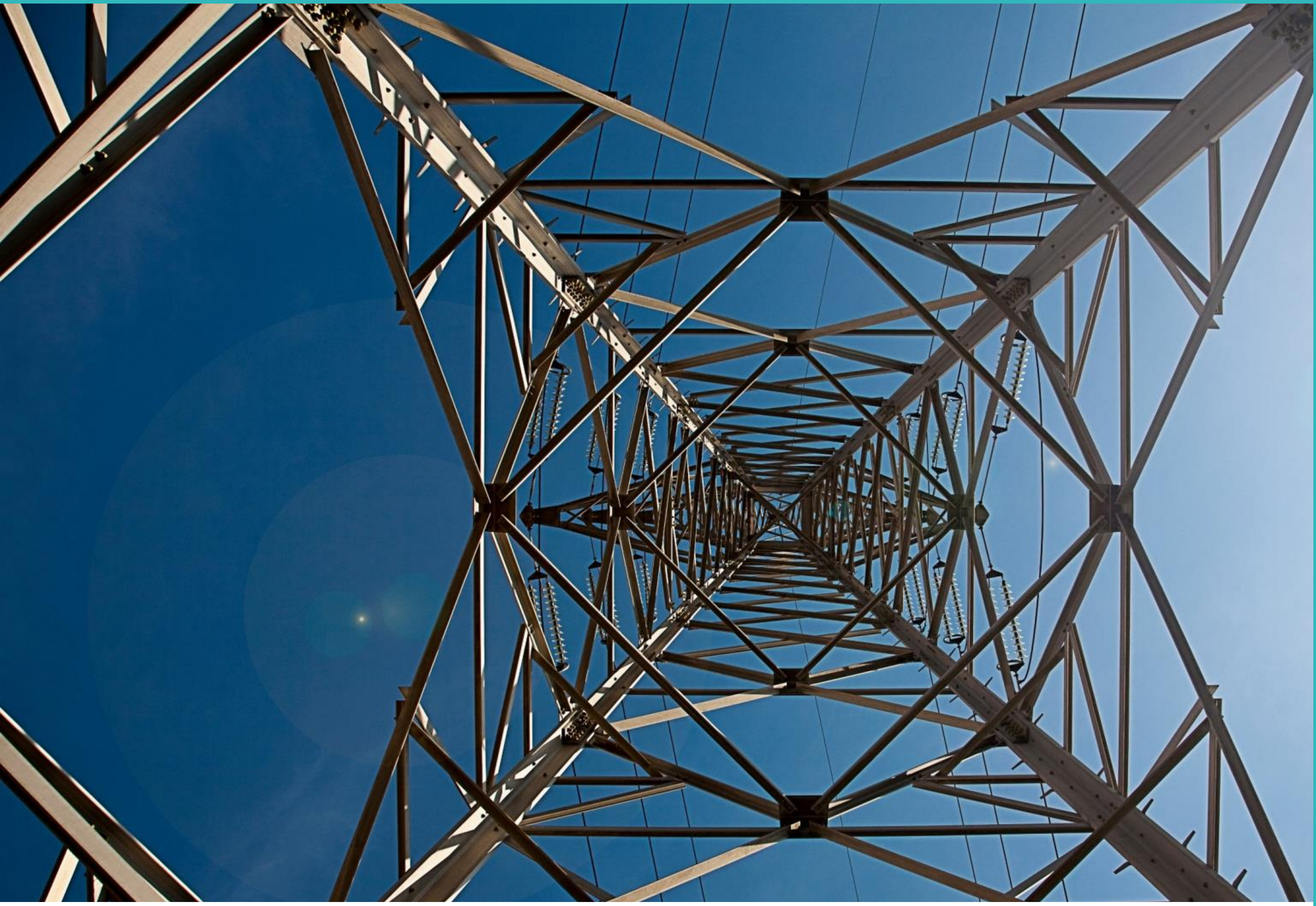

REPORT

Laboratory Examination and Testing of Recovered Overhead Line Conductor.

For dissemination via Smarter Networks portal

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Executive Summary

UK Power Networks (UKPN) has in excess of 24,000 km of high voltage (HV) overhead line (OHL) conductors on its distribution networks, comprising over 280,000 spans.

In order to determine the typical deterioration rates of HV OHL conductor on the distribution network, a Network Innovation Allowance (NIA) project was developed by UKPN. This project involved the sampling and laboratory testing of approximately 300 randomly selected samples of different types of OHL conductor, from various locations across the network (both the EPN and SPN licence areas were involved in the project).

UKPN commissioned EA Technology to carry out the laboratory testing of the recovered samples of OHL conductor to determine the present condition and identify significant trends in the acquired results.

The key objective of these tests was to determine the typical condition of the conductors within specified age ranges, determine whether the condition of the conductors vary between locations (e.g. costal or industrial) and to develop a deterioration algorithm.

Conclusions

C1. The analysis indicated that there is some evidence to suggest that the expected service life for both ACSR and Copper type overhead line conductor does reduce with proximity to coast.

C2. The ability to explore the relationship between expected service life and proximity to coast was limited due to the sample sizes across the condition ranges.

C3. Variability in age at end of life would suggest that other factors are significantly influencing the results.

C4. Increasing the sample sizes, with particular focus on conductors that are closer to the coast (i.e. within 20 km of the coast) and conductors that are at or approaching end of life could help strengthen the correlation between proximity to coast and expected service life.

C5. Other factors known to influence the rate of degradation of conductors are operating temperature and number of faults experienced during service.

Recommendations

R1. UKPN should consider the benefit of undertaking a further programme of condition assessment in order to increase sample sizes in specific areas: conductors that are closer to the coast (within 20 km of the coast) and conductors that are at or approaching end of life.

R2. It is recommended that UKPN explore whether information exists regarding operating temperature and number of faults experienced during service for the conductor samples assessed during this project.

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1. Background and Introduction

UK Power Networks (UKPN) has in excess of 24,000 km of high voltage (HV) overhead line (OHL) conductors on its distribution networks, comprising over 280,000 spans.

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UKPN commissioned EA Technology to carry out the laboratory testing of the recovered samples of OHL conductor to determine the present condition and identify significant trends in the acquired results.

The key objective of these tests was to determine the typical condition of the conductors within specified age ranges, determine whether the condition of the conductors vary between locations (e.g. costal or industrial) and to develop a deterioration algorithm.

2. Sample Details

A total of 291 conductor samples were removed from UKPN overhead line network and submitted to EA Technology for laboratory testing. These samples were recovered from both the EPN and SPN licence areas, with 187 and 104 samples from each area respectively.

The samples provided for testing were comprised of the following four conductor types: aluminium conductor steel reinforced (ACSR), copper (Cu), aluminium (Al) and all aluminium alloy conductor (AAAC). The number of samples by type and licence area are detailed below in Table 1.

Table 1 Breakdown of conductor samples by licence area and type

Licence area	Number of samples by type			
	ACSR	Cu	Al	AAAC
EPN	100	68	1	18
SPN	73	27	1	3
Total	***173***	***95***	***2***	***21***

For each conductor type except aluminium, sampling was additionally undertaken across a variety of conductor sizes; the two aluminium conductors were both size Ant. The breakdown of ACSR, Cu and AAAC conductors by size and licence area are detailed in Table 2, Table 3 and Table 4 respectively.

Further characteristic details for each conductor type and size involved in this project is provided in Appendix II of this report.

Table 2 Breakdown of ACSR conductor samples by size

Licence area	Number of ACSR samples by size				
	Squirrel	Gopher	Ferret	Rabbit	Dog
EPN	-	49	-	45	6
SPN	19	25	11	18	-
Total	***19***	***74***	***11***	***63***	***6***

Table 3 Breakdown of Cu conductor samples by size

Licence area	Number of Cu samples by construction (stranding and wire diameter (number/mm))				
	3/2.65	3/3.75	7/3.55	19/2.50	7/4.30
EPN	21	18	-	23	6
SPN	9	9	7	-	2
Total	***30***	***27***	***7***	***23***	***8***

Table 4 Breakdown of AAAC conductor samples by size

Licence area	Number of AAAC samples by size		
	Almond	Fir	Hazel
EPN	2	3	13
SPN	-	3	-
Total	***2***	***6***	***13***

For each individual conductor sample, the following information was provided by UKPN: type, size, sample length, year of installation[1], pole number, route, environmental information, voltage and grid reference. For a small number of samples, a postcode was additionally provided.

3. Laboratory Testing Information

The following test procedures are used in order to assess the condition of a sampled OHL conductor. Where a test is type specific, this is stated.

3.1 External / Internal Condition of Conductors

When assessing the condition of an OHL conductor it is important to accurately determine the condition of the strands, identify the presence of any internal corrosion and thoroughly assess the quality, quantity and condition of grease that is present. This is because the overwhelming failure mechanism for conductors arises out of internal corrosion due to the ingress of moisture and aggressive pollutants. For ACSR conductors greasing is applied at the time of manufacture to prevent this from occurring. However, the quantity of grease present within a conductor will depending upon the requirements stipulated by the asset owner at the time of purchase. Additionally, it is reasonable to expect that the quality of the grease applied to a conductor will vary between manufacturers.

During the operating life of a conductor, the greases themselves are subject to aging which in severe environments leads to a reduction in the effectiveness of the grease.

3.2 Torsion Testing

For ACSR conductors the critical degradation process and dominant long-term failure mode is corrosion. Corrosion particularly at the steel/aluminium interface results in the progressive loss of ductility of the aluminium strands. Eventually these fail in a brittle manner and transfer the current to the steel, which overheats and fails. Once corrosion takes hold the lifetime of a conductor is relatively short. Corrosion can be accurately monitored by the ductility of the aluminium strands as measured by a simple torsion test. A new strand gives 25-30 twists to failure. Once this value falls below 10 twists, strand failures during service are likely.

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[1] It should be noted that the year of installation corresponds to the route from which the conductor was sampled.

3.3 Copper Conductor Degradation and Failure Modes

The age-related process that can ultimately lead to failure of copper-based conductors is fatigue. This is an insidious process that eventually leads to the development of a crack and failure of individual strands. For the great majority of a component's lifetime there will be virtually no visible effects and therefore fatigue is difficult to detect prior to the final stages of the degradation process. However, previous experience with conductors where fatigue has been observed has shown that evidence of other mechanical damage, in particular wear associated with fittings[2], is often an indicator of impending fatigue failure.

In order to assess the condition and likely performance of the copper conductor it is therefore necessary to look for evidence of mechanical damage.

3.4 Wrapping Test

For AAAC conductors the critical degradation process and dominant long term failure mode is corrosion. Corrosion results in the progressive loss of ductility of the aluminium alloy strands, resulting in eventual failure in a brittle manner. Once corrosion takes hold the life time of the conductor is relatively short. Corrosion can be accurately monitored by measuring the ductility of the aluminium strands.

The ductility of individual aluminium alloy strands is measured by a wrapping test, as detailed by BS EN 50183:2000. This test involves wrapping an individual strand through eight turns around a mandrel of diameter equal to that of the strand. A new strand should not break during this test.

3.5 Mechanical Testing and Calculation of Breaking Load

For OHL conductors, tensile testing is carried out to ascertain whether the strength of the conductor complies with the British Standard. Mechanical testing is performed on selected individual strands taken from each layer of a conductor sample; from which a breaking load for the conductor is calculated.

The calculated breaking load of an ACSR conductor can be taken to be 95% of the sum of the strengths of the individual component wires. This is calculated from the sum of the measured breaking loads of the aluminium wires plus the sum of the measured breaking load of the steel wires extrapolated at 1% elongation.

3.6 Expected Remnant Life

Based on the results of the laboratory testing, an estimated remnant service life was calculated for each conductor sample using EA Technology's proprietary conductor condition assessment criteria. For conductor sampled from service, the expected remnant service life will fall into one of four bands:

- 15-20 years (where a conductor is considered as good as new)
- 10-15 years (where some measurable degradation to the conductor has occurred)
- 5-10 years (where significant degradation to the conductor has occurred)
- Less than 5 years (conductor is considered to be at end of life)

4. Condition Assessment

Detailed below is the methodology used in the condition assessment of each conductor type. For illustrative purposes, a single sample has been selected at random from each conductor type and the condition assessment described.

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[2] The copper conductor samples supplied for this project did not include fittings.

4.1 ACSR Conductor Assessment

4.1.1 External / Internal Condition of Conductor

The external surface of the conductor was found to be in a relatively good condition although greyed due to environmental exposure (Figure 1). There was some lichen growth across the length of the conductor.

Figure 1 External surface of the conductor – Tag ID 271

Internally, the conductor was relatively clean of debris ingress and exhibited only a low level of corrosion product. An adequate quantity of grease was present at the aluminium/steel strand interface. Overall, this grease was golden in appearance and pliable (Figure 2).

Figure 2 Inner surface of outer aluminium strands – Tag ID 271

The core steel strand was coated in an adequate quantity of grease (Figure 3). This grease was overall both golden in appearance and pliable. Cleaned of grease the steel core strand displayed no evidence of degradation.

Figure 3 Condition of core steel strand – Tag ID 271

4.1.2 Torsion Testing

The results of torsion tests carried out on the selected aluminium conductor strands are shown in Table 5.

Table 5 Torsion test results for individual aluminium strands

Sample	Sample Point	Number of turns to fracture for each strand sample						Total Average
Tag ID 271	Aluminium strands	23	22	22	26	24	16	**22**

When torsion tested, the conductor strands of the sample produced an average number of turns to failure less than 25. This suggests that some measurable reduction had occurred in the ductility of the conductor strands.

4.1.3 Mechanical Testing

Mechanical tests were carried out on individual conductor strands. The results of the measurements of the selected aluminium strands are shown in Table 6 and selected steel core strands in Table 7.

Table 6 Results of mechanical testing for individual aluminium strands

Sample		Aluminium Strands	
		Maximum Load (N)	Tensile Stress (N/mm^2)
Tag ID 271	1	1535	174
	2	1511	171
	3	1552	176
	4	1510	171
	5	1551	176
	6	1546	175
Average		**1534**	**174**

Table 7 Results of mechanical testing for individual aluminium strands

Sample		Maximum Load (N)	Tensile Stress (N/mm^2)	Load at 1% Elongation (N)	1% Proof Stress (N/mm^2)
Tag ID 271	1	14074	1597	12492	1417
	2	14093	1599	12522	1421
Average		**14084**	**1598**	**12507**	**1419**

4.1.4 Calculated Breaking Load

The calculated breaking load of a conductor can be taken to be 95% of the sum of the strengths of the individual component wires. This is calculated from the sum of the measured breaking load of the aluminium wires plus the sum of the measured breaking load of the individual steel wires extrapolated at 1% elongation. These values are shown in Table 8. The British Standard (BS EN 50182) minimum specified breaking load values are shown alongside for comparison.

Table 8 Calculated breaking load of conductor

Sample	Calculated Breaking Load (kN)	British Standard Breaking Load (kN)
Tag ID 271	**20.63**	18.42

4.1.5 Summary of Results

When combining the results from the visual examination and mechanical testing an expected end of life can be determined for the conductor. Based on the assessment, an expected end of life of 10-15 years is predicted for the route. This is due to the measured reduction in the ductility of the conductor strands.

Table 9 gives a summary of the visual examination and the mechanical testing that has been used to determine the expected end of life.

Table 9 Summary of results and expected end of life

Sample	Grease Condition	Corrosion	Average Turns to Fracture	Actual Breaking Load as a % of British Standard	Expected Remnant Life (Years)
Tag ID 271	Adequate levels. Overall, golden and pliable	Low levels of aluminium oxide	22	112	**10-15**

4.2 Copper Conductor Assessment

4.2.1 External / Internal Condition of Conductor

The external surface of the conductor was found to be in a relatively good condition. There was a normal level of verdigris (a greenish copper carbonate corrosion product) across the external surface (Figure 4).

Figure 4 External surface of the conductor – Tag ID 140

A low level of debris ingress was observed between the external conductor strands. Although the inner surface of the outer conductor strands exhibited a near full covering of corrosion product, this appeared to be mostly superficial with no evidence of significant material loss (Figure 5).

Figure 5 Inner surface of copper strands – Tag ID 140

The outer surface of the inner copper strands displayed a near full covering of corrosion product. Again, however, this corrosion appeared to be mostly superficial with no evidence of significant material loss (Figure 6).

Figure 6 Outer surface of inner copper strands – Tag ID 140

The inner surface of the inner copper strands was both clean of debris ingress and free from significant corrosion product (Figure 7).

Figure 7 Inner surface of inner copper strands – Tag ID 140

The core copper strand was found to be bright in appearance, clean of debris ingress and free from significant corrosion product (Figure 8).

Figure 8 Condition of core copper strand – Tag ID 140

4.2.2 Copper Conductor Degradation and Failure Modes

The conductor sample was examined for evidence of metal damage. No evidence of significant mechanical damage or material loss was observed.

4.2.3 Mechanical Testing

Mechanical tests were carried out on the individual conductor strands using an Instron tensile testing machine. For the test, six strands were selected at random from each layer of the conductor, along with the central core strand. The results showing the measurements of selected strands are shown in Table 10.

Table 10 Results of mechanical testing for individual copper strands

Strand	Outer Copper Strands		Inner Copper Strands		Core Copper Strand	
	Maximum Load (N)	Tensile Stress (N/mm^2)	Maximum Load (N)	Tensile Stress (N/mm^2)	Maximum Load (N)	Tensile Stress (N/mm^2)
1	2167	442	2275	463	2259	460

Strand	Outer Copper Strands		Inner Copper Strands		Core Copper Strand	
	Maximum Load (N)	Tensile Stress (N/mm^2)	Maximum Load (N)	Tensile Stress (N/mm^2)	Maximum Load (N)	Tensile Stress (N/mm^2)
2	2219	452	2266	462	-	-
3	2152	438	2278	464	-	-
4	2155	439	2239	456	-	-
5	2177	431	2205	449	-	-
6	2142	436	2277	464	-	-
Average	**2169**	**440**	**2257**	**460**	**2259**	**460**

4.2.4 Calculated Breaking Load

British Standard 7884:1997 states that after stranding, the individual strands of a copper / copper alloy conductor should achieve a breaking load no less than 92.5% of the specified minimum breaking load. The average breaking load for all strands should be no less than 94% of the specified minimum breaking load. For hard drawn copper wire of diameter 3.55mm the specified minimum breaking load is 4027N.

The tested conductor sample met both of these requirements, with the minimum wire breaking load measured at 106% and the average at 111% of British Standard specified minimum breaking load (Table 11).

Table 11 **Calculated breaking load of conductor**

Calculated Average Copper Strand Breaking Load (N)	Measured Minimum Copper Strand Breaking Load (N)	British Standard Specified Minimum Breaking Load (N)
2212	2117	1997

4.2.5 Summary of Results

When combining the results from the visual examination and mechanical testing an expected end of life can be determined for the conductor. Based on the assessment, an expected end of life 15-20 years is predicted for the route. This is due to the absence of significant degradation, along with the good measured breaking load.

Table 12 gives a summary of the visual examination and mechanical testing, which has been used to determine the expected end of life.

Table 12 **Summary of results and expected end of life**

Verdigris	Pollution Ingress	Average Breaking Load as % of British Standard	Minimum Copper Strand Breaking Load as a % of British Standard	Degradation and Material Loss	Metal Fatigue	Expected Remnant Life (Years)
Normal level	Low	111	106	No significant	None	**15-20**

4.3 Aluminium Conductor Assessment

4.3.1 External / Internal Condition of Conductor

The external surface of the conductor was found to be in a relatively good condition although greyed due to environmental pollution (Figure 9).

Figure 9 External surface of the conductor – Tag ID 005

Internally, the conductor was relatively clean of debris ingress and free from significant corrosion product (Figure 10). The inner surface of the outer aluminium strands was coated in a low level of grease. Overall, this grease was both golden and pliable, however some hardening of the grease was observed in locations.

Figure 10 Inner surface of outer aluminium strands – Tag ID 005

The core aluminium strand was coated in a low quantity of grease (Figure 11). This grease was overall both golden in appearance and pliable, however some hardening of the grease was observed in locations. Cleaned of grease the aluminium core strand displayed no evidence of degradation.

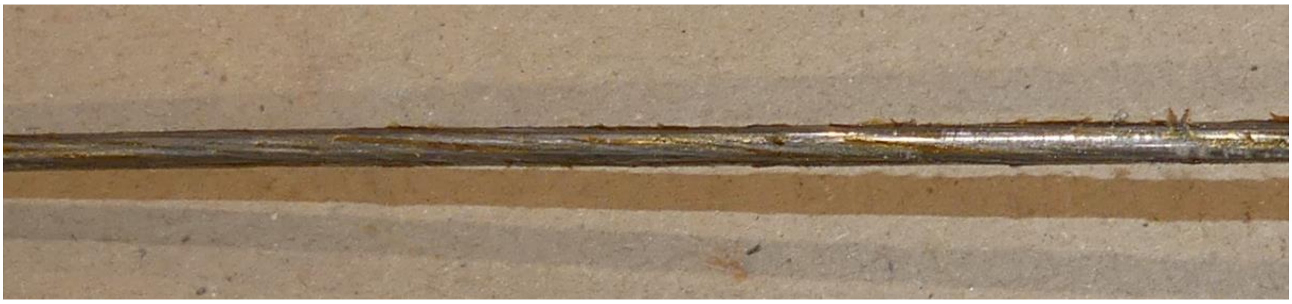

Figure 11 Condition of core aluminium strand – Tag ID 005

4.3.2 Torsion Testing

Torsion testing was undertaken on the six outer aluminium strands. The results of torsion tests carried out on the selected aluminium conductor strands are shown in Table 13.

Table 13 Torsion test results for individual aluminium strands

Sample	Sample Point	Number of turns to fracture for each strand sample						Total Average
Tag ID 005	Aluminium strands	24	27	24	25	25	25	**25**

When torsion tested, the conductor strands produced an average turns to failure of 25. This suggests that no significant reduction has occurred in the ductility of the conductor strands.

4.3.3 Mechanical Testing

Mechanical tests were carried out on the individual conductor strands using an Instron tensile testing machine. The test was performed on all six outer conductor strands and the central core strand. Results showing the measurements of selected strands are shown in Table 14.

Table 14 Results of mechanical testing for individual aluminium strands

Sample		Outer Aluminium Strands		Core Aluminium Strand	
		Maximum Load (N)	Tensile Stress (N/mm^2)	Maximum Load (N)	Tensile Stress (N/mm^2)
Tag ID 005	1	1292	171	1343	178
	2	1241	164	-	-
	3	1268	168	-	-
	4	1308	173	-	-
	5	1315	174	-	-
	6	1268	168	-	-
Average		**1282**	**170**	**1343**	**178**

4.3.4 Calculated Breaking Load

The breaking load of the conductor sample, calculated from the sum of the strengths of the individual component wires, is shown in Table 15. The British Standard (BS EN 50182) minimum specified breaking load value is shown alongside for comparison.

Table 15 Calculated breaking load of conductor

Sample	Calculated Breaking Load (kN)	British Standard Breaking Load (kN)
Tag ID 005	**9.03**	8.72

4.3.5 Summary of Results

When combining the results from the visual examination and mechanical testing an expected end of life can be determined for the conductor. Based on the assessment, an expected end of life 15-20 years is predicted for the route. This is due to the absence of significant degradation, along with the good measured breaking load.

Table 16 gives a summary of the visual examination and the mechanical testing that has been used to determine the expected end of life.

Table 16 Summary of results and expected end of life

Sample	Grease Condition	Corrosion	Average Turns to Fracture	Actual Breaking Load as a % of British Standard	Expected Remnant Life (Years)
Tag ID 005	Minimal level. Hardened in locations.	No significant	25	104	**15-20**

4.4 AAAC Conductor Assessment

4.4.1 External / Internal Condition of Conductor

The external surface of the conductor was found to be in a relatively good condition although greyed due to environmental pollution (Figure 12).

Figure 12 External surface of the conductor – Tag ID 001

A low level of debris ingress was observed between the external conductor strands (Figure 13). The inner surface of the outer aluminium strands was free from significant corrosion product.

Figure 13 Inner surface of outer aluminium alloy strands – Tag ID 001

The core aluminium alloy strand was found to contain a negligible quantity of grease (Figure 14). Although slightly dulled due to debris ingress, the core strand showed no evidence of significant degradation.

Figure 14 Condition of core aluminium alloy strand – Tag ID 001

4.4.2 Wrapping Test

The results of the wrapping test carried out on the aluminium alloy strands of the conductor are shown in Table 17. The test was performed on the six outer strands of the conductor.

Table 17 Wrapping test results for individual aluminium alloy strands of conductor

Sample	Strand	Wrapping Test
Tag ID 001	1	**Fractured**
	2	Cracked

Sample	Strand	Wrapping Test
	3	Passed
	4	Cracked
	5	**Fractured**
	6	Passed

When subjected to a wrapping test, a new AAAC strand is expected to perform eight turns around a mandrel of equal diameter to that of the strand without failure. The wrapping test resulted in two strand failures prior to achieving eight turns. Additionally, two strands cracked during the testing. This suggests that some reduction in the ductility of the conductor strands has occurred.

4.4.3 Mechanical Testing

British Standard BS EN 5183:2000 stipulates a minimum tensile strength of 295 N/mm^2 and minimum permanent elongation after fracture of 3.5% (on a gauge length of 250mm) for AAAC wires of type Almond.

Mechanical tests were carried out on individual conductor strands using an Instron tensile testing machine. From each layer of the conductor sample six strands were selected for testing. The test was performed on all six outer conductor strands and the central core strand. Results showing the measurements of selected aluminium alloy strands are shown in Table 18.

Table 18 **Results of testing for individual aluminium alloy conductor strands**

Strand	Outer Aluminium Alloy Strands			Core Aluminium Alloy Strand		
	Maximum Load (N)	Tensile Stress (N/mm^2)	Elongation (%)	Maximum Load (N)	Tensile Stress (N/mm^2)	Elongation (%)
1	1202	279	5.9	1294	301	3.6
2	1190	277	5.9	-	-	-
3	1220	284	4.9	-	-	-
4	1192	277	5.8	-	-	-
5	1198	279	6.1	-	-	-
6	1210	281	5.6	-	-	-
Average	**1202**	**280**	**5.7**	**1294**	**301**	**3.6**

4.4.4 Calculated Breaking Load

The calculated breaking load of a conductor can be taken to be 95% of the sum of the strengths of the individual component wires. The calculated breaking load of the conductor sample is shown in Table 19. The British Standard (BS EN 50182) minimum specified breaking load value is shown alongside for comparison.

Table 19 **Calculated breaking load of conductor**

Sample	Calculated Breaking Load (kN)	British Standard Breaking Load (kN)
Tag ID 001	**8.08**	8.88

4.4.5 Summary of Results

Due to the measured braking loads of the conductor sample being significantly below the British Standard specified value, the conductor is considered to be at end of its service life.

Table 20 gives a summary of the visual examination and the mechanical testing that has been used to determine the expected end of life.

Table 20 **Summary of results and expected end of life**

Grease Condition	Corrosion	Wrapping Test	Actual Breaking Load as a % of British Standard	Minimum Elongation after Fracture (%)	Expected Remnant Life (Years)
Minimal	No significant	**Fail**	**91**	3.6	**<5**

4.5 Results of Condition Assessment

The full set of condition assessment results for all 291 conductor samples can be found in EA Technology excel report *A2469 Reports Issue 4*. The accompanying UKPN provided background information is additionally included in this document.

5. Statistical Analysis

5.1 Introduction

In order to identify any significant trends in the acquired results of the condition assessments undertaken, a statistical analysis was performed. For OHL conductor types ACSR and copper this statistical analysis is detailed in section 5.2 and section 5.3 of this report respectively.

Due to the low population sizes for the condition assessed conductor types AAAC and Aluminium (21samples and 2 samples), it was agreed with UKPN that there would be little value in undertaking a statistical analysis of the results collected for the assessment of these samples. As such, the AAAC and Aluminium conductor samples were not included in the statistical analysis.

5.2 ACSR Conductor

5.2.1 Sample Details

A total of 173 conductor samples were provided of five different types as summarised in Table 21 below. As shown below, the number of samples varied considerably from 6 for type Dog to 74 for type Gopher. The largest sample sizes were Rabbit and Gopher. The small sample sizes for Squirrel, Ferret and Dog make it unlikely for any reliable correlations to be determined for these conductor types.

Table 21 **Summary of ACSR samples by type**

Code	British Standard Code	Number of samples
Squirrel	21-AL 1/3-ST1A	19
Ferret	42-AL 1/7-ST1A	11
Rabbit	53-AL 1/9-ST1A	63
Dog	105-AL 1/14/ST1A	6
Gopher	26-AL 1/4-ST1A	74

All ACSR conductor samples	**173**

The ages of the samples ranged from 13 years old to 81 years old, with the majority of samples (86% or 149 of the 173 samples) being 50 years old or older as summarised in Figure 15 below.

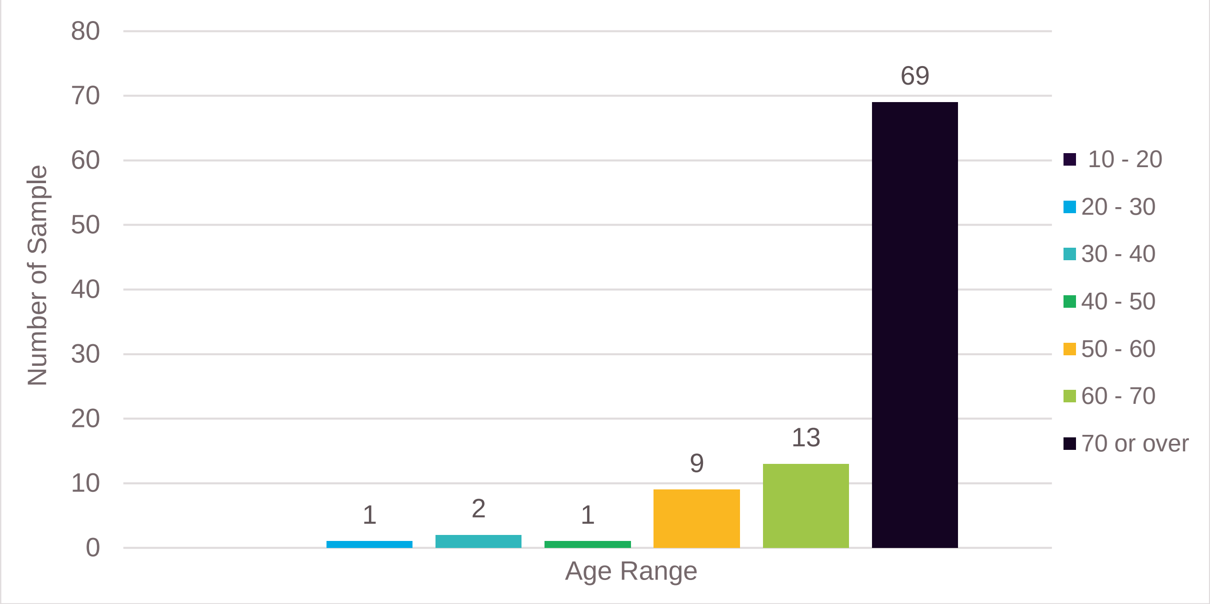

Figure 15 **Age of ACSR samples**

5.2.2 Comparison of Age and Years to End of Life

The following table shows the age (determined from the installation date) and the estimated years to end of life following testing for these samples by conductor type.

Table 22 **Summary of ACSR samples by type, age and years to end of life**

Type	Age Range (years)	Number of samples by Years to End of Life				
		15 - 20	10 - 15	5 - 10	<5	Total
Squirrel	10 - 20	0	0	0	0	0
	20 - 30	0	0	0	0	0
	30 - 40	1	1	0	0	2
	40 - 50	3	0	0	0	3
	50 - 60	0	1	0	0	1
	60 - 70	8	5	0	0	13
	70 - 80	0	0	0	0	0
	Total	**12**	**7**	**0**	**0**	**19**
Ferret	10 - 20	0	0	0	0	0
	20 - 30	0	0	0	0	0
	30 - 40	1	0	0	0	1
	40 - 50	0	0	0	1	1
	50 - 60	1	2	0	2	5
	60 - 70	1	3	0	0	4
	70 - 80	0	0	0	0	0
	Total	**3**	**5**	**0**	**3**	**11**
Rabbit	10 - 20	0	0	0	0	0
	20 - 30	0	0	0	0	0
	30 - 40	2	4	1	0	7
	40 - 50	2	2	0	0	4
	50 - 60	22	22	0	0	44

Type	Age Range (years)	Number of samples by Years to End of Life				
		15 - 20	10 - 15	5 - 10	<5	Total
	60 - 70	0	3	1	0	4
	70 - 80	1	3	0	0	4
	Total	**27**	**34**	**2**	**0**	**63**
Dog	10 - 20	0	0	0	0	0
	20 - 30	0	0	0	0	0
	30 - 40	0	0	0	0	0
	40 - 50	0	0	0	0	0
	50 - 60	0	0	0	0	0
	60 - 70	6	0	0	0	6
	70 - 80	0	0	0	0	0
	Total	**6**	**0**	**0**	**0**	**6**
Gopher	10 - 20	1	0	0	0	1
	20 - 30	0	1	0	0	1
	30 - 40	1	0	1	1	3
	40 - 50	1	0	0	0	1
	50 - 60	17	0	0	0	17
	60 - 70	21	6	0	3	30
	70 - 80	5	16	0	0	21
	Total	**46**	**23**	**1**	**4**	**74**

The results above are shown graphically below, indicating the percentage (%) of each sample type by years to end of life.

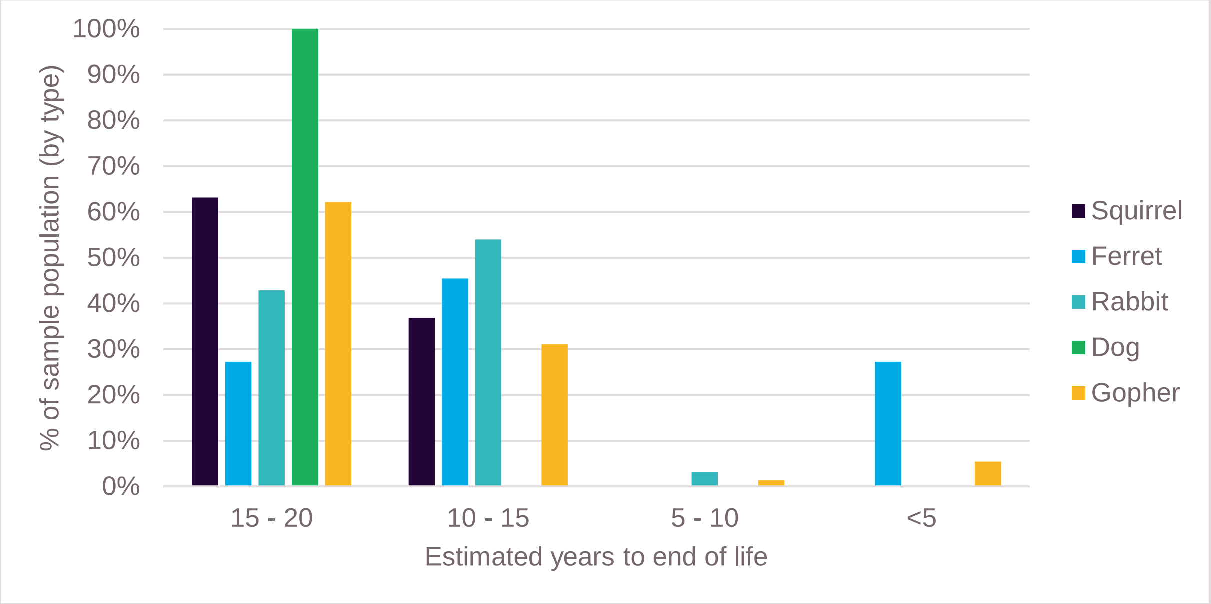

Figure 16 **Years to end of life against percentage of sample population**

Figure 16 shows that the majority of the ACSR samples (52% or 91 of the 173 samples) have an estimated 15 to 20 years remaining life. It is important to note that the 15-20 years estimate is considered to be a minimum, and it is possible that the remaining life of some of the samples would be higher than this value. Approximately 94% of the samples (163 of the 173 samples) tested had a remaining life of 10 or more years.

Only 7 of the 173 assets (4%) of the sample population were found to have a remaining life of 5 years or less, and these were type Ferret and Gopher only. No other ACSR conductor types were found to have a remaining life of 5 years or less.

Of those 7 assets found to have a remaining life of 5 years or less, six were found to have no grease and one had minimal grease. The following table provides a summary of the proportion of each conductor type found to have minimal or no grease. Ferret had the highest proportion of samples with no grease (18%, or 2 of the

11 samples). Gopher had the highest proportion of sample with some greasing issues (i.e. 45% or 33 of the 74 samples were found to have either no or minimal grease.

Table 23 **Summary of ACSR samples by type and grease condition**

Type	Total Samples	Of which	
		No grease	Minimal grease
Dog	6	0%	0%
Ferret	11	18%	9%
Gopher	74	7%	38%
Rabbit	63	0%	13%
Squirrel	19	0%	21%

5.2.3 Comparison of Distance to Coast and Years to End of Life

The following table shows the distance from coast (determined from the grid reference) and the estimated years to end of life following testing for the ACSR conductor samples.

Table 24 **Summary of ACSR samples by type, distance to coast and years to end of life**

Conductor Type and Size	Distance to Coast	Number of samples by Years to End of Life				
		15 - 20	10 - 15	5 - 10	<5	Total
Squirrel	>25km	5	0	0	0	5
	20-25km	5	0	0	0	5
	15-20km	2	0	0	0	2
	10-15km	0	0	0	0	0
	5-10km	0	6	0	0	6
	0-5km	0	1	0	0	1
	Total	**12**	**7**	**0**	**0**	**19**
Ferret	>25km	0	1	0	1	2
	20-25km	0	0	0	2	2
	15-20km	0	0	0	0	0
	10-15km	1	1	0	0	2
	5-10km	2	2	0	0	4
	0.5km	0	1	0	0	1
	Total	**3**	**5**	**0**	**3**	**11**
Rabbit	>25km	27	29	2	0	58
	20-25km	0	5	0	0	5
	15-20km	0	0	0	0	0
	10-15km	0	0	0	0	0
	5-10km	0	0	0	0	0
	0-5km	0	0	0	0	0
	Total	**27**	**34**	**2**	**0**	**63**
Dog	>25km	6	0	0	0	6
	20-25km	0	0	0	0	0
	15-20km	0	0	0	0	0

Conductor Type and Size	Distance to Coast	Number of samples by Years to End of Life				
		15 - 20	10 - 15	5 - 10	<5	Total
	10-15km	0	0	0	0	0
	5-10km	0	0	0	0	0
	0-5km	0	0	0	0	0
	Total	**6**	**0**	**0**	**0**	**6**
Gopher	>25km	37	20	0	2	59
	20-25km	0	0	0	2	2
	15-20km	1	0	0	0	1
	10-15km	4	0	0	0	4
	5-10km	3	3	0	0	6
	0-5km	1	0	1	0	2
	Total	**46**	**23**	**1**	**4**	**74**

The data summarised in the following graph shows that the majority of samples (75% or 130 of the 173 samples) were located 25km or more from the coast; typically beyond 25km costal effects are not seen to be significant contributing factor in the degradation of assets and as such this is considered to be an acceptable upper limit of distance banding for the purpose of the statistical analysis.

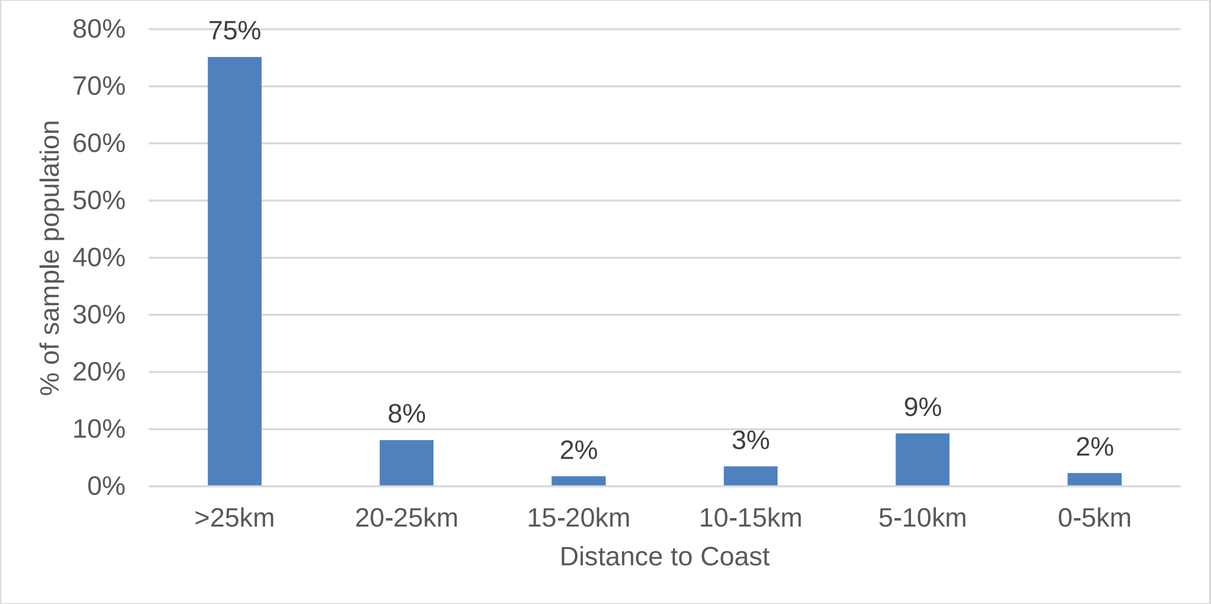

Figure 17 **Distance to Coast against sample population for ACSR Conductor Samples**

The Common Network Asset Indices Methodology (referred to as CNAIM), which is used to derive a Health Score for regulatory reporting, defines a range of modifiers that influence the rate of deterioration of assets. One of these modifiers is the distance to coast. Assets situated close to the coast are generally regarded to have a shorter expected life[3] than those situated inland. Within CNAIM this experience is captured via a Distance to Coast Modifier'. The scope of CNAIM does not currently encompass conductors on woodpole overhead lines, but the modifiers for conductors on tower overhead lines are shown below.

Table 25 **CNAIM Distance from Coast Modifier**[4]

Distance from Coast	Modifier

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[3] The time to the onset of critical degradation

[4] Common Network Asset Indices Methodology v1.1, Table 22

≤1km	2.0
>1km and ≤5km	1.5
>5k and ≤10km	1.2
>10k and ≤20km	1.0
>20km	1.0

The modifier indicates the extent to which the expected life varies with distance to coast. A conductor situated within 1km of the coast would be expected to have an expected life half that of an otherwise identical conductor located >10km from the coast. As shown in Figure 17, 11% of the population of conductor samples (i.e. 20 of the 173 samples) are located within 10 km of the coast.

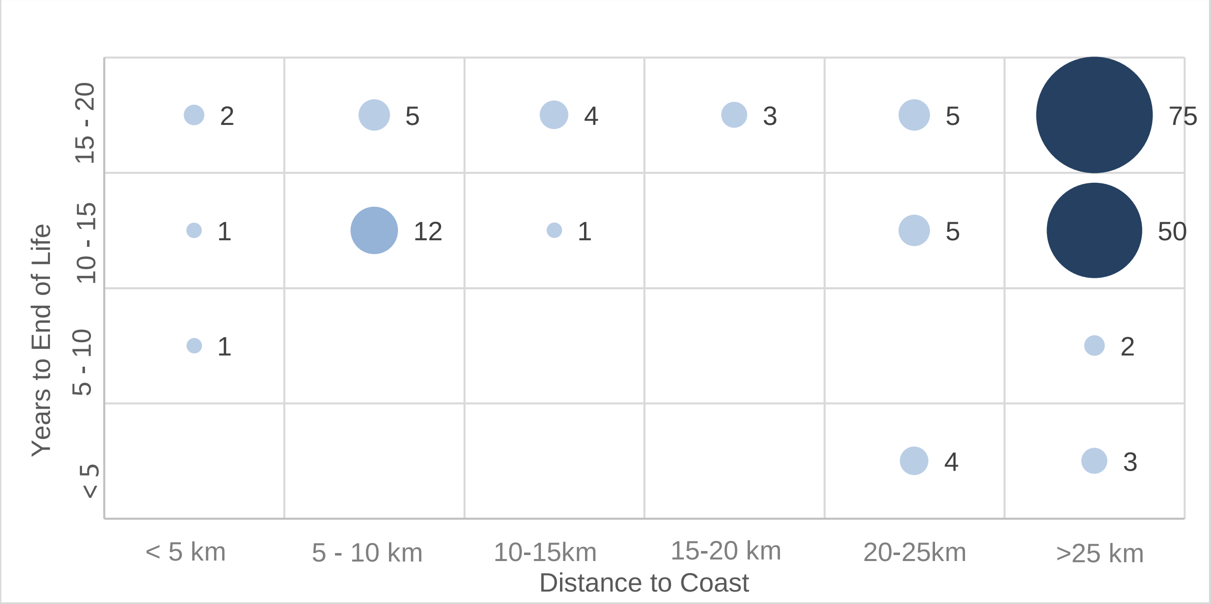

Figure 18 **Years to End of Life by Distance to Coast (as a heat map)**

The data shown in Figure 18 presents Years to End of Life vs Distance to Coast as a heat map, where the size of the marker indicates the number of samples with those criteria, i.e. there are 12 samples located within 5-10 km of the coast that have a remaining life of 10 - 15 years. This graph shows there is a very large cluster of samples located more than 25km from the coast and with at least 15 to 20 years of remaining life. This combined with the limited numbers of samples located close to the coast, gives low likelihood of finding a strong correlation between distance to coast and conductor life.

The following graph shows the average age at end of life by conductor type. This shows that the average age at end of life varies from approximately 68 years to 78 years.

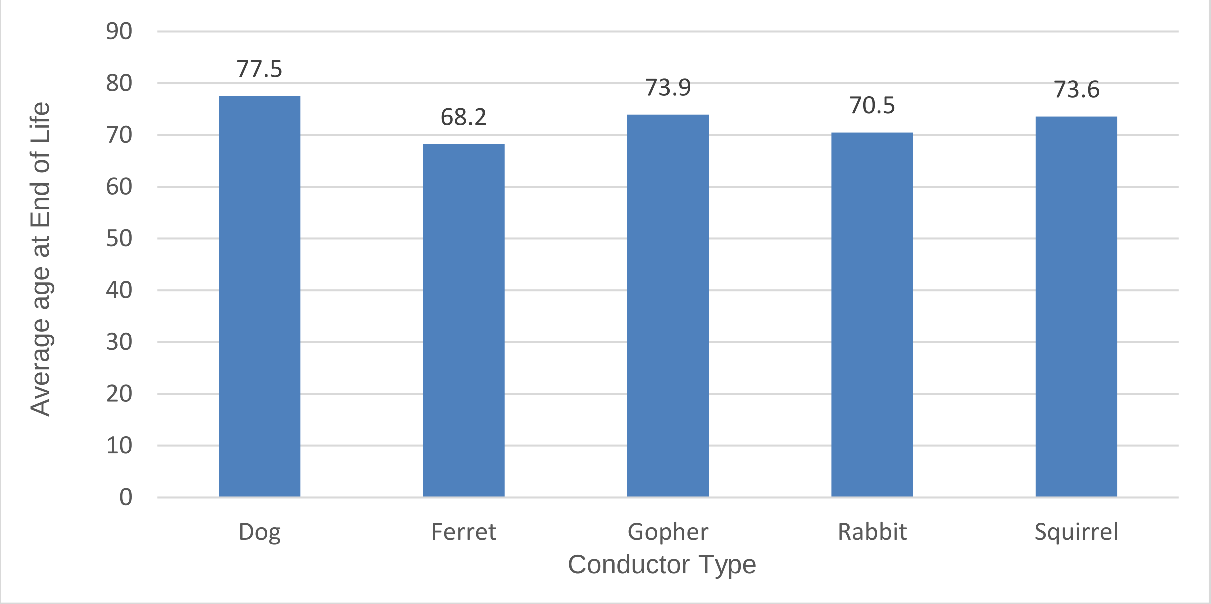

Figure 19 **Age at End of Life by conductor type (173 samples)**

The years to end of life is taken as the mid-point of the expected range, so for an asset of 50 years with an estimated 15 to 20 years of remaining life, the expected age and end of life is taken to be 67.5 years. The results of analytical tests provide a prediction of the years to end of life **of up** to 15 to 20 years, with a recommended interval of 15 years for resampling. Therefore, 15-20 years remaining life represents a minimum rather than an expectation, making it difficult to use as a predictor of useful life, particularly for young assets. Therefore, the data presented below shows the average age at end of life excluding all assets with 15 – 20 years remaining life.

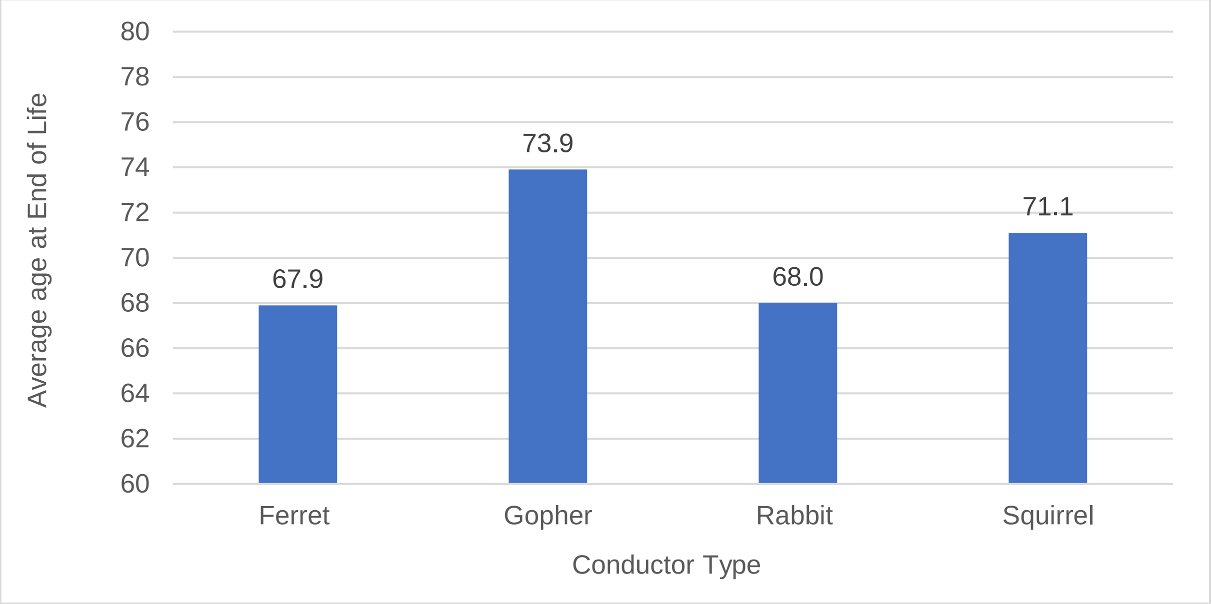

Figure 20 **Age at End of Life by conductor type (excluding assets with 15 – 20 years remaining life (82 samples)**

This shows that the average age at end of life varies between approximately 68 years and 73 years. Ferret has the shortest age at end of life, whilst Gopher has the longest life. Across all conductor types, the average age at end of life is 70 years.

The following graphs show the same data, but now as a scatter plot of the expected age at end of life, both including and excluding assets with 15 to 20 years remaining life.

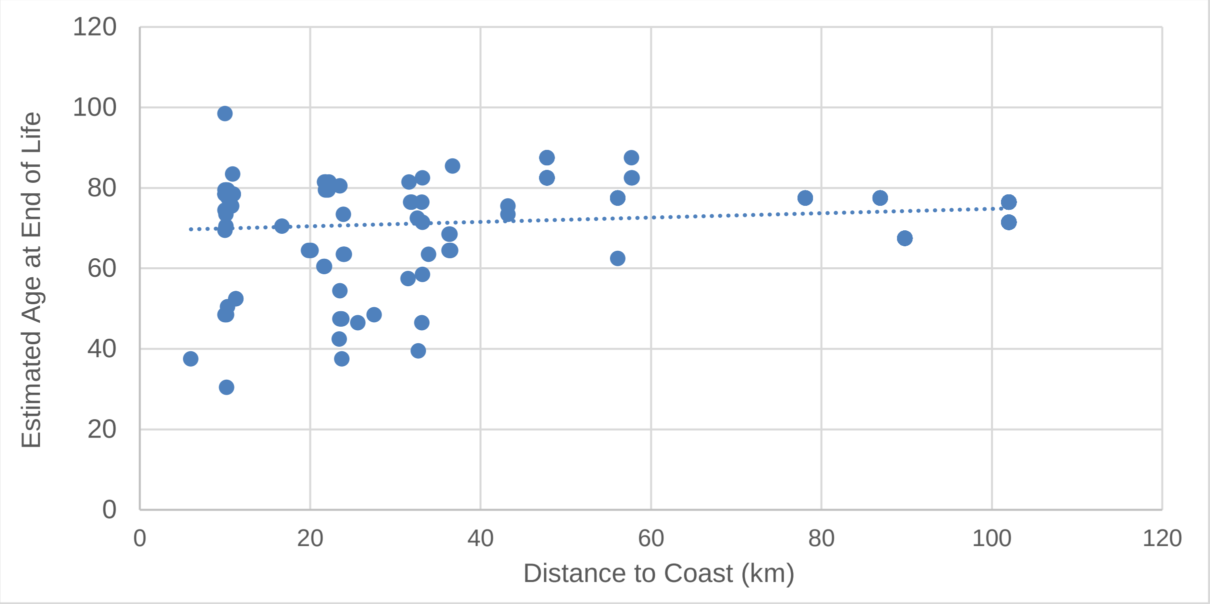

Figure 21 **Scatter plot of age at end of life by distance to coast, all samples**

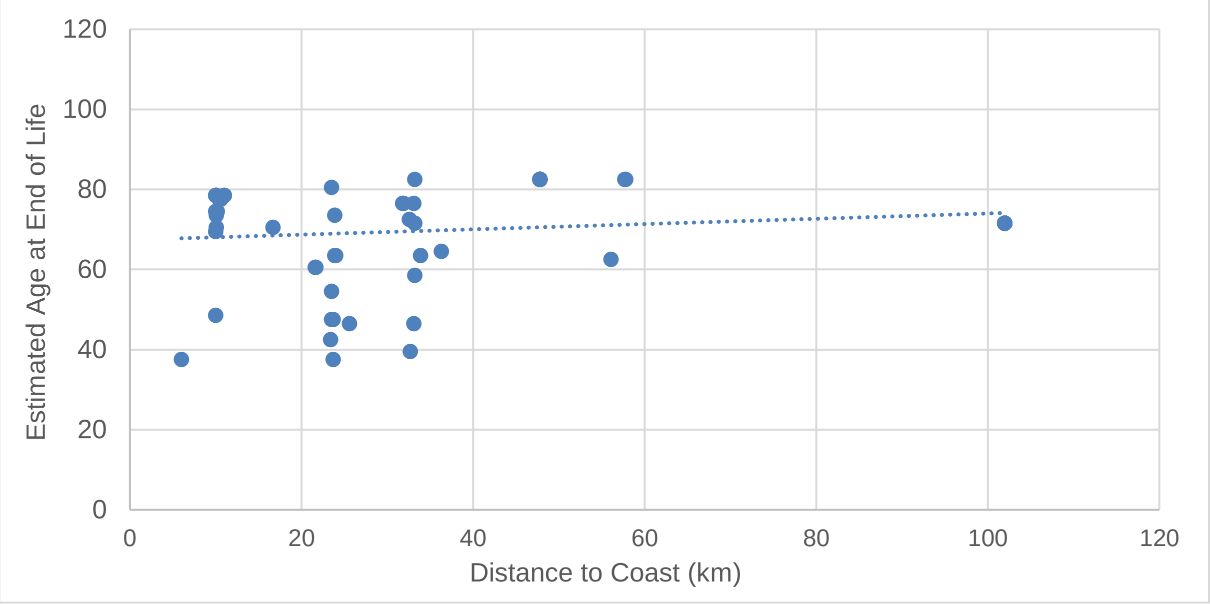

Figure 22 **Scatter plot of age at end of life by distance to coast, excluding samples with 15 to 20 years remaining life**

When all samples are considered, the estimated age at end of life ranges from 30.5 years to 98.5 years. When assets with a remaining life of 15 to 20 years are excluded, the age at end of life varies between 37.5 years and 82.5 years. Thus, indicating there are both young assets and old assets with a remaining life of 15 to 20 years, with the youngest asset at 13 years old and the oldest at 81 years. This suggests that the age of some ACSR conductors can approach 90 to 100 years, which is considerably above the average across the sample population.

Figure 21 and Figure 22 both suggest a trend of decreasing age at end of life with decreasing distance to coast, however, there is a considerable amount of variation and the trendline does not represent a good fit with the data. The data presented in Figure 22 is presented again in Figure 23 but now by conductor type.

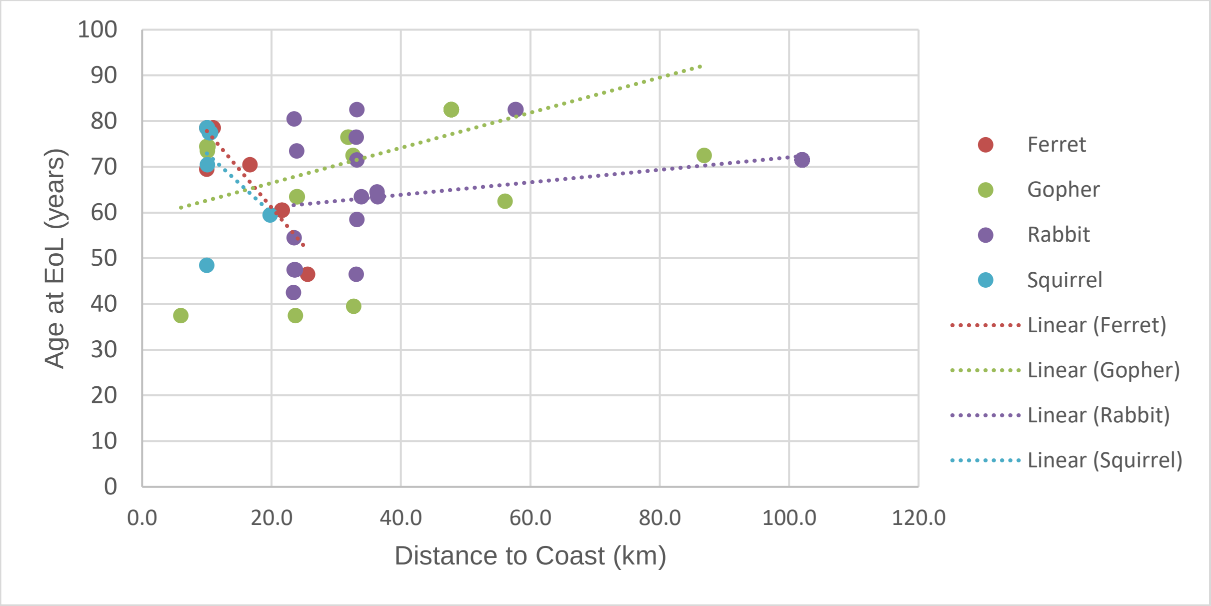

Figure 23 **Age at end of life by distance to coast and conductor type, excluding samples with 15 to 20 years remaining life**

There is no data for conductor type Dog shown in Figure 23 as all samples were considered to have 15 to 20 years remaining life and are therefore excluded. There is evidence to suggest a trend of decreasing age at end of life with decreasing distance to coast for conductor types Rabbit and Gopher, but again there is considerable variation in age at end of life for any distance to coast. However, for Ferret and Squirrel, the trend is reversed. As highlighted in Table 23, Ferret has a high number of asset with no grease, which may be skewing the results shown in Figure 23. Therefore, these are excluded in Figure 24, which also excludes samples situated more than 50km from the coast, as it would be expected that the impact of distance to coast is much reduced the further an asset is from the coast.

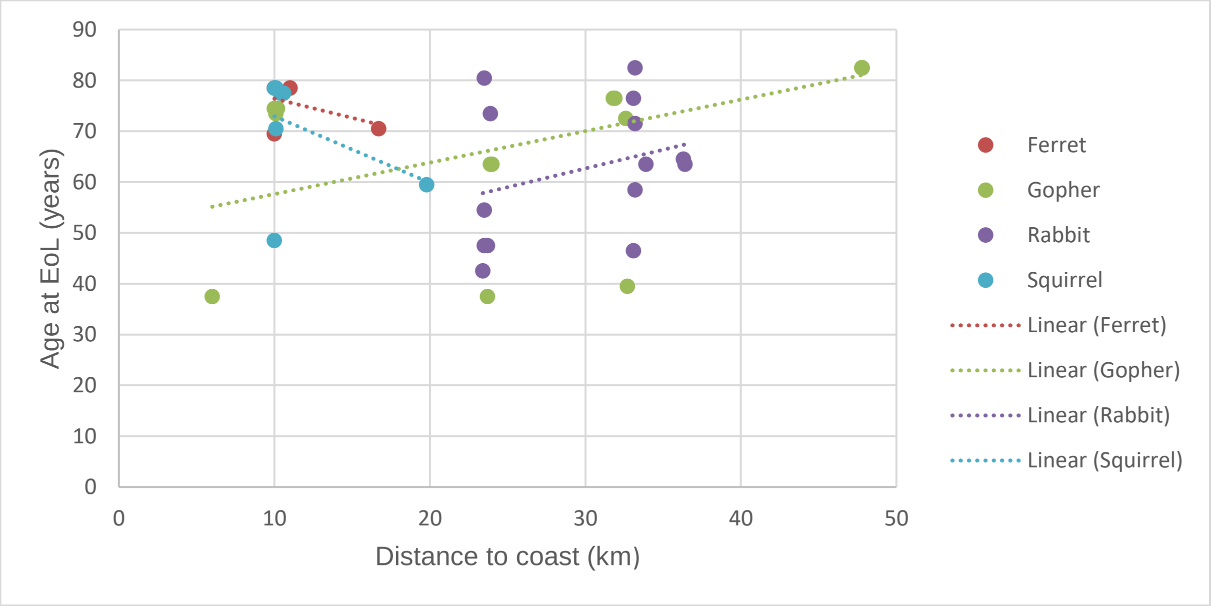

Figure 24 **Age at EoL vs. distance to coast (asset <50km) by conductor type, excluding samples with 15 to 20 years remaining life**

Figure 24 shows that excluding the impacts of no or minimal grease, and removing assets situated a long way from the coast, still suggests a trend of reduced life for assets that are situated closer to the coast for Gopher and Rabbit. However, there is still significant variability, i.e. linear regression does not yield a strong correlation. In the case of Squirrel and Ferret, the results might suggest a 'reverse' trend. However, it is important to note that the sample size for these assets is very small, and the results are skewed by one or two samples.

Therefore, there is insufficient data to draw any firm conclusions on the link between distance to coast and age at end of life for these conductor types based on the samples.

The end of life determined by the range of mechanical and visual tests, is closely linked to the torsion test results. The torsion strength result is more granular than the overall estimate of years to end of life. Therefore, Figure 25 explores the relationship between torsion strength and end of life and distance to coast for all ACSR conductor samples.

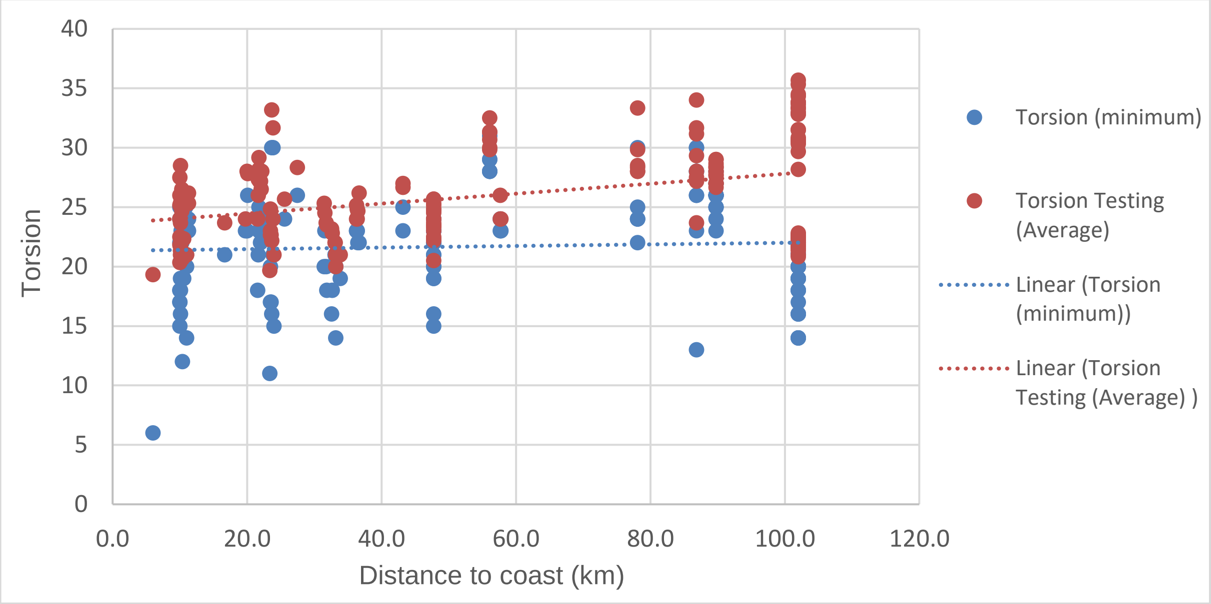

Figure 25 **Torsion results vs. distance to coast (all 173 ACSR samples)**

As shown in Figure 25 there is still considerable variability in the results, although there is (again) evidence that torsion strength does reduce with distance to coast. However, this does not take account of the effects of asset age. Therefore, Figure 26 shows the relationship of torsion to distance to coast for samples aged 60 to 70 years old. Again, there is too much variation in the results to indicate a reliable correlation.

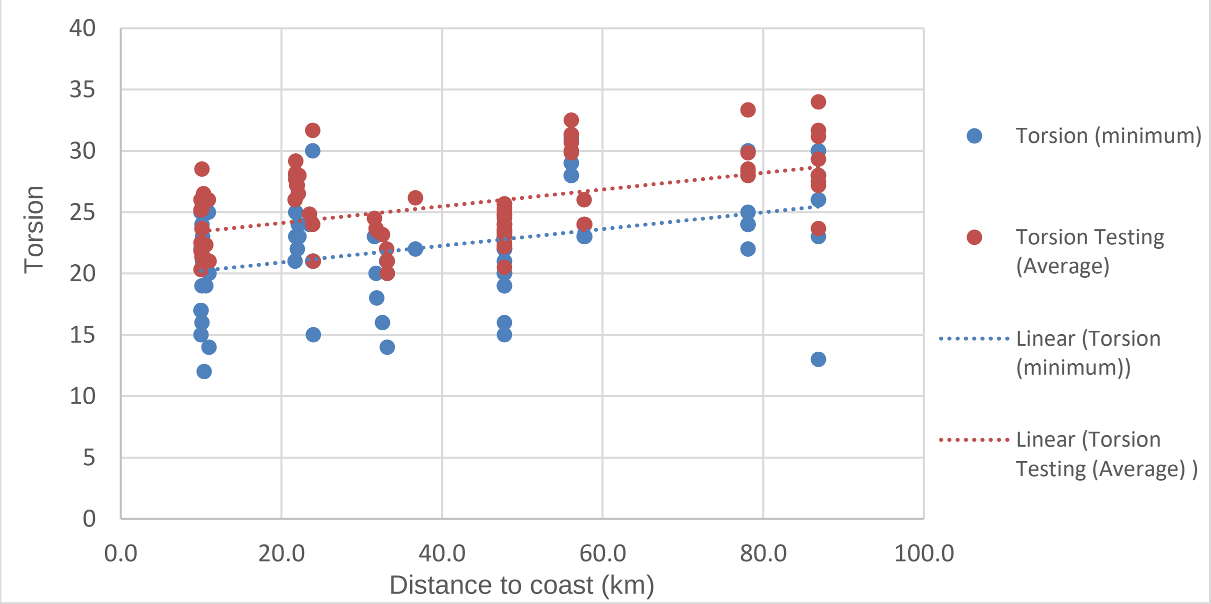

Figure 26 **Torsion results vs. distance to coast (ACSR samples aged 60 to 70 years old)**

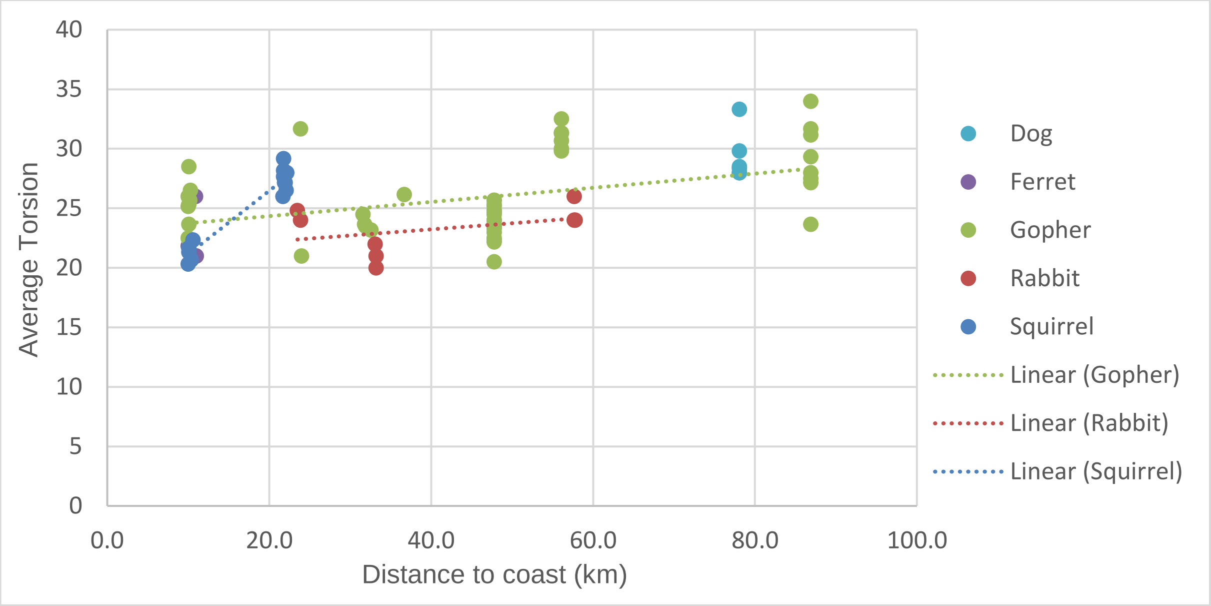

Figure 27 **Torsion results vs. distance to coast by conductor type (samples aged 60 to 70 years old)**

Figure 27 above shows the same data as that in Figure 26, but presented by conductor type. Linear regression indicates that distance to coast alone does not provide a reliability indication of the torsion strength of the Gopher and Rabbit samples aged 60 to 70 years. Linear regression analysis does indicate a good correlation exists for Squirrel. However, the sample size is very small, and comprises 13 assets which form two distinct clusters, with half the samples located at approximately 11km from the coast and the other half situated at approximately 22km from the coast. The line of best fit (the dashed lines in Figure 27) is significantly steeper for Squirrel compared to Gopher and Rabbit. However, there are no Squirrel samples located a long way from the coast (as is the case for Gopher and Rabbit), therefore, more Squirrel samples located further from the coast would be required to be able to draw any firm conclusions.

5.3 Copper Conductor

5.3.1 Sample Details

A total of 95 Cu conductor samples were provided of five different types (classified by Breaking Load) as shown in Table 26. The sample sizes for type 4027 and 5675 were small (five and eight respectively), making it unlikely for any reliable correlations to be determined for these conductor types.

Table 26 **Summary of Cu samples by type**

Type	British Standard Minimum Strand Breaking Load (N)	Number of samples
Cu	1997	23
Cu	2244	30
Cu PVC and Cu	4027	5
Cu	4494	29
Cu	5675	8
All Cu conductor samples		**95**

The ages of the samples ranged from 25 years old to 88 years old, with the majority (69 of the 95 samples, or 72%) aged 70 or over.

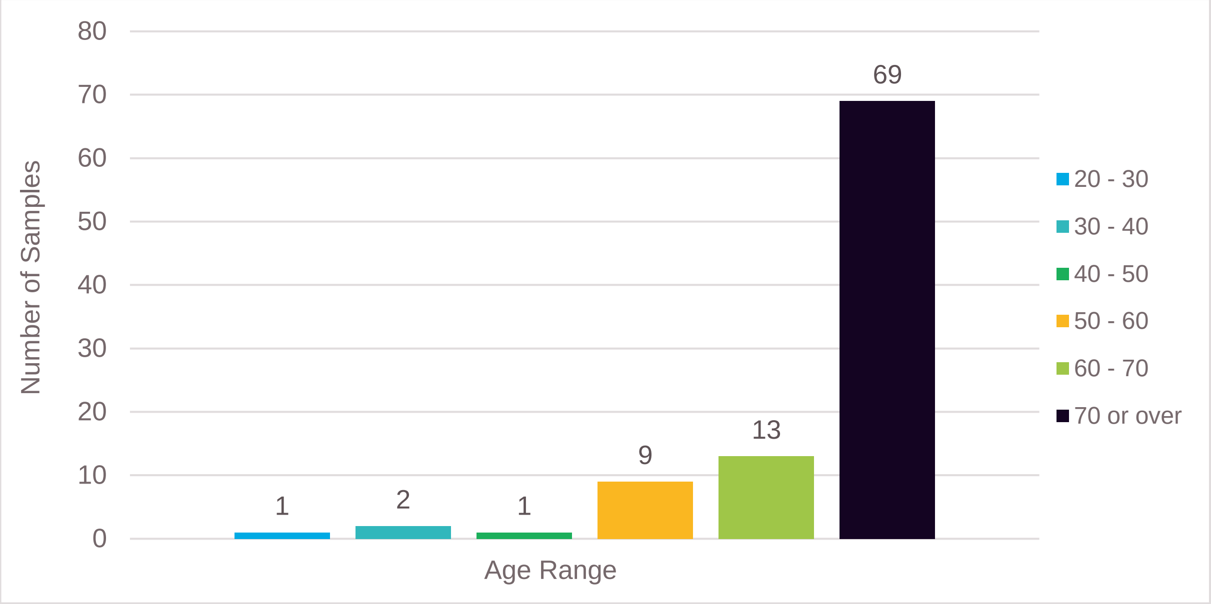

Figure 28 Years of Cu Samples

5.3.2 Comparison of Age and Years to End of Life

The following table shows the age (determined from the installation date) and the estimated years to end of life following testing for these samples.

Table 27 Summary of Cu samples by type, age and years to end of life

Type	Age Range (years)	Number of samples by Years to End of Life				
		15-20	10 - 15	5 - 10	<5	Total
2244	20 - 30	0	0	0	0	0
	30 - 40	1	0	0	0	1
	40 - 50	0	0	0	0	0
	50 - 60	1	0	0	0	1
	60 - 70	8	0	0	0	8
	>70	20	0	0	0	20
	Total	**30**	**0**	**0**	**0**	**30**
4494	20 - 30	1	0	0	0	1
	30 - 40	1	0	0	0	1
	40 - 50	1	0	0	0	1
	50 - 60	2	0	0	0	2
	60 - 70	4	0	0	0	4
	>70	2	0	0	18	20
	Total	**11**	**0**	**0**	**18**	**29**
5675	20 - 30	0	0	0	0	0
	30 - 40	0	0	0	0	0
	40 - 50	0	0	0	0	0
	50 - 60	1	0	0	1	2
	60 - 70	0	0	0	0	0
	>70	1	0	0	5	6
	Total	**2**	**0**	**0**	**6**	**8**

Type	Age Range (years)	Number of samples by Years to End of Life				
		15-20	10 - 15	5 - 10	<5	Total
4027	20 - 30	0	0	0	0	0
	30 - 40	0	0	0	0	0
	40 - 50	0	0	0	0	0
	50 - 60	2	0	0	2	4
	60 - 70	1	0	0	0	1
	>70	0	0	0	0	0
	Total	**3**	**0**	**0**	**2**	**5**
1997	20 - 30	0	0	0	0	0
	30 - 40	0	0	0	0	0
	40 - 50	0	0	0	0	0
	50 - 60	0	0	0	0	0
	60 - 70	0	0	0	0	0
	>70	23	0	0	0	23
	Total	**23**	**0**	**0**	**0**	**23**

The results above are shown graphically below, indicating the % of each sample type by years to end of life.

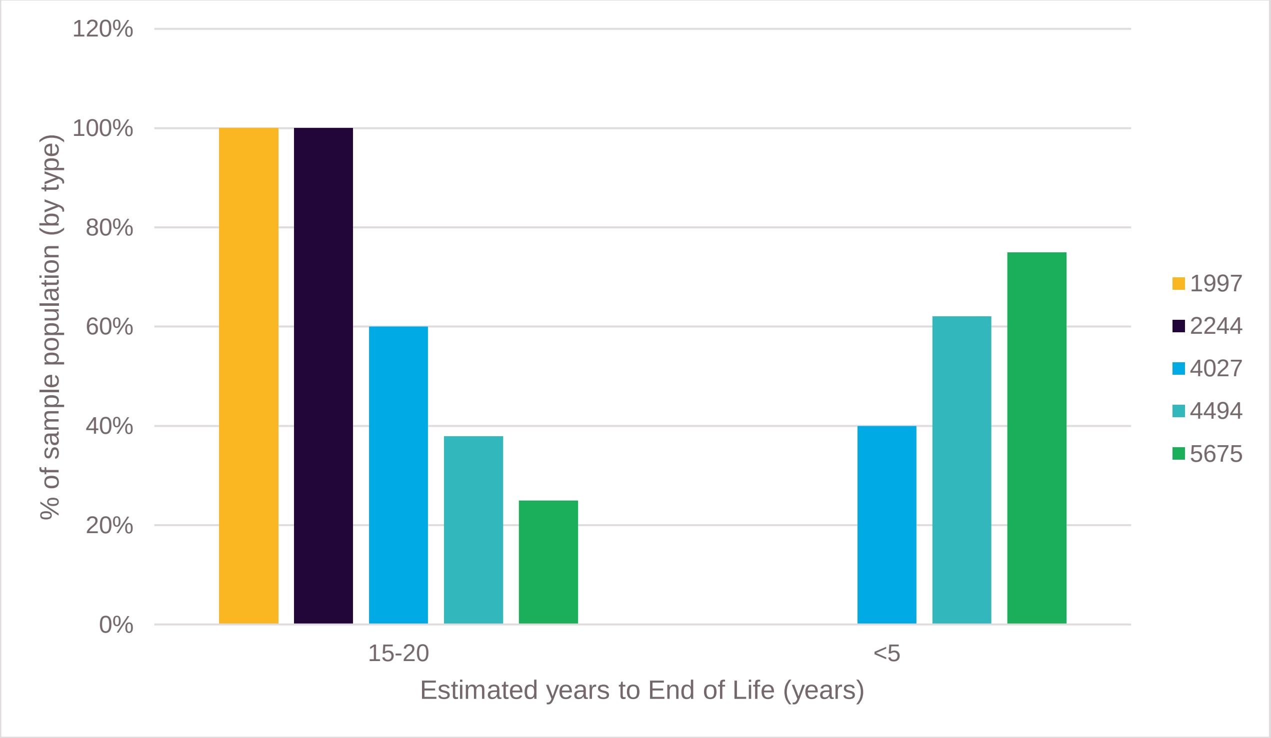

Figure 29 **Years to end of life against percentage of sample population**

Table 29 shows that all of the Cu-1997 and Cu-2244 samples have an estimated 15 to 20 years remaining life. The majority (43 of the 53 samples, or 81%) of these samples were aged 70 or over.

In the case of the Cu-5675 assets, the majority (6 of the 8 samples, 75%) have a remaining life of less than 5 years; all samples of this type were more than 50 years old. Similarly, the majority (18 out of 29 samples, or 62%) of the Cu-4494 samples were estimated to have a remaining life of 5 years or less. All but 2 of the 20 Cu-4494 samples aged 70 years or more, were found to have less than 5 years of remaining life. Interestingly, the two exceptions were the two oldest assets (both aged 88 years).

Of the five Cu-4027 samples, two were found to have a remaining life of 5 years or less. The Cu-4027 samples comprised three samples with Cu-PVC, and these sample types were all found to have a remaining life of 15 to 20 years. The samples of type Cu-4027 were aged between 52 and 62 years old.

If the samples are representative of the overall population of Cu conductors in terms of age profile, these results would suggest that Cu-2244 and Cu-1997 conductors are in good condition and can remain in service for a further 15 to 20 years. Conversely, the results would suggest that 75% of Cu-5675 conductors may be due for replacement within the next 5 years. However, the sample size of 8 is extremely small, and thus the results may not be representative of the population as a whole.

The results for Cu-4494 suggest that around 62% of the population of conductors of this type may need replacing (again assuming the sample is representative of the entire population of conductors of this type, based on a sample size of 28).

Cu-4027 samples comprised both PVC and none PVC samples. All PVC samples (three of the five samples) Cu-were found to have a remaining life of <5 years; but the sample size is too small to draw any firm conclusions on the population of these conductors as whole.

5.3.3 Comparison of Distance to Coast and Years to End of Life

The following table shows the distance from coast (determined from the grid reference) and the estimated years to end of life following testing for the Cu conductor samples.

Table 28 Summary of Cu samples by type, distance to coast and years to end of life

Type	Distance to Coast	Number of samples by Years to End of Life				
		15-20	10 - 15	5 - 10	<5	Total
2244	>25km	29	0	0	0	29
	20-25km	1	0	0	0	1
	15-20km	0	0	0	0	0
	10-15km	0	0	0	0	0
	5-10km	0	0	0	0	0
	0-5km	0	0	0	0	0
	Total	**30**	**0**	**0**	**0**	**30**
2294	>25km	2	0	0	18	20
	20-25km	0	0	0	0	0
	15-20km	5	0	0	0	5
	10-15km	4	0	0	0	4
	5-10km	0	0	0	0	0
	0-5km	0	0	0	0	0
	Total	**11**	**0**	**0**	**18**	**29**
5675	>25km	1	0	0	5	6
	20-25km	0	0	0	0	0
	15-20km	0	0	0	0	0
	10-15km	0	0	0	0	0
	5-10km	0	0	0	0	0
	0-5km	1	0	0	1	2
	Total	**2**	**0**	**0**	**6**	**8**
4027	>25km	0	0	0	0	0
	20-25km	0	0	0	0	0
	15-20km	0	0	0	0	0
	10-15km	3	0	0	2	5
	5-10km	0	0	0	0	0
	0-5km	0	0	0	0	0
	Total	**3**	**0**	**0**	**2**	**5**
1991	>25km	23	0	0	0	23
	20-25km	0	0	0	0	0
	15-20km	0	0	0	0	0
	10-15km	0	0	0	0	0

Type	Distance to Coast	Number of samples by Years to End of Life				
		15-20	10 - 15	5 - 10	<5	Total
	5-10km	0	0	0	0	0
	0-5km	0	0	0	0	0
	Total	**23**	**0**	**0**	**0**	**23**
All	>25km	55	0	0	23	78
	20-25km	1	0	0	0	1
	15-20km	5	0	0	0	5
	10-15km	7	0	0	2	9
	5-10km	0	0	0	0	0
	0-5km	1	0	0	1	2
	Total	**69**	**0**	**0**	**26**	**95**

The data summarised in the following graph shows that the majority of samples (82%) were located 25km or more from the coast.

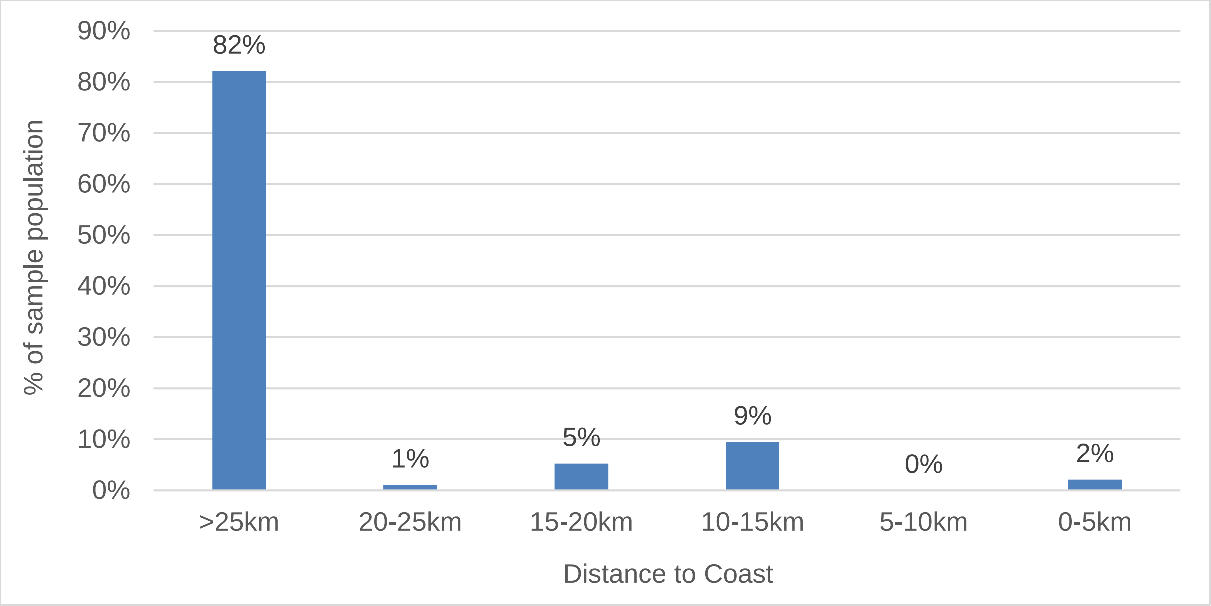

Figure 30 Distance to Coast by Population for Copper Conductor Samples

The Common Network Asset Indices Methodology (referred to as CNAIM), which is used to derive a Health Score for regulatory reporting, defines a range of modifiers that influence the rate of deterioration of assets. One of these modifiers is the distance to coast. Assets situated close to the coast are generally regarded to have a shorter expected life[5] than those situated inland. Within CNAIM this experience is captured via a Distance to Coast Modifier'. The scope of CNAIM does not currently encompass conductors on woodpole overhead lines, but the modifiers for conductors on tower overhead lines are shown below.

Table 29 CNAIM Distance from Coast Modifier[6]

Distance from Coast	Modifier
≤1km	2.0
>1km and ≤5km	1.5
>5k and ≤10km	1.2
>10k and ≤20km	1.0

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[5] The time to the onset of critical degradation
[6] Common Network Asset Indices Methodology v1.1, Table 22

>20km	1.0

The modifier indicates the extent to which the expected life varies with distance to coast. A conductor situated within 1km of the coast would be expected to have an expected life half that of an otherwise identical conductor located >10km from the coast. As shown in Figure 30, only 2% of the population of conductor samples (i.e. 2 of the 95 samples) are located within 10 km of the coast. Therefore, there is limited information available to draw conclusions on the impact of distance to coast and years to end of life. The data is plotted as a heat map in Figure 31.

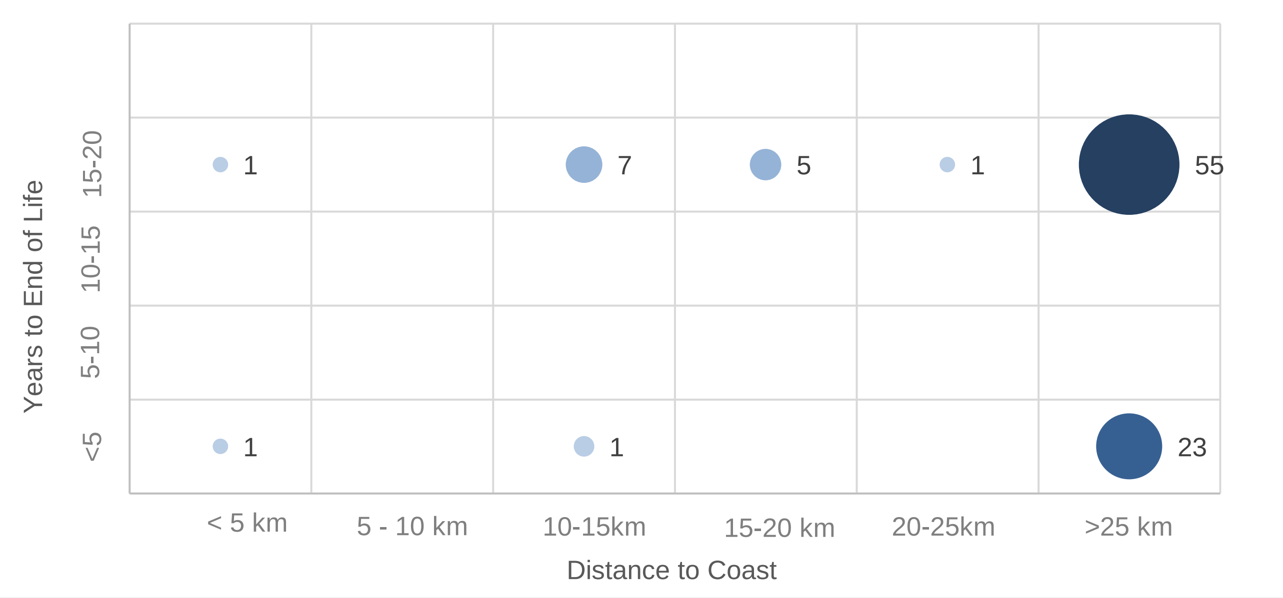

Figure 31 **Years to End of Life by Distance to Coast (as a heat map)**

The data shown in Figure 31 presents Years to End of Life vs Distance to Coast as a heat map, where the size of the marker indicates the number of samples with those criteria, i.e. there are 7 samples that are located 10-15km to the coast with 15-20 years remaining life. Figure 31 shows there is very large cluster of samples (55 of the 95 samples) located more than 25km from the coast and with at least 15 to 20 years of remaining life. This combined with the limited numbers of samples located close to the coast, gives low likelihood of finding a correlation between distance to coast and conductor life.

Figure 32 shows the same data, but now as a scatter plot showing the expected age at end of life (i.e. sample age plus remaining years to end of life). The years to end of life is taken as the mid-point of the expected range, so for an asset of 50 years with an estimated 15 to 20 years of remaining life, the expected age at end of life is taken to be 67.5 years.

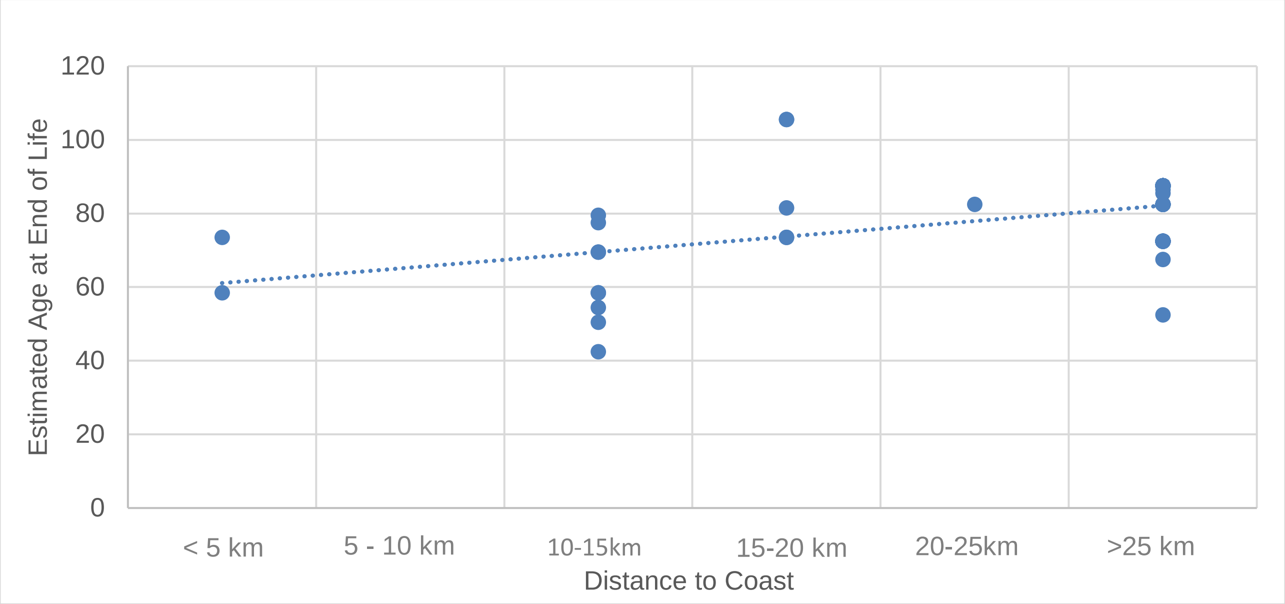

Figure 32 **Estimated Age at End of Life by Distance to Coast 9 (all 95 Cu samples – scatter plot)**

The estimated age of the conductor samples at the end of life ranges from 42.5 years to 105.5 years. However, it is important to note that the results of analytical tests only give a years to end of life **of up** to 15 to 20 years, with a recommended interval of 15 years for resampling. Therefore, the upper limit on years to end of life is a minimum rather than an expectation, making it difficult to use as a predictor of useful life. Figure 33 below presents the results for samples where the years to end of life is less than 5 years.

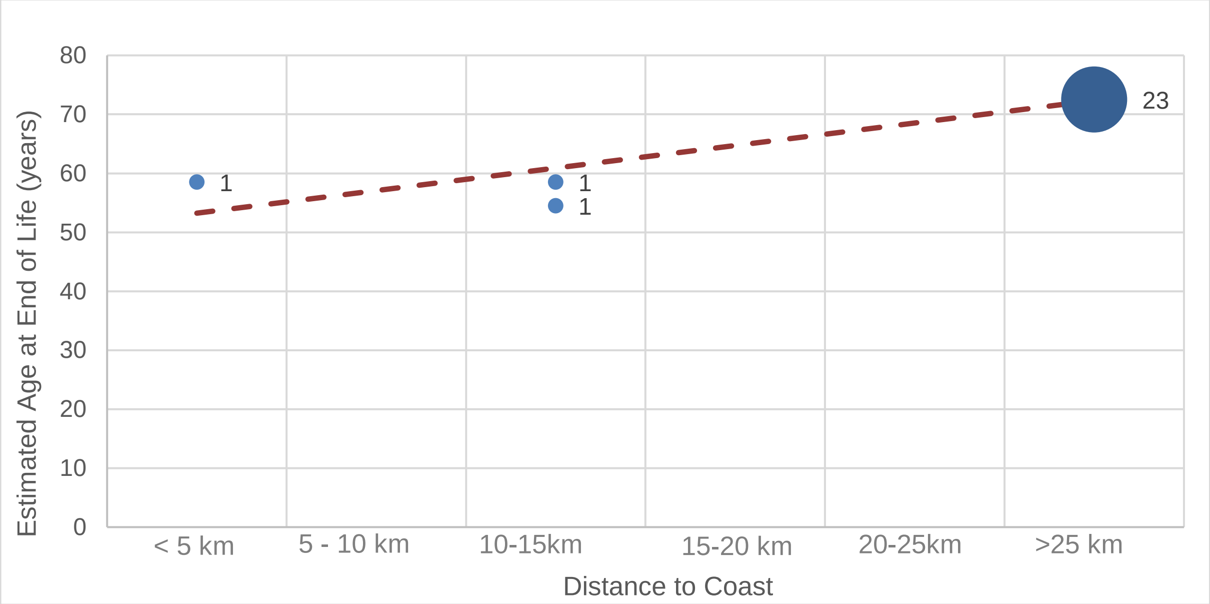

Figure 33 **Estimated Age at End of Life by Distance to Coast (Cu Samples with <5 years to End of Life)**

This shows that there may be evidence of a trend of decrease in the expected life of assets located closer to the coast. However, there are only three samples located within 15km of the coast compared to 23 located more than 50km away. Therefore, there is insufficient data to produce a reliable algorithm to predict end of life using distance to coast based on this sample size.

6. Discussion

6.1 Summary of Condition Assessment

A condition assessment was performed on the 291 supplied overhead line conductor (OHL) samples, using EA Technology's standard OHL conductor assessment procedure. This procedure involves a combination of a visual examination of the individual strand layers and mechanical testing of selected strands; the exact tests undertaken vary slightly between conductor types.

From the results of the condition assessment, an expected remnant service life was calculated for each conductor. These estimates ranged from less than 5 years (considered end of life) to 20 years (the upper limit of estimation).

The full set of condition assessment results for all 291 conductor samples can be found in EA Technology report *A2469 Reports Issue 4*. The accompanying UKPN provided background information is additionally included in this document.

6.2 Summary of Statistical Analysis

UKPN have conducted an extensive study of the deterioration of HV overhead conductors. A total of 291 samples were provided, of the following types:

- ACSR: 173
- Copper: 95
- Aluminium: 2
- AAC: 2
- **Total 291**

The following information was provided for each sample:

- Conductor identification including ID number, pole number, feeder ID, region, voltage
- Conductor type
- Grid reference

The analysis has looked at the correlation between age at end of life and the following variables:

- Conductor type
- Greasing
- Distance to coast
- Corrosion zone

In addition, torsion strength has been used as a 'proxy' for remaining life for ACSR conductors as it is a continuous variable where-as years to end of life is provided as one of four discrete bands.

The sample sizes have made it difficult to explore the relationships. This was especially true in the case of the Copper conductors. The majority of the Copper conductor samples (over 80%) were located more than 25km from the coast. Furthermore, a significant proportion (69 of the 95 Copper samples) were found to have 15 – 20 years remaining life; this is a minimum rather than a prediction, making it difficult to predict the true end of life for these assets. Therefore, there was limited data available to explore the relationship between distance to coast and age at end of life for Copper conductors.

In the case of ACSR conductors, the following relationships were explored:

- Average Age at End of Life by conductor type
- Age at End of Life vs Distance to Coast
- Age at End of Life vs Distance to Coast, excluding samples with 15 – 20 years remaining life

- Age at End of Life vs Distance to Coast, excluding samples with 15 – 20 years remaining life, by conductor type
- Age at End of Life vs Distance to Coast, excluding samples with 15 – 20 years remaining life, by conductor type, excluding samples with minimal or no grease
- Age at End of Life vs Distance to Coast, excluding samples with 15 – 20 years remaining life, by conductor type Rabbit (with adequate greasing), by corrosion zone rating
- Torsion (average and minimum) vs distance to coast
- Torsion (average and minimum) vs distance to coast, samples aged 60 to 70 years
- Torsion (average) vs distance to coast by conductor type, samples aged 60 to 70 years

The results indicated there is some evidence that ACSR conductors deteriorate more rapidly near the coast, but distance to coast alone did not fully explain the variability in age at end of life, even after taking account of conductor type, greasing and corrosion zone. This is likely to be due to the small sample sizes after the effects of greasing and corrosion zone have been considered. Increasing the number of samples may help, particularly focussing on conductors that are closer to the coast (i.e. within 20 km of the coast) and conductors that are at or approaching end of life. In addition, it may be important to consider what other factors may influence the rate of degradation. Other factor known to influence the rate of degradation of conductors is operating temperature and number of faults. Therefore, it is suggested that UKPN explore if there is any associated information for the existing conductor samples. If data exists, it is suggested that the analysis be extended to explore whether a deterioration algorithm based on location, temperature and fault records can be formulated.

6.3 Limitations of Analysis

Although the statistical analysis did find evidence of some correlation between degradation rates and proximity to coast for both ACSR and copper conductors, the variability in age at end of life would suggest that other factors are significantly influencing the results. There are a number of unknown variables and factors which it would be reasonable to expect have influenced the results to a degree, although the extent of this influence cannot be determined with the information available.

Firstly, the condition assessment showed that for both conductor types, a significant number of the samples were in a relatively “as new” condition[7], with no significant degradation or material loss and measured breaking loads exceeding British Standard stated values. This resulted in an expected remnant service life of 15-20 years for over 50% of the tested ACSR conductor and 70% of the copper conductors; this is the upper limit of EA Technology’s standard condition assessment for samples removed from service. What this means, is that it is reasonable to expect these conductors to perform satisfactorily in service for a further 15 years, at which point the lines should be re-assessed. As such, it is reasonable to expect that a significant range of actual asset lifetime exists within that bracket; thus, a larger margin of error within this bracket for the conductor age at end of life used for the statistical analysis.

It is likely that by re-assessing the condition of the conductor lines, with an expected remnant service life of 15-20 years, in 15 years’ time, more significant variations in condition between conductors within this bracket would be measured. It is expected that a stronger trend in the data would then be seen due to the better understanding of conductor age at end of life.

Secondly, the condition of the conductor at the time of installation is not known. As such, the interpretation of degradation is based on comparisons to what would be expected from a “typical” new conductor, rather than an actual measure of reduction for the specific conductor. As such, it is assumed that when installed the conductors complied with British Standard requirements (regarding visual appearance, greasing and mechanical properties). However, it is not possible to retrospectively determine whether a conductor which when tested did not comply with British Standard, did comply at the time of installation.

During the condition assessment, it was found that 6 of the 7 ACSR conductors considered to be at end of life were dry of grease. The absence of any grease residue within these samples could indicate that these samples were not adequately greased at the time of installation. With the grease both inhibiting the onset of galvanic corrosion (sometimes referred to as dissimilar metal or bi-metallic corrosion) between the galvanised steel

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[7] There is no measurable difference in properties between these samples and what would typically be expected from a new conductor.

core strands and the aluminium conductor strands, and acting as a barrier from moisture and debris ingress into the conductor (both of which promote internal degradation), the absence of grease would significantly reduce the expected life of an ACSR conductor.

Conversely, where a conductor did meet British Standard at installation, the tolerance on that compliance is not known. For example, ACSR tag ID 039 was installed in 1950 and 70 years later produced a calculated breaking load 110% of the British Standard stated value. In comparison ACSR tag ID 281 was installed in 1990 and 30 years later produced a calculated breaking load of 102% of the British Standard stated value. Whilst it cannot be entirely discounted that sample 281 has experienced significantly greater degradation rates during its relatively short service life than sample 039, it is likely that this variation is (to a significant degree) due to sample 039 having a larger tolerance above British Standard minimum breaking load at the time of installation than sample 281, i.e. it was effectively “over engineered” compared to modern day conductors.

As such, it is not possible to accurately determine the degradation rates for a conductor based on a single test. This is one of the main reasons that the EA Technology standard condition assessment provides a minimum remnant service life rather than a definitive end of life estimate; where degradation has stabilised, it is possible that a conductor today given an estimated remnant service life of 10-15 years, will after re-assessment in 10 years times, again provide an estimated remnant service life of 10-15 years.

It is reasonable to assume that the quality of manufacture for a conductor, would be consistent for a given manufacturer (although again this may still vary for a single manufacturer over a period of time). As such, trending the results of the condition assessment by conductor manufacturer could provide valuable information towards the development of a deterioration algorithm. However, it is unlikely that any records exist today in regard to who a manufacturer of a conductor was for a particular route. Additionally, none of the 291 laboratory examined conductor samples contained a manufacturer identifier tape.

Thirdly, it is possible that some of the asset ages used for the statistical analysis are incorrect. The year of installation provided by UKPN for each conductor sample corresponds to the route from which the conductor was sampled (with the date itself taken from the woodpole). As such, it is possible that some of the lines have been replaced over the years and the conductors provided are consequently younger than believed. After a relatively short time in service, the external surface of an OHL conductor dulls, following which it is not possible to discern the relative age of a conductor during a laboratory examination. Therefore, it is possible that asset age spread for those conductors in the 15-20 years remnant service life estimate is partially due to inaccurate asset age information.

Finally, we do not know the historical operating conditions for the conductors. Both in terms of electrical loading and fault currents and environmental conditions. The electrical loading on an overhead line will vary along the length of a route, depending on proximity to feeders. It would also be expected to change over time with changing network demand. The local environment could also change over decades due to changing industry. As such, the corrosion zones applicable today will unlikely be consistent with those 50 years ago. Additionally, the air itself is overall much cleaner today than it was when many of these routes were installed. These factors will all contribute to the service life of an OHL conductor.

6.4 Implications and Recommendations

The analysis indicated that there is evidence to suggest that the expected service life for both ACSR and copper type overhead line conductor does reduce with proximity to coast. This is to be expected, primarily due to the higher levels of sodium chloride in the atmosphere, a known aggressive pollutant for the metal / metal alloys used in the construction of OHL conductor. However, the ability to explore this relationship was limited due to the sample sizes across the condition ranges.

Increasing the sample sizes, with particular focus on conductors that are closer to the coast (i.e. within 20 km of the coast) and conductors that are at or approaching end of life could help strengthen the correlation between proximity to coast and expected service life. UKPN should consider the benefit of undertaking a further programme of condition assessment in order to increase these sample sizes.

Additionally, it is recommended that UKPN explore whether information exists regarding operating temperature and number of faults experienced for the conductor samples assessed during this project. These are both considered to be contributing factors that influence the rate of degradation of OHL conductor and may be useful in the formation of a deterioration algorithm.

7. Conclusions

C1. The analysis indicated that there is some evidence to suggest that the expected service life for both ACSR and Copper type overhead line conductor does reduce with proximity to coast.

C2. The ability to explore the relationship between expected service life and proximity to coast was limited due to the sample sizes across the condition ranges.

C3. Variability in age at end of life would suggest that other factors are significantly influencing the results.

C4. Increasing the sample sizes, with particular focus on conductors that are closer to the coast (i.e. within 20 km of the coast) and conductors that are at or approaching end of life could help strengthen the correlation between proximity to coast and expected service life.

C5. Other factors known to influence the rate of degradation of conductors are operating temperature and number of faults experienced during service.

8. Recommendations

R1. UKPN should consider the benefit of undertaking a further programme of condition assessment in order to increase sample sizes in specific areas: conductors that are closer to the coast (within 20 km of the coast) and conductors that are at or approaching end of life.

R2. It is recommended that UKPN explore whether information exists regarding operating temperature and number of faults experienced during service for the conductor samples assessed during this project.

Appendix I Test Equipment

The following calibrated test equipment was used during this project.

Manufacturer	Type	Model	Serial No.	Calibration Due
Instron Ltd.	Tension/Compression	3367	303579	July-2021

Appendix II Conductor Characteristics

The following tables outline the key characteristics for the conductors sampled during this project:

Table 30 Characteristics of aluminium conductors steel reinforced – Type AL1/ST1A

Code	Old Code	Areas			No. of Wires		Wire Diameter		Rated Strength
		Al	Steel	Total			Al	Steel	
		mm^2	mm^2	mm^2	Al	Steel	mm	mm	kN
21-AL1/3-ST1A	SQUIRREL	21.0	3.50	24.5	6	1	2.11	2.11	7.87
26-AL1/4-ST1A	GOPHER	26.2	4.37	30.6	6	1	2.36	2.36	9.58
42-AL1/7-ST1A	FERRET	42.4	7.07	49.5	6	1	3.00	3.00	15.27
53-AL1/9-ST1A	RABBIT	52.9	8.81	61.7	6	1	3.35	3.35	18.42
105-AL1/14-ST1A	DOG	105.0	13.6	118.5	6	7	4.72	1.57	32.65

Table 31 Characteristics of hard drawn copper stranded conductors

Nominal area of cross-section of stranded conductor	No. of Wires	Wire Diameter		Rated Strength
		Wire	Cond.	
mm^2		mm	mm	kN
16	3	2.65	5.70	6.194
32	3	3.75	8.06	12.400
70	7	3.55	10.65	25.930
95	19	2.50	12.50	34.140
100	7	4.30	12.90	36.540

Table 32 Characteristics of aluminium conductors – Type AL1

Code	Old Code	Areas	No. of Wires	Wire Diameter		Rated Strength
				Wire	Cond.	
		mm^2		mm	mm	kN
53-AL1	ANT	52.8	7	3.10	9.30	8.72

Table 33 Characteristics of aluminium alloy conductors – Type AL3

Code	Old Code	Areas	No. of Wires	Wire Diameter		Rated Strength
				Wire	Cond.	
		mm^2		mm	mm	kN
30-AL3	ALMOND	30.1	7	2.34	7.02	8.88

Code	Old Code	Areas	No. of Wires	Wire Diameter		Rated Strength
				Wire	Cond.	
		mm^2		mm	mm	kN
48-AL3	FIR	47.8	7	2.95	8.85	14.11
60-AL3	HAZEL	59.9	7	3.30	9.90	17.66

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