NETWORKS

International Storm Resilience Strategies for Power Networks

Issue date: August 2026

DOC-280726-INE

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Executive Summary

Background

Ireland experienced two severe storm events during winter 2024/2025, with Storm Darragh in December 2024 followed by Storm Éowyn in January 2025. Storm Éowyn recorded peak gusts of up to 184 km/h, the highest ever observed in Ireland, resulting in extensive damage to the electricity network and widespread customer outages.

These events reflect a broader trend of increasing climate-related impacts being experienced across electricity networks internationally, reinforcing the need for continued adaptation.

In response, on 5 February 2025, the Government tasked ESB Networks with developing an Enhanced Winter 2025 Grid Resilience Plan, setting out immediate, targeted actions alongside longer-term measures to strengthen resilience in vulnerable and storm-affected areas. This was published on April 8th, in parallel with this, ESB Networks has also:

- Conducted a Lessons Learned Review of Storm Éowyn.
- Published an Interim Review (March 2026) of overhead line standards for extreme wind conditions; and,
- Commissioned an International Review of Utility Storm Resilience (conducted by KPMG) to identify leading practices applicable to Ireland.

This report focuses on the findings from this international review, identifying resilience measures most relevant to the Irish distribution network.

Review Methodology

The international review employed a comprehensive, multi-phase methodology, conducting comparative assessments of utilities across Europe, North America, and Australia. Utility selection was predicated on network characteristics, topology, vulnerability to severe weather events, and relevance and transferability to Ireland.

International measures were assessed across three main areas of **Resilience; Prevention, Restoration**, and **Supporting Activities**, alongside key strategic enablers required for effective implementation in Ireland. The review also considered how utilities are managing the scale and pace of adaptation required, while maintaining cost efficiency for customers.

Key Findings from the International Review

The review identified five consistent insights:

- **Integrated resilience strategies are essential:** Leading DSOs take a coordinated strategic asset management, and investment planning approach, combining preventative and restoration measures within long-term resilience programmes.
- **Vegetation management is critical:** Proactive management of forestry corridors and hedgerows remains one of the most effective interventions for improving storm resilience.
- **Automation accelerates restoration:** Investment in resilience focused network automation, remote control, and advanced fault location technologies materially improves restoration times and customer outcomes.
- **Balanced short- and long-term actions are required:** Immediate fault impact mitigation is most effective when combined with sustained investment in underlying network resilience.
- **Locally tailored approaches are essential:** While common approaches are evident internationally, the effectiveness and cost-efficiency of measures depend on local geography, network characteristics, and risk profiles.

The review highlights good alignment between international practice and current activities in Ireland, with many of these measures already progressing under ESB Networks' PR5 and PR6 programmes.

Strategic Enablers

Effective resilience delivery is underpinned by a set of key strategic enablers that underpin planning, prioritisation, and delivery of resilience measures at scale including:

- Updated resilient design standards, to reflect evolving operating conditions.
- Data-driven investment prioritisation, focused on highest-risk areas of the network.
- Risk-based programme governance, to support consistent and transparent decision-making; and,
- Enhanced legislative and regulatory frameworks, particularly in relation to vegetation management.

These enablers ensure resilience investments are targeted, affordable, and scalable while supporting long-term adaptation to climate risks.

Application to the Irish Network

Based on the international review, ESB Networks should:

- Implement a phased, multi-year resilience programme: In alignment with PR6 delivery and future PR7 targets, combining short-term measures (e.g. automation and monitoring) with long-term investments (e.g. network reinforcement and vegetation management).
- Strengthen vegetation management frameworks: Work with Government and regulators to establish statutory forestry corridors and restrict planting near network assets, enabling proactive risk mitigation.
- Adopt targeted, context-specific solutions: Ensure measures reflect Ireland's rural, overhead network profile, local geography, and environmental conditions.
- Accelerate resilience focused network automation deployment: Expand remote control, sensing, and fault detection capabilities to improve storm related outage response times and reduce customer disruption.

1 Introduction

Introduction

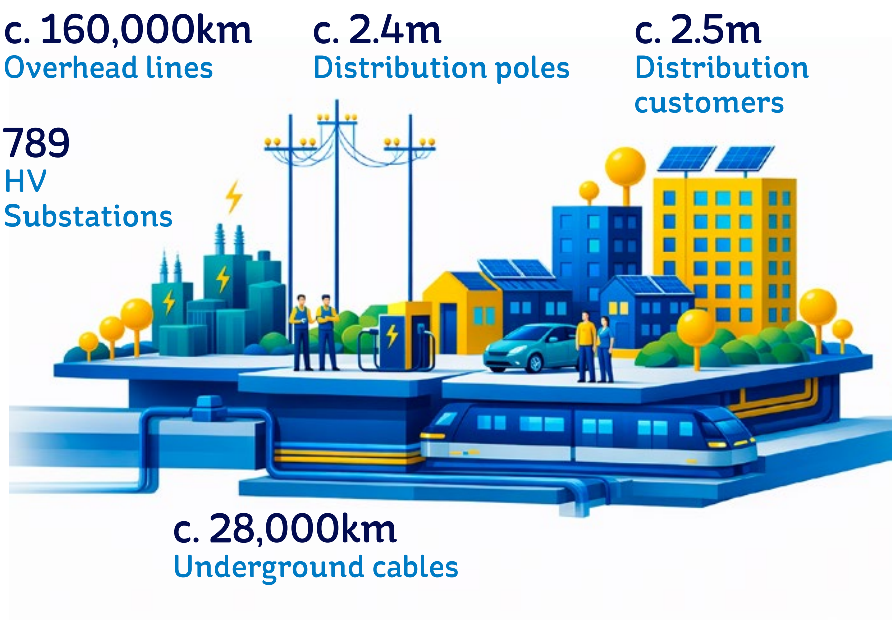
As climate change accelerates, Ireland is projected to experience more severe windstorms[1]. Therefore, the imperative for resilience has never been greater. This section sets out the Irish context, outlining the unique network characteristics, operational challenges and environmental factors that affect the Irish electricity distribution network. Detailed examination of these factors enables understanding of the rationale behind key resilience measures and the strategic investments required to safeguard electricity supply for customers and communities across Ireland.

1.1 Irish Context

1.1.1 Network Characteristics and Operating Context

Ireland's distribution system delivers electricity to approximately 2.5 million customers[2] and operates across a sparsely populated predominantly rural footprint. As a result, Ireland has a longer network per person than most European countries and a predominantly overhead configuration, with roughly 5.7 times more overhead line than underground cable.

Figure 1: ESB Networks Distribution Statistics



Ireland's network was developed rapidly at the time of rural electrification. Overhead lines were a key part of the ability to install the network across a dispersed population, enabling efficient coverage of remote areas and connecting communities that were previously without access to electricity. Further expansion has occurred to the network to the present ensuring a cost-effective robust system which continues to deliver a safe and reliable service. The network's construction standards cover low voltage systems below 1kV, medium voltage systems at 10 to 20kV, 38kV distribution networks for industrial, commercial, and rural areas, as well as selected 110kV distribution networks, with predominant use of wooden pole lines and a large number of pole mounted transformers.

1 *National Climate Change Risk Assessment, 2025*

2 *ESB Networks Distribution Annual Performance Report 2024, ESB 2024*

Regulatory direction recognises these characteristics. Under Price Review 6[1], the Commission for Regulation of Utilities (CRU) has signalled a substantial step change in network investment. ESB Networks' PR6 Business Plan[2], which reflects the organisation's long-term Networks for Net Zero strategy, sets out a major programme to deliver safe, reliable, and resilient infrastructure for 2026 to 2030, aligned with the strategic objectives defined by the CRU. This includes significant upgrades to distribution and transmission assets and a comprehensive resilience focus. The CRU's Final Determination outlines a reinforced national storm resilience programme in excess of €1bn of investment across both capital investment and operating costs[3]. It provides for 50,000 pole replacements[4] expanding on the ongoing programme continuing from previous price reviews, and targets replacement of ageing poles and those experiencing accelerated decay.

Further, PR6 includes a plan to deliver more than 1,000 kilometres of upgraded overhead lines, and 70 new or refurbished substations. The programme also allows for a step change in network automation including more than a four-fold increase in the quantities of reclosers to be installed compared to PR5 [5]. The current allowances in the PR6 Final Determination do not account for the design and implementation of resilient forestry corridors, although provision exists for a re-opener mechanism where a change in legislation or regulatory requirements necessitates additional investment. It is noted that after Storm Arwen in the UK, the DSOs were given additional funding for resilience investments. It is clear that an acceleration of investment in the right resilience measures will have a positive impact on the resilience of the network.

1.1.2 Weather and Climate Change

Ireland's storm regime is shaped by Atlantic systems, with Met Éireann records indicating several active storm seasons since 2015, including a particularly intense 2023/24 period. Storm Éowyn in January 2025 produced Ireland's strongest recorded winds, reaching peak gusts of up to 184 kmh[6] and causing extensive disruption across the energy and forestry sectors. Observed climate trends show continued warming, heavier rainfall and wetter winters. The projection also points at fewer but potentially stronger windstorms. Met Éireann's annual climate statements place recent years among the warmest on record[7], while Environmental Protection Agency (EPA) and Irish Centre for High-End Computing (ICHEC) projections point to further rises in extreme rainfall, longer wet seasons and significant hydrological change. The EPA's National Climate Change Risk Assessment identifies exposure of energy and communications infrastructure to extreme wind and flooding as priority risks requiring timely action. The impact on the forestry sector continues, with an estimated 10 million cubic metres of timber blown, equivalent to over 2.5 times[8] of the annual national harvest, continuing to be salvaged and is expected to run into 2027 for some owners.

1 *PR6: Investing in Ireland's Energy Future, CRU 2025*

2 *ESB Networks Price Review 6 Business Plan, ESB 2024*

3 *PR6 Distribution Revenue 2026 - 2030, CRU 2025*

4 *PR6: ESB Networks is planning to ramp-up MV pole replacement rate from 4,000 to over 9,000 per annum and replace a further estimated 4,550 poles at LV level over the course of PR6. Pole reinforcement following design reviews is already at an adopted practice at ESB Networks.*

5 *PR6 Distribution Revenue 2026 - 2030, CRU 2025*

6 *ESB Networks Storm Éowyn Review, ESB 2025*

7 *Annual Climate Statement for 2025*

8 *Department of Agriculture, Food and Marine press release states that Coillte estimated that ca. 10 million cubic metres of timber had been damaged, predominantly in spruce plantations older than 20 years of age. By way of comparison, in 2023, 4.3 million cubic metres of timber was harvested from Ireland's forests.*

In summary, climate change is amplifying the weather-related stresses already inherent in a long, predominantly overhead and rural distribution network. The resulting pressures increase the strategic importance of rapid isolation, automation, vegetation risk analytics and targeted route hardening. For more details on drivers changing the Irish climate, see *Appendix: Ireland's Changing Climate*.

1.1.3 Forestry and Vegetation Interface

Ireland's expanding forest estate intersects approximately 4 percent of the total overhead network (3,800km of network length excluding low-voltage (LV) lines) and contributes materially to storm related outages where tree strike and corridor closures occur. The network also intersects sections of Ireland's c. 2980 sq. km of hedgerow environments across public and private lands. National statistics indicate forest cover at about 11% to 12% of land area in recent years[1] which is among the lowest in the EU, with coniferous species dominating and Sitka spruce the largest single species. Hedgerows make up for a further 4-4.2% land cover and have seen an increase of c. 9000km since 1994 under environmental schemes. These characteristics, together with site conditions, influence windblow risk during storms.

Figure 2: Factors causing instability in Irish forestry.

Commercial forest plantations in Ireland are generally single age monocultures of fast-growing coniferous species. A significant proportion of them have been planted on soils with impeded drainage and high-water tables, resulting in shallow rooting systems and generally poor stability, especially as forests reach maturity. In recent decades Ireland's afforestation programme has focused on marginal farmland with relatively high densities of electricity network infrastructure interacting with it. This has resulted in an expanding area of forest cover with relatively poor storm resilience in close proximity to electricity network infrastructure. Consequently, there is heightened risk of windblow-related network damage.

1 *Ireland's Forests - Annual Statistics, Dept. Agriculture, Food and the Marine 2025*

Government and Coillte[1] assessments attribute windblow damage to more than 26,000 hectares of forests nationwide across Storms Darragh and Éowyn, with a commercial value of €500[2] which was estimated at the time of Storm Eowyn based on 2024 harvesting figures, of which about 14,500 hectares were on the Coillte estate, necessitating an exceptional salvage and replanting programme which is now expected to continue into 2027.

The ESB Networks Winter 2025 Grid Resilience Plan, published in March 2025, calls for a co-operative effort between ESB Networks, forestry owners and the Department of Agriculture, Food and the Marine to identify the most at-risk segments of the network for priority remediation. In July 2025, the government approved the drafting of the Electricity (Supply) (Amendment) bill to provide for the establishment and maintenance of forestry corridors. The bill will enable the Minister to introduce regulations on the dimensions and conditions of forestry corridors and will provide ESB Networks with additional vegetation management powers. The bill also intends to bring clarity on roles and responsibilities with respect to maintenance obligations increasing resilience of the network infrastructure whilst ensuring application of relevant environmental protection.

Oireachtas Committee reviews[3] have considered the risk of wind-blow related damage to electricity infrastructure, noting both the scale of the disruption and the systemic vulnerabilities exposed. In joint hearings of the Joint Committee on Climate, Environment and Energy and the Joint Committee on Housing, Local Government and Heritage, members highlighted that Storm Éowyn caused severe and prolonged outages, particularly in rural and forestry dominated regions, despite timely warnings and coordinated activation of the National Emergency Coordination Group. Committee discussions pointed to the need for enhanced, proactive vegetation management measures, drawing on the National Directorate of Fire and Emergency Management's review. The recommendations from this review proposed legislative powers for proactive vegetation management, roadside height limits and the formal establishment of forestry corridors to safeguard electricity and telecommunications infrastructure.

1 *Coillte on target to have windblown forests recovered by end 2026 and replanted by 2027, Coillte 2025*

2 *Oireachtas Joint Committee on Climate, Environment and Energy and Joint Committee on Housing, Local Government and Heritage, joint hearings on storm impacts and infrastructure resilience 2025; National Directorate of Fire and Emergency Management, review of storm-related impacts on critical infrastructure 2025. The review made recommendations for enhanced proactive vegetation management to protect the electricity and telecommunications network. These included powers to address vegetation posing risks to the electrical network, the establishment of height limitations for roadside vegetation with clear enforcement responsibilities, and the establishment and maintenance of forestry corridors to improve network resilience and operational safety.*

3 *According to Central Statistics Office, The total value of Ireland's 2024 forest harvest was €236 million from 4.4 million tonnes of timber. Based on an estimated 10 million tonnes of windblown timber resulting from Storm Éowyn, as monitored by the European Space Agency's Sentinel-2 satellite and reported by the DAFM, the value of the affected timber could exceed €500 million.*

The above mentioned reviews of storm Éowyn have brought forth recommendations on strengthening critical infrastructure and reducing risk to systems from vegetation and forestry. Comparable reforms under consideration in Great Britain show how clarifying statutory responsibilities and streamlining land access can accelerate resilient vegetation management. The ongoing Department for Energy Security and Net Zero (DESNZ) consultation[1] in the UK proposes reforming necessary wayleaves to reduce delays and uncertainty by streamlining compulsory processes, extending standard wayleave terms from 15 to 40 years, and encouraging earlier resolution of disputes while maintaining landowner protections.

Forestry and vegetation are significant, but not the only drivers of storm related risk. The species planted, site conditions, maintenance practices and ownership patterns coinciding with narrow or ambiguous corridor widths, difficult access and long spans on MV/LV (medium-voltage/low-voltage) networks also contribute to acute impact. This is further amplified by climate change resulting in earlier and longer growing seasons, amplifying the instability in the forestry corridors. The regulatory and legislative direction of travel is toward consistent corridor standards and obligations that will facilitate and enable timely, risk-based management.[2] Experience from the UK's operational framework combines safety clearances with risk-based interventions, providing an audited route to measurable resilience on overhead networks. These practices provide a useful reference for risk-prioritised cutting in Irish forestry corridors. More detail on what are the underlying factors that characterise Irish forestry are in the *Appendix: Irish Forestry*.

1.2 A Summary of Challenges Faced by ESB Networks

The challenges faced by ESB Networks are shaped by a complex interplay of environmental change, legacy infrastructure, and regulatory factors. The key issues currently impacting network resilience and restoration efforts across Ireland are:

1. **A dispersed rural network:** Ireland's low population density and reliance on overhead lines increase exposure to vegetation-related faults and storm impacts are compounded by restricted access for repair crews in rural areas, increasing restoration complexity.
2. **Forestry corridor constraints and access:** Mixed ownership, defined yet voluntary corridor widths, and wet ground conditions limit consistent vegetation management and safe access, yet gaps in statutory framework restrict proactive risk mitigation, requiring landowner agreement for removal of hazards.
3. **Escalating weather volatility:** Increasing storm intensity, heavier rainfall and wetter winters increase both fault likelihood and restoration complexity, particularly where flooding limits site access.

1 *Electricity Network Infrastructure: Consents, Land Access and Rights. Department for Energy Security & Net Zero 2025*

2 *Forestry Standards Manual, Dept. Agriculture, Food and the Marine 2024*

1.3 Summary of the Irish Context

- Ireland's electricity distribution network can be characterised as a long, predominantly rural, overhead network with inherently higher exposure and restoration complexity than urban systems.
- National Policy has resulted in afforestation[1], which, coupled with Ireland's extensive hedgerows in proximity to the electricity network intensifies tree risk exposure on specific spans and corridors. It is one element of a broader risk picture.
- Climate change is increasing the potential likelihood of high impact conditions and the risk of an increase in severe storms, thereby increasing the need for robust resilience plans.
- Future updated legislative and regulatory frameworks would support a risk based programme of vegetation and forestry corridor management including improved access for ESB Networks. In parallel, regulatory frameworks should provide adequate allowances to support appropriate resilience improvement investment.

The PR6 Final Determination provides the framework to implement a larger resilience programme compared to previous price review periods, including accelerated pole replacement, enhanced refurbishment, and new or upgraded overhead lines, alongside digitalisation and data driven targeting. Programme governance and optimised sequencing of investment delivery will be critical to ensure benefits are delivered for allowed investments consistent with targeted outcomes.

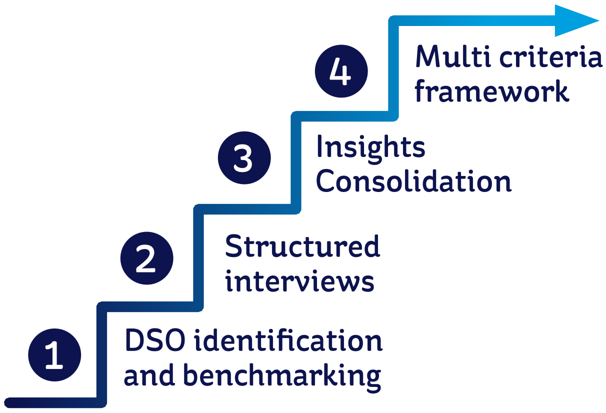
1 *Ireland's current national forest policy, "Forests, products and people: Ireland's forest policy – a renewed vision" (DAFM, 2014), and subsequently published Ireland's Forestry Strategy 2023-2030 aim to address significant developments in the forestry sector since "Growing for the Future" (1996). The policy aims to increase forest cover from current 11.6% forest cover to 18%, emphasising sustainable management and reforestation, with targeted annual reforestation strategy to plant 19,768 acres (8,000 hectares) of new forests annually across Ireland.*

2 Approach and Methodology

2 Approach and Methodology

The approach for this review followed a structured sequence designed to identify, assess and prioritise resilience measures that align with ESB Networks operational and regulatory context. The methodology began with an international benchmarking exercise focused on utilities that have experienced severe storm impacts and have subsequently implemented resilience measures. This was followed by interviews with selected stakeholders across those utilities to capture operational practices, governance structures, and decision frameworks not available through published sources. The resulting insights were evaluated through a defined assessment framework to produce a list of resilience measures and associated enablers, which then informed a prioritised shortlist of practical measures suitable for the Irish electricity network.

Figure 3: Approach of the international review



2.1 Benchmarked Utility Selection

The utility selection phase focused on identifying international operators with characteristics comparable to Ireland or those offering transferable learning on storm resilience, forestry interaction and regulatory practice. The initial list of 18 utilities was screened through a detailed review of storm trends, regulatory structure and network characteristics that had shaped resilience approaches in each jurisdiction. The availability of the utility to attend an interview was also considered as part of the screening process.

2.1.1. Utility Selection Criteria and assessment results

To ensure relevance to Ireland, each utility was assessed against seven criteria that materially influence resilience planning and response:

1. **Network Characteristics:** Required comparable topology, voltage mix and rural overhead exposure.
2. **Governance and Regulatory Settings:** Examined the alignment of regulatory incentives, compliance obligations and oversight structures.
3. **Legislative Drivers:** Considered statutory powers for access, vegetation management and resilience investment.
4. **Storm Events and Weather Patterns:** Focused on operators exposed to similar storm types, including wind driven faults.
5. **Forestry Type and Ownership:** Reviewed forestry characteristics, land ownership models, predominant species and associated vegetation risks.
6. **Forestry Corridor Design and Management:** Assessed the standards, protocols and design practices governing corridor clearance and maintenance.
7. **Storm Resilience Measures:** Evaluated the presence of hardening strategies, automation deployment and reinforcement programmes.

Ten utilities were selected for detailed interviews. These represented diverse geographies with common resilience challenges relevant to ESB Networks. Their contexts included rural overhead networks, dense forestry interfaces, coastal storm exposure, and regulatory regimes mandating resilience investment. Table 1 provides a summary of the selected utilities with their relevance to ESB Networks scored against the above criteria.

Table 1: Overview of selected utilities

Criterion Scoring		
High	Med	Low

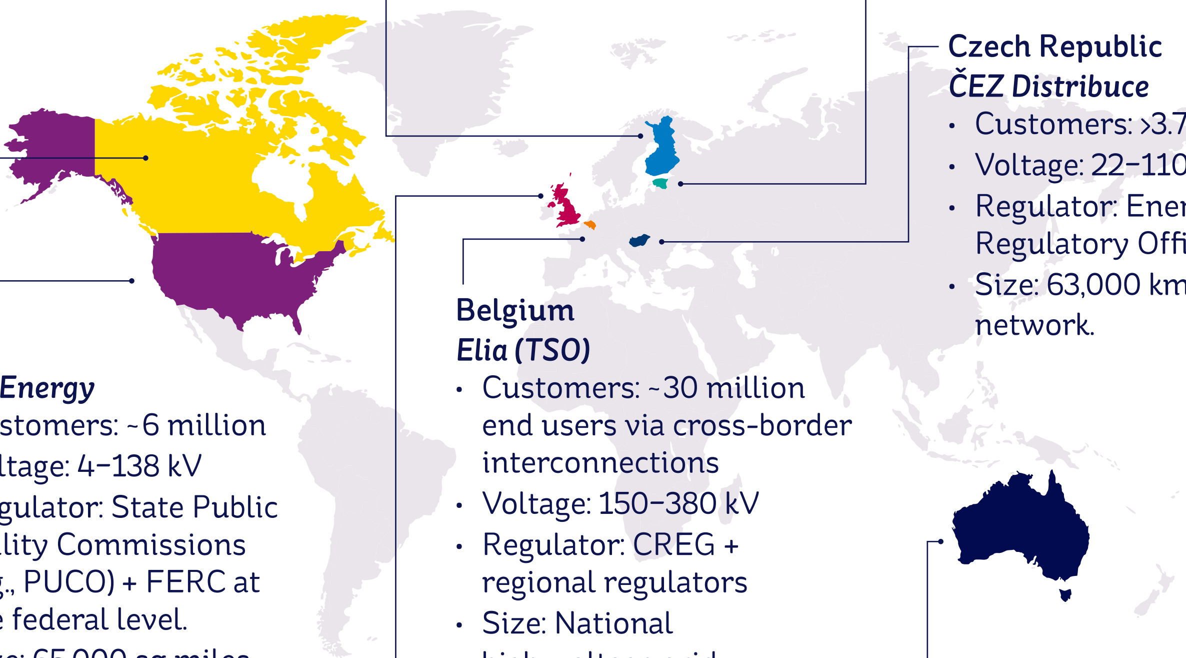
Utility	Country	Key areas of alignment	Relevance to ESB Networks: 1	2	3	4	5	6	7
AusNet Services	Australia	The network consists of extensive overhead lines and prioritises resilience against storms and bushfires. It employs advanced vegetation clearance techniques and automation to reduce outage risks.	High	High	High	High	High	Med	High
Caruna	Finland	The network faces boreal forest exposure and severe winter storms. The utility operates under a mandate for zero lengthy outages and demonstrates strong regulatory-driven resilience through network design and strict trimming, alongside innovative policy, and technology adoption.	Med	High	High	Med	Med	Low	High
CEZ Distribuce	Czechia	The operator works under EU regulatory frameworks and focuses on storm-proofing an aging grid. The utility also abides to a legal vegetation management framework.	Med	High	High	High	High	High	High
Elektrilevi	Estonia	The utility demonstrates strong regulatory alignment and has a comprehensive weatherproofing strategy. It uses advanced corridor machinery and maintains a clear focus on storm resilience.	High	High	Med	Med	Low	Med	High
Elia	Belgium	The utility integrates eco-friendly corridor management with biodiversity considerations and introduces storm resilience innovations to enhance reliability. It is considered an exemplar of Integrated Vegetation management.	Med	Med	High	Med	Low	High	High
FirstEnergy	United States	The utility manages a large service territory and uses vegetation risk analytics to inform grid modernisation efforts aimed at improving storm resilience.	Med	Med	High	Med	Low	Med	High
National Grid	UK	The utility is a large-scale DSO with proactive vegetation management strategies. It employs LiDAR-based risk assessment and partners on biodiversity initiatives to balance resilience and environmental goals.	Low	Low	Med	Low	High	High	Med
Nova Scotia Power	Canada	The utility faces Atlantic storm risk and operates a heavily forested network. It implements targeted hardening measures and vegetation management programs to mitigate outages.	Med	Low	High	High	Med	Med	High
SSEN	Scotland	The utility operates in a similar rural overhead network and is exposed to Atlantic storms, just like ESB Networks. It has implemented advanced resilience initiatives and shares an aligned regulatory ethos.	Med	Med	High	Med	Med	Med	High
UK Power Networks (UKPN)	England	The utility experiences similar storm exposure and maintains a rural overhead mix. It has advanced vegetation management practices and benefits from RIIO incentives that support resilience.	Med	High	High	High	High	Med	High

Figure 4: Eight DSO regions being reviewed

Canada
Nova Scotia Power
- Customers: ~550,000
- Voltage: 26.4kV - 69kV
- Regulator: Nova Scotia Energy Board (NSEB)
- Size: 31,800 km lines, rural + forested province

Finland
Caruna
- Customers: ~0.79 million
- Voltage: 0.4 kV; 10/20 kV; 110 kV for HV
- Regulator: Finnish Energy Authority
- Size: 88,000 km network across rural Finland

Estonia
Elektrilevi
- Customers: >533,000
- Voltage: 0.4–35 kV
- Regulator: Estonian Competition Authority
- Size: 63,000 km network, 95% of Estonia



Czech Republic
ČEZ Distribuce
- Customers: >3.7 million
- Voltage: 22–110 kV
- Regulator: Energy Regulatory Office (ERU)
- Size: 63,000 km network.

USA
FirstEnergy
- Customers: ~6 million
- Voltage: 4–138 kV
- Regulator: State Public Utility Commissions (e.g., PUCO) + FERC at the federal level.
- Size: 65,000 sq miles across 8 states

Belgium
Elia (TSO)
- Customers: ~30 million end users via cross-border interconnections
- Voltage: 150–380 kV
- Regulator: CREG + regional regulators
- Size: National high-voltage grid

Australia
AusNet Services
- Customers: ~802,000
- Voltage: 22 kV (MV); 66 kV (sub-transmission)
- Regulator: Australian Energy Regulator (AER)
- Size: 80,000 km² in eastern and north-eastern Victoria

UK
National Grid (NGED)
- Customers: ~8 million
- Voltage: up to 400 kV (includes sub-transmission)
- Regulator: Ofgem (RIIO-ED2)
- Size: Midlands, SW England, S. Wales

UK SSEN
- Customers: ~3.9 million
- Voltage: 6.6/11–33 kV
- Regulator: Ofgem (RIIO)
- Size: Highlands + Central Southern England

UK Power Networks
- Customers: ~8.3 million
- Voltage: 11–132 kV
- Regulator: Ofgem, RIIO-ED2
- Size: London + SE + East of England

The following profiles offer useful comparisons of operational and strategic responses to severe weather conditions and vegetation related risks:

- SSEN and UK Power Networks, reflecting Atlantic storm exposure and advanced vegetation management.
- Caruna and Elektrilevi, offering insights into weatherproofing obligations, undergrounding mandates and standardised management of vegetation along network lines.
- AusNet Services and Nova Scotia Power, demonstrating resilience strategies in forested and high-risk regions.
- ČEZ Distribuce, Elia and National Grid, presenting legislative and biodiversity aligned corridor practices and risk based hardening measures.
- FirstEnergy, contributing methods in vegetation risk analytics and grid modernisation.

The eight utilities from the list that were not selected for interview were mostly due to lower alignment against the selection criteria or having low or no availability to participate in interviews. They were: Andel (Denmark), Distributie Oltenia, Tensio AS (Norway), Transgrid (New South Wales/ Australian Capital Territory, Australia), Transpower (New Zealand), Enedis (France), Hydro One Ontario (Canada), and Westnetz (Germany).

Below a table is provided summarising the key network characteristics of DSOs engaged with ESB Networks included as a reference point:

Table 2: DSO network characteristics

Country & DSO	Ownership	Distribution voltage	Network length	Network Construction Type	Notable factors (forest, storm and climate profile)
ESB Networks (Ireland)	State-owned utility	110kV in the capital region of Dublin MV: 10kV, 20kV; and 38kV for Industrial LV: <1kV	~188,000km	Predominantly Overhead (est. 85%)	Frequent Atlantic storms with prolonged wind exposure and unsettled forests
AusNet Services (Australia)	Private, regulated monopoly	HV: 66kV MV: 22kV LV: 240/415V	~55,000km	Predominantly Overhead (est. 70%)	Exposure to bushfire, storms, floods and extreme heat. Large forestry interface of MV lines with 34% areas bushfire prone
Caruna (Finland)	Private (pension fund owned)	HV: 110kV MV: 20kV predominantly with 10kV legacy and 1kV in isolated LV: 230/400V	~89,000km	Predominantly Underground (est. 60%)	Winter storms & high winds, snow and ice loads and flooding. Interface through large stable forestry cover (75%)
CEZ Distribuce (Czechia)	Majority state-owned	HV: 110kV MV: 22kV and 35kV with legacy 10kV LV: 400/230V European standard	~167,000km	Predominantly Overhead (est. 70%)	Snowloads, windstorms and floods with heavy rainfall. 34% nationwide forest cover requires partnerships with state forest agency for maintenance

<table>
<thead>
<tr><th>Country & DSO</th><th>Ownership</th><th>Distribution voltage</th><th>Network length</th><th>Network Construction Type</th><th>Notable factors (forest, storm and climate profile)</th></tr>
</thead>
<tbody>
<tr><td>Elektrilevi (Estonia)</td><td>State-owned</td><td>HV: 35kV
MV: 10kV and 15kV with legacy 6kV
LV: 230/400V</td><td>~63,000km</td><td>Predominantly Overhead (est. 75%)</td><td>Severe storms, winter hazards including snowloads and flooding. Large forestry and forestry edge interface</td></tr>
<tr><td>FirstEnergy (USA)</td><td>Investor-owned utility</td><td>MV: 12kV & 13.2kV with legacy 4kV lines
LV: 120/240V single phase or 120/208 three phase</td><td>~432,000km</td><td>Predominantly Overhead (est. 80%)</td><td>Severe Atlantic winds and thunderstorms and winter storms, flooding. Significant exposure to eastern deciduous forests</td></tr>
<tr><td>Nova Scotia Power (Canada)</td><td>Private monopoly</td><td>HV: 69kV and some 138kV
MV:25kV and 12.47kV and legacy 4kV
LV: 120/240V single phase and 120/208 three phase</td><td>~32,000km</td><td>Predominantly Overhead (est. 85%)</td><td>Prolonged wind bearing events, hurricanes and winter storms along with coastal flooding. Heavily forested province with frequent tree snaps</td></tr>
<tr><td>SSEN (UK)</td><td>Private (part of SSE Group)</td><td rowspan="3">HV: 132kV and 33kV
MV: 11kV and legacy 6.6kV
LV: 400/230V</td><td>~55,000km</td><td>Predominantly Overhead (est. 55%)</td><td rowspan="3">Flooding and storms with high wind events becoming frequent. Sparse forests causing windthrow damage</td></tr>
<tr><td>UKPN (UK)</td><td>Private</td><td>~188,000km</td><td>Predominantly Underground (est. 65%, due to city coverage, i.e. less rural)</td></tr>
<tr><td>National Grid (UK)</td><td>Private, regulated monopoly</td><td>~220,000km</td><td>Predominantly Underground (est. 40%, due to areas of natural beauty & city coverage, i.e. less rural)</td></tr>
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2.2. Interviewing Stakeholders from Utilities

A structured interview set was developed to validate the initial benchmarking findings and capture insights that are not reflected in publicly available documents. The interview themes were aligned with ESB Networks objectives and ensured coverage of governance, network design, forestry and hedgerow interaction, operational practice and investment logic.

2.2.1 Themes Covered

- **Strategic Context:** Roles, responsibilities, storm preparation, metrics and overall resilience frameworks.
- **Investment and Evaluation:** Cost benefit methodologies, prioritisation tools, regulatory influences and decision metrics.
- **Network Design:** Standards for non-forestry resilience, loadings, configuration choices, and the effectiveness of measures such as covered conductors and undergrounding.
- **Forestry Corridor Design:** Species selection, topography, mandatory versus voluntary standards.
- **Forestry Corridor Management:** Ownership models, land access management, wayleave processes, easements and the integration of environmental obligations.
- **Non-Forestry Vegetation Management:** Approaches to hedgerows, roadside trees and local authority coordination.
- **Technology Deployment:** Use of LiDAR, drones, satellite monitoring, automation, sensors, AI driven prediction, and robotics.

2.2.2 Interview Process

The interviews were supported by desktop research, and the responses were recorded in a standardised format to enable comparability and traceability. Where information gaps emerged, follow up questions were issued and addressed.

Outputs from this phase included the formal question set and evidence-based findings, summarised in Section: Insights from International Review. Structured playback sessions with ESB Networks were used to test validity and ensure alignment with the Irish context.

2.2.3 Literature Review

Review of the publicly available information, including DSO and regulators' publications, regulations and legislations, and news articles was conducted to further close information gaps and enrich the findings.

2.2.4 List of Resilience Measures

Using insights from interviews and research, potential measures were identified, consolidated into a list, and checked for completeness and alignment with ESB Networks' operations through a structured process. Duplicates were removed to ensure a coherent set of measures. This list can be referred in Section: List of International Resilience Measures.

2.3 Evaluation Framework

A Multi-Criteria Decision Assessment (MCDA) framework was established to prioritise the list of resilience measures. Its purpose was to apply a consistent, transparent methodology that weighted measures against ESB Networks priorities and enabled a logically derived shortlist.

2.3.1 Measure Evaluation Criteria

The evaluation framework assessed each measure across the following criteria:

1. **Capex:** Upfront investment requirements.
2. **Opex:** Ongoing maintenance implications.
3. **Ease of Implementation:** Regulatory alignment, permitting constraints and societal acceptability.
4. **Environmental Impact:** Ecological sensitivity, habitat disruption and carbon considerations.
5. **Resilience Benefits:** Based on the four Rs of resilience (More detail in *Appendix: Resilience themes derived from the 4 Rs*) - robustness, redundancy, rapidity and resourcefulness.

2.3.2 Application of the Framework

The MCDA process produced a ranked list of the resilience measures, from which the top-performing initiatives were shortlisted. In formulating the final recommendations, the shortlisted measures were balanced across three resiliency themes – Prevention, Restoration, and Supporting Activities ensuring identification of an integrated portfolio of resilience improvement opportunities.

The recommendations were further assorted into the workstreams with clear actionable and timebound outcomes consistent with logical investment portfolios. These workstreams are - Network Reinforcements, Forestry Corridor and Hedgerow Management, Network Monitoring and Automation, Power Restoration Efforts, Vegetation Monitoring and Management.

2.3.3 Strategic Enablers

Enablers such as legislative reform, technical standards, data and analytics frameworks and portfolio governance are required to realise the resilience benefits of the measures. These enablers make resilience actions scalable, consistent and cost effective, and were identified as essential conditions for successful delivery across multiple jurisdictions.

2.3.4 Interpretation of Results

Higher scoring measures indicate strong resilience benefits relative to cost and implementation complexity and were prioritised for inclusion in the shortlist. Lower scoring measures were retained for consideration or further analysis. The approach ensured visibility of trade-offs between cost, benefit and implementation feasibility.

3 Insights from International Review

3. Insights from International Review

Given that each jurisdiction applies its own definitions and interpretations based on its operating context, the findings presented in this section have been retained in their original form and have not been adjusted for the Irish context, to preserve their intended scope and meaning.

3.1 Introduction

Many DSO's face similar challenges relating to maintaining network resilience against the backdrop of increasing likelihood of high impact severe storms. The approaches to electricity network resilience are shaped by local climate, geography, forestry cover (e.g. Finland's forestry cover is 75% and Estonia's 51.5%, contrasted with Ireland's 11-12%)[1 2], customer willingness to pay and regulatory drivers. The countries have developed distinct approaches and strategies to address storm resilience and vegetation management, reflecting both local risks and broader policy trends. A summary of the development is provided in Figure 5.

Figure 5: Summary of International Findings

Nordic & Baltic
Weatherproofing

Finland and Estonia have set mandates to harden networks after severe storms. These cold-climate countries with significant forestry cover treat storm resilience as a national security issue, with Finland DSOs aiming for high undergrounding by the mid-2030s while Estonia aims to weatherproof 85% of its network by 2035, which involves a combination of underground cabling, insulated overhead conductors, network hardening and extensive corridor management.

UK & North America
Enhanced Vegetation Management & Automation

Britain, Canada, and the US emphasise rigorous tree trimming cycles and risk-based clearance programs. Legally enforced clearances (e.g. UK's ESQCR) and increased budgets post-storm (Nova Scotia doubling tree-trimming spend) are key tools to reduce outages.

Further, the use of HV sensors by the DSOs also contribute in outage detection and quick restoration leading to grid level deployment.

Central Europe & Belgium
Regulated Corridors, Moderate Hardening

Czechia and Belgium enforce strict right-of-way clearance zones by law (e.g. 7 m for 22 kV lines in Czechia). With milder climates and already high rates of underground cables, focus is on maintaining legal corridors and upgrading critical overhead spans as needed.

Australia
Bushfire-Driven Standards

In Australia, especially Victoria (AusNet Services), vegetation clearance standards are among the strictest due to bushfire risk. Regulations mandate larger clearances in high-fire zones (several metres for high-voltage lines) and frequent inspections, which also improve storm resilience.

1 *Forest resources in Finland - Maa- ja metsätalousministeriö*
2 *Forestry | Ministry of Climate*

3.2 Major Storm Events

Major storm events have historically led to changes to policy and work practices including new investment programmes, and regulatory changes focused on resilience. For example, severe storms in Northern Europe in 2011 prompted Finland's government to "weatherproof"[1] networks leading to large-scale undergrounding, most of which has been through co-construction initiatives between the DSOs and telecom companies where network cables share trenching with fibre-optic cables thereby reducing costs.

In the UK, the extreme winds of Storm Arwen in 2021 led to special resilience funding and updated industry guidance (ENA's ETR 132) to harden networks and increase funding for reliance measures, particularly for network automation. Hurricane Fiona (2022) in Nova Scotia, Canada, resulted in a doubling of tree-trimming budget allocations and an urgent need to strengthen poles and segment lines. Similarly, Australia's Black Saturday bushfires (2009), albeit a fire event, drove new vegetation clearance standards that also improve storm resilience. In the US, events like 2012's Superstorm Sandy led utilities like FirstEnergy to reinforce critical circuits and pursue selective undergrounding[2] of vulnerable sections of the network. These examples demonstrate how extreme weather events led to accelerated implementation of resilience measures.

A synopsis of changes triggered by storm events in some of the geographies is shown below:

2011 – Storm Tapani (Finland)
A pair of severe storms (Tapani and Hannu) leaves 500k+ without power in Finland. In response, by 2013 Finland amends its Electricity Market Act to require "weatherproof" grids (max 6 h urban / 36 h rural outage). DSOs like Caruna launch massive undergrounding programmes.

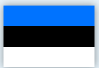
2012 – Superstorm Sandy (US)
Sandy devastates NJ and eastern PA. FirstEnergy's JCP&L sees extensive damage. NJ regulators demand a hardening plan leading to targeted upgrades (stronger poles, some undergrounding) in subsequent years. Vegetation management is intensified on critical circuits.

2021 – Storm Arwen (UK)
A rare extreme windstorm hits Scotland and NE England, toppling thousands of trees. Prolonged outages ensue. Ofgem reviews DNO performance and in 2022 invites resilience funding proposals. SSEN secures ~£10m for storm hardening projects (e.g. tree harvesting, network automation).

1 *Weatherproofing in general refers to a set of engineering practices and modifications applied to electricity networks to protect infrastructure from adverse weather conditions, such as storms, snow, ice, and heavy rainfall. This includes measures like replacing bare overhead lines with insulated conductors, replacing overhead lines with underground cables, and reinforcing structures to minimise outages and damage caused by natural events.*

2 *After Hurricane Sandy, utilities like FirstEnergy adopted targeted strategies, reinforcing vulnerable infrastructure and selectively undergrounding critical cables in high-risk areas. Full undergrounding was deemed too costly, so the industry shifted to a mix of selective undergrounding and broader network hardening measures rather than total conversion.*

2022 – Hurricane Fiona (Canada)
Fiona, the worst storm in Nova Scotia's history, knocks out 425k customers. Restoration takes up to 2 weeks in areas. The aftermath: NS government mandates reliability improvements, NSP doubles its tree-trimming budget (from $25m to $45m) and accelerates grid reinforcement.



2023 – Storm Agnes (Estonia)
After heavy snowstorms, Estonia's Elektrilevi partners with state foresters to clear "danger trees". The government allocates extra funds for grid upgrades. By early 2025, 75 percent of Estonia's grid is weatherproof and plans are made to reach 85 percent within a decade.

2025 – Storm Éowyn (Ireland)
On January 24, 2025, Storm Éowyn hit Ireland with record winds, causing major damage to the electricity network and leaving over 768,000 customers without power. Vast majority of restorations were completed by 31st Jan, with full restoration by 11th February with ESB Networks managing and delivering extensive infrastructure fixes with international support.

In recent years, Europe has experienced notable shifts in its climate, with the severity of storm events projected to increase. In November 2023, Storm Ciarán struck Europe with over ten countries across the continent experiencing wind gusts over 100km/h and countries such as Belgium, France, Germany, and Italy wind gusts of up to 160km/h.[1]

Storm Kristin in January 2026 resulted in Portugal experiencing its largest storm related outage in history before continuing its disruption across Spain. Following that, Storm Therese resulted in widespread disruption across the Canary Islands in March 2026. These recent storms have had significant implications for electricity networks.

1 *AccuWeather - France, Ireland, Spain, Portugal and the United Kingdom were among the countries impacted by the storm, which produced wind gusts of over 100 mph (160 km/h) and offshore waves that were nearly 70 feet (21 metres) high, Nov 2023.*

3.3 DSO Strategies per Region

The following table summarises how DSOs across different regions have developed their resilience strategies to tackle climatic challenges.

Table 3: Summary of resilience strategies per region

Region(s)	Climate & Storm Profile	Notable changes post climatic events	Key Resilience Themes	Key Insight for Ireland
Australia (Victoria)	Extreme heat, wind and bushfire risk creating high consequence failure scenarios	Black Saturday bushfires drove mandatory clearance codes and the Powerline Bushfire Safety Program	Prescriptive, audited vegetation clearance standards embedded in law with annual management plans	Demonstrates the value of detailed standards, annual plans and enforceable oversight for risk-based vegetation regimes
Central Europe	Severe windstorms, heavy rainfall events, localised flooding, and increasingly mixed storm systems producing both wind damage and high precipitation	Continued enforcement and refinement of statutory corridors, with Belgium integrating ecological corridor management	Legally defined protection zones in Czechia to ensure vegetation is managed along lines and managed ecological corridors in Belgium	Clear statutory corridor responsibilities reduce delivery friction and enable consistent vegetation control
Nordic & Baltic	Recurrent windstorms with snow and ice loading driving outages on overhead networks	Post-storm Tapani, tightening of outage limits and accelerated undergrounding programmes, most clearly in Finland	In Finland, statutory outage limits and co-construction driving widespread undergrounding, while Estonia targets weatherproofing network	Structural resilience can be mandated by law, but delivery is capital-intensive and long term and requires collaboration of multiple agencies
North America	Convective and tropical storms, Hurricanes and winter/ice storms leading to widespread vegetation related faults	Enforcement of stricter performance standards has led Nova Scotia Power to proactively increase expenditure for vegetation management along risk areas and widening corridors	Enhanced vegetation management with focus on stronger utility poles, reclosers and smart grid technology	Identification of risk-based areas and proactively managing vegetation is effective but requires clear directives
UK	Atlantic windstorms and flooding with vegetation a dominant fault driver on overhead systems	Storm Arwen and major U.S. storms led to increased scrutiny of vegetation risk leading to mandated risk clearance of vegetation	Enhanced vegetation management combined with automation to restore supply faster on overhead networks	Closest analogue to Ireland, showing quickest resilience gains from vegetation risk reduction and automation rather than mass undergrounding

The following subsections provide a deeper examination of the varied operational strategies and design standards adopted by the DSOs across different regions. It also provides comparative insights into how legislative frameworks, regulatory expectations, and local environmental factors shape approaches to resilience, with a particular focus on vegetation management, customer restoration standards, and technical requirements.

3.4 Operation and Design Standards

When looking at different geographies and jurisdictions, several themes and differences emerge.

Resilience Standards

A number of countries impose explicit resilience standards by law, whereas others rely on utility-defined standards guided by industry codes. For example, Caruna (Finland) and Nova Scotia (Canada) have government mandates (Finland's binding outage restoration maxima[1] , Nova Scotia's legislated reliability spending[2]) that have driven DSOs to enhance design standards and accelerate upgrades. In the UK and certain US states, regulators set resilience performance targets but do not prescribe detailed design rules, leaving utilities to develop their own engineering standards using best practice guidelines. Thus, UK and US operators follow internal standards, often informed by bodies like the Energy Networks Association or IEEE, under regulatory oversight, rather than a regulation dictating specific design standards explicitly. This approach allows DSOs to deliver acceptable resilience levels nationally, whilst varying local resilience to meet regulatory and customer expectations.

The regulatory and governance landscape also plays a vital role in adoption and enforcement of the standards. Information in relation to this is covered in detail in Regulatory and Governance Landscape.

Design Criteria and Network Hardening

Engineering design standards for distribution infrastructure set the baseline functional requirements for withstanding weather events including storms. Most DSOs design overhead distribution lines using internationally recognised standards (e.g. those from IEEE, CENELEC, or national codes)[3] that specify wind loading through reliability-based and region-specific criteria rather than a fixed threshold; in practice, this commonly corresponds to baseline design wind conditions on the order of roughly 80–115km/h for distribution networks in non-cyclonic regions, with higher requirements applied where local climate or exposure warrants. In storm-prone regions, new line construction may be specified to endure higher speeds, though detailed criteria are often contained within internal standards rather than in public documents. For example, ČEZ Distribuce designs overhead lines according to ČSN EN 50341 with Czech national annexes, which adopt Eurocode wind loading (EN 1991-1-4) and region-specific climatic parameters corresponding to basic wind speeds in the order of ~81–108 km/h.

1 *The Finnish "Electricity Market Act" (588/2013) requires that by 2028 (revised to 2036 for some DSOs operating in rural areas) power cuts caused by extreme weather, cannot last more than 6 hours in urban areas and 36 hours in rural areas. Consequently, DSOs are improving networks to be weather-proof*

2 *As part of the Public Utilities Act (R.S.N.S. 1989, c.380, as amended), Nova Scotia has certain performance standards set forth by Nova Scotia Utility and Review Board around Reliability (System Average Interruption Duration/Frequency Index - SAIDI/SAIFI), Storm Response, Customer Service and Power Quality. Failure to uphold standards lead to penalty while a Reliability Plan (currently 2025-29) is detailed by NS Power focusing on investments to achieve these targets.*

3 *European Committee for Electrotechnical Standardization (CENELEC) provides a harmonised framework but explicitly allows national deviation. Most European DSOs therefore design to nationally defined reference wind pressures, which typically equate to basic wind speeds of roughly 22–32 m/s (80–115 km/h) for overhead distribution lines under normal terrain assumptions, increasing in high-exposure areas. IEC (International Electrotechnical Commission) 60826 requires national authorities to define basic reference wind velocities using local climatology and reliability targets. For many European countries, these basic wind speeds, when converted to gust equivalents for overhead lines, commonly fall in the 100–130 km/h range for standard distribution reliability classes, with higher values mandated in coastal, mountainous, or cyclonic regions.*

The sag and sway is also considered for long HV transmission lines to develop a robust design margin. For example, Elia (Belgium) ensures its transmission lines can sway safely up to ~20m under extreme winds.

A notable shift is the adoption of stronger poles and structures in critical locations. Wooden poles remain common for cost and ease, but many operators are upgrading to higher rated poles, steel, concrete, or composite poles for resilience. For instance, Nova Scotia Power (Canada) is installing higher-class (stronger) wood poles and selectively introducing steel poles in hurricane-prone areas. FirstEnergy (USA) has been deploying steel poles on lines that have experienced storm damage in the past. In the UK, some DNOs are trialling composite poles in remote, exposed areas to reduce failures whilst also lowering maintenance needs since composites and steel are more durable than timber. These material upgrades significantly improve pole robustness against high winds and heavy snow/ice, albeit with higher upfront, capital cost.

Many DSOs are also replacing bare LV and HV overhead conductors with insulated or covered conductors in vulnerable spans. Covered conductors, often insulated cables known as Aerial Bundled Cable (ABC), can prevent short-circuits when branches or tree(s) contact lines. Finnish utilities have widely deployed covered conductors on remaining overhead lines passing through forests as part of their weatherproofing programs. Australian utilities similarly use covered/insulated conductor such as HVABC in high-risk bushfire areas which minimises instances of storm-induced faults. While insulating a line does not prevent poles or wires from falling in an extreme storm, it greatly reduces transient faults from contact with trees and can limit fire ignitions, contributing to overall resilience.

Other storm hardening[1] measures observed include strategic deployment of remote-control switches, network sectionalisation and automation providing utilities with the ability to isolate faults and restore supply to unaffected sections faster. Also, flood-proofing substations in flood-prone zones and selective undergrounding of the most critical or failure-prone circuit segments are measures that have been implemented or are under consideration. The mix of solutions reflects each DSO's risk profile and regulatory environment.

Detailed insights on technological implementations are covered in Key Technological Implementations for Networks Resilience.

3.5 Regulatory and Governance Landscape

Across all benchmarked jurisdictions, the governance of electricity distribution is anchored in statute, translated into enforceable technical instruments, and overseen by independent regulators that align performance incentives, compliance audits, and customer protections. Common elements include legal powers to enter and use land, structured processes to create and register corridor rights, explicit restoration or quality obligations, and regimes for penalties or compensation. The jurisdictions differ in how they codify corridor authority, restoration obligations, and operator accountability.

1 *Storm hardening refers to the set of measures taken to strengthen electricity network infrastructure so that it can better withstand severe weather events. In practice, this includes upgrading poles and structures to stronger materials such as steel, concrete, or composite poles, which provide greater robustness against high winds, heavy snow and ice loads, and tree impacts.*

Two important aspects of governance stand out:

1. Vegetation management for UK overhead lines is governed by regulatory and technical frameworks. The Electricity Safety, Quality and Continuity Regulations (ESQCR) outlines safety and resilience requirements, including clearances from vegetation and storm-related duties. ENATS 43-8 specifies minimum clearance standards and safe work practices, while ETR 132 provides a risk-based approach to assessing and prioritizing vegetation threats. Under RIIO-ED2[1], DSOs must justify spending, implement risk-based maintenance, and reduce vegetation-related faults in their business plans; and
2. Finland's binding outage restoration maxima (which resulted from the country's history of problems with severe outages due to storms and heavy snow loads), coupled with scaled outage compensation imposed by the regulator, has become the main driver for bringing investment discipline for resiliency projects spanning multi decade horizons.

1 *RIIO-ED2 is Ofgem's 5-year price control (April 2023–March 2028) for UK's 14 electricity DSOs. The period includes strict, audited annual performance reporting on safety, reliability, and environmental impacts reported annually to Ofgem.*

The following table outlines the governing measures, restoration obligations, and land access rules implemented by regulatory bodies in different regions, enabling a clear understanding of how each area addresses resilience and reliability in their electricity networks.

Table 4: Key regulations governing DSO operations

Country	Regulatory Body	Key Governing Measures	Restoration Obligations	Land Access & Easements
Australia (Victoria)	Energy Safe Victoria Essential Services Commission	Electricity Safety (Electric Line Clearance) Regulations 2026 dictate strict vegetation clearances in high-risk bushfire areas; and Code of Practice for Electric Line Clearance defines vegetation maintenance responsibilities.	Guaranteed Service Level payments apply where outage duration, outage frequency, appointments, or reconnection standards are not met, subject to code exclusions.	Clearance responsibility is allocated by the electricity safety framework and approved management plans, rather than by a single easement code.
Canada (Nova Scotia)	Nova Scotia Energy Board	CSA C22.3 No. 1 for overhead systems, alongside board-set utility performance standards.	Restoration performance is monitored through Nova Scotia Power performance standards, with penalties available for non-compliance.	Utilities rely on rights-of-way and easements, with Crown land processes relevant where provincial land is affected.
Czechia	Energetický regulacní úrad (ERÚ)	Energy Act protective-zone provisions, supported by grid-code and implementing quality rules.	Service quality and restoration are governed through statutory quality standards and compensation rules, rather than a vegetation-specific restoration code.	Access is based on protective zones and utility rights over land, functionally similar to servitudes or easements.
Estonia	Competition Authority TTJA	Building Code protection-zone rules dictate the vegetation clearances; and Electricity Market Act / Grid Code quality requirements define Security of Supply indicators monitored by Competition Authority.	Network operators are subject to quality requirements on outage duration and fault clearance, with regulatory consequences where standards are breached.	Access rests on statutory protection zones and servitude-style toleration duties around infrastructure.
Finland	Energiavirasto Tukes	Electricity Market Act 588/2013 sets security of supply (outage limit) standards SFS 6000 & SFS 6001 set safety requirements that vegetation management must not violate.	Statutory maximum interruption times apply under the Electricity Market Act, commonly summarised as 6 hours in urban/planned areas and 36 hours elsewhere.	Access is secured through easements or expropriation/redemption procedures, with full compensation determined in the expropriation process. Maintenance responsibility lies with DSOs.
UK	Ofgem	ESQCR guidelines for safety while working near electricity lines. ENA/ENATS 43-8 vegetation clearance standards; and ETR 132 risk-based resilience guidance for vegetation management.	Guaranteed Standards of Performance drive customer compensation for prolonged interruptions and related service failures.	Access is usually secured by negotiated wayleaves or easements, with statutory necessary wayleaves available under the Electricity Act where agreement is not reached. Under consultation to move right of maintenance towards DSOs.

3.6 Vegetation Management Practices in Forestry Corridors and Along Hedgerows

Across benchmarked jurisdictions, utilities increasingly combine mechanical, technological and ecological methods to maintain safe corridors while supporting biodiversity objectives. These practices provide a foundation for a more resilient network by ensuring that vegetation risks are managed consistently, transparently, and in a manner that supports long-term operational performance.

The following table provides a comparative overview of operational practices governing utility activities across various jurisdictions.

Table 5: Vegetation management practices

Country & Utility	Risk Assessment Model	Vegetation Control	Technology Used
ESB Networks (Ireland)	Risk prioritisation based on tree proximity to lines, outage history, and storm exposure	Targeted tree and vegetation clearance around overhead lines, including forestry corridors	Drones, field patrols, GIS mapping
AusNet Services (Australia)	Hazard tree identification using clearance criteria and risk to supply reliability	Mechanical trimming and removal of hazard trees within regulated clearance zones	LiDAR, GIS-based vegetation maps
Caruna (Finland)	Weather and forest risk driven, focused on storm resilience	Reduced reliance on clearance through undergrounding; remaining overhead line vegetation management	GIS, network information systems, digital grid twins
Elia (Belgium)	Biodiversity-focused evaluation approach, monitoring biological indicators and conducting cost-benefit assessments to measure ecological impact, habitat restoration effectiveness, and long-term corridor management performance	Where biodiversity considerations are material, integrated vegetation management models have reduced lifecycle cost while improving ecological outcomes, notably in Belgium and France through the LIFE Elia programme, which complements safety-led corridor objectives with graded edges, compatible species and managed habitats	GIS, drones, field patrols, biological monitoring
CEZ Distribuce (Czechia)	Legal protection zone-based assessment tied to statutory clearance distances	Mandatory trimming and removal within protection zones, with landowner obligations	GIS and asset registers
Elektrilevi (Estonia)	Mapping of vegetation risk along line corridors, focusing on trees at risk of falling	Corridor clearing and felling of dangerous trees in cooperation with forest authorities	Satellites, drones, digital grid models
FirstEnergy (USA)	Risk-based prioritisation using vegetation proximity and outage exposure	Mechanical pruning, removal, and selective herbicide use in transmission and distribution corridors	LiDAR, aerial patrols, GIS
Nova Scotia Power (Canada)	Predictive risk modelling of vegetation-related outages	Routine trimming and targeted hazard tree removal	Satellite imagery, AI-based analysis
SSEN (UK)	Integrated Vegetation Management, combining risk clearance and ecological sensitivity	Targeted cutting, selective herbicide use, and low-growth species promotion	Field surveys, infrared imaging, GIS
UKPN (UK)	Clearance and criticality-based risk scoring for overhead lines	Planned and prioritised trimming programmes	LiDAR, satellite imagery, AI analytics
National Grid (UK)	Risk-informed approach integrated with biodiversity and asset risk management	Vegetation clearance aligned with safety standards and biodiversity objectives	Satellite imagery, AI-supported vegetation monitoring

From the tables above, it is highlighted that across several jurisdictions, vegetation management is not solely an operational activity but is underpinned by defined regulatory requirements. Clearance zones like those applied in Czechia and Australia establish legally mandated distances between vegetation and network assets. Similarly, in the UK and the United States, minimum line clearances are through specific regulations or formal standards, creating binding obligations on utilities to manage vegetation accordingly. These regulatory frameworks ensure a consistent baseline for vegetation clearance, within which DSOs apply risk-based and operation practices to balance safety, reliability, and environmental considerations.

A leading example in integrated forestry corridor management is the approach adopted by Elia through the LIFE Elia[1] programme. The project started in 2011 and has transformed transmission corridors from areas managed solely for operational safety into multifunctional ecological corridors that simultaneously support network reliability and biodiversity objectives. The project activities include the creation of structured forest edges, restoration of meadows, peatlands and wetlands, establishment of orchards, targeted control of invasive species, and the use of mowing and grazing regimes to maintain low-growth vegetation. The programme demonstrated that integrated vegetation management can reduce the need for repeated intervention cycles while improving habitat connectivity, stakeholder acceptance, and long-term corridor stability. Outcomes from the project showed that biodiversity-focused corridor management can be delivered whilst ensuring continued safety and reliability of transmission lines assets, with lifecycle costs becoming comparable to, and in some cases lower than, traditional vegetation clearance approaches.

Corridor Design and Line Clearance Standards

The design of forestry corridors and the establishment of line clearance standards are fundamental to the resilience and reliability of electricity distribution networks. Across the benchmarked geographies, corridor widths along both urban and forestry areas and line clearance requirements are primarily defined by statutory regulations, technical standards, and risk-based guidelines. Furthermore, the nature of the forest itself plays a vital role – a stable or resilient forest as such in Estonia would allow smaller clearances whereas a plantation-type majority forested area, as it is prone to windblow, would demand wider corridors.

Clearance standards are closely linked to voltage level, with higher voltages necessitating wider clearances across both forestry corridors and hedgerows to ensure safety and operational reliability. For example, the UK's ENATS 43-8 when coupled with ETR-132 resilience cutting standard leads to a V-cut profile with a typical line clearance of approximately ~7.4 metres for distribution voltages on either side of the line. While Finland mandates a one-sided 5-metre corridor for MV Distribution lines and up to 21 metres right of way for HV Transmission lines. Estonia's protection zones range from 2 metres on either side relating to LV Distribution lines with up to 25 metres on either side for HV Transmission lines.

It is also a practice to have vegetation clearances over underground cables to ensure access. Estonia defines the protection zone of an underground cable line as the area along the cable line, bounded on both sides by notional vertical planes extending 1 metre from the outermost cables of the line.

1 *Life Project | Elia*

Risk-based approaches are increasingly common, as seen in the UK's ETR 132 guidelines, which requires progressive compliance to resilience clearance and prioritises high-risk sections. UK utilities aim to make 0.8% of their overhead line network (in terms of length) resilient to the risk of falling trees incrementally. In Victoria, the clearances along the network lines are applied based on the area the line is crossing being high risk or low risk.[1] Victoria's Electric Line Clearance regime also ties clearance distances and cycles to local risk with audited plans. Nova Scotia and FirstEnergy in the USA use granular risk assessments and high-resolution aerial imagery for monitoring. Nova Scotia Power, as part of their 2025-29 Reliability Plan, will identify and manage problem areas within underperforming circuits more effectively.

A recent CIGRE [2] international survey highlights significant variability in how corridor widths are defined: 41% of countries rely on legislation, 15% on obligatory standards, and others on operator guidelines. The trend is towards risk-based, measurable, and enforceable guidelines that prioritise resilience and safety.

Safety and Resilience Clearances

Safety clearances are mandatory minimum distances maintained between vegetation and live conductors, defined by voltage level, conductor movement, and electrical safety standards. Their primary purpose is to prevent flashover, arcing, fire ignition, and electrocution risks for both the public and workers. These clearances represent a non-discretionary, baseline compliance requirement for network operation and are consistently established across all reviewed jurisdictions. Notably, international experience demonstrates that safety clearances remain unchanged even after major storm events, as they are not intended to mitigate the dominant storm failure modes such as tree fall, uprooting, or canopy collapse.

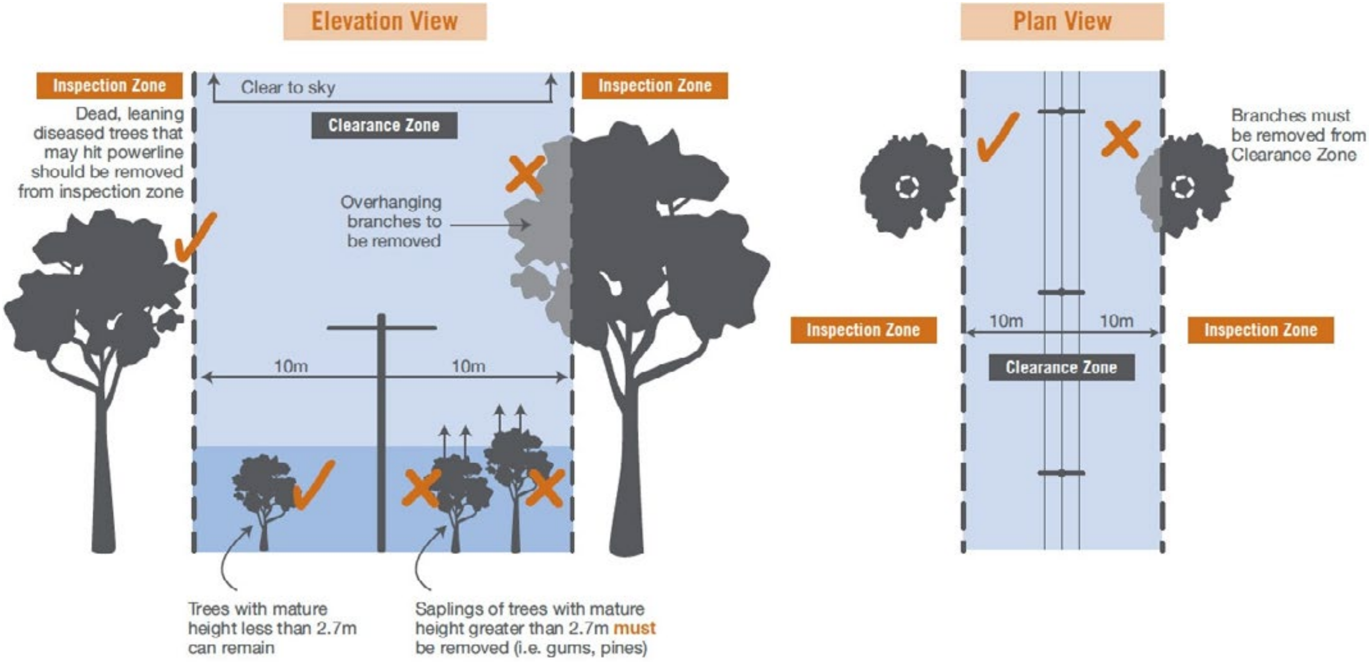
In contrast, resilience clearances go beyond statutory minimums and are specifically designed to reduce storm vulnerability. They typically involve the removal of hazard trees capable of striking lines, the establishment of wider or asymmetric corridors in forestry-exposed areas, and prioritisation based on storm exposure, soil conditions, and historical outage performance. While resilience clearances are not universally mandated, global trends indicate a growing shift post-storm towards empowering DSOs to apply risk-based interventions where justified, granting greater authority to implement these measures for enhanced network resilience.

Illustrative examples are provided in Figure 6 and Figure 7 to demonstrate how safety and resilience clearance zones are applied internationally including prescribed tree planting practices.

1 *HBRA (Hazardous Bushfire Risk Area) and LBRA (Low Bushfire Risk Area) are classifications used primarily by the Country Fire Authority (CFA) and Energy Safe Victoria (ESV) to manage fire risks associated with electricity infrastructure. These designations determine the requirements for vegetation clearance around powerlines and, in some cases, the necessity of placing powerlines underground.*

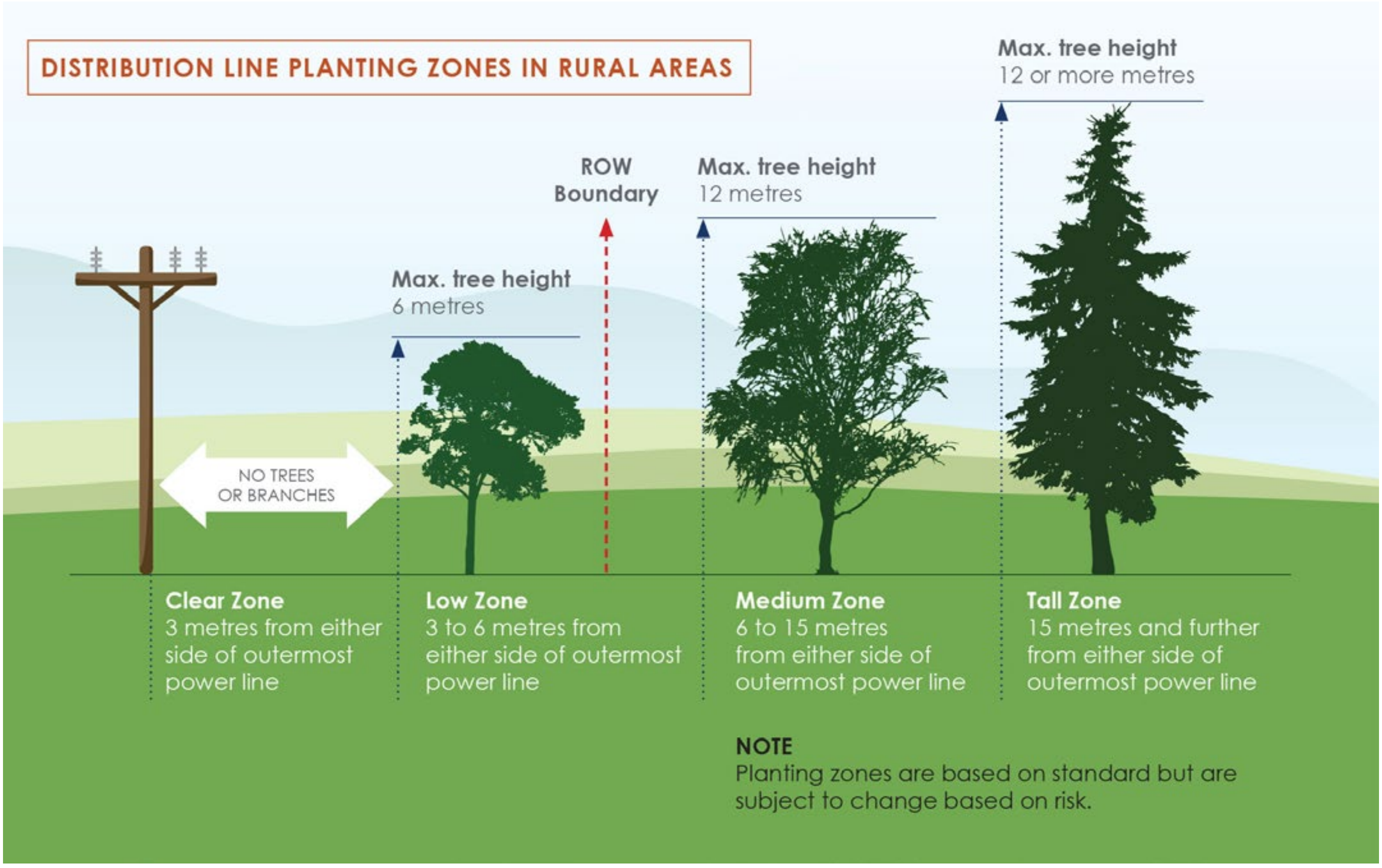
2 *Sustainable Corridor Management | ELECTRA*

Figure 6: Illustrative example of safety clearance and buffer zones around electricity distribution lines



The illustrative example in Figure 6 is from Powercor, a DSO operating in Victoria, Australia and demonstrates the application of clearance and inspection zones relating to domestic connection lines on private land. The clearance standards presented are based on the "The Electricity Safety (Electric Line Clearance) Regulations" and requires additional clearances to account for regrowth between pruning cycles. The standard adopts the use of a 20 m wide clearance zone that is maintained beneath and adjacent to the line (10 m either side), with an additional inspection zone beyond this area. Overhanging branches within the clearance zone must be removed, dead or leaning trees that could strike the line should be cleared from the inspection zone, and only low-growing vegetation with a mature height below 2.7 m can remain beneath the line. Trees capable of growing taller than 2.7 m must be removed from the clearance zone.

Figure 7: Illustrative example of safety clearance and planting zones around electricity distribution lines[1]



Planting zones are used in many jurisdictions including prescribed practices relative to safety clearance zones. Figure 7 shows an example from a Canadian power utility depicting a 'Clear Zone' along with graduated zones (low, medium, tall) outside the clear zone requiring varying maximum tree heights which increase with distance from the distribution line. The clear zone in this case is designed to ensure that the Minimum Vegetation Clearance Distance (MVCD) industry standards are met whilst the planting zones are prescribed as part of this power utilities broader Integrated Vegetation Management program.

The clearances, be they safety or resilience clearance, in forestry corridors and across hedgerows differ in each jurisdiction due to a multitude of factors including forest composition, terrain, network exposure, climatic events. While clearances typically vary in relation to voltage level, conductor type and risk across jurisdictions, the actual clearances specified vary based on local context. The table below summarises vegetation clearance practices and regulatory approaches across selected countries, based on the information presented.

1 *SaskPower, Trees and Power Line Safety*

Table 6: Vegetation clearances across regions

Country / Region	Clearance distances	Key requirements / notes
Czechia	1 m for LV; 7 m (uninsulated); 2 m for 1–35 kV; 12 m for 35–110 kV	CEZ Distribuce requires defined vegetation clearance distances measured from the outer conductor. Vegetation within the protective zone must not exceed a height of 3 m to ensure safety and reliability.
Estonia	2 m for up to 1 kV; 10 m for 6–20 kV; 25 m for 35–110 kV (each side of line)	Clearance corridors are defined in regulation by voltage. DSOs have full responsibility to remove or lop dangerous trees within corridors, while landowners manage risks outside the corridor.
Victoria, Australia	1.5–1.8 m (LBRA); 2.25–2.75 m (HBRA)	Clearances are legally mandated based on fire safety regulations and bushfire risk. Distances vary by span and include additional allowances for conductor sag and sway.
United Kingdom	~1 m for LV; 3–5 m for 11 kV and 33 kV	No single statutory minimum distance. DNOs follow ENA Technical Specification 43-8 to maintain safe clearances, using a V-cut profile and allowing for conductor movement (up to ~7.4 m envelope and 45° sway).
Nova Scotia (Canada)	~3 m for LV (typical practice)	No fixed legal distance; utilities follow best practice aligned with the Canadian Electrical Code. Clearance is typically around 3 m for primary distribution lines and subject to municipal by-laws.
Finland	Tree lopping for 0.4 kV; 5 m for 20 kV; 13–21 m for 110 kV	No explicit legal numeric clearance. In practice, DSOs maintain standard corridor widths (e.g. ~10 m for 20 kV lines, wider for higher voltage). Trees outside the corridor are managed if they can strike the line.
United States	No fixed nationwide distances specified	No national standard for distribution clearances. Utilities implement vegetation management plans based on industry standards such as ANSI A300 and OSHA, rather than explicit legal distances.
Elia (Belgium)	A safety corridor over 50 m wide can be maintained.	Elia manages vegetation beneath and around transmission lines to maintain statutory electrical safety clearances and security of supply. In forested areas, Elia increasingly uses a V-shaped ecological corridor approach rather than complete clearing, promoting low-growing vegetation while preventing trees from encroaching on conductors. By 2030, Elia aims to apply ecological corridor management to around 90% of its woodland transmission corridors in Belgium

More detailed description of clearances standards and resilience measures adopted for vegetation management can be found in *Appendix: Safety and Resilience Clearances by Region.*

3.7 Key Technological Implementations for Networks Resilience

The table below details the top eight advanced technologies that have been deployed by international utilities to improve their network resilience, emphasising monitoring, automation, and targeted risk reduction. Automated Circuit Reclosers (ACR), FLISR and having localised backup solutions have the largest crossover, implemented in Victoria, UK, Nova Scotia and Eastern US to aid in fault detection, isolation of affected areas and acceleration of restoration. AusNet Services operates with a heightened risk of bushfires, and REFCLs act to limit the current during earth faults. These operational technologies are supported by management and monitoring systems (ADMS, vegetation). By implementing applicable technologies, these DSOs have been able to reduce outage duration, improve storm response, protect services and support a proactive approach to network resilience that targets high-risk assets, locations and conditions rather than a uniform application across the networks.

Table 7: Technology implementations for network resilience

Technology	Notable DSO(s)	Definition	Workstream	Outcome
Automatic Circuit Reclosers (ACRs)	AusNet Services, UK Power Networks, Nova Scotia Power, FirstEnergy	Protection devices that detect and clear faults, attempting restoration automatically.	Network Monitoring & Automation	Reduces outage duration, automates restoration, reduces bushfire ignition risk.
Rapid Earth Fault Current Limiters (REFCLs)	AusNet Services	Neutral earthing technology that suppresses earth fault current and extinguishes arcs.	Network Reinforcements	Cuts bushfire ignition risk and maintains supply continuity on healthy phases.
Increased Sectionalising	AusNet Services	Automated MV switches and sectionalisers dividing feeders into smaller segments.	Network Monitoring & Automation	Isolates faults to smaller areas and supports FLISR for faster restoration.
Fault Location, Isolation and Service Restoration (FLISR)	AusNet Services, UKPN, Nova Scotia Power, FirstEnergy	Automated detection, isolation, and restoration system.	Network Monitoring & Automation	Speeds restoration and reduces customer outage impact.
Remote Control Switches	Nova Scotia Power	Remote monitoring and switching devices integrated with control centre systems.	Network Monitoring & Automation	Enables rapid reconfiguration and remote switching for faster restoration.
Advanced Distribution Management System (ADMS)	AusNet Services, Nova Scotia Power, FirstEnergy	Unified platform integrating OMS, DMS, DERMS and automation tools.	Network Monitoring & Automation	Improves storm response with centralised automation and enhanced visibility.
Localised Backup Solutions	CEZ, AusNet Services, UKPN, Elektrilevi, SSEN	Fleet of mobile generators and transformers for temporary emergency supply.	Power Restoration Efforts	Maintains critical services and reduces disruption during long outages.
Satellite Vegetation Monitoring	Nova Scotia Power	Satellite scans identifying vegetation proximity for targeted vegetation programmes.	Vegetation Monitoring & Management	Supports risk-based vegetation management and reduces outages.

DSOs often perform a robust analysis of selection of technology with AusNet Services' Advanced Distribution Management System (ADMS) Business Case[1] clearly outlining how a distribution system operator translates strategic and regulatory drivers into a disciplined approach for large scale technology implementation along with the associated benefits and expected risks.

1 *Business Case: Advanced Distribution Management System (AMDS), (EDPR 2027-31), 2025*

3.8 Key Observations

International experience has shown that storm resilience strategies range from advanced engineering solutions to fundamental measures, dependant on local network characteristics, climate exposure and regulatory frameworks. While common methods exist, there is no single approach that fits all contexts.

Range of approaches:
Strategies vary from extensive undergrounding (Finland) to strengthening overhead networks supported by enhanced vegetation management and automation (UK, US, Canada).

Context-specific solutions:
Finland's long-term undergrounding programme was enabled by specific national policy, regulatory mandates and large-scale co-construction project as described in section 3.2. Other jurisdictions too have prioritised reinforcement of existing assets including, for example, Enedis in France who are planning to install additional underground cables post storm-Ciarán as part of a targeted programme as described in section 5.3.

Best practice:
Despite national differences, utilities are increasingly adopting common measures such as sustainable forestry corridors and other vegetation measurement techniques, targeted automation and more frequent inspections.

Role of regulation:
Resilience strategies are influenced by legal and regulatory frameworks. Where governments set clear requirements (e.g. Finland's strict outage duration law, Victoria's fire safety vegetation code, or Czechia's legally defined clearance zones), utilities align their standards and investments to comply. Utilities also apply standards (such as the UK's industry-developed ENA engineering recommendations, or the U.S. utilities' internal manuals) to meet reliability targets.

Ireland, like the other countries that were reviewed, has its own characteristics, particularly in terms of the vegetation and forestry profile and the way these interact with the electricity network. This means Ireland's resilience approach needs to be fit for purpose. The measures shortlisted in the report consider international best practice and lessons learned. They also consider suitability for Ireland's climate, network, regulatory regime, impact on cost and legal regime among other key factors.

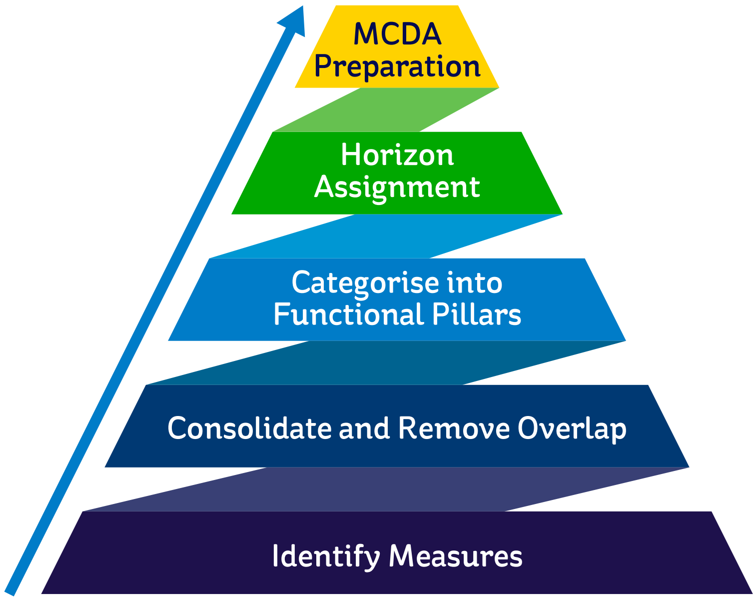
For ESB Networks, these international insights offer actionable guidance as it strengthens the Irish network. Key takeaways include the value of targeted network hardening such as the use of stronger poles and/or insulated conductors, the importance of short vegetation cycles with hazard tree removal, the acceleration of network automation in terms of resilience and addressing storm-specific risks, and the impact of a supportive regulatory framework that enables pre-emptive resilience investments. By combining approved PR6 investments with additional proven measures from abroad, and balancing cost with benefit, ESB Networks can enhance its storm resilience in line with global best practices.

4 List of Resilience Measures and Strategic Enablers

4 List of Resilience Measures and Strategic Enablers

This section presents a comprehensive list of resilience measures, developed through a review of global utility practice and informed by structured interviews across benchmark DSOs. Building on the insights from these interviews and research, the measures were consolidated and a list was developed. Through a structured, multi-stage process, the measures and their implementation were verified for completeness, consistency and alignment with ESB Networks' operational context.

Figure 8: List Creation Process



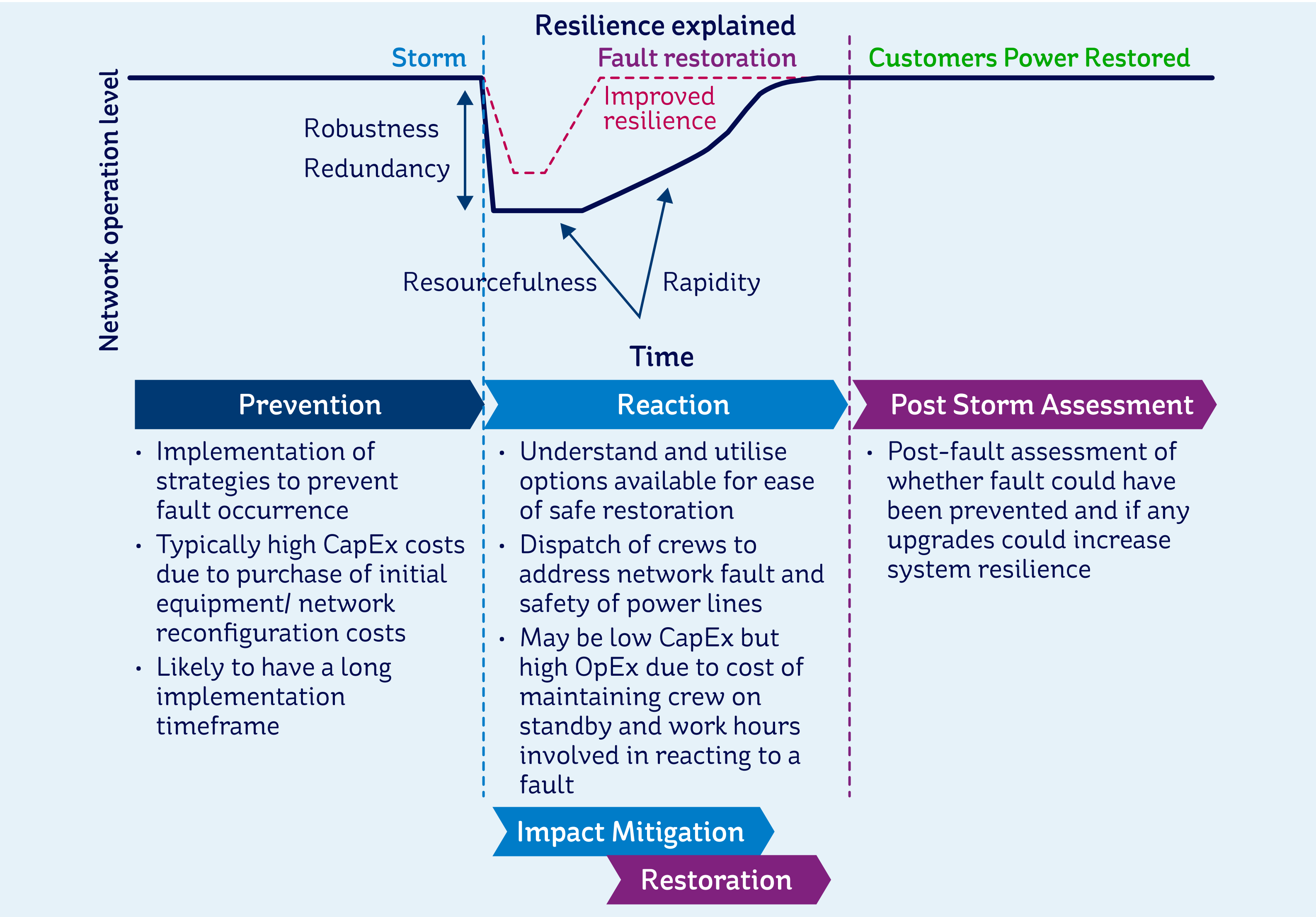
Potential measures were first identified from benchmarking and interview evidence, then consolidated to remove duplication and ensure a coherent set of measures. These measures were subsequently organised into workstreams, detailed below. Finally, all measures were prepared for subsequent Multi-Criteria Decision Analysis (MCDA) assessment to support structured prioritisation in the next phase of the review (detailed in the section: Shortlisted Measures). Resiliency themes were considered during the MCDA assessment stage; however, for clarity, the list is presented using functional workstreams.

Investing in data analytics and planning tools will help target key areas for maximum benefit. In the review, these actions are identified as strategic enablers which are essential for achieving sustained, strategic change. These are covered in detail in Strategic Enablers.

4.1 Functional Workstreams

Figure 9 below illustrates the '4R's' of network resilience including robustness, redundancy, resourcefulness and rapidity and how these relate to network operation levels and customer restoration following storm related faults. Each of the 4R's are mapped to the time-based phases prevention or reaction, which can be used to categorise measures that can support overall resilience improvements.

Figure 9: Resilience in terms of preventative and restoration measures.



For clarity, the list of resilience measures are grouped into five workstreams, with each workstream identified as being either prevention or restoration based, or as supporting activity.

4.1.1 Prevention

Network Reinforcements:
Physical enhancements to the network to harden infrastructure against storms, such as upgrading to insulated overhead conductors, selective undergrounding to eliminate weather exposure, and pole reinforcement or replacement. Such investments improve the network's robustness so that fewer faults occur even under extreme wind or falling trees. They often require significant capital and time to implement, so they are targeted where they will yield the greatest resilience benefit.

Forestry Corridor and Hedgerow Management:
Long-term strategies for managing vegetation and forestry along forest corridors and hedgerows to minimise tree-related outages. The shortlist emphasises enhanced vegetation clearance practices; for example, resilience tree cutting, progressively widening corridor clearances in forested areas, and sustainable corridor management. Effective corridor management is seen as essential in the Irish context to reduce the frequency and impact of storm damage, given the high exposure of overhead lines to forestry and hedgerows.

4.1.2 Restoration

Network Monitoring & Automation:
Deployment of advanced control systems and sensors to accelerate fault detection, isolation, and service restoration. Using ADMS, FLISR, auto-reclosers, and remote-controlled switches together can reduce outage durations by minimising the need for manual intervention.

Power Restoration Efforts:
Capabilities and configurations that enable faster restoration of supply after outages and provide alternative sources of power during emergencies. This workstream includes measures like establishing mutual aid agreements and improving network reconfiguration strategies to restore power more quickly.

4.1.3 Supporting activities

Vegetation Monitoring & Management:
Complementary measures that enable data-driven and proactive management of vegetation risks by using monitoring technologies and equipment. Supporting measures like the timber value protocols that encourage co-operation with landowners by returning value from cleared trees and ensure that the preventive actions are targeted to the right locations and are executed with stakeholder buy-in, thereby maximising their effectiveness. When considering the resilience measures relating to forestry corridor and hedgerow management it is recommended to consider the differences in relation to safety and resilience clearances as described in section 3.6.

4.2 Resilience Measures List

Given that each jurisdiction applies its own definitions and interpretations based on its operating context, the list of measures presented in this section have been retained in their original form and have not been adjusted for the Irish context, to preserve their intended scope and meaning.

Measures are set out in a structured table, with each row summarising the measure, its associated technical workstream and a short descriptor. Where relevant, certain terminology and approaches from international benchmarking have been retained in the presentation of measures, even though these may not be directly tailored or factored for Irish applicability. Each measure is also tagged against one of three resilience themes: Prevention, Restoration or Supporting, shown in a separate column to highlight its primary contribution to network resilience.

Table 8: List of resilience measures

Workstream	Measure	Definition	
Network Reinforcements	Selective Undergrounding	Replaces overhead lines in high-risk areas - identified by factors like storms or population density - to cut faults and boost supply reliability.	Prevention
	Insulated Overhead Conductors	Reduce vegetation-related faults by providing more insulation than bare conductors.	
	LV ABC Replacement	Replacing bare LV wires with insulated aerial bundled cables.	
	Pole Reinforcement / Replacement	Transitioning to utility poles constructed from advanced, high-strength materials such as fiberglass, designed to significantly enhance structural integrity and improve resilience against extreme weather events, including high winds and severe storms.	
	Conductor Upgrades	Combining corridor works with larger conductor cross-section conductors for increased stability to improve network resilience.	
Forestry corridor and hedgerow management	Progressive Corridor Width Increase	Gradually widens MV and HV corridors: starting with legal clearance, then resilience-level, and finally selective risk-based treatment for key spans.	
	Resilience Tree Cutting	Uses risk-based standards like ETR 132 along with minimum clearance standard like ENATS 43-8 to assess tree health, fall risk, and corridor importance, enabling targeted thinning.	
	Sustainable Corridor Management	Turns cleared corridors into stable, biodiverse zones by planting slow-growing or compatible species, minimising regrowth and long-term maintenance.	
Network Monitoring & Automation	Auto reclosers & sectionalising	Improve how faults are isolated by creating smaller, automatically controlled network segments.	Restoration
	Remote control switches	Allow operators to reconfigure the network without sending field crews, reducing restoration times.	
	Fault Location, Isolation and Service Restoration	FLISR - Provides automated processing of faults, allowing faster identification, sectionalising and restoration of unaffected customers.	
	Tree Management	Live-line harvesting is used to safely remove trees near power lines. It allows vegetation clearance without de-energising lines using specialised tools, reducing the risk of power cuts.	
	Advanced Distribution Management System	ADMS - Centralises operational control, integrating monitoring, switching and optimisation tools to support remote and automated network management.	
	Advanced HV monitoring	Implementing sensors on HV systems for real-time fault location and conductor clearance.	
	Decentralised device-to-device automation	Enabling field devices to communicate and make switching decisions locally.	
	Smart Meter Fault Identification	Contribute near real time customer level outage data that aids precise fault localisation.	

Workstream	Measure	Definition	
Power Restoration Efforts	Localised Backup Solutions	Deploying community-level grid solutions such as batteries, generators, and transformers for resilience during outages.	**Restoration**
	Mutual Aid Agreements	Allow distribution system operators to share crews, materials, and equipment during major outages, enabling faster restoration when local resources are limited and minimising the effects of widespread faults.	
	Deployable Generation & Injection Strategy	Maintain a fleet of mobile generators and transformers to provide temporary power supply during extended outages, complemented by the installation of permanent connection points at strategic locations to enable rapid deployment when required.	
Vegetation Monitoring & Management	Timber Value Protocols	Processing timber from corridor clearing to maximise landowner value and ease negotiations.	**Supporting**
	LiDAR Inspection (Drone)	Provides high resolution clearance mapping in areas where detailed three dimensional modelling improves accuracy.	
	LiDAR Inspection (Vehicle)	Delivers efficient scanning along accessible routes for broader coverage.	
	Satellite Vegetation Monitoring	Supplements these methods with large area imagery that tracks growth patterns and identifies emerging clearance issues across the network.	
	Drone Visual Inspection	Supports targeted condition assessment of assets and vegetation in locations that require close range inspection.	
	Helicopter Visual Inspection	Enables rapid assessment of long or inaccessible corridors. (Currently in implementation for HV networks)	

4.3 Strategic Enablers

As ESB Networks moves forward with building upon its storm resilience, close coordination with regulators and stakeholders will be needed to align incentives (for example, updating allowed investment levels or tree-trimming standards) with the resilience objectives. Similarly, continuing to invest in data analytics and planning tools will help prioritise investments for maximum return (e.g. focusing on the worst-performing feeders or most critical customers). These actions form the strategic enablers required for a coordinated and enduring change.

The 4 strategic enablers identified during the review are detailed below:

Standard of Resilient Design
Codify resilient design and materials including revised clearance standards for forestry corridors and for spans adjacent to hedgerows, and revised technologies where risk warrants, backed by compliance audits. Subsequently, linking technical standards to lifecycle planning and renewal policies so assets are replaced to a common, storm durable specification which reduces whole life cost and simplifies maintenance. All stakeholders engaged have undertaken steps to arrive at technical standardisation for materials and processes.

Data Driven Prioritisation
International peers are using bottom-up data driven approaches to identify the need for and prioritise resilience investments supported by best practice investment decision making data and tools. However, the application of investment prioritisation modelling differs per jurisdiction based on agreed criteria such as SAIDI/SAIFI, Security of Supply, density, load and asset conditions along with nature of faults and climatic events and their frequency. Other countries have introduced value for customer resilience parameters to support investment decision making.

Robust Programme Governance
This enabler entails using a risk-based targeting model that fuses monitoring technologies (Satellite/LiDAR analytics) to understand species growth, wind exposure and fault history to produce an actionable span-level view which gives prioritised plans for crews in line with international peers. This helps in tying monitoring investments to measurable reliability outcomes by focussing efforts on clearance, risk-based treatment and resilience cuts where, for example, the SAIDI/ SAIFI benefit per euro is highest. As the intensity of climatic events is increasing, this prioritisation helps achieve more focussed effort for vegetation management.

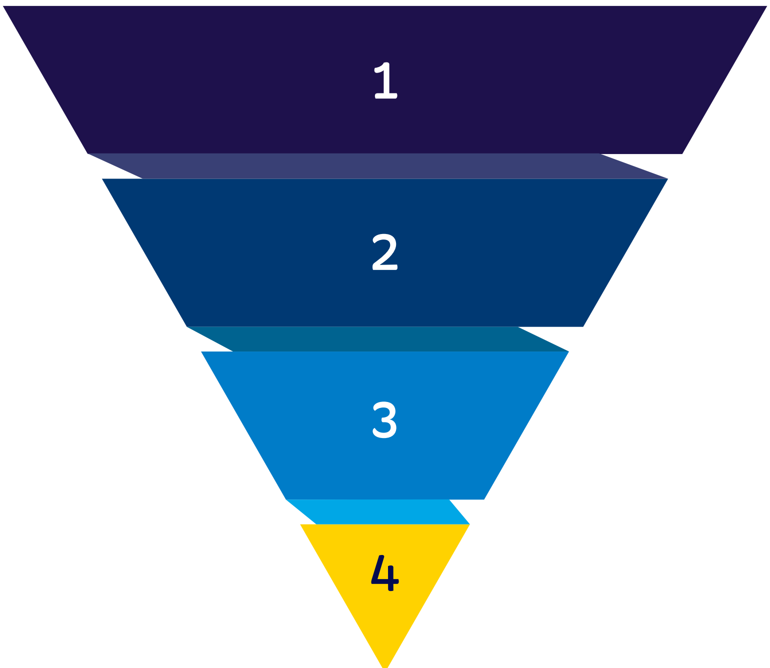
Legislative and Regulatory Support
Establish statutory clarity for forestry corridors and resilience by defining protection zones, enabling risk-based fall clearance treatment and hazard tree removal, streamlining wayleave/access processes, and aligning funding mechanisms with regulatory oversight. This also entails coordinated engagement with regulatory and legislative bodies ensuring powers, duties and investment allowances support pre-emptive vegetation control and targeted hardening, reflecting lessons from peers. Finland, Estonia, Great Britain and Victoria.

5 Shortlisting of Measures

5 Shortlisting of Measures

This section explains how the list of 25 resilience measures was reduced to a focused shortlist using a Multi-Criteria Decision Analysis that assessed each measure against cost (CAPEX and OPEX), ease of implementation, environmental impact, and resilience benefit aligned to the Four Rs. The ranked results were then filtered for Irish applicability, reflecting the characteristics of the predominantly rural overhead network, storm exposure, forestry and hedgerow interfaces, the regulatory and legislative context, and initiatives already in ESB Network's business plan, to ensure practicality and value. The resulting shortlist is balanced across prevention, restoration, and supporting activities, sequencing near-term deliverables alongside longer-term investments so that operational gains can be realised while structural upgrades progress. Delivery is underpinned by strategic enablers that make the programme scalable and agile, namely standardisation for resilience, data-driven prioritisation, robust programme governance, and legislative & regulatory support.

Figure 10: Refining measures into a shortlist.



1. All Options
All resiliency measures and insights that the review identified (as detailed in section 6) agnostic to the Irish context.

2. MCDA Initial Assessment
All resiliency measures and insights that the review identified (as detailed in section 4) agnostic to the Irish context.

3. MCDA Applicability to Ireland
Applying local considerations of network characteristics, climate and legislative and regulatory landscape.

4. Shortlisted Measures
Each applicable measure is analysed for its current maturity to make a prescription for ESB.

5.1 Multi Criteria Decision Analysis Initial Assessment

To identify a focused set of measures to build storm resilience, the project team applied a MCDA to the list of 25 candidate measures drawn from international insights. The initial assessment was conducted in an agnostic manner, i.e. treating all measures on their inherent costs and benefits without yet bringing in the unique Irish context. Each measure was scored and weighted against the following criteria:

- **CBA (Capex/Opex):** The upfront capital expenditure required and any ongoing operational and/or maintenance costs. High capital or operating costs results in a lower score against this criterion. These costs were derived from reports and studies published by the utilities surveyed.
- **Ease of Implementation:** The practical feasibility of rolling out the measure, including alignment with regulations, requirement of skilled resources, permitting requirements, and societal acceptability. Measures that face fewer regulatory hurdles or public opposition were scored higher.
- **Environmental Impact:** The expected environmental implications, such as ecological sensitivity, habitat disruption, afforestation targets, carbon sequestration or greenhouse gas emissions, etc. Measures with minimal negative environmental impact were scored higher.
- **Resilience Benefit:** The degree to which the measure improves storm resilience, evaluated in terms of the “Four R’s” – i.e. how much it enhances robustness, redundancy, resourcefulness, and rapidity for the network. High-impact measures that significantly strengthen the network’s ability to withstand and recover from storms scored highest against these criteria. The resilience themes derived from the “Four Rs” were Prevention, Restoration and Supporting Activities, as detailed in the *Appendix: 4 Rs of Resilience.*

The MCDA initial assessment process ranked the list of resilience measures, and the top 22 initiatives were selected to be evaluated further for their applicability to Ireland. Final recommendations were framed against the resiliency themes - Prevention, Restoration and Supporting Activities – to ensure a well-rounded set of complementary measures that broaden resilience improvements for ESB Networks, meeting both immediate and long-term needs. The shortlisted measures can be referred in subsection: Shortlisted Measures.

As part of the review, it was noted that the execution of these measures is greatly aided by strategic enablers such as supportive regulation, clear policy frameworks, funding mechanisms, and organisational commitment. The review emphasised that strong regulatory and legislative support is often a prerequisite for comprehensive vegetation management and hardening programmes.

5.2 Applicability to Ireland Assessment

After compiling a list of 25 resilience measures and scoring them via the MCDA initial assessment, the next step was to further assess these measures through the lens of Ireland's unique context. To ensure the shortlist is truly relevant for ESB Networks, the Irish-specific factors – including climate and weather patterns, the characteristics of Ireland's distribution network, vegetation and forestry conditions, the regulatory and legislative landscape, and ESB Networks' ongoing initiatives – were applied to the measures that passed the initial MCDA assessment. This applicability assessment identified which measures are feasible and impactful in Ireland, and which are less suitable.

As discussed in Section 3, Ireland's Atlantic-based climate system is increasingly influenced by climate change and is facing risks of more severe storms, such as Storm Darragh (Dec 2024) and Storm Éowyn (Jan 2025), which brought record maximum wind gust speeds of 184 km/h.[1] These storms have led to significant damage to the electricity network.

The Irish regulatory and policy environment is increasingly supportive of resilience investment. The Electricity Supply (Amendment) Bill and PR6 make provisions for statutory forestry corridors and investment for refurbishment and upgrades across the network respectively.

The Commission for Regulation of Utilities (CRU) has provided network resilience funding under Price Review 6 (PR6) (2026–2030), building on groundwork laid in PR5 and lessons from Winter 2025 storms. PR6 final determination provides a strong foundation for the continued enhancement of storm resilience across the Irish electricity network and demonstrates clear alignment with many of the measures identified through this international review. In addition to the enhanced storm resilience allowance, the programme includes significant investment in network renewal and reinforcement, including an increase of 150% in pole replacements[2] when compared to PR5, more than 1,000 kilometres of new or upgraded overhead lines and 70 new or refurbished substations. Alongside these asset investments, ESB Networks is already progressing several resilience-focused operational and digital capabilities identified as leading practices internationally, including the advanced deployment of an Advanced Distribution Management System (ADMS), expanded network automation through reclosers and remote-control switching, and smart meter-enabled fault identification to improve fault localisation and restoration performance. For instance, the PR6 Final Determination allows for more than a four-fold increase on the installation of reclosers compared to PR5 respectively. PR6 also provides for continued investment in network inspection, monitoring and risk-based vegetation management capabilities. ESB Networks' PR6 Business Plan refers to the use of drone technology and data analytics to target timber cutting, while the Winter 2025 Grid Resilience Plan confirms the use of drone patrols on MV networks and vulnerable forestry corridors.[3]

There is no evidence of allowances in PR6 for the design and implementation of resilient forestry corridors. It is noted that ESB Networks will need to further accelerate investment in resilience measures including resilient forestry corridors, enabled by the Legislative and Regulatory Support as described in section 4.3 above.

1 *ESB Networks Storm Éowyn Review, ESB 2025*

2 *Based on ESB Networks PR6 Business Plan which references an annual PR5 replacement rate of 4,000 per annum.*

3 *ESB Networks, Price Review 6 Business Plan, 2024; ESB Networks, Winter 2025 Grid Resilience Plan, 2025*

5.3 Measures Inapplicable to Ireland Assessment

With the above considerations in mind, each measure from the MCDA-ranked list was scrutinised for feasibility and impact in Ireland. Some measures that scored well in general and have been effective in other countries are less applicable to ESB Networks due to safety standards, the nature of Ireland's network and forest and hedgerow characteristics. The table below summarises the measures excluded from the shortlist after applying the Irish context filter, along with the reason for exclusion and notes on their international use for comparison.

Table 9: Measures excluded from the list.

Measure	Reason for Exclusion (In Ireland)	International Context
Deployable Generation and Injection Strategy (Mobile diesel generators to temporarily restore supply)	Limited benefit for Ireland's predominantly dispersed rural network. Logistically challenging to deploy enough generators across many remote outage sites; not a scalable solution for large storms. Deploying mobile generators can divert network technicians from restoration works.	Commonly used in other countries for short-term relief in localised outages. After Storm Arwen (UK 2021), reviews noted mobile generators help reduce outage durations but have practical limits and are not cost-effective for widespread rural faults. DNOs are increasing generator fleets modestly for critical needs, but they remain a support tool rather than a primary resilience measure.
Localised Backup Solutions **(e.g. community battery energy storage system (BESS) and/or microgrids)**	Outside ESB Networks' direct remit as the Distribution System Operator. Implementing local backup generation/ storage falls to consumers or energy market providers; not funded under network resilience programs.	In some regions, "community energy schemes" or local authorities pursue backup power (e.g. community centres in the UK equipped with generators after Storm Arwen). Such solutions require market incentives or government programs; they are rarely led by network operators under regulated funding. In Victoria, Australia, this measure has seen success because of collaboration between Energy Safe Victoria and awareness on local level to get buy-ins from local communities, especially in regions at high-risk of bushfires.
Decentralised Device-to-Device Automation (Peer-to-peer automatic network reconfiguration)	This technology is superseded by advanced Distribution Management Systems (ADMS) and modern FLISR capabilities that ESB Networks is already implementing. Older autonomous switching schemes add complexity without integrating into today's smarter grid control solutions.	Earlier-generation networks (and some remote microgrids) used device-to-device automation for isolation and restoration. Today, leading DSOs use centrally managed automation (ADMS with FLISR) for faster fault response, making peer-to-peer schemes largely obsolete.
Advanced High-Voltage (HV) Line Monitoring (Sensors for real-time line condition/fault monitoring)	De-prioritised as a standalone measure – provides redundant capabilities already delivered by other shortlisted solutions. Broader network monitoring and automated fault detection (including feeder sensors and "tree fall" detectors) are being pursued, covering the intended benefits.	Utilities have tested dedicated high-voltage line monitoring (e.g. line sag, thermal or acoustic sensors) and some are implementing these. Some DSOs achieve similar resilience benefits via comprehensive SCADA, smart metres, and distributed sensors for fault detection. The trend is to integrate monitoring into wider network automation and analytics which can include HV monitoring.

Undergrounding as a Resilience Measure

The approach to undergrounding for resilience was reviewed as part of this benchmarking report. Undergrounding is more common in urban rather than rural environments. The review and applicability assessment suggests that neither mass nor selective undergrounding is a practical resilience strategy for Ireland's electricity distribution network. Undergrounding of rural networks is substantially more expensive compared to overhead lines and is unlikely to achieve cost-effective resilience benefits when considered against the measures already being implemented by ESB Networks and those additional measures recommended as part of this review. International evidence[1] highlights that undergrounding carries costs significantly higher than overhead line solutions which would be borne by electricity consumers. It is also important to point out that an undergrounded cable through a forest or hedgerow still requires clearances and access for maintenance.

In Finland, mass undergrounding was driven by a unique combination of technical, regulatory and legal conditions. In Estonia weatherproofing including undergrounding over time and managing forestry corridors to legal maximums is implemented given its particular network and weather conditions. The other DSOs reviewed do not pursue mass undergrounding due to its significantly higher cost and because comparable resilience benefits can be achieved through the range of other resilience measures outlined in this report. Selective undergrounding is typically used only where a clear, evidence-based case exists, typically considering factors such as cost, environmental impact, amenity, resilience benefit, customer impact, ground conditions and access among other factors. Enedis in France are planning to install at least 1,100km of MV and LV underground cable solutions in the Brittany area (this is approximately 1% of Enedis' total network in Brittany, which amounts to 0.16% of total national network length) in the wake of storm Ciarán targeting network prone to strong winds operating in wooded areas[2]. This is in addition to their already planned undergrounding of 3,500km of cables in Brittany.

1 *Undergrounding transmission and distribution lines is significantly more costly than overhead construction, with the U.S. DOE's Grid Deployment Office noting higher capital costs and additional complexity in challenging ground conditions especially in wetlands. The UK Storm Arwen Review reinforced this, recognising that while undergrounding reduces storm-related faults, mass deployment is economically prohibitive and not a practical resilience strategy for rural networks. Turner & Townsend's independent cost analysis found undergrounding to be between 4.5 and 5 times more expensive than overhead lines for comparable capacity, further confirming the substantial cost premium.*

2 *Enedis unveiled a recovery plan of additional reinforcement of 2,000 km of lines in Brittany to accelerate the adaptation of the electricity network to climate change on October 28, 2024, post Storm Ciarán. With Enedis controlling of over 95 percent of continental France, the undergrounding undertaken will equate to 0.16% of their current overhead network.*

For Ireland, evidence suggests that the overhead distribution network is intrinsically robust. Storm events such as Éowyn demonstrated that most failures, over 59% of damage assessments for over 12,500 faults, stem from hedgerow timber and forestry rather than conductor failure.[1] A recent ESB Networks Asset Management Interim Report - Review of Distribution Overhead Line Standards for Extreme Wind Events, states that the Irish distribution network (LV, MV & 38kV) can withstand sustained wind intensities similar to those experienced in Storm Éowyn. Therefore, the most impactful and expedient approach to network resilience improvements lies in continuing to strengthen overhead network assets, enhancing automation and appropriate forest and hedgerow management, not undergrounding. PR6 includes allowances for extensive pole replacement and conductor upgrades. Evidence from the UK and other comparable systems suggests that reinforced overhead lines, building resilient forestry corridors and increased automation can deliver major gains in storm resilience at lower cost than undergrounding, and aligns more closely with Ireland's geography, exposure to wind events and regulatory context.

5.4 Successful Shortlisted measures

The shortlisted measures represent priority opportunities for improving the resilience of the electricity distribution network based on international evidence and applicability to the Irish context. The assessment process distinguishes between measures that ESB Networks are already progressing, some of which may require acceleration or broader rollout, and measures that represent new or emerging areas of activity that should be prioritised for development.

The shortlisted measures are grouped across three resilience themes: prevention, restoration and supporting activities, as described in section 4.1. These themes reflect each measure's role in delivering positive resilience outcomes including reducing the number of faults, minimising the impact to customers of faults sustained and speeding up restoration of supply following a fault. This is detailed in the *Appendix: 4 Rs of Resilience.*

A detailed definition of each of the measures is provided in the appendix.

1 *Storm Éowyn Review, ESB 2025 states that in over 59% of cases, hedgerow timber or forestry was recorded as the primary cause, with just over 50% relating to hedgerow timber, and over 8% related to forestry. Some further analysis of the hedgerow timber issues reported that a large proportion related to trees falling on the network. For the other 40%, where hedgerow timber or forestry wasn't recorded as the cause, the main damaged asset was recorded (e.g. broken conductor, damaged pole). Within some of these damage assessments, photos and commentary / notes indicate that the fault was due to external factors such as debris, but the information recorded focuses on repair of the network equipment, and not the cause.*

Table 10: Shortlisted measures

Workstream	Measure	
Network Reinforcements	1. LV wire replacement with Aerial Bundled Cables	Prevention
	2. Insulated conductors	
	3. Reinforcement of poles	
Hedgerow Management	1. Resilience tree cutting across hedgerows	
Forestry corridor management	1. Resilience tree cutting across forestry corridors	
	2. Sustainable Vegetation Management	
Network Monitoring & Automation	1. Fault Location, Isolation, and Service Restoration (FLISR)	Restoration
	2. Advanced Distribution Management System (ADMS)	
	3. Auto reclosers and increased sectionalising	
	4. Smart meter fault identification	
	5. Remote control switches	
Power Restoration Efforts	1. Mutual aid agreements	
Vegetation Monitoring & Management	1. Enhancing landowner value through timber processing	Supporting activities
	2. Lidar inspection (Vehicle)	
	3. Lidar inspection (Drone)	
	4. Drone visual inspection	
	5. Helicopter visual inspection	
	6. Satellite vegetation monitoring	

Legend
Measure – New measures / measures to be accelerated
Measure – Currently in implementation / early stage adoption

It is crucial to evaluate these measures through the perspective of ESB Networks' current activities, identifying those requiring acceleration or initiation across the entire network, forestry corridors, and zones where the network interfaces with hedgerows. Furthermore, strategic enablers are essential to maximise the effectiveness and impact of measure implementation.

6 Conclusion

6 Conclusion

This review confirms that ESB Networks' current approach to storm resilience is in line with international best practice, particularly in relation to network reinforcement, automation, and core vegetation management activities. Peer utilities facing comparable exposure to severe wind events are also deploying similar resilience strategies including strengthening of predominantly overhead rural networks through targeted prevention measures, complemented by network automation solutions that enable rapid restoration when faults occur.

A key finding from the review is that vegetation remains one of the dominant drivers of storm related outages across comparable jurisdictions, including in Ireland. This is heightened where forestry and hedgerows are situated in close proximity to rural overhead line networks.

The international evidence demonstrates that resilience outcomes are maximised where measures are deployed as part of a coherent multiyear strategy rather than as isolated interventions. The shortlist of recommended measures therefore seeks to strike a balance between preventive measures, particularly in the areas of forestry corridor management, which can be delivered over the medium to long term and restoration measures that can be deployed more quickly whilst continuing to invest in vegetation management and monitoring. These measures build upon established practices to further strengthen the resilience of the Irish distribution network against severe storms. The shortlisted measures outlined in section 5 are recommended as key areas of focus for ESB Networks.

In summary, the below recommendations are made to ESB Networks for consideration:

Across the network:
ESB Networks should continue with their current plans, enhancing them with the appropriate shortlisted measures. As per their business plan this will centre on reinforcement of poles and conductor upgrades. When implemented, restoration will be enhanced by FLISR, auto reclosers with increased sectionalising, and remote-control switches, supported by ADMS. This will be complimented by smart meter fault identification, and mutual-aid agreements.[1] Identification of at-risk cross-sections will be done by LiDAR inspection from vehicles and drones and by visual inspection using helicopters and drones. LV wire replacement with Aerial Bundled Cables (ABC) are already implemented as standard by ESB Networks.

Through forestry corridors:
Storm resilience in forestry requires an appropriate design for the establishment and maintenance of resilient corridors supported by landowner engagement enhancing timber processing. LiDAR and visual inspections, and satellite vegetation monitoring further ensure that the resilient corridors will be maintained and monitored for risk.

1 *Price Review 6 Business Plan Business Plan, ESB 2024*

Network interacting with hedgerow:
Building resilience focuses on a resilience tree cutting programme and insulated conductors, this approach will be implemented based on risk. This will ensure that decisions regarding tree cutting and vegetation management consider the health and status of individual trees, thereby optimising interventions to address the most critical threats while supporting long-term network reliability and sustainability.

Strategic enablers:
Successful delivery of targeted resilience outcomes over the medium- and long-term relies on a range of strategic enablers that should be considered for implementation by ESB Networks. Four strategic enablers have been identified across regulation and legislation, standardisation for resilience, vegetation prioritisation, and investment prioritisation. These support prioritisation, scaling, and delivery of the shortlisted measures and are detailed in Section 4.3 Strategic Enablers.

Taken together, the findings of this review support the development of a balanced, risk-based storm resilience strategy for Ireland that builds on existing strengths while addressing the most material vulnerabilities. By progressing the shortlisted measures within a coherent, multiyear programme that is underpinned by the identified strategic enablers, ESB Networks can continue to strengthen the resilience of the distribution network in a manner that is proportionate, cost effective, and aligned with international best practice, while remaining tailored to Ireland's specific network, environmental, and regulatory context.

7 Bibliography

7 Bibliography

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8

Appendix

8 Appendix

Definitions and Conventions

ADMS (Advanced Distribution Management System):
A software platform designed to optimise the performance and reliability of electrical distribution grids by integrating functionalities like supervisory control and data acquisition (SCADA), distribution management system (DMS), and outage management system (OMS) into a single, unified platform.

ACR (Automated Circuit Recloser):
A mechanical switching device capable of making, carrying and interrupting currents under normal circuit conditions and also making and automatically interrupting, under specified abnormal circuit conditions such as those of short-circuit, currents flowing in a circuit, followed by an automatic reclosing operation.

Applicability to Ireland assessment:
The filter applied to ranked measures to reflect Ireland's network characteristics, storm exposure, vegetation interface, and the legal and regulatory context.

DSO (Distribution System Operator):
A utility responsible for operating and maintaining the electricity distribution network. Used when referring to international peers of ESB Networks benchmarked in this review.

FLISR (Fault Location, Isolation, and Service Restoration):
A technology used in electrical distribution systems to automatically detect and isolate faults and minimise outage times.

Forest:
Land with a minimum area of 0.1 hectare (or 0.5 hectare under international forestry standards) under stands of trees 5 metres or higher, having a minimum width of 20 metres and a canopy cover of 20% (or 10% internationally) or more within the forest boundary; or trees able to reach these thresholds in situ.

Forestry corridor:
An area within a given distance of transmission system apparatus and/or distribution network apparatus within which forestry vegetation can be restricted by agreement and or by law.

Hedgerow:
Made up of native trees, shrubs and flowers to form a network of wildlife corridors across the landscape with benefits including carbon storage, flood control, crop protection, livestock shelter and wildlife corridors.

Hedgerow span:
Overhead line sections that interface with hedgerows and roadside trees where clearance and selective hazard tree management are applied.

Integrated Vegetation Management:
A holistic, long-term approach to controlling undesirable vegetation while promoting stable, low-growing plant communities. It combines manual, mechanical, chemical, and biological methods to enhance safety, environmental health, and cost-efficiency. IVM is commonly used in utility rights-of-way, forestry, and land management to prevent invasive species, reduce fire risks, and minimise maintenance needs.

List of measures:
The comprehensive set of measures identified through international benchmarking and interviews prior to shortlisting.

Measure:
A discrete intervention assessed in this review for its resilience contribution.

MCDA (Multi Criteria Decision Analysis):
The structured scoring method used to compare measures on cost, ease of implementation, environmental impact, and resilience benefit.

Network hardening:
The set of measures taken to strengthen electricity network infrastructure to better withstand severe weather events. This includes upgrading poles and structures to stronger materials such as steel, concrete, or composite poles, providing greater robustness against high winds, heavy snow and ice loads, and tree impacts.

Resilience themes:
Analytical lenses used to group measures by outcome. The themes are Prevention, Restoration, and Supporting activities.

Resilience tree cutting:
A vegetation management practice involving the selective removal or pruning of trees near electricity lines, prioritising species and techniques that minimise regrowth and risk of future storm-related outages, prioritising long-term network safety.

Right-of-way:
Refers to the designated corridor of land beneath and alongside overhead electricity lines that DSOs ensure is maintained for reliable operation of the network. These are granted as easements. An easement is a permanent legal right granted over land allowing a utility or other party to install, operate, access, and maintain infrastructure. Easements "run with the land", meaning the right continues even when ownership changes, and they are recorded in the land registry.

Route hardening:
The process of strengthening electricity routes through targeted infrastructure upgrades, improved materials, and design modifications to reduce vulnerability to storm damage and enhance overall network resilience.

Shortlist of measures:
The priority subset of measures recommended for ESB Networks following MCDA scoring and applicability assessment.

Strategic enablers:
Cross cutting prerequisites that allow measures to scale effectively, namely Standard of resilient design, Data driven prioritisation, Robust programme governance, and Legislative and regulatory support.

Sustainable corridor management:
The planned management of linear landscape features like hedgerows, waterways, greenways, or roadside verges, to connect habitats and help insects, birds and mammals move safely through the landscape in a way that aids biodiversity.

Vegetation:
The collective plant cover of an area, including trees, shrubs, grasses, mosses and other plant communities, whether natural or semi-natural, and occurring as distinct habitat types influenced by soil, climate, land use and management.

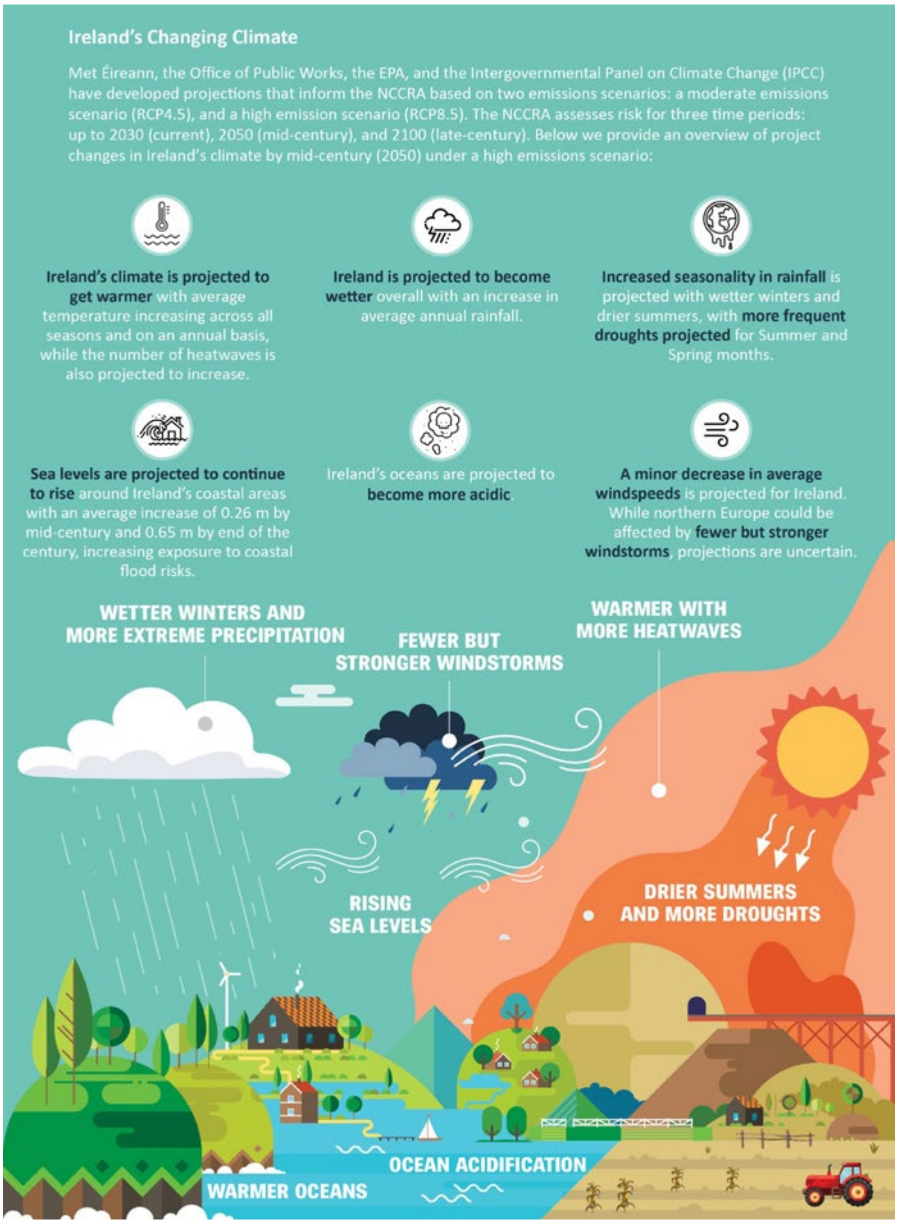
Vegetation management:
The preventative control and trimming of vegetation located near overhead lines to protect infrastructure, minimise power outages during storms or high winds, and to protect public and animals' safety from hazards.

Workstreams:
Delivery groupings used to plan and execute measures. These are- Forestry corridor and hedgerow management, Network reinforcements, Network monitoring and automation, Power restoration efforts, and Vegetation monitoring and management. Themes and workstreams are independent.

8.1 Ireland's Changing Climate

Source: National Climate Change Risk Assessment 2025

Link to Met Eireann, OPW and IPCC document on projections for Ireland's climate under a moderate and high emission scenario.



8.2 Irish Forestry

Ireland has been implementing an afforestation program for nearly five decades. The forested area has expanded to more than 808,000 hectares, representing more than 11.6% of Ireland's landmass. This represents the highest forest cover in over 350 years and is growing at one of the highest rates in Europe. Despite these achievements, Ireland's forest cover remains low by European standards[1], and with current government policy aiming to further increase forest cover across Ireland, any policies relating to electricity network interactions with forests put in place now will also affect future forest areas.

Half the area of forests in Ireland is in public ownership, mainly managed by the state-owned forestry company Coillte, with the remainder owned privately. National Parks and Nature Reserves are also in public ownership. Private afforestation increased considerably in the mid-1980s following the introduction of new grant schemes, and today there are over 23,500 private forest owners in the country, mainly farmers.[2] Of the total forest area, 69% is conifer forest, 31% is broadleaved forest. Sitka spruce is the most common tree species, occupying 45% of the total forest area. The most prominent broadleaf species consist of willow and birch, followed by ash, oak and alder, respectively.[3]

1 *State of Europe's Forests 2020*

2 *Forest Statistics Ireland 2025*

3 *Ireland's Forest Strategy 2023-2030, Department of Agriculture, Food and the Marine, Government of Ireland.*

What are the underlying factors that can cause instability in Irish forests?
When compared to other geographies, much of Ireland's forest cover is relatively unstable at semi-mature and mature growth stages and is prone to windblow damage during storm events. This instability stems from site conditions (wet, poorly drained soils and strong Atlantic winds) and species traits (shallow-rooting, fast-growing crops). It is amplified by silviculture & structure (monocultures, even-aged stands, and delayed thinning) and operations on wet ground (cultivation, mechanised harvesting) that reduce anchorage. These influencing factors are further expanded below.

Wet soils – Irish commercial forests have historically been planted on wet land that is considered marginal for agricultural use, such as peat, peaty gley or gley soils[1]. All these site types are wet with high water tables and very slow natural drainage. While these site types have fostered good tree growth, they are also restrictive in terms of rooting depth[2], so that when fast-growing trees have matured, they are inherently less stable than those grown on drier, more free draining soils.

Shallow rooting species – Sitka spruce, the preferred species in Irish commercial forests, is inherently a shallow-rooted species. Consequently, it lacks the same level of stability as deep-rooted or taproot species. When shallow-rooted trees reach a critical height, there is a heightened risk during storm events of root plates dislodging from the soil and being lifted by the tall crown above.

Windy climate – Ireland's location as an island on the Atlantic western fringe of Europe means that Irish forests are subject to regular storm events with high wind speeds.

Planted trees vs naturally regenerated trees – Naturally regenerated trees, where trees are irregularly spaced, have grown from seed in-situ and have developed a full site adapted root architecture[3], are inherently more stable than trees that have been transplanted using nursery stock into regularly spaced cultivation. All Irish commercial forests are planted, and the use of natural regeneration as a stocking strategy is rare.

1 *The Irish National Forest Inventory (NFI, 2022) reports that 38.4% of Irish forests are on peat soils and 30.7% are on gley soils.*

2 *Saville & Evans (1986) in "Plantation Silviculture in Temperate Regions" report that Sitka spruce roots are "commonly shallow and severely restricted at about 10cm below the surface sue to lack of oxygen. This results in poor anchorage, and crops are prone to windthrow."*

3 *Saville & Evans (1986) in "Plantation Silviculture in Temperate Regions" report that "the roots of many planted trees are generally much less adapted to the function of mechanical support at the outset" and that "there is general agreement that natural regeneration or direct seeding offer the best prospects for good root development and that bare-rooted stock offer the worst".*

Monocultural stands – In single species (monocultural) stands, all rooting is to the same depth. This lack of diverse rooting depth afforded in mixed species stands results in reduced resilience against windblow in storm events.

Fast growing species – Sitka spruce has become the majority tree species in Ireland's commercial forestry because of its ability to grow quality timber of marketable dimensions in relatively short rotations, i.e. it is fast growing. Fast growing stands are inherently less stable than slow growing stands, which have longer to develop appropriate rooting, stem profiles, and crown shapes, allowing them "acclimatise" better to strong winds.

Simple stand structure – Irish plantation forests contain trees which are all of a similar age. These grow at comparable rates and develop a relatively uniform, single canopy of trees of similar height and crown depth. This is known as a simple structure, as opposed to a stand of complex structure with different canopies, heights, and crown depths. Simple stand structures are known to be more vulnerable to storm damage.[1]

Cultivated ground – In most cases, Irish forests have been grown on cultivated ground prior to establishment. Cultivation methods include mounding and ploughing, in which trees are planted into an elevated mound or ploughed ridge.[2] While this facilitates rapid establishment and early growth, it restricts root development. In many cases, a full root architecture is not developed as a result, leaving trees more vulnerable to instability issues when they progress to a later stage of development[3].

1 *M. Hanewinkel, A. Albrecht, & M. Schmidt (2013) in Living with Storm Damage to Forests state that "Empirical modelling studies suggest that on sites of moderate exposure, an irregular stand of spruce is more wind stable than a conventionally thinned regular stand, although the advantage disappears with increasing exposure. Hence, irregular stands may provide structures with more stable characteristics."*

2 *The Irish NFI (2022) reports that "Soil cultivation has been carried out on 81.2% of the public forest estate area, while the area cultivated in the Private (grant aided) estate rises to 98.9%. Pit planting (18%) and mounding (47.6%) are the dominant cultivation types in the public forest estate, while mounding dominates (79.4%) in the Private (grant aided) estate.*

3 *Saville & Evans (1986) state that "since rooting can never be deep on upland peats and gleys, crop stability must depend on widespread rooting in all directions. Furrows of any kind are likely to reduce stability."*

Delayed thinning – While not all stands are thinned, the later thinning is initiated in stands, the more likely they are to be vulnerable to windblow.[1] As forest trees grow taller, they develop a dependence on neighbouring trees for stability and lose their own independent stability.[2] Early thinning allows individual trees to maintain or engender stability. Delayed thinning results in openings in the stand that expose trees that have lost this independent stability and resilience to wind damage. This is particularly the case in the first one- or two-years post- thinning before the canopy gaps close over with subsequent growth.

Soil Compaction Caused by Heavy Machinery on Wet Soils – Irish forests are thinned and harvested using mechanical harvesters and forwarders that cut and extract timber from the forest to the forest roadside. These are big heavy machines which require room in the forest to manoeuvre and, in certain circumstances, can cause soil compaction and damage. It is often the case that the entry point for wind damage into forests is along the machine paths or where a road has been inserted in a forest. This is due to both the openings made in the stand and soil compaction and resulting root plate damage along machine routes.[3]

1 *Albrecht, A., Hanewinkel, M., Bauhus, J., Kohnle, U. (2012). European Journal of Forest Research, 131, 229-247, state that "if carried out at an early stand age, thinning can increase the stability of trees".*

2 *Saville & Evans (1986) state that recently thinned stands are particularly vulnerable as they are "unable to dissipate the energy of the wind by crown contact."*

3 *Saville & Evans (1986) state that "anything which injures tree roots can predispose the crop to risk. This might include soil compaction by machinery during the usual forest operations."*

8.3 Safety and Resilience Clearances by Region

Definitions used: Statutory safety clearance means a legally enforceable minimum approach distance, clearance space, or protection-zone distance. Resilience clearance means additional clearance or corridor treatment aimed at reducing tree strike, fall-in, storm, snow-load, or bushfire risk beyond basic electrical safety.

Country/ Region	Statutory safety clearance	Resilience clearance
Czechia	Fixed statutory/protection-zone distances are defined under Energy Act 46 and reflected by ČEZ Distribuce: overhead LV up to 1 kV has minimum (1m) overhead protection zone; >1 kV to 35 kV is 7 m for bare conductors, 2 m for basic insulated conductors and 1 m for suspended cable lines; >35 kV to 110 kV is 12 m for bare conductors and 5 m for basic insulated conductors. Vegetation above 3 m is prohibited in the protection zone.	No separate fixed statutory fall-in/tree-strike distance defined beyond the protection zone. A specific forest-clearing access provision under Energy Act requires landowners to allow the DSO to maintain a 4 m free strip on one side of support foundations, with the DSO bearing those costs.
Estonia	Building Code and Ministerial Regulation No. 73 defines the line protection zones on each side of the line: 2 m for up to 1 kV; 10 m for 1 to 35 kV; and 25 m for 35 to 110 kV. Within these zones the DSO has full rights and responsibility to remove or lop trees that endanger the line.	Beyond statutory corridors, resilience is treated through "danger tree" removal and weatherproofing. After Storm Agnes, Elektrilevi worked with state foresters to clear danger trees and that Estonia had reached about 75% weatherproof grid by early 2025. Landowners are responsible for trees outside the immediate corridor that pose a danger to the lines.
Victoria, Australia	Statutory clearance is set through the Electricity Safety (Electric Line Clearance) Regulations 2026 and associated Code of Practice. The Statutory Rule 71/2026 and the authorised regulation. The clearance principle is treated as minimum clearance space (applicable distance + allowance for sag and sway.) Victoria is the clearest fire-risk adaptation case: LBRA applicable distances for uninsulated HV lines excluding 66 kV range from 1.5 m to 2.5 m, while HBRA applicable distances for uninsulated LV and HV excluding 66 kV range from 2.25 m to 2.75 m, plus sag and sway allowances.	DSOs and councils have the authority to remove trees outside of the standard clearance zone if they are dead, diseased, or structurally defective and pose a risk of falling onto the lines. During the declared fire season (usually October to May), DSOs implement their Electric Line Clearance and Bushfire Mitigation Plans, requiring even more vigilant maintenance and rapid pruning to meet strict ESV targets. For long or large spans (over 45 meters in HBRA), Councils and DSOs perform detailed calculations to factor in extreme sag and sway distances.
United Kingdom	The statutory duty is risk-based: ESQCR requires DSOs to prevent tree interference so far as reasonably practicable. HSE interprets compliance through ENA standards, especially ENA TS 43-8 and ETR 132. This generally translates to a minimum clearance of 3 to 5 metres between trees/vegetation and 11kV or 33kV distribution lines. ENATS 43-8 mandates vegetation clearance to prevent contact with overhead power lines by ensuring trees remain outside the maximum conductor movement envelope giving a V-cut profile with approx 7.4m clearance either side, which accounts for maximum sag under high loads and up to 45° of sway during high winds.	Resilience is standards-based, mainly through ETR 132 falling-tree resilience. The UK utilities aim to make an additional 0.8% of overhead line length resilient to falling-tree risk each year, prioritising high-risk sections.

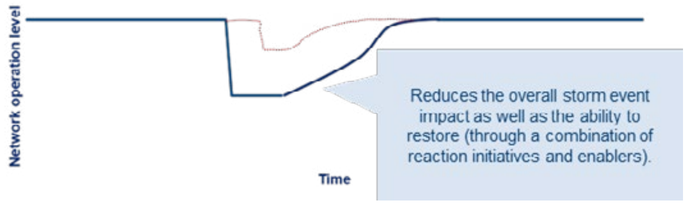
Country/ Region	Statutory safety clearance	Resilience clearance
Nova Scotia, Canada	No fixed statutory vegetation clearance distance defined but statutory safety is framed as minimum approach distance for work near overhead energized lines aligned with Canadian Electric Code guidelines:3m for LV (primary distribution lines), 5 m for >69 kV to 138 kV, and 6 m for >138 kV.	Nova Scotia Power's 2025 to 2029 Reliability Plan focuses on identifying and managing problem areas within underperforming circuits more effectively. Removal of hazard trees (dead, diseased or structurally compromised), the cut beyond 10ft zone on private property can be applied with a written permission.
Finland	Finland states no explicit numeric clearance in law; DSOs must ensure trees do not threaten safety or reliability. In practice, DSOs follow standardized clearances: e.g., ~10 m total corridor for 20 kV distribution lines (~5 m each side); 26-42 m total for 110 kV sub-transmission lines (depending on terrain and design).	The major resilience approach is weatherproofing rather than only wider clearance. Trees outside the right-of-way are managed by felling or topping ("expropriation height") if tall enough to hit the line.
United States	No nationwide fixed statutory vegetation distance exists for ordinary distribution-line vegetation management. State regulations generally require vegetation-management plans, while NERC FAC-003 is transmission-focused and not a general distribution clearance rule. OSHA safety clearances and ANSI A300 are used as work/practice references rather than a single national DSO clearances table.	FirstEnergy implements tree pruning within 10ft of MV lines and promotes "Right tree, Right Place" to encourage planting based on height of mature trees to give a tapered corridor.

8.4 Resiliency Themes Derived from the 4 Rs

The resilience measures in the long list are classified into the above mentioned 3 resiliency themes depending on whether they act as an instrument for Prevention, Restoration or Supporting Activities by understanding at what time they are affecting the network operation level. Each resilience theme is explained below:

1. Prevention:

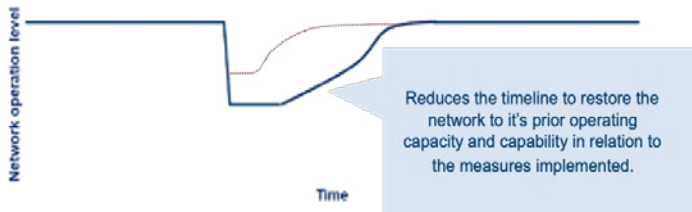
Combining robustness and redundancy, this group focuses on preventing storms from affecting the network, increasing its hardness so that only more severe storms are likely to cause impact. These initiatives also shorten restoration times, for example by enabling easier access for crews to forestry corridors.



These projects and initiatives are long term and require higher capital investment in comparison to reactionary activities, delivering the greatest benefit when supported by appropriate technologies and standards. As implementation timelines are significant, they should begin promptly and be prioritised according to business value to ensure the most critical parts of the network gain benefit as early as possible.

2. Restoration:

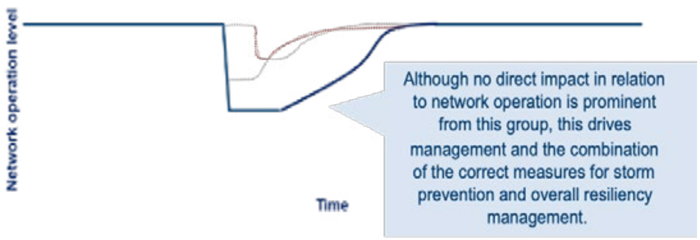
Combining the elements of Resourcefulness and Rapidity, this group focusses on activities which include interim fixes during storm events, with the majority of their intervention leading up to full restoration.



As such they typically consist of lower operational cost investment, yet higher operational investment performance to achieve faster restoration. These activities also perform best when coupled with supporting enablers, including but not limited to technologies and supporting standards.

3. Supporting Activities:

Although often omitted from storm responses, these are a key element of the resiliency lifecycle. The activities under this grouping relate to correlation and impact during storm events and are best suited driven by data and information.



Examples of where supporting activities have led to action, and subsequently results, include the impacts of storm Tapani in Finland which has resulted in greater governmental investment, legislative changes in relation to reconnection times, all coupled with key resilience activities which have actively benefitted the network.

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