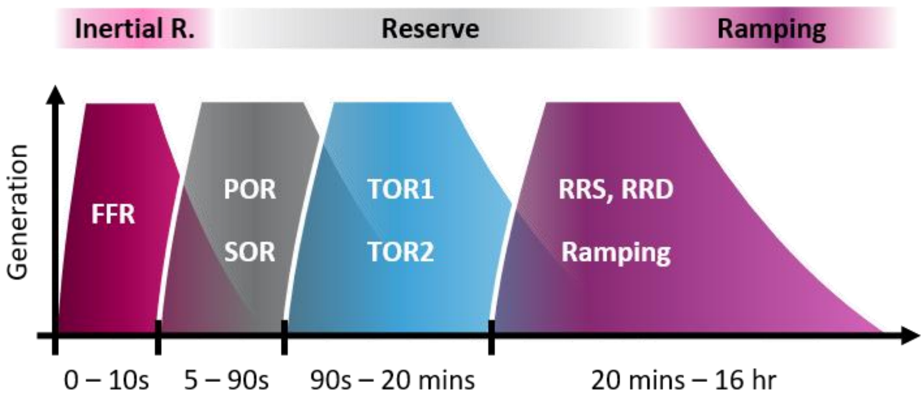
Drops in frequency can cause blackouts in less than a second if not contained. Near instant response of generators is required to slow the change in frequency. Three DS3 services are classified as 'inertial response' services, which act to contain the frequency within the acceptable range (49.5 – 50.5 Hz) and ensure that it does not change faster than 1 Hz per second. These services typically require maximum response times (the time taken to increase generation) of less than 2 seconds, with greater payments given to generators that can respond faster.

A key inertial response service is 'Fast Frequency Response' (FFR). To qualify for an FFR contract a generator must be able to respond within 2 seconds, and continue to generate until 10 seconds have passed since the event. Increased payments are provided for faster responses, down to 0.15 seconds.

Reserve – returning to 50 Hz

Once the drop in frequency has been contained, the frequency must be brought back to 50 Hz. Six of the DS3 services are classified as 'reserves'. Each reserve service acts to replace the output of a generator with a slower one that can generate for longer. To provide 'Primary Operating Reserve' (POR), a generator must respond within 5 seconds of an event, and continue generating until 15 seconds after the event. These plants will be replaced by others providing 'Secondary Operating' Reserve (SOR), which generate between 15 and 90 seconds after the event. In turn this service is replaced by 'Tertiary Operating Reserves' (TOR1 and TOR2) between 90 seconds and 20 minutes, and 'Replacement Reserves' (RRD and RRS) between 20 minutes and 1 hour[15]. This process is illustrated in Figure 6 below. Individual plants can provide multiple reserve services by continuing to generate.

Figure 6: Diagram of DS3 service response times and durations



[15] Replacement Reserves are in-turn succeeded by 'Ramping' services (RM1, RM3, and RM8), that extend out to 16 hours after the event.

2.2.3 Part of a wider programme

Contracts for DS3 services are secured through a broad programme known as 'Delivering a Secure Sustainable Electricity System' (DS3). In 2011, the DS3 programme was established in Ireland with the aim of enabling the Irish grid to achieve a 40% renewable electricity target in 2020, an ambition that was fulfilled. The DS3 programme consists of several advances in the management and operation of the Irish grid including changes to the Grid Code (the set of rules for operators of the grid and generators in it), development of tools to help manage the grid and collect data from it, and an expanded set of DS3 services.

Before the roll-out of the DS3 programme, the arrangements for securing equivalent services in Ireland actively benefitted old, inefficient coal and gas-fired power plants, helping to keep them online. Contracts offered under the suite of DS3 services has been designed to incentivise the fastest responding generators, which can be low-carbon providers, by scaling up their revenue. Although the DS3 programme has enabled significant advancement in decarbonisation of these services, fossil fuel-fired power plants still receive DS3 service payments, which results in substantial carbon emissions. The SOs have committed to a more ambitious 'DS3+' programme to help enable the '70 by 30' target to be met, and address carbon emissions from DS3 service providers.

2.3 Providers of system services

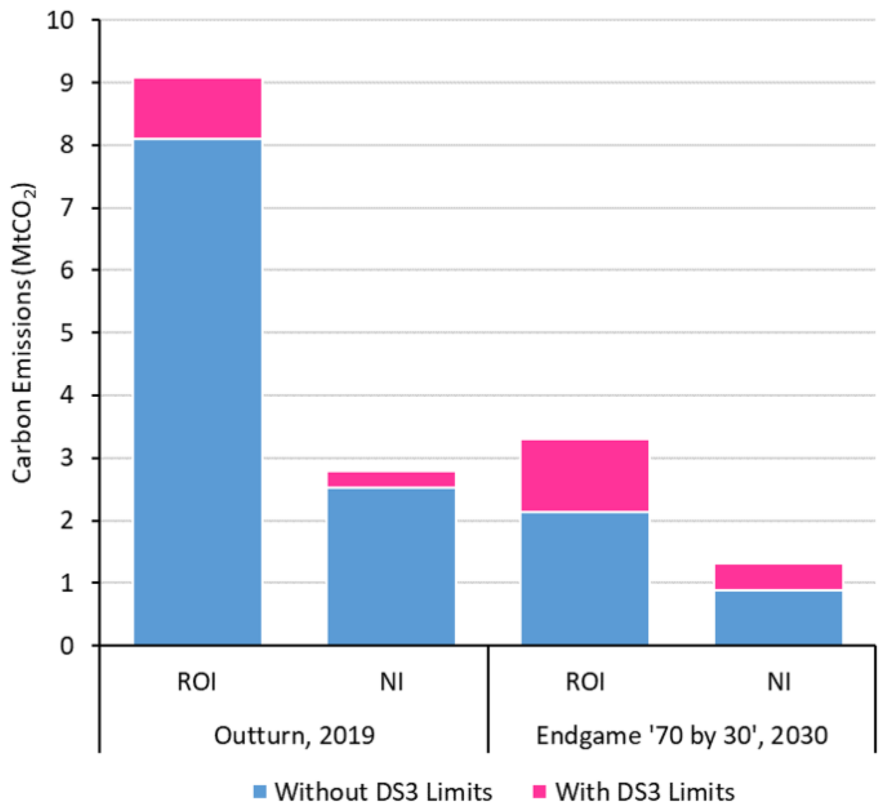
System services, which include both DS3 services and additional actions to maintain DS3 limits, can be provided to varying degrees by conventional fossil fuel-fired power plants. The synchronous nature of these power plants allows them to provide inertia, and some can provide each of the reserve services.

To be able to deliver DS3 services, coal and natural gas-fired power plants must already be generating, but still be able to increase their generation. Running below their maximum level is required as coal and gas-fired power plants cannot respond quickly enough when offline. Therefore, without alternative providers, fossil fuel-fired power plants that may not ordinarily be online according to the day-ahead schedule will be constrained on, increasing carbon emissions and fuel costs, and potentially forcing renewable generation to be curtailed to accommodate them on the grid.

This reliance on fossil fuel-fired generation, which may not be necessary in the day-ahead schedule, results in over 1 million tonnes of CO_2 emissions ($MtCO_2$) from the power sector each year[16], and is expected to grow as the renewable capacity on the system increases. The recent Baringa *Endgame* report found that by 2030, if ROI achieves its target of 70% renewable electricity, around 1.2 $MtCO_2$ of power sector emissions, over one third of the total, would result from deviations to the day-ahead schedule to maintain DS3 limits and keeping coal and gas-fired power plants running to be able to provide reserves. This breakdown of power sector emissions is presented in Figure 7 below.

[16] Estimated based on Baringa analysis.

Figure 7: ROI and NI power-sector CO_2 emissions from the day-ahead schedule and DS3 limits



Zero-carbon solutions to maintaining DS3 limits and providing DS3 services exist today, from proven technologies that have either been deployed in I-SEM already or demonstrated in other geographies:

- Grid-scale batteries, which have sub-second response times, are able to provide both FFR and the full set of operating reserves (POR through to TOR2) without needing to be generating beforehand.
- Pumped hydro storage, in which water pumped uphill using excess electricity is released during hours of high demand to generate electricity when most needed, can provide each operating reserve. The turbines of pumped hydro storage plants are synchronous, and so can also provide inertia to the grid without the use of fossil fuels.
- Synchronous condensers, system service assets that are synchronised with the grid frequency, have freely spinning flywheels[17] that can provide large amounts of inertia without the need for fossil fuel-fired generation. The SEM Committee, the regulating authority in I-SEM, has stated their intent to procure low-carbon inertia[18].
- Uninterruptible Power Supply (UPS) systems act as back-up power supplies for electrical equipment that could be damaged by a loss of power. UPS systems that can interact with the grid, Grid-Interactive UPS (G-UPS), offers an alternative source of zero-carbon system services when deployed on a sufficient scale. In Section 3, we explore how the use of G-UPS systems in Ireland's data centres can be beneficial to power sector decarbonisation.

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[17] Flywheels are mechanical devices that store energy using rotational momentum.
[18] SEM-21-01

3 The role of data centres

3.1 Introduction to data centres and G-UPS

3.1.1 Data centres in Ireland

In a world of ever-increasing internet usage, data centres provide hubs for remote processing power and storage of corporate data. Typically a data centre will contain multiple servers and data storage units, as well as computing infrastructure that allows the data centre to connect to users remotely. The electricity requirement of data centres can vary, from less than 1 MW to upwards of 30 MW. This capacity includes not just the power requirement of the computing equipment, but also the need for cooling – in Irish data centres, this typically makes up around a quarter of the demand[19].

Ireland has seen rapid data centre development over the last decade, with 70 data centres online as of May 2021, totalling 900 MW of connected capacity and around €7 billion of construction investment since 2010[20].

A further 8 data centres, totalling 255 MW, were under construction in May 2021. In the GCS 2020, EirGrid projects that data centre demand in Ireland could reach 1.3 GW by 2029 in their Median scenario, or as high as 1.8 GW in their High scenario. In the Median scenario, demand from data centres is expected to make up 27% of the annual electricity demand in Ireland by 2029.

3.1.2 UPS – security in emergencies

If a data centre was to lose power unexpectedly in the event of a blackout or fault, there is a risk that server hardware would be damaged, and that data would be lost. A near instant supply of back-up power is needed to prevent this, faster than the response time of a backup oil or gas-fired generator.

Uninterruptible Power Supplies (UPS) can provide near immediate backup power in the event of a loss of power, from an on-site storage facility – typically a battery or flywheel. With response times below 0.5 seconds, UPS systems are fast enough to prevent data centres from losing power during a blackout. Data centre-scale UPS systems typically store enough energy for a few minutes of backup power. If the blackout persists the data centre will need to be carefully shut down or rely on an alternative supply such as an on-site oil or gas-fired generator, or a longer duration battery. After providing backup power, UPS systems can recharge their batteries using power from the grid.

3.1.3 G-UPS – an advancement in backup power

As well as drawing power from the grid to recharge, some UPS systems can discharge electricity to the grid. Given the sub-second reaction times of UPS systems, this ability can provide opportunity to provide benefits to the grid such as zero-carbon system services. UPS systems that can continually assess and respond to the need for system services are termed 'Grid-Interactive UPS' (G-UPS) systems.

[19] https://www.bitpower.ie/images/Reports/2020_Q1_Update_Report.pdf

[20] https://www.hostinireland.com/post/biannual-market-update-report-may-2021-now-available

When not being relied upon to provide emergency backup power for the data centre, G-UPS systems are able to provide FFR with response times below 0.5 seconds. Although G-UPS batteries are designed with short durations in mind, a battery with a duration of 5 minutes can provide POR, SOR, and TOR1 in addition to FFR.

In this study we have sought to quantify the benefits of data centre G-UPS systems on the Irish power sector including:

- Carbon emission savings from displacement of fossil fuel-fired power plants used to provide DS3 services;
- Cost savings to the end consumer from reduced payments needed to keep fossil fuel-fired power plants running to provide DS3 services when they would otherwise not be generating in the day-ahead schedule; and
- Reductions in renewable curtailment that would have been needed to make room on the grid for fossil fuel-fired power plants providing DS3 services.

Beyond the ability to provide DS3 services such as FFR and operating reserves, G-UPS systems have the potential to be configured to continually monitor the grid frequency, and respond by providing small bursts of electricity in either direction. These continual actions would act to smooth out any unwanted variation in the grid frequency, helping to hold it at 50 Hz. This is equivalent to providing inertia, but without the use of fossil fuels.

The potential benefits of this ‘synthetic inertia’ from G-UPS systems have also been modelled as part of this study, and the results are presented in Appendix A.

3.1.4 Barriers to deployment of G-UPS

Enabling data centre participation in DS3 services has been the result of many years of design, testing, and analysis. Significant analysis has gone into unlocking the potential for data centres to participate in these services. Technical barriers remain before the data centre industry can widely participate in grid services markets, such as the DS3 programme.

As G-UPS systems would be new developments to Ireland, older data centre sites would not be able to support the grid by providing DS3 services. While it is possible in the lifetime of older data centres, retrofitting a site can be costly and impact operations. Trade-offs must be made on down-time and the total cost of implementation of site retrofits. It is critical for providers to make these decisions early in the design process, and incorporate G-UPS designs and associated infrastructure, network, and services to support it from the beginning.

The design of the DS3 services play a significant role in determining viability of G-UPS system participation. Optimal services for G-UPS systems include those with short durations and limited numbers of events per year. Grid services can utilise excess energy capacity beyond the minimum required by the data centre to provide backup power to the site in blackout events. Available capacity is largely dependent on the start-up time of the longer-term backup generator. Data centre developers seek to ensure the appropriate amount of backup power is reserved to serve the data centre in a blackout event, first and foremost. As batteries degrade over time, the amount of available energy for DS3 services may become more limited as the system ages.

The total cost of implementing a G-UPS system includes not only the cost of the UPS technology, but also the cost of requirements for measuring and monitoring the DS3 service requirement. This cost includes additional infrastructure and software. The build process will vary between data centres.

3.2 Modelling methodology

3.2.1 Electricity system modelling

Baringa has developed an in-house Europe-wide power system model covering Ireland, Great Britain and the majority of mainland Europe for the purpose of power system studies. The model sits within PLEXOS, a third-party commercial software that is widely used in the power and utilities industry. Our 'Pan-EU' model is configured with key inputs and scenario assumptions such as hourly electricity demand profiles, commodity prices, power plant build and retirement, and hourly wind and solar generation profiles. The model simulates over 30 European countries at once, considering the flow of power between them.

Two runs take place in the model:

- In the first 'unconstrained' run, no DS3 limits are considered and generators are chosen on a cost basis, from lowest to highest. This is representative of the day-ahead schedule;
- In a second 'constrained' run, the I-SEM DS3 limits are active, and the generators must operate in a way that maintains them. The requirements for FFR and reserves are also considered in this run.

3.2.2 Modelling the benefits of G-UPS

To determine the cost and CO_2 savings associated with G-UPS systems in Ireland, we have used our Pan-EU model to simulate the Irish energy system in 2025, 2030 and 2040, in three model runs:

- We have initially run the model in an 'unconstrained' mode to simulate the day-ahead schedule in I-SEM. From this run, we determine the hourly wholesale electricity price that is paid to generators for the power they provide. This run also calculates the level of imports and exports of electricity according to the day-ahead schedule (from the hourly stacking of generators from most to least expensive, the model determines whether it is less expensive to import power from other countries than to use domestic generation).
- Next, we have run the model in 'constrained' mode, which considers the DS3 limits and the requirements on generators to provide DS3 services, but have only allowed fossil fuel-fired power plants to provide DS3 services such as FFR and reserves. The '70 by 30' target is achieved in this model run, without the use of zero-carbon system services.
- Finally, we have modelled a second 'constrained' run, with enough G-UPS systems to meet all FFR and operating reserve requirements in I-SEM.

Comparison of the two 'constrained' runs indicates the benefits to the Irish grid and end consumers of using G-UPS systems to provide DS3 services, without relying of fossil fuel-fired power plants.

3.2.3 DS3 service requirements

The SOs, EirGrid and SONI, define the need for DS3 services around the size of the largest individual connection into the I-SEM grid, known as the 'Largest In-Feed' (LIF). The LIF of a grid is typically either a large generator (fossil fuel-fired power plant or wind farm), or an interconnector to another grid. Currently, the LIF in I-SEM is the East-West Interconnector (EWIC), a 500 MW connection to Great Britain (GB). In this study we assume that the LIF increases to 700 MW between 2025 and 2030 when the Celtic Interconnector, the first to connect I-SEM and France, is completed.

The SOs publish their requirements for operating reserves (POR to TOR2). Currently, the requirements for POR and SOR are set at 75% of the LIF[21], with the TOR1 and TOR2 requirements set at 100% of the LIF. In this study we have assumed that the SOs increase their POR and SOR requirements to 100% of the LIF by 2025, in-line with TOR1 and TOR2.

EirGrid and SONI do not publish their requirements for FFR however. We have assumed that the FFR requirement is scaled with the LIF, and reaches 100% of the LIF by 2025 in-line with the operating reserves. We have modelled the system FFR requirement in two parts:

- One that requires delivery in less than 2 seconds, the minimum requirement for FFR; and
- A second that requires delivery in under 0.5 seconds.

We have calculated that the proportion of the FFR requirement that must be delivered in under 0.5 seconds in order for the grid frequency to not break the limits set out in Section 2.1.1 in the event that an outage of the LIF occurs, is around 75%.

A summary of the DS3 service requirements assumed is shown in Table 1 below.

Table 1: Inertial response and operating reserve requirement assumptions

DS3 Service Requirements	Units	% of LIF	2025	2030	2040
Inertial Response					
FFR: Fast Frequency Response (<0.5s)	*MW*	75%	375	525	525
FFR: Fast Frequency Response (<2.0s)	*MW*	25%	125	175	175
Operating Reserve					
POR: Primary Operating Reserve	*MW*	100%	500	700	700
SOR: Secondary Operating Reserve	*MW*	100%	500	700	700
TOR1: Tertiary Operating Reserve 1	*MW*	100%	500	700	700
TOR2: Tertiary Operating Reserve 2	*MW*	100%	500	700	700

In the second 'constrained' run with DS3 service requirements met by G-UPS systems, we have modelled 500 MW of G-UPS in 2025, and 700 MW in 2030 and 2040. We have not attempted to account for any unavailability of G-UPS systems, e.g. if some are providing emergency backup power and so cannot provide DS3 services at the same time. It may be the case that unavailability of this type means that more than the 500 or 700 MW of G-UPS modelled would need to be online to ensure that the DS3 service requirements are met.

3.3 Results and discussion

3.3.1 Carbon emission savings

By providing DS3 services, the modelled G-UPS systems remove the need for coal and gas-fired power plants to be generating specifically to provide them. The carbon emission savings achieved in

[21] The weekly operational constraints updates state that POR and SOR are sometimes procured at greater than 75%; up to 85% for POR and up to 100% for SOR.

the I-SEM are presented in Figure 8 below. The total carbon saving amounts to 1.4 and 0.6 $MtCO_2$ in ROI and NI respectively in 2025, around 15% of ROI and 30% of NI power sector emissions. By 2040, around 0.8 and 0.5 $MtCO_2$ of carbon emissions are saved in ROI and NI respectively, around a third of the power sector emissions in each jurisdiction.

The emission savings presented result from the effect of 500 MW of G-UPS in 2025, and 700 MW of G-UPS systems in 2030 and 2040. On a 'per MW' basis, around 4 thousand tonnes of CO_2 ($ktCO_2$) can be saved in I-SEM per MW of installed G-UPS systems in 2025. Around 2 $ktCO_2$ can be saved per MW in 2030 and 2040. This trend can be seen in Figure 9 below.

Figure 8: Power sector CO_2 emissions saved by the G-UPS systems

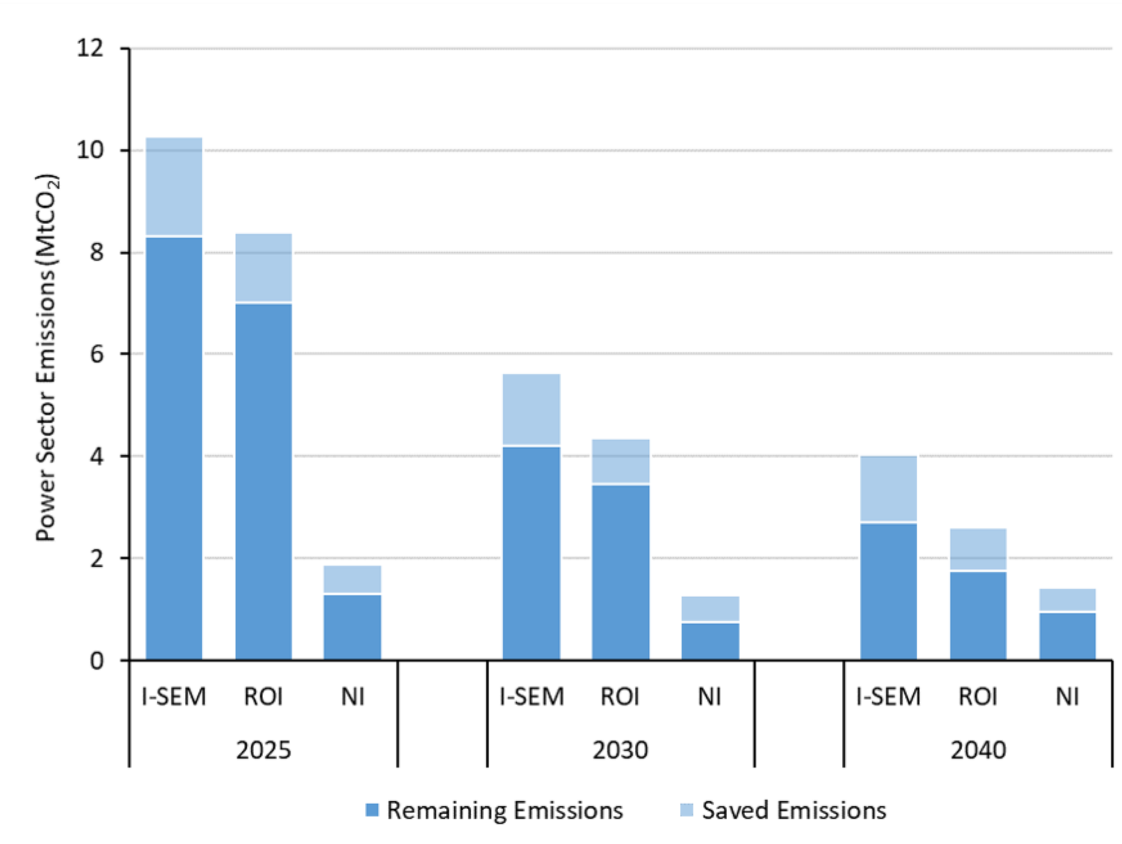
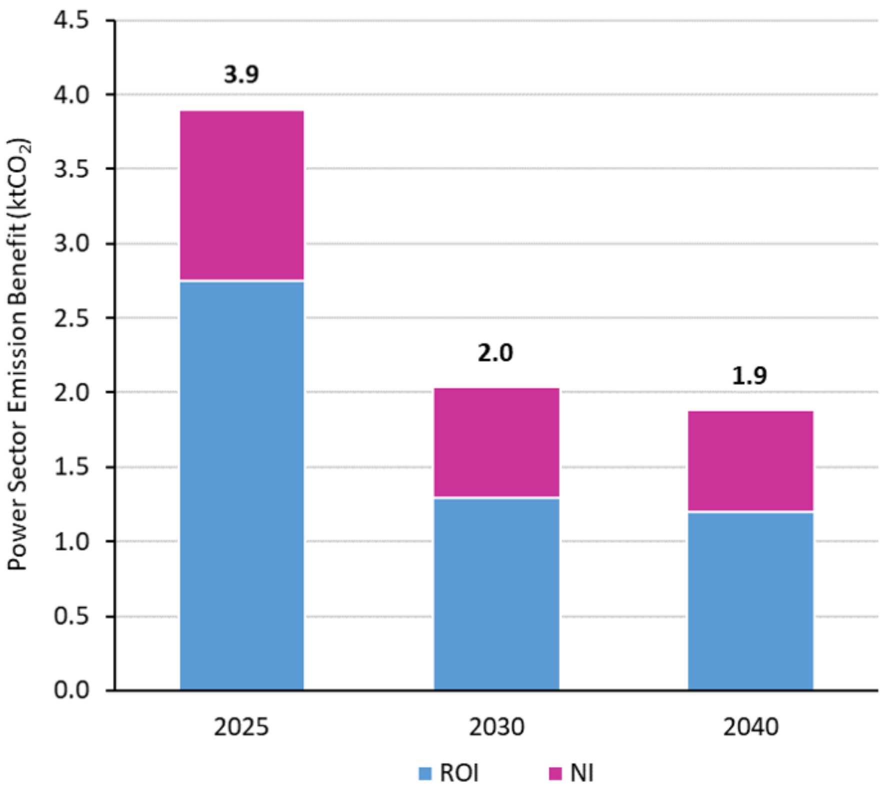


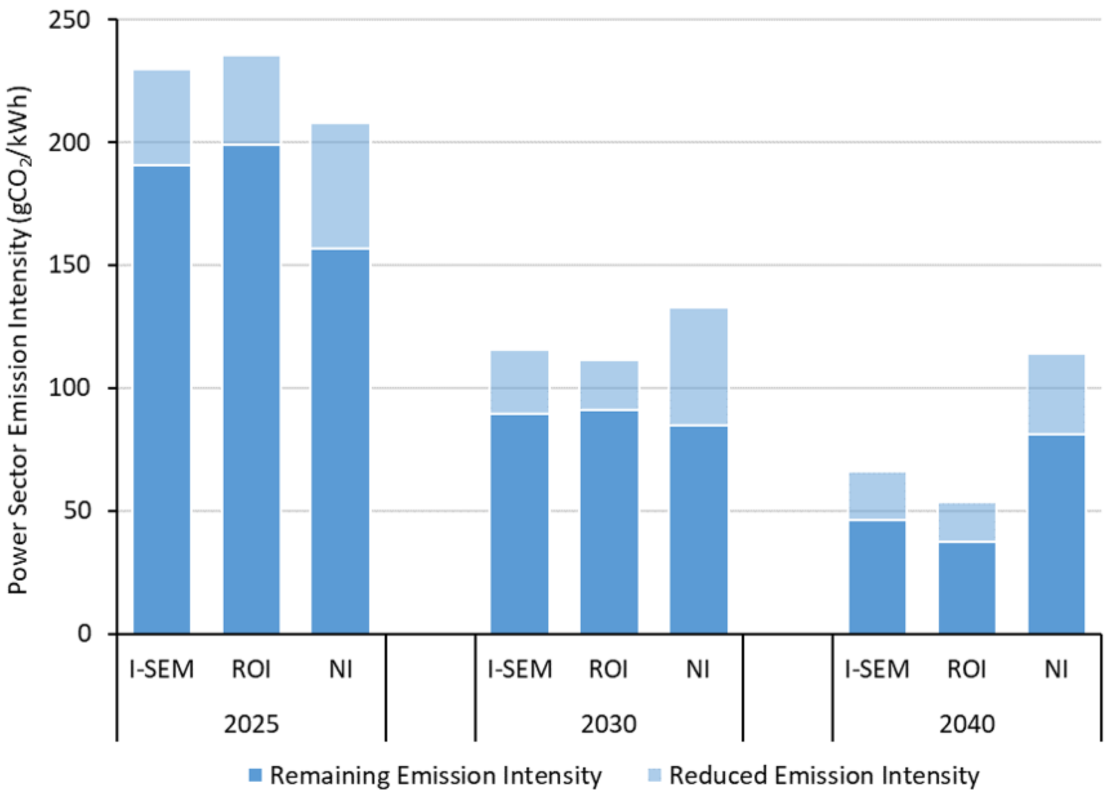
Figure 9: Power sector CO_2 emissions saved per MW of G-UPS



Emission intensity – less CO_2 from every kWh

The total electricity generation in I-SEM increases between and 2025 to 2040 in the model. The grams of CO_2 emitted per kWh of generation (gCO_2/kWh) can be measured as a property called the ‘emission intensity’ of the grid. The displacement of fossil fuel-fired providers of DS3 services by the G-UPS systems reduces the average CO_2 emissions per kWh generated. Figure 10 below presents the emission intensity of the I-SEM grid with and without the G-UPS systems. In 2025, the G-UPS systems reduce the emission intensity of the grid in ROI and NI by around 35 and 50 gCO_2/kWh respectively. In 2040, the ROI and NI emission intensities are reduced by 15 and 35 gCO_2/kWh respectively.

Figure 10: Power sector CO_2 emission intensity savings achieved by G-UPS systems



3.3.2 Consumer cost savings

Keeping fossil fuel-fired power plants running when they otherwise wouldn't be so that they can provide DS3 services increases the cost of electricity to end consumers, from increased fuel and operating costs[22]. The G-UPS systems remove the need for fossil fuel-fired power plants to deviate from the day-ahead schedule in order for DS3 service requirements to be met (there may still be a need for deviation to maintain DS3 limits). The associated cost savings would typically be passed through to end consumers in Ireland as a decrease to the 'imperfections charge' component of electricity bills.

The cost savings achieved by the G-UPS systems are shown in Figure 11 below. Around €270m is saved in ROI in the year 2025. Cost savings are retained in the long-term, with around €250m saved in ROI in 2040. Savings of around €65m are achieved in NI in each year. Around €670k of end consumer costs is achieved in I-SEM per MW of G-UPS in 2025 as shown in Figure 12 below. Around €470k and €440k can be saved per MW in 2030 and 2040 respectively.

All costs presented in Figure 11 and Figure 12 are the costs required to pay generators to meet demand levels, as well as the additional fuel costs they must be paid to maintain DS3 limits and DS3 service requirements. Any additional savings (or costs) that would come from payments for DS3 services have not been assumed.

[22] The costs associated with deviating from the day-ahead schedule to account for DS3 limits and DS3 service requirements are known as 'dispatch balancing costs'.

Figure 11: End consumer power sector costs saved by G-UPS systems

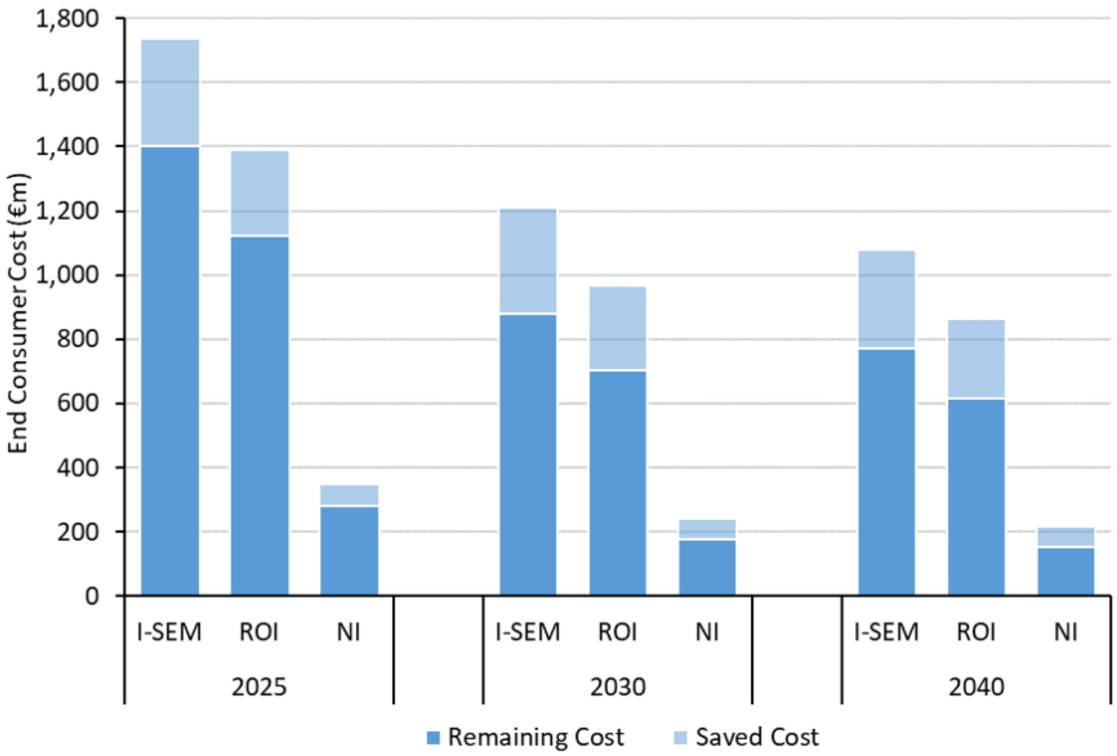
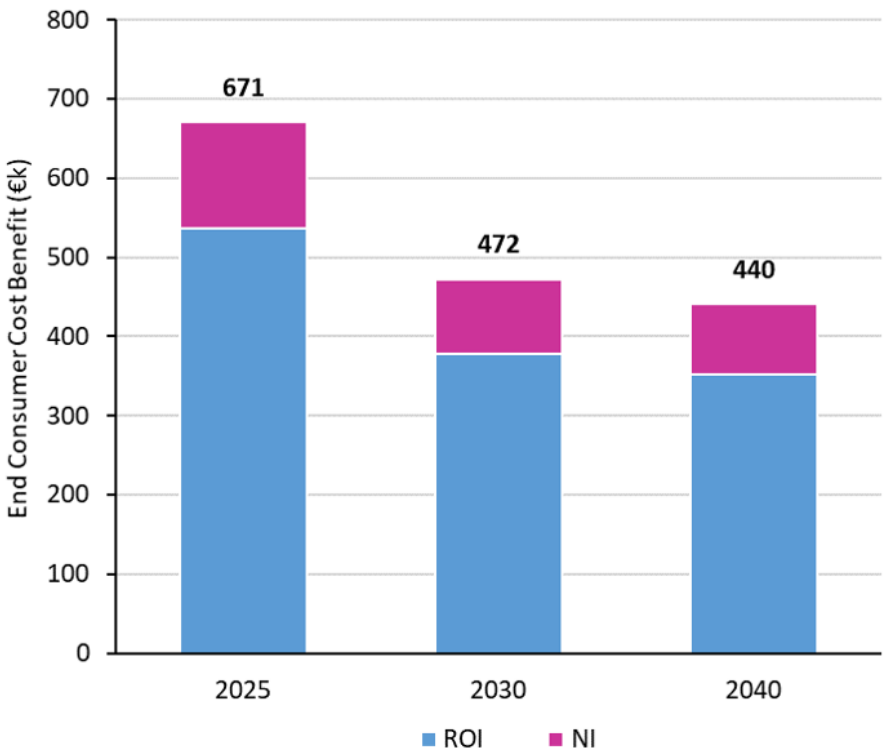


Figure 12: End consumer power sector costs saved by each MW of installed G-UPS

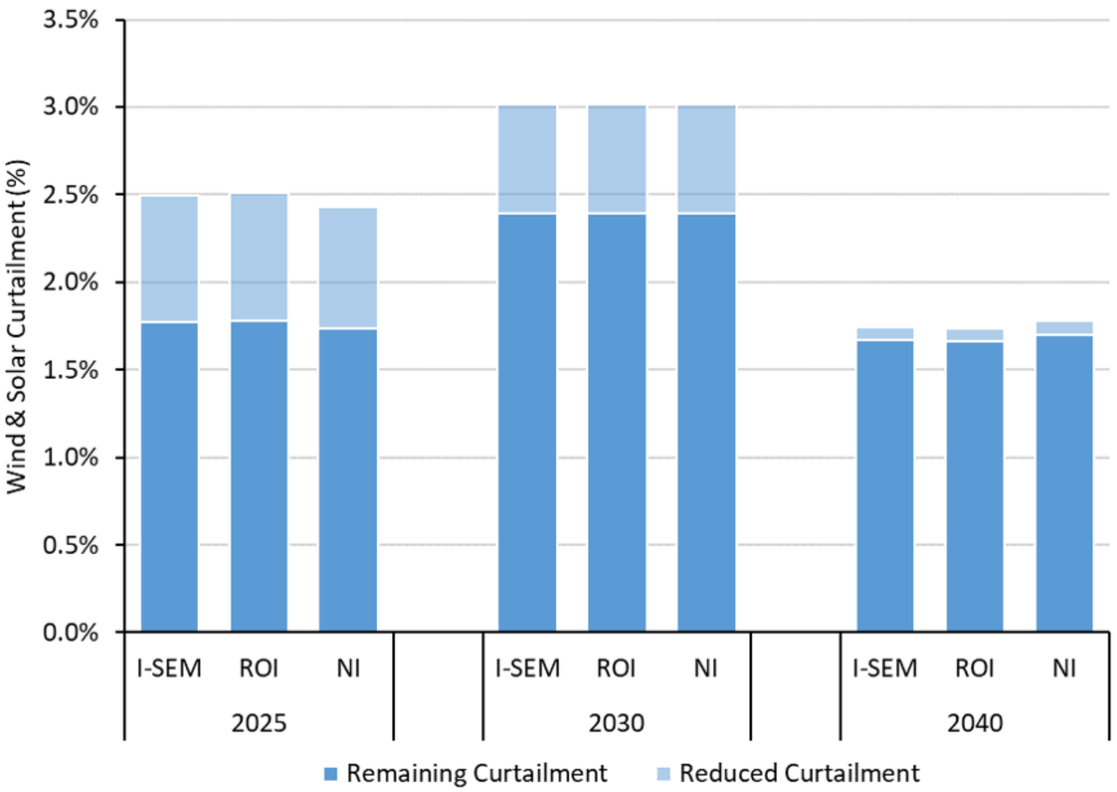


3.3.3 Renewable curtailment benefits

By removing the reliance on fossil fuel-fired providers of DS3 services, the G-UPS systems create space on the grid for renewables that would have been curtailed to accommodate the fossil fuel-fired power plants. This allows the renewable generation on the grid to be closer to the ideal situation of the day-ahead schedule, reducing curtailment levels for these generators[23].

Figure 13 below presents the reductions in curtailment achieved by the G-UPS systems in 2025, 2030 and 2040. Curtailment levels in 2025 are reduced from around 2.5% to 1.8%, with a smaller reduction seen in 2040, around 0.1% in total. Some curtailment remains in all years despite the zero-carbon source of DS3 services. This is because some reliance on fossil fuel-fired power plants is still required to maintain the DS3 limits.

Figure 13: Reduction in wind and solar curtailment levels achieved by the G-UPS systems



[23] 'Curtailment' refers to reduction in generator output ('dispatch-down') resulting from the need to meet DS3 limits and DS3 service requirements. Dispatch-down of renewables can also occur in the day-ahead schedule if the available renewable generation exceeds the total demand for electricity, termed 'oversupply', or after the day-ahead schedule to account for localised transmission bottlenecks in the grid, termed 'constraint'.

4 Conclusions

In this study we have quantified the benefits of zero-carbon DS3 services provided by Grid-Interactive UPS systems installed in Irish data centres. These systems offer an opportunity to reduce the reliance of the I-SEM grid on fossil fuel-fired power plants, reducing power sector carbon emissions and end consumer costs in the process.

If Ireland is to achieve the ambitious targets set out in the *Climate Action Plan* and *Programme for Government*, investment in zero-carbon DS3 services is vital to ensuring that the system is able to operate with sufficient renewable capacity. Given that data centres require backup power supply systems in order to operate, the deployment of G-UPS offers a promising contribution to this ambition.

The results of the modelling conducted in this study indicate three key findings:

- Grid-Interactive UPS systems deployed in Irish data centres would actively contribute towards **power sector decarbonisation**, both in the **Republic of Ireland and Northern Ireland**.
- Displacement of fossil fuel-fired power plants providing FFR and operating reserves would **reduce costs for end consumers**.
- **Renewable generators** would benefit from **reduced curtailment** as the displacement of fossil fuel-fired power plants offers more space on the grid.

Appendix A Inertia from G-UPS systems

A.1 Maintaining two more DS3 limits

As discussed in Section 3.1.3, G-UPS systems have the potential to create synthetic inertia for the grid without the use of fossil fuels. Inertia is required by the grid for stability during outage events; it acts to slow the movement of frequency changes, helping to keep the frequency within the acceptable range of 49.5 – 50.5 Hz.

Minimum Inertia – holding the frequency steady

EirGrid and SONI have defined a DS3 limit, known as the 'Minimum Inertia' limit, to ensure that sufficient inertia is present on the grid. This limit is currently set at 23,000 MWs. The SOs intention however is to decrease this limit, to reduce the reliance of the grid on synchronous fossil fuel-fired power plants.

In this study we have assumed that the Minimum Inertia limit decreases to 15,000 MWs by 2025, and to 10,000 MWs by 2030. In addition, we have assumed that EirGrid's stated intention for no reliance on fossil fuel-fired power plants to meet the Minimum Inertia limit by 2030[24] is achieved and that 10,000 MWs of inertia can be supplied by zero-carbon synchronous condensers in 2030 and 2040. This means that in our assumptions, there is no further requirement on fossil fuel-fired power plants to provide inertia according to the Minimum Inertia limit. However, in certain hours the inertia requirement of the grid can increase beyond this minimum level in order to maintain another DS3 limit.

RoCoF – a frequency speed limit

The 'Rate of Change of Frequency' (RoCoF) limit refers to the maximum rate at which the I-SEM grid frequency can move without the risk of a blackout. As discussed in Section 2.1.1, this limit is maintained at 1 Hz per second. Changes to the power input to the grid alter the frequency, and the larger and faster the change, the faster the frequency moves. Conversely, the greater the inertia on the system, the slower the frequency moves. 17,500 MWs of inertia is required to maintain the RoCoF limit in 2030 when the LIF, the Celtic Interconnector, changes its flow.

Therefore, even if the Minimum Inertia limit is met by synchronous condensers, the additional requirement at times when the Celtic Interconnector changes its flow would need to be met by synchronous fossil fuel-fired plant, or by alternative zero-carbon providers of inertia such as G-UPS systems.

In this Appendix we have modelled the additional benefits of the G-UPS systems to the Irish power sector from their potential to provide synthetic inertia.

[24] http://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-TES-2019-Report.pdf

A.2 Additional benefit results

Each of the benefits modelled is additional to the carbon and cost savings presented in Section 3.3. There may be overlap between the grid benefits associated with DS3 services and inertia, i.e. if the G-UPS systems were configured to provide only inertia, the benefits would be larger than the additional benefits presented in this Appendix.

Additional power sector CO_2 savings

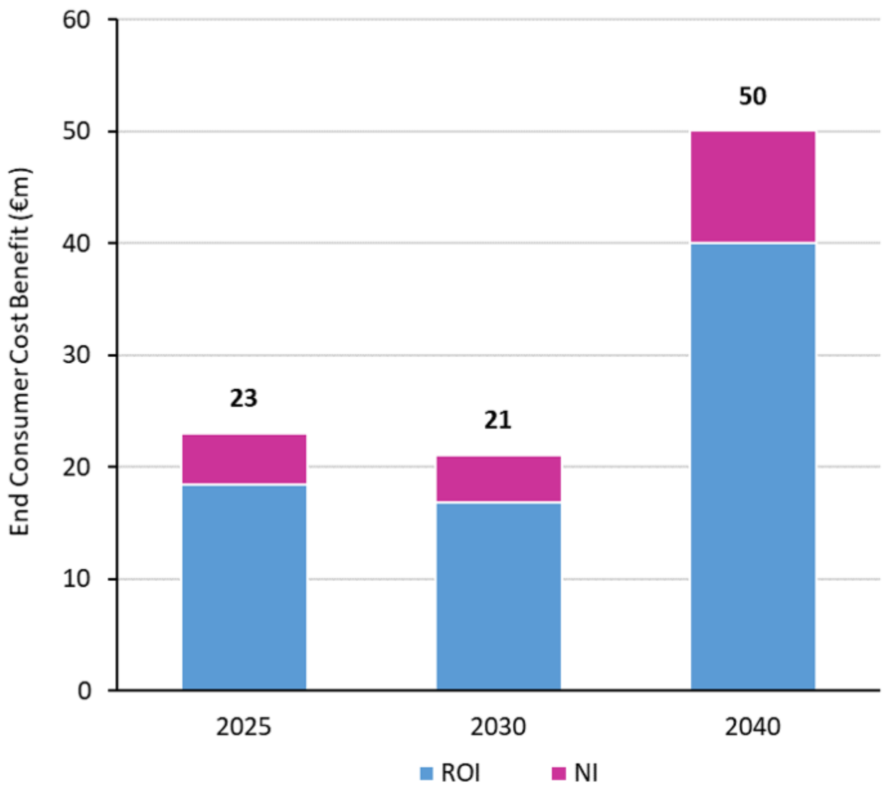
Further displacement of fossil fuel-fired power plants reduces power sector CO_2 emissions in I-SEM. Around 110 ktCO_2 is saved in 2025 and 2030 across ROI and NI as shown in Figure 14 below. The largest savings are observed in 2040, with 200 and 25 ktCO_2 saved in ROI and NI respectively.

Figure 14: Additional power sector CO_2 savings from G-UPS synthetic inertia

Additional end consumer cost savings

The additional cost savings associated with the synthetic inertia provided by the G-UPS systems is presented in Figure 15 below. Around €18m and €5m are saved in ROI and NI respectively in 2025. As with the emission savings, the largest benefits are observed in 2040, with €40m and €10m saved in ROI and NI respectively.

Figure 15: Additional end consumer cost savings from G-UPS synthetic inertia



Appendix B Tabulated input assumptions

I-SEM Input Assumptions	Units	2025	2030	2040
G-UPS Battery Assumptions				
Maximum generation duration	*Minutes*	5	5	5
Recharge time	*Minutes*	42	42	42
Inertia constant[25]	*s*	25	25	25
DS3 Limits (Operational Constraints)				
System Non-Synchronous Penetration (SNSP) limit	*%*	80%	95%	95%
Rate of Change of Frequency (RoCoF) limit	*Hz/s*	1.0	1.0	1.0
Minimum inertia limit	*MWs*	15,000	10,000	10,000
System stability minimum units - I-SEM	*#*	5	4	3
System stability minimum units - ROI	*#*	0	0	0
System stability minimum units - NI	*#*	1	1	1
Inertial Response Requirements				
FFR: Fast Frequency Response (<0.5s)	*MW*	375	525	525
FFR: Fast Frequency Response (<2.0s)	*MW*	125	175	175
Operating Reserve Requirements				
POR: Primary Operating Reserve	*MW*	500	700	700
SOR: Secondary Operating Reserve	*MW*	500	700	700
TOR1: Tertiary Operating Reserve 1	*MW*	500	700	700
TOR2: Tertiary Operating Reserve 2	*MW*	500	700	700
Interconnection Capacity				
Import from GB	*MW*	1450	1450	1450
Export to GB	*MW*	1500	1500	1500
Import from France	*MW*	0	700	1400
Export to France	*MW*	0	700	1400
Commodity & Carbon Prices				
Coal CIF ARA	*$/tonne*	74	74	72
Gas NBP	*p/therm*	53	60	64
Oil Brent	*$/bbl*	65	76	88
Carbon EUA	*€/tonne*	52	52	60

[25] The inertia constant (measured in s) is a measure of the inertia (measured in MWs) produced per MW of electricity generated or consumed. This has only been considered in the modelling presented in Appendix A.

ROI Input Assumptions	Units	2025	2030	2040
Electricity Demand				
Annual demand[26]	*GWh*	36,840	40,710	47,000
Peak demand	*MW*	6,260	6,640	7,620
Renewable Generation Capacity				
Onshore wind	*MW*	4,950	6,160	7,300
Offshore wind	*MW*	860	2,390	3,860
Solar PV	*MW*	300	740	1,170
Hydro	*MW*	220	220	220
Biomass	*MW*	130	200	200
Waste-to-energy	*MW*	90	90	90
Fossil Fuel-Fired Generation Capacity				
Coal	*MW*	860	0	0
Gas	*MW*	4,410	4,200	4,350
Oil	*MW*	940	790	620
Peat	*MW*	0	0	0
Energy Storage Capacity				
Battery storage	*MW*	760	980	1,220
Pumped hydro storage	*MW*	290	290	290
Synchronous Condenser Capacity				
Synchronous condenser	*MWs*	0	8,000	8,000

[26] Annual demand figures exclude exports and demand from energy storage capacity.

NI Input Assumptions	Units	2025	2030	2040
Electricity Demand				
Annual demand	*GWh*	9,210	10,180	11,750
Peak demand	*MW*	1,570	1,660	1,900
Renewable Generation Capacity				
Onshore wind	*MW*	1,540	1,950	2,540
Offshore wind	*MW*	0	270	500
Solar PV	*MW*	440	740	1,170
Hydro	*MW*	0	0	0
Biomass	*MW*	0	0	0
Waste-to-energy	*MW*	30	30	30
Fossil Fuel-Fired Generation Capacity				
Coal	*MW*	0	0	0
Gas	*MW*	1,790	1,800	1,850
Oil	*MW*	350	230	170
Peat	*MW*	0	0	0
Energy Storage Capacity				
Battery storage	*MW*	190	240	300
Pumped hydro storage	*MW*	0	0	0
Synchronous Condenser Capacity				
Synchronous condenser	*MWs*	0	2,000	2,000

Appendix C About Baringa

We set out to build the world's most trusted consulting firm – creating lasting impact for clients and pioneering a positive, people-first way of working. We work with everyone from FTSE 100 names to bright new start-ups, in every sector.

You'll find us collaborating shoulder-to-shoulder with our clients, from the big picture right down to the detail: helping them define their strategy, deliver complex change, spot the right commercial opportunities, manage risk, or bring their purpose and sustainability goals to life. Our clients love how we get to know what makes their businesses tick – slotting seamlessly into their teams and being proudly geeky about solving their challenges.

We have hubs in Europe, Asia, and Australia, and we work all around the world - from a wind farm in Wyoming to a boardroom in Berlin. Find us wherever there's a challenge to be tackled and an impact to be made.

Our Energy Advisory practice offers a full spectrum of specialist advisory and analytical services, and transaction execution support. We bring together an unparalleled knowledge of the European energy sector and a quantitative approach built on evidence-based insight and powerful analytics. Our work is informed by knowledge of markets, regulation, assets, operations and capital, and in-depth insight into their interdependencies and the impact of their interactions. We provide our clients with a unique combination of flexibility, pragmatism, and intellectual rigour.

Ireland has been a key focus market for Baringa for many years, and we have developed an extensive knowledge of the Irish energy sector through a long track record of engagements with regulators, utilities, project developers, investors, and banks. We were heavily involved in the regulatory and operational aspects of the transition to I-SEM and DS3. We advise on asset investments, hedging and trading strategies, retail strategies, regulatory issues, market arrangements, modelling capabilities, and I-SEM business and IT preparation. We have acted as independent market advisors on the majority of the major energy sector transactions in recent years – on the buy-side, sell-side and for debt financing. Lenders frequently rely upon our analysis to make debt-finance decisions.

We have been voted as the leading management consulting firm in the Financial Times' UK Leading Management Consultants 2022 in the categories Energy, Utilities & the Environment, and Oil & Gas. We have been in the Top 10 for the last 15 years in the small, medium, as well as large category in the UK Best Workplaces™ list by Great Place to Work®. We are a Top 50 for Women employer, and are recognised by Best Employers for Race.

Find out more at baringa.com, or on LinkedIn and Twitter.

For further information,
please contact:

Dr Mark Turner,
Partner
+44 7584 290310
Mark.Turner@baringa.com

Alec Granville-Willett,
Senior Consultant
+44 7948 687254
Alec.Granville-Willett@baringa.com

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enquiries@baringa.com

Headquarters: London (UK) | Belgium | Ireland | Germany | Australia | Singapore | USA |