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RENEWABLE ENERGY AND STORAGE
AN ECONOMIC ASSESSMENT OF POLICY REQUIREMENTS IN IRELAND AND THE EU

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Contents

Executive Summary

Renewable energy targets across Europe and the intermittent nature of renewables have necessitated an increase in energy storage development. Across Europe, member states have developed a range of policies to foster the development of energy storage [1-3], however many countries, including Ireland, have set renewable energy targets without developing a strategy for storage. Barriers to storage development include high capital costs, [4] regulatory issues [5], the absence of national policies [6], and a lack of financial incentives for the renewable energy sector to engage with storage [7, 8].

Despite the significant economic, environmental and social gains to be derived from increased level of energy storage [9], particularly in relation to increasing the amount of renewable energy on the grid [10], many countries lack the policy incentives and national framework required to nurture large scale investment in storage [11, 12]. Therefore, the first aim of this document is to assess cross-EU policy-maker attitudes to the current state of energy storage policy and to identify which policies may be required on a broad basis.

Secondly, for policy makers and the renewable energy industry, it is important to identify the attributes of energy storage that are most required by the renewable energy sector. Ireland is currently developing energy storage policy, and as of yet has not established what technologies are being considered by the renewable energy industry, what the renewable energy sector views as barriers to investment and which policies would increase the likelihood of engagement with storage. The second objective of this study is to identify the barriers to and opportunities for storage as well as the economic value of improved storage policy for this sector in Ireland.

This study utilises surveys with STEPS EU partners to establish which policies are required at EU level as well as focus groups, interviews and a choice experiment survey with the renewable energy and storage industry in Ireland to measure the potential economic impact of policy changes.

The EU partner results indicate that, across our partner countries there is a low level of satisfaction with the current level of energy storage development and with current policy mechanisms. Most respondents believe that a range of energy storage technology will be required, particularly to provide support to the grid and balance intermittency. None of the respondents believe that 2030 targets will be achieved without increasing the level of storage and most believe that the current level is not sufficient to even support current renewable energy development.

The EU level results indicate heterogeneity in preferences for policy improvements; however most respondents indicate positive preferences for policies which provide simple and transparent incentives for the renewable energy sector to engage with storage and address the need for increased financial support for storage. Most of the partners agree that the level of public knowledge on storage is not sufficient to support the development of community-led storage. Although hydrogen storage has the potential to create novel markets for wind energy, supports for storage in general rather than targeted hydrogen policies are preferred. National targets, which may include targets for hydrogen, help form a framework for the development of storage and provide a useful signal to the market but without financial incentives, targets are not sufficient.

As the previous results of the EU partner study indicate, the national study of the renewable energy and storage sector in Ireland indicate that a range of technologies are likely required to support the electricity system. Most survey respondents had some experience with storage or have plans to engage with storage solutions with hydrogen, battery and thermal storage technologies being the most frequently referenced. The main motivating factors for the renewable energy sector to engage with storage, according to the interview and focus group respondents appear to be minimising curtailment, increasing the amount of stored renewable energy behind the metre and receiving an additional revenue stream. Most survey respondents who generate renewable energy expect the average level of dispatch down to increase in the future, forming an incentive to invest in storage. Most survey respondents agree that storage offers a good solution to a range of issues including reducing curtailment and supporting the grid; however Principal Component Analysis of attitudinal statements indicates the presence of heterogeneity, with some respondents being sceptical of the merits of storage in general, long-duration storage and the hydrogen market in particular.

In terms of barriers to storage development in the renewable energy sector, focus groups and interviews indicate a lack of government policy support, a lack of equity finance, the limited development of the offshore wind sector, restrictions in the way financial supports are set up, the lack of a dynamic trading market, supply chain barriers, skills shortages, limitations to community development, possible public acceptance issues related to the scale of storage development and potential health and safety concerns. Survey responses echo this, with most indicating that policy supports, incentives, public knowledge and the market for green hydrogen are currently poor in Ireland and that trading in the ex-ante market is risky. However, the Principal Components Analysis highlight a cohort of comfortable investors who are less likely to believe that trade in the ex-ante market is risky, that there are barriers to trade or that there are a lack of business cases for storage. In the choice experiment results, across all models, respondents indicate preferences for changes to current policies. The choice experiment results also indicate heterogeneity in the sample, with one group indicating insignificant preferences for reduced dispatch down levels and policy changes greater than a basic storage target, but strong positive preferences and high willingness to pay (WTP) values for medium and long-duration storage incentives. However, the majority of respondents are WTP to reduce dispatch down levels through storage and to change current policy to allow for direct supports for a “Green Grid” policy, which would allow renewable energy developers to store green energy pulled from the grid. The economic value of further dispatch down reductions from 10%-80% through storage to the majority of survey respondents equates to an average WTP value per person of €22,200 annually in DS3 payments or €36 per MWh through RESS. The introduction of the Green Grid policy for this cohort represents approximately €31,800 annually through DS3 or €52/MWh through RESS.

This study provides a number of recommendations that could improve the level of energy storage development at EU and national level:

- Europe-wide campaign providing information on need for storage, technology, costs and benefits, scale and health and safety.
- Create supports for the development of Renewable Energy Communities and Community Energy Storage.
- Develop homogenous definition of storage across EU and remove barriers to engagement in the ex-ante market.
- Set EU level and national targets for storage.
- Publish Irish Electricity Storage Policy Framework and Hydrogen Strategy.
- Include plans for the creation of additional funding supports as part of the Irish Electricity Storage Policy.
- Prioritise renewable energy supply to the grid before conversion and the development of green hydrogen over other forms of hydrogen.
- Include skills required by energy storage sector in renewable energy employment strategies.
- Make changes to RESS policy to permit storage of renewable power from the grid.

1. Introduction

Across Europe, renewable energy targets require a steep increase in the development of intermittent energy such as wind and solar. Ireland, for example, has committed to generating 80% of its electricity from renewable sources by 2030. This will be met primarily by wind energy, with Ireland committing to the development of 8GW of onshore wind and 5GW of offshore wind by 2030 as well as a further target of 37GW of offshore wind by 2050 [13, 14]. For many renewable energy resources such as solar and wind, it is necessary to extract energy when it is available and stored until required. Energy systems can benefit from applying energy storage in a number of ways, including the increased penetration of renewable energy sources [10] and greater financial outcomes [15, 16]. Additionally, energy storage enables load levelling and peak shaving, frequency regulation, dampens energy oscillations, and improves the power quality and reliability of electricity [17]. Due to the correlated nature of wind or solar power between many countries, energy storage also offers a method of absorbing this energy that would otherwise have to be rejected [18].

The intermittent nature of renewables can create a number of issues including electricity outages [19], efficiency concerns [20], international trade issues [21], and curtailment of energy [22]. There is potential for the renewable energy sector to address intermittency through storage and, across Europe, member states have developed a range of policies to foster the development of energy storage including energy storage targets [1], capital support schemes [2], R&D initiatives [3], energy offtake agreements [23] and auctions for capacity provision and fast frequency response [24], amongst others. However, many countries; including Ireland; have set renewable energy targets without incorporating clear plans for energy storage, which may pose a risk to target achievement based on the intermittent nature of renewable energy [25]. In Ireland and elsewhere there remain barriers to storage development including high capital costs, [4] regulatory issues [5], the absence of national policies [6], and a lack of financial incentives for the sector to engage with storage [7, 8]. There is currently an uneven development of storage across Europe [26], a low level of hybrid renewable energy-storage developments in Ireland [27] and it is not known what policies could influence the level of uptake of storage by the renewable energy sector.

1.1. Level of energy storage in Europe

Figure 1 highlights the level of installed storage capacity (GW) and the number of storage facilities that have been developed, or are at various stages of completion in Europe as of December 2021. In terms of number of facilities, the UK is the clear leader, with 72 operational facilities, 5 under construction and 152 authorised at the time of data collection. The total capacity of these 229 developments is 8.5

GW. Ireland ranks 13th of the countries studied in terms of total number of facilities being developed, with 2 authorised, 3 in the bidding process, 6 operational and 2 under construction at the time of data collection. In total, this amounts to about 0.7GW of storage capacity. Adding announced projects to the analysis increases Irelands total number by 29 facilities, and the total capacity by almost 2.3GW, moving Ireland's ranking to 6th in terms of number of storage facilities.

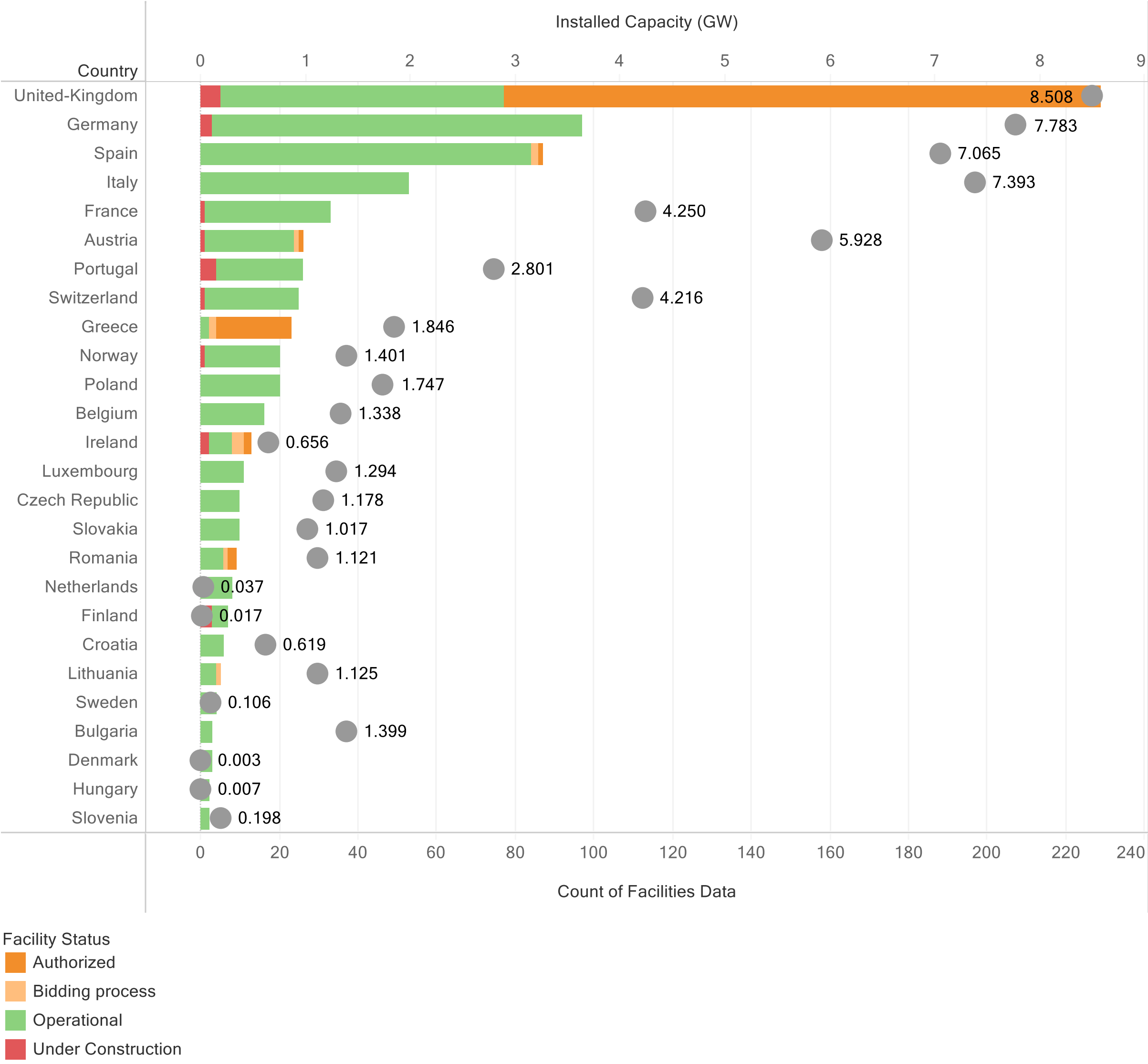

Figure 1: Installed capacity (GW) & number of facilities by facility status and country (Data source: [26])

Figure 2 breaks down the capacity according to technology type. In the UK, the majority of the new projects being developed involve electrochemical technology, which is comprised mainly of batteries, including Sodium sulfur (NaS) batteries and lithium-ion batteries which are the most commonly used battery technology (see Section 2.3.4. for a breakdown of common storage technologies). In total, these projects provide 3.97 GW of the UKs total storage capacity, while the majority of the UKs capacity is being met by mechanical storage either in the form of pumped hydro storage; PHS; (4 GW) and other mechanical forms such as flywheels and liquid air energy storage (LAES). PHS is the most common mechanical storage type across Europe and is the largest capacity provider technology in Europe, providing over 90% of the total storage capacity for Germany, France, Austria and many others.

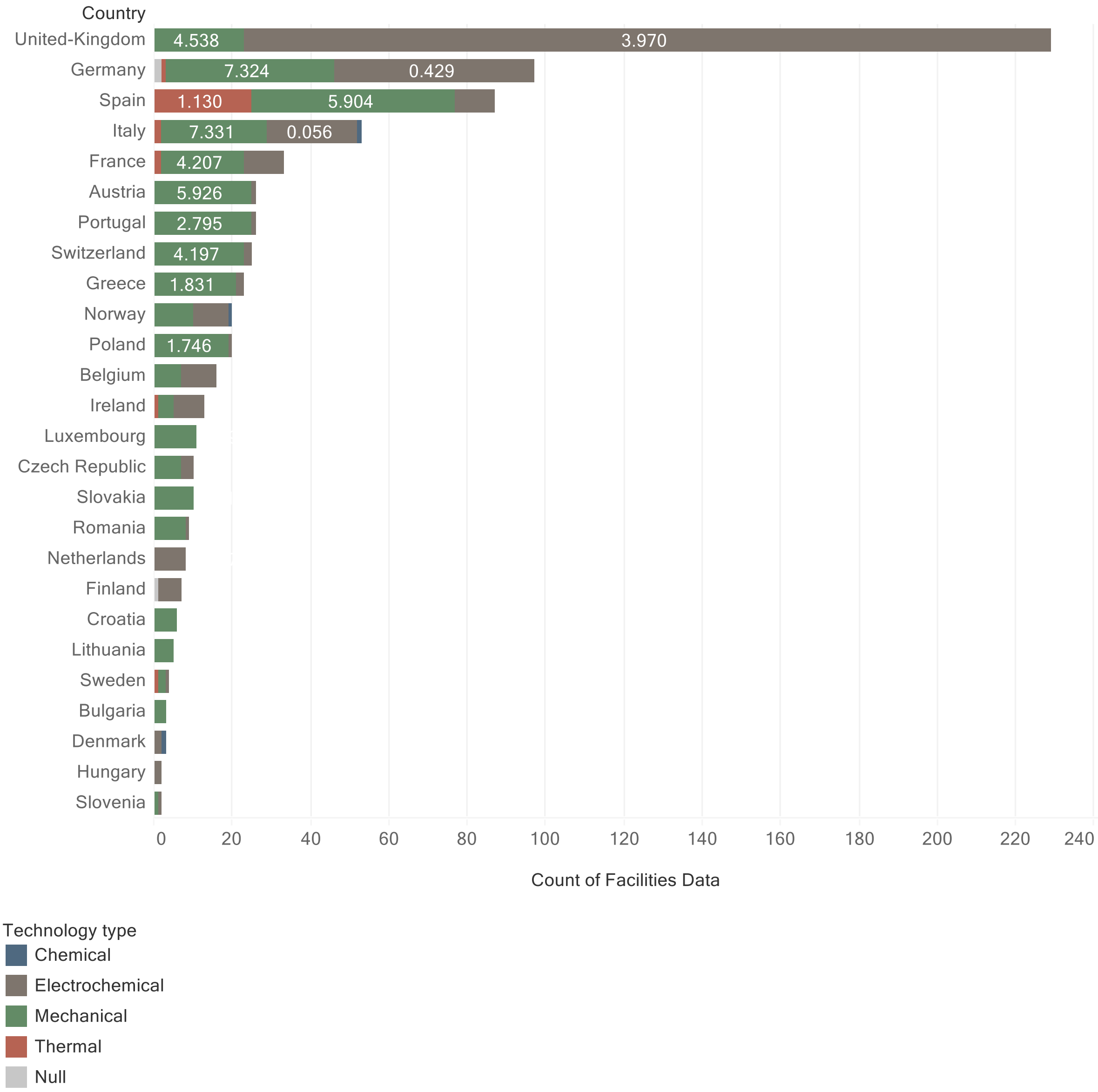

Figure 2: Installed capacity (GW) & number of facilities by technology type and country (Data source: [26])

In Ireland, PHS provides about 0.3 GW of capacity storage, with the remainder coming from battery storage facilities (0.3 GW) and a small amount of thermal storage (4.6MW). In terms of announced projects, Ireland has two additional PHS projects, the Silvermines project in Tipperary with an additional potential 360MW of installed capacity, and the MAREX project in Mayo, offering additional 750MW of capacity. Ireland also has a further 27 battery storage projects with a potential total capacity of 0.5GW.

Figure 3 analyses the commissioning year and installed capacity for grid connected energy storage projects in 3 countries in Europe, the UK, Ireland and the Netherlands. The UK's first large scale PHS project was developed in 1963 in Wales, offering a total installed capacity of about 0.4 GW.

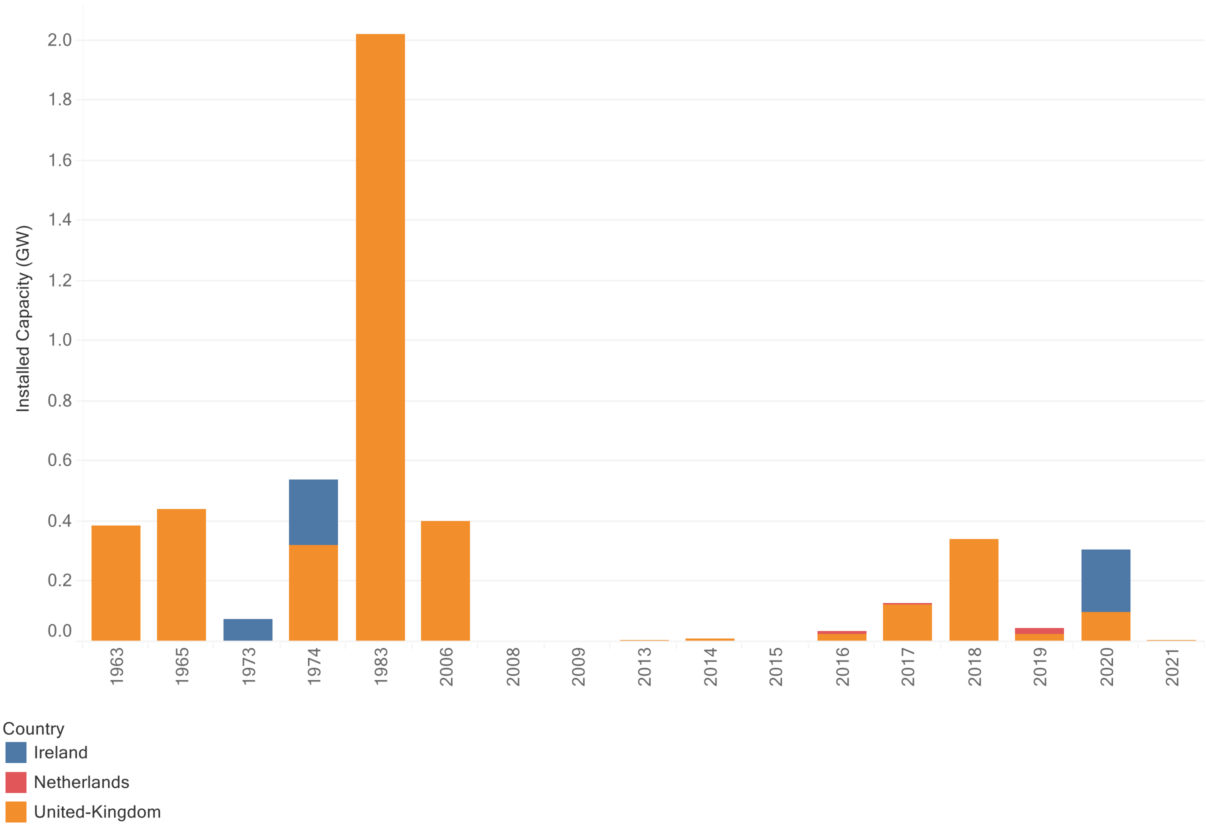

Figure 3: Installed capacity in Ireland, the Netherlands and the UK, 1963-2021. (Data source: [26])

Another PHS project was commissioned two years later in Scotland, with a total capacity of approximately 0.4 GW. Ireland commissioned its first PHS project in 1973 and 1974, Turlough hill, with a total capacity of about 0.3GW. Another PHS was developed in Scotland in 1974. In 1983 the Dinorwig PHS project was commissioned in Wales. It took 10 years to build, cost £425 million and is the largest scheme of its kind in Europe [28, 29]. Following this, no new storage projects were commissioned until 2006 when the 0.4GW EFDA JET Fusion Flywheel Energy Storage System was launched in England. The majority of the development from 2013-2018 consisted of battery storage projects in the UK. In 2016, the Netherlands developed their first stand-alone energy storage project, a 10MW li-ion battery storage project. Two further small-scale battery storage projects were commissioned in 2017 and a further two in 2019. Two large-scale and one smaller scale battery storage projects were commissioned in Ireland in 2020, totalling about 0.2 GW of capacity, along with a li-ion project in the UK offering up to 0.1GW of capacity. An additional small LAES test project was commissioned in the UK in 2021.

1.2. Energy storage policies in Europe

Across Europe, states have developed a range of energy storage policies aimed at addressing various challenges to development. Table 1 outlines a summary of some of the policies that have been established.

Table 1: Examples of energy storage policies by country

Country	Policy Type	Description
Austria	Research and Development	Government funding for innovative photovoltaic projects, including those with electricity storage up to 150kWh net storage volume [30].
Croatia	Capital Funding	State funding for grid connected battery storage systems to balance supply and demand [2].
Czech Republic	Research and Development	German-Czech research collaboration to develop thermal energy storage systems [3].
Denmark	Targets	Strategy to promote energy export through green hydrogen. Aim to build 4-6 GW of electrolysis capacity by 2030 [1].
Estonia	Capital Funding	Government funding of €8 million for energy storage as part of the EU Recovery and Resilience Plan [31].
France	Research and Development	€1.1 billion of funding to support new technology development in decarbonised energy, energy storage, bio resources, low carbon buildings and carbon capture and storage[32].
Germany	Renewable Energy Auctions	Energy storage is encouraged through innovation auctions which reward renewables paired with storage [24].
Greece	Capital Funding	Funding at a municipality level for projects that achieve a range of priorities including renewable energy and storage [33].
Hungary	Research and Development	EU funded project to develop, test and evaluate innovative flexibility solutions, including storage to support the expansion of renewable energy [34].
Italy	Targets	National Hydrogen Strategy Preliminary Guidelines set targets for 2% hydrogen penetration and 5GW of electrolysis capacity by 2030. By 2050 target is 20% including energy storage in the power sector [35].
Lithuania	Capital Funding	EU, National and private financing for large scale energy storage development [36].
Netherlands	Trade Agreements	Netherlands has established hydrogen MoUs with Canada, Denmark and Portugal. Netherlands will invest 1 billion DKK in Denmark to establish Power to X plans, and develop storage and renewable energy technology [23, 37, 38].
Poland	Capital Funding	Under the Polish National Recovery Plan, investments will be made in the development of hydrogen technology, production and storage [39].
Portugal	Renewable Energy Auctions	Energy storage included in renewable energy auction to procure up to 100 MW of storage[40].
Spain	Research and Development	Plan and call for projects to boost domestic production of renewable energy and low-carbon hydrogen [41].

Sweden	Tax Incentives	Tax deductions for private individuals who invest in solar, charging stations and solutions for energy storage of self-generated electricity [42].
UK	Capital Funding	North Sea Transition Deal- joint government, oil and gas sector investment of up to £10 billion for hydrogen production, Glasgow awarded £9.4 million for new hydrogen project at UK's largest onshore windfarm [43].

One of the barriers to the development of energy storage is the cost of capital infrastructure, which can vary depending on the type of technology utilised. Several countries, including Croatia, Estonia and the UK have adopted policies to tackle capital cost issues. Some have used state funding to develop large-scale storage to help balance the grid [2], others have invested in new green storage to transition from reliance on fossil fuels [43] and some have provided capital support funding to develop storage at a local level [33]. Other local level solutions include tax incentives for electricity storage for households [42].

In order to produce novel energy storage solutions, many countries have invested in R&D, including the provision of state funding for innovative co-development projects [30] and new energy storage systems [32, 34].

Some countries incentivise the development of energy storage through national targets, particularly in green hydrogen production and storage [1, 35]. Several trade and off-take agreements related to green hydrogen have also been signed between countries [23, 38, 44].

Allowing for support payments for energy storage providers through energy auctions can also incentivise investment. Several countries have included provision for storage or renewable-co development with storage as part of their auction support system [24, 40].

Policy Spotlight: The Netherlands

As can be seen from the data in Fig. 3, the Netherlands has not developed any large-scale energy storage projects to date, and although there have been some energy storage projects developed that aren't included in this data, such as hybrid solar/wind energy and storage projects and local level storage [45], the level of development has lagged behind other countries in Europe.

In a letter to the Netherlands government, Energy Storage NL; the representative body for the Dutch energy storage sector; outlined the primary reasons for this [11]. They indicate that in the Netherlands there is no profitable business case for energy storage partially due to the lack of incentives and legal and regulatory barriers. They outline a lack of national targets for providing flexible capacity services and the absence of a roadmap from government. Storage is not included as part of offshore wind energy tenders. They also argue that TSO transmission tariffs are much higher than neighbouring countries for storage systems. Producers, such as wind, solar and gas plants do not pay these transportation tariffs, which are instead paid for by the consumer. Energy storage systems are treated as consumers of electricity and so face these additional charges. Energy storage is not included in Dutch energy legislation, which means that storage cannot be pooled with solar or wind behind one connection. They argue there is a lack of clarity and data from grid operators about current grid congestion, which means that it is difficult to calculate the possible additional societal benefits from utilising energy storage. They also argue that the high investment cost of producing hydrogen storage is a barrier to development.

The Netherlands has made steps to develop a hydrogen market, signing trade deals in 2021 with Canada to cooperate in hydrogen development [37] and in 2022 with Denmark to import 8-16 TWh of renewable energy to the Netherlands and to invest DKK 1 billion in large scale Power-to-X plants in Denmark [23]. In March 2023, the Dutch government announced the site for the world's largest offshore wind-to-hydrogen project, which could provide 500 MW of electrolysis capacity. This is planned to be operational in 2031 [46].

Policy Spotlight: The UK

As indicated in the previous figures, the UK is considered a world leader in the deployment of energy storage projects. The increase in new storage projects over the past number of years, adding a record 800MWh of new utility storage in 2022 [47]. This success is largely due to the government's high prioritisation of storage as a key component of achieving a net zero carbon economy. The UK has more installed offshore wind capacity than any other country, being home to 34% of total offshore installations [48]. Offshore wind is expected to provide one-third of the UKs electricity by 2030 [49]. Growth in battery storage development began in 2016, due to the launch of the Enhanced Frequency Response auction, a 200 MW auction to provide grid system services, which resulted in about £66 million of investment in new storage assets [50]. The success of this auction led to an increase in new applications in subsequent years, mainly in stand-alone projects [51]. In 2020, the government published its Ten Point Plan for a Green Industrial Revolution [52], which included aims to develop 40 GW of offshore wind by 2030, and to build more storage to support it. In order to support the development of intermittent renewables, in 2021 the UK government launched the Longer Duration Energy Storage Competition, which would provide £68 million in funding for storage projects. In 2021, the UK government also launched the largest ever round of their renewable energy auction scheme, Contracts for Difference (CfD) [53], which for the first time included a clause permitting co-location with storage and importation of energy from the grid, without the need for a separate balancing mechanism unit. Under this clause, only energy generated from the generating unit is eligible for CfD settlement and energy exported from the storage facility is not eligible [54]. In August 2021, the government published the UK hydrogen strategy, which outlines a roadmap for the creation of a hydrogen economy [55]. The government is aiming for 1 GW of production capacity by 2025 and 5GW by 2030 to be supported by a range of network and infrastructure policies, regulatory and market frameworks, grant funding and research and innovation. As part of the North Sea deal, the government agreed to provide £10 billion in joint government, oil and gas sector investment in the production of hydrogen [56]. In February 2022, 28 storage projects received funding worth £6.7 million to develop innovative solutions for renewable energy storage including thermal batteries, and hydrogen conversion [57]. Later that same year, 5 energy storage projects received a total £32 million in government funding [58]. In 2023, the government outlined plans to legislate to clarify the definition of electricity storage as a distinct subset of electricity generation in the 1989 Electricity Act. It is hoped that this will provide long-term certainty for storage in current and future planning and licencing frameworks and allows flexibility to treat storage as distinct from other forms of generation where appropriate. This legislation is designed to remove regulatory and policy barriers to storage development [59].

1.3. Renewable energy in Ireland

Due to high wind speeds, particularly along the west coast, its unique position in the Atlantic Ocean and from its large ocean footprint, Ireland has a comparative advantage in wind energy over other European countries and has therefore focussed on this form of energy as the primary vehicle to achieve its renewable energy targets [60]. Ireland's marine territory spreads far beyond its coastline, covering approximately 220 million acres meaning its potential capacity for offshore wind energy is extremely large [61].

The first wind farm was connected in the west of Ireland in 1992. Following this, no other wind farms were connected until 1997. Development has steadily picked up pace, with over 300 wind farms currently built in the Republic and just under 400 including Northern Ireland [62]. The Irish government has introduced a target of up to 80% electricity generation from renewable sources by 2030, which is a significant increase from its current level of 36%, most of which will be derived from wind energy [13]. This will require up to 8 GW of onshore wind capacity; which is almost double the current capacity. In its Climate Action Plan, Ireland has set a target of 5 GW of offshore capacity by 2030 [63], a significant increase from the current baseline of 25MW, and has recently announced targets for 2 GW of floating offshore wind by 2030 dedicated to green hydrogen and electricity production for export to the EU and UK [64]. As part of the North Seas Energy Cooperation, Ireland has outlined further aims to develop 37 GW of offshore wind by 2050 [14].

Almost all wind farms in Ireland feed their power into the grid, where it is traded in the Integrated Single Electricity Market (I-SEM), a system that includes multiple auctions which span various time frames and have separate clearance procedures. The goals of this system are to integrate power markets and provide cost reductions [65]. If there is no need for the energy when it is produced, it must either be stored or exported. The Moyle interconnector in the North and the East West interconnector in the Republic connects Ireland to the United Kingdom. Ireland was a net importer of energy in 2021, bringing in 1,672 GWh, the most since 2014. Poor wind energy output in that year resulted in a shortage of domestic electricity supply. Due to technical issues, gas-powered electricity production in Ireland also decreased by 7% in the same period compared to 2020 [66].

The problem of renewable energy intermittency may be avoided by utilising energy storage. When production outpaces demand, excess wind energy may be stored and used when demand increases. This helps to smooth out any possible peaks and troughs associated with intermittent renewable energy. The Electricity Supply Board (ESB) in Ireland provides battery solutions to major power consumers so they may charge at low tariff hours to avoid peak prices. [67]. Ireland is a relatively young adopter of energy storage, but the country has seen rapid growth. One of Europe's largest battery storage projects, located in the Irish midlands, came online in December 2020, and the country has announced plans for an additional 1GW of storage over the whole island. [68].

1.4. Research objectives

One of the core aims of the STEPS project is to connect businesses with energy storage providers based in Europe to ensure that the correct storage technology is being developed to meet demand and that this can be developed locally. Many innovative energy storage technology developers based in Europe are being hampered by fragmented regulations and a lack of funding [69]. One key business market for energy storage could be the renewable energy industry.

Although there may be significant economic, environmental and social gains to be derived from increased level of energy storage [9] , particularly in relation to increasing the level of System Non-Synchronous Penetration (SNSP) [10], many countries; including Ireland; lack the policy incentives and national framework required to nurture large scale investment in storage [11, 12]. Therefore, the first aim of this document is to assess cross-EU policy-maker attitudes to the current state of energy storage policy and to identify which policies may be required on a broad basis.

Secondly, for policy makers and the renewable energy industry, it is important to identify the attributes of energy storage that are most required by the renewable energy sector. Ireland is currently developing energy storage policy, and as of yet has not established what technologies are being considered by the renewable energy industry, what the renewable energy sector views as barriers to investment and which policies would increase the likelihood of engagement with storage. The second objective of this study is identify the barriers to and opportunities for storage as well as the economic value of improved storage policy for this sector in Ireland.

2. Literature Review

2.1. Irish policy context for electricity storage

There have been several key documents developed over the past decade in Ireland which have highlighted the key role that storage plays in the development of a low carbon electricity system.

In the White Paper: Irelands Transition to a Low Carbon Energy Future 2015-2030, the government outlines its framework to shape policy and identifies the key steps that need to be taken to increase the level of energy storage up to 2030. These include removing administrative, market and regulatory barriers and examining cases for strategic large-scale energy storage developments [70].

Irelands Programme for Government contains key commitments to reduce GHG emissions by on average 7% per year from 2021-2030. This document commits to taking action to strengthen the policy framework that will incentivise electricity storage and interconnection and to invest in R&D in green hydrogen [71].

The Climate Action and Low Carbon Development Act 2021 requires that Ireland transition to a climate-resilient, biodiversity rich, environmentally sustainable and climate-neutral economy by 2050. This Act establishes a system of carbon budgets, which set limits on the amount of GHG permitted in a five year period. In 2022, the Government agreed on a 75% reduction in electricity sector emissions by 2030 [72].

The National Energy and Climate Plan: 2021-2030 acknowledges the key role that energy storage plays in terms of energy security and highlights national objectives to increase flexibility in the energy system through increased storage [73].

Irelands Climate Action Plan outlines actions required to achieve a reduction in GHG emissions of 51% by 2030 and acknowledges the role of storage in achieving this. It outlines that the Department of Environment, Climate and Communications will develop storage policy to support these targets and that the Commission for the Regulation of Utilities (CRU) will review the regulatory treatment of storage in terms of licensing, charging and market incentives [13].

2.2. Key Irish energy storage policies

The following section outlines key national policies in Ireland which have driven the development of energy storage to date.

2.2.1. DS3

In response to binding national and European renewable energy targets, EirGrid, the Republic of Ireland's transmission system operator, began a multi-year programme, "Delivering a Secure, Sustainable Electricity System" (DS3). Ireland's EU target was for 16% of the country's total energy consumption to come from renewable energy sources by 2020. In order to achieve the 16% target for energy, EirGrid worked to enable 40% of electricity to come from renewable sources on the island of Ireland by 2020. The aim of the DS3 programme was to safely increase the allowable amount of renewable energy onto the grid, to achieve this target. This meant increasing the amount of System Non-Synchronous Penetration (SNSP), or non-synchronous renewable energy generation on the grid- this type of electricity generation is variable, less reliable and more difficult to bring onto the grid in comparison to synchronous generation, such as gas or oil, which produces the same amount of electricity at all times if needed. The DS3 programme gradually increased the instantaneous levels of renewable generation on the grid to 65% in 2018, 70% in 2021 and 75% in 2022 [10].

As part of the DS3 programme, storage providers can receive payments for the provision of system services. System service products are required to enhance system security if a network limit is forecasted to be breached, for example, in the case of a severe weather event. The 'dynamic' products are used to support the system following a fault. Battery storage and other technology types can provide frequency regulation and smoothing. There are a number of system services which storage providers can assist with including Fast Frequency Response (FFR), which refers to the additional increase in MW output from a unit or a reduction in demand following a frequency event that is available within two seconds of the start of the event and sustainable for at least eight seconds afterwards [74].

Storage providers can also assist with Operating Reserve services, which is the additional MW of generation output or demand relief that is available to maintain supply to customers following a rapid loss of generation. This is comprised of three components. Primary Operating Reserve (POR) is the additional MW output (and/or reduction in Demand) needed at the frequency nadir (minimum), compared to the pre-incident output (or Demand) where the nadir occurs between 5 and 15 seconds after an Event. Secondary Operating Reserve (SOR) refers to the additional MW output (and/or reduction in Demand) needed at the frequency nadir (minimum), compared to the pre-incident output (or Demand) which is fully available and sustainable over the period from 15 to 90 seconds following an event. Tertiary Operating Reserve (TOR1) is the additional MW output (and/or reduction in Demand) needed at the frequency nadir (minimum), compared to the pre-incident output (or Demand) which is fully available and sustainable over the period from 90 seconds to 5 minutes following an event [74].

The DS3 programme currently has a budget of €235 million, with an additional €20 million available in high-wind years. In 2022, EirGrid published a consultation document outlining the increased expenditure on system services in recent years due to the high volume of fast acting technologies with high availability providing system services. As a result, EirGrid and SONI (Northern Ireland's TSO) reduced the tariffs for FFR and Operating Reserve by 10%. As 2021 and 2022 were "very low wind" years, this enabled DS3 to remain in budget, however, further reductions are likely if the spending cap is not increased [75].

2.2.2. Capacity Remuneration Mechanism

The Capacity Remuneration Mechanism (CRM) is designed to ensure that demand for electricity in Ireland is met. Capacity providers, which can be energy generators, demand side units or storage providers, sell qualified capacity through an auction mechanism, based on generation capacity required in a future capacity year. This can be between 1 and 4 years ahead of expected delivery. Participants in the auction submit a bid that indicates how much capacity they can provide and how much they are willing to sell that capacity for. The auction ranks from lowest cost and finishes when the capacity for a given year has been fulfilled. Successful capacity providers then receive a regular capacity payment which can assist with funding generation capacity. If energy prices rise above the set strike price in a capacity auction, producers must refund customers [76]. The amount of new energy storage providing capacity has increased in recent years, in the 2018/2019 auction the only new capacity arose from gas turbines (3.1MW), whereas the 2023/2024 auction included new gas turbines (3159 MW) and “other storage” (127 MW). In the 2024/2025 auction 77MW of new battery storage was successful along with 1376MW of new gas storage capacity. The average clearing price has also increased, from €41,800/MW per year in the 2018/2019 auction to €47,820/ MW per year in the 2024/2025 auction [76].

2.2.3. RESS

The Renewable Energy Support Scheme (RESS) is Ireland’s primary financial support mechanism for the renewable energy sector. Renewable energy providers specify an Offer Price for its project and if successful, this becomes the strike price for that qualified applicant. While RESS 2 supported the development of energy storage by allowing for hybrid renewable energy and storage projects, it contained a clause which indicated that these storage devices could only store energy generated from the project and could not store energy from the grid [77]. This key issue is explored further in both the EU and national policy analysis. The RESS 2 successful applicants were made up of just solar and wind projects without any hybrid storage [27]. The terms and conditions for the upcoming RESS 3 auction also include this clause [78]. The recent Offshore Renewable Energy Support Scheme (ORESS) was only open to offshore wind technology and did not contain any category for hybrid storage projects [79].

2.2.4. Policies in consultation

In July 2022, the Irish government launched a consultation on developing a hydrogen strategy for Ireland [80]. This document outlines the type of hydrogen that could be developed (e.g. green, blue, grey etc.) and hydrogen strategies that have been developed elsewhere in Europe. This document poses key questions to stakeholders on what areas of hydrogen research require more investigation, what the end uses of hydrogen could be, how much hydrogen might be required and what policy options could incentivise the use of hydrogen. This document also asks how green hydrogen might support the development of renewables that may otherwise not receive a grid connection, how green hydrogen could store curtailed renewable energy, if government policy should dictate placement of hydrogen production facilities and what the minimum sustainability criteria should be. The document also specifically asks about the role of hydrogen storage, what level is required, where to place this, what technology is required to store and what are the challenges and opportunities associated with long-term hydrogen storage to meet seasonal demand. This document also explores the potential to develop an export market in green hydrogen.

In November 2022, the Irish government also launched a consultation on developing an electricity storage policy framework for Ireland [12]. This document poses questions to key stakeholders on the potential future role for electricity storage, what barriers exist and which regulatory or policy measures may be needed to support the development of electricity storage. This document also poses whether there is a saturation point for battery storage, and asks which technologies should be considered, with an additional focus on hydrogen storage, thermal storage and long-duration storage. This document also asks if the current DS3 arrangements, which are due to expire in 2024, are sufficient to achieve the SNSP target of 95%. It also inquiries if the current DS3 arrangements provide sufficient compensation for the provision of system services to the grid. CRM arrangements are also under scrutiny, with the document asking if any other systems more effectively provide capacity to the electricity market. The document highlights changes to the RESS system which have allowed for hybrid storage projects, indicating that they expect 100 MW of the 1948 MW approved in June 2022 to include hybrid projects (although auction results did not indicate any hybrid project approved). This document asks if the current RESS arrangements are sufficient to promote the combination of renewables and storage and if any changes to the system are required. Other potential issues and barriers outlined in the document include grid connections; spatial planning; safety; small-scale storage and prosumer development.

2.3. Economic viability of storage

2.3.1. The impact of renewables on electricity markets

Market coupling refers to the linking of two or more electrical markets to enable the combined sale of power and interconnection capacity. It is intended to maximize welfare for all and provide unrestricted flow of power between the linked markets. Ireland established the Integrated Single Electricity Market (I-SEM), a wholesale energy market between the Republic of Ireland and Northern Ireland, in order to align with European integration. Ireland and the British market were effectively integrated at the end of September 2018. The integrated market was created to dismantle monopolies and make it possible for the markets that demand renewable power to access it at a lower cost. The coupled market also offers incentives for using power efficiently [81].

In Europe, the exchange of electricity takes place through a system of markets and auctions. The Day Ahead Market (DAM) and the Intraday Market (IDM) are the system's two ex-ante marketplaces. Customers can buy or sell power in the DAM for usage during the next 24 hours. Orders are placed taking into consideration network limits and societal welfare [82].

The intermittent nature of renewables can have a substantial influence on the trading price of electricity in Europe, despite the fact that the market structures mentioned above are intended to smooth prices and lower volatility. For instance, there are two times of the day when power prices are at their highest in Germany: one early in the morning and one in the evening. Prior to 2011, the early peak occurred about noon and was higher than the late peak. The first peak now occurs earlier in the day and is less expensive than the evening peak, reversing the previous pattern. This is because at midday, a large amount of renewable energy sources, particularly solar energy, is available to satisfy demand [83]. German exports of RES can create bottlenecks in interconnections and drive up prices between the two nations when RES production is strong. Price convergence maximizes consumer surplus and, according to one study, while German customers may lose €265 million in consumer surplus, French consumers may earn up to €2.29 billion [21].

Production that exceeds demand may result from the increase in renewable electricity brought on by support programs, the prioritization of RES-generated electricity, inaccurate estimates of the generation of RES, and the inability of traditional energy plants (like coal and oil) to quickly reduce output. Many European nations have seen this "incompressibility of power systems" in the DAM, IDM, and real-time balancing markets (the market for power that has not been exchanged in advance) [84].

2.3.2. Consumer and producer welfare impacts of storage

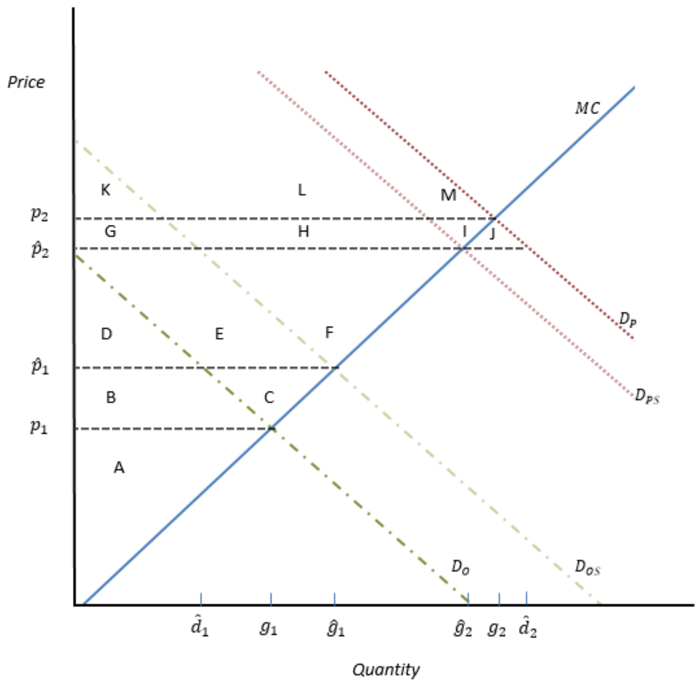

Figure 4: Welfare impacts of storage [85]

The figure above adapted from Sioshansi (2014) highlights the impact of storage on supply, demand and generation for total electricity. D_o represents the demand curve during off-peak times without storage, D_{os} indicates the demand curve for off-peak times with storage, D_p is the demand curve during peak times without storage and D_{ps} is the demand curve during peak times with storage. MC is the marginal cost curve. Following Sioshansi (2014), in a situation without storage, the off-peak price is p_1 and both quantity demanded and quantity generated are g_1. The consumer surplus in this case is denoted by the areas B and D. By storing energy during off-peak times, off-peak generation increases to $\widehat{g_1}$, prices increase to $\widehat{p_1}$ and consumption decreases to $\widehat{d_1}$. This decreases the consumer surplus to D only. The reverse is true during peak times. In the case with no storage, peak prices are p_2 and both quantity demanded and quantity generated are g_2. Without stored energy the consumer surplus is equal to the sum of K, L and M. By bringing back in the stored energy (minus a % loss), less newly generated energy is required and so generation drops to $\widehat{g_2}$ which lowers the price to $\widehat{p_2}$ and increases consumption to $\widehat{d_2}$. The consumer welfare in the case with included stored energy is equal to G, H, I, J, K, L and M. The net consumer gain from introducing storage is the sum of G, H, I, J minus the area B.

The energy producers are also impacted by the introduction of storage. During off-peak times without storage, producer profit is defined as the area A. This increases to the sum of A, B and C with the addition of storage, (prices and generation increase). During peak times without storage producer profit is equal to the sum of the areas A, B, C, D, E, F, G, H and I. Introducing storage during peak times reduces producer welfare by the sum of the areas G, H and I (prices and generation fall) [85].

There are potential disadvantages to renewable energy storage. Firstly, selection of the correct form of storage is difficult as each technological solution offers its own potential shortcomings. Flywheel storage technology (a mechanical storage option) can have fewer environmental impacts than other types but has a lower energy density and higher associated cost. On the other hand, high energy density options such as Ni-Cd batteries can have negative environmental impacts. Other potential issues with storage solutions include risk of explosion (hydrogen), high land requirement (pumped hydroelectric storage), safety concerns (NaS battery) and health issues (Super conducting magnetic energy storage) amongst others [86]. Further details on storage technologies are highlighted in Section 2.3.4.

Storing off-peak renewables for use in peak times also has the potential to increase emissions. In situations where renewables are not the primary source of electricity, storing off-peak wind energy means increased use of non-renewable energy at this time. If the emission rates of those producing energy during peak times are not significantly below the emission rates of those producing at non-peak times then this can lead to increases in short-term emissions [87].

Another potential issue centres on the ownership of the storage facilities. As highlighted previously, the introduction of storage can smooth distortions by lowering electricity prices for consumers and producer profit, which reduces the arbitrage value for storage. According to one study, the loss in arbitrage value from shifting off-peak energy to peak times can be up to 20% for 1 GW of energy [88]. Storage owners may not behave in a way that maximizes external welfare and may instead opt to act in their own interests, despite the possible net welfare improvements from the introduction of storage. Given that they do not receive the external societal advantages of storage and are extremely sensitive to the prospect of lowering the price discrepancies between peak and off-peak hours, independent storage owners will underuse storage. In a similar vein, if the storage units were owned by the power generators, they would also have a tendency to underuse the facility given the decline in producer income caused by transferring off-peak output to peak hours. Given that they do not internalize the loss in producer welfare, consumers who possess storage facilities may have a tendency to overuse them. In a system of perfect competition, when storage is held by an independent competitive storage facilitator, no electrical generator possesses market power, and consumers do not possess monopsony power, these impacts are mitigated [89].

2.3.3. Economic benefits of storage in Ireland

Recent studies find significant benefits from increased energy storage in the SEM (Single electricity market). One study, commissioned by the Irish Energy Storage Association, found that the societal benefits of storage increase up to 1.9GW of energy storage on the system, after which the cost exceeds the additional benefits [9]

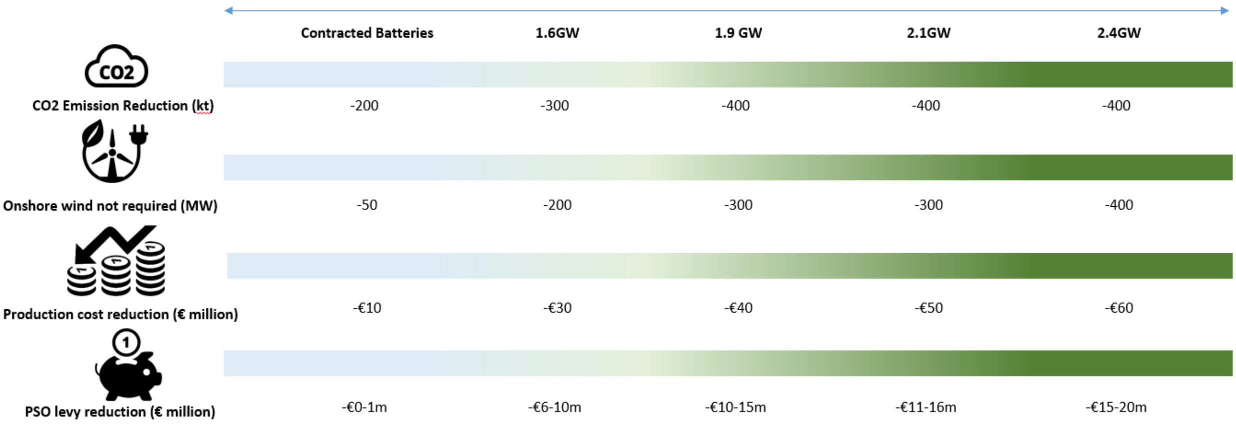

Figure 5: Storage potential by size

Figure 5 highlights the potential of energy storage by size. All of the analysis is compared to a baseline scenario which assumed that by 2030 power demand reaches 53TWh; gas prices are at UK National Balancing Point (58p/therm); carbon prices are €57/tCO2; renewables penetration in SEM is 70% with 8.5GW of onshore wind, 3.7GW of offshore and 2.1GW of solar PV; System Non-Synchronous Penetration (SNSP) limit is 95%; there is 463MW of short-duration battery capacity on the system; 1.2GW of new build thermal capacity; and interconnection capacity increases following the construction of the 500MW Greenlink and 700MW Celtic interconnectors. The first scenario includes increased energy storage which adds all batteries that have successfully secured Capacity Remuneration Mechanism (CRM) contracts- an additional; 363MW on top of the reference. By 2030, the annual net benefit of 1.9GW of storage on the All-Island market is estimated at €34 million (falling to €33 million at 2.4GW). These benefits arise from reduced dispatch down; dispatch down occurs when EirGrid, as the transmission system operator, instructs a renewable electricity generator to produce less electricity than it can or even to shut down entirely; a smaller conventional peaking fleet (fossil fuel generators to meet peak demand) and lower production costs and carbon emissions [9]. This document recommends the development of a national policy for energy storage; that inconsistencies in the CRM are rectified; that clarification on the role of hybrids in RESS is provided and that additional incentives for flexibility are introduced.

By engaging storage in the day-ahead market (the market where market participants purchase and sell electric energy at financially binding day-ahead prices for the following day) another recent study, commissioned by Energy Storage Ireland, finds carbon emissions can be reduced by 50%, helping to achieve 2030 decarbonisation targets [90]

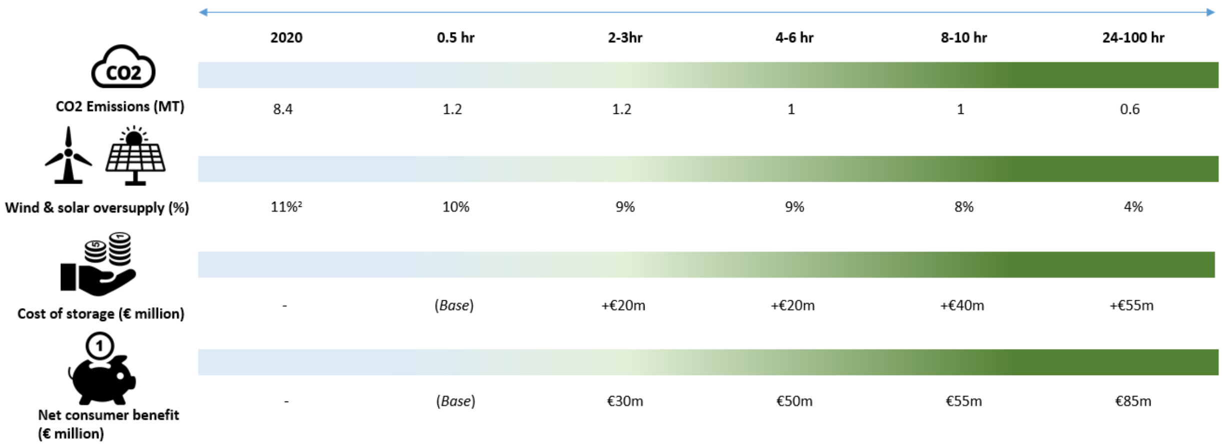

Figure 6: Storage potential by duration

Figure 6 outlines the potential benefits of increase long duration storage on the system in Ireland from this study[1]. The net savings to end customers is estimated at approximately €85 million annually due to improved security of supply, renewable capacity support and fossil fuel displacement. The 0.5 hour base case is assumed as 700 MW of dedicated system service providing 0.5 hour DS3 storage. All other durations are in addition to base case storage, and are assumed to participate in the Day Ahead Market unlike the base case. Storage can reduce oversupply by up to 60%, constraint volumes by up to 90% and curtailment by 100%. However, these higher savings arise from long-term storage (24-100hr), and storage capacity of 6 or more hours duration has yet to be demonstrated in the all-island system. A shift to 2-3hr storage results in net consumer savings of €30 million annually in ROI in comparison to the 0.5hr DS3 baseline scenario. These consumer savings arise from contributions to security of supply, helping to support renewable capacity, and displacement of fossil fuels [90]. This report recommends that a holistic energy storage strategy in Ireland and Northern Ireland is developed; that CRM is reviewed to appropriately consider storage; that an enduring system services framework is established;

[1] ROI data;. Curtailment for wind only ROI (Eirgrid, Annual renewable energy constraint and curtailment report 2020. 2021, Eirgrid: Dublin.)

that energy storage be allowed to part fully in the energy market and that barriers to hybrid projects are removed.

Recent work in Ireland has established that battery storage will reduce the frequency nadir following a system wide loss of generation event, that storage will lower emissions, generation and reserve costs in systems with a high penetration of renewables and that the absence of secure revenue for the provision of ancillary services is a potential risk for investors in battery storage [91].

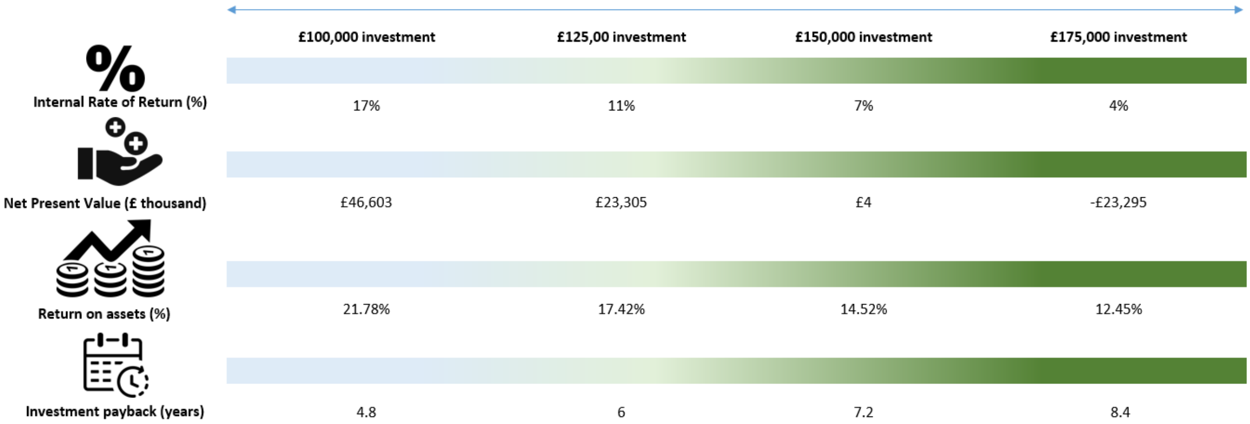

Figure 7: Financial analysis of battery storage in Northern Ireland

Figure 7 outlines the financial analysis from this research. This paper provides the payback for 4 levels of investment in battery storage in Northern Ireland using various measures of return; Internal Rate of Return (used to calculate the interest rate which results in the future payments over the project lifecycle equating to the initial investment); Net Present Value (which calculates the present value of future returns minus the initial investment over the project life cycle-10 years); Return on Assets (averages the future payments over the project life cycle-10 years and divides by the initial investment); and Payback period (the number of years to recover the capital outlay). The NPV measure and IRR measures provide more detailed analysis as the future costs are discounted at the cost of capital. Generally a positive NPV would indicate an acceptable project, and so investments up to £150,000 may be financially viable. The IRR return for £150,000 investment was 7%, which would need to be competitive against other projects to attract investment. The paper found that the lack of guaranteed income and the threat of dilution of payments in the form of a cap on ancillary services payments represented barriers to investment.

2.3.4. Economic viability of storage by technology type

The economic viability of storage can vary significantly according to the type of technology utilised. Figure 8 from [92] categorises the primary form of energy storage according to form of stored energy.

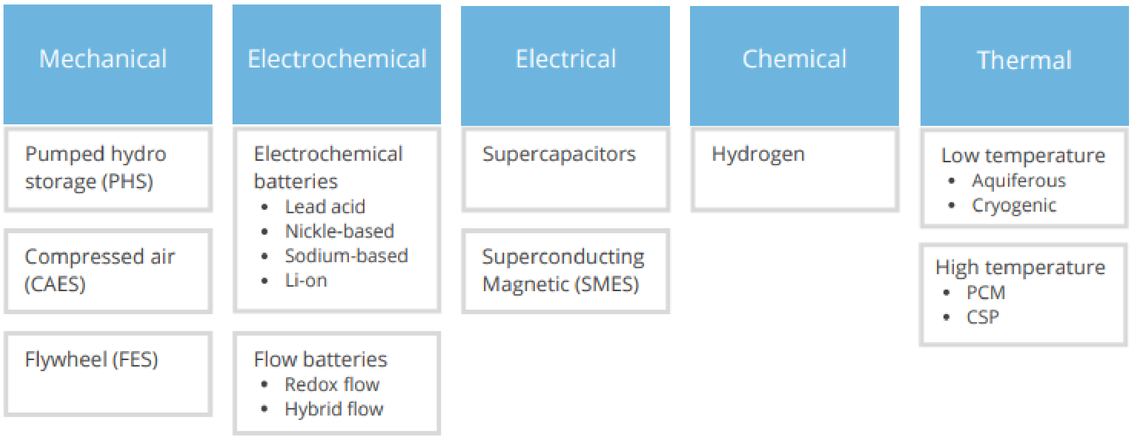

Figure 8: Energy storage by type *[92]*

The following sections outline the primary forms of electricity storage and their corresponding economic potential utilisation for arbitrage, system services and renewable energy storage in particular.

Pumped hydro storage

In terms of energy storage capacity, PHS offers large energy capacity (100-1000MW), a relatively high efficiency (65-85%), a long lifetime (30-60 years), fast frequency response (<1 minute) and low cycle cost ($0.1-1.4/kwh). However, PHS requires a specific topographical area with a large water capacity, it has a long project lead time (~10 years), large footprint, high capital expenditure (€500-1500/kW) and can have a negative impact on the environment [4, 92]. Arbitrage analysis in the US has found that PHS performs the best in terms of economic return due to its long-term storage capacity, low capacity cost and long project lifespan, however its potential is lessened due to the specific geographical requirements of this type of storage [93], which has also restricted its development in Ireland [94]. A study in Ireland on the arbitrage opportunities for hydro storage found that engaging in the day-ahead-market would result in profit, however the profit obtained varies significantly and can become a loss when predicted prices are not extremely accurate. This study concludes that due to the long lifespan of a PHS project, this would be a risky investment even with low costs, low interest rates and an appropriate electricity market [95]. Research in Ireland has found that high wind energy scenarios require greater power system reserves to secure supply and that developing hydro storage to counteract wind energy intermittency is limited in a scenario where carbon and fossil fuel costs remain low [96]. Turlough Hill, Ireland's only current PHS facility, is located in the Wicklow mountains and became operational in 1974. This facility, operated by the semi-state Electricity Supply Board (ESB) offers 292

MW of storage capacity [97]. The proposed Silvermines hydro plant in Tipperary would offer an additional 360 MW of storage [98]. Another proposed project aims to integrate 2000MW of renewable energy and 6GWh of PHES in Mayo for both the Irish and GB market by developing a 750MW HVDC interconnector between the UK and Ireland [99]. The project aims to store surplus wind and wave energy and states that it could export 10TWh of energy to Britain [100].

Compressed air

CAES systems mechanically store excess energy by compressing air in naturally occurring or man-made caverns. It is considered long duration energy storage as it can store capacity for days [92], although in the main it is likely to be used for daily peak shifting [101]. The benefits of this type of storage system include a large storage capacity, quick response rate and high efficiency (70-80%). The capital cost is comparatively low ($400-800/kWh), it has a lifespan of approximately 40 years and limited environmental impact on the surface [92], however, this type of storage has a very large footprint [102]. A 2012 study found that a wind farm coupled with CAES engaging in the day-ahead market would not generate sufficient revenue to cover capital costs in a scenario where wind competes freely in the marketplace [103]. A US study has also concluded that arbitrage-only revenues would not be sufficient to warrant CAES investment in the majority of market locations, but the addition of reserve revenue could support CAES investment in several markets [104]. [105] finds in a study of the arbitrage value for PHS and CAES, that as European markets become more efficient and interconnected, the value derived from the arbitrage from energy storage is reduced. Although CAES resulted in greater arbitrage returns than PHS, this is dependant on the cost of natural gas required to operate. A study using US market data finds that CAES was second-most cost effective in terms of revenue from arbitrage, behind PHS, but that significantly more technology development is required before it is likely to be adopted at scale [93]. A study using Irish data which analyses the profitability of the provision of arbitrage and ancillary services from CAES concludes that it may not prove profitable at current prices in Ireland but if financial mechanisms which capture the system-wide benefits of CAES (such as supporting the greater integration of renewables, CO_2 emission reductions) are established, this may improve [106]. Although no CAES project has been developed to date in Ireland, the EU has funded a 300MW CAES project which will be located in Co. Antrim, Northern Ireland. This project, which has received over €100 million in funding, will store energy as compressed air in underground salt caverns [107].

Flywheel

In FES systems, kinetic energy from a rotating mass is stored in a flywheel. While charging, this acts like a motor and then due to the rotational energy during discharge, acts as a generator [92]. Flywheels are considered long duration storage, capable of providing seasonal storage [101]. Flywheels can provide fast frequency response [94], have a long lifetime (15-20 years), long cycle life (10,000-100,000 cycles) high efficiency (90-95%) [92] and low environmental impacts [108]. However, in comparison to other storage systems such as batteries, FES systems have comparatively lower power density, higher cost and noise, require more maintenance and have greater safety concerns [17, 109, 110]. This also has limitations in terms of storage duration, with a general discharge time from seconds up to 1 hour [92, 111]. A US report concludes that in a system with a high penetration of renewables, flywheels offered one of the most cost effective methods of maintaining balancing requirements [112]. A study simulating the internal rate of return (IRR) for multiple technology types found that flywheels may be a good option in the provision of ancillary services and frequency regulation but return negative IRRs in all US markets analysed and may not be suitable for systems that require high power, low energy cycling [113]. [114] propose that a hybrid hydrogen-flywheel system could improve power quality and smooth the impact of renewables on the grid. In Ireland, a flywheel-battery hybrid utility-scale storage system has been installed in Co. Offaly. The system incorporates four 150kW flywheel units with battery technology to provide rapid system services to the grid [115]. The flywheels can provide full energy output for five minutes and the connected batteries more than twenty minutes [116].

Electrochemical batteries

Batteries are the most common and technologically mature energy storage options and can provide daily peak shifting with hours of storage, grid support and intermittency management and longer seasonal storage, depending on the type utilised [101]. Electrochemical batteries store energy by generating electrically charged ions through chemical reactions between positive and negative plates. Lead-acid batteries; which utilise metallic lead, lead dioxide and sulphuric acid to operate; are low cost ($150-50/kWh), have a lifetime of between 3 and 12 years and have a fast response time. However, they have a low energy density and power, limited cycle life (200-1800 cycles), high associated maintenance and may have negative environmental impacts [17, 92]. Nickel-based (NiCd) batteries operate using nickel hydroxide, metallic cadmium and aqueous alkaline solution. They have a high energy density and a long life cycle (2000-2500 cycles), however can have a negative environmental impact due to their use of toxic heavy metals, their lifetime is reduced if repeatedly recharged after partial discharge and they have a relatively high cost ($800-1500/kWh) [92]. Sodium sulfur (NaS) batteries have a lifetime of about 10-15 years, relatively high energy density, low maintenance, high energy efficiency (75-90%), long life cycle (2500-4500 cycles), fast response time (<5ms) and high recyclability. However, they have high annual operating and initial capital costs, and under certain circumstances can suffer from fire safety issues. Sodium nickel chloride (NaNiCl) batteries have similar characteristics but have better safety credentials and lower power density [92]. Lithium-ion (li-ion) is composed of lithium-based compounds and graphite carbon. As li-ion batteries are a comparatively new technology, they have a relatively high cost ($600-2500/kWh), but have a high power density and can last between 1000-10,000 cycles. However, the lifetime of these batteries is sensitive to temperature and they can have associated safety issues [92].

Despite these drawbacks, li-ion battery storage systems are the most common grid-scale batteries currently [117]. A UK case study analysing the profitability of storage in the form of li-ion batteries vs Purchase Power Agreements (PPA) found that, for a wind farm developer, there may be scenarios where it was more financially beneficial to own a battery storage unit and trade in the wholesale market rather than hold a PPA with another party. The profitability of one over the other is impacted by the discount rate of the PPAs, the capital cost of the wind farm and the strike price of the GB renewable support mechanism, Contracts for Difference [118]. Another recent study analysed if there a possible synergies between both energy arbitrage and fast frequency response with the use of battery storage systems. This project provides an outline for a management system, which allows for charging outside of the window for delivering fast frequency response and concentrates arbitrage around peak times. This allows the storage system to capture the greatest arbitrage revenues while minimising revenue loss from the provision of capacity services. This research argues that by optimising the blend of these two priorities, operating profits can be increased by 25% [15]. Another recent study argues that significant revenue can be generated for wind farm developers if they integrate battery storage systems to trade electricity in the day-ahead-market. This also has the added private and societal benefit of reducing wind energy curtailment [16]. A study of US market data indicates that it is not currently profitable for new entrants to enter the market for arbitrage in battery storage without additional sources of revenue from ancillary services. The addition of new battery storage projects has reduced the intra-day wholesale price spreads making investment less attractive [119]. In Ireland, there are limited examples of operational grid-scale battery storage projects. Ireland's first battery project became operational in 2020. This was a hybrid li-ion battery and wind energy project developed by Stadkraft, which combined 11MW of battery storage with 23MW of onshore wind [120]. RWE, another renewable energy operator, currently has 2 battery storage projects in operation in Ireland, one 8.5MW project in Dublin and one 60MW facility in Monaghan [121]. In 2022, the ESB opened its first battery project in Ireland to add 19MW of storage to the system [122]. Two battery storage projects; developed jointly by Lumcloon Energy in Ireland and Hanwha Energy Corporation, a South Korean conglomerate; were energised in 2021 [123]. These storage developments, which utilise 100MW li-ion battery units in each project, aim to provide system services to the grid to increase stability and support the addition of intermittent renewable energy [124].

Flow batteries

Flow batteries are regarded as long-term storage solutions, suitable for seasonal storage [101]. By charging two liquid electrolyte solutions and releasing the stored energy, they transform electrical energy into chemical potential energy. The electrochemical cell, which transforms chemical energy directly into electricity and vice versa, is fed with the electrolytes that have been externally stored in tanks or reservoirs. The electrolytes used can be readily replaced or increased and so the capacity can be easily scaled up [92]. Redox flow batteries are suitable for large-scale renewable energy storage due to their power capacity, high efficiency and very long charge/discharge life cycle [17, 125]. Vanadium redox batteries are the most technologically mature form of redox flow battery and are more efficient than other types (75-85%), have a longer life cycle (12,000-14,000 cycles) and lower operating cost and maintenance [92]. This battery type requires vanadium oxide in its production, which is also used in steel production. This has experienced price fluctuations in recent years, peaking at $28 USD per lb in June 2018 [126]. Total system costs related to energy capacity for vanadium flow batteries are estimated at between €89-€1738 kWh [127]. The hybrid flow battery combines elements of conventional batteries and redox flow batteries. In this system, one of the electrochemically active elements is stored in the electrochemical cell and another is dissolved in liquid electrolytes stored in a tank [17].

In a study by [128], the authors suggest that vanadium redox flow batteries are not optimal for energy arbitrage compared to others due to the amount of electricity lost in the charging and recharging process and their higher operation and maintenance cost. [129] find that, in the commercial and industrial sector, flow batteries cannot compete with li-ion across a number of scenarios and at a 4 hour duration must be much cheaper, often by 20-30% on a dollar per installed kWh to break even with other battery types. However, due to their larger energy capacity they may be more suitable for storing large amounts of renewable energy generation, relieving congestion from renewables or shifting energy to more profitable times of the day if li-ion battery costs do not reduce or for durations of longer than 8 hours in off-grid systems. This study also finds that using less efficient flow batteries could also raise grid-level emissions, with the current fuel mix in most regions as lower storage efficiency means greater overall energy consumption with increased charging.

Supercapacitors

Supercapacitors are a comparatively new storage technology by which energy storage is achieved through the form of an electric field between two electrodes [92]. While batteries can store up to 30 times more charge per unit mass, supercapacitors can deliver thousands of times the power of the same mass battery and can be cycled more [17]. This technology is suitable for daily peak shifting, with a fast response time but its rapid discharge makes it unsuitable for seasonal storage. The capital cost for supercapacitors is between €200-1000 per kWh, making it more expensive than other short duration storage options such as CAES or batteries [130]. Several studies have analysed the potential use of supercapacitors, particularly in supporting off-grid renewables. [131] find that a hybrid isolated energy system which incorporates solar, wind and supercapacitors only is cost effective, but unreliable; however combining with batteries can enhance consistency, stabilisation and performance. A techno-economic study of the levelised cost of hybrid storage systems finds that supercapacitors in combination with batteries or hydrogen fuel cells (HFC) are less economical than other HFC-battery hybrids [132]. [133] conclude that electromagnetic storage devices, such as supercapacitors, are only suitable for high power and short duration application such as frequency regulation and ensuring an uninterruptible power supply. Devices such as supercapacitors may also have a higher O&M cost than others due to the chemical handling required.

Superconducting magnetic energy storage

Superconducting magnetic energy storage (SMES) is another recent technological addition. This method induces a DC current through a coil of superconducting wire following which electrical energy is stored in a magnetic field. Superconductivity occurs when this wire reaches the required temperature of -270C [92]. SMES coils can discharge large quantities of power very quickly and can facilitate an unlimited number of charging and discharging cycles efficiently. This storage type is particularly useful for providing system stability, frequency regulation and ensuring an uninterruptible power supply [17]. In a comprehensive review of SMES costs, [134] note the cost of energy from SMES systems as being between $700-10,000 per kWh, making it a costly storage option, however the authors note there is the potential for significant economic and environmental benefits from SMES by storing generated energy that would otherwise be lost. [135] present an economic evaluation of an adapted SMES system for renewable energy storage and estimate the total investment payback period to be between 5.44 and 18.41 years. [136] conduct a study to assess the optimal placement and sizing of wind turbines with SMES to minimise energy loss and improve voltage stability, and find that the combination of both can significantly improve the performance of energy distribution network. While [137] also find that SMES can help improve stability of the system while incorporating wind energy, they conclude that there are challenges in optimising SMES capacity, location and control.

Hydrogen

In hydrogen energy storage, hydrogen is generated from a chemical reaction but is not the source of energy. Commonly, hydrogen is produced by splitting water from energy provided by fossil fuels, renewable or other sources [17]. Hydrogen can then be stored for use at a later time, which can be beneficial in a system with intermittent renewable energy. There are many forms of storage for hydrogen. In a fuel cell, which consists of two electrodes on either side of an electrolyte, chemical energy is transformed into electrical energy. The chemical energy, in this case hydrogen, is fed into the anode and either air or oxygen is provided to the cathode. Electrical and heat energy is then released. Most cell types can reverse this process, therefore when a current is provided, the cell produces hydrogen and oxygen from water. This means that when electricity is required, the hydrogen stored can feed the fuel cell and generate electricity [92]. Hydrogen can also be stored as a compressed gas or liquid, which requires large amounts of energy and specialised infrastructure. Other storage options; including absorptive storage, whereby hydrogen is absorbed into and released from porous frameworks, and chemical storage where hydrogen is stored in chemical bonds; can be used, amongst others [17]. Hydrogen storage can have a very large storage capacity of up to 100 GWh and can store energy for months making it suitable for a wide variety of uses including integrating renewables, balancing the grid both seasonally and weekly, energy arbitrage and in hydrogen refuelling stations for transport. However, the capex costs are high (€2000-5000 per kWh), the round-trip efficiency of hydrogen is low (20-40%) and it has a low energy density (30-2550 kWh/m^3 in hydrogen tank storage) [4].

The potential for hybrid wind-hydrogen developments have been studied extensively in the literature. [138] utilise a novel analytical model to assess the viability of hydrogen production from potential offshore wind projects in Ireland. The study assesses discounted payback period and net present value and finds that a hybrid system is profitable in 2030 at a hydrogen price of €5/kg and underground storage capacities from 2 days to 45 days of hydrogen production. The hydrogen price of €5/kg is the lower end of the band (€5-€10) outlined in the Hydrogen Roadmap for Irish Transport, 2020-2030 [139]. An early paper by [140] notes the potential for hydrogen to support wind energy in Ireland through arbitrage revenue and by providing stability to the grid. However, this paper concludes that large-scale demonstration projects are required in order to prove the technology, improve cost competitiveness, reduce potential market barriers and to increase public awareness and acceptance. [141] examine strategies for incorporating renewable energy and hydrogen storage, highlighting optimal day-to-day decisions on how much energy to store as hydrogen, buy or sell to the electricity market and how much hydrogen to use as gas. This work, based in the Netherlands, indicates the potential for a 51% increase in operational revenue for wind farm developers through the addition of hydrogen storage and competitive hydrogen market prices. This study highlights the importance of hydrogen offtake agreements and subsidies in reducing capital cost risk, particularly at the early development stage of the hydrogen economy. Recent work by [7] into the potential of hydrogen storage for excess wind energy alone concluded that it is not currently economically viable as this would limit hydrogen production to just 14% of the total available hours (based on 2018 Danish wind energy production). Recent research analysing the potential revenue streams from offshore wind in Ireland find that a hybrid system that converts wind energy to hydrogen when energy is curtailed and/ or when system marginal cost is low can be profitable only if the value of hydrogen is greater than the levelised cost of hydrogen (€3.77/kg) [8]. As with [7], this work finds that profitability from curtailment reduction alone is not sufficient to attract investment in hydrogen storage currently, and the percentage of curtailment and/or the cost of hydrogen would need to increase [8].

Thermal

Thermal Energy Storage (TES) systems may store heat in insulated repositories in a variety of ways for later use in a wide range of industrial and domestic uses, including space heating or cooling, the provision of hot water, or the generation of electricity. TES systems are used to aid in meeting supply and demand for thermal energy, making them very useful in the integration of RES. A typical TES system includes a tank-based storage medium, a built-in refrigeration system or chiller, pipes, pumps, and controls [92]. TES systems for thermal hot water may include a tank which stores heated water for a short time (up to a few days), and is generally used to supply heating to residential and tertiary buildings. TES thermal systems are crucial for the integration of renewables. The CAPEX costs for such systems are low, approximately €40/kWh for small residential systems or €15/kWh for multi-dwelling setups, but this corresponds with the low power range, which provides a maximum of 40kW for domestic or 400kW for multi-dwelling buildings [4]. Thermal adsorption heat storage uses a combination of two different materials, one is a solid material adsorbent and one is a gaseous material adsorbate. This type of heat storage can prevent heat loss over a long period of time. Zeolite and silica gel are examples of thermo-chemical storage materials, with storage densities of 180kWh/m^3 and 220kWh/m^3 respectively. This type of heat storage is applicable for small-scale heat storage in household appliances or buildings with thermal solar collectors, for cooling, air-conditioning or in combination with heat pumps or in CHP plants with heat storage for demand side management [4].

A 2018 study in Ireland investigated the impacts and benefits of utilising thermal heat storage in a wind energy dominated electricity market [142]. The study found that heat pump electrification of 20% of the domestic heating sector adds about 11% to the yearly total system costs in comparison to the business as usual scenario and direct electric heating of the same proportion adds about 52% to the annual total system costs. However, adding thermal energy storage provides significant savings by reducing the total system cost by up to 5% for heat pump electrification and 30% for the direct electric heat scenario. Optimised management of heat electrification with storage minimises the increase of total system dispatch costs from increased SNSP on the system, and the addition of ancillary services will allow wind farms to receive a higher level of REFIT support. However, this study concludes that the main barrier to decarbonisation in the heating sector and to thermal storage is an absence of appropriate policy instruments [142].

Currently in Ireland there are commercially available thermal energy storage systems available, which for businesses can provide reductions in cooling system running costs, increased efficiencies and waste heat storage [143]. Domestically thermal energy storage is available in the form of an insulated cylinder or accumulator tank which can provide space heating and/or mains hot water. These are commonly used in combination with biomass heating systems, solar water heating, or heat pumps [144].

2.4. Choice experiment and industry engagement studies

Despite the potential economic impacts of renewable energy storage, there are limited stated preference studies which analyse the renewable energy sectors attitudes towards electricity storage, most of which focuses on PV developers. Studies which analyse the attitudes of solar PV purchasers find preferences for direct ownership of storage facilities over use rights [145, 146], although [145] find that respondents would prefer to not to have any storage at all and [147] report that PV owners prefer external control and maintenance of the storage system to reduce any technical knowledge burden. [148] find business owners prefer to utilise a renewable energy powered electricity system that incorporates battery storage in order to reduce reliance on diesel back-up generators. [149] conducted a choice experiment with 42 utility and institutional investors to assess preferences for grid-scale battery storage and green hydrogen technologies. The attributes included the IRR, the type of technology (solar PV, solar PV with hydrogen storage; solar PV with battery storage); share of total revenue; project partner (the German state; international company; local company) and different business models (outsourced development and operation; outsourced development but own operation and own development and operation). This study found that expected return on investment was the most important feature for investors and that a lack of viable business cases was a key barrier to energy storage investment.

Some choice experiment studies focus on the public as a key stakeholder. [150] find that public knowledge on hydrogen energy storage is low, but that they are willing to accept a hydrogen-based energy storage system over the current business as usual situation. Respondents indicate insignificant willingness-to-pay (WTP) values for most attributes in the study, except for the autonomy attribute; respondents are WTP €100 per month to be more energy self-sufficient via the hydrogen technology. In a recent study in Ireland [151] find general positive public preferences for the use of battery storage to manage excess wind energy, however there was significant heterogeneity in values for storage. The likelihood of positively valuing storage was increased if the respondent was a general advocate of wind energy and decreased if they were concerned about the potential negative impact of renewable energy infrastructure; were sceptical about wind energy and educated only to primary level.

There are limited choice experiment studies which assess the preferences of the wind energy sector generally [152], and none which assess the renewable energy sectors preferences for storage policy changes.

Some limited qualitative work has been carried out on the topic of energy storage, which have included the renewable energy sector and/or policy makers as key stakeholders. A recent study in Ireland included policymakers in a focus group discussion which included energy storage as a topic [151]. The policymakers concluded that battery storage was a key element of renewable energy development in Ireland, but that there was a significant challenge for policymakers, planners, developers and the public to catch up with the new technologies required to meet 2030 target. A recent study in Australia utilised 10 interviews with renewable energy industry and policy experts to discuss the requirement for developing energy storage systems and the role of hydrogen. This concluded that the capital cost of hydrogen components, the low round-trip efficiency as well as limited practical industry experience inhibit the development of hydrogen storage. Government support, collaboration, knowledge sharing and increased innovation could reduce risk and cost and increase uptake of hydrogen storage systems [153].

3. Methodology

In this study, we carry out a number of interview, focus groups and surveys with policy makers and the energy storage and renewable energy industry. The following sections outline the methodologies and models used.

3.1. Focus groups and interviews

Focus groups are frequently conducted as a first step in non-market valuation research to aid in designing surveys [154-156]. Focus groups allow for interactions, which can be particularly helpful when discussing new renewable energy projects, which are frequently associated with conflict, uncertainty, and top-down decision-making, and can provide "depth" in responses and insights into the sources of complex behaviour and motivations [157, 158]. Focus groups can provide insights into the sources of complex behaviour and motivations by allowing for interaction, consensus forming or identification of points of disagreement. Stakeholder analysis can be crucial in determining perspectives of organisations, firms or government, particularly if those actors can impact a decision-making process or phenomenon [159]. This insight can be gathered through engagement and discussion between participants during focus groups, which can enable the efficient collection of data from a wide range of stakeholders, which may be more difficult using other methods such as surveys [158]. While studies involving the public typically consist of 4 to 6 focus groups, smaller numbers are not uncommon when engaging with a specific sector or industry, where often only one or two focus groups are considered sufficient [160-162]. Interviews can also be used as either a stand-alone qualitative methodology or in conjunction with focus groups [162].

In order to understand the wind energy and storage sector, 10 interviews were carried out with a number of participants from the energy storage industry and representative groups in Ireland and the UK, the wind energy sector, renewable energy representative organisations and the Irish Department of the Environment, Climate and Communications. Two online focus groups were also held, the first in December 2022 with representatives from the wind energy and storage sector and the second in January 2023 with participants representing storage policy. The first developer focus group had 16 participants and the policy focus group consisted of 11 participants. Discussion topics included reasons for engaging with storage, barriers to storage engagement, types of storage technology, policy changes required, ownership of storage and support mechanisms. The findings from the interviews and focus groups are outlined in the results section, along with the survey results categorised by discussion topic. Discussions were loosely structured and participants discussed issues relevant to their own areas of expertise as well as specific questions related to greater engagement between storage and the wind energy sector.

3.2. EU policy maker survey

In order to capture information on policy maker attitudes to energy policy development in Ireland and elsewhere, a policy survey was deployed to the STEPS project partners, which represent energy storage policy makers across several key European countries. Question topics included:

- The importance of key factors to the wind energy industry when investing in storage
- The current level of energy storage in their country
- Types of storage technology required in their country
- Rating of their countries support policies and market for storage
- Preferred energy storage developers

The survey also included a policy ranking statement, in which respondents were asked to rank the policy most likely to increase engagement in storage from the wind energy sector in their country. The policies and descriptions are outlined in Table 2:

Table 2: EU policy descriptions

Policy	Description
Storage Target	The national government announce a target for energy storage by 2030 of double current MW levels.
Community Energy Storage Systems	A special category of funding is provided to foster storage systems with community ownership and governance to generate local socio-economic benefits such as higher penetration and self-consumption of renewables and reduced energy bills.
Green Grid Storage	Renewable energy support schemes provide support payments for hybrid wind and storage projects that store energy from the wind farm and green energy pulled from the grid. Payments are calculated based on the % of green energy on the grid at the time of storage.
Auction Includes Storage	Storage providers will be supported via an open tender auction process which will determine the optimal mix of generation and storage for electricity. An agreed revenue “floor” will help cover operating costs and the government will pay the difference when revenues fall short and receive a share of the profits when profits exceed an agreed “ceiling”.
Support for Hydrogen Storage	Capital support payments are provided by national government to develop hydrogen storage technologies and novel markets for the hydrogen output, particularly in the transport sector.

The first EU partner policy, *Storage Target* was selected based on the recent Irish report which indicated that in order to achieve 2030 renewable energy goals, 1700Mw of storage would be required [90]. This would mean an increase of more than double current Irish levels [163]. This attribute also reflects the call to set targets for energy storage at a European level [164].

The next EU partner policy, *Community Energy Storage Systems* was based on the potential of Community Energy Storage (CES) outlined in [165]. This paper outlines that CES could provide technical and social innovation and provide wider societal benefits in comparison to standard developer-led models. This attribute was designed to reflect the similar status of community-led renewables in the current RESS system in Ireland [77] and the value placed on Renewable Energy Communities at a European level [166].

The next EU partner policy, *Green Grid Storage* aims to address the issue that certain energy storage technologies would not be economically viable if used to store excess wind alone [160, 161] and answers calls by [9, 90] to fully address the role of hybrid storage in RESS. This policy would also provide additional societal benefits in terms of grid balancing and make more efficient use of the national storage technology available, rather than a developer using it to store site specific wind energy alone.

The *Auction Includes Storage* policy reflects the recent holistic renewable energy and storage policy developed in Australia, in which a tender is run to identify the optimal blend of long-term renewable energy and energy storage projects [167] and provides a guaranteed revenue stream for developers.

The *Support for Hydrogen Storage* policy addresses key barriers to the development of a hydrogen storage technology including capital cost concerns [4, 140] and the need to develop a market for hydrogen outputs [141].

This survey was deployed to the members of the STEPS partnership which represent members from several countries in Europe. 8 responses were received from partners in Ireland (3 responses), the Netherlands (2 responses), Germany (2 responses) and Belgium (1 response).

3.3. National industry survey and choice experiments

Following the focus groups and interviews, a survey was deployed to members of the renewable energy and energy storage industry in Ireland. The survey topics included:

- Company experience with storage
- Preferred storage technologies
- Reasons to invest in storage
- Perceptions of the current status of energy storage in Ireland
- Company experience in renewable energy development
- Demographic information

The survey also included a choice experiment to explore trade-offs between several storage policy developments and dispatch down levels. The choice experiment attributes and levels are outlined in Table 3.

Table 3: National industry choice experiment attributes and levels

Attribute	Description	Levels
Dispatch Down	It is necessary to reduce the output of renewable energy generators below their maximum available level when energy system security limits are reached. This is known as "dispatch down". This attribute describes the percentage reduction in required dispatch down for renewable energy in a system with increased energy storage.	10% less dispatch down 40% less dispatch down 80% less dispatch down
Policy Scenario	This attribute outlines three potential policy scenarios for energy storage in Ireland. In each scenario, the storage provider can receive additional revenue through arbitrage.	**Storage Target**: DECC announce a target of 1700MW of storage by 2030 (current level 792MW). **Green Grid Storage**: Renewable energy developers receive support payments for energy generated and stored from each renewable energy site and green energy pulled from the grid. Payments are calculated based on the % of green energy on the grid at the time of storage. **Long-Term Energy Auction**: A tender auction process determines the optimal mix of energy generation, storage technology and location. Successful applicants will receive long-term revenue support for generation (up to 20 years) and energy storage (up to 40 years).
Duration	This attribute outlines 3 options for your preferred type of energy storage technology to be prioritised for development, by duration.	Short duration: (Up to 3 hr) Medium duration: (Up to 8 hours) Long duration: (More than 24 hours)
Cost	This attribute indicates the amount of RESS/DS3 support payment that you would be willing to give up for a system with reduced	5% less 10% less 25% less 40% less

	dispatch down, broader policy support and targeted storage duration.

The *Dispatch Down* attribute was selected based on interview and focus group feedback of a key driver for renewable energy developer's investment in energy storage. [90] found that by increasing the level of longer-duration storage on the system, renewable energy oversupply could be reduced by 63%. The levels were selected to reflect small, medium and high levels of reduction.

The *Policy Scenario* attribute reflects three of the key policies used in the EU Policymaker survey, outlined in the previous section. The *Community Energy Storage System*s and *Support for Hydrogen Storage* policies were omitted to simplify the choice task and to ensure the selection was technology agnostic. The auction attribute and description was edited slightly from the one used in the EU Policymaker survey. *Long-Term Energy Auction* was edited to better reflect the long-term revenue support provided by this policy, which could help de-risk investment. This closely matches the recent long-term strategy launched in NSW [167].

The *Duration* attribute aims to identify the preferred type of storage development that the industry believes is required, without defining a technology. [90] outline the significant economic and societal benefits which could be derived from the development of longer-duration storage. The industry interviews and focus groups indicated diverse attitudes to the type of duration which should be prioritised and so three levels were selected, reflecting short, medium and longer duration storage.

A willingness-to-pay structure was selected, using either the RESS or DS3 support payments as the payment vehicle depending on whether the respondent was a renewable energy developer or storage developer. Respondents were told the average RESS or DS3 payment amount (€98 per MWh for RESS 2 and €60,000 per MW for DS3 in 2020). Respondents indicated their WTP 5%, 10%, 25% or 40% of the average relevant support payment.

The choice sets also contained an opt-out status quo which outlined that *Dispatch Down* would remain at the current level; there would be no policy change; no priority by duration and no change to the cost.

The surveys were provided to 127 wind energy, solar energy and energy storage developers in Ireland and they were circulated to the Wind Energy Research Network, Wind Energy Ireland, the Irish Wind Farmers Association and the Irish Energy Storage Association. 19 surveys were completed which is a small sample but similar to other renewable energy industry surveys [168-170]. This data is combined with the interviews and focus groups to provide final conclusions and policy recommendations.

3.4. Principal Component Analysis

Principal Component Analysis is a method of reducing the dimensions in a dataset by minimising the number of fields into those most likely to explain the majority of the variance. Likert-scale questions are often used to carry out this analysis. The use of a method such as PCA in combination with choice experiments can help identify the social factors that may influence heterogeneity in preferences towards energy developments [171]. This method in combination with choice experiment data can reveal greater information on the probability of an individual $i's$ membership of class c.

If X is a vector of n data fields with population variance-covariance matrix Σ, then Σ can be determined as:

$$\Sigma = \sum_{i=1}^{n} \lambda_{ie_ie_i'} \quad (1)$$

where λ_i represents the eigenvalues and e_i the eigenvectors. The principal components can be are classified as:

$$\begin{aligned} Y_1 &= e_{11}x_1 + e_{12} + \cdots + e_{1n}x_n \\ Y_2 &= e_{21}x_1 + e_{22} + \cdots + e_{2n}x_n \\ &\cdots \\ Y_n &= e_{n1}x_1 + e_{n2} + \cdots + e_{nn}x_n \end{aligned} \quad (2)$$

While incorporating all possible n covariates would explain all variance, this would not lead to a reduction in the amount of data. However, if the X variables are correlated then a significant proportion of the variance can be explained while at the same time reducing the data size.

3.5. Multinomial Logit Model

In the industry survey, respondents are given three options for energy storage development in the choice set, including status quo option, which represents the current state of energy storage policy. The respondents then choose the option that provides them with the highest personal utility. This decision can be viewed as the likelihood of selecting one of the three options and therefore we can analyse these decisions in a logit structure. Due to the high number of choice sets, a full factorial design which presents all possible combinations of attributes and levels would not be possible and so this study utilises a sequential experimental Bayesian framework. A Multinomial Logit Model is used to provide the base results.

Although the MNL model can provide some information on observed heterogeneity it is not without its limitations, primarily the Independence of Irrelevant Alternatives (IIA), which presumes that the likelihood of selecting option A over A' is independent of the range of other options in the choice set. This assumption may not hold in reality and so this study also utilizes another model which does not presuppose this restriction, a Latent Class Model (LCM).

3.6. Latent Class Model

The LCM places individuals into groups based on the likelihood of them belonging to that class and provides different marginal utility levels for each class. For example, a LCM can indicate that investors are more likely to be in one class but also allows the possibility that they could be in another class with a lower likelihood. Through a LCM structure we can assess the marginal utility parameters that emerge from different classes and determine the set of external drivers that result in an individual's response.

As outlined in [172], the LCM assumes that the likelihood of an individual i selecting option j in choice set t is a function of that individuals class membership c. The choice probability density function for individual i can be denoted as:

$$P\,(y_i|z_i) = \textstyle\sum_{c=1}^{C} P(c{:}\, z_i)\, \prod_{j=1}^{J} P\,(y_i{:}\, x_i|c\,) \qquad (3)$$

where y_i refers to the full set of choice responses which lead to maximum utility for individual i, with y_i=0 if individual i selects option j in choice set t and 0 if they do not. z_i denotes certain characteristics associated with individual i and x_i is the combination of attribute alternatives and levels within each individuals choice set.

$P(c{:}\, z_i)$ refers to the probability of respondent i being in class c which is unconditional on y but varies with z_i. z_i is comprised of individual covariates, which in this study refers to experience with storage development.

Through the inclusion of the cost attribute via DS3/ RESS as a payment vehicle, the willingness to pay for each class c can be determined as:

$$WTP_{(k|c)} = \frac{\beta_{(k|c)}}{\beta_{(e|c)}} \qquad (4)$$

where β_k is the utility coefficient for a non-monetary attribute k and β_e refers to the utility coefficient for the cost attribute.

4. Results

4.1. Objective 1: European partner survey results and EU policy recommendations

A partner survey was deployed to key members from each country involved in the STEPS project. In total 8 responses were received from 4 partner countries: Ireland (3 responses), Germany (2 responses), the Netherlands (2 responses) and Belgium (1 response). Respondents were asked to provide answers from the perspective of the wind energy sector in each of their respective countries. The topics of the survey included technology types, policy scenarios and ownership issues, amongst others.

Table 4 outlines the business size for the respondents who completed the survey. All of the respondents except those from Ireland are from government organisations. All respondents were male.

Table 4: Size of business

Business size	No of respondents
Micro (<10 employees)	2
Small (10-49 employees)	3
Large (250+ employees)	3

4.1.1. EU partners preferred technology

Firstly, respondents were asked to indicate the importance of a series of factors when selecting a storage technology. The two most important aspects according to the respondents were expected lifetime and cycle cost, with 4 respondents indicating that these were very important and 4 stating that they were important. When asked to select the most important factor of those listed, 4 respondents; one from each country; selected cycle cost. 4 other respondents selected duration (Ireland); environmental considerations (Ireland); expected lifetime (the Netherlands) and public acceptance (Germany).

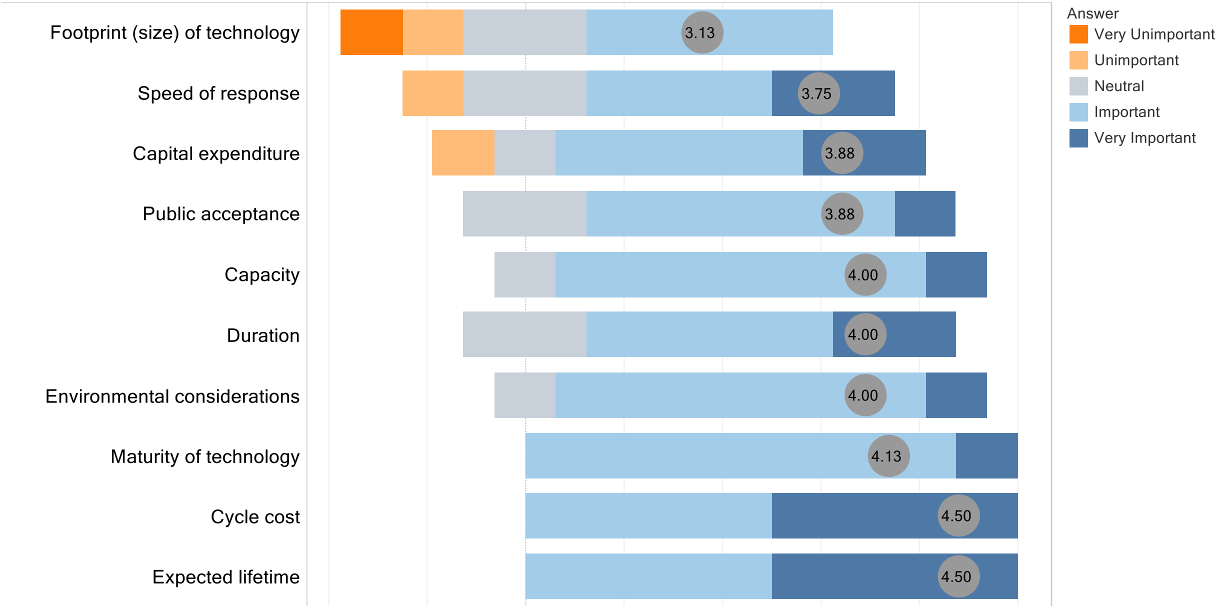

Figure 9: Importance of key factors in selecting technology type for wind energy sector

Respondents were then asked to select all of the storage technology types they believed were required to support the wind energy sector in their country. Hydrogen was the most selected option with 7 out of 8 respondents selecting it (Belgium did not select this type). The range of technology required differed significantly by country, with the Irish respondents selecting the most variety (see Table 14 in Appendix).

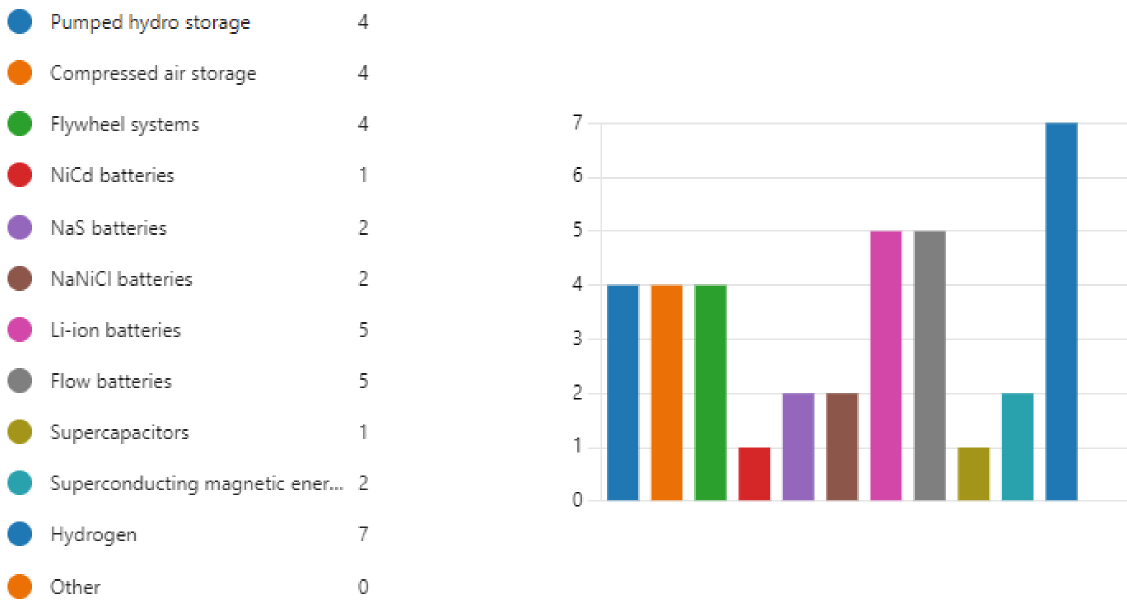

Figure 10: Types of storage required

When asked to indicate what the number one priority area requiring new development was in their country, most respondents selected grid support/balancing intermittency. One respondent from

Germany selected daily peak shifting and one respondent from the Netherlands indicated seasonal storage.

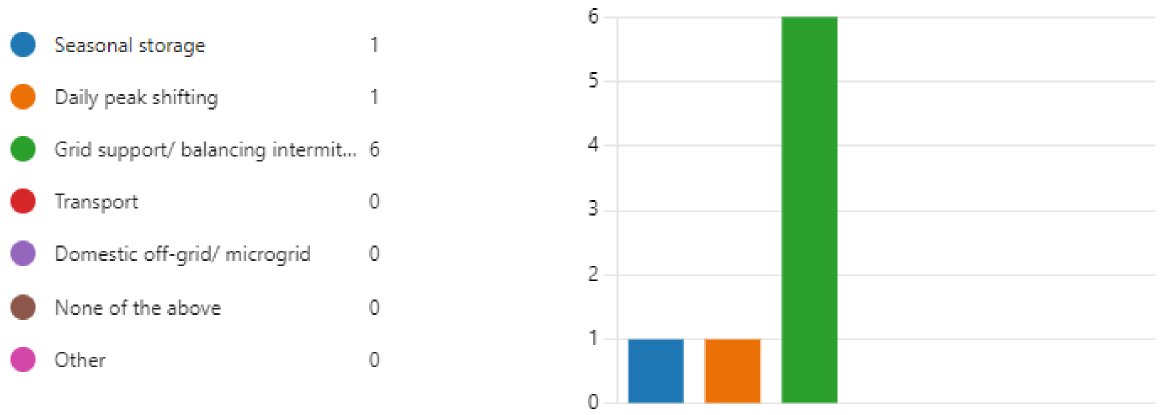

Figure 11: Priority area for new storage

When asked what duration of storage was most required, respondents were divided across the spectrum from very short term to very long term. The respondent preferences for technology type is listed with their priority duration in Table 14 in the Appendix.

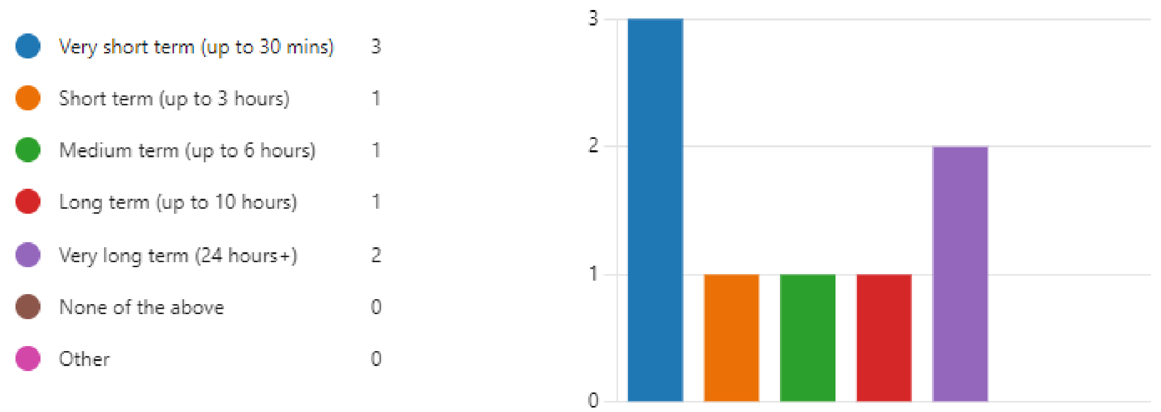

Figure 12: Duration of storage

In order to establish if respondents had preferences for the type of stored energy, they were asked to indicate if they had preferences for grey, green, national or local energy. Two respondents from Ireland and one from Germany preferred green energy regardless of where it was generated. One respondent from Ireland and one from the Netherlands preferred green energy generated nationally. One respondent from Belgium and one from Germany preferred local green energy and one respondent from the Netherlands indicated no preference.

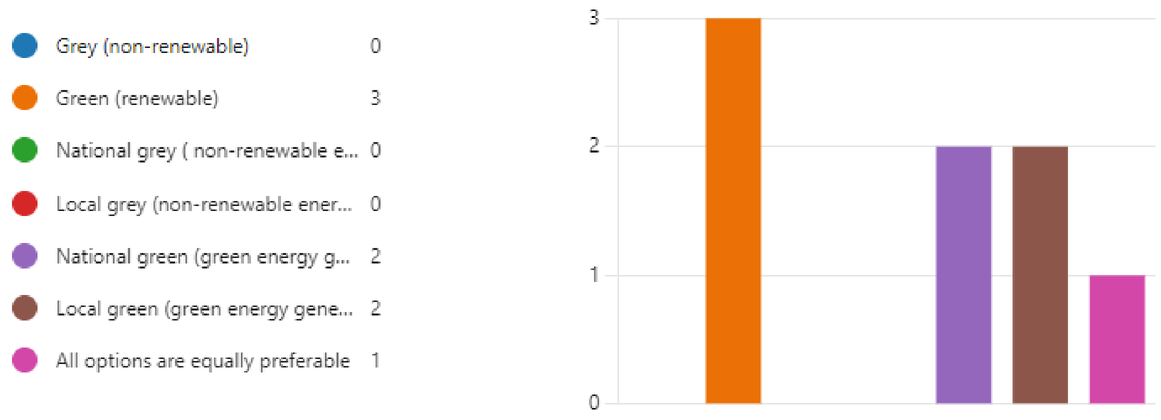

Figure 13: Preferences for type of stored energy

When asked who is best placed to build and manage storage developments in their country, most respondents (6/8) selected a consortium of private energy storage developers, wind developers, government agencies and local communities. Two respondents indicated that local communities were the preferred developers (Belgium and Germany).

In terms of preferred locations for new energy storage developments; 3 respondents selected locations identified by the TSO (Ireland, Netherlands, Belgium); 2 selected on site at wind farm projects (Netherlands, Germany); 2 selected primarily in grid constrained areas (both Ireland) and 1 selected ad-hoc locations across the country (Germany).

4.1.2. Current storage policy situation

Respondents were then asked to indicate their understanding of the current level of storage in their country. None of the respondents agreed that there was sufficient energy storage being developed in their country to meet 2030 renewable energy targets. Most agreed that more was required to meet targets and support current renewable development with one respondent indicating that there was insufficient levels to provide basic capacity support and system services to the grid.

Table 5: Current level of storage nationally

Statement	Country	No of respondents
There is sufficient energy storage being developed to support current renewable energy development but more is required to meet 2030 renewable energy targets	Belgium	1
	The Netherlands	1
There is not enough energy storage being developed to support current renewable energy development or to meet 2030 renewable energy targets	Germany	2
	Ireland	2
	The Netherlands	1
There is not enough energy storage being developed to provide capacity support and system services	Ireland	1

In order to establish the baseline policy situation in each country, respondents were asked to rate a number of issues from 1 (Very poor) to 5 (Very good). The results indicate a generally low level of satisfaction with the current level of support and knowledge of renewable energy storage. All respondents agreed that public knowledge on renewable energy storage was poor or very poor. All but one respondent from Germany also agreed that the legal framework for storage and the level of financial support for system services was at least poor. The trading market for renewable electricity is good according to the Netherlands respondents. One respondent from Belgium and one from Germany indicate that the transparency of the TSO is good (however the other German respondent indicated that it was poor). One Netherlands respondent also indicated that the level of R&D funding was good.

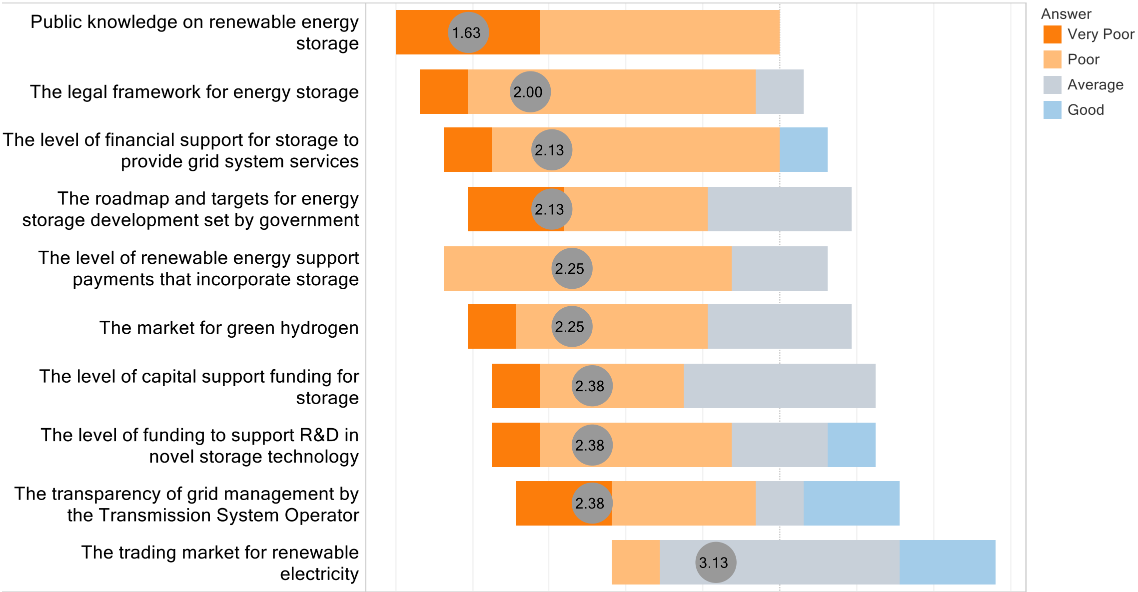

Figure 14: Attitude towards national storage policy issues

4.1.3. Storage as a solution across countries

The next question probed for specific motivating factors for the wind energy sector when considering storage. 6 respondents (three from Ireland and one from Belgium, Germany and the Netherlands) agreed that being able to produce more wind than the grid connection allows was at least an important factor. The key motivating factors varied significantly by country, with Ireland indicating that each factor was at least important, but all three respondents agreed that the ability to develop and store offshore wind energy was very important. The respondent from Belgium indicated that receiving an additional revenue source, reducing renewable energy costs to end customers and the ability to develop in grid constrained areas were very important factors. The ability to develop in grid constrained areas, supporting greater non-synchronous generation on the grid and reducing costs of renewables to end customers were the most important factors to the German respondents. While neither respondent from the Netherlands agreed that any factor was very important, reducing dispatch down/ curtailment was at least important to both respondents.

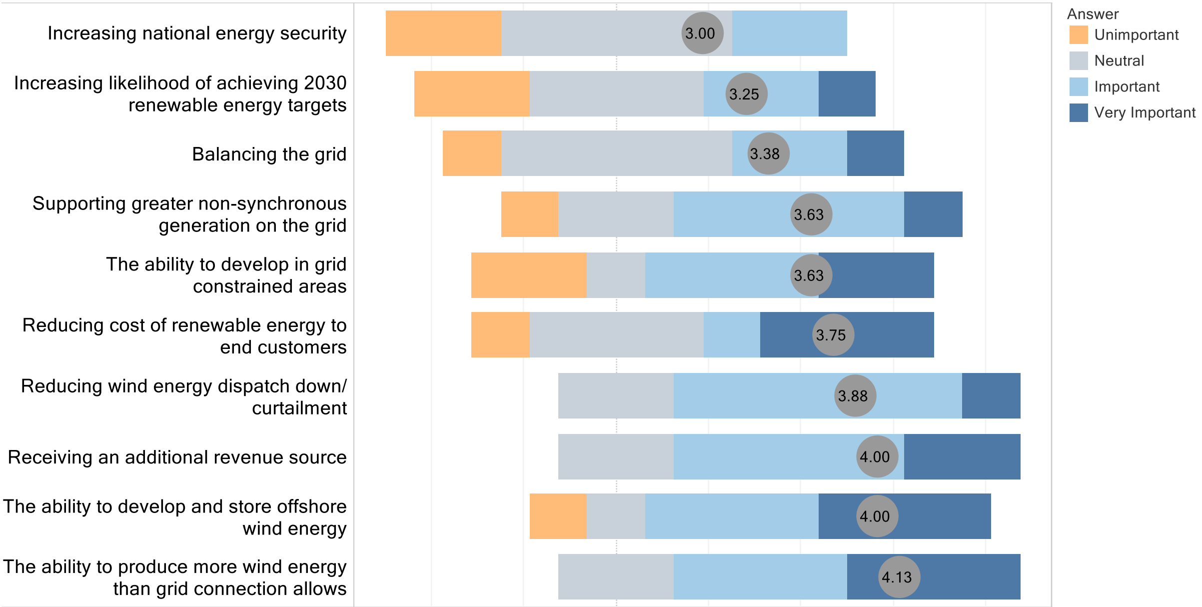

Figure 15: Importance of motivations for wind energy sector to engage with storage

Respondents were then asked, via an open ended questions, for possible solutions to renewable energy cannibalism, which occurs when renewables of the same generation profile produce simultaneously, depressing the wholesale electricity price. The responses by country are outlined below:

Table 6: Solutions to renewable energy cannibalism

Country	Solution
Belgium	Markets that support flexibility will automatically create the pull for the right type of technology.
Germany	Energy storage and smart grids
Germany	Grid support and balancing
Ireland	Dumping surplus power into storage both at the facility and Nationally so that the Grid can manage the level of intermittency (i.e. large scale deployment of storage options such as Hydrogen and Pumped Hydro and CAES)
Ireland	Electricity storage
Ireland	Renewable energy cannibalism, also known as the "duck curve," is a real challenge for the integration of high levels of intermittent renewable energy sources such as wind and solar into the grid. In Ireland, wind energy has become an important source of electricity generation, and as more wind farms come online, the problem of cannibalism may become more acute. One possible solution to this issue is to improve the coordination and communication between wind farms and grid operators. By sharing data and forecasting production levels more accurately, wind farms can adjust their output to avoid oversupply and reduce the impact of cannibalism on wholesale prices. Another approach is to

	incentivize wind farms to curtail their output during periods of oversupply, such as through demand response programs or by offering financial compensation for curtailment. Furthermore, energy storage systems such as batteries could be used to absorb excess wind energy during periods of low demand, thereby reducing the impact of cannibalism on the grid. This would also help to balance the grid and improve overall grid stability.
The Netherlands	Storage and conversion
The Netherlands	There is no solution to this effect. It's the energy market.

Most countries suggest storage as a solution to this issue, however one Irish respondent also highlighted the need for greater coordination with the grid operator, better forecasting and compensation for curtailment. Belgium suggests the right market mechanisms may solve the problem, Germany outlines the need for grid support and one Netherlands respondent indicates that there is no solution.

4.1.4. Cross EU policy preferences

Next, respondents were faced with five hypothetical policy scenarios, and asked to rank these from those most likely to increase engagement from the wind energy sector to least likely (see methods section for full description of each policy).

On aggregate, the Green Grid Storage policy ranked highest and Storage Target the lowest, however, the preferred rankings differed for each country.

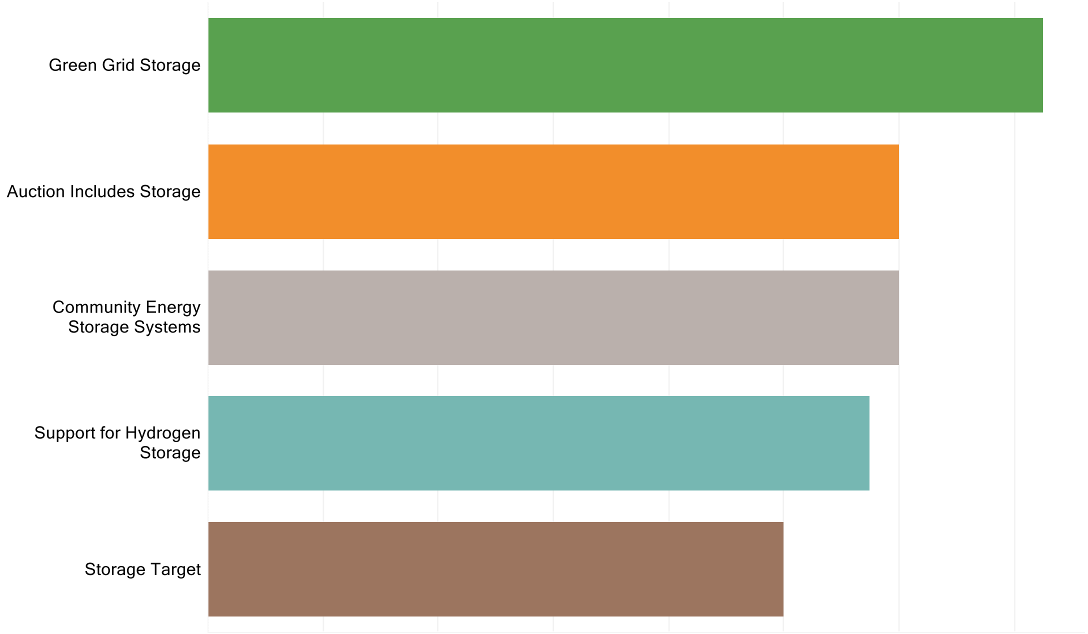

Figure 16: Preferred policy rankings

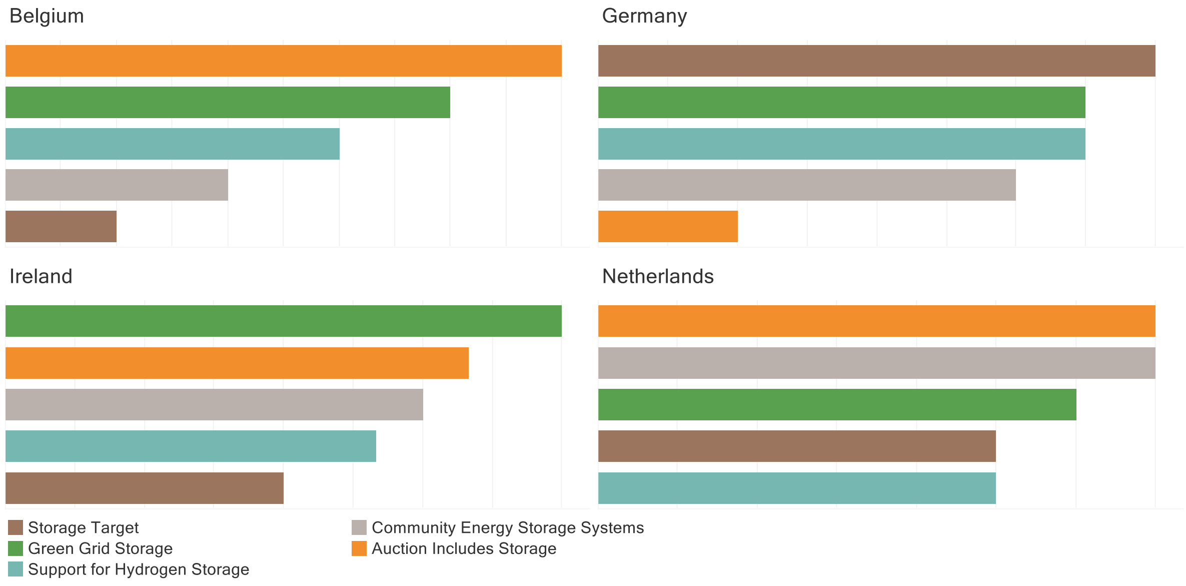

Figure 17: Preferred policy rankings by country

On average, the auction policy ranked higher for 3 of the 4 countries, with Germany selecting this as the worst option. While again 3 of the 4 countries ranked the storage target policy lower, Germany selected this as the most preferred option. One German respondent explained this preference for targets:

> National targets by the governments set the frame and are therefore important.
>
> [Respondent 7]

The Belgium respondent explained their preference for simple and transparent policy incentives, such as the auction policy:

> Clear policies will perform better, especially if they don't need multiple partners to succeed.
>
> [Respondent 4]

The Irish respondents focussed on the need for financial incentives to engage the wind energy sector. 2 out of the 3 Irish respondents selected the Green Grid Storage Policy as the most preferred option, explaining that "revenue incentives will be preferred most". Two of the respondents stated reasons for their hesitancy about the Storage Target:

> Storage targets are meaningless without incentives.
>
> [Respondent 6]

> While a national energy storage target can provide a clear signal to the market and help to drive investment in storage, it is less likely to directly increase engagement from the wind energy sector compared to the other policies on this list, as it does not provide a specific financial incentive for integrating storage with wind projects.

[Respondent 3]

One Netherlands respondent indicates that their preference for the Auction policy is driven by its ability to account for full system integration for offshore wind and also outline their reluctance to select storage targets:

> Offshore wind tenders increasingly ask for system integration aspects to be taken into account, including storage and conversion. Community ownership is not yet a thing for offshore wind in NL, and the government has always refrained from quantitative targets for storage as more storage is not a societal goal in itself.

[Respondent 7]

Several respondents ranked the Hydrogen Storage policy lower as; although it may have potential to create novel markets for wind energy in particular; it is just one form of technology, which should get the same preferential treatment as other types.

To further explain preferences for the different policy options, some follow-up questions were presented. On average, respondents disagreed that their country already has a sufficient energy storage auction framework, that hydrogen was *not* a suitable energy storage option and that the wind energy sector received sufficient support revenue. Most agreed that communities are not knowledgeable enough to develop storage systems and would not be capable of building the large amount of storage required to meet 2030 targets.

Table 7: Policy scenario follow-up statements

Statement	Belgium	Germany	Ireland	The Netherlands	Average score
My country already has a sufficient energy storage auction framework	1	3	1.3	2	1.8
The storage target outlined is not achievable	1	3.5	3.7	3.5	2.9
Hydrogen is not a suitable energy storage option	2	1.5	2.3	2.5	2.1
Communities will not be able to develop the large amount storage required	3	4	4.3	4.5	4.0
I prefer other energy storage technologies to hydrogen	3	3	3.3	3.5	3.2
The storage target outlined is too low	3	3.5	3.7	3.5	3.4
The wind energy sector receives sufficient support revenue	3	2	2.3	4	2.8

Communities are not knowledgeable enough to develop storage systems	4	4.5	3.0	4	3.9
The green grid storage policy will be too complicated to develop	4	4	3.3	3	3.6

When asked if they had any alternative policy suggestions, one Irish respondent outlined a community-developer model where the financing comes from the developer and the community have an element of control to ensure higher environmental sustainability. Another Irish respondent suggested that the SEAI Home Energy Grant be introduced for battery storage. One respondent from Belgium suggested a long-term policy commitment from the government.

4.1.5. Objective One summary

These results indicate that; although many agree that storage offers the ability to increase the level of on and offshore wind, reduce curtailment and provide an additional source of revenue, across our partner countries there is a low level of satisfaction with the current level of energy storage development and with current policy mechanisms. Most respondents believe that a range of energy storage technology will be required, particularly to provide support to the grid and balance intermittency. None of the respondents believe that 2030 targets will be achieved without increasing the level of storage and most believe that the current level is not sufficient to even support current renewable energy development.

In order to improve on this, several actions need to be taken: the level of public knowledge on energy storage needs to be increased; the legal framework must be ensured and capital, capacity and R&D financial supports across most countries needs to be increased. The policy preference question indicates heterogeneity in preferences for policy improvements; however most respondents indicate positive preferences for the Green Grid Storage and Auction policies. These policies provide simple and transparent incentives for the wind energy sector to engage with storage and addresses the need for increased financial support for storage. While the Community Energy Storage System may improve public support for storage development, most of the partners agree that the level of public knowledge on storage is not sufficient to support such as scheme. Although hydrogen storage has the potential to create novel markets for wind energy, supports for storage in general rather than targeted hydrogen policies are preferred. National targets, which may include targets for hydrogen, help form a framework for the development of storage and provide a useful signal to the market but without financial incentives, targets are not sufficient.

4.2. Objective Two: The economic value of energy storage policy changes for the renewable energy and storage sector in Ireland

4.2.1. Demographics

10 interviews with the energy storage industry and representative groups in Ireland and the UK, the wind energy sector, renewable energy representative organisations and the Irish Department of the Environment, Climate and Communications were carried out. Two online focus groups were also held (16 in one groups, 11 in another) with representatives from the wind energy sector, storage sector and those working in storage policy. Of the 10 interviews, 2 involved female participants and the remainder were male. In total, 6 of the 27 focus group attendees were female.

19 respondents in total completed the industry survey. Of these respondents, 6 were engaged in renewable energy (all engaged in wind energy and 2 of which also developed solar); 3 developed both renewables and storage (2 wind and storage, 1 solar and storage); 6 developed energy storage; and 4 were engaged in other activities including operating an energy utility; government policy; intelligent controls and other storage related activities. The company size for respondents is outlined in Table 8. 4 of the responses were from Irish semi-state companies.

Table 8: Size of business

Business size	No of respondents
Micro (<10 employees)	4
Small (10-49 employees)	9
Medium (50-249 employees)	2
Large (250+ employees)	4

Most of these companies are based close to the business' current or planned renewable energy developments (8); with 3 being located away from the renewable energy developments, 3 headquartered outside Ireland and 5 based in Ireland but not developing renewables.

Only one survey respondent was female, with 16 males making up the majority of respondents and 2 preferring not to indicate gender.

4.2.2. Experience with storage and preferred technology

Focus group & interview responses

During the interviews and focus groups, attendees were asked about preferred technology types. The energy storage developers were themselves engaged in a range of storage technologies including batteries, compressed air energy storage and hydrogen.

A wind energy developer stated that for small-scale wind, batteries offered a suitable option but beyond this the only viable solution would be hydrogen, particularly in terms of managing large-scale offshore wind. Hydrogen also offers a solution in areas lacking grid infrastructure. The hydrogen developed could diversify revenue for developers by supplying to the transport market and exporting energy.

In terms of the type of storage required, one energy storage developer believed that the primary focus should be on long duration storage as battery storage cannot store over 2 hours and it is not cost effective to trickle charge. Another storage developer indicated that there would be no need for wind energy developers to have a two-tier system for short and long-term energy storage, and a focus on longer-term storage would be more efficient. Another storage developer suggested that lithium batteries were required for short-term frequency response, 4-12 hours storage was required to provide medium scale storage and long duration storage through hydrogen was also needed. A participant from an energy storage representative organisation stated that currently in Ireland half hour batteries for energy storage have been developed to monitor system frequency. These can ramp up output quickly as the payments provided incentivise fast frequency response. They stated that all of this energy storage development is coming from private companies. This participant noted that there is between 500 and 600MW of storage either available or soon to be available to the grid, which means the short-term storage market in Ireland is saturated. This necessitates a focus on longer-term storage. This participant suggested that wind energy developers need somebody to provide storage to allow them to produce their output and so short duration and longer duration storage is required to provide security of supply. Another individual from an energy storage representative group stated that DS3 is now saturated, and prices are coming down, so lots of storage developers are moving to a minimum of 2 hour storage as larger batteries can earn higher revenues and trade more energy. According to this participant the main technology used currently is battery storage, but the cost for lithium has gone up, and there are supply and demand challenges. Another member from an energy storage representative organisation stated that many projects are developed in constrained regions, which means that the duration of storage is crucial as there may be a need for storage for days. The cost of significant constraints might make the development of long duration storage in these areas of the grid more appealing. A participant from DECC noted that the department was remaining technology neutral but that there is a need for longer duration battery to 2030, and beyond that the focus would likely be on hydrogen.

A participant from a smart grid company noted that the potential change in future corporate power purchase agreements which may require alignment of the timing of generation with the timing of usage will change the landscape and that a mix of storage was required, including thermal storage for heat.

In terms of the appropriate developers of storage, one energy storage developer indicated that the gas industry could develop hydrogen storage but it could be collaborative in nature with a wind energy developer. This participant suggested that a wind energy developer with no experience in the storage sector may leave value on the table as they may not be aware of the value of by-products of the storage process or all of the possible grid services. Another storage developer, focussed on storage from offshore wind, stated that there could be a role for the government to develop storage but that it is likely to be a mix of groups including wind energy developers and storage developers working together to build capacity. The high cost of development could mean that groups of offshore wind operators create a consortium rather than individual companies. A representative of DECC suggested that there was a mix of storage developers with some specialists who work entirely in storage and others who work in a variety of areas such as the ESB who will be developing storage capacity. There could also be a role for community storage and hybrid community wind energy projects which incorporate storage could be supported through RESS. A member of an energy storage industry group noted that some energy storage developers sell on the end project to investors and some keep the project. Some developers may not have the expertise in energy trading and hand over to a third party optimiser. In terms of community level storage behind the meter, there hasn't been a big market to date due to a lack of incentives. This individual also noted that most storage will be developed as stand-alone storage projects- but that the state could have a bigger role in the strategic planning in terms of the most effective areas to develop to reduce grid constraint. There are currently no locational signals from the government, so people are developing where its best for them and this is not as efficient.

Survey responses

Respondents were first asked their experience with energy storage development to date. Just under half of respondents had some experience with storage ranging from investment in storage technology to managing storage projects. 26% of respondents had not yet invested in storage but have plans to and the remainder have no current plans to engage with storage. Those who had engaged with storage were asked how many years of experience they had. Responses ranged from 2 years up to 7; with one company which had invested in cutting-edge storage representing the longest experience.

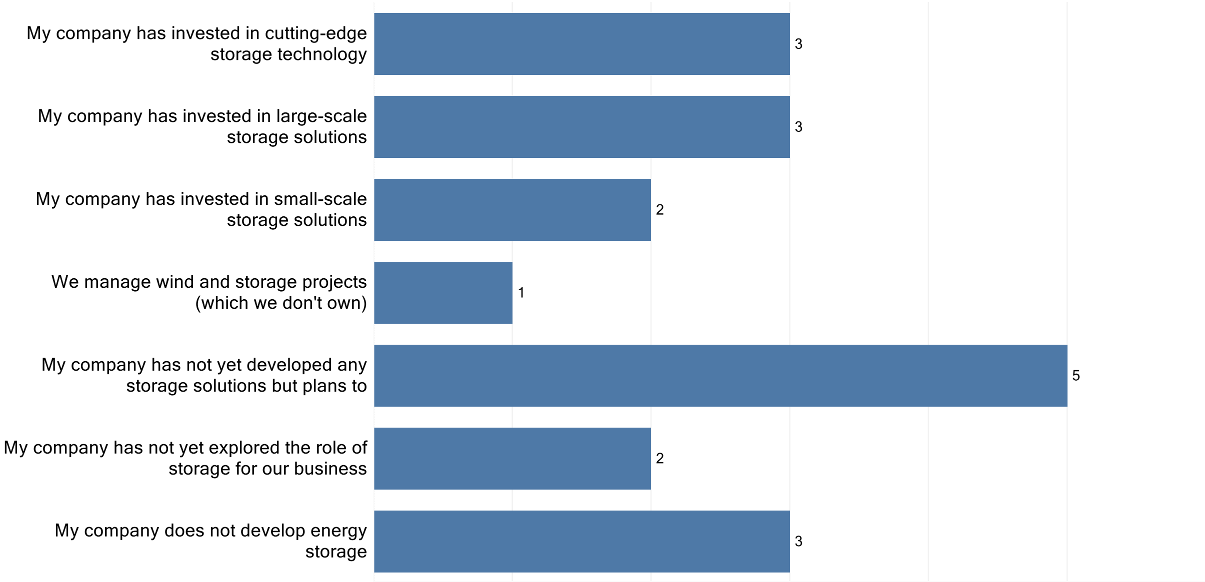

Figure 18: Engagement with storage

Those with experience or plans to develop were then asked to indicate which technology they have worked with or plan to work with.

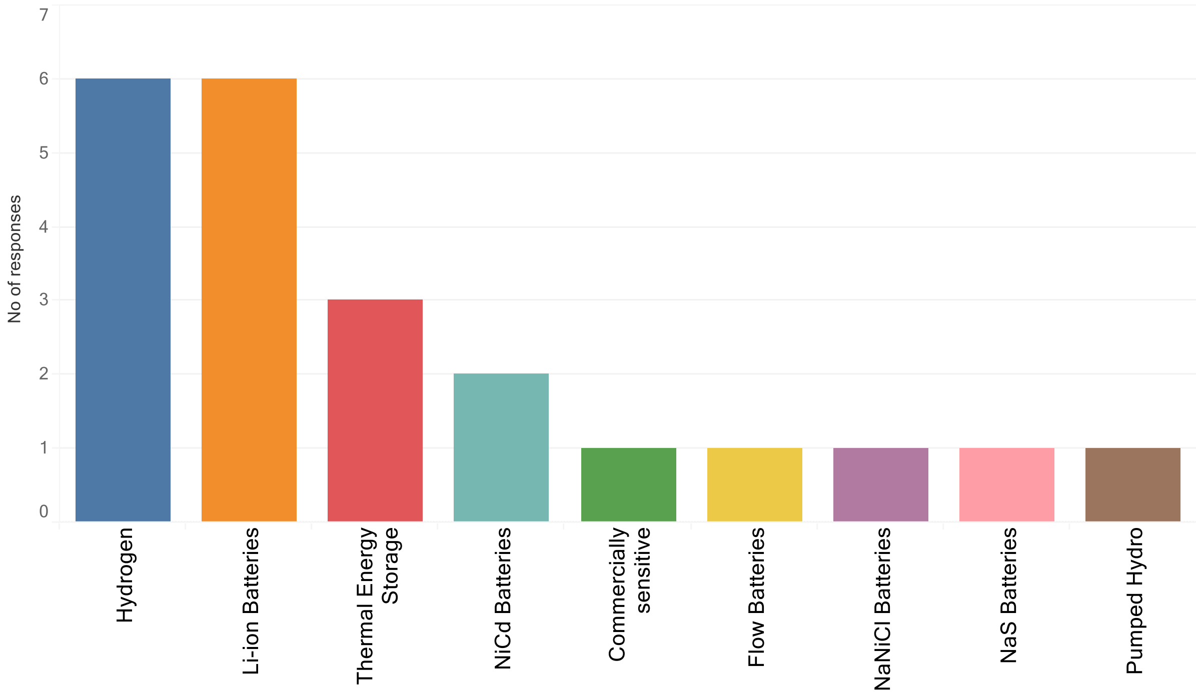

Figure 19: Selected technology

Hydrogen storage was selected by 6 respondents which included respondents who had invested in small, large and cutting-edge storage as well as those who have not yet developed but plan to. Li-ion batteries were also selected by respondents across a range of experience. Thermal energy storage was selected by large scale and cutting edge technology developers as well as one respondent who plans to develop storage. One cutting-edge developer indicated that their technology was not listed but commercially sensitive and the remainder of the technology types were selected by respondents that have not yet developed but plan to.

Survey respondents were also asked what the priority use for energy storage development should be. 7 respondents selected seasonal storage; 6 selected grid support/ balancing intermittency; 5 selected daily peak shifting and 1 selected district heating.

When asked what the most important factor was in selecting an energy storage technology, payback period was the most frequently chosen option.

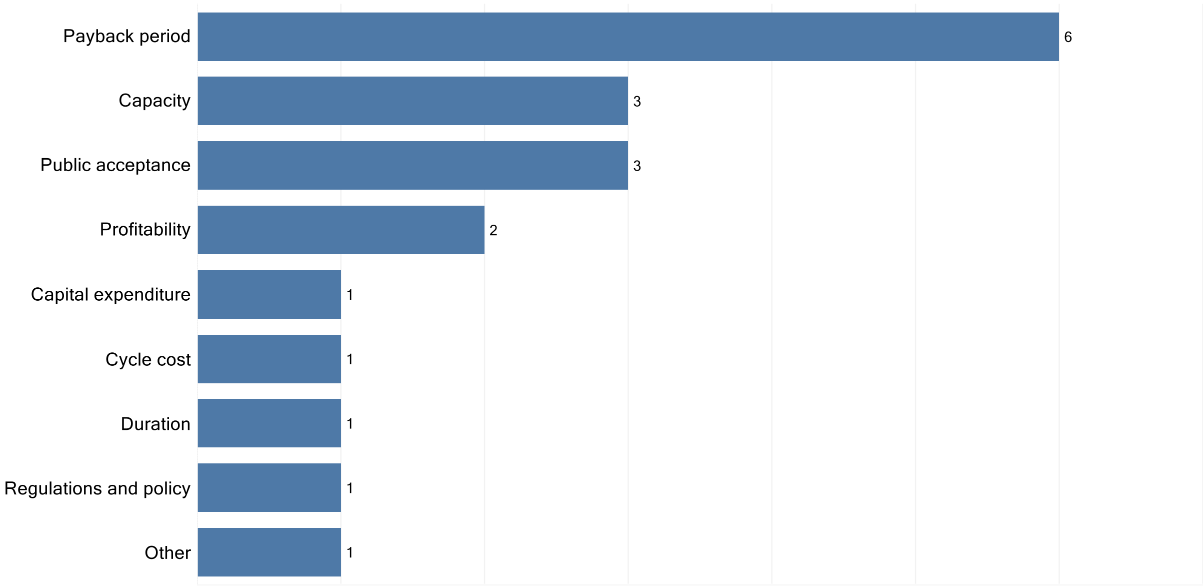

Figure 20: Key factor when selecting a storage technology

This factor was selected by respondents with a wide range of experience from cutting-edge developers to those who have not yet explored storage as an option. Capacity was selected by a cutting-edge developer, small-scale developer and one with plans to develop. Public acceptance was selected by respondents who do not develop storage and one with plans to do so.

When asked who would be best placed to develop energy storage projects, most respondents selected private energy storage developers. The respondents who selected this option are engaged in renewable energy (2 respondents); renewable energy plus storage (3); energy storage (2); and other related industries (2). Those that selected private wind energy developers are all primarily wind energy developers. Those that selected the consortium were asked who might be involved. One energy storage developer suggested developers with government stakeholders for backing and regulation. Another energy storage developer suggested private storage developers should work with Irish semi-states and communities. One renewable energy developer suggested working with communities for local impact assessments and community-based decision making with the others taking on the technical and financial aspects.

Table 9: Preferred storage developer

Developer	No of respondents
Private energy storage providers	9
Consortium involving several partners	3
Private wind energy developers	3
Irish semi-state bodies	2
Industries	1
Other	1

4.2.3. Storage as a solution

Focus group & interview responses

Focus group and interview participants were asked what they believed the most important motivating factors would be for renewable energy developers to engage with storage. Most participants believed that the primary reason was to compensate from lost revenue from curtailment. One energy storage developer, which is also engaged in the wind energy sector, indicated that the company has chosen to develop storage, primarily hydrogen storage, to reduce dispatch down from their wind energy projects. This developer noted that a planned offshore wind energy project would need to be curtailed approximately 20-30% of the time due to grid constraints, which resulted in the project being shelved.

Another energy storage developer noted that curtailment can last up to 12 hours and so energy storage needs to have same storage power as the wind farm can generate. According to this participant, potential revenue streams for developers include constraint management, generation support, import/export arbitrage with their own project returning a possible 15% internal rate of return through the provision of ancillary services.

A large-scale wind energy developer noted the need to increase storage to support the incorporation of non-synchronous generation onto the grid. This developer highlighted that it would be very difficult to meet renewable energy targets without also developing storage for the corresponding intermittent generation.

A representative from an energy agency noted again that investment in storage by wind energy developers could compensate for loss in revenue from curtailment. A representative from DECC noted that storage is an important part of a balanced portfolio which also includes demand side management and greater interconnection and that more storage would reduce curtailment.

A participant from an energy storage industry representative organisation noted that there was a certain amount of interest in developing storage from the wind energy sector. This participant outlined that curtailment will become a bigger problem as greater renewables are accommodated on the grid. Wind energy developers can put excess energy into a battery rather than reduce output and sell into the grid when the prices are higher. Another noted benefit was that a developer could put in more wind turbines for the size of connection- e.g. if the developer has a 50mw connection, they could install 60mw turbines and 10mw of storage. There is a potential issue for wind energy developers in that they need to ensure the batteries are not being charged from grid due to RESS contract restrictions requiring all energy produced to be green. This participant noted the difference in incentives for storage between wind energy developers on older support contracts vs newer contracts as those on older contracts are compensated for the energy curtailed, but those on the newer contracts are not.

Another participant from an energy storage representative organisation stated that DS3 revenue would be the main motivation for a wind energy developer to incorporate storage, with most storage projects receiving 80-90% of their revenue from DS3. This individual also noted that the grid in Ireland is highly constrained, approximately 20-30%, which can make a project unviable. Storage could be viewed as a complimentary solution to the grid.

A large-scale wind energy developer noted the potential for developing storage to support large-scale energy exports:

> We know that deals have been signed between Germany and Canada and we also know that we have a 30GW opportunity off our coastline, that if we were to capitalise on that some form of storage will be required in order to make that a reality.
>
> [Developer 2]

Survey responses

In the industry survey, respondents who develop renewable energy were asked their average dispatch down level for last year. 3 respondents indicated it was less than 3%; 4 between 7-10%; 1 between 11-15%; one between 16-20% and 1 more than 20%. When asked how they expect this level to change in the future; most expect it to increase, with respondents across a range of average dispatch down levels selecting this answer.

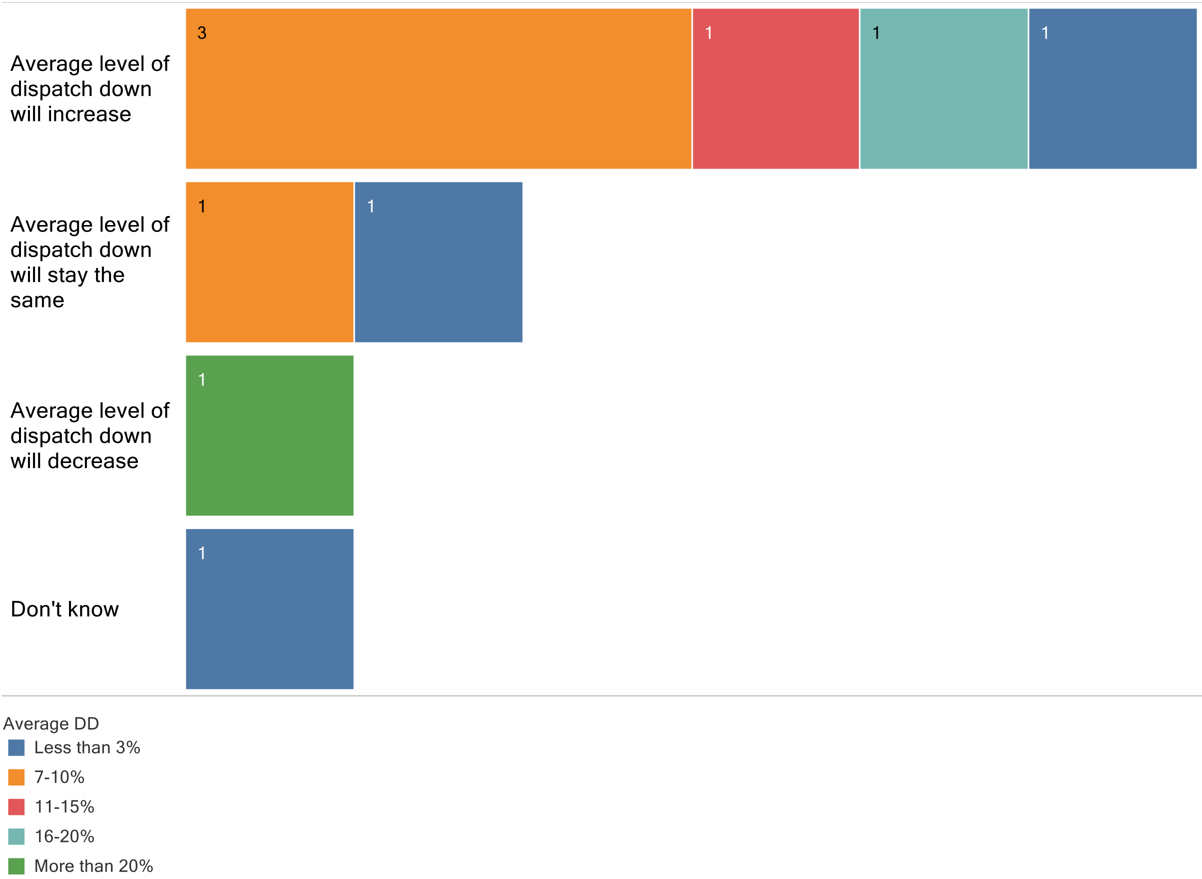

Figure 21: Expected change in dispatch down

All respondents were then asked to what extent they believed that renewable energy storage offered a solution to a range of issues. Respondents were asked how the solution offered by storage to address the following issues should be rated, from 1 (Very poor) to 5 (Very good). Don't know was scored as 3 (neutral). Most respondents were positive towards all of the solutions provided by renewable energy storage. 74% of respondents believed that renewable energy storage offers a good or very good option to diversify an investment portfolio and reduce dispatch down (with 53% of respondents selecting that storage offered a very good solution to dispatch down); 79% of respondents believe that storage can offer a good or very good method of developing in grid constrained areas and reducing cost of renewables to end customers; 84% of respondents believe that renewable energy storage is a good or very good method to produce more energy than allowed by the grid connection and achieve renewable energy targets; and 95% of respondents believe that storage offers a good or very good solution to the provision of grid system services.

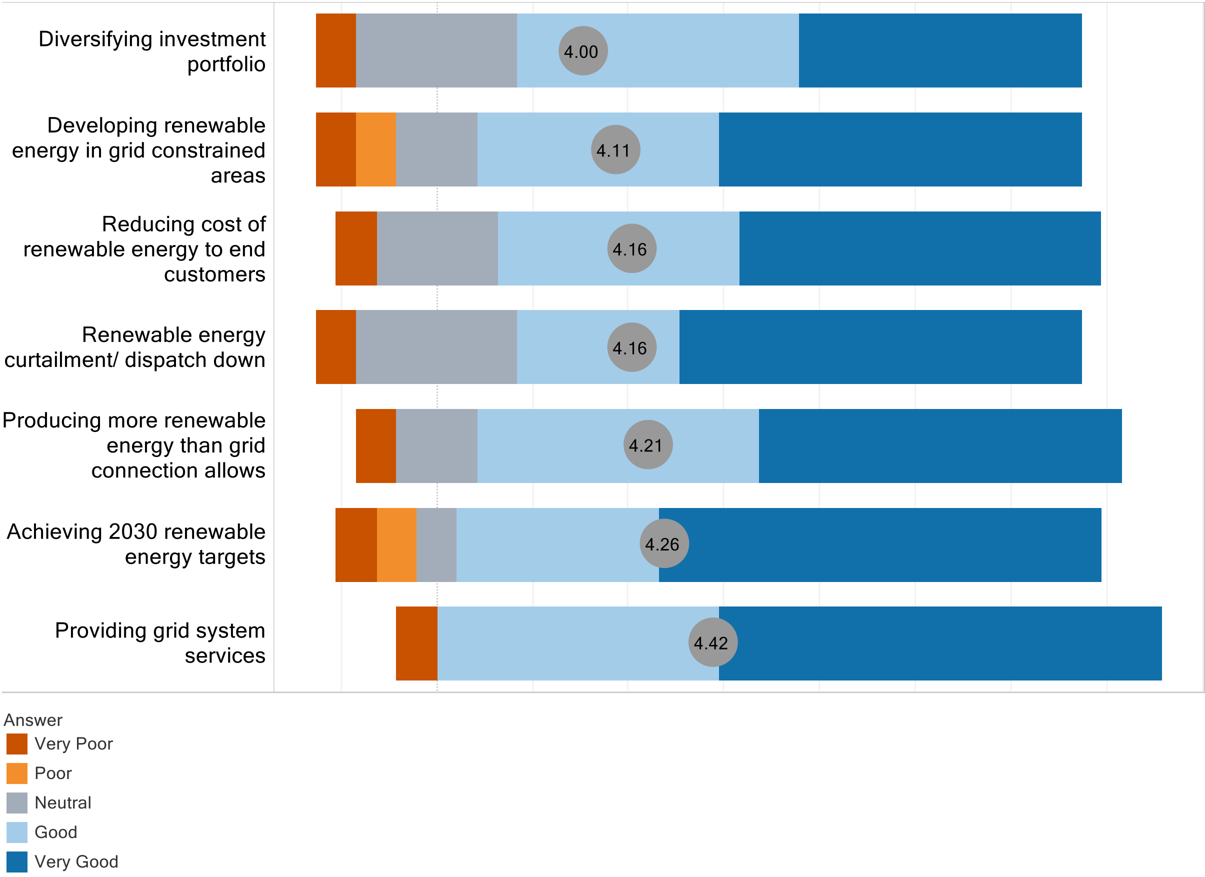

Figure 22: Renewable energy storage as a solution

4.2.4. Barriers to storage

Interview & focus group responses

Most participants outlined the importance of government support to ensure the development of the sector. One energy storage developer highlighted support mechanisms such as the net zero hydrogen fund in the UK and the perceived haphazard and disorganised policy by government and regulators in the Republic of Ireland and Northern Ireland. This participant believed that the planning agencies are disorganised which can delay planning applications. Another energy storage developer suggested that equity finance is a big barrier to the industry and it is the government's job to solve chicken and egg situation by supporting emerging technology in the storage sector that is not currently economically viable. This developer highlighted funds such as the UK & NI's Small Business Research Initiative, which provides seed funding for SME's to bring their idea to market and provides up to 100% of the project costs. Another energy storage developer, which focuses on storing energy from offshore wind also acknowledged that the main barrier to development is cost as well as and the lack of development in floating and fixed offshore wind. This developer, based in the UK, received BAES funding to support the development of their project. A representative from DECC highlighted the changes that have taken place in the RESS auctions which means that storage can now participate in a way it couldn't before.

They noted that if the battery is behind the metre and is pulling energy directly from the renewable project, then it is entitled to support but if it is in front of the metre and pulling from grid this support is not provided. They acknowledge that support for storage is in its infancy, with battery storage mainly getting support from DS3. This participant highlighted that the budget for RESS has been breached, or close to, recently and so the tariffs provided to storage side supports have been reduced. They stated that the business case doesn't exist currently for long duration storage and while there are lots of potential storage projects, no funding is currently provided in Ireland for demonstration projects. A member from an energy storage representative group also highlighted the barrier of supports for storage. This participant noted recent proposed changes to the de-rating factors by EirGrid, which aims to address the "cannibalism" effect of greater storage on the system. This participant believed that these changes would kill off the Capacity Remuneration Mechanism and that new policies to reduce rates for system services means supports are moving the wrong direction for storage currently. It was noted that there was a plan to bring in a competitive short-term market for system services but this is not developed yet.

A participant from an energy storage representative organisation stated that the limited existing supports are restrictive, highlighting again that in order to receive RESS support, the storage couldn't pull from the grid. This creates a disadvantage for a developer as if they can only store when there is excess wind then the battery would have to be very large which may not make economic sense. Other hybrid projects which do not connect the storage to RESS, such as a storage site with wind energy or solar PV can import from the grid. This participant also stated that they are currently in discussion with DECC to develop a RESS-type scheme for long duration storage and highlighted that the UK is progressing towards long duration storage.

It was highlighted by a wind energy developer that there was a lack of general energy storage policy in Ireland:

> Energy storage needs to be as much of a focus as renewable energy, and I don't think it's there yet.
>
> [Developer 1]

In terms of other policy requirements to support storage, a member of a storage industry representative group highlighted the difference between Ireland and GB in terms of markets for storage. Ireland's DS3 has a set amount of products and rates, in GB there is a much more dynamic and active trading market, with more energy being traded and greater revenue. This individual stated that the market systems in Ireland are complex and don't easily incorporate storage whereas in GB they don't have that issue. This individual also noted that up until recently storage providers were double-charged as both generators of electricity and an entity placing demand on the grid. Storage is now treated as demand in Ireland and not levied as generation. This individual stated that there should be new category for storage and that there will likely be something changed in the future around the definition of storage. Another member from an industry representation group noted that in comparison to the UK, Ireland are now lagging in the market for storage and system services. It was noted that the UK has taken a different approach by developing the market incrementally with separate auctions for different services whereas Ireland has tried to develop a single market incorporating all services at once.

A participant from the smart-grid sector noted that the policy focus to date has been on the provision of ancillary services and that more long duration policy was required.

One energy storage developer believed that cost and reliability would be the two most important factors to wind energy developers in engaging with storage. It was noted that there were significant supply chain barriers, and energy targets to meet without a proper roadmap to achieve them. There may also be a skill shortage in the energy storage sector.

A participant from an energy agency stated that curtailment may also be an issue for community wind energy projects, which are a separate category in the RESS process. This individual noted that the recent changes to the RESS process requiring community projects to be 100% community owned rather than a hybrid between the communities and developers could mean a lack of expertise in developing storage solutions. A wind energy developer noted that while energy storage is complex, there is plenty of money ready to move into storage but a lack of policy in place. Storage for capacity rather than just DS3 system services will not be developed until the correct policy is in place. A participant from DECC noted that the department was currently working on the Energy Storage Policy Framework.

An energy storage developer believed that there were no issues in terms of public acceptance with green hydrogen development from wind energy because the technology is not likely to be suitable for on-site coupling, noting that the success or otherwise of the sector was an economic question rather than one of public acceptance. Another energy storage developer, focussed on capturing green hydrogen from offshore wind, noted that the space required to store offshore wind in batteries would be enormous. They developed their prototype to have minimal environmental and public acceptability impact as the device does not have to sit on shore. A member of an industry representative group stated that energy storage has mainly flown under the radar in terms of community acceptance and noted just a few recent localised issues, with the main concerns centring on fire safety with battery storage. This participant noted that the government is supportive of storage but there is a need to communicate information on storage to the wider public. The individual from the DECC did acknowledge that there was the potential for public acceptance issues around fire safety, environmental impact and whether or not storage represents the best use of land.

Survey responses

Respondents were asked to rate a number of policy related issues from 1 (Very poor) to 5 (Very Good); with "don't know" being classified as neutral. Responses indicate a negative view of the current state of policy support, public knowledge and market mechanisms. 69% of respondents believe that the incentives to engage with storage in the ex-ante market are poor or very poor; 64% believe that policy support to allow for the time aggregation of storage is poor or very poor; no respondents indicated that the government support for storage was good; just 2 respondents indicated that public knowledge was good or very good; 2 respondents believe the market for green hydrogen is good or very good and no respondent agreed that the transparency of grid management by EirGrid was good. However; 37% of respondents believe that the trading market for renewable electricity in Ireland is good or very good.

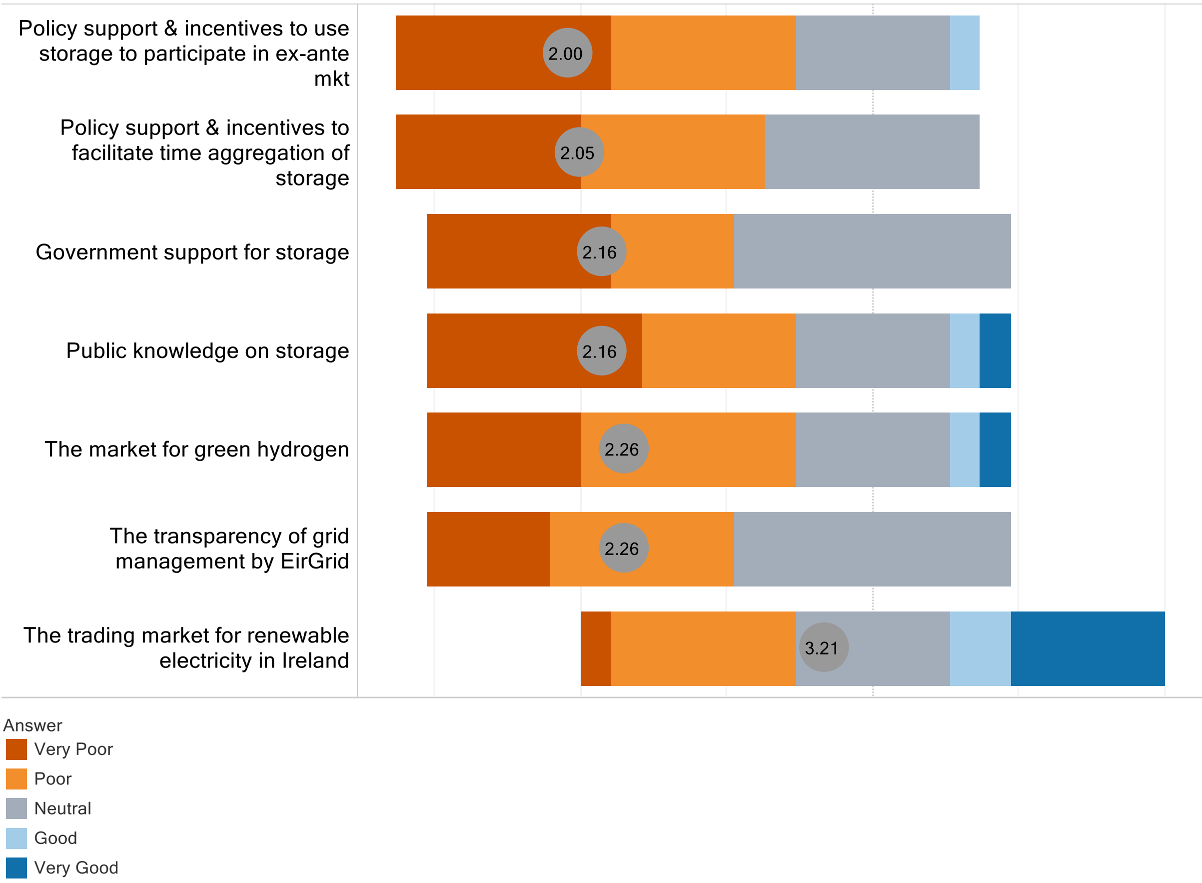

Figure 23: Attitudes towards current policy and market mechanisms

Respondents were then asked to rate their agreement with a number of statements relating to barriers to development and reasons to invest in storage (1: Fully disagree, 5: Fully agree; Don't know classified as neutral). Respondents were mixed in their agreement in the potential for short-term energy storage; with 26% of respondents disagreeing but 42% agreeing or fully agreeing that short-term storage could be a favourable investment. 42% of respondents agree or fully agree that energy storage returns are low in comparison to wind energy. Over half of respondents agree or fully agree that trading in the ex-ante market is risky. 42% agree or fully agree that there are too many barriers to trade stored energy in the ex-ante market and that there are not enough viable business cases for energy storage. 53% of respondents believe, however, that long-term storage could present a favourable investment option. 58% of respondents agreed or fully agreed that renewable developers they respect are investing in storage.

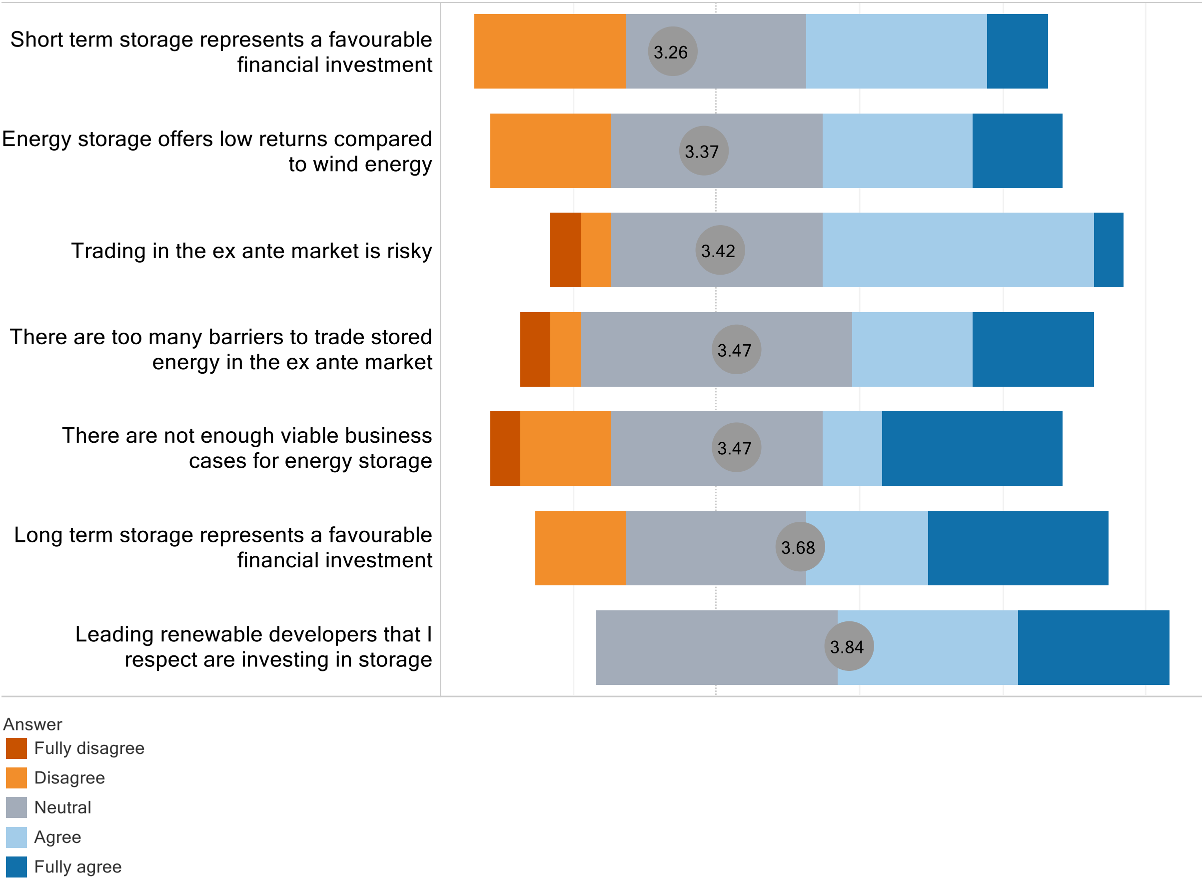

Figure 24: Potential for investment in energy storage

4.2.5. Industry modelling results

Firstly, a Principal Component Analysis (PCA) was applied to some of the attitudinal questions in the survey which were either scaled from 1 (very poor) to 5 (very good) or 1 (fully disagree) to 5 (fully agree), with "don't know" responses classified as neutral (see Table 15 in Appendix for full question structure). The results from the component correlation matrix, retrieved using Alteryx Designer 2020.4 are outlined in Table 10 with stronger correlations for each component highlighted in bold. The first component accounts for approximately 24% of the variance in the data. This group are more likely to agree that storage offers a solution to issues such as curtailment, allowing more development in grid constrained areas and reducing cost to end customers, although they are less likely to be influenced to invest based on the actions of other developers. This cohort may be described as *Solution Focussed*. The second component accounts for approximately 16% of the variance in the data. This group are less likely to agree that trading in the ex-ante market is risky, that there are too many barriers to investment in the ex-ante market, that there are not enough viable business cases and that leading developers they respect are investing in storage. This cohort may be categorised as *Comfortable Investors*. The final component, which accounts for approximately 13% of the total variance. This group are less likely to agree that storage is a good solution to curtailment and that long-term storage offers a favourable investment and are more likely to agree that storage offers low returns in comparison to wind. This group can be classified as *Storage Sceptics.*

This initial analysis indicates that there may be heterogeneity in the preferences for energy storage policy and so models which take account of this heterogeneity in the choice analysis may be more appropriate.

Table 10: Principal Component Analysis

	PC1	**PC2**	**PC3**
Solution to curtailment	**0.352**	-0.053	**-0.321**
Solution to grid system services	0.235	-0.060	0.098
Solution to produce more energy than grid connection	0.269	0.005	-0.061
Solution to develop in constrained areas	**0.308**	-0.166	-0.029
Solution to diversify portfolio	0.287	-0.078	-0.079
Solution to 2030 targets	0.281	-0.118	0.016
Solution to reduce cost to customers	**0.318**	-0.076	-0.078
Trade in ex ante market is risky	-0.247	**-0.310**	0.067
Too many barriers to trade in ex ante market	0.119	**-0.700**	0.024
Storage offers low returns compared to wind	-0.104	-0.092	**0.301**
Not enough viable business cases	-0.075	**-0.291**	0.233
Short term storage is a favourable investment	0.228	-0.020	0.069
Long term storage is a favourable investment	-0.022	0.038	**-0.597**
Leading developers I respect are investing	-0.197	**-0.321**	-0.228
Seeing other developers invest made me believe it was worth trying	**-0.351**	-0.107	-0.277
Government support for storage	-0.060	-0.168	-0.267
The trading market for storage	-0.087	0.136	0.040
Public knowledge on storage	0.005	0.263	-0.133
Transparency of grid operation by EirGrid	0.067	0.094	-0.126
Hydrogen market	-0.074	-0.057	-0.277
Policy support to use storage in ex ante market	-0.224	-0.122	-0.004
Policy support to facilitate time aggregation of storage	-0.117	-0.039	-0.218
Proportion of variance	0.24	0.16	0.13

Table 11 outlines the statistics for up to 3 segments for the Latent Class model. As the Pseudo R^2 does not penalise for increased numbers of parameters, other statistics which do; such as the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC); can be more useful in model selection. Both measures are useful in terms of determining goodness-of-fit and neither has clear advantages over the other [173]. Although the 3 class model returns the best Pseudo R^2 and log likelihood, the lowest AIC and BIC arise from the 2 segment model. Due to the small sample size and the results from the AIC and BIC, the 2 class model was selected as the best fit. Ultimately, the decision of the suitable number of classes should also be determined by the analysts judgement on the interpretation of the results [174, 175].

Table 11: Latent Class selection criteria

No. of classes	No. of parameters (k)	Log likelihood	AIC[2]	BIC[3]	Pseudo R^2[4]
1 (MNL)	8	-188.31	392.6	200.09	0.12
2	18	-163.09	370.6	193.81	0.33
3	28	-159.85	375.7	201.07	0.36

Table 12 outlines the results for a baseline MNL model and the 2 segment Latent Class Model estimated using Nlogit 5. In these models, the *Dispatch Down* level of 10% , the *Storage Target* and *Short Duration Storage* levels are dropped as the baseline for comparison. The MNL model indicates positive preferences for the various dispatch down reductions, the policy changes and the prioritisation by duration, however most variables are insignificant. The *Green Grid* policy is positive and significant at the 10% level indicating the additional value derived by this level over the basic *Storage Target* policy. The cost attribute is negative and significant at 10% and the value for the status quo is negative and highly significant. This negative value for the status quo indicates that the sample generally derive negative utility from the current level of dispatch down, storage policy and prioritisation.

The Latent Class Model was estimated using a variety of demographic and attitudinal variables and the Principal Components, however due to the small sample size, the majority of these variables returned insignificant results and did not improve the model fit. One Principal Component is included to provide an indication of heterogeneity, *Comfortable Investor* which represents respondents who are less likely

[2] AIC measures the quality of models for a given set of data with lower numbers signifying a better model fit. AIC= $-2/(LL-k)$.

[3] BIC is also used as a criterion for model selection, again the lowest BIC is preferred. BIC= $-LL+[(k/2)Ln(N)]$.

[4] In the McFadden pseudo R^2 the log likelihood of the intercept model is interpreted as the total sum of squares and the log likelihood of the entire model as the error sum of squares. Although the pseudo R^2 can't be directly compared to those of linear model, results of between 0.30 and 0.40 are generally considered similar to those of between 0.60 and 0.80 in a linear model (Domencich and McFadden, 1975; Hensher et al., 2005).

to agree that there are barriers to engage in the storage market, that the market is risky and that there are not enough viable business cases.

The first class of individuals, which make up the majority of the sample (63%), derive significant positive utility from a reduction in *Dispatch Down* of 80% over the baseline 10% level and for the *Green Grid* policy. This group also has significant negative preferences for the prioritisation of *Long Duration* storage over *Short Duration* storage and for the current *Status Quo*. The *Comfortable Investor* interaction indicates that this group is less likely to contain respondents which are comfortable engaging in the ex- ante market, however this result is not significant.

The second class of individuals, which are the reference class and make up approximately 37% of the sample, only derive strong positive utility for the prioritisation of *Medium Duration* and *Long Duration* storage over *Short Duration* storage. This group is more likely to contain *Comfortable Investors* (although this interaction is insignificant).

Table 12: MNL and Latent Class Model (2 classes)

Attribute	**MNL**	**LCM (2 Classes) (standard error in parenthesis)**	
		Class 1	**Class 2**
Utility model			
DD Reduction 40%	0.078	0.187	0.300
	(0.337)	(0.462)	(0.667)
DD Reduction 80%	0.143	0.466*	-0.333
	(0.177)	(0.241)	(0.458)
Green Grid	0.322*	0.669**	-0.344
	(0.193)	(0.271)	(0.482)
Auction	0.172	0.122	0.538
	(0.206)	(0.269)	(0.483)
Medium Duration	0.094	-0.344	1.329***
	(0.199)	(0.275)	(0.492)
Long Duration	0.159	-0.689**	2.355***
	(0.194)	(0.280)	(0.623)
Cost	-0.010*	-0.013	-0.011
	(0.006)	(0.008)	(0.017)
Status quo	-2.26***	-4.298***	-0.189
	(0.397)	(1.293)	(0.703)
Class probability model			
Constant		0.622	0.00
		(0.676)	
Comfortable Investor		-0.408	0.00
		(0.310)	
Average class probabilities		0.63	0.37
Log-Likelihood	-188.31	-166.34	
McFadden Pseudo R^2	0.12	0.33	
No. of observations	228	228	
No. of respondents	19	19	

Note: ***, **, * =Significance at 1%, 5%, 10% level

Table 13 outlines the willingness to pay estimates for the MNL model and the LCM 2 class model, in terms of a reduction in the average percentage of DS3 (annual) or RESS 2 (per MWh) payment. Where the results are positive, they indicate a willingness to pay value, where negative they indicate the additional percentage in payment that respondents require to compensate for a change in that attribute.

The MNL model, which treats the entire sample as homogenous, indicates positive WTP values for each attribute, although only the value for the *Green Grid* policy is significant. These results suggest that our sample are WTP 31% of the average annual DS3 payment or RESS 2 MWh payment for a policy scenario that includes the *Green Grid* option instead of a *Storage Target*. This equates to €18,750 annually (DS3) or €30.63/MWh (RESS 2).

In the LCM, we see that Class 1, which represents the majority of the sample (63%), are WTP approximately 37% of the average DS3 annual payment or RESS 2 MWh payment to move from a *Dispatch Down* reduction of 10% to 80%. This equates to a reduction in annual DS3 payment of €22,200 or €36 less per MWh through RESS. This sample are WTP even more to introduce the *Green Grid* policy over the basic *Storage Target,* the equivalent of €31,688 annually through DS3 or €52/MWh through RESS. Class 1 derive strong negative utility from the prioritisation of *Long Duration* storage in comparison to *Short Duration* storage, and require an additional €32,604 annually through DS3 or €53/MWh through RESS for this policy scenario.

The respondents for Class 2 represent the preferences of approximately 37% of the sample. Although these respondents indicate insignificant preferences for most of the policy changes, they are willing to pay significant sums for the prioritisation of *Medium* and *Long Duration* storage over *Short*. This class are WTP 120% of the value of the average DS3/ RESS payment for *Medium Duration* storage. This amounts to €71,814 annually in DS3 or €117/MWh through RESS. The amount they are WTP to prioritise *Long Duration* storage is even higher, at the equivalent of €127,302 annually in DS3 or €208/MWh through RESS.

We can perform a simple back-of-the-envelope calculation to extrapolate what these RESS values may mean for a wind farm developer in Ireland. If we take the lesser MNL value for the *Green Grid* policy at €30.63 per MWh, and assume the developer operates a 2 MW wind farm, receives the average RESS 2 payment of €98 per MW/h, and has a 30% load factor, this suggests that the value of introducing the Green Grid policy equates to €160,991[5] in annual RESS payment equivalent. This value increases or decreases with greater or lesser wind farm size and load factor.

[5] (MW*hours in year*load factor)*€30.63 per MW/h

Table 13: WTP estimates (percentage DS3-annual/ RESS2-MWh)

Attribute	**MNL**	**LCM (2 classes)**	
		Class 1	**Class 2**
DD Reduction 40%	7.6%	14.77%	-27.06%
DD Reduction 80%	13.86%	36.78%*	-29.99%
Green Grid	31.25%*	52.78%**	-30.98%
Auction	16.69%	9.63%	48.45%
Medium Duration	9.07%	-27.10%	119.69%***
Long Duration	15.43%	-54.34%**	212.17%***
Average class probabilities		0.63	0.37
Log-Likelihood	-188.31	-166.33	
McFadden Pseudo R^2	0.12	0.33	
No. of observations	228	228	
No. of respondents	19	19	

4.2.6. Objective Two results summary

As the previous results of the EU partner study in Objective One indicate, this national study of the renewable energy and storage sector in Ireland indicate that a range of technologies are likely required to support the electricity system. Most survey respondents had some experience with storage or have plans to engage with storage solutions with hydrogen, battery and thermal storage technologies being the most frequently referenced. The main motivating factors for the renewable energy sector to engage with storage, according to the interview and focus group respondents appear to be minimising curtailment, increasing the amount of stored renewable energy behind the metre and receiving an additional revenue stream. Most survey respondents who generate renewable energy expect the average level of dispatch down to increase in the future, forming an incentive to invest in storage. Most survey respondents agree that storage offers a good solution to a range of issues including reducing curtailment and supporting the grid; however Principal Component Analysis of attitudinal statements indicates the presence of heterogeneity, with some respondents being sceptical of the merits of storage in general, long-duration storage and the hydrogen market in particular.

In terms of barriers to storage development in the renewable energy sector, focus groups and interviews indicate a lack of government policy support, a lack of equity finance, the limited development of the offshore wind sector, restrictions in the way the RESS scheme is set up, changes to the de-rating factors for the CRM, the lack of a dynamic trading market, supply chain barriers, skills shortages, limitations to community development, possible public acceptance issues related to the scale of storage development and potential health and safety concerns. Survey responses echo this, with most indicating that policy supports, incentives, public knowledge and the market for green hydrogen are currently poor in Ireland and that trading in the ex-ante market is risky. However, the Principal Components Analysis highlight a cohort of comfortable investors (PC2) which are less likely to believe that trade in the ex-ante market is risky, that there are barriers to trade or that there are a lack of business cases for storage. In the choice experiment results, across all models, respondents indicate preferences for changes to current policies. The choice experiment results also indicate heterogeneity in the sample, with Class 2 indicating insignificant preferences for reduced dispatch down levels and policy changes greater than a basic storage target, but strong positive preferences and high WTP values for medium and long-duration storage incentives. However, the majority of respondents (Class 1) are WTP to reduce dispatch down levels through storage and to change current policy to allow for direct supports for renewable energy developers storing green energy pulled from the grid. The economic value of further dispatch down reductions from 10%-80% through storage to the Class 1 survey respondents equates to a WTP value of €22,200 annually in DS3 payments or €36 per MWh through RESS. The introduction of the Green Grid policy for this cohort represents approximately €31,800 annually through DS3 or €52/MWh through RESS.

5. Discussion

With respect to our first Objective, our findings from the EU partner study indicate that there is a general low level of satisfaction with current energy storage policy. Our EU partners believe that, in their respective countries, the legal framework for energy storage, the level of financial support for storage, the targets set by government and the capital support funding is insufficient. Across Europe, the level of energy storage development has been uneven, with countries such as the UK leading in terms of installed capacity and others such as Netherlands lagging behind [26]. The UK has prioritised energy storage as a key component of achieving a net carbon economy and due to its reliance on large-scale offshore wind [49], has made many strategic decisions in recent years in order to achieve their current high level of energy storage [52]. These policies include an auction for grid system services [50], funding for long-duration storage [58], support for renewable energy co-development with storage [53], the development of a roadmap for the hydrogen economy [55], innovation funding [57] and legislative changes [59]. In comparison, countries such as the Netherlands and Ireland lack incentives for the provision of flexible capacity services and direction from government [9, 11].

In terms of storage technology; batteries and pumped hydro storage dominate currently across Europe [26]. Our EU partner respondents believe that a range of storage technology will be required to support renewable energy development, with hydrogen storage being the most cited form of required technology by our respondents. Despite this, our EU respondents do not appear to strongly support a storage policy focussed on hydrogen. Although these respondents remain positive about hydrogen storage, they prefer policy supports that remain technologically agnostic. Across Europe, the increased cost of electricity and concerns about energy security as a result of the war in Ukraine has led to a rush to develop offshore wind [176, 177]. This has increased the need for large-scale energy storage and therefore interest in hydrogen storage [13, 178]. The increase in gas prices fuelled by the war in Ukraine has made green hydrogen, traditionally an expensive fuel [8], comparatively more affordable [179]. Many countries have developed hydrogen strategies [180], with Ireland's national hydrogen strategy currently out for consultation. Despite positivity related to hydrogen storage, it is not without its critics, particularly due to the relationship between hydrogen production and the fossil fuel industry [181]. In the UK, the North Sea Transition deal provides £10 billion in government, oil and gas sector investment in the production of "low carbon" hydrogen, which utilises carbon capture, usage and storage [182]. A recent study found that the GHG emissions from this type of "blue hydrogen" in fact produces very high emissions, only about 12% less than that of "grey hydrogen" [183]. Critics warn against the overreliance of green hydrogen to meet renewable energy targets as the extraction of hydrogen takes an enormous amount of energy and may be an inefficient use of renewable resources, particularly at peak demand times when that energy could be feeding the grid [184]. Environmental organisations suggest that direct electrification should be considered before investing in green hydrogen [185]. To address this, the EC has recently brought in clarification on "additionality", that is, that electrolysers which produce hydrogen must be connected to new renewable energy production to ensure that the generation of green hydrogen incentivises an increase in the amount of renewable energy available to the grid [186].

The EU partners were in general agreement that the ability to store more energy than allowed by grid connection, the option to store offshore wind, diversifying revenue streams and reducing dispatch down were all important factors for the renewable energy sector when considering investment in storage. Most also agreed that storage could also help provide flexibility to prevent renewable energy cannibalism, which occurs when renewables of the same energy type produce simultaneously, depressing the wholesale electricity price. However, cannibalism also exists in the energy storage market, whereby each additional storage device has a lower amount of "full load hours" than the one before, reduces the price spread between peak and off-peak prices and therefore worsens its own economic outcomes [187, 188].

In terms of the policy scenarios, in general, the partner respondents preferred the *Green Grid Storage* policy; however, there was heterogeneity in preferences. Most respondents indicated that while setting targets was an important signal to the industry, they believed that targets alone would not be sufficient to motivate the renewable energy sector to invest in storage. Most felt that some form of financial incentive, either in the form of the *Green Grid* or *Auction policy* was more likely to succeed. Indeed, financial incentives have been crucial motivating factors for the development of renewable energy in

Europe to date, with one study finding that a 1% increase in tariff supports leads to an increase in renewable generation of between 0.4-1% [189].

On average, the partners ranked the *Community Energy Storage Systems* policy lower than most of the other alternatives, generally agreeing that while, in theory, the policy was positive, communities would not be able to develop the large amount of storage required and that communities are not knowledgeable enough to develop energy storage systems. Across Europe there is an increased interest in the *energy community* with the EU Clean Energy Package defining Renewable Energy Communities as a legal entity which is owned/controlled by shareholders/members who reside near the renewable energy projects [190], their main goal being to deliver environmental, economic or social benefits including energy justice to its shareholders, members or the local community and not primarily financial gain [190, 191]. Their endorsement is founded on the basis that they make the transformation of the energy system more fair [192], sustainable [193], are effective at addressing social acceptance concerns [156, 194, 195] building social coherence [196-198] and at providing access to additional private capital which "results in local investment, more choice for consumers and greater participation by citizens in the energy transition"[199]. However, grass-roots community projects can find it difficult to recruit volunteers willing to take part, and can also suffer from a lack of local knowledge and difficulties in raising capital [200, 201]. Consenting processes are demanding, pre-development risks daunting and community-led initiatives have slowed in recent years due to the financial barriers to developing utility scale developments [202]. Although some community energy initiatives are engaging with storage, there are few examples of Community Energy Storage (CES) in Europe to date. Current market set-ups also do not allow for local energy markets. CES may benefit from emerging digital local energy markets which allow for consumers to directly share or transact energy and from a change in energy policy and supports such as time-of-use tariffs and location-based net metering [165].

We turn next to our Objective Two outcomes. The national renewable energy and storage respondents generally also agree that a mix of energy storage duration and technology will be required to support the energy transition in Ireland. Most survey respondents indicate experience with energy storage development or plans to develop, with hydrogen and batteries being the most frequently selected technology type. A recent report indicates that Ireland could become a "green hydrogen powerhouse" by producing the cheapest green hydrogen in Europe by 2030 [203]. These savings arise from Ireland's high wind speeds and rising congestion in the electricity transmission system. This report concluded, however, that significant changes in government policy and financial support will be required in order to achieve this, with Ireland currently not being considered attractive for development due to the lack of a national hydrogen strategy.

Most national survey respondents believe that energy storage offers a good solution to a range of issues including the provision of grid system services, achieving renewable energy targets, supplying more energy than grid connection allows, reducing dispatch down and reducing cost of renewable energy to end customers. This corresponds with the findings of [9] and [90] which outline that increased energy storage and longer duration storage in Ireland could reduce dispatch down, lower CO_2 emissions and costs to end customers. Focus group respondents also highlighted the potential for storage to support large-scale offshore wind development. Ireland has set targets for 5 GW of offshore capacity [63], and 2 GW of floating offshore wind by 2030, the latter dedicated to green hydrogen and electricity production for export to the EU and UK [64]. A recent study in the UK has found that, despite being a leader in energy storage development, the current storage capacity can't keep up with the growth in renewable output. This led to costs of €592 million in 2021, resulting in higher emissions due to wind turbines being forced to stop output and higher energy bills for consumers [204].

The majority of our national industry respondents believed that current policy supports, the level of public knowledge about storage and the market for green hydrogen in Ireland was poor or very poor. Focus group and interview participants pointed to the percieved haphazard and disorganised policy development and the lack of financial supports. Participants compared the Irish system negatively to that in the UK, which they believed offered a range of funding including SME supports, funding for experimental development and a more dynamic trading market. A representative from DECC indicated that changes to the RESS system has meant that storage can participate to some degree but acknowledged that most support still comes from DS3. It was suggested that the UK is looking towards more longer-duration storage, and that there are discussions underway with DECC on the feasibility of developing an auction-based system for longer duration storage. The general concensus was that storage was seen as an afterthought to renewable energy development. The first incentive scheme for wind energy development was launched in Ireland in 1995 with the aim of installing 75 MW of wind energy by 1997. This was followed by a revised strategy in 1999 with the target of 500 MW by 2007 [205]. The Renewable Energy Strategy Group was formed in 1999 by the then Minister of State for the Department of Public Enterprise to assist in achieving the targets set to 2005 and influence future policy. This group published a document in 2000 which briefly acknowledged the need for storage to support intermittent renewables [206]. In 2006, the first REFIT programme was launched, which has since been followed by the RESS programmes. The DS3 programme was launched in 2011, 16 years after the first renewable incentive scheme, to safely increase the allowable amount of SNSP on the grid [10]. RESS 2, launched in 2022, was the first programme to provide support for hybrid renewable energy plus storage projects, however these storage devices could only store energy generated from the project and could not store energy from the grid [77], resulting in no successful hybrid projects [27]. The terms and conditions for the upcoming RESS 3 auction also include this clause [78] and the recent Offshore Renewable Energy Support Scheme (ORESS) was only open to offshore wind technology and did not contain any category for hybrid storage projects [79]. Despite the first renewable energy incentive scheme being launched almost 30 years ago, a national energy storage policy framework is still under development.

The Principal Component Analysis indicates that there may be heterogeneity in preferences amongst our sample. The first component represents respondents who see storage as a very good solution to curtailment, developing in constrained areas and as a way of reducing costs to end customers. The second component represents those who are less risk averse when it comes to trade or the amount of current business cases which exist. The final component represent those who do not view long-term storage as a viable investment and believe that storage offers low returns in comparison to wind. A recent Irish study, commissioned by Energy Storage Ireland found significant net consumer benefits for longer duration storage but indicates that the cost increases significantly beyond 4-6 hour storage [90]. Irish studies which have analysed the potential for utilising long duration storage for renewables have found that technology such as PHS can be risky due to the long lifespan and potential for losses when engaging in the day-ahead-market [95] and can have limited profitability when carbon and fossil fuel prices are comparatively low [96]. An Irish study has found, however, that hybrid wind-hydrogen projects that provide capacity for up to 45 days may be profitable in 2030 at a hydrogen price of €5/kg [139]. Recent international studies have also found that for a wind farm developer it may be profitable to own a battery storage unit and trade in the wholesale market [118], particularly if this arbitrage is concentrated around peak times [15].

The Latent Class Model results further emphasise the heterogeneity in preferences and priorities when it comes to storage policy development. Most of the sample derive significant utility from greater reductions in the level of dispatch down. In Ireland, the average level of dispatch down for wind energy from 2019-2021 was 8.5% [207-209] and the baseline level used for analysis for this attribute was a 10% reduction, which would equate to a dispatch down level of about 7.7%. Class 1 respondents, which represent the majority of respondents, indicate significant preferences from moving from a reduction of 10% of the average to a reduction of 80%, which would equate to an average dispatch down level of 1.7% using 2019-2021 as a reference. These respondents are WTP the equivalent of €22,200 in the annual DS3 payment or €36 less per MWh through RESS for large reductions in dispatch down. The level of curtailment and constraint of renewable energy can be a significant factor in terms of the viability of a project, particularly for large-scale offshore wind [210], with one of our interview participants indicating that their planned offshore wind farm was cancelled due to the high level of grid constraint. These WTP amounts highlight the significant value attributed to reductions in dispatch down to the majority of our respondents.

Class 1 respondents also derive positive utility from the introduction of the *Green Grid* policy. This sample are WTP the equivalent of €31,800 annually through DS3 or €52/MWh through RESS for a scenario with this policy in comparison to a baseline *Storage Target* policy. As previously outlined, the current RESS 2 framework does not allow support for energy storage devices that pull energy from the grid. Multiple interview and focus group respondents pointed to this issue as a limiting factor in developing the level of storage within the renewable energy sector. Many studies have found that utilising energy storage for excess wind energy alone makes certain storage technologies economically unviable [160, 161]. Although hybrid battery-wind projects can increase profitability of a wind farm [15], this can depend on the developers ability to trade in the day-ahead market [16], which is currently limited in Ireland [90]. These issues have therefore created a barrier to the development of hybrid wind-storage projects and the potential additional societal benefits in the form of a balanced grid and reduced curtailment.

Class 1 respondents derive significant negative utility from a scenario that prioritises long duration storage in comparison to short duration storage as the baseline. The respondents require an additional €32,604 annually through DS3 or €53/MWh through RESS for this policy scenario, indicating strong disutility for long-duration centred policy. In contrast, Class 2 respondents indicate positive preferences for the prioritisation of medium and long duration storage ahead of short duration storage. These respondents are WTP €72,000 annually in DS3 or €118/MWh through RESS for medium storage prioritisation and the equivalent of €127,000 annually in DS3 or €208/MWh through RESS for long duration storage prioritisation. These heterogeneous preferences are reflected in the responses of our interview and focus group participants who indicated mixed attitudes in terms of the duration required. Some felt that long duration storage was most needed, particularly to support large scale offshore wind farm development, and that the short-term market was saturated. Others felt that short-term storage was still required for fast frequency response and to support small-scale wind farm development. This divide is also reflected in the technology that our respondents have experience with or plan to work with, with an almost even spread between the number of votes for longer duration storage such as hydrogen, thermal energy storage and pumped hydro, and shorter duration storage via batteries. It is possible that these very high WTP/WTA values for longer duration storage is reflective of the high cost of this type of technology, particularly for large-scale development. For example, compressed hydrogen storage can cost up to €144,000 per MW of electrolysers for one day of hydrogen production. If a 500MW wind farm was to install a weeks worth of storage it could add €504 million to the CAPEX cost [8]. For some of our respondents that are interested in and have value for longer duration storage, it may be that they are WTP significant sums to compensate for the high cost of development. For those who prefer shorter duration storage, a policy which prioritises longer duration storage may negatively impact their business and investment decisions and so they may require additional payment to compensate for this. These results indicate that a policy which prioritises storage by duration may not lead to positive outcomes for all.

There are caveats associated with this analysis. The EU policymaker analysis did not include responses from all partner countries, but does still provide important insights into the current policy situation across 4 key countries in Europe. In terms of the national analysis, there is a difference in total euro value between the DS3 and RESS 2 payment percentages, however both options were provided to gather relevant responses from both the renewable energy and storage sector. The choice experiment sample is small, and as the cost attribute is insignificant for both Classes when separated, the WTP values for the Class 2 in particular should be taken with caution. Splitting this group out, however, allows for an analysis of heterogeneity and suggests that most do derive positive preferences from a policy change and from the positive benefits associated from increased storage through reduced dispatch down levels. Although our sample is small, the interviews, focus groups, survey and choice experiment results in combination indicate that most renewable energy and storage developers engaged with in this study derive positive utility from policy changes that incentivise the uptake of storage and are willing to pay to achieve this. These results also indicate that preferences may be heterogeneous and a one-size-fits-all policy may not be suitable.

6. Conclusion

Renewable energy targets across Europe have led to an increase in the development of intermittent energy such as wind and solar. This in turn necessitates the development of storage to improve the quality and reliability of electricity supply. The level of energy storage development across Europe has also grown over recent years, but the degree of expansion has been uneven, as has the development of energy storage policies. Energy storage has the potential to influence the trading price of electricity, producer and consumer welfare, reductions in CO_2 emissions and the level of renewable energy development in Europe. The suitability of various energy storage technologies for use by the renewable energy sector depends on capacity, efficiency, capital costs, cycle costs and footprint, amongst others and a lack of policy incentives can create barriers and prevent the renewable energy sector from engaging with novel technologies.

This study, which included engagement with our national and international project partners, has identified a number of actions that may be required in order to improve the level of renewable energy storage development across Europe. Firstly, the perceived level of public knowledge on energy storage is insufficient. As project partners across countries generally agree that the level of public knowledge on storage is low, a Europe-wide campaign providing members of the public with information on the need for storage to support renewables, the types of energy storage development, public costs and benefits and potential scale and health and safety information is warranted.

The EU partner study also concludes that our partners believe that communities may not be able to develop the large amount of storage required to support renewable and are not knowledgeable enough to develop storage systems. As highlighted in the previous section, the EU has acknowledged the importance of energy communities to ensure greater participation by citizens in the energy transition.

There are significant financial, human resource and market barriers to the development of Renewable Energy Communities (REC) and Community Energy Storage (CES) across Europe. It is recommended that citizens be empowered to engage further with RECs and CES. This can be done in a number of ways. Auction processes can provide additional funding and support for grass-roots community projects [211], the renewable energy industry and communities can co-develop projects [212, 213], citizens can be provided with incentives to develop domestic storage [42] and local energy markets which allow consumers to directly share or transact energy can be developed [165].

The EU partners study also concluded that the legal framework for energy storage is generally poor. Energy storage development across Europe has, in the past, been hampered by the 2009 Electricity Directive in which storage was not defined [214], but also by a lack of homogenous legal frameworks across Europe [215], double charging on grid charges and levies [216] and the absence of a framework and market to support benefit stacking [217]. While the 2019 Electricity Directive aimed to address some of these issues, many countries have differing definitions of storage which can lead to unfair grid fees and prohibit investment [94, 218], and in many cases barriers to revenue stacking remain in place [94, 219]. It is recommended that a homogenous legal definition of electricity storage be established to end unfair charges and that barriers preventing engagement of storage in the ex-ante markets be removed.

The EU partner study highlights the importance of national storage targets for providing a clear message to the market but also acknowledges that without financial incentives, this may not be sufficient to encourage the renewable energy sector to develop storage. It is recommended that EU level targets for storage are set, following best practice. This could include targets for long and short duration storage, and hydrogen storage specifically. This will ensure a holistic approach to increasing storage and follow the example of renewable energy, which was driven by EU level targets [164]. It is also recommended that financial incentives be developed to support the sector. This could take the form of capacity and grid system service auctions [50], support for novel storage technology [52], the development of a long-term holistic renewable energy and storage auction [167] and changes to renewable energy supports to avoid financial barriers created by curtailment-only storage [160, 161].

Although Ireland has been recently cited as a potentially attractive country to develop energy storage by industry experts, this opportunity is being hampered by a lack of national strategy [203, 220]. This is echoed in the opinions of our industry participants, who generally agree that policy development in Ireland has been disorganised and haphazard. To take advantage of the opportunities provided by energy storage development, it is imperative that Ireland publish its energy storage and hydrogen strategies. As the Latent Class results indicate heterogeneity in preferences for duration, the storage strategy could include plans and targets for the development of short, medium and long duration storage, without prioritising one over another. Although respondents did not indicate strong preference for the *Auction*

Includes Storage policy, they did indicate that the lack of policy supports and innovation funding and the limited amount of DS3 support in Ireland creates a barrier to the development of storage from the renewable energy sector. It is recommended that the national storage strategy also include plans for the creation of additional funding supports for storage development, particularly to address capital cost and supply chain issues and to incentivise innovation in the sector.

The national hydrogen strategy should take into account new EU regulations on additionality and green hydrogen definitions [186], ensure that as much renewable energy as possible is provided to the grid as a first priority before any conversion to hydrogen takes place [184] and that green hydrogen remain the development priority rather than other forms, such as blue hydrogen [183]. The development of a hydrogen strategy could be of particular benefit to the offshore wind energy industry, which may require greater storage duration and capacity. ORESS 1 did not contain any category for hybrid projects, but a consultation paper for ORESS 2 includes the potential creation of industrial clusters to use offshore wind energy to replace fossil fuels in certain sectors including maritime or aviation fuel, green hydrogen production and long duration storage and the possibility of including weighting for co-location with storage [64]. Phase three of the offshore development plan may include projects dedicated entirely to the production of green hydrogen, for domestic use and export. However, due to the amount of energy required to extraction hydrogen, it is recommended that phase three of ORESS include a caveat that new offshore wind energy feeds the grid as a priority before conversion to green hydrogen [184, 185].

The lack of skills and training in the energy storage sector could create a barrier to development. In March 2023 the Joint Committee on Enterprise, Trade and Employment released the Report on Offshore Renewable Energy which acknowledges the role that storage, and hydrogen in particular, will play in the development of offshore wind. This report recommended co-ordinated planning for training, prioritisation of training in high demand sectors, including hydrogen specialists and engagement with the fishing community to provide opportunities to transition into the offshore wind sector. It is recommended that training development plans also include skills required by the energy storage sector in general, which may include manufacturing, engineering, finance, sales and trading, permitting and interconnection and maintenance, amongst others [221].

The general positive preferences and WTP for the development of the *Green Grid* policy reflects the current limitation of national support policy that restricts the use of hybrid storage within RESS to curtailed energy only. It is recommended that changes to RESS policy are made to permit hybrid projects which store energy from the grid. Support could be provided to energy storage developers based on the percentage of renewables on the grid at the time of storage and could follow the new EU regulations for hydrogen facilities which connect to the grid, in that power is only sourced from the grid during a period of imbalance or curtailment [186].

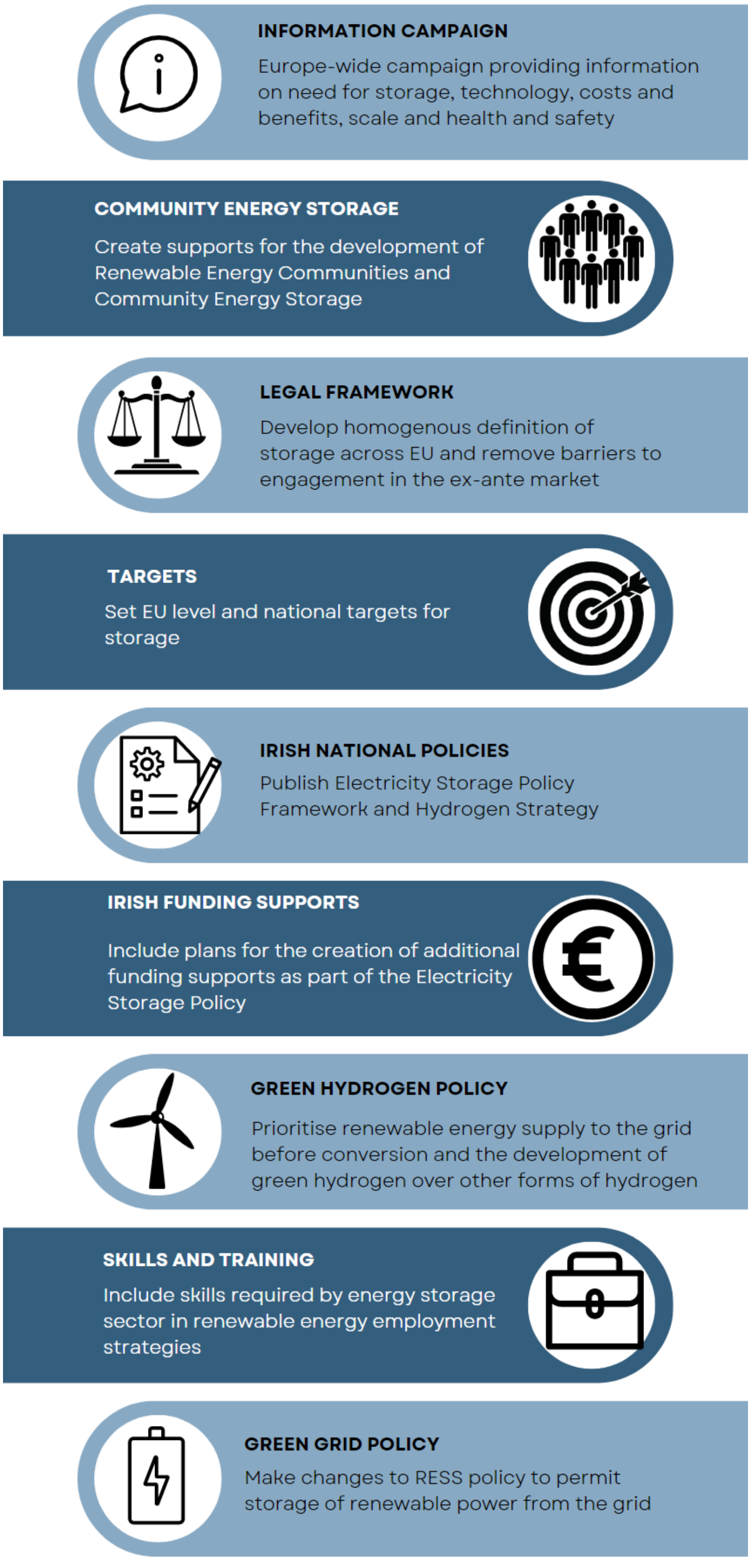

Figure 25: Summary of EU and national policy recommendations

Finally, the public are also key stakeholders in the development of renewable energy and energy storage projects, as reflected in Ireland's Energy White Paper which states that citizens should have ongoing opportunities to provide input into energy policy development and that they should be properly consulted on the infrastructure that affect them [70]. Although some members of the public may have positive preferences towards energy storage development, a significant cohort may have insignificant or negative preferences towards greater energy storage, and may have reservations about nearby development [151]. Acceptance of storage technology may be contingent on the degree to which safety, environmental and reliability concerns are dealt with and whether or not storage projects are deemed to be fair [222]. As the level of energy storage development across Ireland is likely to increase to support renewable energy targets, in order to prevent public acceptance issues it is imperative that those living near energy storage developments are consulted with and that public knowledge on energy storage technology generally is increased. One path to increase engagement and knowledge on energy storage technology is to directly involve citizens in storage developments. The Climate Action Plan outlines support for 500 MW of local community-based renewables by 2030 and improved citizen engagement pathways and uptake on sustainability initiatives [13]. As highlighted earlier, it is recommended that RES and CES be fostered in Ireland as a method of addressing public acceptance concerns, attaining greater energy efficiency, and achieving greater participation by citizens in the energy transition. These actions could help to achieve the core goals of the STEPS project by reducing barriers to energy storage development in Europe, increasing awareness of energy storage technologies, generating new jobs in the energy storage industry, and developing tailored energy storage technologies to meet the demand of a key storage market [69].

7. Appendix:

Table 14: Technology type required by country

Country	Priority duration	Preferred technology type
Belgium	Short term (up to 3 hours)	Li-ion batteries;Pumped hydro storage;
Germany	Very short term (up to 30 mins)	Flywheel systems;Li-ion batteries;Hydrogen;
Germany	Long term (up to 10 hours)	Superconducting magnetic energy storage;Hydrogen;
Ireland	Very short term (up to 30 mins)	Pumped hydro storage;Li-ion batteries;Flow batteries;Hydrogen;Flywheel systems;
Ireland	Medium term (up to 6 hours)	Pumped hydro storage;Compressed air storage;Flywheel systems;NaS batteries;Li-ion batteries;Flow batteries;Supercapacitors;Hydrogen;Superconducting magnetic energy storage;NaNiCl batteries;
Ireland	Very long term (24 hours+)	Hydrogen;Flow batteries;Flywheel systems;Compressed air storage;NiCd batteries;NaS batteries;NaNiCl batteries;Li-ion batteries;
The Netherlands	Very short term (up to 30 mins)	Compressed air storage;Flow batteries;Hydrogen;
The Netherlands	Very long term (24 hours+)	Pumped hydro storage;Compressed air storage;Flow batteries;Hydrogen;

Table 15: Likert scale questions for Principal Component Analysis

To what extent do you think the storage of renewable energy provides a solution to the following

Very Bad Solution ***Very Good Solution***

1 *2* *3* *4* ***5***

Don't know responses recoded as 3 on scale.

Renewable energy curtailment/ dispatch down
Providing grid system services
Producing more renewable energy than grid connection allows
Developing renewable energy in grid constrained areas
Diversifying investment portfolio
Achieving 2030 renewable energy targets
Reducing cost of renewable energy to end customers

Please indicate your level of agreement with the following:

Fully Disagree ***Fully Agree***

1 *2* *3* *4* ***5***

Don't know responses recoded as 3 on scale.

Trading in the ex ante market is risky
There are too many barriers to trade stored energy in the ex ante market
Energy storage offers low returns compared to wind energy
There are not enough viable business cases for energy storage
Short term storage (< 3 hrs) represents a favourable financial investment in Ireland
Long term storage (> 24 hrs) represents a favourable financial investment in Ireland
Leading renewable energy developers that I would respect are investing in storage
Seeing other renewable energy developers invest in storage made me think it is worth trying

How do you rate the following:
Very Poor ***Very Good***
1 *2* *3* *4* ***5***
←→
Don't know responses recoded as 3 on scale.

The level of government support for storage
The trading market for renewable electricity in Ireland
Public knowledge on renewable energy storage
The transparency of grid management by Eirgrid
The market for green hydrogen
Policy support and incentives to use storage to participate in the ex-ante markets
Policy support and incentives to facilitate time aggregation of storage

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