CLIMATE CHANGE AND ITS EFFECT ON NETWORK RESILIENCE

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Executive summary

Communications networks and services play a vital role in Ireland's economy and wider society. A web of interconnected networks are woven into the fabric of all our lives helping us to communicate, socialise, stream media content, and do business. Our reliance on these networks will only grow in the future as they increasingly support different aspects of our domestic and work lives.

However, communications infrastructure by its nature can be vulnerable to certain types of weather as communications infrastructure:

- is buried underground (and therefore vulnerable to flood and water ingress);
- uses overhead cables (which are vulnerable to wind and falling vegetation); or
- is located in high and exposed sites (subject to severe wind, rain and cold conditions).

The consensus is that, globally, climate change will lead to gradual change in weather patterns and will increase the frequency and severity of weather events which will affect Ireland's weather. Climate change may thus exacerbate existing communications infrastructure vulnerabilities or even give rise to new ones.

The Irish government has undertaken work to help Ireland prepare for and adapt[1] to climate change. In 2018 it published its first National Adaptation Framework ("NAF").[2] This set out the national strategy for the application of adaptation measures in different sectors to reduce the vulnerability of Ireland to the negative impact of climate change, and to take advantage of any positive impact of climate change. It set out a unified governmental and societal approach to climate change adaptation in Ireland. In doing so it provided a framework to ensure that local authorities, regions, and key sectors can assess the key risks and vulnerabilities to climate change and implement actions to build resilience. In 2019 Government published the *Adaptation Plan for the Communications Sector*.[3] This plan detailed adaptation steps for the telecommunications and broadcasting sector. The adaptation plan concluded that:

- as the climate is predicted to continue changing over the coming decades, the communications sector must prepare for, and adapt to, the changes associated with the climate; and
- by identifying areas of vulnerability, steps can be taken, and measures put in place, to avoid or minimise future adverse impacts within the communications sector, and exploit opportunities.

In this context ComReg has commissioned this study to consider in detail how communications networks are vulnerable to those weather events that may increase in frequency and severity as a result of climate change. The report presents findings on:

- communications networks' vulnerabilities to climate change;

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1 Adaptation refers to strategies, initiatives and measures aimed at reducing the vulnerability of natural and human systems to the effects of global warming.

2 National Adaptation Framework (NAF), Department of the Environment, Climate and Communication, published 19th January 2018.

3 Adaptation Plan for the Communications Sector, Department of the Environment, Climate and Communication, published 30 October 2019 https://www.gov.ie/en/publication/deec0-communications-sector-climate-change-adaptation-plan/ .

- climate change preparation and adaptation measures implemented across networks; and
- potential steps to further adapt to climate change.

The findings in this report are based on detailed information sourced from, including discussions undertaken with, communications network operators in Ireland as well as climate and weather experts in Ireland (Climate Ireland and Met Éireann).

Communications network operators are vulnerable to weather-related events

Despite the efforts of communications network operators to build resilient networks, severe weather events still lead to outages for users. As a result of weather-related incidents, almost 1.5m user hours were lost in 2020.[4] In 2021, Storm Barra damaged network infrastructure in all 26 counties of the Republic of Ireland resulting in outages for more than 200,000 users. These outages have a real cost to end users and businesses that rely on these networks.

1.5m user hours were lost to storms 2020

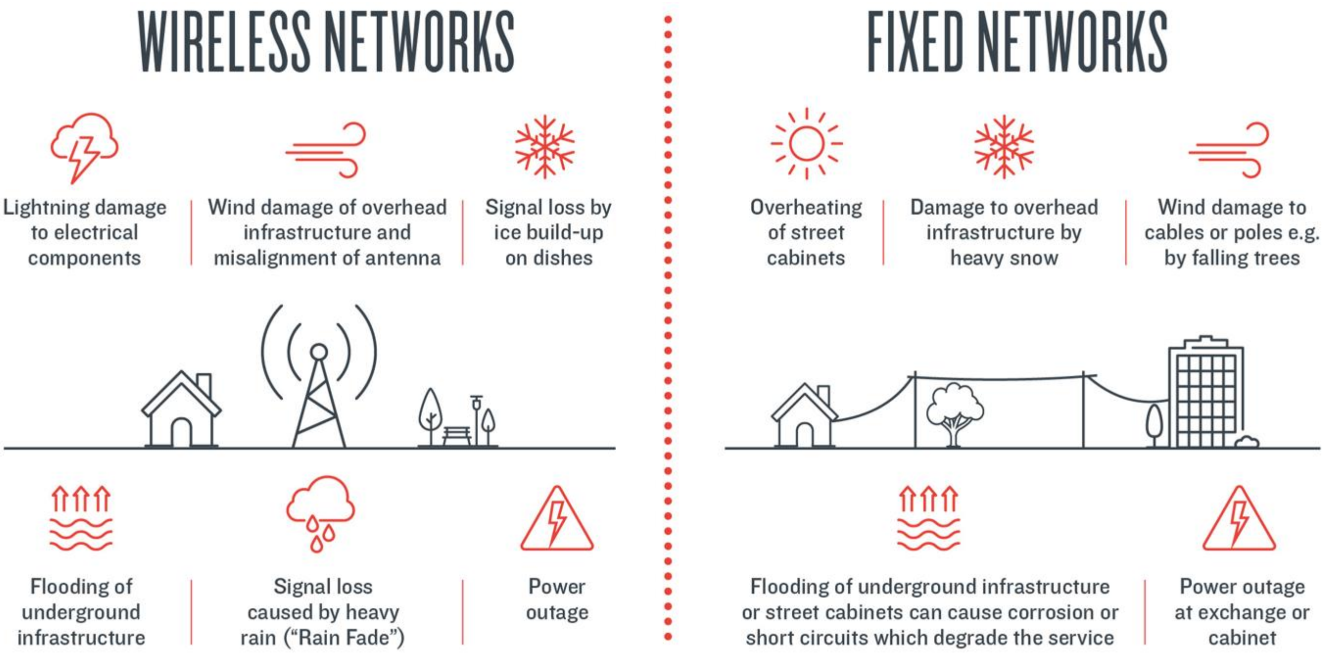
200,000 users affected in 2021 as a result of Storm Barra

ComReg 21/29. Network Operations Annual Report 2020

Different types of weather events can affect different network vulnerabilities (Figure 1). In fixed networks damage to overhead cables resulting from wind and storms, is the biggest cause of weather-related incidents. In wireless networks power outages due to weather events are the biggest cause of weather-related incidents, with lightning strikes and “Signal Fade” due to heavy precipitation also affecting users’ services. Sometimes outages can persist when they affect remote sites, as access to the sites to undertake repairs can be affected by physical damage, blockages to road infrastructure or from snow in prolonged cold conditions.

4 ComReg 21/29. Network Operations Annual Report 2020. https://www.comreg.ie/media/2021/03/ComReg-2129.pdf.

Figure 1 Network vulnerabilities



Source: Frontier Economics

Climate change will affect Ireland's weather

Climate change means that Ireland's weather is changing. Ireland's Environmental Protection Agency ("EPA") sponsored a 2020 study projecting climate trends in Ireland over the next 50 years.[5] The Department of The Environment, Climate and Communications' ("DECC") consultation on its review of the NAF in 2022 noted that these climate projections for Ireland should be analysed and reflected in national adaptation policy.[6]

The projections of Ireland's climate reported in the study for the EPA suggest that although average (mean) wind and rain will decline, Ireland will potentially see an increased intensity of storms (with high wind and heavy rain), particularly in winter months and an increased frequency of heavy rain events. This will affect fixed networks as overhead infrastructure is at risk from weather (from falling trees or vegetation), and storms lead to power outages which affect all services in areas local to the power outage. It will also affect wireless networks since storms can damage equipment on high and exposed sites, lead to power outages, and rain can affect the wireless signal in point-to-point ("P2P") links. Climate change will lead to increased average temperatures and lead to higher frequency of very hot days, which has the potential to affect some network equipment. However, warmer average temperatures will reduce the likelihood of snow and ice causing network disruption.

5 Nolan, A.P. and Flanagan, J., 2020. High-resolution Climate Projections for Ireland – A Multi- model Ensemble Approach. [online] EPA Research.

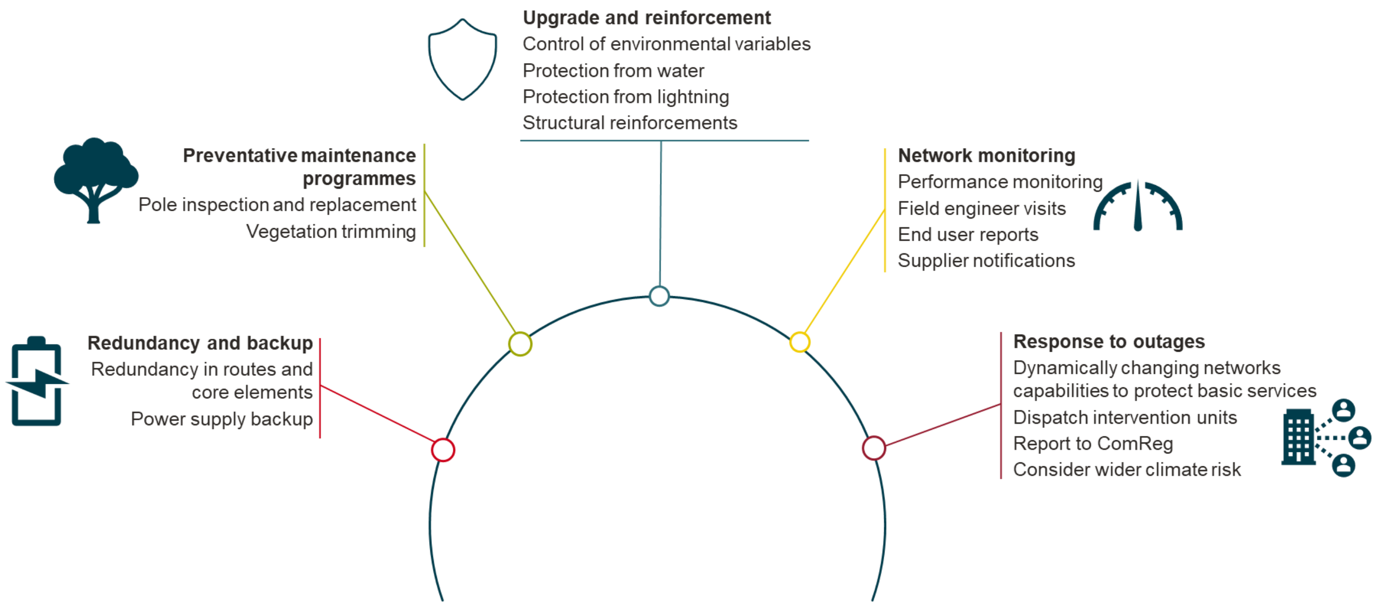
6 Department of The Environment, Climate and Communications (2022) Consultation on Review of the National Adaptation Framework page 20.

Communication network operators already undertake actions which help them adapt to climate change

Given the challenges of severe weather, network operators already design resilience into their networks.

- Some parts of communications networks use alternative redundant inputs (i.e. alternative redundant paths routing traffic through pre dimensioned fallback network equipment or nodes), or backup inputs (alternative inputs where one input fails).
- Communications network operators undertake programmes to inspect and maintain infrastructure. Fixed operators inspect pole infrastructure and trim vegetation which is at risk of damaging infrastructure. Wireless operators inspect towers and antennas.
- Communications network operators ensure that their equipment is resistant to environmental challenges. Furthermore, the technology cycles in networks imply that network equipment is replaced on a regular cycle which offers opportunity for renewal and upgrade. For example, mobile networks are being upgraded to 4G and 5G; and fixed operators (Eir, SIRO, Virgin, NBI, and others) are rolling out new fibre networks which are more resilient and reliable than legacy copper networks.
- Communications networks are actively monitored to identify any faults or outages.
- Networks are managed to dynamically respond to issues as they arise in a way that maintains levels of services to end users.

Figure 2 Actions undertaken by network operators to support resilience



Source: Frontier Economics

There are potential inconsistencies and gaps in reducing vulnerabilities

However, there are potential inconsistencies and gaps in how communications network operators make their networks resilient to weather events and thus adapt to future impacts of climate change, such as the following.

- Few operators *specifically* consider climate change as a risk to their networks, and instead design their networks to be resilient to a range of environmental conditions. Only one operator had commissioned a specific climate change risks report.
- All operators monitor upcoming weather, though operators have different approaches to codifying their response to severe weather. Some operators have a clear and detailed “storm plan”, another has a storm protocol which defines how they respond to severe weather events. Others have less well-defined protocols.
- Some communications network operators provide backup power (with batteries and or generators) of up to two days in some parts of the network, whereas others have backup power for as little as 10 minutes in parts of their network (enough time for equipment to power down safely, but not to maintain service).
- Electronic Communications Service providers or other network operators that rely on the physical infrastructure of another operator, noted that they had very limited information about the physical state of the infrastructure, which made assessing weather-related risks to its network difficult.

Network operators have undertaken actions to reduce power consumption

Communications network operators have three distinct but aligned incentives to take action to improve power efficiency. More efficient networks lead to lower running costs and reduced carbon emissions; but they can also lead to more resilient networks. This is because more efficient power usage will make networks more resilient to power failures, as there is less drain on backup batteries and generators. More efficient networks also support the sector’s contribution to mitigating climate change[7] by lowering emissions. The sudden increase in energy prices observed in 2022 has given operators a new impetus to examine ways to reduce power. However, operators will only commit to large-scale roll out of investments that reduce power, where these investments are of economic benefit for the operator whilst also improving the services provided to their customers.

Potential for further adaptation

As the climate is predicted to continue changing over the coming decades, network operators need to prepare for, and adapt to, the changes associated with climate change. The actions currently undertaken by operators to make their networks resilient to environmental challenges show they have already taken steps to prepare for future changes associated with climate change. Nonetheless, by identifying areas of vulnerability, and considering the differing approaches taken by network operators, this report identifies a number potential further measures that could be put in place, to avoid or minimise future adverse impacts within the communications sector to adapt to climate change. The findings from the report have been grouped into three main areas (Figure 3).

7 Mitigation refers to actions aimed to reduce and stabilize the levels of heat-trapping greenhouse gases in the atmosphere.

Figure 3 Strategies for improving resilience in networks

Source: Frontier Economics

First, some operators have adopted a proactive approach to planning for climate and weather-related risks (in line with Action 4[8] of the Adaptation Plan for the Communications Sector).

- The implementation of an operator specific Climate Action Plan can identify current and future risks of climate change to their networks.
- Many communications network operators regularly review their contingency plans for responding to weather-related outages. These could be published to provide assurance to end users and other stakeholders on how communications network operators respond to outages.

Second, this report has highlighted adaptations that could reduce the weather-related vulnerabilities of networks.

- Communications network operators already have a programme of maintenance and technology upgrades which support increased resilience of their networks. This ongoing programme could include any risks identified as part of their Climate Action Plans, and include a review of their infrastructure's vulnerabilities to changing climate conditions.
- Greater availability of fibre backhaul to more remote network sites (which are often located on high ground in exposed locations) would enable them be more resilient.

Third, given that a significant number of weather-related outages for fixed and mobile end users result from a loss of power to parts of the network there are a variety of actions that have been suggested, or shown, to enhance resilience of power supply (in line with Actions 6[9], 8[10] and 11[11] of the Adaptation Plan for the Communications Sector).

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8 Action 4: "*Communications network companies to continue to ensure climate change is taken into account in planning and design standards and engineering management practices*".

9 Action 6: "*Identify measures required to adapt to climate change impacts on vulnerable infrastructure. These measures should be tailored to the particular utilities infrastructure.*"

10 Action 8: "*Increased sharing of best practice in respect of both long term climate adaptation planning and emergency management between network operators*".

11 Action 11: "*Development of an increased awareness amongst government Departments with responsibility for policy relating to critical infrastructure networks of the interdependencies between the sectors*".

- Communications network operators' sites should have appropriate battery backup in the event of a power outage.
- Tower companies ("TowerCos") could consider offering battery backup and generator backup services bundled with site rental which may be a more efficient and cost-effective way to provide a resilient power backup.
- Communications network operators could continue to pilot and investigate the use of renewable energy including microgeneration to support their power requirements.
- Active monitoring of the power consumption of operator infrastructure and active identification of power reduction measures can support efforts to identify and enact power efficiencies.
- Some Communications network operators noted that given they supply to Critical National Infrastructure services (such as emergency services and broadcasters), that there is a case to argue that communications networks should be considered as a high priority when ESB Networks is conducting repairs.

1 Introduction

1.1 Climate and weather affect ECNs in Ireland

Electronic Communications Networks ("ECNs") play a vital role in Ireland's economy and wider society. They are central to how the population interacts with each other; they provide the means to consume many digital services that are in daily use; and they support all aspects of business activity. With the introduction of new forms of media and digital communication the role of ECNs in our society and economy has been steadily increasing over the past decades.[12] ECN operators therefore recognise the importance of ensuring that their networks are resilient, not least as when part of the network fails it can affect many users.

ECNs can be vulnerable to weather and climate elements[13], due to their infrastructure often being located outside at remote sites, exposed to weather conditions such as wind, snow, and rain; or buried underground in roadside or pavement vaults, where flood and water ingress is possible. Furthermore, ECNs are powered by electricity networks which themselves are vulnerable to weather events.

Climate change thus presents a challenge to ECN operators. Expert consensus is that, globally, climate change will gradually increase the frequency and severity of weather events which will affect Ireland's weather. The Irish government's National Adaptation Framework ("NAF") notes that: "*Ireland's climate is changing in terms of sea level rise, increases in average temperature, changes in precipitation patterns and weather extremes. The observed scale and rate of change is consistent with regional and global trends and these changes are projected to continue and increase over the coming decades*."[14] As a consequence, *"the frequency and severity of climate and weather extremes across the EU is increasing*".[15]

There are two broad types of response to climate change: reducing and stabilising the levels of heat-trapping greenhouse gases in the atmosphere ("mitigation"[16]); and reducing the vulnerability of natural and human systems to the present and expected effects of climate change ("adaptation"[17]).

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12 Connected and smart devices become more commonplace. A recent survey showed that 97% of the respondents use a mobile phone and 83% of participants have broadband. ComReg, 2021.Technology Survey https://www.comreg.ie/media/2021/03/ComReg-2132b.pdf, ComReg, 2022. OTA & eSIM Consumer Survey https://www.comreg.ie/media/2022/06/ComReg-2248c.pdf, ComReg, 2021. Connectivity Survey https://www.comreg.ie/media/2021/03/ComReg-2130.pdf .

13 We refer to weather events as punctual events such as heavy rainfall, or storms. Longer-term trends such as annual average temperatures are referred to as climate.

14 National Adaptation Framework (NAF), Department of the Environment, Climate and Communication, published 19th January 2018, p.7 https://www.gov.ie/en/publication/fbe331-national-adaptation-framework/.

15 Climate Action Plan 2021, Department of the Environment, Climate and Communication, published 4 November 2021 , p. 200 https://www.gov.ie/en/publication/6223e-climate-action-plan-2021/.

16 Mitigation refers to actions aimed to reduce and stabilize the levels of heat-trapping greenhouse gases in the atmosphere.

17 The Climate Action and Low Carbon Development Act 2015 defines "adaptation" as: "*any adjustment to: (a) any system designed or operated by human beings, including an economic, agricultural or technological system, or (b) any naturally occurring system, including an ecosystem, that is intended to counteract the effects (whether actual or anticipated) of climatic stimuli, prevent or moderate environmental damage resulting from climate change or confer environmental benefits*".

In this context, ComReg has asked Frontier Economics to advise it on the risks that current and future implications of climate change pose to ECNs and on adaptation actions that can be taken to improve network resilience.

1.2 Policy context for this report

The Irish government has undertaken actions to support the resilience of Ireland's economy in the face of climate change. The *Climate Action and Low Carbon Development Acts of 2015 to 2021 ("Acts of 2015 - 2021")* required the development of national and sectoral climate "adaptation" frameworks.[18] In response, in 2018, the Department of the Environment, Climate and Communications ("DECC") published the NAF, setting out the Government's *"national strategy for the application of adaptation measures in different sectors and by local authorities in their administrative areas in order to reduce the vulnerability of the State to the negative effects of climate change and to avail of any positive effects that may occur."*[19] The NAF provides a framework to ensure that local authorities, regions, and key sectors can assess the risks and vulnerabilities of climate change and implement actions to build resilience. Resilience was defined in the NAF as "*the capacity of a socio ecological system to absorb stresses and maintain function in the face of external stresses imposed by climate change and adapt, reorganise and evolve into configurations that improve the sustainability of the system, leaving it better prepared for future climate change impacts*".[20]

The *Acts of 2015 - 2021* required the Government to request all relevant Government Ministers to prepare Sectoral Adaptation Plans covering the relevant sectors under their remit within a specified period.[21] Accordingly, several government departments with responsibility for priority sectors, including the DECC, have developed sectoral adaptation plans – in line with the requirements of the *Acts of 2015 to 2021*. The Government published the *Adaptation Plan for the Communications Sector* in 2019.[22] This plan detailed adaptation steps for the Telecommunications and Broadcasting sectors. The adaptation plan concluded that:

- as the climate is predicted to continue changing over the coming decades, the communications sector must prepare for, and adapt to, the changes associated with the climate; and
- by identifying areas of vulnerability, steps can be taken, and measures put in place, to avoid or minimise future adverse impacts within the communications sector, and exploit opportunities.

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18 The Climate Action and Low Carbon Development (Amendment) Act 2021 amended the Climate Action and Low Carbon Development Act 2015, *inter alia* to require ComReg to: "in so far as practicable, perform it functions in a manner consistent with-

(a) the most recent approved climate action plan,

(b) the most recent approved national long term climate action strategy,

(c) the most recent approved national adaptation framework and approved sectoral adaptation plans,

(d) the furtherance of the national climate objective, and

(e) the objective of mitigating greenhouse gas emissions and adapting to the effects of climate change in the State."

19 National Adaptation Framework (NAF), Department of the Environment, Climate and Communication, published 19th January 2018, p.9 https://www.gov.ie/en/publication/fbe331-national-adaptation-framework/ .

20 National Adaptation Framework (NAF), Department of the Environment, Climate and Communication, published 19th January 2018, p.61 https://www.gov.ie/en/publication/fbe331-national-adaptation-framework/.

21 The Climate Action and Low Carbon Development Act, 2015, section 6.

22 Adaptation Plan for the Communications Sector, Department of the Environment, Climate and Communication, published 30 October 2019 https://www.gov.ie/en/publication/deec0-communications-sector-climate-change-adaptation-plan/.

> **CAP 21 - Action 63**
>
> **"Understand the effects of climate change on telecoms networks"**
>
> **Climate Action Plan 2021, DECC**

In 2019 the DECC published a *Climate Action Plan* ("CAP 2019")[23], which was revised in 2021[24] ("CAP 2021"). The CAP 2021 set out actions to ensure Ireland achieves a 51% reduction in overall Greenhouse Gas ("GHG") emissions by 2030 and reaches net-zero emissions by no later than 2050. The CAP 2021 contains a detailed series of actions which in combination supported Ireland's climate change mitigation strategy. As part of the plan for ensuring that the public sector will "*lead by example*"[25] CAP 2021 includes an action to "*understand the effects of climate change on telecoms networks*". In line with the EU Effort Sharing Regulation[26], the CAP 2021 also requires the telecommunication sector to implement emission reduction programmes to achieve a GHG emission reduction target of 30% in 2030 compared to 2005 levels.

ComReg has responsibility for ensuring compliance and oversight of ECN operators' activities and their compliance with the legislative and regulatory conditions. In particular, the security and integrity obligations set out in EU law[27] and transposed in Irish law in Framework Regulations 23 and 24, require, among other things, that operators must "*manage the risks posed to security of networks and services*"[28] and "*take all appropriate steps to guarantee the integrity of their networks, thereby ensuring the continuity of supply of services provided over those networks*"[29]. The requirement for ECNs to "*manage the risks posed to the security of networks*" is also reflected in Article 40 of the European Electronic Communications Code.[30] In the event of an incident which has a significant impact on the operation or integrity of their network, including those related to weather events, operators must inform ComReg, who then must apprise the relevant Minister for the Department of the Environment Climate and Communications (the "Minister"). Where there is evidence of a significant incident, ComReg must also, where appropriate inform other National Regulatory Authorities ("NRAs") and the European Union Agency for Cybersecurity ("ENISA").

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23 Climate Action Plan, Department of the Environment, Climate and Communication, published 17 June 2019. https://www.gov.ie/en/publication/ccb2e0-the-climate-action-plan-2019/

24 Climate Action Plan 2021, Department of the Environment, Climate and Communication, published 4 November 2021 https://www.gov.ie/en/publication/6223e-climate-action-plan-2021/.

25 Ibid section 9.

26 European Commission, Effort Sharing Regulation: https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3543 .

27 Directive 2002/21/EC (the "Framework Directive"). The Framework Directive has been repealed (along with Directives 2002/19/EC, 2002/20/EC and 2002/22/EC) by Directive 2018/1972, establishing the European Electronic Communications Code (the "Code") with effect from 21 December 2020. However, as matter of Irish law, the Framework Regulations are still in effect, and have not yet been replaced by new measures transposing the EECC.

28 Regulations 23 (1) of the European Communities (Electronic Communications Networks and Services) (Framework) Regulations 2011, S.I. 333 of 2011.

29 Regulations 23 (3) of the European Communities (Electronic Communications Networks and Services) (Framework) Regulations 2011, S.I. 333 of 2011.

30 Directive (EU) 2018/1972 establishing the European Electronic Communications Code.

1.3 Purpose and scope of this study

ComReg has commissioned this study in light of:

- the NAF's aims to identify and apply mechanisms in the Communications sector to adapt to climate change;
- the conclusion of the *Adaptation Plan for the Communications Sector* to identify the communication sector's vulnerabilities and put in place measures to avoid or minimise future adverse impacts within the communications sector; and,
- the CAP 2021's action to "*understand the effects of climate change on telecoms networks*".

Communication services are delivered to the population of Ireland using many different interconnected networks. Each network has specific characteristics, reflecting its technological architecture (for example whether wired or wireless) or the end user requirements (serving a small number of users or many millions). These characteristics dictate how the network is designed and hence how it could be vulnerable to different types of weather events. This report therefore considers how different ECNs (which are described in Annex B -) are vulnerable to severe weather events and may be affected in future by the impact that climate change will have on Ireland's weather. The specific ECNs considered in this report are:

- fixed-line networks including copper, fibre and hybrid fibre-coaxial;
- wireless networks such as mobile networks (including 2G, 3G, 4G and 5G radio access technologies) and fixed wireless access networks;
- passive infrastructure[31] used by ECNs;
- high-capacity networks including transport networks; and,
- international connectivity networks.

The report summarises the adaptation actions of ECN operators which are aimed to address vulnerabilities and to ensure their network's resilience. The report identifies potential gaps in these adaptation actions. It describes the strategies that ECN operators have adopted to reduce power consumption on their networks as a way to both adapt to climate change, and to mitigate its impacts by reducing the emission of GHG into the atmosphere.

The report then concludes by making observations on how adaptation in the communications sector could be improved to address current and future impacts of climate change on the ECN.

1.4 Research methodology

The findings in this report are based on detailed research, and an investigative and interactive engagement with ECN operators in Ireland. Frontier Economics worked with ComReg to scope the information required to meet the report's objectives.

[31] Passive infrastructure refers to infrastructure that is not part of ECNs' electrically powered equipment conveying signals from place to another, including but not limited to, sites, buildings, shelters, towers, masts, poles, ducts, trenches, electric power supply, and air conditioning.

Frontier Economics then conducted the written consultation and bilateral workshops with fixed and wireless ECN operators. Frontier Economics also gathered written evidence from tower companies, international connectivity providers and a communications service provider.

Table 1 Industry stakeholders consulted for this report

Fixed network operators	Wireless network operators	Tower companies	International connectivity providers	Service provider
BT Ireland	Eir	Cellnex	Aqua Comms,	Sky
Eir	Imagine	ESB Telecoms	BT Ireland	
Enet	Three	Phoenix	Century Link	
SIRO	Vodafone	Vantage Towers	Eir	
Virgin Media		2RN	EuNetworks	
NBI			GTT	
			Vodafone	
			Zayo	

Frontier Economics questioned ECN operators about:

- their experience in responding to severe weather and the weather-related vulnerabilities of their network;
- their approach to power reduction; and
- actions taken to limit the impact of climate change on their networks.

The template information questionnaire sent to parties is set out in Annex A - .

Frontier Economics engaged with experts from both Climate Ireland and Met Éireann to understand the previous, current and future climate and weather-related trends in Ireland.

1.5 The structure of this report

The structure of this report is as follows:

- section 2 looks at how climate change affects Ireland’s weather;
- section 3 summarises insights from the engagement with stakeholders on the network elements that are most vulnerable to weather events (a detailed description of different types of networks is found in Annex B -);
- section 4 provides an assessment of ECN’s future vulnerability to climate change;

- section 5 summarises adaptation actions implemented by operators to cope with current and future climate change related risks;
- section 6 provides information on the current and future power reduction strategies applied by operators; and
- section 7 concludes by identifying potential measures that could be put in place to avoid or minimise future adverse weather and climate-related impacts within the communications sector.

2 Climate change in Ireland

It is well understood that the global climate is changing[32], for example global average surface temperature between 2001 and 2020 was 1°C higher than between 1850 and 1900.[33] Ireland's climate is changing in line with global trends.[34] For example, Ireland has experienced a gradual increase in average temperature of about 0.8C° over the period 1900-2012, an average of about 0.07°C per decade.[35]

However, climate change does not just affect *average* weather. It can also be associated with greater frequency of *severe* weather events. According to the IPCC[36], "*changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events*".[37] This implies that Ireland's ECN operators need to prepare not just for changes in *average* weather conditions, but also changes in the extremes of weather conditions.

ECNs have long asset lives with some parts of the networks designed to last many decades. ECN operators' ability to build networks which are resilient to weather-related impacts, therefore relies on understanding how Ireland's weather will change in the coming decades. There are four key meterological conditions that are relevant in terms of the vulnerability of ECNs to weather conditions: wind; rain and flooding; temperature; and snow and ice (discussed in more detail in section 3).

This section summarises the evidence on trends in these weather conditions in Ireland to understand likely future risks to ECNs. Based on a review of Met Éireann data and scientific literature this section:

- describes historical trends in weather (section 2.1);

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32 For example according to the IPCC: "*It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred*." IPCC, 2021: Summary for Policymakers. A.1. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 4, doi:10.1017/9781009157896.001.

33 IPCC, 2021: Summary for Policymakers A1.2. Note also that according to the IPCC "*Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years (high confidence). Temperatures during the most recent decade (2011–2020) exceed those of the most recent multi-century warm period, around 6500 years ago13 [0.2°C to 1°C relative to 1850–1900] (medium confidence). Prior to that, the next most recent warm period was about 125,000 years ago, when the multi-century temperature [0.5°C to 1.5°C relative to 1850–1900] overlaps the observations of the most recent decade (medium confidence).*" IPCC, 2021: Summary for Policymakers A2.2. In: IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. In Press.

34 Dwyer, N. (2013) 'The status of Ireland's climate, 2012'. Wexford, Ireland: Environmental Protection Agency. https://www.epa.ie/publications/research/climate-change/CCRP26---Status-of-Ireland's-Climate-2012.pdf

35 Draft National Adaptation Plan for the Communications Sector.

36 The Intergovernmental Panel on Climate Change (IPCC) is an intergovernmental body of the United Nations responsible for advancing knowledge on human-induced climate change.

37 IPCC, 2012: Summary for Policymakers. A. Context. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, p. 7. https://www.ipcc.ch/site/assets/uploads/2018/03/SREX_Full_Report-1.pdf

- reports on severe weather warnings issued by Met Éireann since 2012 (section 2.2);
- summarises climate projections (incuding from the Climate Status Report[38] and climate projections by Nolan and Flanagan[39] sponsored by the Environmental Protection Agency[40] ("EPA") which indicate how Ireland's weather might change in the future (section 2.3).

2.1 Historical trends in Ireland's climate

Looking back at data over previous decades several patterns can be observed in Ireland's weather. Broadly those of more recent years are:

- lower average wind speeds on Ireland's west coast, though not on its east coast;
- lower frequency of days with high winds across both the east and west coast;
- an increase in annual rainfall (particularly since the 1970s); and a
- gradually increasing average temperature.

While data on trends in weather should be interpreted with caution since there can be natural fluctuations in weather conditions which can last years, these changes do illustrate how Irelands climate has changed since 1940. The following section describes historical trends regarding Ireland's: wind, precipitation and temperature.

2.1.1 Wind in Ireland

Ireland's location off the Atlantic Ocean means that it can bear the brunt of Atlantic weather systems, bringing strong winds particularly in winter.[41] Figure 4 below shows trends in average wind speed and days with gale gusts for both the Valentia observatory on the west coast of Ireland and Dublin Airport on the East coast since the 1940s. Average wind speed and the number of days with gale gusts has declined in Valentia. While on the east coast at Dublin Airport, days with gale gusts have decreased slightly though average wind speed has remained broadly flat (in the range 4.5 – 6 metres per second[42]). However, Met Éireann consider that the decreasing trend must be interpreted with caution and is statistically weak given the considerable variability

38 Cámaro, W., Dwyer, N. and Lambkin, K. (2021) Climate Status Report for Ireland 2020.

39 Nolan, A.P. and Flanagan, J., 2020. High-resolution Climate Projections for Ireland – A Multi- model Ensemble Approach. [online] EPA Research.

40 The Environmental Protection Agency (EPA) is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution. The report was published as part of the EPA Research Programme 2014–2020. The EPA Research Programme is a Government of Ireland initiative funded by the Department of Communications, Climate Action and Environment (now DECC). It is administered by the Environmental Protection Agency, which has the statutory function of co-ordinating and promoting environmental research.

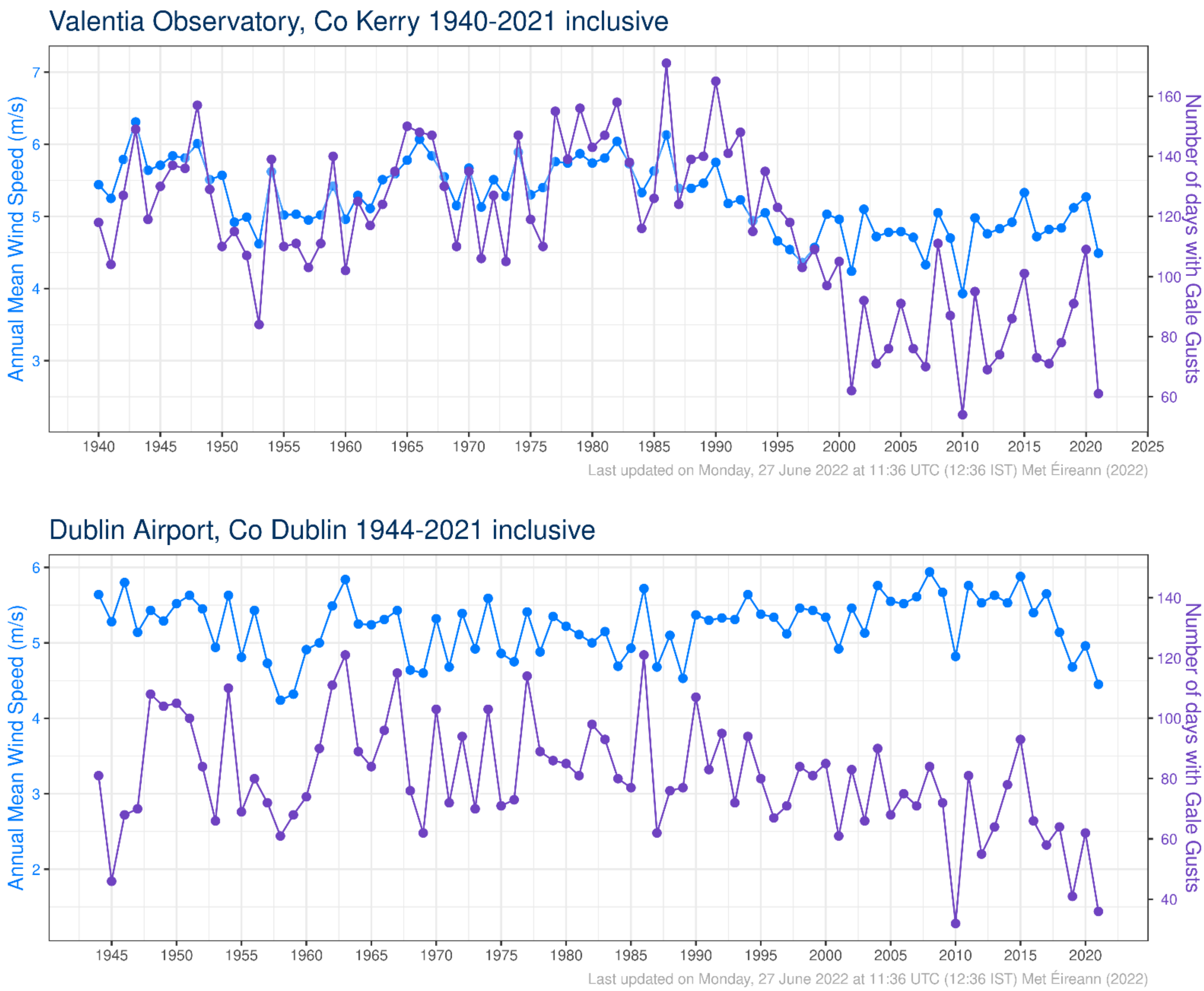
41 Source: https://www.met.ie/climate/climate-of-ireland.

42 Conversion table m/s – km/h.

m/s	km/h
1	3.6
7	25
45	162

each year.[43] The Climate Status Report also noted that due to changes in measurement techniques, wind trends beyond the past 20 years are not easily comparable.[44]

Figure 4 Annual mean 10-minute wind speeds and number of days per year with gale gusts



Source: Met Éireann

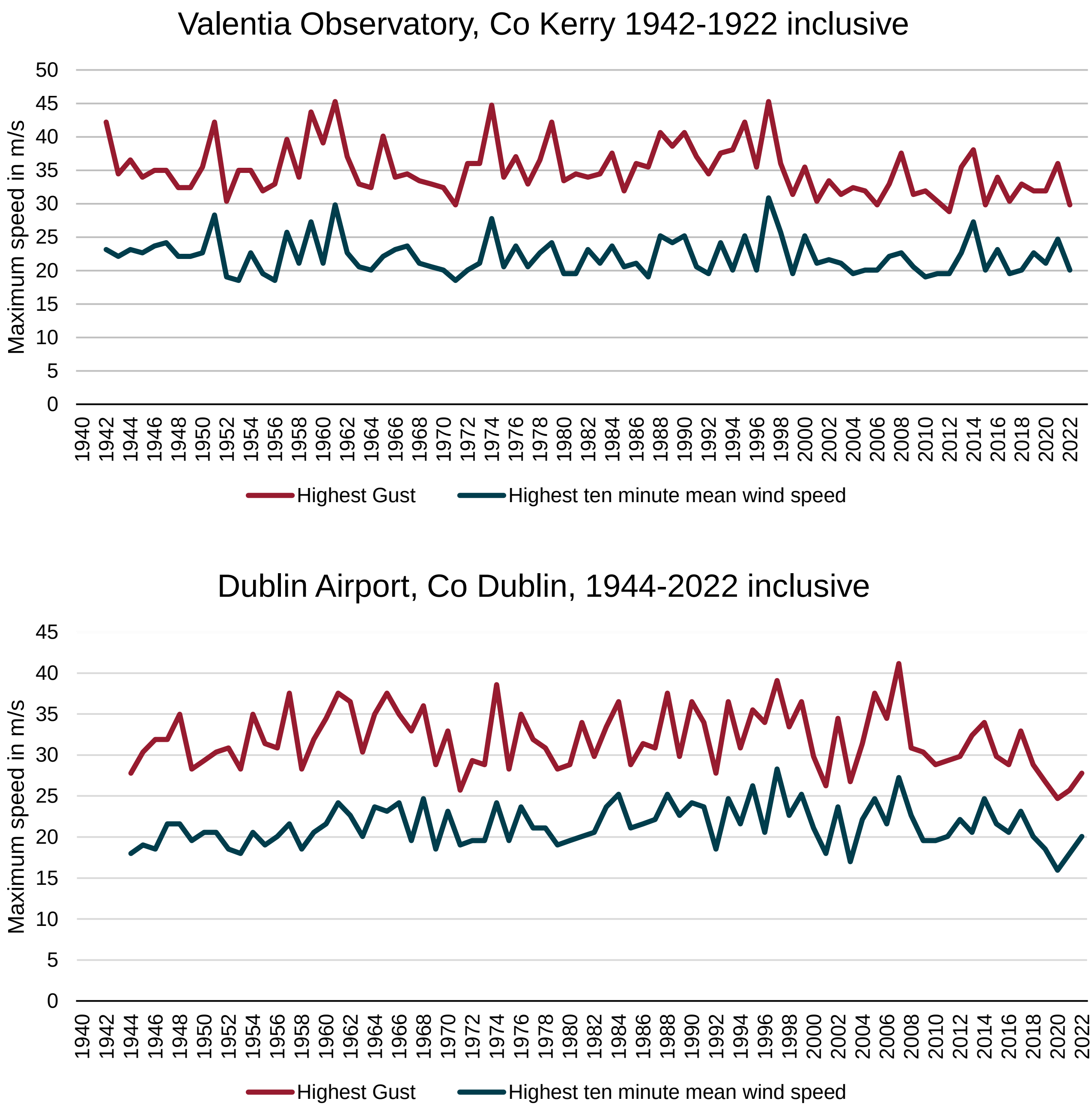
Note: Valentia averages from 2010 and 2011 are based on incomplete data.

43 Provided in an Email from Met Éireann to Frontier Economics on 27/06/2022: *"[…] there appears to be a decreasing trend at these stations, even though it would be considered a weak trend statistically as there is considerable variability each year. Please note, we have some missing data in 2010 and 2011 at Valentia Observatory.*

44 Cámaro, W., Dwyer, N. and Lambkin, K. (2021), Surface Wind Speed and Direction in Climate Status Report for Ireland 2020.

The figure below shows the annual *maximum* 10-minute wind speed, as well as the annual highest gust speed as measured at the Valentia observatory and Dublin Airport. Observations at both locations show no obvious trend of increasing maximum wind and gusting wind.[45]

Figure 5 Annual maximum gust and 10-minute wind speeds



Source: Met Éireann - Historical data, here https://www.met.ie/climate/available-data/historical-data

Note: data to August 2022 inclusive. Vertical axis measurement units apply to both of the line measures presented

45 Annual averages of daily data of highest 10-minute wind speeds and highest gust speeds, as well as annual variances in these speeds, similarly show no increasing trend in strong winds.

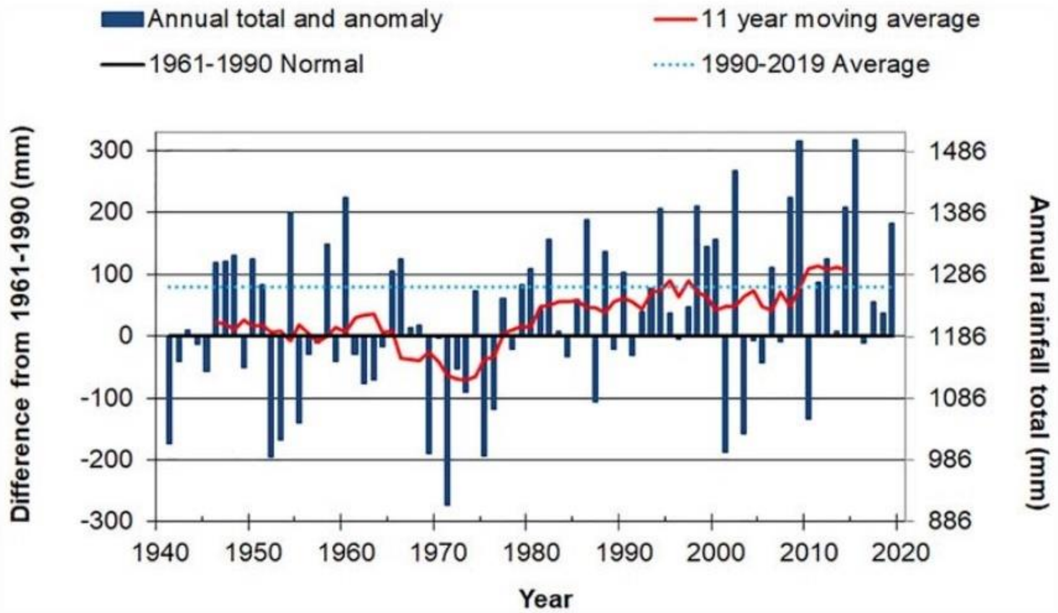
2.1.2 Precipitation in Ireland

The same weather systems that can bring strong winds can also bring precipitation (rain and snow). Low pressure "depression"[46] weather systems can form over the Atlantic and pass over the sea and bring rainfall to Ireland from the west, particularly in autumn and winter months.[47]

There has been a gradual increase in rainfall in Ireland since the late 1960s with the decade leading up to 2015 being the wettest on the record from 1711-2016. There has been a slight increase in the length of "wet spell days" (i.e., maximum number of consecutive days characterised by rainy conditions) in the observed period 1961-2018. The Climate Status Report observes, for example, one additional day per decade in the annual maximum wet spell days in Valentia, Co Kerry[48] (with no clear trend for dry spell days have been observed). The average increase in rainfall therefore may be accompanied by an increase in extreme rainfall events.

Figure 6 shows that average annual precipitation has increased over the past decades. The 1990-2019 average (shown in light blue) is 7% above the 1961-1990 average (in black).

Figure 6 Average annual rainfall 1941-2019



Source: Cámaro, W., Dwyer, N. and Lambkin, K. (2021), Precipitation in *Climate Status Report for Ireland 2020*

Heavy rainfall can contribute to river and coastal flooding. Ireland's Climate Status Report describes *"major impacts [… due to] floods or droughts […] in recent years."*[49] By illustration 2015/2016 saw record-high

[46] A depression is an area of low pressure.

[47] Source: https://www.met.ie/climate/climate-of-ireland.

[48] Cámaro, W., Dwyer, N. and Lambkin, K. (2021), Precipitation in Climate Status Report for Ireland 2020.

[49] Cámaro, W., Dwyer, N. and Lambkin, K. (2021), Precipitation, Story Box 3, and Sea State in Climate Status Report for Ireland 2020.

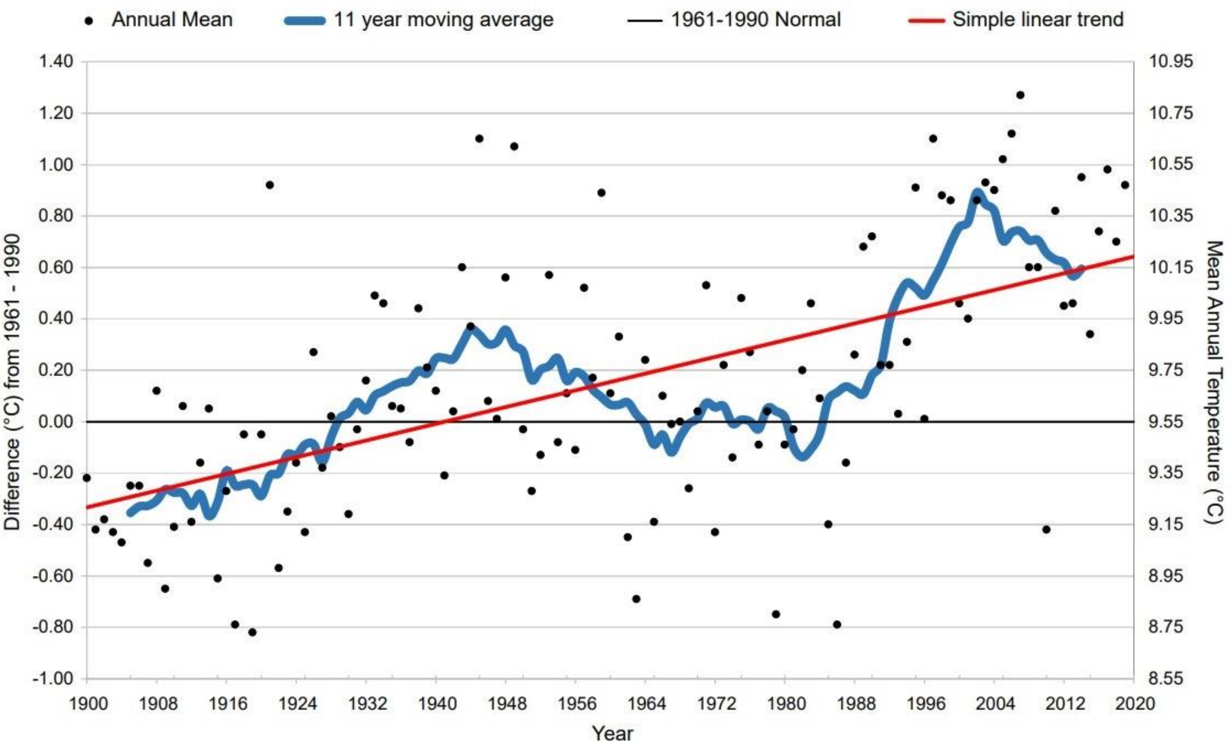
flooding in many places in Ireland. Increasing average wave heights in the North Atlantic over the past 70 years is attributed to coastal flooding.[50]

Storm weather systems can often be accompanied by lightning[51], though satellite observation of lightning is a recent development meaning that historical analysis of lightning strikes is not possible.

2.1.3 Ireland's temperature

Ireland's annual mean temperature is increasing. While there is natural variation in air temperature from year to year, a clear upward trend in annual mean temperatures can be observed. Figure 7 shows that over the last 120 years, Ireland's mean annual surface air temperature has increased by approximately 0.9 ºC. Each black dot represents the annual mean observed temperatures, with the baseline (the black solid line) drawn at the average temperature between 1961 and 1990[52] (at 9.55 degrees Celsius).

Figure 7 Mean surface air temperature (1900-2019)



Source: Cámaro, W., Dwyer, N. and Lambkin, K. (2021), Surface Air Temperature in *Climate Status Report for Ireland 2020*

The increase in mean temperatures can be observed across all seasons, with both winter and summer minimum temperatures of 1990-2018 being higher than the 1961-1990 normal. The Climate Status Report

50 Cámaro, W., Dwyer, N. and Lambkin, K. (2021), Precipitation, Story Box 3, and Sea State in Climate Status Report for Ireland 2020.

51 Lightning is a powerful discharge of electrical energy that can accompany some storms. Lightning is geographically focused but can have an significant impact. However lightning observation is a recent development in the 21st century - only two decades of data are available for a trend analysis. This data shows high variability in occurrences of lightening pulses over time. The majority of lightning occurs in summer. Within the observed time period, 2003 was the year with most frequent lightning strikes over the Irish land mass.

52 Standard climatological normals are calculated over uniform 30-year cycles. 1961-1990 is one uniform cycle.

points out that while 2010 was an unusually cold year in the 1990-2020 period, the observed temperatures would have been typical in the early 20th century.[53]

Ireland is also facing increased frequency in heatwaves.[54] This was illustrated in July 2022, when Irish temperatures reached a high of 33 degree Celsius on 18 July 2022, the second hottest temperature on record in Ireland.[55]

2.2 Met Éireann provides warnings for upcoming severe weather events

While historical data in section 2.1 shows trends in average weather over time, it is the less frequent occasions of "severe weather" that can significantly affect ECNs. Since April 2012, Met Éireann has published official weather warnings, which indicate when severe weather will impact the population.[56] These weather warnings form an important resource for ECN operators, who use them to plan for extreme weather events. They also illustrate the mix of severe weather that is likely to lead to outages at ECN.

Met Éireann classify weather warnings by the type of weather (Fog, High Temperature, Low Temperature, Rain, Snow/ Ice, Thunderstorm, and Wind) and by county. The warnings therefore also provide information on the location and hence approximate number of people affected. Each weather warning falls into one of three colours, yellow, orange and red (more detail of Met Éireann's weather warnings are given in Annex C -).

- **Yellow** - not unusual weather but localised danger.
- **Orange** - infrequent weather that is dangerous/disruptive.
- **Red** - rare weather events that are extremely dangerous or destructive.

Figure 8 illustrates that wind is the most frequent cause for orange and red weather warnings issued. Almost half (45%) of all orange and red weather warnings relate to wind (implying mean speeds of at least 65 km/h or gusts of at least 110 km/h). This is followed by rain, snow/ice and fog. However, given that wind has more localised effects than other weather conditions the population affected by wind weather warnings is on a par with rain warnings and snow warnings, and lower than low temperature and thunderstorm warnings.

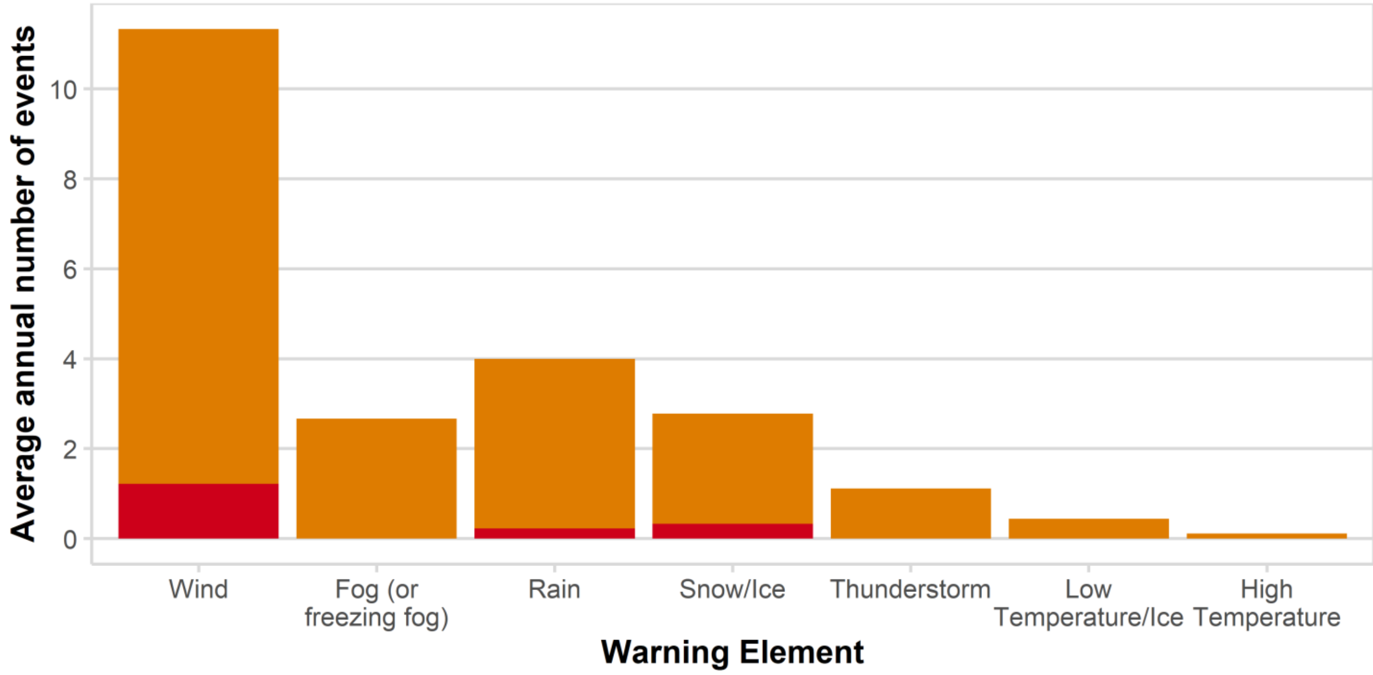
53 Cámaro, W., Dwyer, N. and Lambkin, K. (2021), Surface Air Temperature in Climate Status Report for Ireland 2020.

54 Cámaro, W., Dwyer, N. and Lambkin, K. (2021), Precipitation in Climate Status Report for Ireland 2020 *and* IPCC, 2021: Summary for Policymakers. A.3. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 8, doi:10.1017/9781009157896.001.

55 The highest temperature on record for Ireland was 33.3°C observed at Kilkenny Castle on Sunday 26 June 1887 https://www.met.ie/temperature-records-broken-as-met-eireann-establish-new-climate-services-division.

56 Met Éireann archived weather warnings https://data.gov.ie/dataset/archived-weather-warnings. Archived data of 22/02/2021 to 29/05/2022 was received via email from Met Éireann upon request.

Figure 8 Mean annual orange and red weather warnings by type of warning



Source: Frontier Economics analysis

Note: Weather warnings of the years 2013 through 2021 were considered. Orange warnings are depicted in orange, red warnings in red.

2.3 Long term climate projections

To ensure that their networks remain resilient to weather events, ECN operators need to understand how Ireland's climate will change in the coming decades. To support all public and private stakeholders' understanding of the likely changes to Ireland's climate, in 2020 Ireland's EPA sponsored a study on projecting climate trends at a regional level in Ireland over the next 50 years (hereafter "Nolan and Flanagan").[57] This study is also referenced as source for climate information in the DECCs consultation for the updated NAF in 2022.[58] Nolan's preceding report[59] was the base for climate projections used in the current NAF.[60] This section presents the approach and results to the climate forecast modelling undertaken for the EPA.

2.3.1 Approach taken to projecting Ireland's climate

The projections model the impact that global climate change trends will have on Ireland's climate in the coming decades. Nolan and Flanagan use eight existing global climate models which project climate trends

57 Nolan, A.P. and Flanagan, J., 2020. High-resolution Climate Projections for Ireland – A Multi- model Ensemble Approach. [online] EPA Research.

58 The Government noted that Nolan and Flanagan's "*climate projections for Ireland will need to be analysed and reflected in national adaptation policy*." DECC, 2022. Consultation on Review of the National Adaptation Framework. p.20. https://assets.gov.ie/225041/1ae2a9b0-7e6f-4e36-a738-b476752bbb3f.pdf.

59 Nolan, P. (2015). Ensemble of regional climate model projections for Ireland EPA Research Report No.159. EPA.

60 National Adaptation Framework (NAF), Department of the Environment, Climate and Communication, published 19th January 2018. p.28.

globally. These are then used to create three regional climate models at a high spatial resolution (i.e., small areas of between 3.8 km and 4 km grid size). The models project expected changes in weather for the period 2041-2060 against a baseline of average trends in the period 1981-2000. Outputs are given in ranges, to represent the results of all eight ensemble models[61]. Model outputs were validated against observational data for 1981-2000. The authors consider that their projections are robust, due to their "multi-model approach"[62] (i.e., combining results from existing climate models) and their results are in broad agreement with previous research.[63]

As well as forecasting the average (mean) temperatures Nolan and Flanagan also report the change in the standard deviation in forecast weather. Analyses of changes in the standard deviation provide information on projected changes in the variability of the distribution weather outcomes. For example, in relation to rain, no change in the future *mean* rainfall, but an increase in forecast standard deviation would imply an increase in both wet and dry events.

The projections necessarily rely on assumptions about future economic, social and physical changes (including the likely path of future CO_2 emissions), which affect the climate over the forecast period. The assumptions on future CO_2 emissions are termed "Representative Concentration Pathways" ("RCP"). RCP scenarios will describe different CO_2 emissions resulting from climate change mitigation actions taken to reduce CO_2 in the atmosphere. The projections provided in this report are based on two RCPs (4.5 and 8.5) as described below.

RCP8.5 is considered to represent "*an unlikely high-risk future scenario*" [64] (i.e., emissions and climate change are generally expected to be lower than represented by RCP8.5) and represents a global warming, until 2100, of over four degrees Celsius. RCP4.5 on the other hand represents a more optimistic and likely pathway.[65]

61 See Nolan, A.P. and Flanagan, J., 2020. High-resolution Climate Projections for Ireland – A Multi- model Ensemble Approach. [online] EPA Research. Pp.1-8 for a detailed description on the modelling approach.

62 Multiple models are used to generate the climate projections. For each scenario, the outcomes of the different models are then combined to reach a joint projections. Variations between different model outcomes gives additional information on the robustness of the projections.

63 The authors refer to a number of other studies that have broadly similar results. For example, Gleeson et al. (2013) have similar results in their temperature projections, in the projection of heavy rainfall events and projections of dry periods. Nolan (2015) is also reported to project similar temperatures, heavy rainfall events, trend in dry periods and similar projections for extreme storm events and trends in average 10-metre wind speeds. The authors further refer to Nolan et al. (2017) for similar projections in heavy rainfall events and dry periods, as well as O'Sullivan et al. (2015) for similar temperature projections.

Sources:

Gleeson, E., McGrath, R. and Treanor, M. (eds), 2013. Ireland's Climate: The Road Ahead. Met Éireann, Dublin.

Nolan, P., 2015. Ensemble of Regional Climate Model Projections for Ireland. Environmental Protection Agency, Johnstown Castle, Ireland.

Nolan, P., O'Sullivan, J. and McGrath, R., 2017. Impacts of climate change on mid-twenty-first-century rainfall in Ireland: a high-resolution regional climate model ensemble approach. International Journal of Climatology 37(12): 4347–4363 .

O'Sullivan, J., Sweeney, C., Nolan, P. and Gleeson, E., 2015. A high-resolution, multi-model analysis of Irish temperatures for the mid-21st century. International Journal of Climatology 36(3): 1256–1267. https://doi. org/10.1002/joc.4419.

64 Hausfather Z., Peters G., 2020. Emissions – the 'business as usual' story is misleading. Nature 577, 618-620. https://doi.org/10.1038/d41586-020-00177-3.

65 Met Office ,2018. UKCP18 Guidance: Representative Concentration Pathways. https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance---representative-concentration-pathways.pdf .

Representative Concentration Pathway (RCP)

For climate projections, scientists use assumptions on RCPs to represent a range of scenarios for GHG that affect climate. The IPCC has defined four RCPs used in climate projections.

- RCP2.6, is the most ambitious mitigation scenario assuming a very high reduction in the level of CO_2 concentration as a result of actions to reduce emissions.
- RCP4.5, which is an optimistic intermediate mitigation scenario. Emissions in this scenario peak around 2040 and then decline.
- RCP6.0 is less optimistic intermediate mitigation scenario. Emissions peak around 2080 and then decline.
- RCP8.5 represents a scenario with very high emissions.[66]

2.3.2 Wind speed forecasts

Mean annual 10 metre wind speed[67] is projected to decrease slightly by 2041-2060. The variability of wind speed (measured as the change in the standard deviation around the average) indicates that high wind speeds will occur slightly less often. However, the intensity of winter storms is projected to increase.

[66] IPCC, 2014: Topic 2 - Future Climate Changes, Risks and Impacts. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, Box 2.2 https://ar5-syr.ipcc.ch/topic_futurechanges.php.

[67] Wind speed measured 10 metres above ground level.

Table 2 Projected wind changes 2041-2060 compared to 1981-2000

Measurement	RCP4.5 projection	RCP8.5 projection
10 metre mean wind speed[68]	1-2.7% decrease	1.6-3.3% decrease
10 metre wind speed standard deviation	0.3-2.0% decrease	0.2-2.5% decrease
Driving rain (mean annual wind speed multiplied by mean annual rainfall)	1-7% decrease	0-8% decrease
Storms	Increased intensity of winter storms. 10% decrease[69] in number of storms.	Increased intensity of winter storms. 10% decrease[70] in number of storms.

Source: Nolan, A.P. and Flanagan, J., 2020. High-resolution Climate Projections for Ireland – A Multi- model Ensemble Approach. [online] EPA Research.

The authors also developed a model to project trends in rare extreme storms. The model forecasts a decrease in the number of storms. However, Nolan and Flanagan also reference other scientific literature that projects both increases in frequency and intensity of autumn and winter storms.[71] The lack of consistency in the projections from different studies is explained by the authors by the difficulty in modelling what are relatively rare events (i.e., extreme storms). Note that due to the rarity of the event, the projections of the number of extreme storm events do not skew projections of 10 metre wind speeds.[72]

2.3.3 Precipitation

The average precipitation experienced in Ireland is projected to reduce slightly by 2041-2060 compared to 1981-2000. However, the variability of precipitation is projected to increase, with both more dry and wet spells (i.e., dry / wet spells describe consecutive days with dry / wet weather). Nolan and Flanagan note that precipitation projections are less robust than temperature projections, potentially due to the opposing impacts of reduction in mean precipitation, against an increase in the frequency of heavy precipitation events.

68 Wind speed measured 10 metres above ground level.

69 Note that this is debated and the authors only cautionary interpret these results. Extreme storm events are rare and as such projections rely on little data. Other papers project an increase or no change for the number of storms, see Doddy Clarke, E, Sweeney, C, McDermott, F, et al. 2022. Climate change impacts on wind energy generation in Ireland. Wind Energy. 25(2): 300- 312. https://doi.org/10.1002/we.2673 *and* Mölter, Tina, Dirk Schindler, Axel Tim Albrecht, and Ulrich Kohnle. 2016. "Review on the Projections of Future Storminess over the North Atlantic European Region" Atmosphere 7, no. 4: 60. https://doi.org/10.3390/atmos7040060.

70 see footnote above.

71 For example, Haarsma, R.J., Hazeleger, W., Severijns, C., de Vries, H., Sterl, A., Bintanja, R., van Oldenborgh, G.J. and van den Brink, H.W., 2013. More hurricanes to hit Western Europe due to global warming. Geophysical Research Letters 40(9): 1783–1788. https://doi.org/10.1002/ grl.50360 *and*
Zappa, G., Shaffrey, L.C., Hodges, K.I., Sansom, P.G. and Stephenson, D.B., 2013. A multimodel assessment of future projections of North Atlantic and European extratropical cyclones in the CMIP5 climate models. Journal of Climate 26(16): 5846–5862.

72 Wind as measured 10 metres above ground.

The increase in heavy precipitation events is a potential cause of more flooding. Furthermore, the risk of flooding can be exacerbated by two climate related factors. First, after long wet periods, the soil will be saturated and unable to absorb the additional rainfall; and second, during prolonged dry periods the soil dries and will not initially absorb rain which runs off the surface leading to increased risk of flooding. With dry periods increasing in frequency, a rise in heavy precipitation events will potentially cause more frequent flooding. This may be offset by a projected increase in evapotranspiration (soil evaporation[73] and crop transpiration[74]). The EPA projects an increase in river floods for both the RCP4.5 and the RCP8.5 scenarios.[75]

Table 3 Projected precipitation changes 2041-2060 compared to 1981-2000

Measurement	RCP4.5 projection	RCP8.5 projection
Mean annual precipitation	Small reductions across the country, with the largest reduction in summer	Small reductions across the country, with the largest reduction in summer
Summer precipitation	0-11% decrease	2-17% decrease
Heavy precipitation events	5% increase	19% increase
Dry periods (5 consecutive days or more with rain <1mm)	11% increase in all periods except spring, especially summer	48% increase in all periods except spring, especially summer
Snowfall	51% decrease	60% decrease
Humidity	7% increase	10% increase

Source: Nolan, A.P. and Flanagan, J., 2020. High-resolution Climate Projections for Ireland – A Multi- model Ensemble Approach. [online] EPA Research.

2.3.4 Sea levels

Global mean sea levels will continue to rise. In comparison to the global mean sea level of 1995-2014, the IPCC projects the sea level in 2100, to rise by 0.44-0.76 metre (RCP4.5) to 0.63-1.01 (RCP8.5).[76] This may have impacts on likelihood of coastal flooding, which is projected to increase in frequency and geographic coverage under both the RCP4.5 and the RCP8.5.[77]

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73 Though the increase in humidity limits evaporative cooling, which will amplify adverse effects during heatwaves.

74 Meaning water movement from the soil to the atmosphere by evaporation and from the soil to the atmosphere via plants by transpiration.

75 EEA. 2021. Wet and dry — heavy precipitation and river floods. https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/wet-and-dry-1/wet-and-dry-heavy.
These projections seem to be in line with the projections shown on the Office of Public Works national flood information portal (https://www.floodinfo.ie/map/floodmaps/).

76 B.5.3 in Fox-Kemper, B., Hewitt, H. T., Xiao, C., Aðalgeirsdóttir, G., Drijfhout, S. S., Edwards, T. L., Golledge, N. R., Hemer, M., Kopp, R. E., Krinner, G., Mix, A., Notz, D., Nowicki, S., Nurhati, I. S., Ruiz, L., Sallée, J.-B., Slangen, A. B. A. and Yu, Y., 2021, 'Ocean, cryosphere, and sea level change', in: Masson-Delmotte, V., Zhai, P., Pirani, A., et al. (eds), Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

77 Office of Public Works national flood information portal https://www.floodinfo.ie/map/floodmaps/.

2.3.5 Temperature

According to the projections the overall average temperature is expected to increase in Ireland in the period 2041-2060 compared to a baseline of average trends in the period 1981-2000. This implies a continuation of the trends observed in section 2.1.3. Additionally, extreme heat events will increase in intensity and frequency. Frost and ice days are projected to become less frequent and less cold.

Table 4 Projected temperature changes 2041-2060 compared to 1981-2000

Measurement	RCP4.5 projection	RCP8.5 projection
Mean temperatures	Increase by 1.0-1.2 °C	Increase by 1.3-1.6 °C
Warmest 5% of daily maximum temperatures	Increase by 1.0-1.6 °C	Increase by 1.4-2.2 °C
Coldest 5% of daily minimum temperatures	Increase by 0.9-1.8 °C	Increase by 1.2-2.4 °C
Heatwave events	1-8 more heatwave events over a 20-year period	3-15 more heatwave events over a 20 year period
Days with min. temperature < 0 degrees Celsius	Decrease by 45%	Decrease by 58%
Days with max. temperature < 0 degrees Celsius	Decrease between 68%	Decrease between 78%

Source: Nolan, A.P. and Flanagan, J., 2020. High-resolution Climate Projections for Ireland – A Multi- model Ensemble Approach. [online] EPA Research.

The change in temperature alongside other climate related changes will affect the Irish ecosystem with the growing season projected to increase by 12% (18% in RCP8.5), starting 15 (24 in RCP8.5) days earlier than it did over the period 1981-2000.

2.3.6 Summary of climate projections

According to the projections of Ireland's climate commissioned by the EPA Ireland will experience the following changes in the period 2041-2060 compared to a baseline of average trends in the period 1981-2000.

- Average wind is projected to decrease slightly. *Storms are projected to increase in intensity*, while the future trends for frequency of storm events differ across projections.
- Precipitation is projected to decrease slightly overall, though with *an increase in the frequency of heavy precipitation events*.
- *Coastal and river flooding may be more likely in terms of frequency* and areas affected as a result of increased frequency of storm events and heavy precipitation events, aggregating factors such as rain falling on either waterlogged or parched dry ground, and a rise in sea levels in coastal areas and estuaries.

- Overall temperature is projected to rise moderately in both RCP scenarios and there is projected to be *an increased number of heatwaves* and a decrease in days with snow and ice.

3 Weather-related vulnerabilities of ECNs

Vulnerabilities can be described as potential points of failure that can lead to an outage resulting in a degradation or loss of service to end users. In the context of ECS that consumers receive, impacts are generally measured in: downtime of network elements, user hours lost, and the number of users affected[78]. Some events can be significant (high number of users, long duration), and others are more localised and minor.

As the focus of this report is the vulnerabilities associated with *networks*; the vulnerabilities associated with Consumer Premises Equipment ("CPE") (such as internal cabling, routers, or satellite dishes) is not considered.

This section summarises the weather-related vulnerabilities of different types of ECN and presents quantitative information gathered from ECN operators on the weather-related vulnerabilities of their networks in recent years (section 3.5).

The following sections give an overview of the weather-related vulnerabilities of fixed and mobile network elements in Ireland based on evidence gathered from ECN operators as part of this study.

3.1 Weather-related vulnerabilities of fixed-line networks

The key weather-related vulnerabilities for fixed ECN are described below. These include damage or impairment of the ECN infrastructure, as well as vulnerabilities related to power failures on the electricity supply network.

Wind damage to ECN overhead infrastructure

Types and causes of wind damage	Strong winds can cause damage to overhead infrastructure. This can be due to direct damage to cables, clamps and poles from excessive wind load or more usually due to the impact of wind related debris such as falling vegetation (trees, branches etc) hitting poles or cables.
Impact of wind damage	The impact of the damage will depend on where in the network it occurs. If it is lower in the network hierarchy in the access network (drop cables), it might affect just one, or a small number of households. If it is upstream (distribution and feeder cables), in the transport network, it can potentially affect many thousands of households There were many incidents (39 reported between 2017 and 2022[79]) relating to wind damage to overhead infrastructure. Apart from those caused by storms, such incidents tend to be local and affect a limited number of users.

[78] Or subscriber-hours in the case of fixed networks for which the potential use by more than one user per subscription is not taken into consideration.

[79] ECNs' responses to Frontier's Information Request.

Lightning strikes

Types and causes of lightning damage	A direct lightning strike can cause significant damage to all types of electrical equipment. The energy from a nearby lightning strike can travel through metallic wires (those used for communication and others), directly from a utility pole into ECNs' active equipment or buildings' electrical panels.
Impact of lightning damage	Such events are rare. One operator has reported one incident on its cable network over the last five years[80] and another operator has reported[81] one occurrence of damage to several antennas after a site in Galway was struck by lightning. Another operator reports[82] that while lightning may hit houses and buildings but there is no record of lightning damaging its cabinets.

Water ingress and flooding

Types and causes of water damage	Heavy rain can lead to localised flooding at street cabinets, exchanges or in ducts. This can cause corrosion or short circuits in exposed copper / coaxial cabling and electric equipment related to all types of transmission material (including the deterioration of optical cabling) and can impact on the provision of services to end users. Water ingress can cause electrical issues as well as degradation of bandwidth from damage to the conductive skin of a copper cable and losses in fibre by dispersing the transmitted light due to water between the fibre and the sheath.
Impact of water damage	Such vulnerabilities were identified by two operators[83] [84]. Though no related incidents have been reported in the last five years[85]. One of the operators noted that its independent climate risk assessment report identified flooding as a higher risk climate event on a small number of specific sites. In hybrid-fibre coaxial ("HFC") networks, the vulnerability to water ingress is deemed very limited because of the waterproof cables and connectors[86] when correctly installed and maintained.

80 Information provided by stakeholder in course of study.

81 Information provided by stakeholder in course of study.

82 Information provided by stakeholder in course of study.

83 Information provided by stakeholder in course of study.

84 Information provided by stakeholder in course of study.

85 In exchanges where incidents occurred, sump pumps have been installed to adapt to the risk.

86 Information provided by stakeholder in course of study.

Heatwaves

Types and causes of heat damage	The failure rate of an electrical component increases exponentially with temperature hence, equipment can only operate reliably within a set temperature range. Equipment and facilities may require cooling to operate in hotter weather. Longer and more intense heatwaves increase the risk of performance degradation of operator equipment (for batteries[87] in particular) and even failure. The only heat-related vulnerable equipment identified by ECNs would be base stations' cabinets, co-location or exchange facilities, if powered air conditioning fails or is absent and if mechanical cooling is insufficient.
Impact of heat damage	One operator noted one heatwave causing loss of service in June 2021[88] all other ECNs consider that heatwaves are not a risk in access networks. Mechanical cooling of cabinets is likely to be sufficient for the temperatures that can be expected in Ireland, even if further warming could take place. Another operator reports[89] that in base stations without powered air conditioning, temperatures can reach 40 to 50 °C. This causes a reduction of batteries' operating life.

Newer network equipment is less vulnerable

ECN operators have noted that newly built fixed access ECNs that rely on fibre are more resilient than legacy copper ECNs. This is because fibre-based infrastructure is more resilient to water ingress and lightning strikes relative to copper. Fibre overhead lines are exposed to strong winds, however, fibre cables are lighter than the same diameter copper cable. This implies that after copper cable is retired the weight loading on overhead routes and the corresponding damage risks will be reduced which will make the overhead lines less vulnerable to wind damage.

87 Batteries also have issues in lower temperatures, below zero degrees. Lead acid and other batteries generally have a temperature rating and charging has to be adjusted when its higher or lower than a given temperature range, otherwise damage may occur.

88 Information provided by stakeholder in course of study.

89 Information provided by stakeholder in course of study.

Power failure in the electricity supply network

Types and causes of power outages	Street cabinets for copper, Fibre To The Home ("FTTH") and HFC ECNs, all require power. Likewise, elements in upstream segments of networks, such as, local exchanges, colocation facilities or metro nodes, rely on electricity to support the equipment in the exchange and in the case of the legacy copper voice ECNs, to power the telephone at customer premises. A power outage to an ECN site (such as, a cabinet, exchange or remote network node) will mean that the equipment at the site will be unable to operate once backup solutions (battery or generators) are exhausted. This would then result in a service outages for consumers dependant on the impacted ECN site. Power interruptions can be caused by hardware failures (for example works that accidently cause damage to the power network), routine maintenance of the electricity grid, weather events (heavy rain and wind) affecting the electricity network or ECNs' power equipment. It is difficult for ECNs to identify precisely the cause of each electricity outage but one operator notes[90] that these occurrences would more often be seen during severe weather warnings[91] issued by Met Éireann.
Impact of power outages and duration of outages	Power outages on the electricity supply network lasting from seconds to hours are reported by two operators[92] [93] to occur around three to four times per week. During a severe weather event ESB Networks ("ESBN") may have many different faults to repair across its power network. According to several operators[94], ESBN does not assign a higher priority to repairing faults which affect ECNs than other faults. This may lead to long interruptions in electricity supply for ECNs. During power outages, there is further vulnerability from interdependence between ECNs and the power supply network. Where severe weather has caused damage to both ECNs and the electricity network at the same site, repair work to ECNs may not be feasible until electrical damage has been made safe.

3.2 Weather-related vulnerabilities of wireless networks

The key weather-related vulnerabilities for wireless ECNs are described below. Mobile base stations are often located in high and exposed sites (to support a wider coverage area). This makes them more vulnerable

90 Information provided by stakeholder in course of study.

91 Weather warnings rated Orange / Red. See section 2.2.

92 Information provided by stakeholder in course of study.

93 Information provided by stakeholder in course of study.

94 Information provided by stakeholder in course of study.

to extreme weather, than network equipment that is located in more sheltered locations. In addition, it also means that when storm conditions cause damage at the site, any repair that requires climbing can only take place when storm conditions have subsided sufficiently.

Excessive precipitation causes drop in radio signal level

Types and causes of Rain Fade	"Rain Fade" describes the decrease in the strength of the radio signal received which can result from high precipitation / heavy rain. This phenomenon is caused by the absorption of a radio signal by water in the form of rain, snow, or ice. Rain Fade can have a greater impact on ECN using higher radio frequency spectrum. It can happen anywhere on the path of radio transmission: in the air or directly on active equipment in the case of snow/sleet build up on antennas. All wireless transmissions can be subject to Rain Fade and are designed for a maximum acceptable level. However, Rain Fade incidents reported by ECNs are typically related to microwave backhaul links which are operated at higher frequencies (to provide wireless backhaul or provide Fixed Wireless Access ("FWA"); rather than lower frequencies used to provide mobile connectivity services[95] to end users. One operator explained[96] that when there is more than 30mm rain per minute, microwave ("MW") link signal degrades rapidly.
Impact of Rain Fade	One operator reported[97] that its microwave backhaul links have been affected by Rain Fade during excessive precipitation (rain or snow), which resulted in a short duration of complete loss of signal; with the number of premises affected, varying from a few hundred to thousands. One operator noted that rain fade events generally last a couple of minutes, and that normal service usually returns when the rain either stops or reduces in strength.

95 It is worth noting that increasingly mobile services use also high frequency spectrum to accommodate additional capacity needs – but over shorter distances than MW backhaul.

96 Information provided by stakeholder in course of study.

97 Information provided by stakeholder in course of study.

Snow and ice

Types and causes of snow and ice damage	Ice storms and heavy snowfalls can increase weight on structures and potentially cause damage to both passive infrastructure and active equipment. Even without causing direct damage, radio systems can be affected when antennas are covered in ice since the ice on an antenna directly interferes with the reflective surface of an open dish and the mechanical load from ice might cause the dish to go out of alignment and induce excessive signal attenuation. Snow and ice can also cause damage to road infrastructure, which incidentally increases the impact of outages as ECN operators are unable to access remote sites to conduct repairs.
Impact of snow and ice	Two operators[98] report occasional damage to cabinets, buildings, antennas, outdoor Heating Ventilation Air Conditioning ("HVAC"), fences, cable management and vehicles from ice forming on and falling from structures. Three operators[99] [100] [101] report rare occurrences of ice build-up on dishes with impacts on signal levels in MW links. One operator reports[102] that snowfall and freezing temperatures brought by Storm Emma in March 2018 created difficulties in reaching damaged sites with some of the workforce unable to get their vehicles out from their homes.

Strong winds may damage and displace equipment on mobile masts

Types and causes of wind damage	High winds may pose a challenge for the alignment of microwave dishes that provide backhaul services. In order to operate efficiently they need to be positioned and aligned to precise measurements. Two operators occasionally experience service issues due to misaligned dishes.[103] One operator observes[104] that its dishes and antenna are firmly anchored and that such wind-related incidents do not occur on its network.

98 Information provided by stakeholder in course of study.

99 Information provided by stakeholder in course of study.

100 Information provided by stakeholder in course of study.

101 Information provided by stakeholder in course of study.

102 Information provided by stakeholder in course of study.

103 Information provided by stakeholder in course of study.

104 Information provided by stakeholder in course of study.

Impact of wind damage	Incident reports collected during this project indicate that the impact is limited for end-users with 278 user-hours losses measured between 2017 and 2022 (see Table 5). Dish realignment can only take place when conditions are safe enough, which can create a delay in return to normal service.

Lightning strikes

Types and causes of lightning damage	Modern network equipment is protected from the impact of lightning strikes by circuit breakers. However, even when electrical equipment is protected from direct lightning damage with tripped circuit breakers, these need to be manually reset before equipment can be restarted causing a loss of service.
Impact of lightning damage	One operator has reported 10 occurrences[105] of tripped breakers due lightning strikes.

Water ingress

Types and causes of water ingress	Heavy rain and wind-induced cable fatigue occasionally cause water ingress in cabinets and damage to MW links.
Impact of water ingress	One operator noted[106] that its high sites have suffered damage during winter storms of persistent wind eventually fracturing the outer shielding of cables on its towers, which allowed water ingress into cables. Such water ingress has resulted in electrical shorting of the cable, or allowed water to travel down the cable and led to damage in the “Power over Ethernet device” in the cabinet at the base of the tower. The operator also reported that coastal high sites suffer from corrosion of antennae and outdoor microwave units due to the combined effects of salt, rain, wind and ice. Such erosion is, however, a slow process and the impact on end users can be avoided if equipment and cable are replaced in time. Two operators[107] [108] also reported rare occurrences of water ingress causing failure of MW link equipment after heavy rains.

105 Information provided by stakeholder in course of study.

106 Information provided by stakeholder in course of study.

107 Information provided by stakeholder in course of study.

108 Information provided by stakeholder in course of study.

Power outages

Types and causes of power outage	Mobile base stations rely on power for all the equipment at the site (as described in Figure 19). This means that storm conditions can lead to a failure of power supply on the electricity supplier's network which has an impact on ECN equipment.
Impact of power outage	70% of network incidents reported by wireless operators are related to a power outage. The impact that a power outage has on site will depend on the ECN operator's approach to providing power backup (discussed in section 5.1.1). Mobile ECNs operators can use backup power supply to maintain service in the event of an outage. However, different ECN operators have different strategies for providing backup power to their network sites, with some ECN operators offering a few minutes (see Table 8) or no backup whereas others use on on-site generators or mobile generators that can be brought to site (though with a delay). Any prolonged loss of the main power supply to base stations which exhausts the backup power options (whether battery and / or generator) can therefore affect the availability of services to end users.

3.3 Other weather-related vulnerabilities

In addition, ECNs are vulnerable to weather-related events as a result of a number of organisational and logistical reasons.

ECN operators face staffing, safety and access constraints which may impede remedial work and delay incident resolution during severe weather events. For example, one operator has experienced field staff shortages[109], when multiple simultaneous power outages required significantly more field personnel to attend remote sites than it typically has on stand-by.

Wind speeds must fall to a safe level before any repair works that require climbing towers or working on overhead lines can commence. Several operators[110] [111] [112] [113] have had to delay interventions due to safety reasons during wind related warnings until the weather improved and the weather warning was reduced to yellow or below.

109 Information provided by stakeholder in course of study.

110 Information provided by stakeholder in course of study.

111 Information provided by stakeholder in course of study.

112 Information provided by stakeholder in course of study.

113 Information provided by stakeholder in course of study.

One of the operator's ability to send mobile generators to sites has, on a few occasions, been affected where road conditions were dangerous.[114] During storm Emma in March 2018, snowfall and freezing temperatures restricted access to some of another operator's sites and some of the workforce could not get their vehicles out from their homes.[115] Inaccessible sites in case of snow, storm or localised flooding have also been reported by another operator.[116]

3.4 Vulnerabilities in international connectivity networks

International connectivity networks are designed to be highly resilient to weather events. The ECN operators reported no weather-related outage in at least the past five years.

Coastal flooding risk at Cable Landing Stations (CLS) is considered low in Ireland. None of CLS operators consulted for this report have built CLS within 100m of the shoreline.[117]

CLS are all equipped with long lasting backup generators and are periodically inspected including for any structural weakness or damage that may be a risk during storms or high winds. All other infrastructure is below ground and thus not at risk of wind related events.

One operator has built protections in its international connectivity facilities which include: sealing of the beach manhole with two lockable covers with the lowest 30 centimetres below the top cover and multiple armour levels of protection around its subsea cable segments.[118] The operator also carried out significant future proofing on its underground infrastructure which runs out of the Dublin area by digging down very deep during the deployment phase to ensure erosion was not a concern at this location.

One operator states that the site for its CLS is outside of flood zone areas and well drained with surface water on site draining to a public sewer.[119] The operator also conducts monthly visual inspections on the beach, fronthaul and beach manhole.

ECN operators typically rely on several, redundant submarine cables for international connectivity to provide resilience. In the unlikely event that an international connectivity network encounters service disruption, due to weather events, users may not experience any decline in service, or may only observe a limited drop in performance, rather than a complete service outage.

114 Information provided by stakeholder in course of study.

115 Information provided by stakeholder in course of study.

116 Information provided by stakeholder in course of study.

117 Responses from all cable landing station operators to Frontier.

118 Information provided by stakeholder in course of study.

119 Information provided by stakeholder in course of study.

3.5 Quantifying weather-related vulnerabilities

Table 5 below provides an overview of weather-related incidents reported by ECNs as part of this report. It should be noted that the granularity and the criteria used by ECNs to describe network incidents are variable.[120]

In fixed networks, wind is the biggest cause of weather-related incidents. In wireless networks power outages due to weather events are the biggest cause of weather-related incidents, with secondary cause being signal fade due to snow/ice build-up and lightning also causing outages.

Different types of incidents, affect different numbers of users. Table 5 shows that power outages have the biggest impact on users for both fixed and wireless networks with respectively 23,765 and 2,533 reported user-hours lost between 2017 and 2022 (where data is available, noting that two operators did not provide data on user hours lost). Overall it is worth noting that there significantly more User Hours lost for Fixed Networks even though they show a smaller number of incidents. One possible explanation is that mobile networks more are by design more redundant, with cells overlapping in many areas. The fact that end users are often able to attach to multiple base stations may therefore help overcome the effects of isolated incidents.

120 Network operators do not use the same methodologies to track incidents. Typology of incidents is sometimes not available and incidents affecting different sites on a same day may be aggregated. This information was provided by stakeholders in course of the study.

Table 5 Number of user-hours losses and incidents between 2017 and 2022

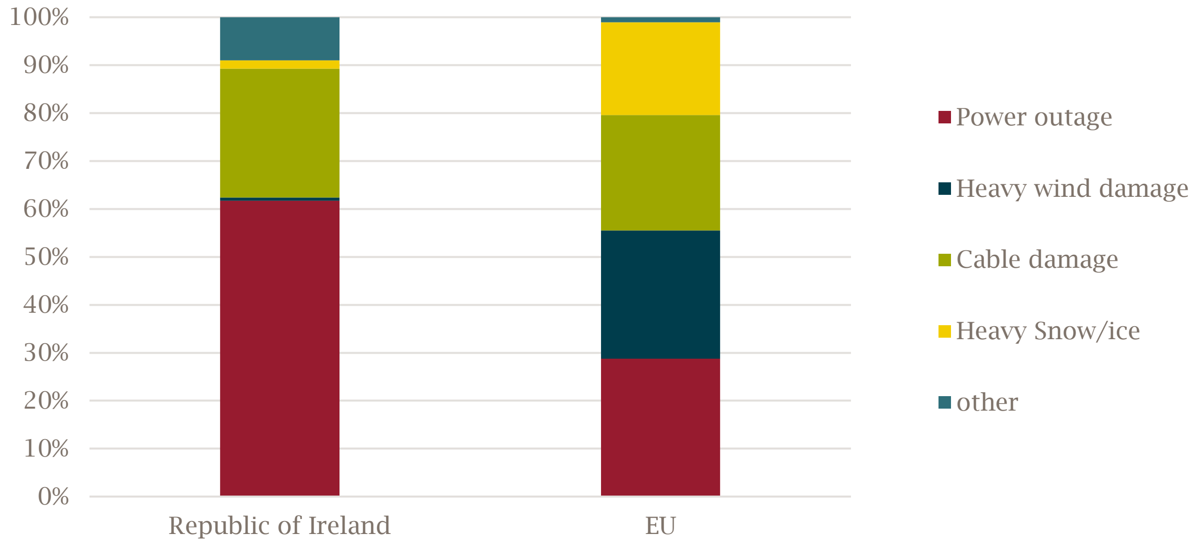
Type of incident	Number of incidents		Number of user-hours lost	
	Fixed landline networks	Wireless networks	Fixed landline networks	Wireless networks
Weather-related power outage (1)	6	111	23,765	2,533
Wind damage to MW equipment	-	4	-	191
MW Dish moved in high winds	-	8	-	87
Rain causing drop in signal level	-	7	-	4
Ice/snow causing drop in signal level	-	13	-	746
Lightning strike damage	1	12	3,000	74
Water ingress	-	3	-	644
Damaged feeder cable	-	1	-	99
Overhead Cable Damage	39	-	11,444	-
Total	**46**	**159**	**38,209**	**4,378**

Source: Incident reports from ECNs provided to Frontier.

Note: Wireless Networks include mobile and fixed wireless networks. (1) Power outage can refer to electric grid power fault or power equipment on site. No data on user-hours lost from two operators. Indirect estimation for another operator. One operator provided data on number of incidents aggregated for fixed and wireless but did not split by category.

Figure 9 compares the impact of different types of serious weather-related incidents at ECN across the EU to the reported weather-related incidents in Ireland. While the two are not directly comparable they show that power related outages and cable damage are both significant causes of user hour losses across both the EU and Ireland. Ireland's ECNs tend to be significantly less effected by snow and ice than the EU.

Figure 9 Share of user-hours losses in Ireland and in the EU



Source: EU: ENISA - Telecom Security Incident 2020 - Annual Report, EU: written responses to Frontier's Information Request
Note: ENISA only reports more serious incidents

4 ECN vulnerability assessment of climate change risk

Based on the climate forecasts presented in section 2.3 and the assessment of vulnerabilities (in section 3), the current risk to ECNs from weather events is set out in Table 6 (fixed access ECN) and Table 7 (mobile access ECN). The tables[121] report how this risk could change in the future based on the projections. Specifically, the tables report how change in projected weather events will impact on the ECNs, through a change in intensity, as well as any change in the frequency of weather events.

Table 6 Fixed access network vulnerability assessment of climate change risk

Vulnerability	Current impact – frequency and users affected	Likely change in future in weather conditions	Future impact	Commentary on future risks for ECNs
Water ingress and flooding at exchanges, in street cabinets, and underground sites	Low frequency / few users affected	Increase in river and coastal flooding, increase in flash flooding.	Low, though higher risk than current.	The likelihood of occurrence will increase where network equipment is located near areas prone to flooding (rivers, coastal areas, estuaries).
Wind damage to overhead ECN infrastructure	Medium frequency / medium number of users affected	Slight decline in annual wind mean speeds. Decreased frequency[122] but increased intensity of storms.	Medium – potentially higher risk than current due to more intense storms.	The increased intensity of storms could increase risks for ECN. This could be aggerated by the increased growth season which could increase the volume of vegetation and hence increase risk of damage the overhead infrastructure.
Overheating of cabinets	Low frequency / few users affected	Increasing average and peak temperature.	Low, though higher risk than current.	Low level of risk. The scale of temperature increases remains

[121] Tables do not include international connectivity for which the risks are deemed low since they are built to be very secure and resilient.

[122] Note that due to the rarity of extreme storm events, storm projections are less robust. While Nolan and Flanagan (2020) project a decline in the frequency of extreme wind events, other academic papers project an increase or no change in the frequency of storm events. We refer to section 3.3.2.

Vulnerability	Current impact – frequency and users affected	Likely change in future in weather conditions	Future impact	Commentary on future risks for ECNs
				limited compared to cooling capacities according to most ECN operators. Though some operators note that higher temperatures affect battery life for backup services.
Inaccessibility of sites due to snow and ice	Low frequency / medium number of users affected	Decreasing number of frost days projected.	Low and decreasing risk	Low level of risk.
Lightning strikes	Low frequency / medium number of users affected	Potentially increasing due to increased frequency of intense storms (though forecasts of lightning are not available)	Low / medium and potentially increasing.	While it is not possible to forecast lightning, increased intensity of storms could increase likelihood of lightning.
Power outages as result of weather events affecting exchanges and active street cabinets	High frequency / many users affected	Slight decline in annual wind mean speeds. Decreased frequency[123] but increased intensity of storms.	High impact and potentially increasing.	Power outages due to weather events is likely to remain the most likely cause for ECN weather-related outages.

Source: Frontier Economics

123 Note that due to the rarity of extreme storm events, storm projections are less robust. Other academic papers project an increase or no change in the frequency of storm events. We refer to section 3.3.2.

Table 7 Wireless networks vulnerability assessment of climate change risk

Vulnerability	Current impact – frequency and users affected	Likely change in future in weather conditions	Future impact	Commentary on future risks for ECNs
Heavy precipitation causes drop in radio signal level	Medium frequency / few users affected	Increase in number of heavy precipitation events	Low impact but with increasing frequency of severe precipitation events	Low impact due to the short duration of rain fade. Decreasing impact with network equipment upgrades and installation of modern equipment which is less affected by rain fade.
Snow/ice build-up causes drop in radio signal level	Medium frequency / medium number of users affected	Substantial decrease in days with below zero temperatures	Decreasing risk	Low and declining impact
Strong winds displace equipment on mobile masts	Medium frequency / low number of users affected	Slight decline in annual wind mean speeds. Decreased frequency[124] but increased intensity of storms.	Medium – potentially higher risk than current due to more intense storms, though low impact	Medium and increasing impact particularly in winter months.
Water ingress and flooding[125]	Low frequency / medium number of users affected	Uncertain: Decreased frequency[126] but increased intensity of storms, offset by lower average rainfall	Low impact and uncertain change in impact (lower mean rainfall offset by increased storm intensity)	Given the potential for increasing future impacts (albeit with uncertainty) ECN operators should be prepared for increased flooding.
Power outages as result of weather events	High frequency / many users affected	Slight decline in annual wind mean speeds. Decreased frequency[127] but increased intensity of storms.	High impact and potentially increasing.	Power outages due to weather events is likely to remain the most likely cause for ECN weather-related outages.

Source: Frontier Economics

124 Note that due to the rarity of extreme storm events, storm projections are less robust. Other academic papers project an increase or no change in the frequency of storm events. We refer to section 3.3.2.

125 There a potential risk for flashing flooding in areas traditionally not prone to flooding but this risk has not been reported by ECNs during Frontier's consultation.

126 See footnote above.

5 How ECN operators adapt to manage climate and weather-related risks

This section describes current and planned adaptation strategies used by operators to make their ECNs resilient to weather-related events. It considers:

- what ECN operators do to prevent weather-related outages (section 5.1);
- how operators monitor their ECNs to detect weather-related faults (section 5.2);
- how operators take into account wider climate risks (section 5.3);
- how operators respond to outages to restore supply (section 5.4); and,
- what the potential gaps are in adaptation actions (section 5.5).

5.1 Building in resilience in network design and preventative maintenance support network functioning

All operators have programmes to maintain, operate and improve their ECNs which include measures to protect them from weather-related outages. These actions include provision of backup power supply, “redundant” transmission links, maintenance and reinforcing existing equipment.

5.1.1 Redundancies and backup

While there is no fixed definition of redundancy and backup, in terms of risk planning, this report uses the following definitions.

- “Redundancy” describes the use of multiple substitutable inputs (e.g., of power supply or data transmission) which means that continuity of service can be ensured even if one of the inputs fails. For example, a datacentre or local exchange might have multiple data transmission links which work contemporaneously.
- “Backup” describes an alternative (different) service that can be used if the primary service fails. For example, where power supply from the electricity grid fails, a network node can switch for a short period to an alternative power source such as a battery or generator.

Redundancy and backup can apply to both power and data transmission.

Power supply backup

As described in section 3, ECNs experience occasional outages of the electricity supply, with increased occurrences during storms or other bad weather. ECN operators manage these incidents by using backup solutions which kick in when a power outage is detected.

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[127] See footnote above.

Lead-acid and lithium-Ion batteries are widely deployed in access networks (many street cabinets, most mobile sites) for short term resilience. Operators design their backup batteries to last from a few minutes to a full day.[128]

Table 8 Duration of battery backup

Stakeholder type	Battery backup duration
Fixed Access Network	15 minutes to 25 hours[129] [130] [131]
Radio Access Network ("RAN")	10 minutes to 8 hours[132] [133] [134]
Tower company ("TowerCo")	Up to 8 hours [135]

Note: Durations indicated above do not necessarily relate to similar network elements

Most of the durations detailed above are deemed sufficient to allow for a mobile diesel generator to be brought to the site to provide power for prolonged outages that extend beyond the battery life. However, one fixed and one radio access network operator only provide limited battery backup (about 10-15 minutes)[136] in many of their Fibre To The Cabinet ("FTTC") cabinets and mobile sites. This typically would provide sufficient time only for equipment to power down safely but inadequate to maintain continuous service provision.

The impact that storms have on power outages can be observed in the duration of power outages during typical outages compared with storm days. By illustration, Figure 10 shows for between June 2019 and June 2022 the average duration of power outage (for all reasons) recorded by ESB Networks lasted between two and three hours. Only 2% of the outages in that time period were resolved in under 15 minutes and about half of the outages lasted up to four hours.[137] Battery backup of 8 hours would be sufficient for the vast majority of "typical" outages and would not have required further backup (such as a mobile diesel generator on site) in 87% of outage cases.

128 Large scale batteries can last much longer but take up space and are only an option where rooms are large enough.

129 Information provided by stakeholder in course of study.

130 Information provided by stakeholder in course of study.

131 Information provided by stakeholder in course of study.

132 Information provided by stakeholder in course of study.

133 Information provided by stakeholder in course of study.

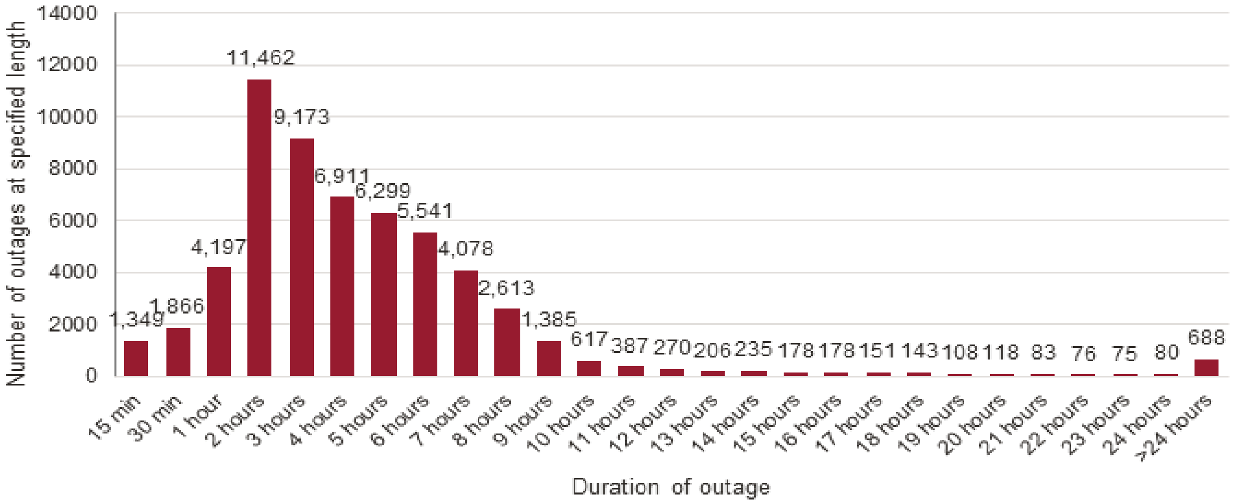
134 Information provided by stakeholder in course of study.

135 Information provided by stakeholder in course of study.

136 Information provided by stakeholder in course of study.

137 These numbers include both planned and unplanned outages.

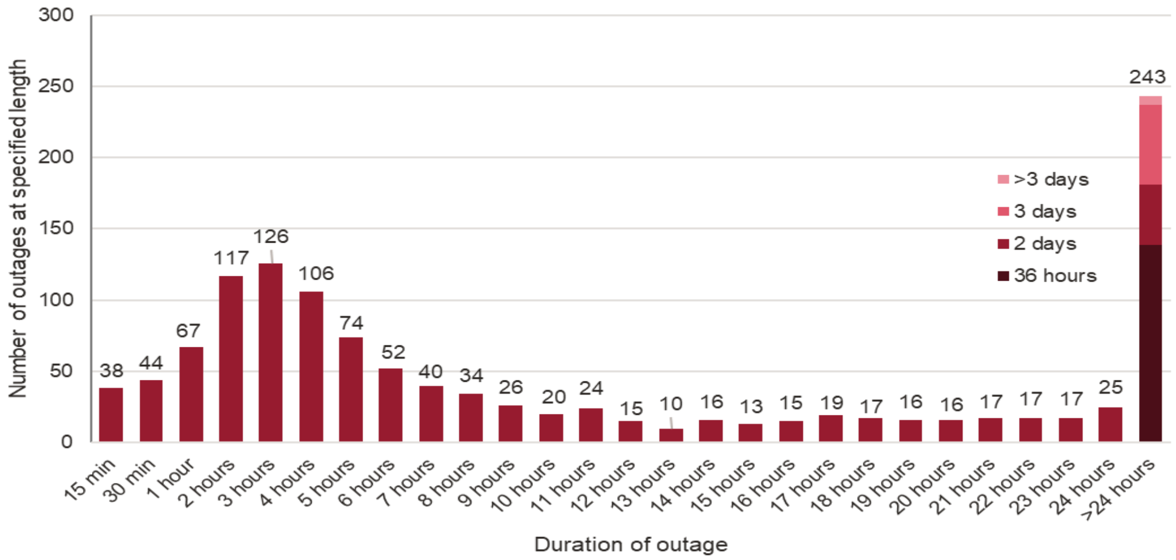
Figure 10 –ESB Networks recorded electricity outage durations – *all reasons* (June 2019 - June 2022)



Source: ESB Networks data on network outages as supplied to ComReg.
Note: Numbers including both planned and unplanned outages.

The distribution of outage increases on days with large storm events. Figure 11 shows a sub-set of the outage data discussed above for the four largest storms of the storm season 2021/2022.

Figure 11 –ESB Networks recorded electricity outage durations *on storm days* 2021/2022 during red weather warning named storms



Source: ESB Networks data on network outages as supplied to ComReg.
Note: Outages on the days of Storm Arwen, Barra, Eunice and Franklin.

Almost 20% of outages during these storms lasted longer than 24 hours, compared to 1% when looking at overall data. Only 40% (compared to over 50%) of outages was resolved within four hours. A significant proportion of outages on storm days last longer than two days.

While batteries provide a reliable source of backup, they have some drawbacks for operators. They are expensive and bulky, they have a finite life, with their capacity diminishing over time and with extremes of temperature they require regular inspections and replacement and they are subject to theft. One operator notes that it replaces 20% of its “hub site”[138] batteries every year.[139]

In a remote site, which can host multiple operators (for example each of the three mobile operators, fixed wireless operators, and backhaul suppliers), each operator generally[140] has its own battery backup located in the site requiring space and adding costs to all operators.

In addition to batteries, operators install high capacity stationary[141] power generators in more critical elements of networks, where the need for resilience increases along with the potential impact of failure. These generators can last up to several days. Two operators[142] [143] report that they pro-actively ensure that generators are refuelled upon news of upcoming weather events. Another operator also reports[144] that it has fuel dumps located strategically around the country if required to ensure fast refuelling.

In sites where it is not cost effective to install stationary generators, operators will typically supply a mobile generator to the site in the event of a power outage which is expected to exceed the capacity of the battery backup. Therefore, in response to a power outage each operator may provide its own mobile generator to the site to provide backup power (meaning there can be many different generators provided at a multi-operator site, each powering a different ECN’s equipment).

The precise form of backup, and the mix of batteries, mobile or stationary generators for power supply varies from one ECN to another and is affected by: the available room on site or in the furniture where equipment is located; the cost; the likelihood (or history) of power outages; and the criticality of the network element.

Redundancy in routes and core elements

Redundancy in routes describes the availability of more than one discrete and separate connection to a part of the ECN which is used at some critical parts of the network. In fixed access networks redundancy is not offered to private end users. Business users may acquire redundant access in their fixed network services. In the case of mobile ECNs, in many areas a limited form of redundancy is enabled since mobile handsets may be able to connect to other base stations if one site experiences an outage.

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138 Hub sites are cell sites that are users as feeder sites to other smaller or more remote cell sites.

139 Information provided by stakeholder in course of study.

140 This can depend on the operator and agreed SLA with the TowerCos.

141 Permanent units hard-wired into the site which can be started manually or even automatically in the event of a power outage.

142 Information provided by stakeholder in course of study.

143 Information provided by stakeholder in course of study.

144 Information provided by stakeholder in course of study.

Transport networks on the other hand rely on diverse routes and in the event of a fault on transport links, switches automatically redirect the traffic. Core network infrastructure is generally built with a so called *1+1* or *2N* resilient architecture which ensures that for each component there is at least one independent redundant component (+1). Similarly, interconnections between ECNs are built with multiple levels of geographic redundancy to avoid single points of failure.

5.1.2 Preventative maintenance programmes

The vulnerability of overhead cables and poles to strong winds is a key concern for operators. As shown in previous sections, the largest category of extreme orange and red weather warnings are wind warnings (section 2.2), which can cause damage to infrastructure (section 3.5). Some operators therefore run preventive maintenance programmes to trim vegetation that is too close to cables and inspect/replace poles.

Pole inspection and replacement

Poles deployed in Ireland are made of timber with an expected life span of 35-40 years. The largest operators have extensive infrastructure with over 1 million poles.[145] Other operators are making extensive use of large operators' infrastructure but also poles itself.[146] One operator uses electricity operator's infrastructure, which is at higher standard to distribute (potentially hazardous) electricity. The electricity operator inspects its power network infrastructure regularly to ensure its safety, and hence these inspections also ensure that any vulnerabilities of its ECN infrastructure are checked.

One operator reports[147] that its teams have a programme regularly test and replace poles, with each pole due for testing every 10-12 years. In addition to these programmes, the operator replaces poles that are found to be damaged or decayed or after significant weather events. The operator also undertakes specific tests and replacement of defective poles in the context of the rural fibre rollout or pole provision for the National Broadband Plan.

There is no specific programme by the operator to bury segments of its overhead cable infrastructure to increase its resilience. The rural nature of much of the fixed access network means that burying cables is not usually economically feasible.[148]

Another operator noted that it did not know the state of the pole infrastructure (approximately 150k poles) that it rented from other operators. According to the operator,[149] this information is not disclosed. Therefore, the operator at its own expense undertook its own inspection of its rented pole infrastructure. The operator has not yet put in place a system of monitoring the conditions of its own poles, since it has only begun deploying its poles and so these are still at the beginning of their expected lifetime.[150]

145 Information provided by stakeholder in course of study.

146 Information provided by stakeholder in course of study.

147 Information provided by stakeholder in course of study.

148 Information provided by stakeholder in course of study.

149 Information provided by stakeholder in course of study.

150 Information provided by stakeholder in course of study.

Vegetation Trimming

Routes are surveyed by field crews or appointed partners. When the existing foliage, trees and hedges are deemed too close to cables or if there is no clear line of sight from pole to pole that affects the safe erection of a new overhead route, tree trimming is deemed necessary. In practice, one operator reports that tree trimming activities typically clear 1.5 metres around overhead cables.[151]

Vegetation trimming is subject a number of legal and environmental constraints including:

- The Wildlife Act[152] states that tree trimming will not be carried out between 1st March and 31st of August each year.
- The Communications Regulation Act 2002, Section 58 (2), requires for 28 days written notice to be given to landowners regarding tree trimming activities undertaken on their land.
- A tree preservation order under section 205 of the Planning and Development Act 2000 prohibits the cutting or lopping of trees or woodlands without the planning authority's consent.

Tree trimming operations are not necessarily carried out at a regular frequency. Figures provided by one operator[153] show that over the last five years the length of vegetation trimmed each year varied between 30 km and 3000 km.

One ECN operator, which rents access to infrastructure from another ECN operator, carries out all tree trimming works as part of route preparation undertaken in advance of its fibre deployment on the access provider's poles. In the past year, the access provider operator has undertaken tree trimming work between September 2021 and February 2022 of over 45,700 pole spans.[154]

5.1.3 Upgrade and reinforcement of equipment

There are various technologies and opportunities that allow operators and tower companies ("TowerCos") to reinforce their network infrastructure against weather events.

Table 9 Operators and TowerCos' efforts to upgrade and protect their networks

Control of environmental variables	All operators protect their active network equipment from weather-related elements using HVAC systems to control environmental variables (section 3.1). There are however differences between them in the scope of network elements with HVAC systems: One operator has installed HVAC in all its mobile sites[155]

151 In its written submission the operator explains that "*cutting back of all growth with an all-round clearance (i.e. underneath, overhanging, sides and rear of the new FTTH aerial fibre cable route) from within 1.5m of overhead FTTH aerial cable route.*"

152 Wildlife Act 1976 s40.

153 Information provided by stakeholder in course of study.

154 Information provided by stakeholder in course of study.

155 Information provided by stakeholder in course of study.

	whereas another operator reports[156] that its "*end of line*" sites[157] generally rely on natural cooling. Another operator notes[158] that in some cabinets without mechanical cooling, vents would have to be manually opened on a very small number of cabinets to aid air flow.
Protection from water	One operator reports[159] that it uses weather resistant equipment such as pressurisation of underground cables[160] and sealing of copper wires.[161] In the event of flood warnings, another operator reports[162] that it sometimes erects flood barriers in advance to protect its facilities.
Protection from lightning	Protection from lightning strikes is generally designed in to ECN equipment using a combination of ground rods, surge protective devices ("SPD"), surge suppressors and uninterruptible power supplies.
Indirect benefits from capacity upgrades	Planned network upgrades which are designed to improve the capacity and capabilities of ECN also offer opportunities to make infrastructure more resilient. For example, two operators have plans to overbuild their copper and HFC networks with FTTH networks and to replace MW backhaul links with fibre links. While the motivation for these programmes is not directly related to resilience to weather events, there are consequential benefits since new fibre networks tend to be less vulnerable to weather events. This is because: (i) copper infrastructure is in some cases very old and therefore degraded and more prone to fault; (ii) copper is more susceptible to damage resulting from water ingress; and, (iii) fibre links are not vulnerable to Rain Fade unlike MW links.
Structural reinforcement of passive infrastructure	On radio towers, TowerCos have maintenance programmes, which provide for structural reinforcements to cope with additional installation of equipment from existing or new tenants. Two operators have ongoing programmes to replace wooden pole structures with metal monopoles from their network as wooden poles are prone to splintering and cracking and are not suitable for mobile operators. On particularly vulnerable sites one operator reports[163] that buildings are designed with reinforced cables and roofs to protect from ice impact.

156 Information provided by stakeholder in course of study.

157 Sites that are located in remote areas, do not onward transmit traffic to other sites and that rely on MW links for backhaul.

158 Information provided by stakeholder in course of study.

159 Information provided by stakeholder in course of study.

160 Dry air thus generated is then injected into the telecommunication cables and sensors are installed and queried on a regular basis to detect anomalies due to flooding, geological stresses, or civil engineering.

161 Water and electricity do not mix well. It is important to keep the cables dry in order to ensure high data flows.

162 Information provided by stakeholder in course of study.

163 Information provided by stakeholder in course of study.

Moreover, culvert systems[164] are installed on access roads subject to flooding and fences are installed with additional ground bracing for wind survival.

5.2 Monitoring ECNs to detect outages

Operators need to determine, at all times, whether their networks are running optimally. Their networks are continually monitored and where faults occur, a dedicated Network Operation Centres ("NOC") is alerted. It is the responsibility of a NOC to oversee the network and identify potential faults and outages (which may or may not be weather-related) and direct responses.

The paragraphs below describe the main approaches used to monitor networks that have been reported by ECN operators.

Network monitoring tools

These tools measure how traffic is moving between network nodes and track the status of elements at different network levels. Typical KPIs that are monitored by ECNs are traffic volumes, bandwidth utilisation, radio signal levels, uptime, temperature, or battery voltage and capacity levels.

ECN operators have reported the following:

- One operator's NOC identifies degradation in Received Signal Levels and packet loss to detect issues on transmissions paths, for both MW & fibre circuits.[165] The operator's cabinets have internal and external temperature sensors installed to monitor equipment and batteries.
- One operator has temperature monitoring in place in all hub sites and at optical node level on the access network.[166]
- Another operator monitors power, network devices, and signal levels.[167]
- One operator checks transmission links for any errors or at-risk links that may be impacted.[168]
- Another operator can establish whether there has been any power, temperature, or access failure in respect of any equipment.[169]
- Another operator uses real time tools to monitor power alarming, temperature alarming and all out node and site level alarming.[170]

164 A culvert is a large-calibre rigid conduit used to channel water to drainage networks.

165 Information provided by stakeholder in course of study.

166 Information provided by stakeholder in course of study.

167 Information provided by stakeholder in course of study.

168 Information provided by stakeholder in course of study.

169 Information provided by stakeholder in course of study.

170 Information provided by stakeholder in course of study.

Bespoke Software Monitoring tools

ECN operators have developed bespoke tools to analyse their network data to identify irregular patterns that may be related to malfunction. For example, one operator has developed an inhouse digital tool to identify MW links with reduction in “fade margin”[171], which may be an indication of wind impact which caused movement or shift in the antenna’s position.

Field engineers’ reports during site visits

Automated tools installed in the network cannot provide a comprehensive view of the state of all network elements and ECNs still rely on human inspections.

Operators have reported the following examples of field reporting.

- One operator’s teams take stock of rented poles deterioration.[172]
- One operator’s teams test batteries on a quarterly basis for voltage levels & capacity quality and carries out preventative maintenance surveys on each site on an annual basis.[173]
- One operator inspects every site at least twice per year and its key sites are inspected on a quarterly basis.[174]
- One operator has winter and summer readiness actions performed by its field teams.[175]
- One operator inspects its power systems once per year.[176]
- One operator reviews its telecom towers on an annual basis.[177]
- One operator conducts regular audits of its colocation sites.[178]

End users reports

End users can report on faults with their service, or damage to infrastructure through dedicated channels or general customer service. For example, Eir receives damage reports from its users via its Dangerous Plant Reporting Line.[179]

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171 Information provided by stakeholder in course of study.

172 Information provided by stakeholder in course of study.

173 Information provided by stakeholder in course of study.

174 Information provided by stakeholder in course of study.

175 Information provided by stakeholder in course of study.

176 Information provided by stakeholder in course of study.

177 Information provided by stakeholder in course of study.

178 Information provided by stakeholder in course of study.

179 Information provided by stakeholder in course of study. See: https://www.openeir.ie/dangerous-plant-reporting/ .

Supplier notifications

ECN operators receive notifications from their suppliers (of electricity, wholesale network products, field intervention services, generators, etc.) and receive updates on incidents using ticketing systems:

- One operator's NOC receives alerts collected by multiple vendor management systems and sent to its industry standard monitoring platform.[180]
- Another operator's outages tracking process includes ticketing systems with suppliers and internal stakeholders.[181]

Using these monitoring approaches, operators can quickly identify and anticipate issues that can undermine network performance and lead to outages. The processing of the information gathered and the classification of outages varies between ECNs but generally involves a matrix of severity and scale (number of end users affected) with thresholds distinguishing what is business as usual from more or less serious incidents.[182] Once NOCs have detected and prioritised the impacts of weather events on their networks, they organise the appropriate responses using remote network controls or field interventions where appropriate.

5.2.1 Responding to weather warnings

All operators noted how they rely on the weather warnings from Met Éireann to prepare and support the resilience of their networks. When Met Éireann warns of upcoming orange or red weather warning events and when the number of outages due to a weather event goes above pre-defined thresholds, NOCs can increase the monitoring of the impacted area and investigate all outages or anomalies in transmission links with particular attention.

In response to orange or red weather warnings, operators can proactively plan to manage the impact of severe weather. For example, one operator (which has an extensive and geographically dispersed network and workforce) outlined that it can put teams in certain geographic areas "on alert". In the case of severe disruption, it can repurpose teams away from installations in certain areas to remedying faults; or it can move teams around to different parts of the country to anticipate potential faults in certain affected areas. Operators stated that the warnings provide the opportunity to contact their external contractors who support their sites.

One operator stated[183] that the inherent uncertainty about where, and what types of faults might occur, meant that significant pro-active planning was not feasible, and that they instead respond reactively to faults that arise.

All operators noted how the warnings can also constrain how repairs can take place, given that a red weather warning implies that individuals should take action to protect themselves, for example by staying inside. This

180 Information provided by stakeholder in course of study.

181 Information provided by stakeholder in course of study.

182 Information provided by stakeholder in course of study.

183 Information provided by stakeholder in course of study.

can imply that it is not possible to travel to site to repair faults. Conditions implied by orange wind warnings[184] mean that winds may be too high to climb structures to make repairs.

One operator noted that orange wind warnings could cover relatively wide geographic areas, for a prolonged period, and that localised conditions within the warning area may not be as severe as indicated by the weather warning.[185] The operator questioned whether in some cases the warning could unnecessarily delay the repair work by restricting the actions of contractors and employees. However, other operators noted that the decision of whether it is safe to climb structures would be taken by the individuals concerned based on local weather conditions (for example measured using handheld anemometers that measure wind speed), not the warning itself.

5.2.2 Reporting outages to ComReg

As part of the reporting obligations under Regulation 23 of Framework Regulations 2011[186], ECN operators are required to notify ComReg if the outage has as a significant impact on the operation of their network. During storms operators may also be required to provide to the National Emergency Coordination Group[187] ("NECG") twice daily updates about:

- the service the outage affects (i.e., fixed/mobile voice, fixed/mobile broadband/data);
- the areas affected;
- the number of sites affected (for mobile networks), but HFC Nodes or exchanges could be given for fixed networks too; and
- the general cause (ESBN power failure etc.), and an estimate, if possible, of the number of end users affected.

These updates continue until the networks return to, or approach, normal levels of availability (0.5-1% of sites out).[188]

After weather events with a large impact, three operators[189] [190] [191] conduct post incident reviews to document what happened; try to identify the causes; review the details of remedial work; and assess if steps could have been taken to reduce the overall service downtime.

184 An Orange Wind warning implies mean Speeds between 65 and 80 km/h, and gusts between 110 and 130 km/h.

185 Information provided by stakeholder in course of study.

186 Directive 2002/21/EC (the "Framework Directive"). The Framework Directive has been repealed (along with Directives 2002/19/EC, 2002/20/EC and 2002/22/EC) by Directive 2018/1972 establishing the European Electronic Communications Code (the "Code") with effect from 21 December 2020. However, as matter of Irish law, the Framework Regulations are still in effect, and have not yet been replaced by new measures transposing the EECC.

187 The NECG is the central government platform established as part of the response to a threatened or ongoing national level emergency and is convened and chaired by the relevant lead government department.

188 ComReg Standard Operating Procedure: Network Resilience: Storms and Other Natural Phenomena 1.1.5.

189 Information provided by stakeholder in course of study.

190 Information provided by stakeholder in course of study.

191 Information provided by stakeholder in course of study.

5.3 Considering wider climate risks

Most operators in Ireland currently do not explicitly consider climate change related risks to their networks. Only two of the operators interviewed have reported specific work on the subject.

One operator has commissioned a climate risks report from external consultants.[192] This report assessed the network's resilience to weather-related risks and to climate change. It was commissioned as part of the operator's wider Environmental, Social and Governance ("ESG") objectives and highlighted potential vulnerabilities of the network, as a result of climate change, which the operator took action to remedy.

Another operator[193] participated in a Climate Scenario Analysis Workshop (alongside its fellow "sister" operators active in other countries), organised by its parent company, to identify the risks and opportunities of different climate change scenarios.[194] The workshop was carried out in order to understand financial implications of climate change risks and strategic resilience of its networks, and to help with reporting required for the Task Force on Climate-Related Financial Disclosures[195] ("TCFD"). Once the exercise has been completed, the operator will use the findings to inform a similar exercise at the Ireland level.[196]

While other operators did not specifically consider climate change related risks, they design their networks to be resilient to a tolerable range of temperatures and to reasonable expected changes in environmental conditions.

5.4 Dynamically changing networks capabilities to protect basic services

During outages, wireless ECNs can temporarily reduce the capacity provided or shutdown functionalities over wireless transmissions to maintain a basic standard of service. Table 10 describes such capabilities in Ireland's ECNs.

Table 10 Dynamic network management

Operator	Reported actions
Wireless operator	Traffic management techniques - such as reducing bandwidth to reduce power consumption - are part of procedures on equipment that run on non-refuellable power supplies.[197]

192 Information provided by stakeholder in course of study.

193 Information provided by stakeholder in course of study.

194 Three scenario were considered: Scenario 1 – an orderly transition to 1.5 degrees; Scenario 2 – a delayed transition whereby action ramps up sharply after 2030, leading us to a 2 degrees outcome; Scenario 3 – no action beyond current policies, with a temperate outcome of 4 degree rise by the end of the century.

195 https://www.fsb-tcfd.org/about/ .

196 Information provided by stakeholder in course of study.

197 Information provided by stakeholder in course of study.

Operator	Reported actions
	In its hub sites, the operator also prioritises MW links with so called "*child sites*" (or "end of line sites) over local service in order to allow for longer duration of off-grid operation.[198]
Wireless operator	Voice service is considered a priority and protected by *"locking down layers with a higher power usage such as 5G and some 4G layers"*.[199]
Wireless operator	In times of poor weather conditions, the transmission of signal on MW links can be adapted to cater for reduced Received Signal Levels on MW links.[200]
Wireless operator	Power efficiency features in the RAN network can deactivate technology layers for 4G and 5G where traffic levels are lower, while at all times, sustaining voice and data performance for its customers.[201]

5.5 Gaps in adaptation actions

As set out above operators invest significant amounts to support the resilience of their networks, including resilience in the face of weather events. However, the challenge of climate change means that ECN operators need to build resilience not just to current conditions, but to future changes in Ireland's climate. Discussions with ECN operators suggest that there may be some gaps that could support the ability of the sector to adapt to climate change.

These relate to:

- gaps in information on weather trends, past events or network infrastructure.
- scope for greater cooperation between stakeholders to maintain networks.
- a more consistent approach across ECN operators to some aspects of responding to weather events.
- scope to increase the power resilience of ECN.

5.5.1 Information on network vulnerabilities and climate risks

Network vulnerabilities

The lack of information on the location of network vulnerabilities in previous years may affect the ability of newer ECNs to design their network in a way that is resilient. For example, one newer operator[202] noted that it did not have the same "corporate memory" as more established operators to identify the parts of the network

198 Information provided by stakeholder in course of study.

199 Information provided by stakeholder in course of study.

200 Information provided by stakeholder in course of study.

201 Information provided by stakeholder in course of study.

202 Information provided by stakeholder in course of study.

that are more vulnerable to weather-related risks. The operator suggested that greater sharing of information on potential vulnerabilities could potentially support its network's resilience.

Given the large impact on network services from the electric grid's outages (planned or weather-related), information sharing between electricity suppliers and ECNs could benefit from more frequent or granular updates. For example, one operator sources its electricity from a third party and explains that it does not have visibility of the duration or cause of power outages. According to the operator[203], it does not receive notification in advance of planned maintenance, and these are thus recorded as faults on its network, which can lead to a suboptimal response. However, other ECN operators considered that communications with ESBN regarding power interruptions were sufficient.

Impact of climate change

Two operators[204] see also a potential need to be able to access more information on how climate change will manifest itself in Ireland over the long term. Both expressed interest in information sessions hosted by state bodies to advise on the current and future impacts of climate change on network resilience as well as best practice in response to weather events and climate change.

While only indirectly related to climate change, two operators[205] expressed more general concerns regarding the stability and security of energy supply from the grid over next months and years, given how geopolitical concerns in 2022 have affected energy supply in Europe.

Weather warnings

Two operators[206] queried whether Met Éireann's warnings could be more precise. The areas concerned and estimated durations are sometimes larger and longer than necessary in certain geographic locations. They are concerned that this may prevent timely interventions from response teams which may choose not to climb or travel while warnings are still active.

5.5.2 Barriers to collaboration

One operator pointed to potential barriers to collaboration[207], which according to it allegedly results from the regulatory framework. The operator questioned whether the regulatory framework inhibited the willingness of another operator to effectively collaborate and share information about the state of its infrastructure.

For example, the renting operator needed to understand risks related to the letting operator's poles (i.e., the age of poles, condition of poles or last time tested) to ensure that its services are resilient. The renting operator opined that the letting operator may have less incentive to maintain a sufficient quality standard for

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203 Information provided by stakeholder in course of study.

204 Information provided by stakeholder in course of study.

205 Information provided by stakeholder in course of study.

206 Information provided by stakeholder in course of study.

207 Information provided by stakeholder in course of study.

overhead infrastructure in areas where its legacy infrastructure will be phased out and hence the renting operator's cable will be the only user left on the letting operator's poles.

5.5.3 Consistency gap

There is some inconsistency in how operators record and respond to severe weather events.

Recording weather-related outages

The granularity of information recorded on weather-related incidents differs between operators. The lack of a shared reference standard to measure basic indicators such as user hours losses[208] limits the possibilities of comparisons between operators' practices.

Operators' storm plans

There are differences in how ECNs codify their responses to severe weather.

As part of its written response to our Information Request, one operator supplied its "*Storm readiness pack*" detailing processes and guidelines that its monitoring and operational teams follow in the event of any storm with the potential to cause damage to the network. The document includes a contact matrix of key stakeholders in the operator's and its suppliers' organisation, the actions to be performed during each stage of storm management (S*torm prep, Enhanced monitoring, Storm mode, Enhanced comms, Storm clean-up, Back to BAU*) and the templates for storm outage tracking, and communication bulletins.

Four operators noted they had a "storm protocol" describing how they responded to storms. Others had less "formal" responses to severe weather events.

5.5.4 Supporting resilience in power supply

As set out in section 3.5 weather-related interruption to power supply has the biggest impact on end users. Therefore, actions to support power resilience could have significant positive impacts for end users.

A more consistent and transparent approach to battery backup

Battery backup is an important network resource which supports the functioning of ECN in case of outages, including for weather-related outages. However, there is a significant variation in the practice of battery backup.

There are clearly good reasons why different networks elements might be associated with different levels of battery backup:

- more backup resources may be allocated to network equipment that has a greater impact on end user; or

[208] The European Electronic Communications Code (EECC) lists criteria to assess how significant a security incident is but it does not include user-hour losses and it do not specify how metrics should be measured.

- the use of alternative approaches to maintaining power in the case of an interruption to supply might negate the need for battery backup.

Nonetheless it appears that some of the variation relates to differences in how operators weigh the costs and benefits of supporting a resilient power supply.

Coordination with ESBN on power supply restoration

ECN operators all reported good relationships with operational counterparts at ESBN who support repair to power networks in the case of outages. However, some ECN operators noted that in the event of outages ESBN would not prioritise the restoration of power to an ECN over other users, even though the ECN supported many end users including some critical services. Operators noted that this could delay restoration of ECN services to end users.

6 Power consumption of ECNs

Power consumption is an important and costly input for operators. More efficient management of power can support efforts to both adapt to the effects of climate change and mitigate climate change by reducing GHG emissions. Reducing power consumption can benefit adaptation as more power-efficient networks require less battery backup and therefore are more resilient to outages (for a given level of battery backup).

This section reports on how operators are adapting networks to reduce power consumption and thereby support adaptation objectives.

6.1 Power is an important input for ECNs

Power is an essential input into ECNs, as it is necessary to run network equipment, ensure transmission of data over long distances and regulate the environmental conditions of sites where equipment is hosted. The key drivers of power consumption in ECNs are environmental control, and the electricity usage of fixed networks, wireless networks, transport and core networks.

Fixed networks

In fixed access networks electricity is needed for switching equipment at exchanges, cabinets and other nodes which process and send optical signals over the fibre lines. It also plays a vital role in copper and coaxial cable networks where information (data and voice) is transmitted by electric circuits between the end user and the exchange.

Two operators explain that power consumption is tightly correlated to access network footprint as network expansions drive new fibre cable to be lit and therefore powered.

Wireless networks

In wireless networks, electricity is needed in both the switching equipment and in base stations, which have the largest share of the energy consumption of cellular networks.[209] The power consumption of a base station can be divided into two groups of elements:

- the antenna system and the RF equipment (power amplifiers and transceivers); and
- the support system which includes alternate current/direct current (AC/DC) power conversion modules, air conditioning elements, analogue and digital signal processors, battery backup.

The element that consumes most energy in the base station is the power amplifier, which converts the low-power RF signal into a higher power signal that can be fed to the antenna. Even if technological progress has enabled significant improvement in power amplifiers' efficiency, there is a trade-off between power efficiency and spectrum efficiency which physically limits further power consumption gains.[210] In the support

[209] Estimated at 57% according to latest literature: Ioannis P. Chochliouros et al. Energy Efficiency Concerns and Trends in Future 5G Network Infrastructures, 2017.

[210] Kazuaki KUNIHIRO et al., High Efficiency Power Amplifiers for Mobile Base Stations: Recent Trends and Future Prospects for 5G, 2018.

system, the elements that consume most power in descending order are air conditioning, digital signal processing and AC/DC conversion elements.

Transport and core networks

At the transport and core level, power consumption increases proportionally to capacity, which is growing with increases in data demand. Offsetting this driver of increasing power demand, is the rate of technological progress which drives efficiencies in how data is processed.

Environmental control

Air conditioning and more generally “environmental control” is used to regulate temperature at important parts of the ECN. Equipment needs to run within a specified temperature range to work efficiently. Running the equipment generates heat which needs to be dissipated for the equipment to run smoothly. In some cases, this is done “mechanically”, i.e. with ventilation which allows heat to escape naturally, passive convection. In other cases, where there is a large concentration of equipment (such as at exchanges, major nodes or in datacentres housing core networks) environmental control is regulated with powered HVAC.

6.2 Power consumption of ECNs in Ireland

ECN operators provided estimates of the power consumption of their networks. There is a degree of variation in how ECN operators monitor power consumption. ECN operators do not all measure electricity consumption with the same degree of granularity. Furthermore, they may rely on different electricity suppliers with variable levels of disaggregation in invoices which makes identifying power consumption at different parts of the ECN problematic.

Figure 12 shows that the annual power consumption of Ireland-wide wireless networks is between 40 GWh and 70 GWh and in total represents approximately 0.6% of Ireland’s total consumption.[211]

Figure 12 Annual power consumption of wireless networks in Ireland

[✂ [redacted] ✂]

Figure 13 shows that before benefits of the transition from legacy technologies, older fixed-line networks require a considerable amount of power compared to other fixed operators (even when adjusting corresponding footprint) or to wireless operators.

Figure 13 Annual power consumption of fixed-line networks in Ireland

[✂ [redacted] ✂]

[211] All-Island Generation Capacity Statement 2021, 2030, Eirgid.

6.3 Power consumption reduction strategies

Operators have three distinct but aligned incentives to reduce power and, or, to reduce their power emissions including the following.

- **To support resilience of the networks.** More power efficient equipment increases the duration of backup solutions and thus reduces the risk of outage due to mains power failure. It may also eventually reduce the need for on-site intervention from field teams to install or refuel backup equipment. One operator in particular listed resilience as an important objective.[212]

- **To manage costs**. Power is a major cost component for delivering ECN. To manage their operational expenditure, operators seek to reduce power. The spike in energy prices observed in 2022 has provided even greater impetus to ECN operators to reduce energy consumption.

- **To promote climate change objectives**. ECNs in Ireland recognise the role that they play in supporting climate mitigation strategies to reduce CO_2 emissions. They therefore seek to reduce unnecessary power consumption on their networks.

Among measures intended to reduce power consumption, many relate to business-as-usual replacement and upgrade of existing network equipment and infrastructure. When existing infrastructure and equipment reaches its end of life ("EOL"), or operators make planned upgrades to their networks (replacing fixed access network infrastructure such as copper or HFC with fibre), then operators can make power efficiency savings.

The following sections describe specific methodologies and practices (including their efficacy and expected savings) used by ECN operators to reduce power consumption in their networks over the next three years.

6.3.1 Power reduction in the core network

Network upgrades offer opportunities to make power consumption reductions and efficiencies.

One operator explains that it is constantly modernising its network platform and in recent years "*has replaced its traditional DMS 100 switches that used to occupy some 250 floor tiles*[213] *each to be replaced with state-of-the-art switches that only cover 24 floor tiles each*".[214] The operator further adds that "*the replacements are more powerful in terms of carrying telephone traffic for less electricity input, are cheaper to cool and have less parts to go faulty thus saving resource and all the additional energy elements of arranging repairs*". [215]

212 Information provided by stakeholder in course of study.

213 Floor tiles are 24" x 24". They provide the means to not only act as a platform to support equipment but also to create a space that can facilitate air circulation air conditioning systems.

214 Information provided by stakeholder in course of study.

215 Information provided by stakeholder in course of study.

Another operator is installing heavy duty dividing curtains in some exchange buildings to reduce the space that requires cooling and reports that the retirement of legacy equipment, subject to regulatory consent, will subsequently reduce energy consumption.[216]

One operator has plans[217] to "*upgrade and replace some elements of core routing, SDH, CWDM and Telephony Switching platforms, with more efficient, higher capacity technologies, over the period 2022-2025*". This is expected to prevent any "*increase in the electrical load offered by its technical sites despite offering higher capacity*".

6.3.2 Power reduction in fixed-line access networks

The planned upgrade of fixed access networks provides opportunities to make power reductions, since copper and HFC networks have much higher power requirements than fibre networks.

One operator estimates that the shutdown of the HFC infrastructure and elimination of the associated electrical load, will reduce its power consumption by approximately 16,000 MWh annually.[218]

Cooling units in fixed access networks also offer scope for power reductions. One operator is currently conducting a Power Usage Effectiveness review across its technical sites.[219] The primary focus of this initiative is environmental control and efficient site cooling. The operator expects to achieve a >10% reduction in power consumption across its technical sites because of this initiative, over the period 2022-2025.

6.3.3 Power reduction in wireless access networks

Upgrading network equipment

Reduction energy consumption in cellular access networks can be achieved by improving the individual components or the way they are used in the functioning of the network.

Mobile ECN operators have built their ECNs with a mix of legacy technologies. When they add a new technology on a site, they can either install new dedicated equipment or decommission all legacy equipment and replace it with a new "Single RAN" base station supporting all spectrum bands. According to one operator[220], upgrades to "Single RAN" base station could allow for 15 to 18 kWh savings per site per day (5.5 to 6.5 MWh per year). This amount is to be compared to an estimated power consumption of 70kWh per day (25 MWh per year) per base station on another operator's network. Another operator is also gradually switching off its 3G network and indicates that 4G can deliver 70% energy saving compared to 3G.

Upgrading power supply components also offers scope for power reductions. The primary electricity source for base stations is Alternating Current ("AC") from the electricity grid. It directly feeds components such as air conditioning but other components such as batteries or baseband and radio units rely on Direct Current

216 Information provided by stakeholder in course of study.

217 Information provided by stakeholder in course of study.

218 Information provided by stakeholder in course of study.

219 Information provided by stakeholder in course of study.

220 Information provided by stakeholder in course of study.

("DC") input. ECN operators therefore use 'rectifiers'[221] to convert AC to DC but this process leads to power conversion losses. To limit such losses, one operator is examining a plan to replace 1,000 standard efficiency rectifier modules (with 91% efficiency) in access network sites with super high efficiency versions (with ~97% efficiency). This initiative is expected to save approximately 2,600 MWh over 3 years.[222] Another operator also references replacement of rectifiers for more power efficient models (from 88% to 98%) equating to approximately 5kWh savings per day (1.8 MWh per year) per site.[223]

Upgrading cooling units offers additional efficiency savings. Cooling units control the temperature in mobile base stations equipment by removing heat through convection, conduction, or liquid technologies with varying levels of energy efficiency. One operator stated that it is replacing its base station cooling units to more power efficient models with expected savings of 7kWh per day (2.5 MWh per year) per site.[224]

Network optimisation techniques to reduce power

When traffic is low, some components or technology layers can be temporarily switched off or put into standby mode which reduces power consumption through dynamic management of network resources.

One operator has activated such power efficiency functionality in its RAN network, deactivating technology layers for 4G and 5G where traffic levels are lower, while at all times sustaining voice and data performance.[225] This initiative uses intelligent data analysis to assess network traffic and reduce technology layers as relevant, for each RAN site. The operator reports that this has delivered over 15% power efficiency savings in 2021.

Another operator has implemented cell sleep functions on new equipment rolled out on its network and observes savings of about 10kWh per day (3.7 MWh per year) per site.[226]

Dynamic management of network resources could be extended beyond current implementation to enable larger savings. For example, it would be technically possible for mobile ECN operators to have reciprocal roaming agreements where one operator completely switches off some base stations during low traffic load and reroute its RAN traffic in an area to a partner network. This could maintain levels of network competition while providing efficiencies. According to literature, such an approach can offer reductions in energy consumption by 20%.[227]

Figure 14 shows the projected effects of the power reduction techniques described in previous paragraphs as reported by one operator. However, the operator also notes that the gains from power efficiency programs

221 Rectifiers refer to two main types of regulated power supplies that can provide a stable direct current: linear power supply and switched-mode power supply. Switching power supplies feature higher efficiencies, lighter weight, longer hold up times, and the ability to handle wider input voltage ranges. Linear power supplies are usually less expensive, but are limited in capability and tend to be larger in physical size.

222 Information provided by stakeholder in course of study.

223 Information provided by stakeholder in course of study.

224 Information provided by stakeholder in course of study.

225 Information provided by stakeholder in course of study.

226 Information provided by stakeholder in course of study.

227 Marsan M.A., Meo M. Energy efficient management of two cellular access networks. ACM SIGMETRICS Perform. Eval. Rev. 2010.

will be offset to a large extent by network growth and additional spectrum as it expects only a 5% reduction in its total RAN power consumption between 2022 and 2025.[228]

Figure 14 Power reduction techniques in one operator's base stations

[✂[redacted]✂]

Micro-generation activities

Some operators are trialling more innovative ways to reduce reliance on the electricity grid. Four operators [229] [230] [231] [232] are exploring the possibility of installing photovoltaic panels and wind turbines on the base station sites to reduce power emissions. Such micro-generation solutions could also support redundancy and backup to a degree, by providing alternative power sources in the event of a power failure. However, these trials are at an experimental stage and the economic case is not yet proven.

6.4 Summary and conclusions

All operators are considering activities to reduce power use within their networks. The sudden increase in energy prices seen in early 2022 gave all operators further incentive to consider how they can reduce energy costs:

- by providing their services in a more energy efficient way (through dynamic network adaptations);
- by using primary energy more efficiently (with newer more efficient equipment); or,
- by increasing the use of microgeneration.

Operators have also raised wider concerns about energy security during the winter period (matters which are beyond the scope of this report).

Dynamic adjustments of network capacity to reflect demand in mobile networks and upgrades of their networks to replace aging equipment with modern more efficient equipment have offered opportunities to reduce power consumption. However, operators have stated that it is in many cases not economical to replace existing equipment that is still "serviceable" with newer, more efficient alternatives.

Several operators also noted that it could be difficult to accurately measure energy consumption, except in an aggregated way for a number of reasons:

- their equipment was not, or could not be individually metered;

[228] Information provided by stakeholder in course of study.

[229] Information provided by stakeholder in course of study.

[230] Information provided by stakeholder in course of study.

[231] Information provided by stakeholder in course of study.

[232] Information provided by stakeholder in course of study.

- they did not directly have a contract with a power company; or,
- their internal systems did not gather and aggregate this data.

This lack of information could impede the ability of operators to identify potential scope for energy reduction, efficiencies and resilience.

7 Conclusions and findings

Network outages resulting from weather-related network failures are not common occurrences for most ECN users, nonetheless, outages related to weather affecting both fixed and wireless ECN occur each year. While most outages might affect only a small number of end users, the occasional severe weather events can lead to larger scale outages affecting more users. These have significant and growing impacts for the end users and businesses that rely on ECNs for many reasons, including:

- a greater volume of data carried on ECNs;
- the increasing propensity of end users to consume media content using ECNs;
- the reliance by businesses on ECNs to communicate and transact with suppliers and customers; and,
- the fact that workers are now more reliant on reliable ECNs to support remote working.

As society’s dependence on ECNs grows, so does the importance of ensuring that ECNs are resilient to the challenges brought by Ireland’s changing climate.

This report summarises the vulnerabilities of ECNs and explains how higher levels of resilience and redundancy are designed into transport segments of networks. But networks can be vulnerable in parts of the network closer to end users, particularly in the access networks that connect users to ECNs.

The impact of climate change may increase the vulnerability of ECNs. Long term projections produced for the EPA present complex changes in Ireland’s climate. This is typified by a slightly more benign weather pattern *on average*, but with *increased frequency or intensity of severe events*. The central projections modelled predict that:

- temperatures will increase with greater frequency of heatwaves;
- *average* wind speeds will decline, though the *intensity* of winter storms will increase; and
- *average* rainfall is projected to decline, though the *frequency* of heavy precipitation events will increase.

As the climate is predicted to continue changing over the coming decades, ECN operators are already preparing for, and adapting to, the changes associated with the climate. As set out in this report their adaptation actions include the following.

- ECN operators already design resilience into their networks ensuring their equipment and infrastructure, is resistant to environmental challenges.
- They regularly monitor the state of their networks and undertake actions to replace worn, degraded elements, or reduce risks (for example tree trimming programmes).
- Furthermore, the technology cycles in ECNs imply that network equipment is replaced on a regular cycle, which offers opportunity for renewal, and replacement with more modern resilient equipment. For example:
  - Three operators are upgrading mobile networks to 4G and 5G; and,
  - Four operators are rolling out new fibre fixed networks which are more resilient that legacy technologies such as copper fixed access networks.

Nonetheless, by identifying areas of vulnerability, and considering the differing approaches taken by ECN operators, this report identifies a number potential further measures that could be put in place, to avoid or minimise future adverse impacts within the communications sector to adapt to climate change. The findings from the report have been grouped into three main areas.

7.1 Adopting a proactive approach to planning for climate and weather-related risks

ECN specific Climate Action Plans can benefit the ECN's resilience to the current and future impacts of climate change

Two operators declared that they conduct risk assessments that specifically consider the risks related to climate change[233] and which contain adaptation measures specific to their business requirements. One operator that undertook such a review noted that the review highlighted vulnerabilities relating to flooding of plant buildings.

Other operators reported that they tended to consider that their networks are resilient to weather and that climate change is a process that has measurable effects on network vulnerability potentially beyond the asset lives of network equipment.[234]

A climate risks assessment could consider the risks and vulnerabilities of the ECN's network in the context of the climate change projections. This could include provisions to ensure current and future climate change impacts are specifically accounted for in the planning and design standards for their ECN.[235] As standards are changed and updated to reflect changing climate risks, these can be reviewed and if necessary incorporated into ECN providers' Climate Action Plans.

Many ECN operators regularly review their contingency plans for responding to weather-related outages

In response to our consultation, many operators noted that they have written and codified plans for responding to weather-related events. For example, four operators outlined that they had a "storm protocol" describing how they responded to storms. Others had less "formal" responses to severe weather events. Plans can include detailed description of how ECN operators monitor and respond to Met Éireann's orange and red warnings (e.g., ensuring that they are aware of the warnings as soon as they are published). Contingency plans can set out how teams can be put on alert to quickly respond to outages, and if necessary, how resources can be reallocated to repairing faults. These plans could be published to provide assurance to end users and other stakeholders on how communications network operators respond to outages.

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233 See section 5.3.

234 Information provided by stakeholder in course of study.

235 ECN providers can rely on many different standards which are agreed by standards bodies which set out best practice for the design and installation of ECN equipment. One example is the CSN standards on Communication conductors and cords, LF, HF and coaxial cables, though there are many others.

7.2 Supporting the resilience of ECNs' network infrastructure

ECNs are designed to withstand reasonable variation in environmental conditions. Nonetheless, this report has highlighted adaptations that could reduce the vulnerability of point-to-point wireless links to weather-related events.

Ensure that planned maintenance and upgrade programmes account for climate risks

ECN operators already have a programme of maintenance and technology upgrades which support increased resilience of their networks. This ongoing programme could reflect any risks identified as part of their Climate Action Plans and ensure that equipment and approaches used to build and maintain their infrastructure remain consistent with best practice standards which evolve to reflect the changing climate.

Greater resilience can be achieved when remote communication nodes are connected with fibre links

One operator noted that remote nodes, that rely on point-to-point wireless links, face a number of weather-related challenges given their locations (often in exposed positions in high ground)[236]. Heavy precipitation can lead to Rain Fade which can impair the signal; or wind can shift an antenna's position out of alignment reducing the capacity of the link. If fibre backhaul was available to these sites, they would be more resilient.

7.3 Enhancing power security of ECNs

A significant source of weather-related outages for fixed and mobile end users comes from a loss of power to certain ECN nodes. Therefore, there are several findings that could benefit power security of ECN infrastructure.

Ensuring ECN operator sites have appropriate battery backup in the event of an outage

There is a wide range of practices adopted by ECN operators regarding battery backup.[237] ECN providers make their own judgement on the appropriate backup solutions, based on their assessment of the risks and cost of providing back up. While different ECNs and sites would require different backup needs (sites supplying small number of users might have less backup than hub sites supplying large number of users), there currently appears to be wide variation in backup provided. This inevitably means that end users can have variable outcomes from severe weather events, depending on the choices that their ECN providers make.

TowerCos could provide battery and generator backup services with site rental

In multi-operator sites operated by TowerCos, each operator has responsibility for providing its own battery or generator backup. This can be costly, especially where there is limited space to store the bulky equipment. It may also be inefficient when, in the event of a power failure, a number of distinct generators are supplied to site by each of the operators which are tenants at the site. It could be more efficient for TowerCos to provide a central backup solution directly to the tenants of the site. This could guarantee a minimum level of

236 See section 5.1.1.

237 See Table 8, section 5.1.1.

backup if there is a power outage, negating the need in many cases for operators to supply their own equipment.

Continued activities by ECN operators on the use of renewable energy

All ECN operators recognise the contribution that ECNs play in climate change. While ECNs can support climate goals (for example by reducing transport emissions) they also consume power which can cause GHG emissions. Some ECN operators have considered the use of microgeneration at their network sites (such as solar PV) to reduce the power requirements of the network. However, operators reported that at this stage it is unclear that switching to microgeneration is economically viable or practicable in some cases.[238] ECN operators could continue to pilot and investigate how to commercialise renewable energy. They could consider whether collaborating in investing in renewable energy sources (for example at remote sites) would prove more cost effective.

Monitoring of the power consumption on ECN and active identification of power reduction measures

For many ECN operators reductions in power consumption are considered mainly as a by-product of network upgrades. Some operators noted that they did not have ready access to power consumption data at different network nodes and sites, which in turn makes it difficult to assess variation at power consumption at the sites and consider the economic viability of investment to support power reduction.

ECNs Critical National Infrastructure (“CNI”) yet their services are not routinely considered as a priority by ESBN when it undertakes actions to restore power.

Three ECN operators noted that given ECNs supply services to CNI services (such as emergency services and broadcasters), ECN could be considered as a high priority when ESBN is conducting repairs (see section 3.1).

238 Microgeneration using renewable electricity sources is unlikely to support a site’s full load but could help extend operation during power outages as a cheaper alternative than diesel generators.

Annex A - Questionnaire to stakeholders

A1. Identifying vulnerable elements in Fixed Access/Mobile Access Network

In this questionnaire we wish to understand how different extreme weather events can create vulnerabilities at different points in ECN. The scope of network infrastructure considered in the questionnaire includes all passive and active elements that you operate (user terminals, sockets / wiring in premises and handsets are not included)

1. Please use Table 1 to provide a qualitative description of the different types of extreme weather-related vulnerability, which affects your ability to deliver services. If available, please provide actual examples, illustrating the different types of weather related outage, specifying the date, location, type of outage and providing any photos if available.

For each type of weather event, can you describe whether and how this creates vulnerabilities for your network:

- what exact parts/elements are damaged? (RF equipment, masts, poles, overhead/underground cables, microwave backhaul equipment, chambers, street cabinets, Heating Ventilation Air Conditioning[239] (HVAC), primary or backup power supply, or even indirect elements like roads needed to access damaged sites);
- what kind of damage;
- how often such incidents occur;
- how severe are they in terms of user-hours lost and difficulty to repair?

Table 1 Classification of vulnerabilities separate table

Extreme weather event	Network elements affected	Describe damage to network elements	Frequency of occurrence (rare, occasional, most common)	Impact on users and network (none, limited, large)
Excessive Wind				
Precipitation				
Rising sea levels and coastal flooding				
Localised flash flooding				
Lightning strikes				
Heatwave[240]				

[239] This should include HVAC overload due to heating or cooling maximum ratings being exceeded.

[240] Since ICT equipment and facilities usually require proper cooling for their performance management, longer and more intense heat waves increase the risk of performance degradation and even device failure

Extreme weather event	Network elements affected	Describe damage to network elements	Frequency of occurrence (rare, occasional, most common)	Impact on users and network (none, limited, large)
Severe Cold[241]				
Snow and ice fall				
Other? (landslides, humidity, bush fires…)				

Note: * **Please specify if the network element affected is part of RAN, fixed access network or backhaul / transport network**.

2. In your operations, describe differences between vulnerability of copper or coaxial cable vs fibre elements on your network? For example, is there increased risk of corrosion or short circuit from flooding or water ingress with copper elements, how does this affect users?
3. Please describe how different network elements are damaged or degraded *over time (i.e., not necessarily during a weather event)* as a result of weather (impact of wind or precipitations).

A.1.1 - Inventory of weather-related incidents

4. Please provide an inventory of weather-related outages that have occurred *on your communications network* since January 2017 using Table 2 as a template (see attached excel spreadsheet). For the avoidance of doubt, these should include named storms, as well as other weather-related outages. Where data is not available, please explain why this is not available.

Table 2 Inventory of weather related outages in your network

Date	Description of Weather event *	Network elements affected[242]	Cause of outage	User hours losses	Users affected

Note: Each weather event represents one row. Description of weather event can be a named storm or otherwise a description of the weather that affected your network. Network element affected should specify whether the failure was on your network or on a supplier's network. * **Please specify if the network element affected is part of RAN, fixed access network or backhaul / transport network.**

5. Please describe how different factors can act as a barrier to remedying a weather-related outage, for example lack of access to sites, failures of supplier networks (please specify), component or workforce shortages. Please provide relevant examples where this has happened.

A.1.2 - Current and planned mitigation/adaptation measures to reduce risks associated with weather related outages

241 Semiconductor parts are most often specified for use in the ''commercial'' 0-70°C range.

242 Please if the network element affected is part of RAN, fixed access network or backhaul / transport network.

6. Can you describe how your communications network is monitored for weather-related failures and how these are detected?
7. What level of service outage is considered an outage that is greater than Business As Usual ("BAU") and how is this defined? (what KPIs are used?)
8. In relation to redundancy provisions to mitigate weather related outages:

   Can you describe redundancy provisions across the different parts of your network which mitigate weather related outages?

   How do you assess the requirement for power diversity or redundancy? Where is backup power supply typically installed (Exchange, street cabinet, Radio Access Network cell tower, etc)? What type of backup power supplies are used (diesel generators, battery, micro generation).

   Do you have alternate routing procedures for transport network to mitigate risk of network failure? If yes, please specify whether they are automatic or manual? And do you have plans to build further routing diversity or redundancy?

   Can you manage traffic on your parts of your Radio Access Network to maintain a basic standard of service in as wide a coverage area as possible (e.g. temporarily shut down specific technology layers, temporarily capping data rates and/or specific carrier layers when using backup power supplies.
9. Can you describe your tree trimming programme?
   - What was the expenditure on tree trimming in the last five years?
   - What is the level of BAU tree trimming (eg number of trees trimmed)? If so provide data for the last five years.
   - Who is responsible for trimming trees close to your overhead cables? (your organisation, other networks (power provider), local government, landowners)?
   - Are there legal/practical barriers to access trees that need to be trimmed?
   - How are tree related risks identified/monitored, prioritised and actioned?
10. Can you describe your pole replacement programme?
    - How many poles do you own? And how many do you replace every year?
    - What is the mix of materials for poles installed in your asset base and their corresponding expected lifetime?
    - How is the state of poles monitored?
    - Are there plans to bury some segments of overhead cables? If so, what are these?
11. Are there any specific work programmes in place to improve the resilience of your network to weather related events?
12. What other BAU actions are undertaken by your organisation to protect from different extreme weather events: wind, electrical storm, flood, heat, snow and ice?
13. How do you quantify the effectiveness of measures implemented to mitigate weather related damage ? (eg tracking outages, number of people affected, hours lost).
14. Does your company have a Climate Action Plan, or similar, which identifies vulnerable infrastructure within your communications network to the current and future impacts of climate

change. If not done so via a Climate Action Plan is there another methodology your company uses to capture this information?

15. Does your company have any interactions with state bodies such as Climate Ireland and Met Éireann relating to developments in and understanding of climate change impacts?”

16. What further adaptation actions do you consider need to be taken in your communications network to address current and future impacts of climate change on network resilience (description of action, planned dates, expected impact etc).

A.1.3 - Weather related service outages as a result of a network failure on a supplier

17. How often do you experience weather related outages from suppliers of telecommunications or power services that you use (PIA, wholesale products, ESB) and from which ones?

18. How do you mitigate risks, which affect infrastructure of suppliers? How do you monitor failures and report them to suppliers? Can you describe the type of SLAs in your contracts with suppliers?

A.1.4 - Power reduction actions

ComReg intends to explore current and future power reduction methodologies applied by providers. In particular ComReg would like to quantify the energy consumption savings currently being achieved and also additional savings which can be achieved in the next 3 years.

19. Can you provide information on the total power consumption of your communications network[243] with a split where possible between Radio Access Network, Transport Access Networks and Core Infrastructure?

20. How do you expect the power consumption in the operation of your communications network to develop over the next three years (in MWh) and what are the hypotheses and rationale underlying your projections?

21. Please describe the *current* different methodologies and practices[244] (including their efficacy) used by you to reduce unnecessary power consumption within the operation of your Radio Access Network, Transport Access Network, Core Infrastructure (i.e. excluding back office supports, consumer equipment, etc.). For each methodology or practice quantify the current and projected[245] energy consumption savings (kWh) compared to the counterfactual that the methodology or practice had not taken place and explain the assumptions used to estimate projected energy savings.

22. Please describe any additional practices or adaptation actions that are planned to be implemented *in the future* to further reduce unnecessary power consumption within the operation of your communications network (for the avoidance of doubt this might include planned actions relating to future technologies within your deployment roadmaps). For each plan or programme, please provide projections of the power consumption savings in kWh over the following 3 years (to 2025),

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243 Power consumption in the operation of your network infrastructure, excluding back office support, consumer equipment, etc.

244 e.g. enhancing RAN efficiency through modernisation of legacy equipment/technology, use of Cell Sleep and other Radio Unit Power Reduction Methodologies; migrating from copper to fibre access, power reduction in low traffic hours, etc.

245 If available, please provide your projections for the next 3 years and detail assumptions used to build them

broken down yearly and with respect to any rollout plans over that timeframe relative to the counterfactual that the methodology or practice had not taken place.

A2. TowerCos questionnaire

A.2.1 - Identifying vulnerable elements in TowerCos infrastructure

In this questionnaire we wish to understand how different extreme weather events can create vulnerabilities at different points in your infrastructure.

1. Please describe the infrastructure that you supply to ECN (e.g. wooden poles, steel monopoles, steel lattice structure, rooftop, or exchange or datacentre building infrastructure).
2. Please use Table 3 below to provide a qualitative description of the different types of extreme weather-related vulnerability, which affects the operation of your infrastructure. If available, please provide actual examples, illustrating the different types of weather related outage, specifying the date, location, type of outage and providing any photos if available.

For each type of weather event, can you describe whether and how this creates vulnerabilities for your network:

- what exact parts/elements are damaged? (mast and structural elements, fronthaul & backhaul cables, shelter, HVAC[246], primary or backup power supply);
- what kind of damage (break bending, etc);
- how often such incidents occur;
- how severe are they in terms of user-hours lost and difficulty to repair?

Table 3 Classification of vulnerabilities

Extreme weather event	Network elements affected	Describe damage to network elements	Frequency of occurrence (rare, occasional, most common)	Impact on users and network (none, limited, large)
Excessive Wind				
Precipitation				
Rising sea levels and floods				
Lightning strikes				
Heatwave247				
Severe Cold248				

246 This should include HVAC overload due to heating or cooling maximum ratings being exceeded.

247 Since ICT equipment and facilities usually require proper cooling for their performance management, longer and more intense heat waves increase the risk of performance degradation and even device failure

248 Semiconductor parts are most often specified for use in the "commercial" 0-70°C range.

Extreme weather event	Network elements affected	Describe damage to network elements	Frequency of occurrence (rare, occasional, most common)	Impact on users and network (none, limited, large)
Snow and ice fall				
Other? (landslides, flash floods, humidity, bush fires…)				

Source: Frontier

3. Please describe the business as usual activities that you undertake which improves the reliance of your infrastructure to weather events. For example do you have a physical infrastructure replacement programme (e.g. monopole replacement)?
4. Are there any other specific work programmes in place to improve the resilience of your infrastructure to weather related events (stiffening of the structure or modification of mast design to avoid bending and improve resistance to extreme wind)?
5. Do you and own and provide the electricity connection to sites on the infrastructure that you provide. If so, what resilience is configured to this supply. Do you currently provide, or plan to provide, emergency power backup on your sites. Please provide details.

A.2.2 - Inventory or weather related incidents

6. Please provide an inventory of weather related events which have damaged your infrastructure leading to a loss of service for ECN that rely on the infrastructure since January 2017. For the avoidance of doubt, these should include named storms, as well as other weather-related outages. Where data is not available, please explain why this is not available.

Table 4 Inventory of weather related outages in your network

Year / date	Description of Weather event	Network elements affected	Cause of outage	Duration and impact of outage[249]	Remedial actions

Note: Each weather event represents one row. Description of weather event can be a named storm or otherwise a description of the weather that affected your network. Network element affected should specify whether the failure was on your network or on a supplier's network.

A3. Landing stations questionnaire

A.3.1 - identifying vulnerable elements in cable landing station network facilities

[249] If available, please also provide information on the number of customers affected by outages

In this questionnaire we wish to understand how different extreme weather events can create vulnerabilities at different points in your network.

1. Please use Table 5 to provide a qualitative description of the different types of extreme weather-related vulnerability, which affects your ability to deliver services. If available, please provide actual examples, illustrating the different types of weather related outage, specifying the date, location, type of outage and providing any photos if available.

For each type of weather event, can you describe whether and how this creates vulnerabilities for your network:

- what exact parts/elements are damaged? (cable, landing station, HVAC[250], primary or backup power supply);
- what kind of damage;
- how often such incidents occur;
- how severe are they in terms of user-hours lost and difficulty to repair?

Table 5 Classification of vulnerabilities

Extreme weather event	Network elements affected	Describe damage to network elements	Frequency of occurrence (rare, occasional, most common)	Impact on users and network (none, limited, large)
Excessive Wind				
Precipitation				
Rising sea levels and floods				
Lightning strikes				
Heatwave[251]				
Severe Cold[252]				
Snow and ice fall				
Other? (landslides, flash floods, humidity, bush fires…)				

Source: Frontier

2. We understand that landing stations in their nature are often built close to the coast. In order to identify risks of coastal erosion and or coastal flooding to your landing station, could you please specify how many of your landing stations are within 100m of the shore?

[250] This should include HVAC overload due to heating or cooling maximum ratings being exceeded.

[251] Since ICT equipment and facilities usually require proper cooling for their performance management, longer and more intense heat waves increase the risk of performance degradation and even device failure

[252] Semiconductor parts are most often specified for use in the ''commercial'' 0-70°C range.

3. Do you have any current coastal erosion mitigation measures in place for any of your landing stations?
4. Are there any specific work programmes in place to improve the resilience of your network to weather related events?

A.3.2 - Inventory or weather related incidents

5. Please provide an inventory of weather related outages that have occurred *on your communications network* since January 2017 using Table 6 as a template. For the avoidance of doubt, these should include named storms, as well as other weather-related outages. Where data is not available, please explain why this is not available.

Table 6 inventory of weather related outages in your network

Year / date	Description of Weather event	Network elements affected	Cause of outage	Duration and impact of outage[253]	Remedial actions

Note: Each weather event represents one row. Description of weather event can be a named storm or otherwise a description of the weather that affected your network. Network element affected should specify whether the failure was on your network or on a supplier's network.

A4. Climate stakeholders questionnaire

A.4.1 - historical data on extreme weather events

We understand that extreme weather events are classified as yellow, orange, or red according to their intensity. A dataset of archived Met Éireann weather warnings, found on data.gov.ie , details weather warnings issued from 25 April 2012 to 17 February 2021. We have some queries regarding this dataset.

Q1. Do you also have the data available for the time period from 17 February 2021 - today that you could send us?

Q2. We understand that these weather warnings are forecasts. Does Met Éireann collect data on actual outturns for the same weather events in a similar format?

A.4.2 - Future climate trends

As mentioned above, we are also looking to understand longer term future climate trends in Ireland, specifically regarding the development of occurrences of extreme weather events.

We are currently specifically looking at information from the Environmental Protection Agency:

253 If available, please also provide information on the number of customers affected by outages

- N. Dwyer, 'The status of Ireland's climate, 2012. Wexford, Ireland: Environmental Protection Agency. 2013.
- P. Nolan, Ensemble of Regional Climate Model Projections for Ireland, Environmental Protection Agency, Report No. 159, 2015.

We are also taking the list of links provided by you on https://www.met.ie/climate/climate-change into account.

Q3. We know that Met Éireann is also involved in climate modelling work. Do you have any additional views on longer term climate trends in Ireland and/or can you point to further or more recently published information on this?

Annex B - Electronic Communication Networks in Ireland

Communication services are delivered to the population of Ireland using many different interconnected networks. Each network has specific characteristics, reflecting its technological architecture (for example whether wired or wireless) or the end user requirements (serving a small number of users or many millions). These characteristics dictate how the network is designed and hence how it could be vulnerable to different types of weather events. This report therefore considers how different ECNs are vulnerable to severe weather events, and may be affected in future by the impact that climate change will have on Ireland's weather. The basic architecture of ECNs are described in section B1. The specific ECNs considered in this report are each described:

- fixed-line networks including copper, fibre and hybrid fibre-coaxial (Annex B2.);
- wireless networks such as mobile networks (including 2G, 3G, 4G and 5G radio access technologies) and fixed wireless access networks (Annex B3.);
- passive infrastructure[254] that supports ECNs (Annex B4.);
- high-capacity networks including transport networks (Annex B5.); and,
- international connectivity networks (Annex B6.).

B1. How electronic communications networks deliver services to end users

ECNs convey information (voice calls, text messages or data) to and from different users. The arrangement of network elements used in ECNs may vary[255] but can generally be described as a tree-like hierarchy (Figure 15).

"Access networks" refer to the network equipment and infrastructure which connect to end users and their devices to points in the ECN where traffic is aggregated and onward routed to its destination. In fixed-line access networks users connect with an ECN through a terminal equipment installed usually in the customer

254 Passive infrastructure refers to infrastructure that is not part of ECNs' electrically powered equipment conveying signals from place to another, including but not limited to, sites, buildings, shelters, towers, masts, poles, ducts, trenches, electric power supply, and air conditioning.

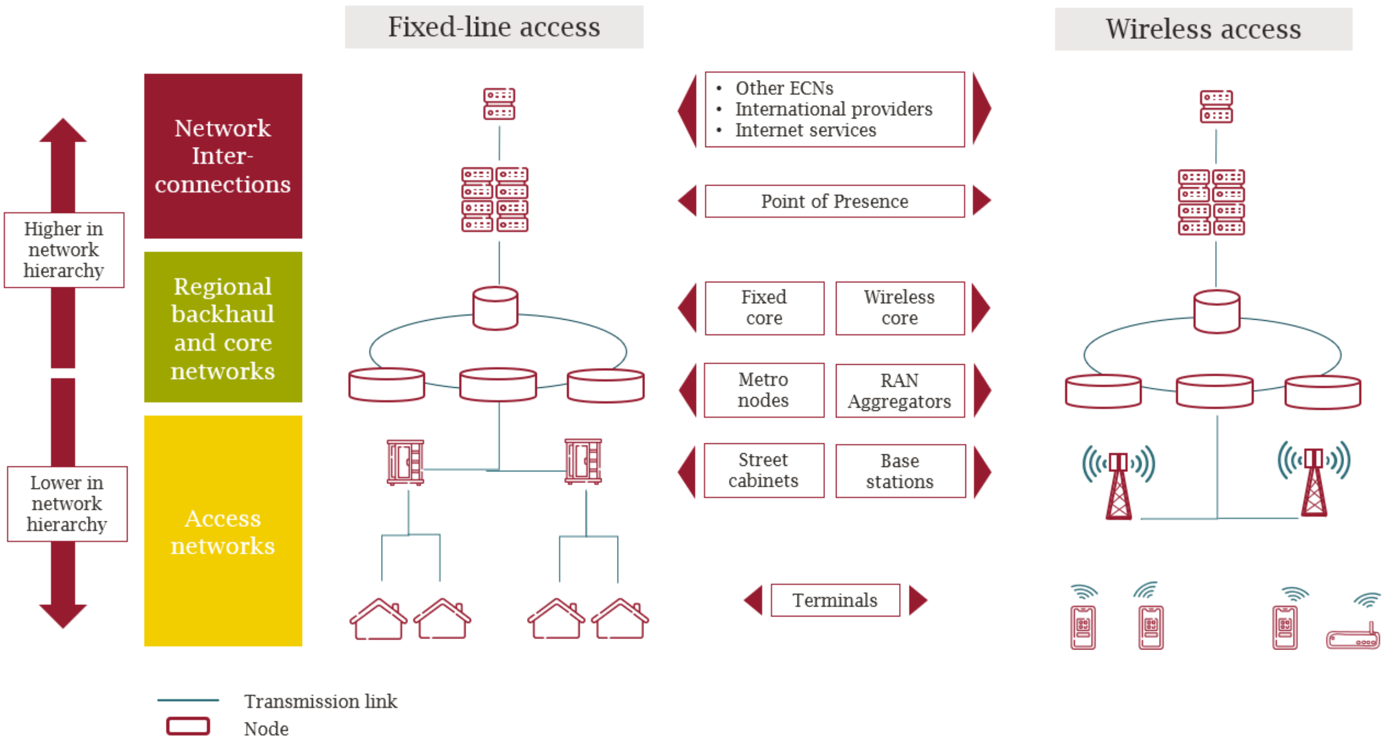
255 Typical architecture is described in Figure 1 but other architecture models exist.

premises. Wire and cable infrastructure conveys users' signals to locations where the connections from several end users are aggregated. In wireless access networks users connect with an ECN through a device that can be handheld (mobile handsets) or in a fixed location (Fixed Wireless Access ("FWA") routers). Communications are transmitted using radio waves to and from these devices to a distant transceiver antenna installed at a base station.

"Backhaul and core networks" refer to the equipment in the ECN operator's network that aggregates traffic and routes the signal either to other parts of the network or to a different network. The traffic is conveyed using high-capacity transmission links ("backhaul") between different "network nodes". A "network node" is a connection point in the network where equipment recognises, processes and forwards transmissions to and from other network nodes. These nodes aggregate and transport data traffic from the nodes lower in the network hierarchy (such as local exchanges/metro nodes in fixed networks or base stations in mobile networks) to nodes higher in the ECN hierarchy.

Network Interconnections are the equipment and infrastructure which provide the physical links between different ECNs which enable voice and data communications to be exchanged between them. This enables the seamless interconnection and coordination of many different ECNs both within Ireland and internationally.

Figure 15 B1 A typical architecture for electronic communications delivery



Source: Frontier Economics

Typically, equipment in the access network tends to serve fewer customers than in the higher parts of the network hierarchy. For example, a single drop wire might supply just one end user. Whereas equipment higher in the network hierarchy will serve gradually more end users: a street cabinet might serve between 100 and 1000 premises; a metro node might serve around 2,000 premises; and a core node might serve around 10,000 premises.

B2. Fixed ECNs in Ireland

Fixed line networks are characterised by wired links which provide a dedicated connection in the access network to an individual location (such as a household or business premises). There are different types of fixed-line access networks which can geographically overlap in some areas, depending on the network. Each type of ECN has its own characteristics that can affect its vulnerability to weather events.

B.2.1 - Copper access networks

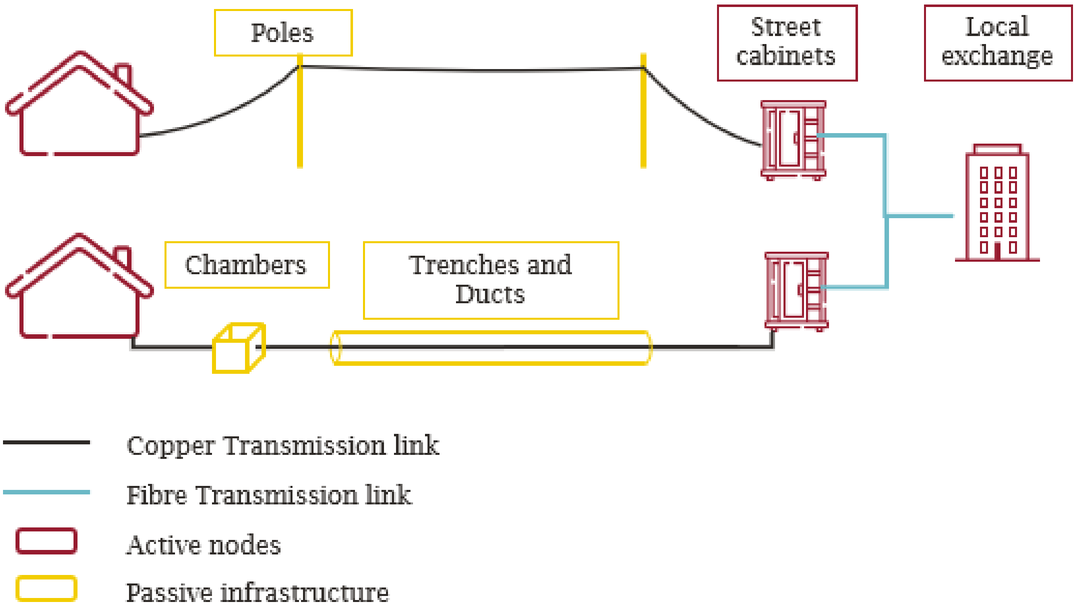
The nationwide copper access network is operated by Eir and reaches an estimated 1.8 million premises.[256] Voice services are offered over its Public Switched Telephone Network ("PSTN")[257] and data is offered over Very-High-Bit-Rate Digital Subscriber Line ("VDSL"). Figure 16 summarises the basic architecture of a copper ECN. The efficiency of copper to transmit data decreases with the length of lines. This means, that in order to provide data services at higher speeds, Eir has invested in its network to upgrade its technology. Eir's legacy access network based on copper has been gradually upgraded with fibre optic cable to the street cabinet, i.e., a Fibre to the Cabinet ("FTTC") network. The final drop from the street cabinet to the premises can be an overhead line (typically deployed on poles), an underground cable (buried or ducted) or a mix. However, even with this technology copper-terminated networks have reached a physical limit on the maximum download speeds, at around up to 100 Mbps. Eir expects to phase out its copper network by 2028.[258]

256 ComReg's quarterly Data Report, Q2 2011

257 The public switched telephone network (PSTN) is the legacy circuit-switched telephone network

258 Copper switch-off: Leaving a legacy for the Future, White paper, Eir

Figure 16 B2 Main elements in copper access networks



Source: Frontier Economics

Note: In Copper Access Networks, active[259] equipment (DSLAM) is installed in the cabinets. Chambers are also referred to as Underground Utility Box, joint boxes vaults or manholes

B.2.2 - Hybrid Fibre-Coaxial Networks

Virgin Media is the only ECN operating a hybrid fibre-coaxial ("HFC") ECN in Ireland. However, this technology is due to be phased out as Virgin Media plans to upgrade its broadband network covering 1 million premises to full fibre.[260]

HFC networks were originally designed to offer cable TV services, but they have over time been adapted to offer broadband and voice connectivity over the same infrastructure. The HFC ECN connects end users to the network with "coaxial cable" to a fibre node.[261] Fibre nodes translate the signal from an electrical signal sent over the coaxial cable to a light beam sent over fibre. The traffic is aggregated at the fibre nodes and conveyed further up the network hierarchy ultimately to a central hub – called the "headend"[262] - in the HFC's core network.

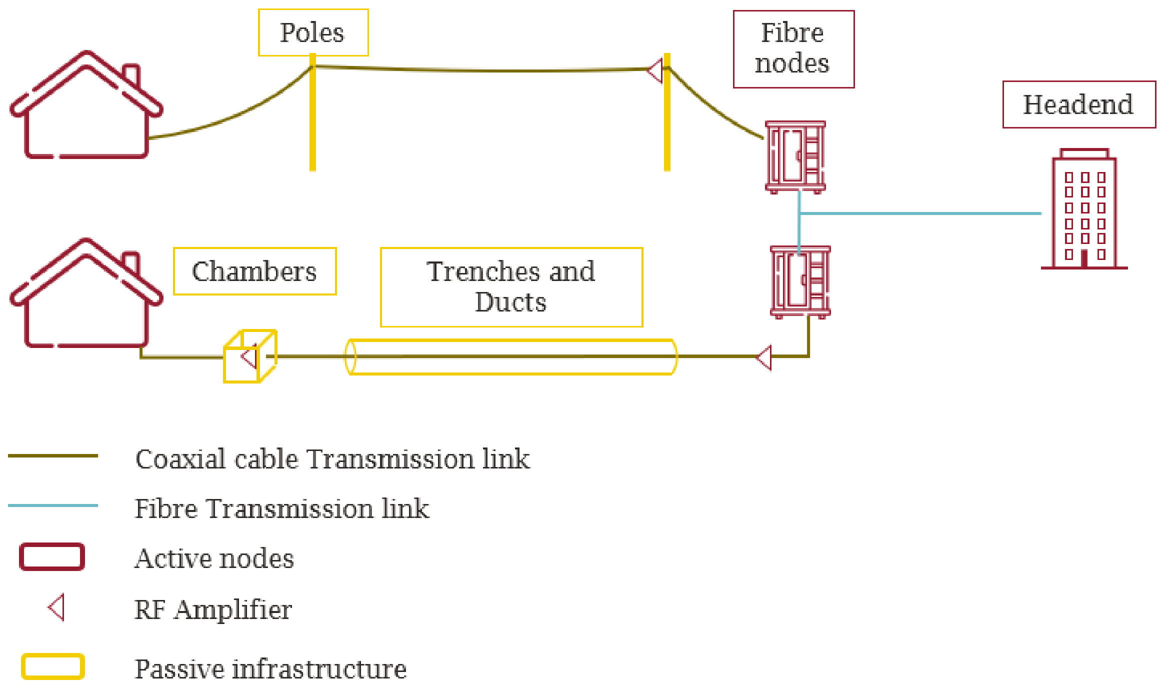
259 Active equipment refers to equipment able to generate, reproduce, direct and route electronic signals using electric power supply

260 https://www.virginmedia.ie/about-us/press/2021/virgin-media-ireland-announces-national-fibre-network-upgrade/

261 A fibre node is a cabinet where signals are converted between optical fibre transmission lines and coaxial cable transmission lines

262 A headend is a facility built to provide security, cooling, and easy access for the electronic equipment used to receive and re-transmit IP and dedicated video signals over the local HFC infrastructure.

Figure 17 B3 Main elements in hybrid fibre-coaxial access networks



Source: Frontier economics

Note: The Headend is connected to fibre nodes by high bandwidth fibre trunks. The local coaxial cable connects to the customer who has a cable modem to receive the services. Radiofrequency (RF) amplifiers are used to regenerate the signal and expand the maximum length of the coaxial network

B.2.3 - FTTH access networks

Fibre To The Home ("FTTH") is provided by different ECN operators including commercially funded networks (including but not limited to Eir, SIRO, Virgin media) and by NBI which is partially funded by state support in areas where the rollout of FTTH is not deemed commercially viable.

- Eir has passed 864k homes (as of August 2022) with plans to roll out to 1.9m homes (or 84% of premises).[263]
- SIRO is a wholesale operator which has passed 450k premises (as of August 2022) with plans to roll out its services to 770,000 homes and businesses.[264] It has built its fibre network using Ireland's electricity distribution network's overhead infrastructure, operated by ESB Networks ("ESBN").

263 https://www.eir.ie/opencms/export/sites/default/.content/pdf/IR/news/eir-Q2-22-PRESS-RELEASE-VF.pdf

264 https://siro.ie/news-and-insights/virgin-media-expands-market-reach-on-the-siro-network/

- Virgin Media is upgrading its HFC access network (see above) to offer FTTH to 1 million homes[265]. It has already rolled out FTTH to over 100,000 locations[266] (as of August 2022) and will also rely on SIRO's network to further extend its footprint.
- NBI is a wholesale operator, selling services to retail operators (NBI has retail agreements with 39 operators[267]), who in turn sell directly to home and business customers. NBI has passed over 80k homes[268] (as of September 2022) and plans to pass 500k homes over the next five years.

FTTH Networks in Ireland are designed using a Gigabit Passive Optical Network ("GPON") architecture (Figure 18). A GPON network consists of OLTs (Optical Line Terminals, located in NGN[269] Nodes), ONUs (Optical Network Units installed at end user premises), and splitters. It is a point-to-multipoint (one OLT to multiple ONUs) access architecture. ONUs connected to end users convert electrical signals from the end user's router to optical signals which are sent to a splitter. The splitter is a passive (i.e. non-powered) piece of equipment which then combines optical signals from multiple fibre strands (one per ONU) into one fibre and sends the aggregated signal to the OLT. Each splitter typically splits (in downstream communications) or combines (in upstream communication) the signal from a single fibre into 16, 32, or up to 256 fibres.

While in some countries the OLT can be installed in a street cabinet, in Ireland OLTs tend to be installed in higher in the network architecture, which means that there is generally no active equipment needed to power FTTH networks in street cabinets.

GPON networks may rely on different standards (such as the choice of split ratios[270], wavelengths) to accommodate different transmission distances and bandwidths. XG-PON and XGS-PON evolved from the basic GPON technology. XG-PON is designed to achieve 10G bandwidth for downstream and 2.5G for upstream, XGS-PON (the S stands for symmetric) [271] is designed to achieve 10G bandwidth for downstream and 10G for upstream.

265 https://www.libertyglobal.com/virgin-media-ireland-announces-national-fibre-network-upgrade/

266 Virgin Media Fixed Income Release Q2 2022

267 https://nbi.ie/where-can-i-buy/

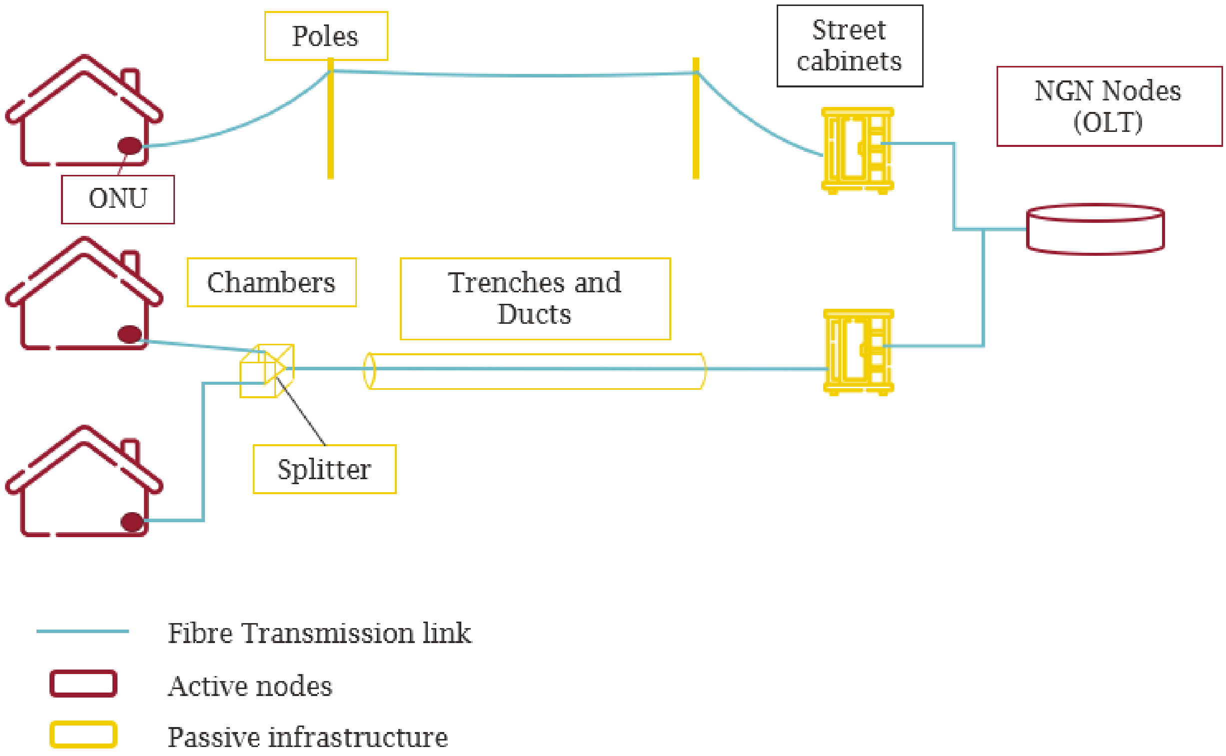
268 https://nbi.ie/news/events/2022/09/26/nbp-rollout-surpasses-80k-premises-passed-including-7k-farms-nbi-minister-ossian-smyth-announce-at-national-ploughing-championships/

269 A next-generation network (NGN) is a type of network relying exclusively on packet-based switching

270 A split ratio in a PON application is the ratio between upstream fibre strands and downstream fibre strands connected to a splitter

271 Information provided by stakeholder in course of study.

Figure 18 B4 Main elements in FTTH access networks



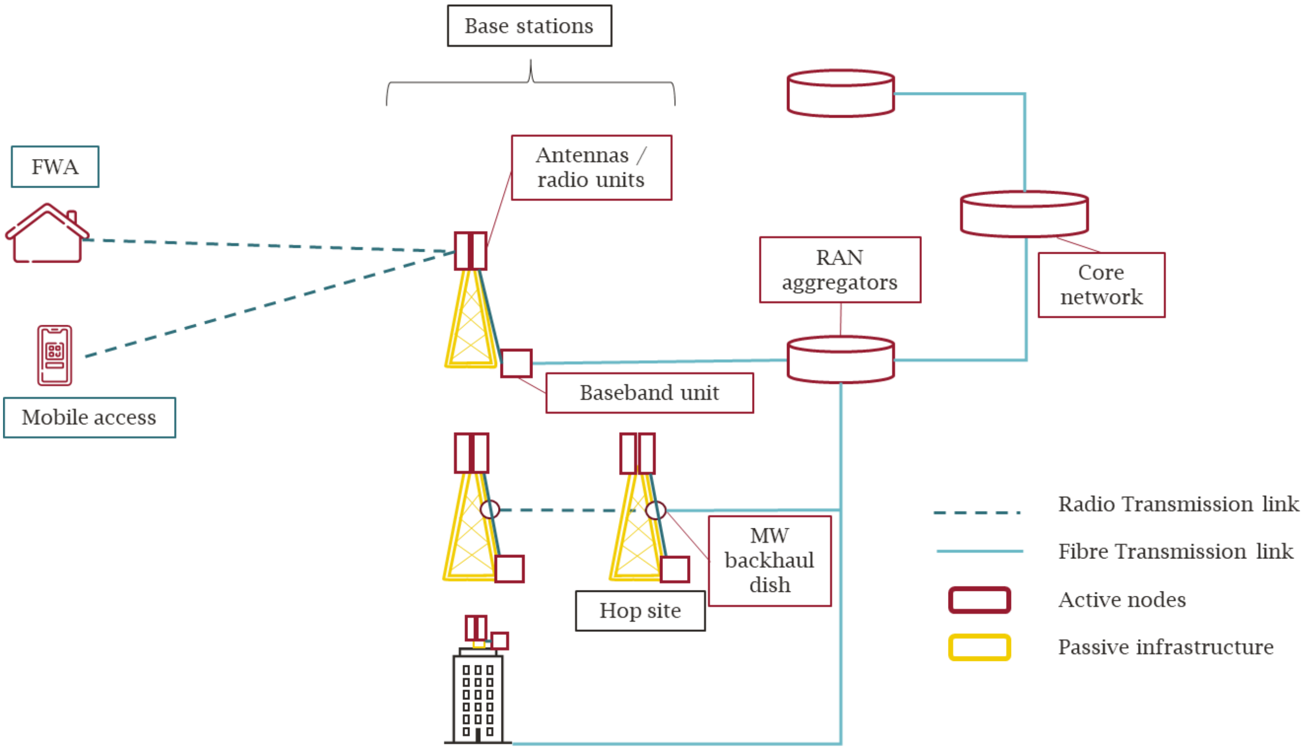
Source: Frontier Economics

Note: Contrary to FTTC or HFC, street cabinets in FTTH networks do not house active equipment. OLTs tend to be installed in more upstream branches of the network architecture, .

B3. Wireless access networks

Wireless networks can provide wireless connectivity to mobile users or to fixed wireless users. Mobile and FWA rely on similar Radio Access Network ("RAN") technology and infrastructure which is depicted in Figure 19 below.

Figure 19 B5 Main elements in wireless access networks



Source: Frontier economics

The wireless ECN operators install base station equipment at dedicated towers or alongside existing structures (such as rooftops, water towers, etc.). The deployment of a base station includes the installation of antennas, radio units, remote radio units (“RRU”), and Baseband Units (“BBU”). Antennas transmit and receive radiofrequency[272] (RF) signals to mobile handsets and or mobile/FWA modems. The RRU has a physical connection with antenna on one side and with BBU on the other side. It converts the RF signal from the antenna into a digital format that the baseband unit can interface with. The BBU provides a set of signal processing functions (error detection, encryption, optimisation) and handles data flows between the base station and RAN aggregators. The backhaul connections from the BBU to RAN aggregators use fibre optic cables and sometimes intermediary micro-wave (“MW”) links to other base stations (also called “hop sites”[273]). A base station that supports the back haul from another base station via a MW link is termed a “hop site”. The mobile core network is the centralised infrastructure in the overall mobile network that enables subscribers to access supported communication services. It provides critical functions for directing, routing traffic appropriate such as subscriber profile information, location, service authentication and necessary switching tasks.

B.3.1 - Mobile access ECN operators

272 A radio frequency (RF) signal refers to a wireless electromagnetic signal used as a form of communication

273 Hop sites are intermediate nodes that are used to connect so called “end of line sites” that are too far to backhaul infrastructures to be connected directly to transport backbone.

There are three mobile networks operating in Ireland with a combined total of 5.4 million subscriptions.[274] Each ECN operator has its own distinct national network and competes on network quality, capacity, coverage and services.

Mobile Network Operators ("MNOs") currently employ four generations of technologies (2G[275], 3G[276], 4G[277] and 5G[278]) to provide their services. They upgrade their equipment every five to eight years, following new technology cycles.

In Q1 2022[279], Three[280] had 2.2m subscribers (March 2022), 99% of 4G population coverage[281] and 5G service "*in every county*". Vodafone had 2m subscribers and 99% of 4G population coverage[282] and 5G service "*in selected areas across 26 counties*". Eir had 1.2m subscribers, 99% of 4G population coverage[283] and 5G service "*in 322 towns and cities in all 26 counties of the Republic of Ireland".*

Ireland's consumers can also access mobile services from Mobile Virtual Network Operators ("MVNOs") (for example Tesco Mobile, Sky Mobile, Lycamobile, Virgin Mobile, GoMo, An Post Mobile, Clear Mobile and 48). MVNOs lease wireless access capacity from: Vodafone, Eir, and Three, for the provision of their MVNO services. However, these operators do not own spectrum or operate RANs.

B.3.2 - Fixed wireless access ECN operators

FWA uses the same underlying technology in its access network as mobile networks. The main difference with mobile access service is the terminal network equipment that end users rely on to connect, which for FWA user is generally a 4G broadband modem instead of a mobile handset. Also, since FWA end users tend to be located, in more rural areas, FWA service can rely on extended 4G coverage but less on more limited 5G coverage.[284]

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274 Excluding M2M and fixed wireless access, ComReg Quarterly Key Data Report Q1 2022

275 2G refers to the second generation of mobile networks based on GSM. It mainly supports digital voice and SMS communication and allows basic data communications up to 64 kbps.

276 3G standard utilises Universal Mobile Telecommunications System (UMTS) as its core network architecture. 3G network combines aspects of the 2G network with new technologies and protocols to deliver a significantly faster data rate. By using packet switching, the original technology was improved to allow speeds up to 14 Mbps. It used Wide Band Wireless Network that increased clarity.

277 4G stands for the fourth generation of mobile networks that are data-only networks enabled by the LTE technology. 4G networks use packet-switching to offer IP-based voice calls and text messages in addition to improved high-speed mobile data rates.

278 5G stands for the fifth generation of mobile networks that are data-only and offer average download speeds of up to 150 to 200 Mbps. It is the latest generation of mobile networks enabled by the New Radio technology (NR). 5G networks can offer latencies as low as one millisecond.

279 ComReg quarterly market report Q1 2022

280 Including MVNOs hosted on Three's Network: Virgin Mobile and Tesco Mobile.

281 https://www.three.ie/coverage-checker

282 https://n.vodafone.ie/network.html

283 https://www.eir.ie/ourmobilEnetwork/

284 Spectrum bands used to provide 5G service (3.6 GHz) operate at higher frequencies which means 5G signals travel shorter distances and are less used in rural areas where base stations are less densely located.

In Q1 2022[285] 5% of fixed broadband subscriptions in Ireland used FWA services. In addition to FWA services provided by mobile operators, Imagine and NBI (to deliver its objective to deliver high-speed connectivity at public Broadband Connection Points as part of the National Broadband Plan) have deployed a network dedicated to the provision of rural broadband using FWA technology.

B4. Infrastructure providers who supply ECNs

Tower companies ("TowerCos") specialise in operating passive[286] wireless network infrastructure (wooden poles, steel monopoles, steel lattice structures, rooftop sites). These can be dedicated to an individual ECN operator or neutral host which facilitates the sharing of towers with multiple tenants and can reduce the costs for wireless ECN operators. TowerCos rent access to the infrastructure to wireless operators who can then install equipment at the site to support deployment of their ECN.

The last decade has seen increased outsourcing of passive infrastructure by mobile ECN operators to third party TowerCos. In Ireland these include amongst others:

- ESB Telecoms;
- Phoenix Towers;
- Cellnex;
- Vantage Towers; and
- 2RN.

Operators also provide its passive infrastructure to support fixed ECNs.[287]

B5. High-capacity connectivity networks

High-capacity connectivity services provide point to point connectivity for businesses, public sector users and to other ECN operators (when supplied as a wholesale input).

These connectivity services are used to support a wide variety of ICT applications: high-capacity access to the internet, private voice and data networks, cloud-based services, backup and disaster recovery, remote monitoring and telemetry applications. High-capacity connectivity links can also support private networks that allow organisations to link business sites together, including data centres, so that offices can exchange data and access corporate applications.

As well as supporting the provision of various retail services, high-capacity connectivity services can also be important network inputs for operators themselves to extend the physical reach of their networks, including

285 Irish Communications Market, Quarterly Key Data Report, ComReg: https://www.comreg.ie/media/2022/06/ComReg-2245-1.pdf

286 "Passive infrastructure" refers to physical infrastructure which does not contain any electronic processing equipment.

287 Information provided by stakeholder in course of study.

for data backhaul and/or voice traffic. This, in turn, enables them to provide a range of fixed and/or mobile communications services to consumers and business customers.

Currently there are several service providers supplying such services in Ireland including: [288]

- Airspeed/ Enet;
- BT Ireland;
- Colt;
- Eir;
- Verizon;
- Viatel;
- Virgin Media.

B6. International connectivity ECNs

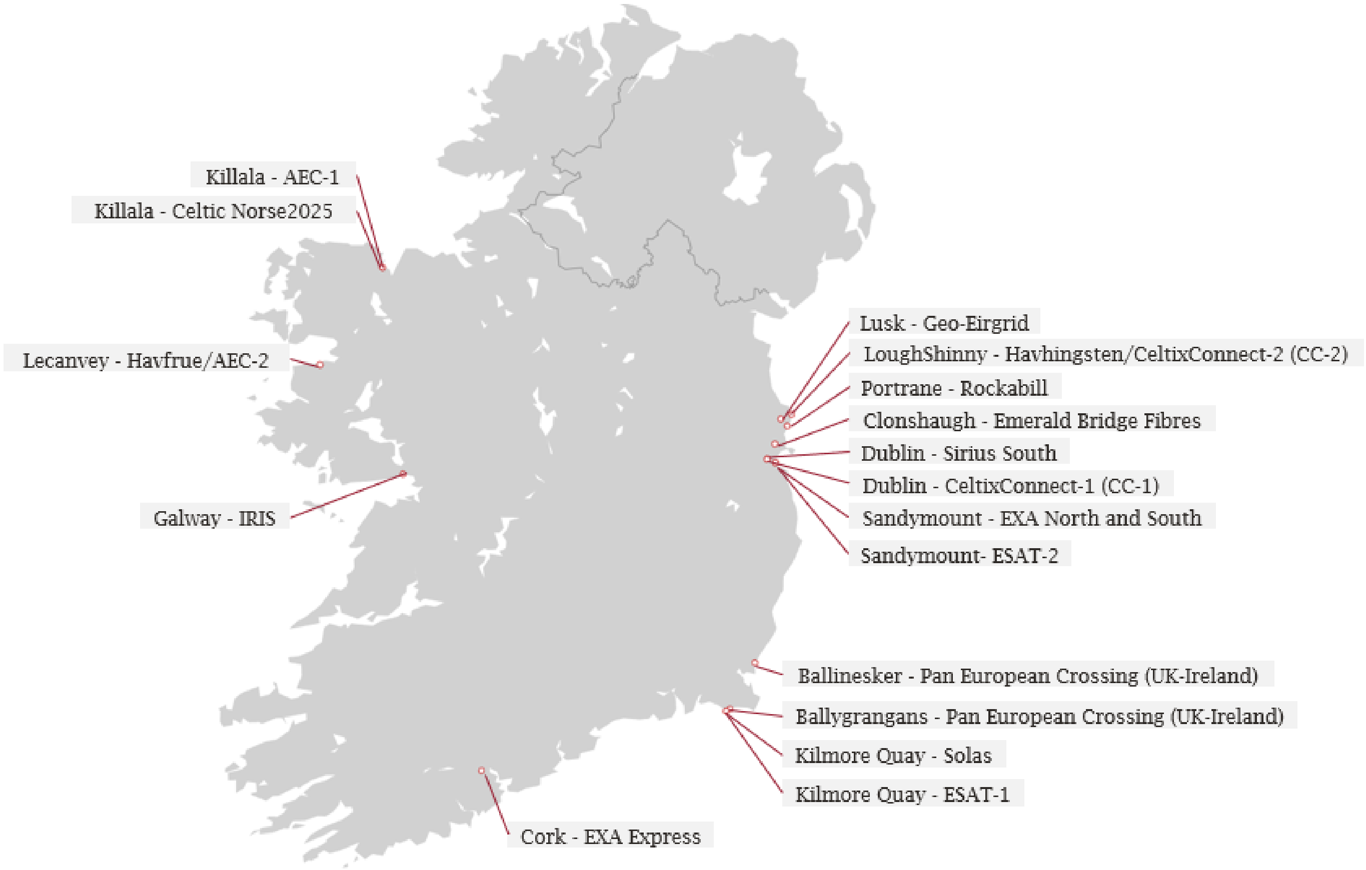
Specialist ECNs provide international connectivity to and from Ireland. These can be provided by very high capacity fixed fibre based “submarine cables” that are deployed on the seabed, or by communication satellites. Submarine cables offer much higher data capacity and greater reliability than is available through satellite communications which are constrained through the technical limitations imposed by wireless communication and the radio spectrum used and can be affected by weather.

Ireland is connected to North America and the UK with 17 submarine cables (Figure 20) These are operated by Zayo, Aqua Comms, euNetworks, BT Ireland, Eir, Vodafone, GTT (Exa Infrastructure) and Century Link (Lumen). Submarine cables connect into the land-based infrastructure at Cable Landing Stations where high capacity backhaul links provide connection to national ECN’s Points of Presence (“PoP”).[289]

288 Market Review, Wholesale High Quality Access at a Fixed Location, ComReg, 2020

289 A point of presence is a network interface point between communicating entities which typically houses servers, routers, network switches, multiplexers, and other network interface equipment, and which is typically located in a datacentre.

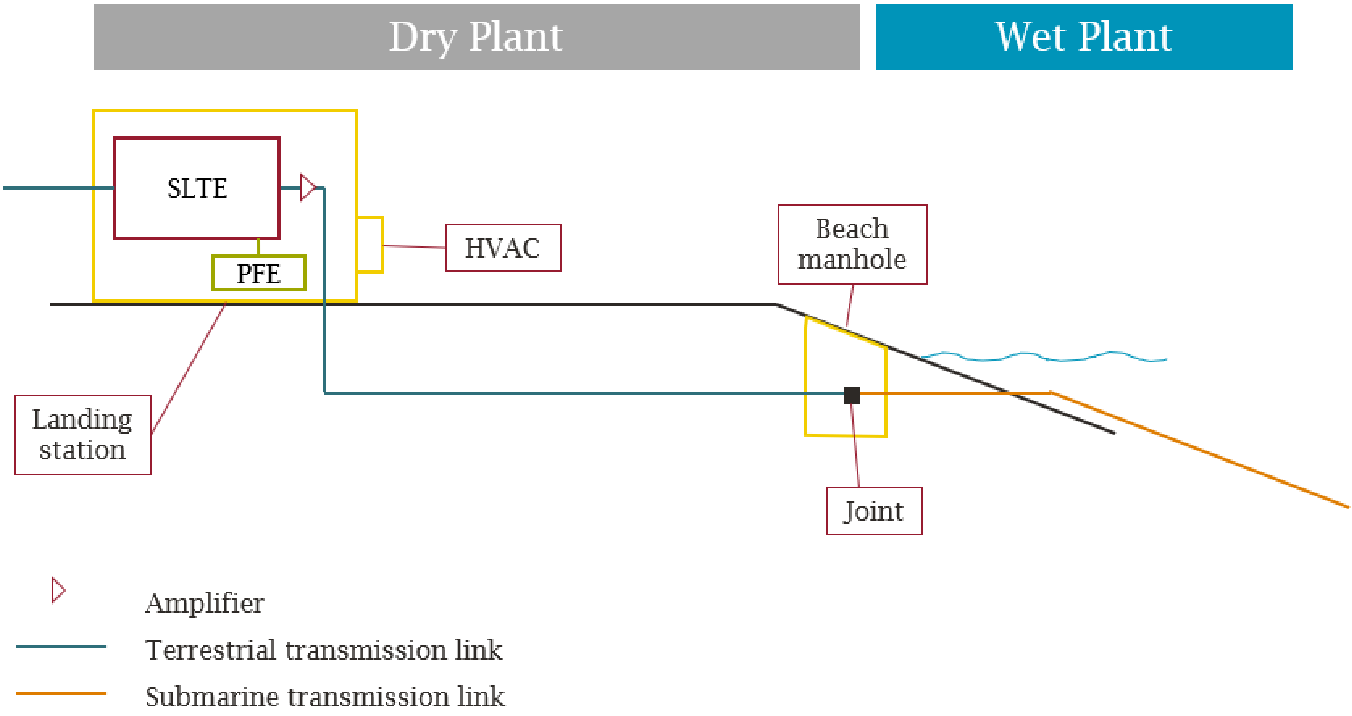
Figure 20 B6 Cable Landing Stations in Ireland



Source: Telegeography, 2022
Note: The figure identifies the landing site locations and the names of subsea cables

A typical schematic of a submarine cable system is shown in Figure 21 below. The Dry Plant of a submarine cable system is a segment between the beach manhole and the cable landing station, comprises land cable, power feeding equipment ("PFE"), HVAC, and submarine line terminal equipment ("SLTE"). The Wet Plant of a submarine cable system lies between the beach manholes and consists of submarine cable which contains optic fibres and a power conductor, branching units which allow the cable to split to serve more than one destination and repeaters which amplify optical signals every 60 or 70 km using the power conductor.

Figure 21 B7 Main elements in international connectivity networks



Source: Frontier Economics, SubmarinEnetworks.com

Submarine cables are heavily armoured to protect against physical damage. They are connected to terrestrial networks in beach manholes which consist of a buried container. The cable landing station, containing high-voltage equipment to supply power the submarine cable, is usually located hundreds of meters from the beach manhole. The PoP is generally located in an urban area and could be hundreds of kilometres from the cable landing station.

B7. Interdependence between different networks

There is a degree of interdependency between different ECNs. This means that ECNs can be negatively impacted by weather events even if their own physical infrastructure and equipment was unaffected by the event. This is because ECNs can depend on the infrastructure and services from other ECNs to supply their services. Many fixed ECNs rely on Eir's and ESBN's existing physical infrastructure (co-location space in cabinets and exchanges, local loop unbundled lines, poles and duct access). All wireless networks rely on TowerCos' services for the physical infrastructure since mobile ECN operators have sold almost all their sites to infrastructure companies who then sub-let the sites back to ECNs. ECNs also procure services from other ECNs including fixed services (such as bitstream, leased lines, backhaul, and private circuits) and wireless services (such as international roaming, and backhaul).

ECNs are also dependent on other networks (utilities such as power) that can also be affected by weather events. ECNs require a continuous and secure power supply from power networks to support their services. Almost all nodes (except optical splitters in Passive Optical Networks) are powered to enable, signal transmission, processing and routing. Therefore, an outage or fault on a power network will lead to an outage on the telecommunications network if there is no back-up power or back-up power is exhausted.

Annex C - Analysis of weather warnings

Met Éireann publishes weather warnings which indicate when severe weather will impact the population. These weather warnings form an important resource for ECN operators who use these to plan for extreme weather events.

C1. Categories of weather warnings

Weather warnings are indicative of the number of extreme weather events in a given year that could affect ECNs. Met Éireann classify warnings by type of weather (Fog, High Temperature, Low Temperature, Rain, Snow/ Ice, Thunderstorm, and Wind) and by county. The warnings therefore, through the proxy of county affected, also provide information on the approximate number of people affected. Each weather warning falls into one of three colours, yellow, orange and red.

- **Yellow** for not unusual weather but localised danger.
- **Orange** for infrequent weather that is dangerous/disruptive.
- **Red** for rare weather events that are extremely dangerous or destructive.

We focus on the more severe orange and red weather warnings, therefore on weather warnings that, depending on element, at least fulfil the following:

Table 11 C1 Met Éireann's Weather warnings status Orange

Element	Description
Wind Mean speed: 10 minute Gust	Widespread mean speeds between 65 and 80km/h widespread gusts between 110 and 130km/h
Coastal Wind Warnings Mean speeds up to 30 nautical miles offshore	Storm Force 10
Rain Amounts can be up to double on windward upper slopes & impacts vary depending on for example soil moisture deficits.	30mm – 50mm in 6 hrs or less 40mm – 60mm in 12 hrs or less 50mm – 80mm in 24 hrs
Snow/Ice	3cm or greater in 6 hrs 5cm or greater in 12 hrs 10cm or greater in 24 hrs
Low Temperature/Ice	Air minima of minus 5C to minus 10C (or lower) expected over a wide area. dangerous surfaces due to ice and/or lying snow/freezing rain. Situation stable.
High Temperature	>30/20/>30/20/>30 Maxima in excess of 30C for three days and minima of 20C for two nights (consecutive).

Element	Description
Thunderstorm	Widespread thunderstorms/severe lightning activity/heavy rainfall/large damaging hail
Fog (or freezing fog)	Dense fog/freezing fog persisting over a wide area causing a widespread and significant driving hazard on national primary routes.

Source: Met Éireann https://www.met.ie/weather-warnings

Note: Numerical limits are strong guidelines. However, orange weather warnings may be issued if circumstances indicate impacts of the severity of an orange weather warning.

Named storms are included in these weather warnings and are therefore not considered separately.

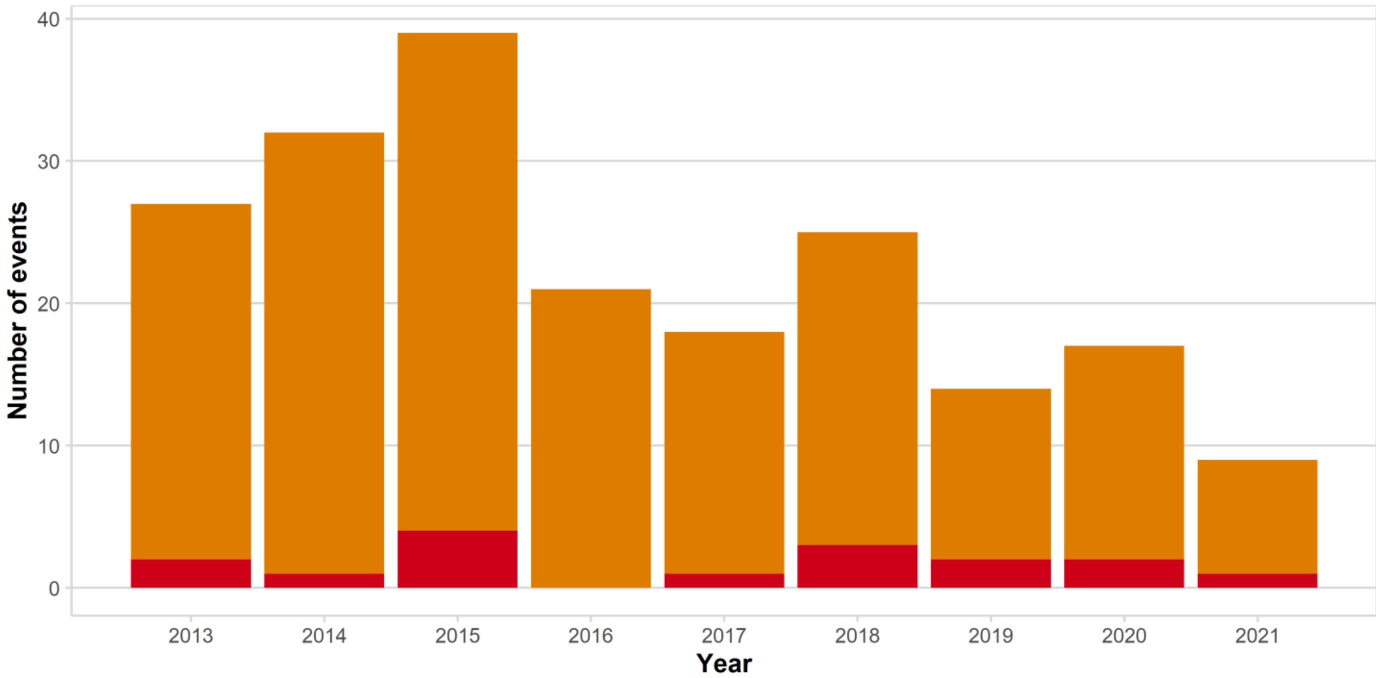
Named storms

Strong winds that are rated an orange or red wind warning and that cover a wide area are named to improve awareness of the weather event. Storms have been named by Met Éireann since the 2015/2016 storm season. Met Éireann has a storm naming partnership with Met UK and KNMI, the Dutch weather services. In each storm season (running from September to August) between 5 and 11 storms are named.

C2. Analysis of past weather warnings

In the last nine years there have been 186 orange warnings and 16 red warnings (Figure 22). There is significant variability in the number of orange and red warnings in each year with the lowest in 2021 (9) and the highest in 2015 (39).

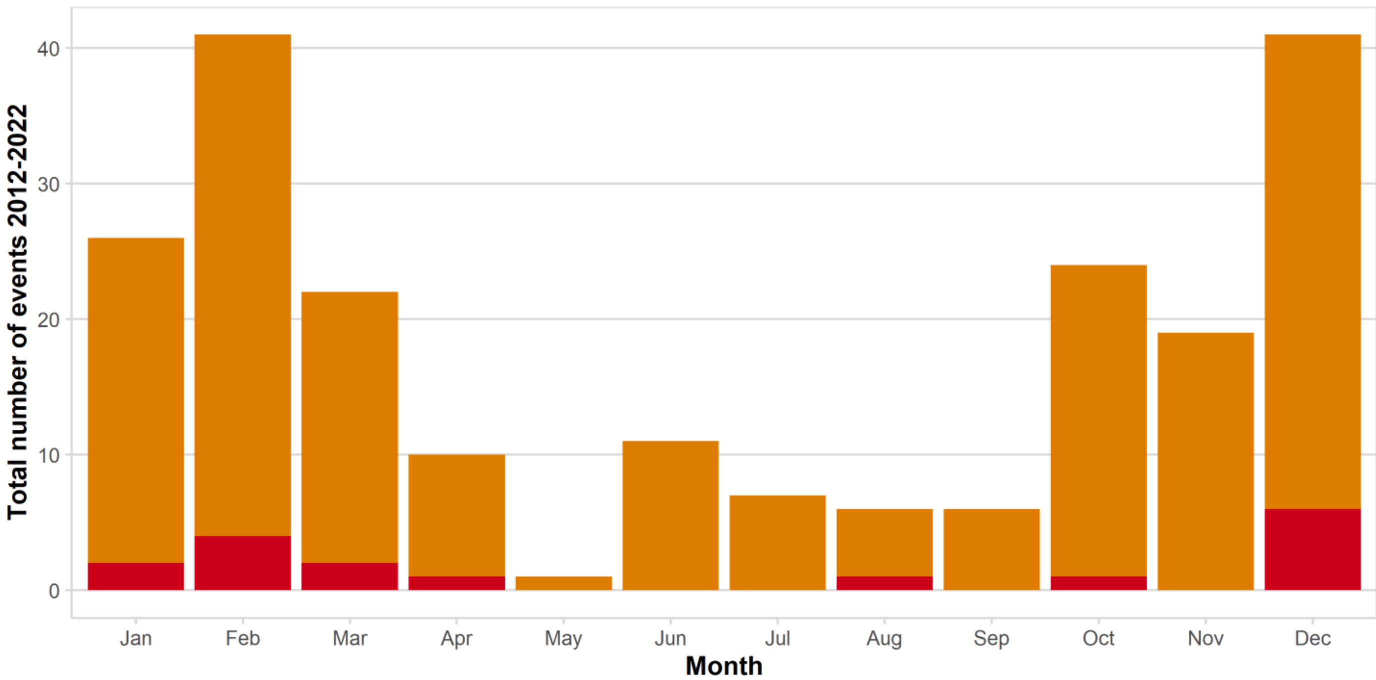
Figure 22 C2 Weather warnings by year



Source: Frontier Economics analysis of Met Éireann historical data
Note: Orange weather warnings are depicted as orange, red weather warnings as red.

As would be expected most weather warnings are in winter, specifically December and February, with May being the calmest month (Figure 23).

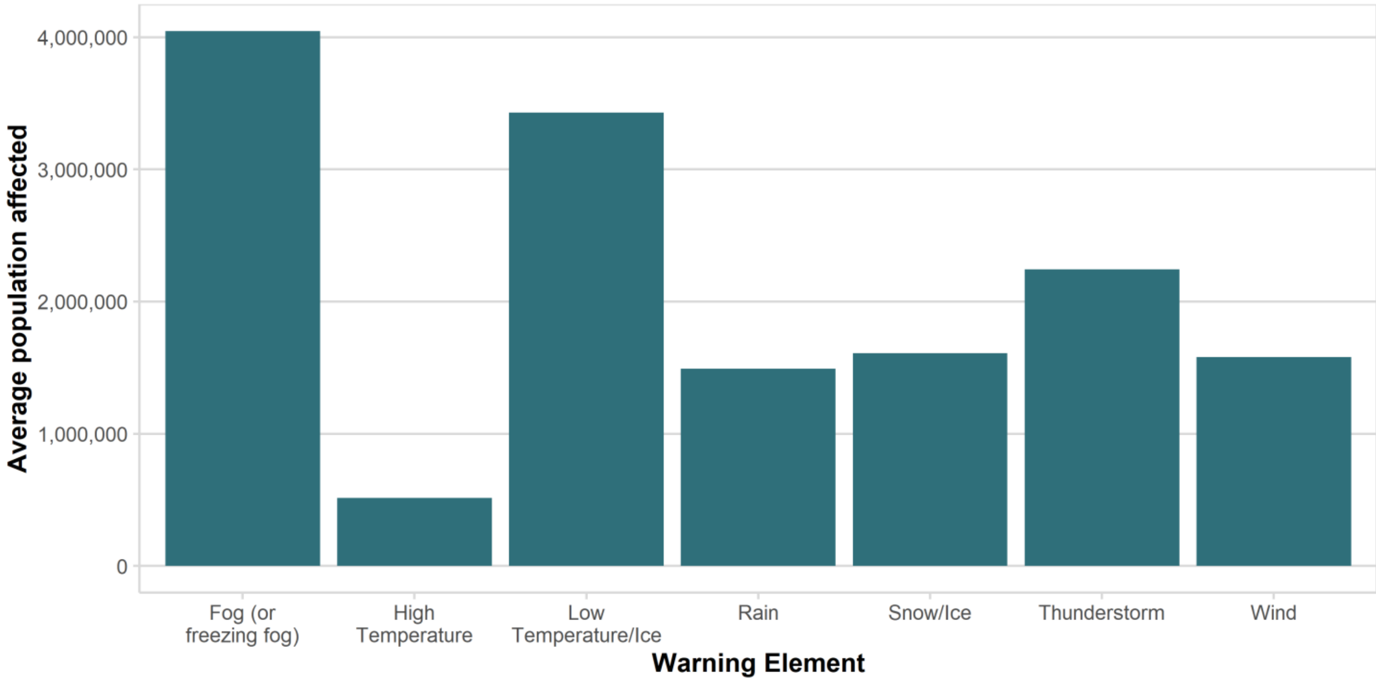
Figure 23 C3 Weather warnings per month



Source: Frontier Economics analysis of Met Éireann historical data
Note: Data includes observations April 2012 up to May 2022

Extreme weather warnings tend to be quite localised, with only around 15% of warnings being for "all Ireland". Of those, most are wind or fog warnings. Figure 24 shows the average number of people (as proxied by county population) affected by each type of weather warning.

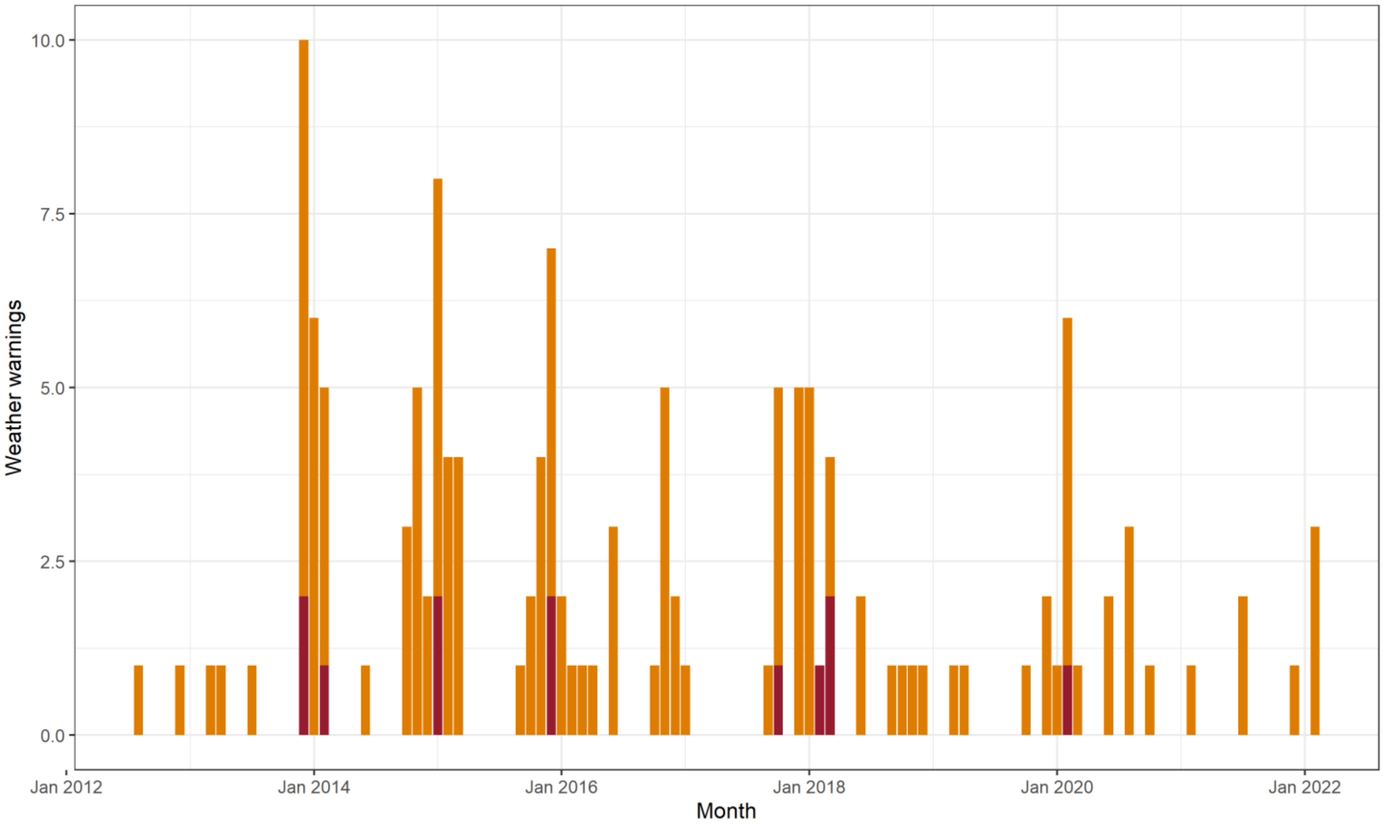
Figure 24 C4 Orange and red weather warnings by population affected



Source: Frontier Economics analysis of Met Éireann historical data
Note: Data includes observations April 2012 up to May 2022

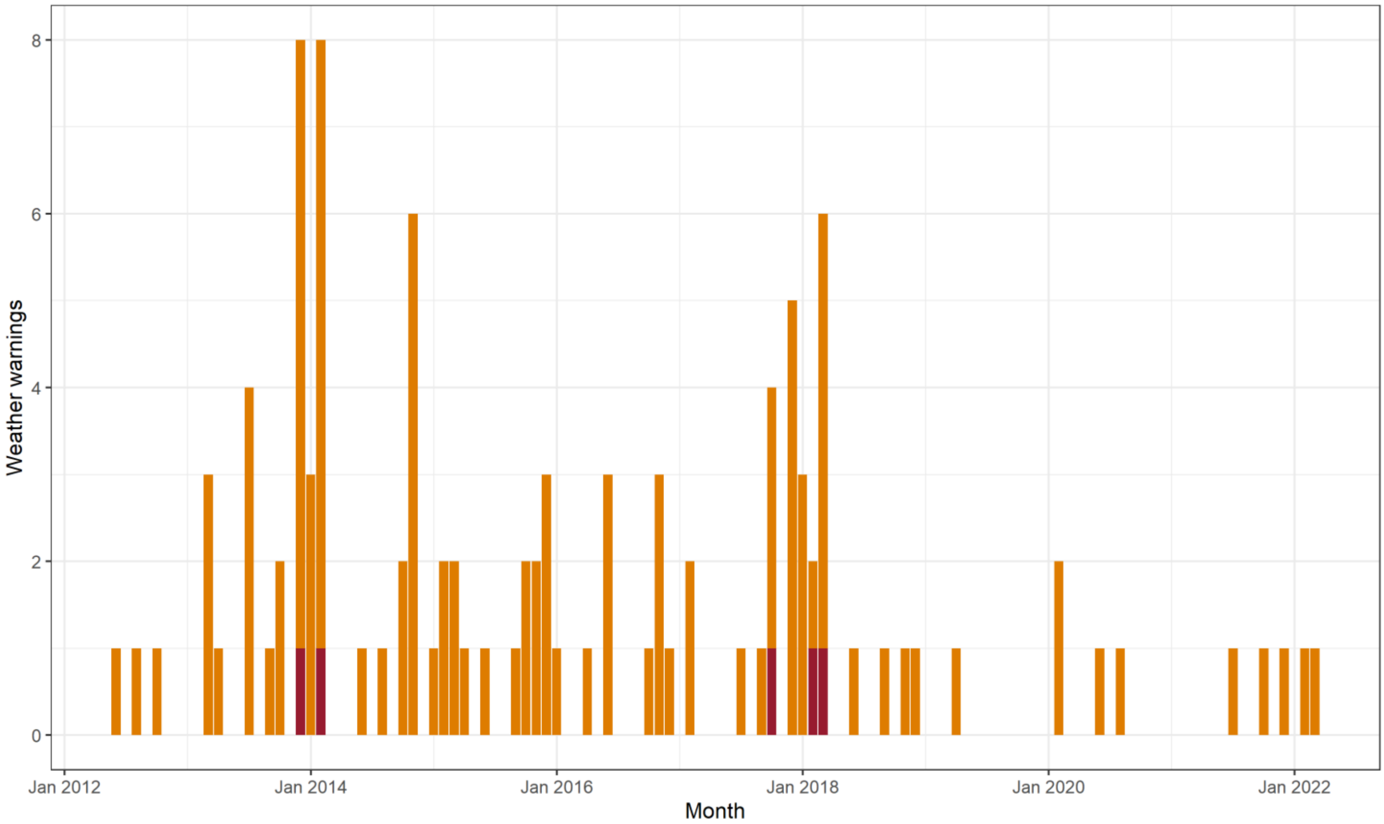
While snow and ice warnings that can affect ECNs are relatively rare, they tend to have national coverage which can increase the burden on ECN operators. Whereas wind warnings (the most common warning) that can affect ECNs can be more localised (Orange and red wind warnings on average affect 1.6 million people). High temperature warnings tend to be more localised and on average only reach about 500,000 people. A higher number of weather warnings might be expected for the Connacht province, facing the Atlantic in the west. However, when considering the data by province, no particular trend for any province can be observed.

Figure 25 C5 Weather warnings in Connacht 2013-2021



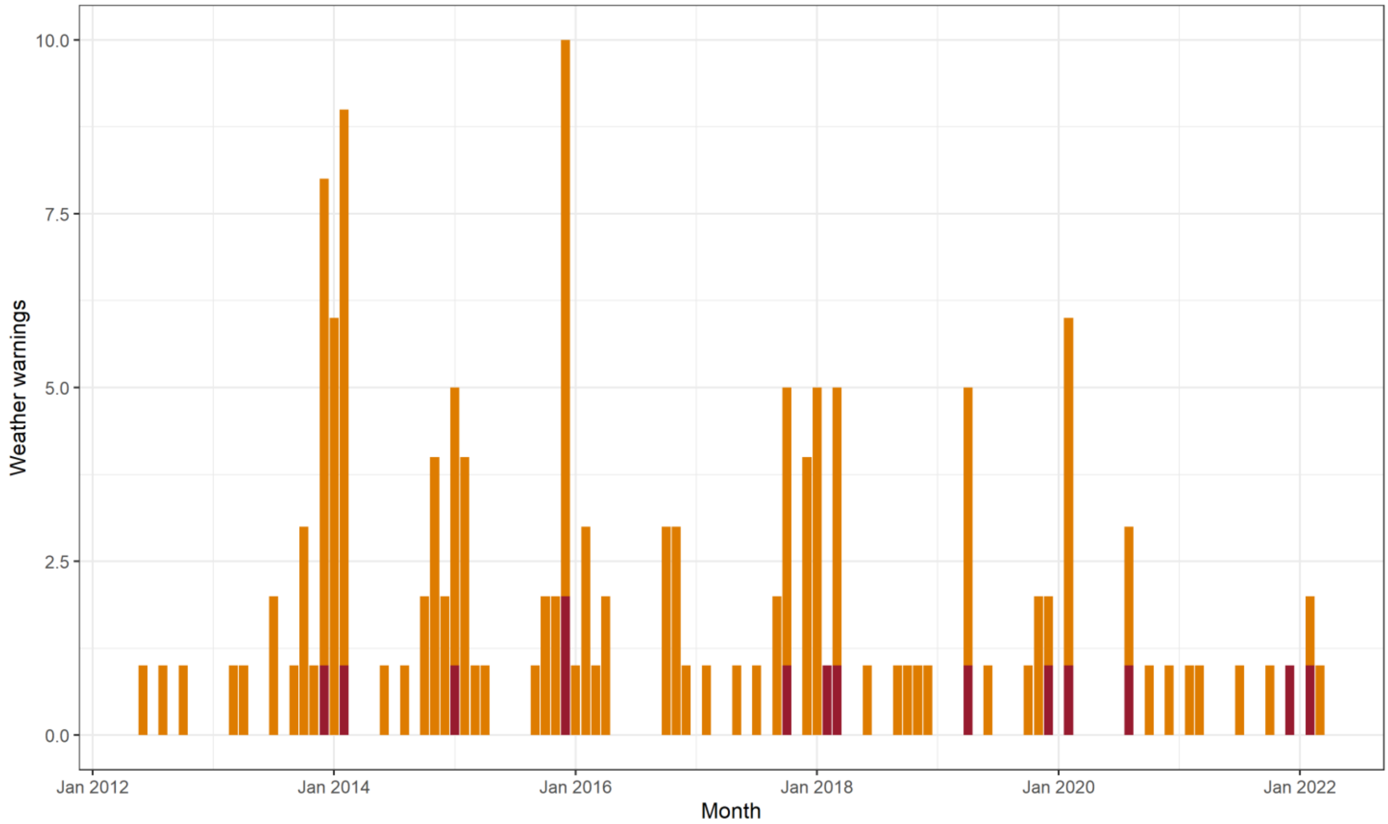
Source: Frontier Economics analysis of Met Éireann historical data
Note: Data includes observations April 2012 up to May 2022

Figure 26 C6 Weather warnings in Leinster 2013-2021



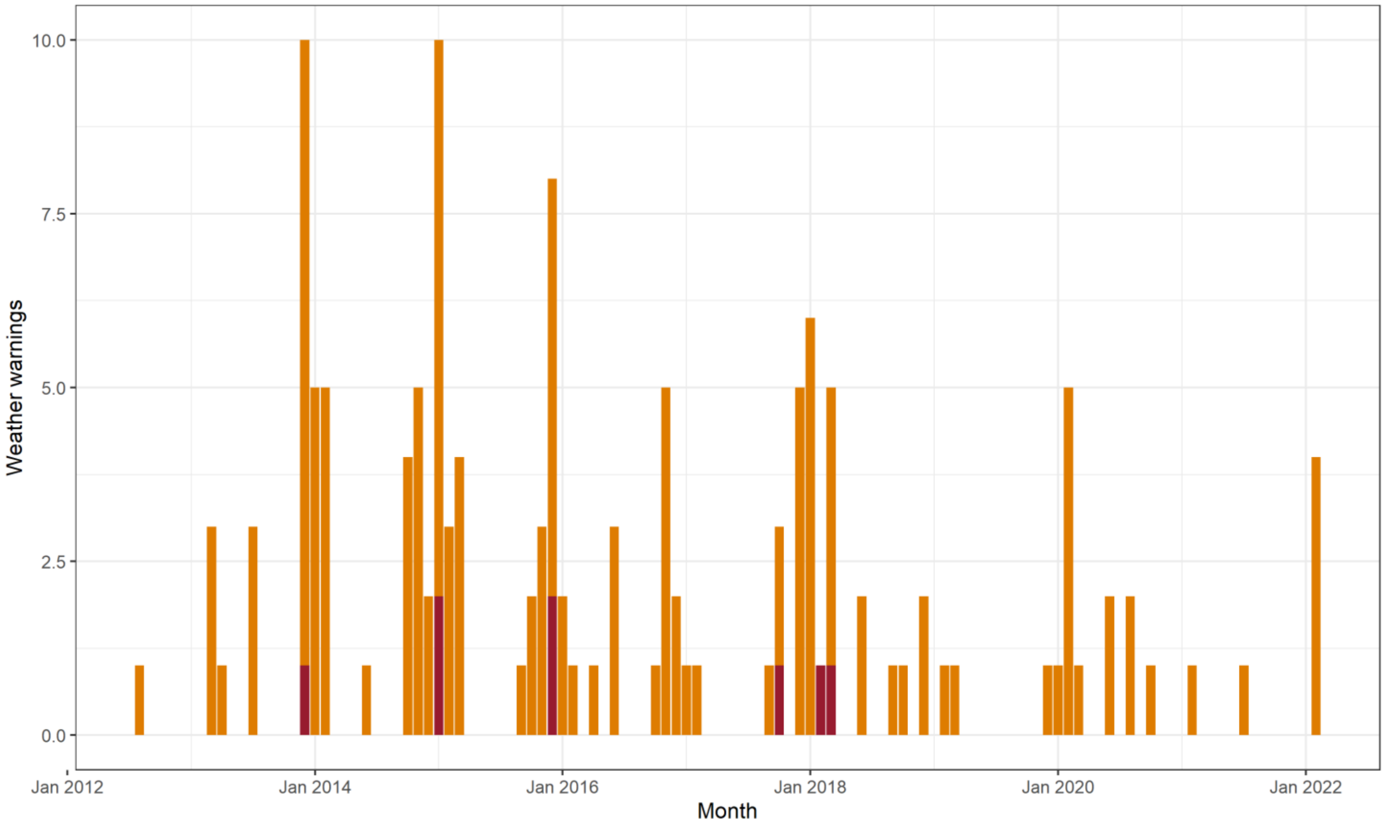
Source: *Frontier Economics analysis of Met Éireann historical data*
Note: *Data includes observations April 2012 up to May 2022*

Figure 27 C7 Weather warnings in Munster 2013-2021



Source: Frontier Economics analysis of Met Éireann historical data
Note: Data includes observations April 2012 up to May 2022

Figure 28 C8 Weather warnings in Ulster 2013-2021



Source: Frontier Economics analysis of Met Éireann historical data
Note: Data includes observations April 2012 up to May 2022