Energy Innovation Summit

28-29 September 2022 | SEC Glasgow

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LV Predict

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Electricity North West

32,411km of LV Cables

34,000 distribution substations

2.4 million connections

Diverse geographical area

Project introduction

- ENWL are aiming to proactively reduce unplanned maintenance of LV assets, through the use of an innovative predictive failure model. This will help to assess network integrity now and in the future, optimise LV asset management decisions and inform future investment planning.

- The LV Predict project aims to develop a probabilistic model that can predict which underground low voltage (LV) cables and joints are most likely to fail.

- Degradation predictions are made to understand the greatest risk to LV asset condition by using a combination of:

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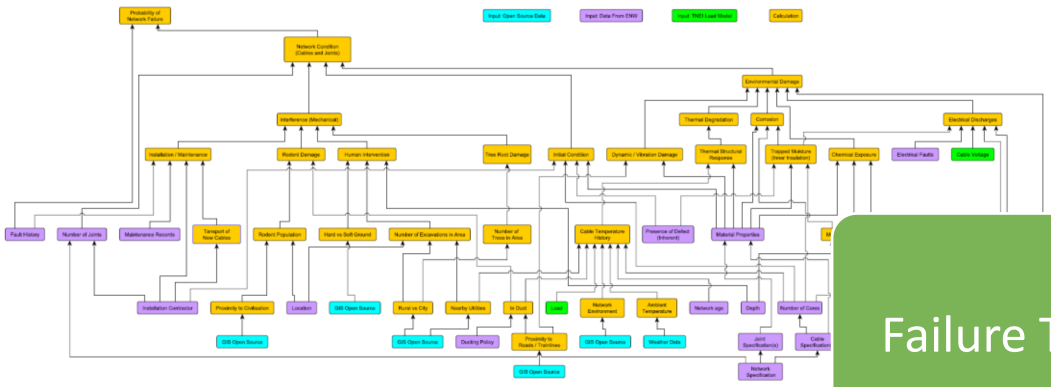
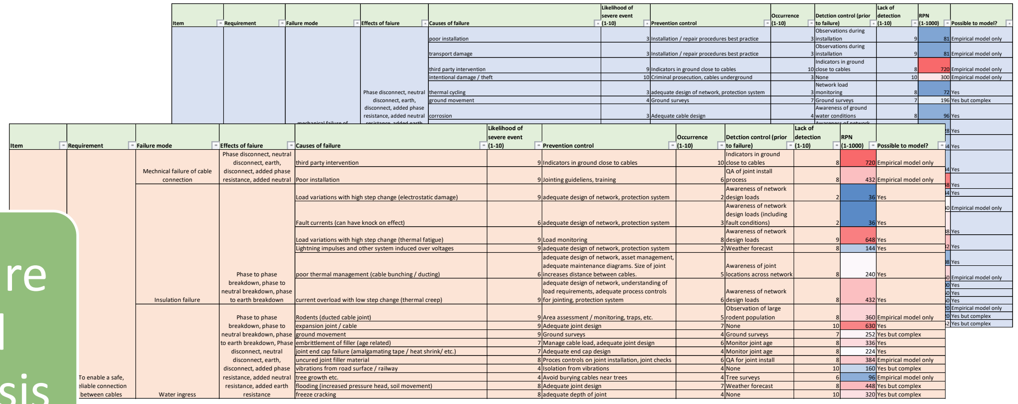
Identification of failure modes





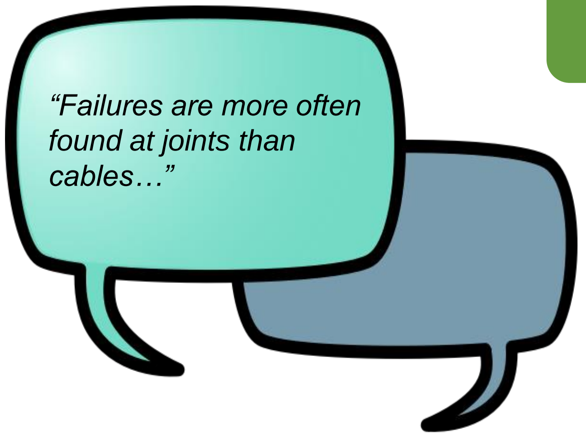
Failure Tree

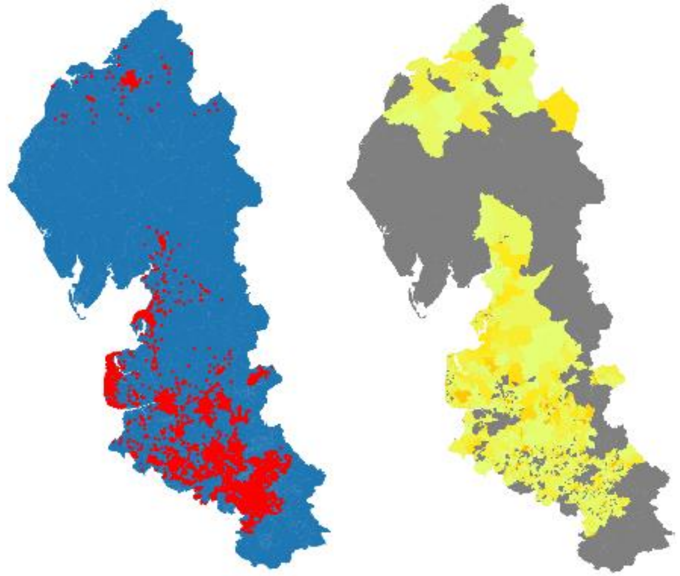
Design Failure Mode and Effect Analysis

Anecdotal Evidence

Failure Data

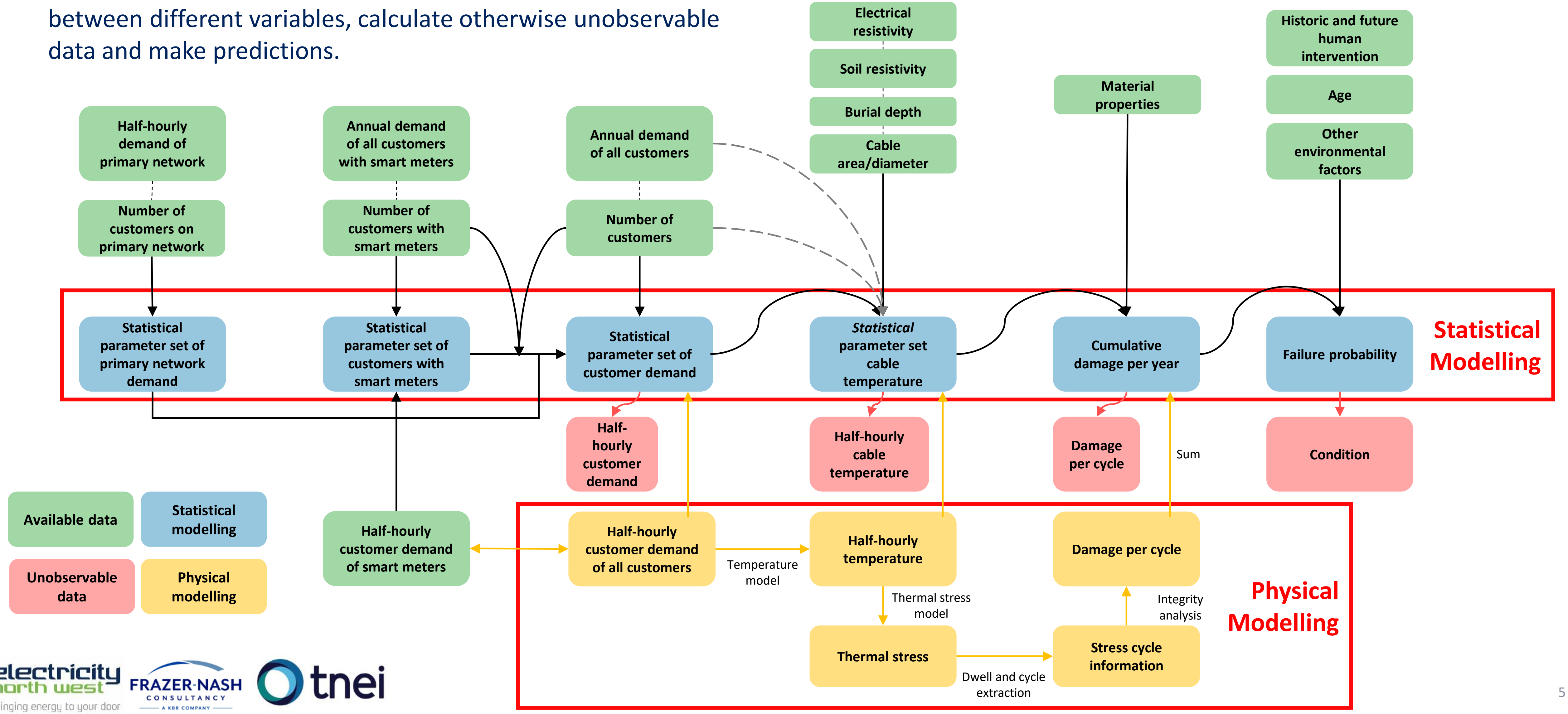
Probabilistic Framework





Probabilistic modelling framework

- A probabilistic modelling framework was created to identify links between different variables, calculate otherwise unobservable data and make predictions.



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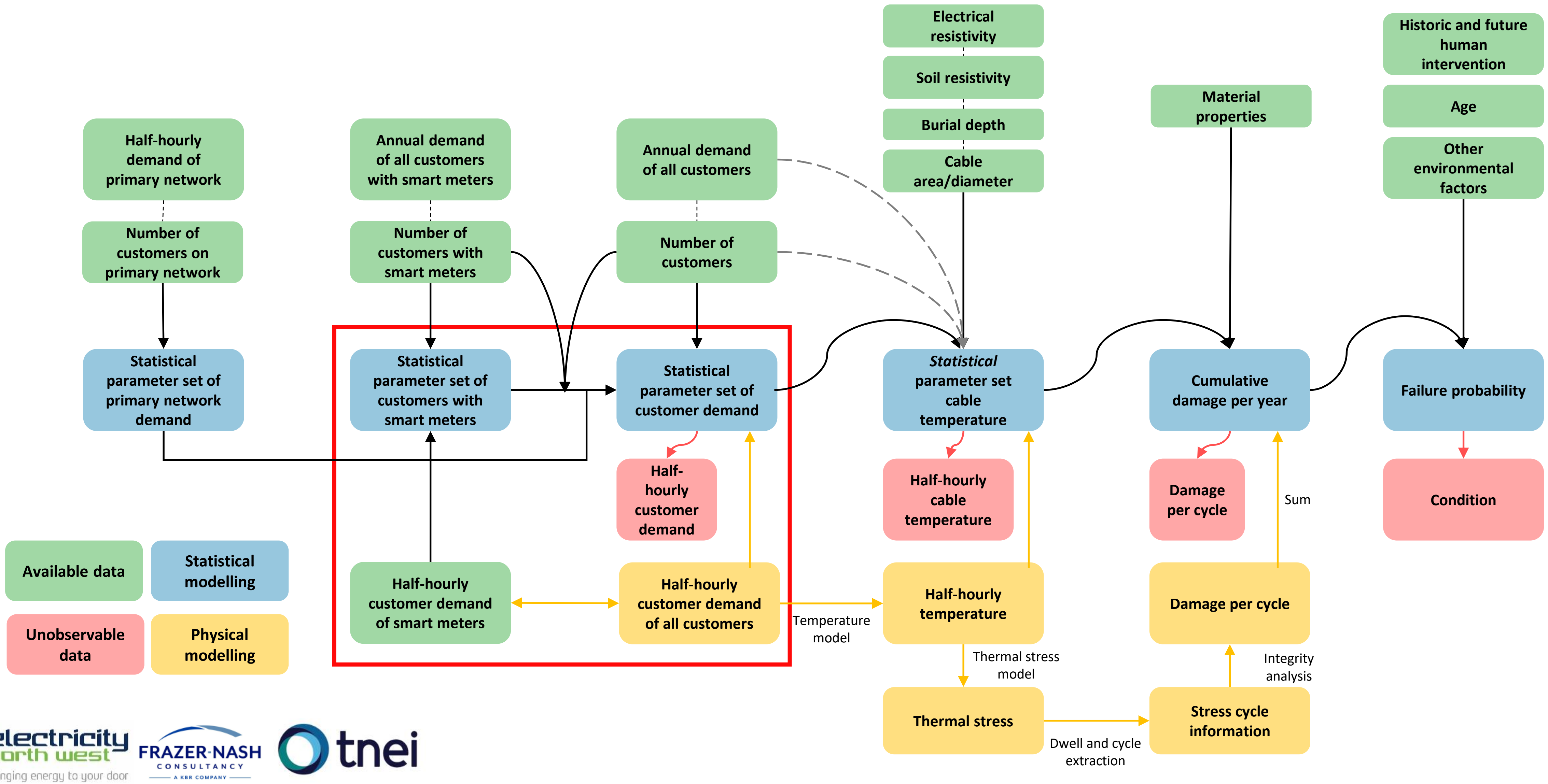
Probabilistic modelling framework: Demand model



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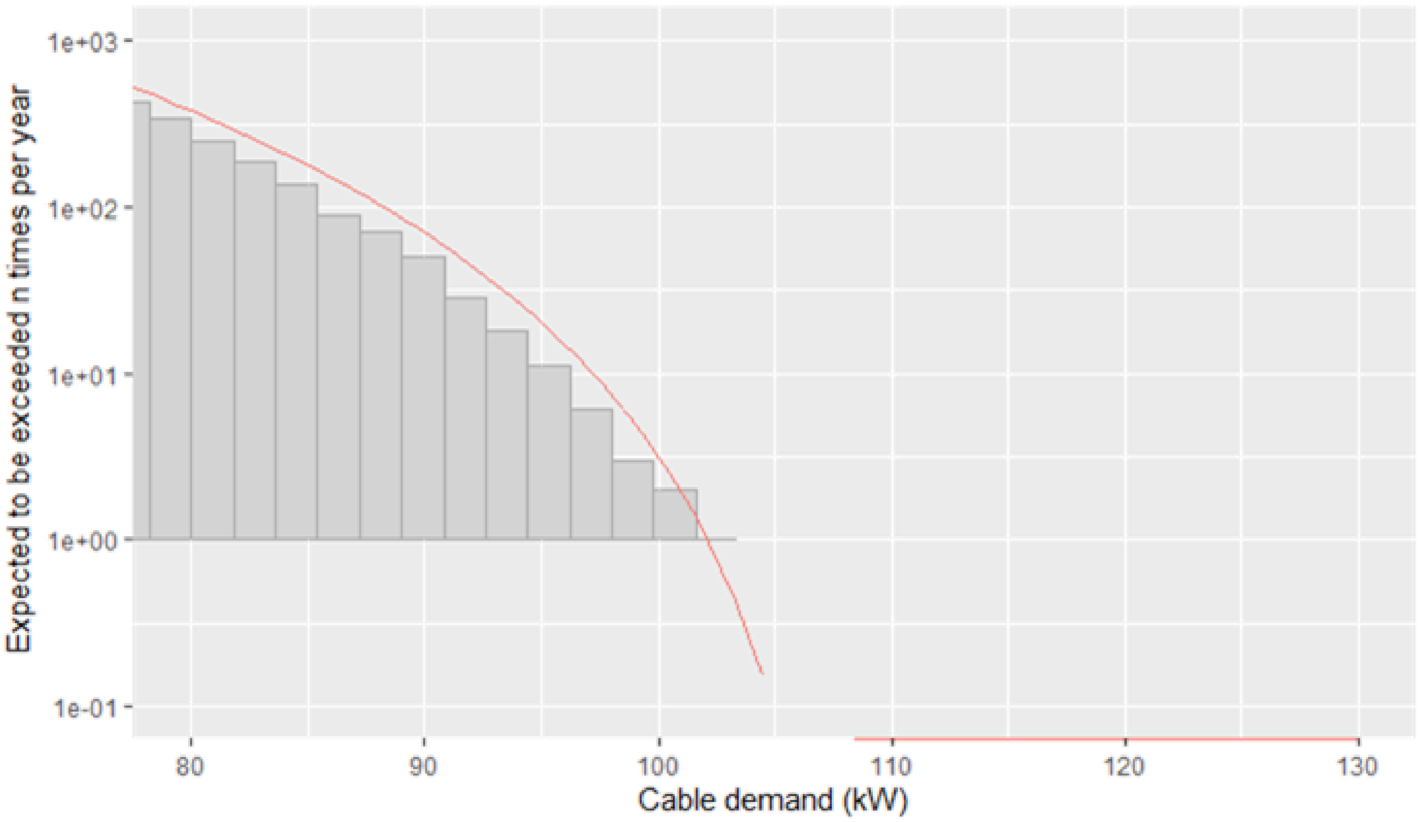
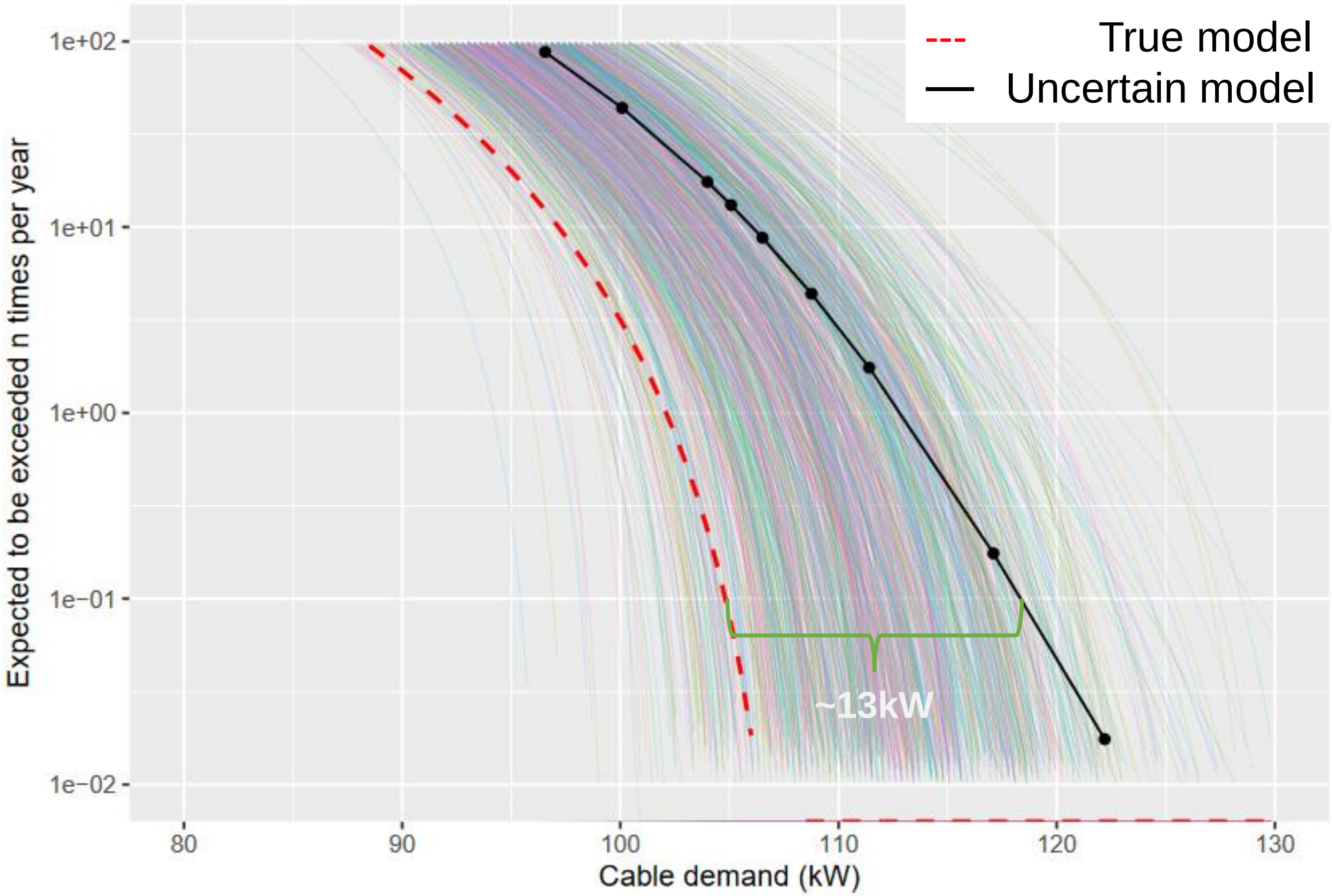
Probabilistic modelling framework: Demand model

- A model was created to predict extreme cable demands based on historic usage data.



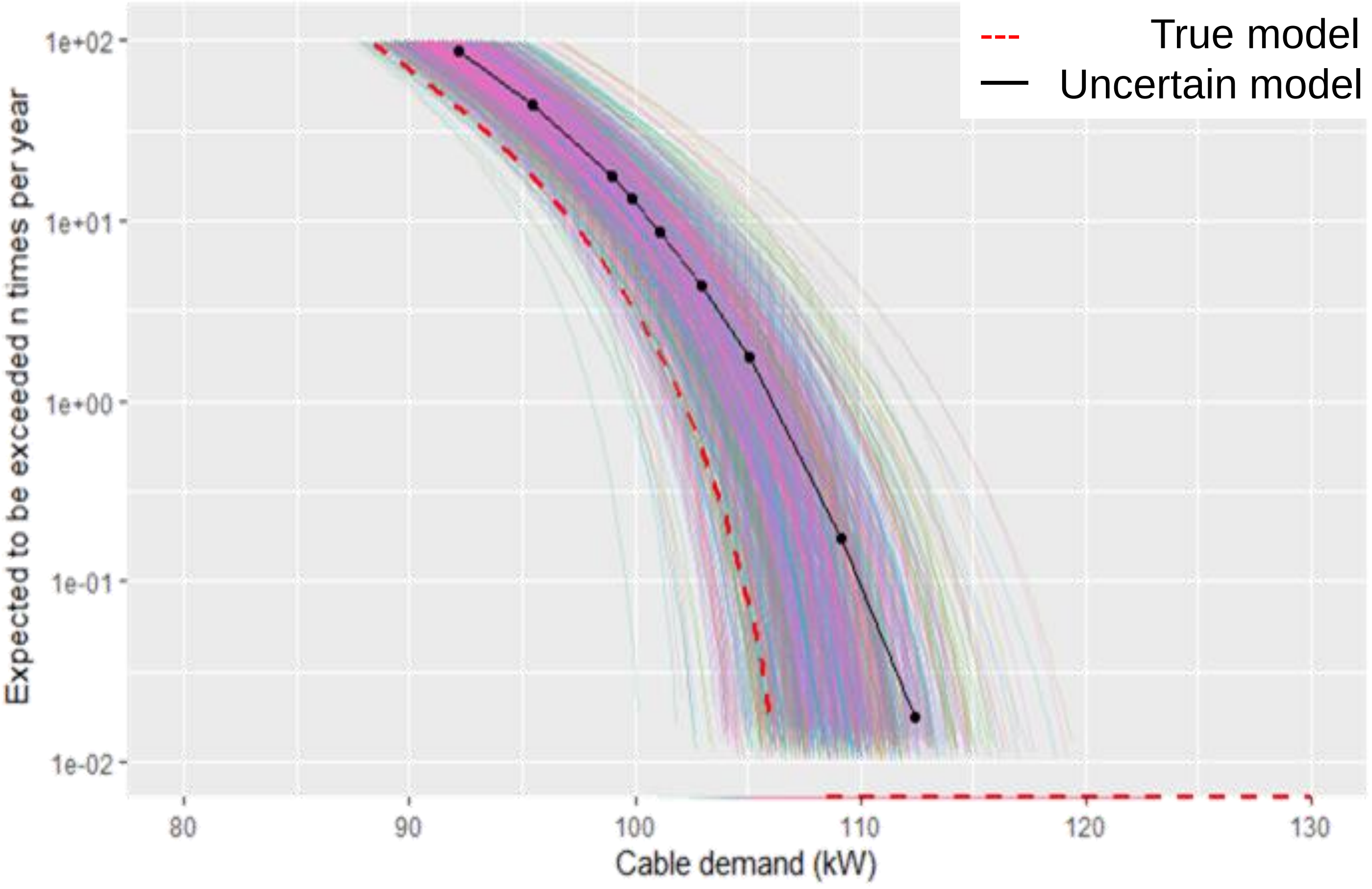
Probabilistic modelling framework: Demand model

- A model was created to predict extreme cable demands based on historic usage data.
- Uncertainty on customer parameters adds a “risk premium” to the demand estimate.



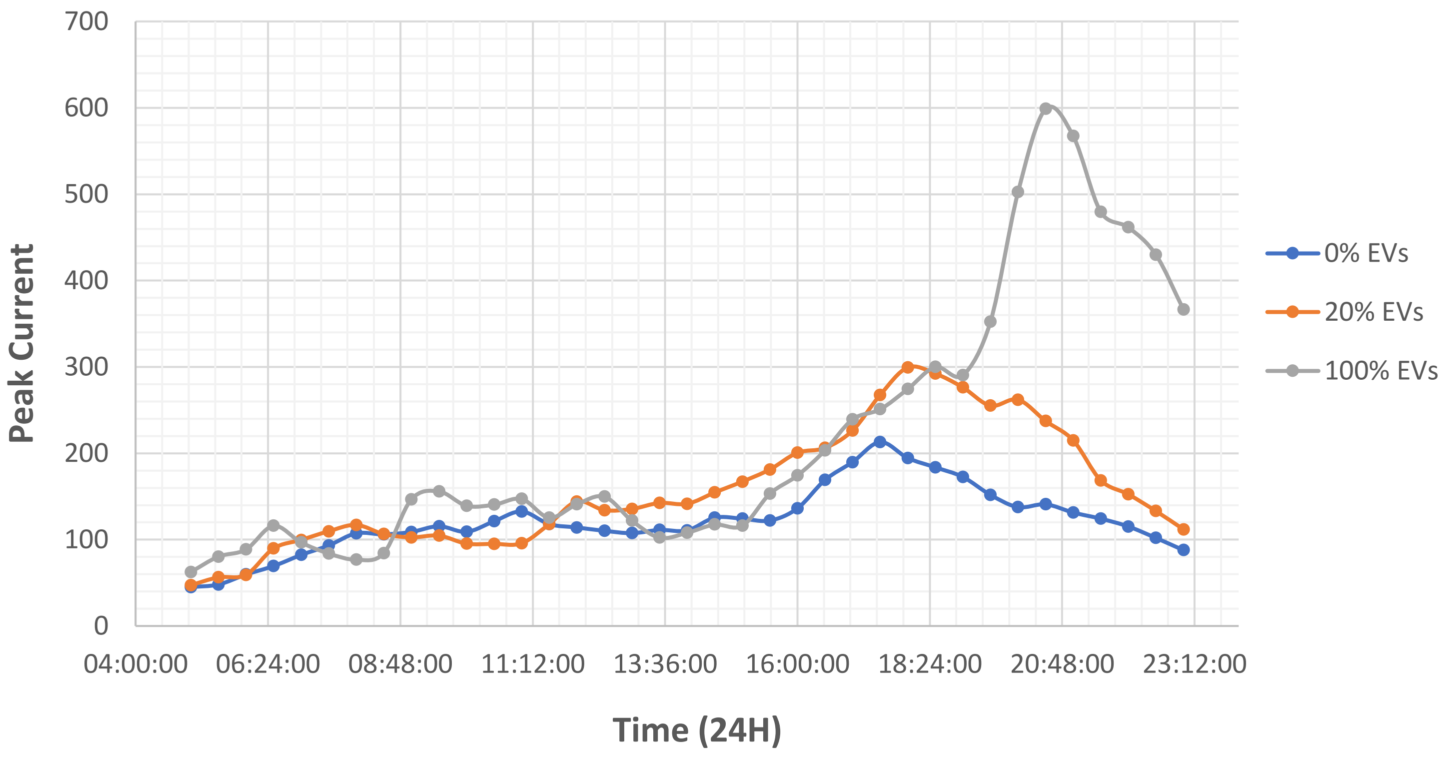
Probabilistic modelling framework: Demand model

- A model was created to predict extreme cable demands based on historic usage data.
- Uncertainty on customer parameters adds a “risk premium” to the demand estimate.
- Partial penetration of smart meters reduces this uncertainty.

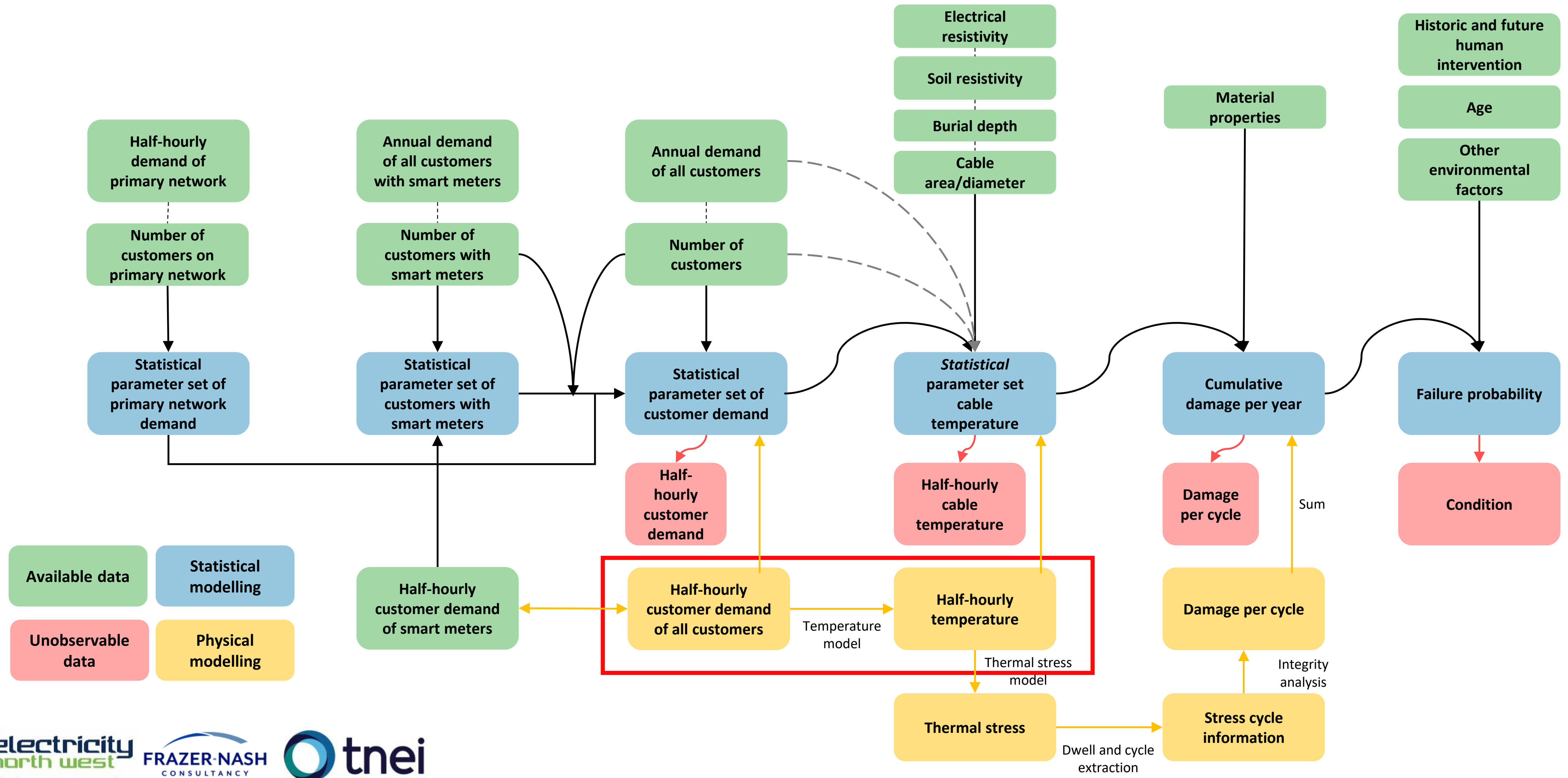


Probabilistic modelling framework: Demand model

- A model was created to predict extreme cable demands based on historic usage data.
- Uncertainty on customer parameters adds a “risk premium” to the demand estimate.
- Partial penetration of smart meters reduces this uncertainty.
- Increased EV usage without smart charging will create larger peak demands.

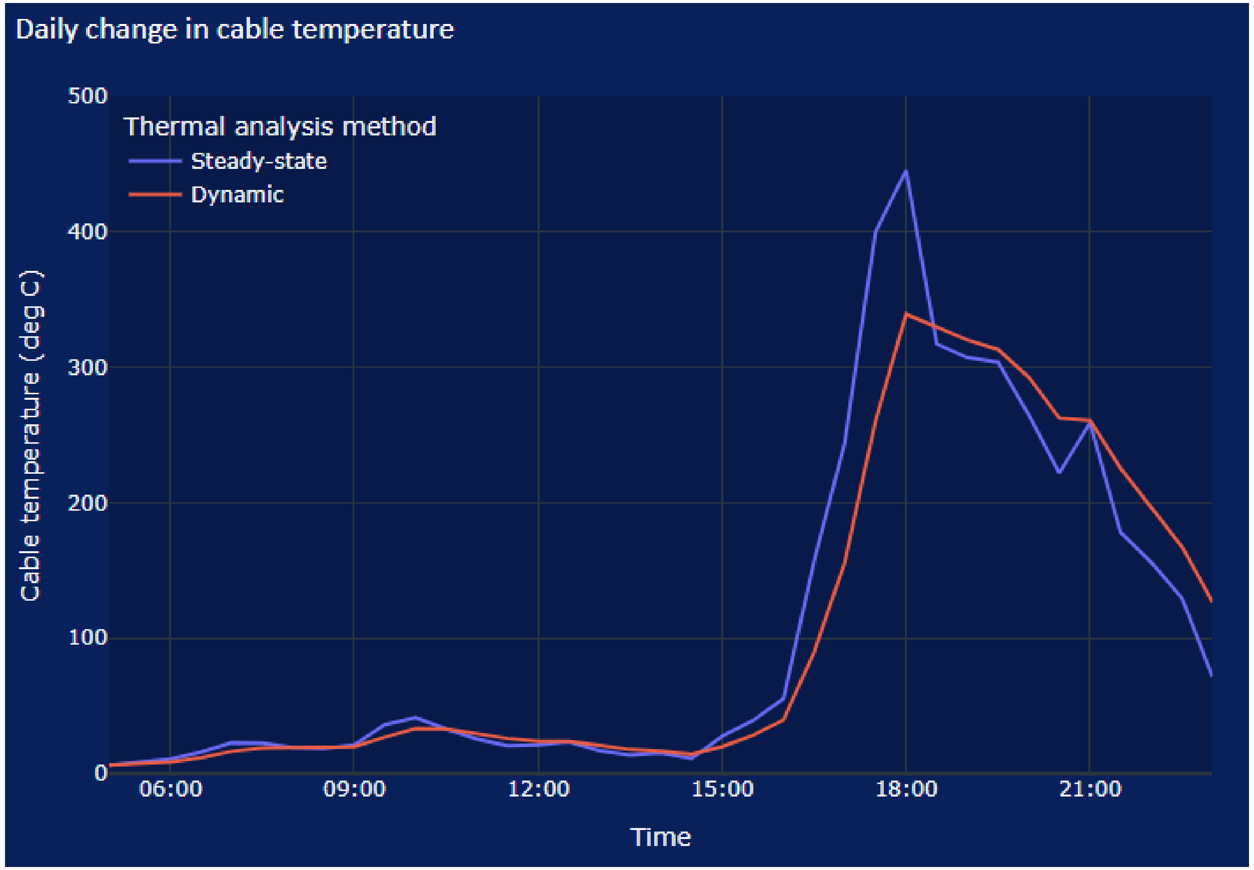


Probabilistic modelling framework: Temperature model



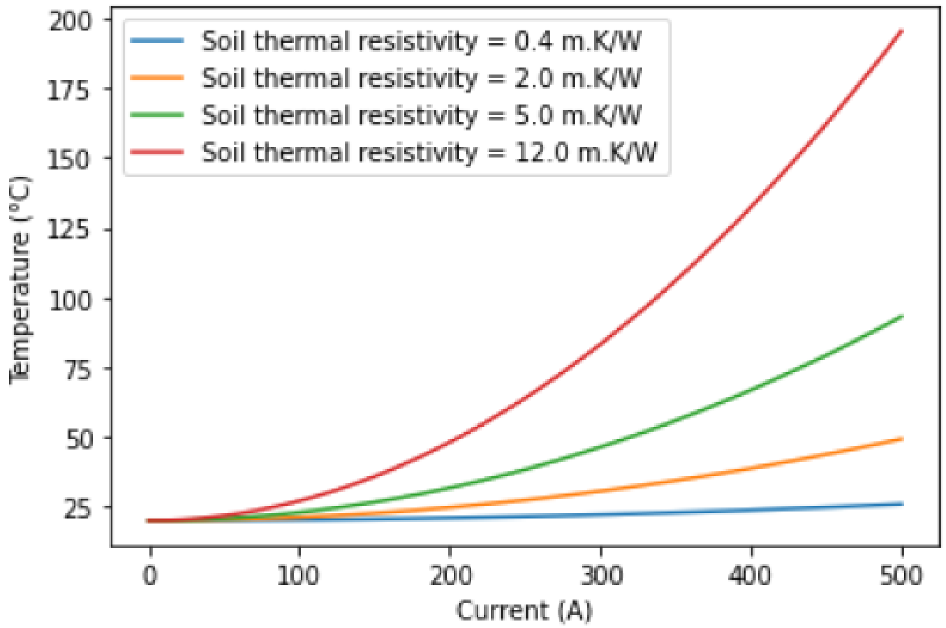
Temperature model

- An analytical model was created to predict cable temperature and account for dynamic heating effects.



Temperature model

- An analytical model was created to predict cable temperature and account for dynamic heating effects.
- A sensitivity analysis showed that the cable temperature varies significantly with the soil thermal conductivity.



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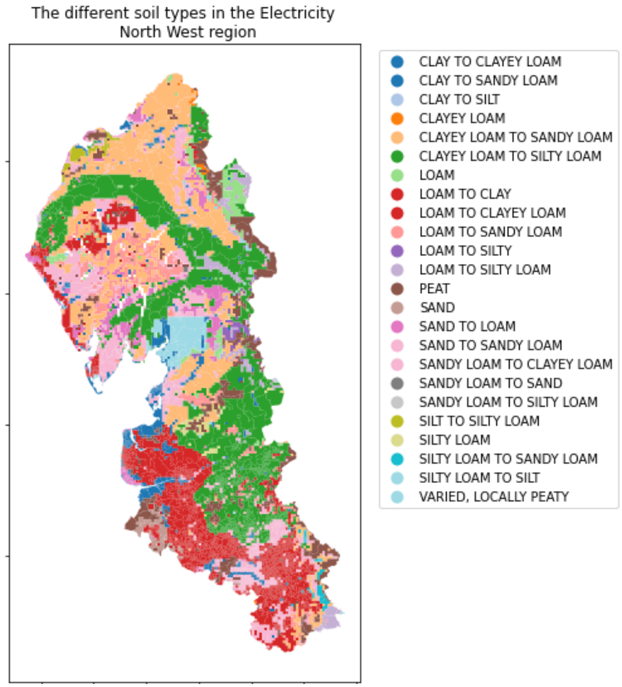
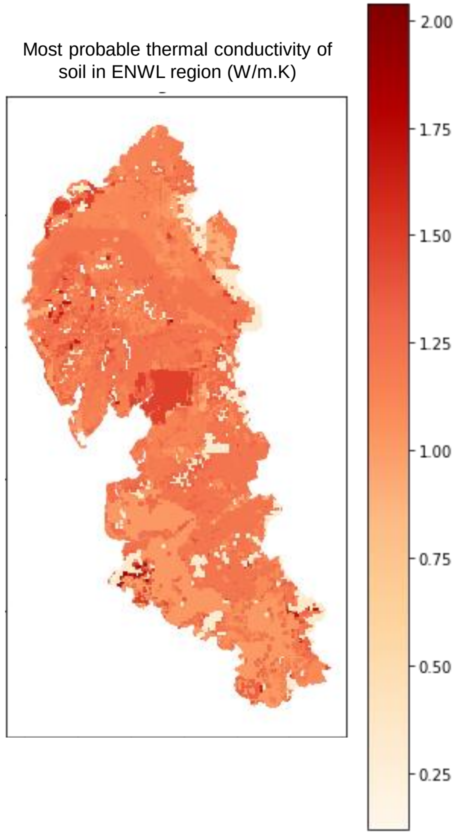
Temperature model

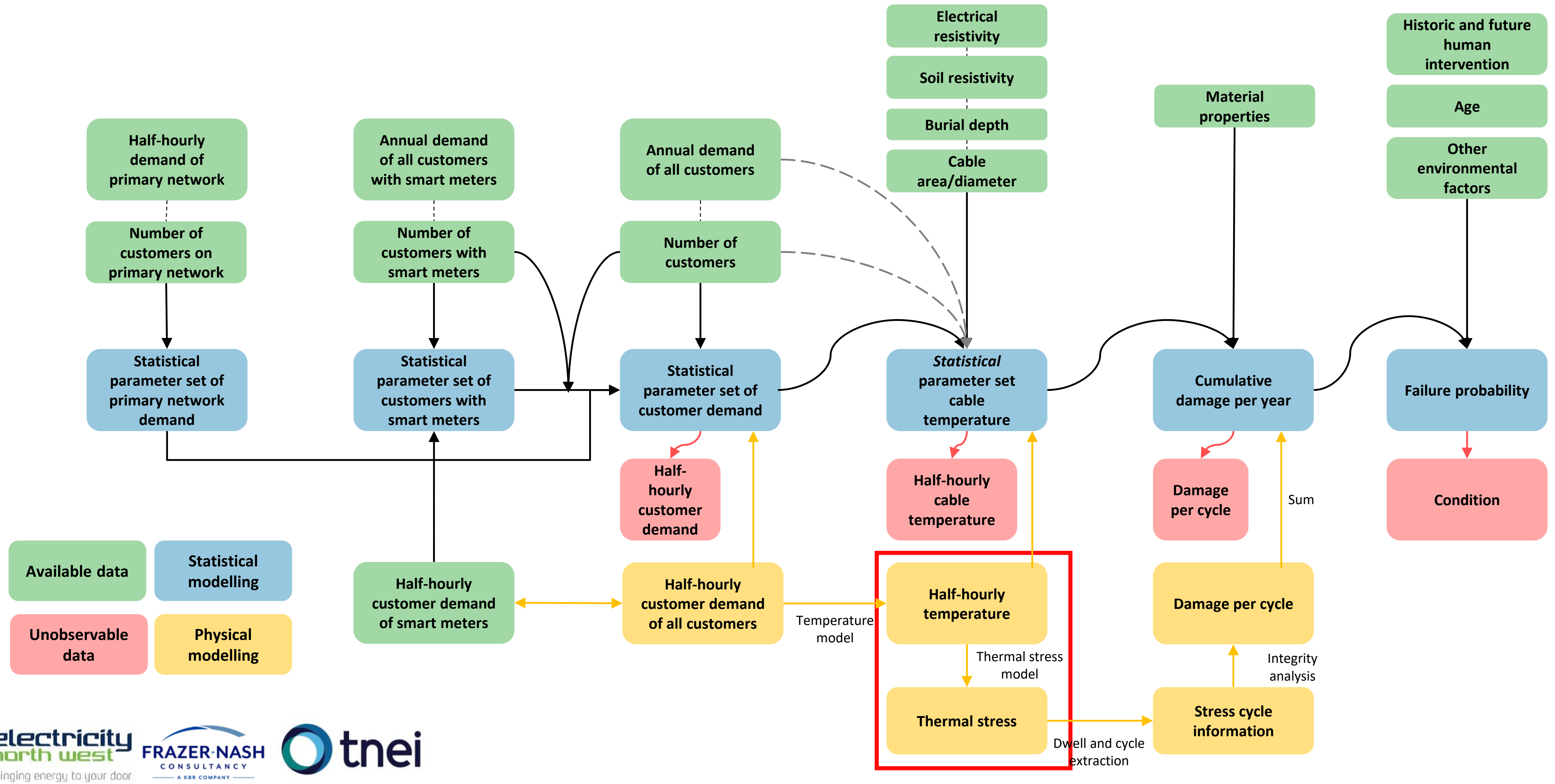
	Thermal Conductivity (W/mK)	
Soil type	Soil that is completely dry	Soil that is saturated with water
Clay	1.11	1.67
Peat	0.08	0.45
Silt	1.67	1.67
Loam	0.91	0.91
Sand	0.77	2.5



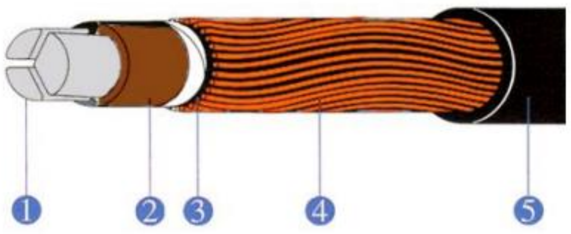


$$K = K_{Dry} + \left(K_{Wet} - K_{Dry}\right) P(soil_{wet})$$

Probabilistic modelling framework: Thermal stress model

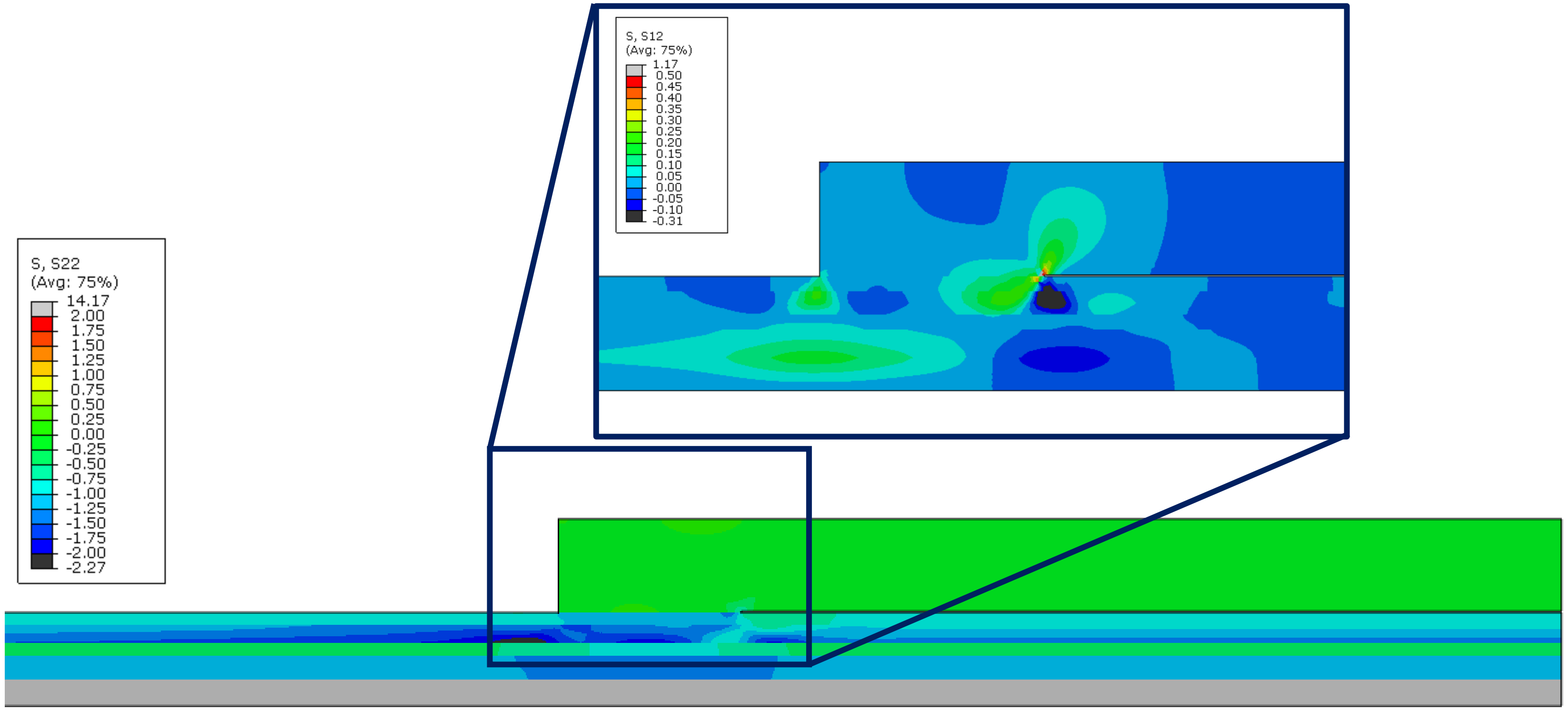


Thermal stress model



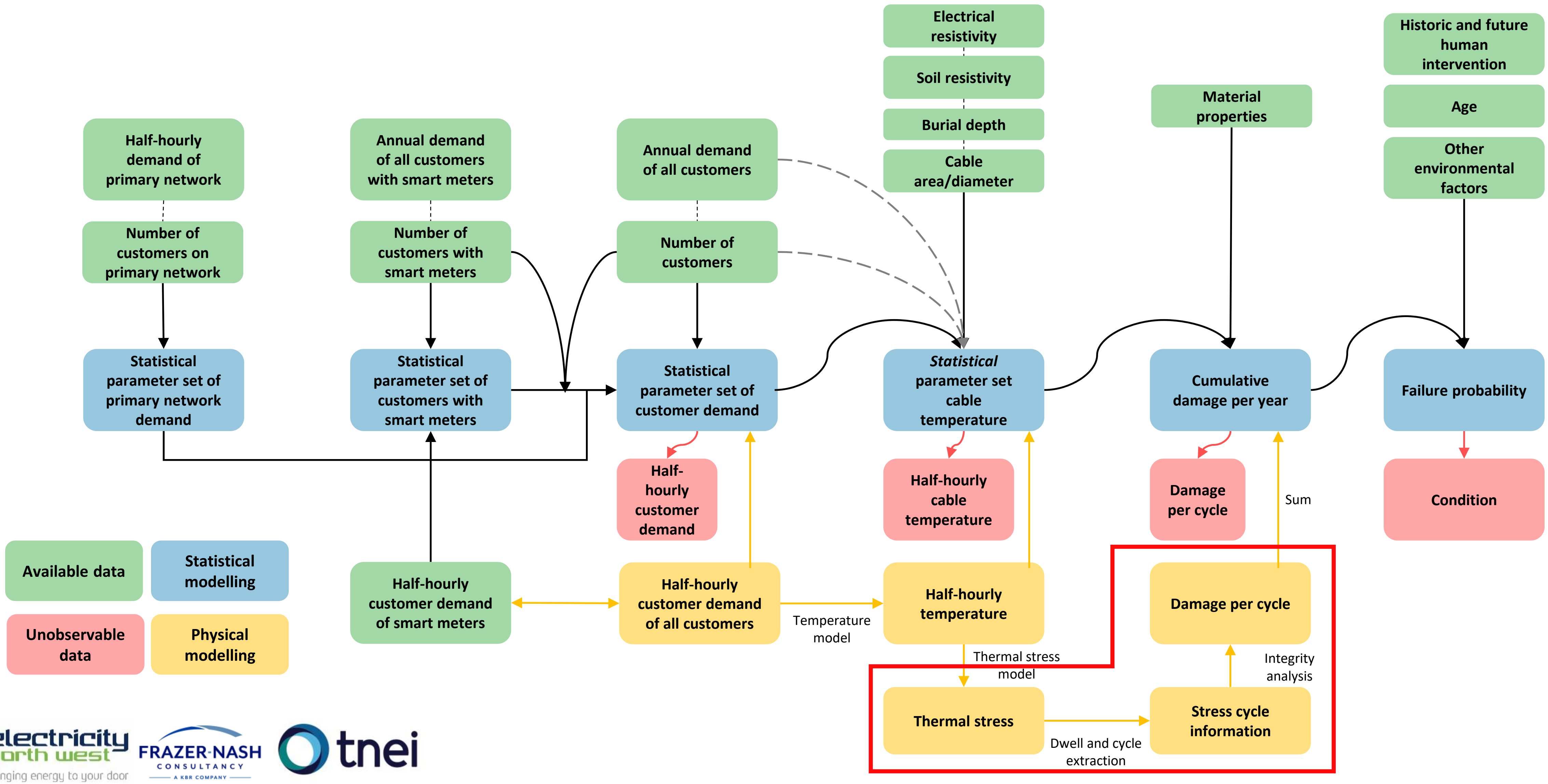
DESIGN & CONSTRUCTION

- **1:** 3 Core Shaped Solid Aluminium Conductor
- **2:** XLPE Insulation (Brown/Black/Grey)
- **3:** Rubber Bedding
- **4:** Waveform Copper Wire Screen
- **5:** Black PVC Sheath



- Use of different material layers and cable/joint burial in different soil types.
- Differential thermal expansion of components leads to high stress regions.

Probabilistic modelling framework: Damage model



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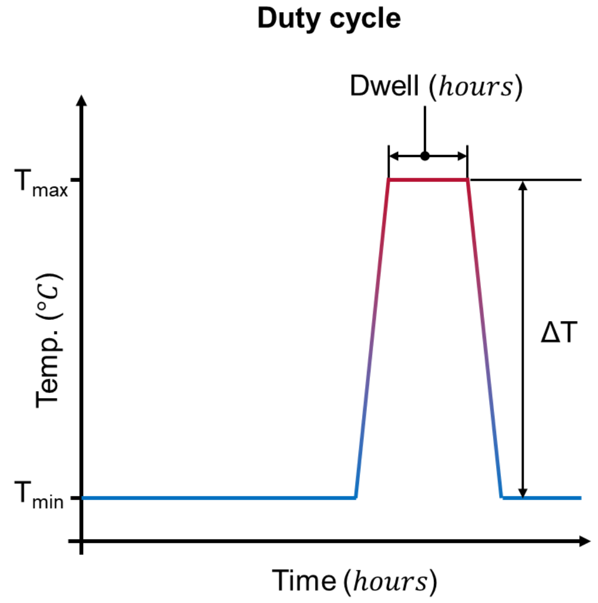
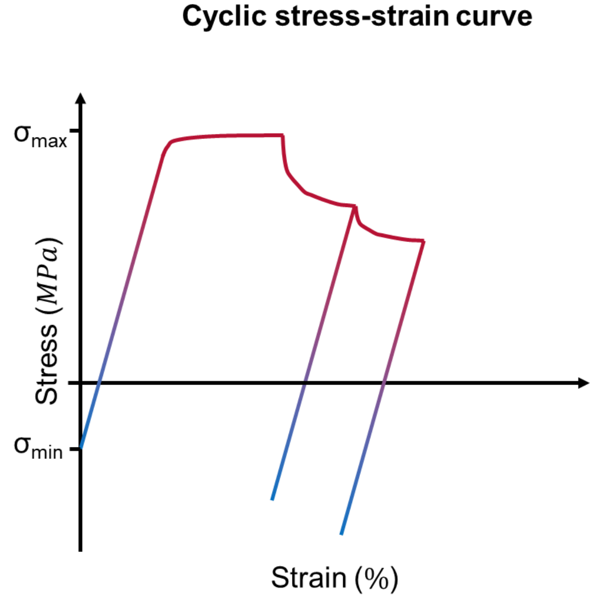
Damage model

- Damage model created to calculate:
  - Fatigue damage
  - Creep damage (including temperature effects)
  - Plastic damage (from overloading the material)

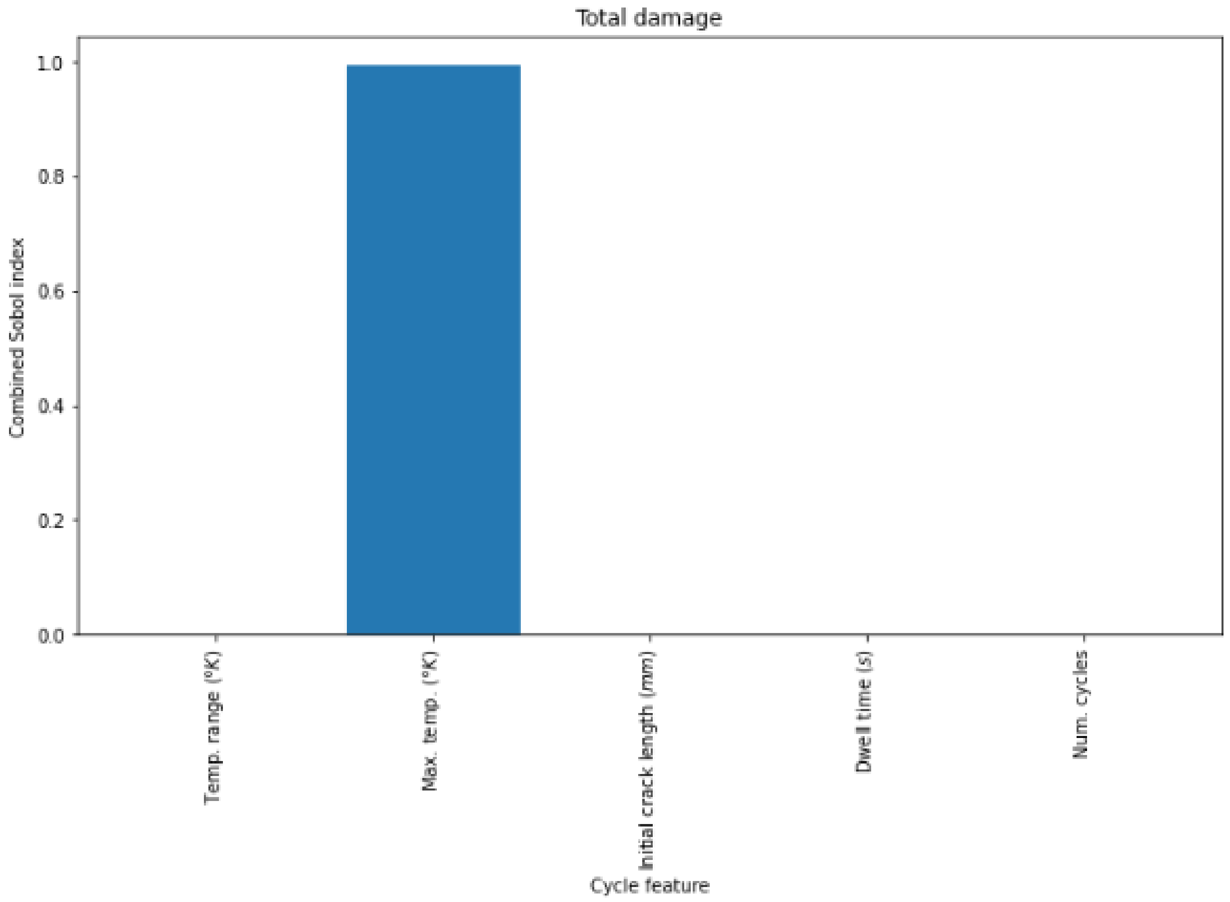




Damage model

- Damage model created to calculate:
  - Fatigue damage
  - Creep damage (including temperature effects)
  - Plastic damage (from overloading the material)

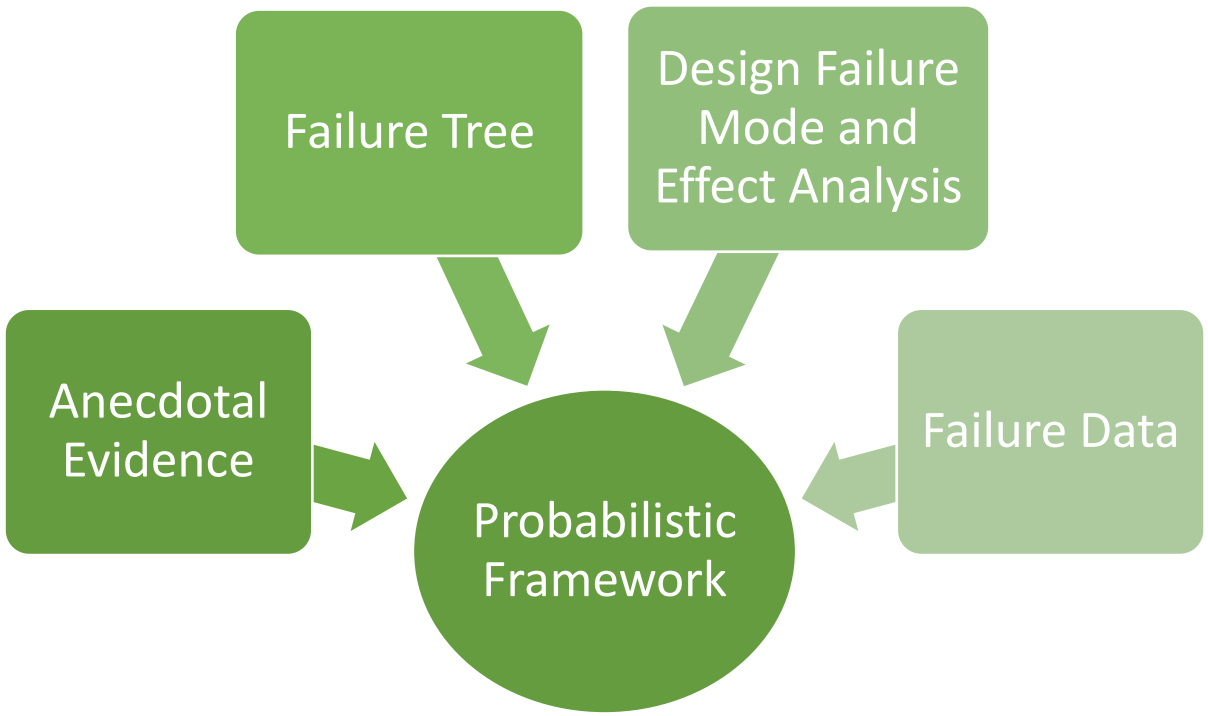
- Peak cable temperature (caused by peak demand) appears to have the strongest influence on joint failure.



Conclusions

Conclusions so far

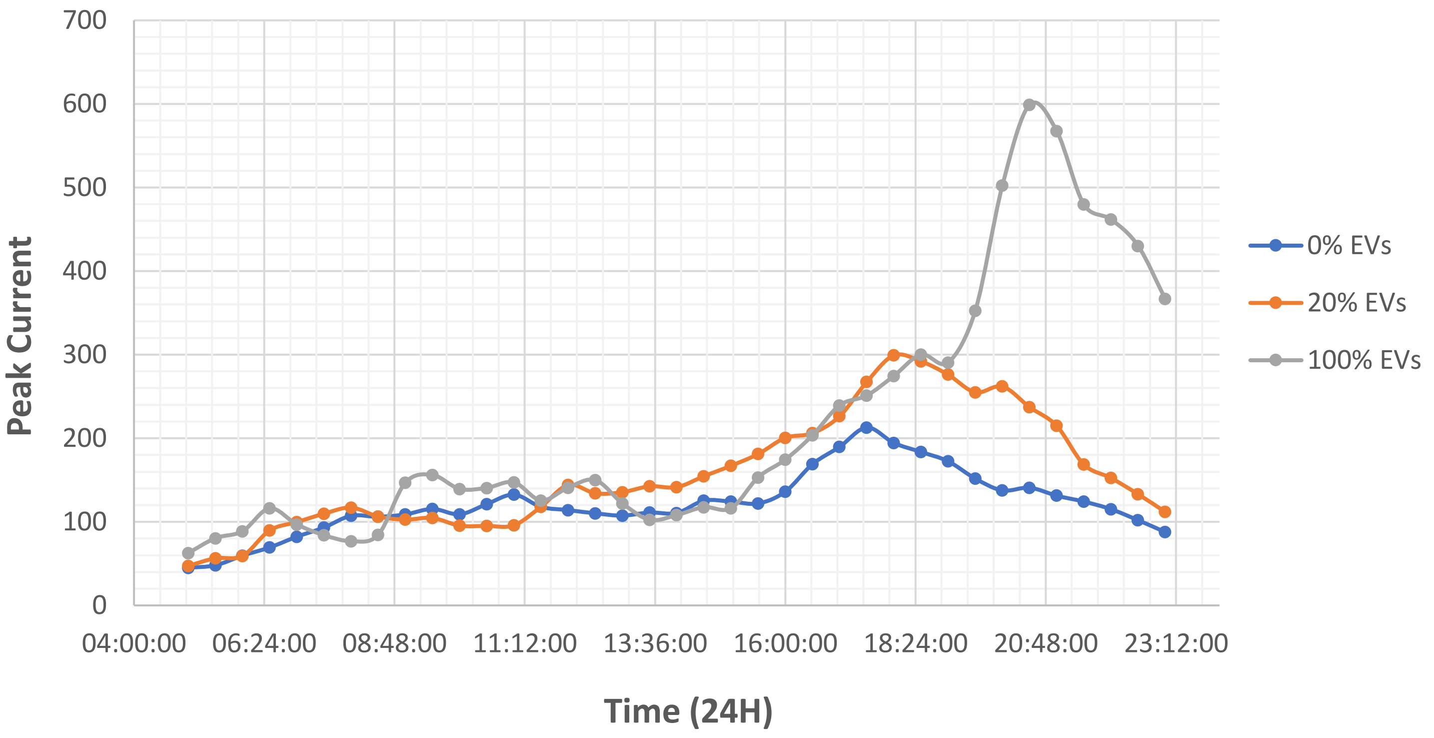
- The probability of underground low voltage asset failure can be simulated through the use of a probabilistic framework.



Conclusions so far

- The probability of underground low voltage asset failure can be simulated through the use of a probabilistic framework.

- Electric vehicle usage can cause a threefold increase in peak current in underground low voltage cables.



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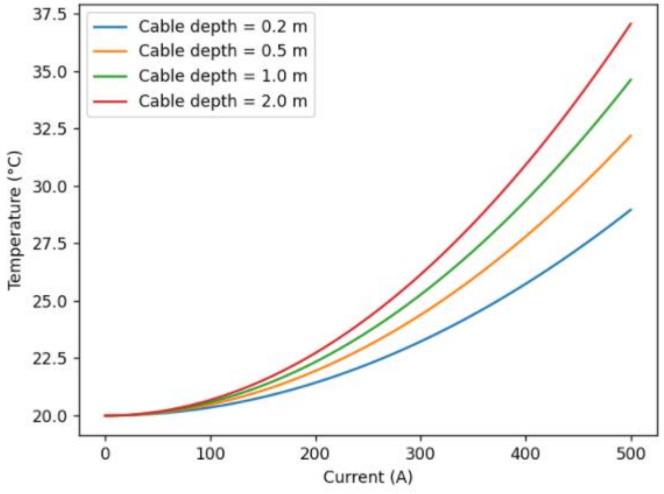
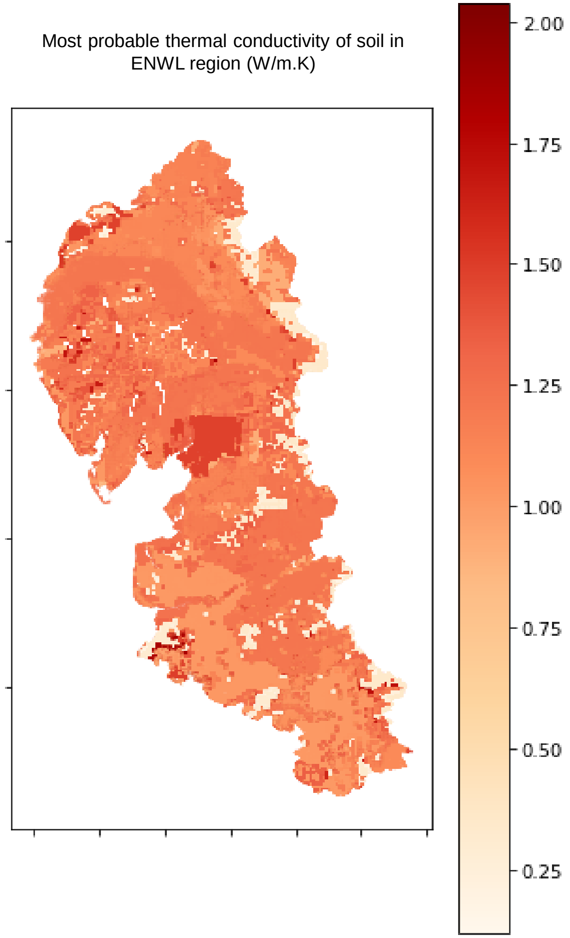
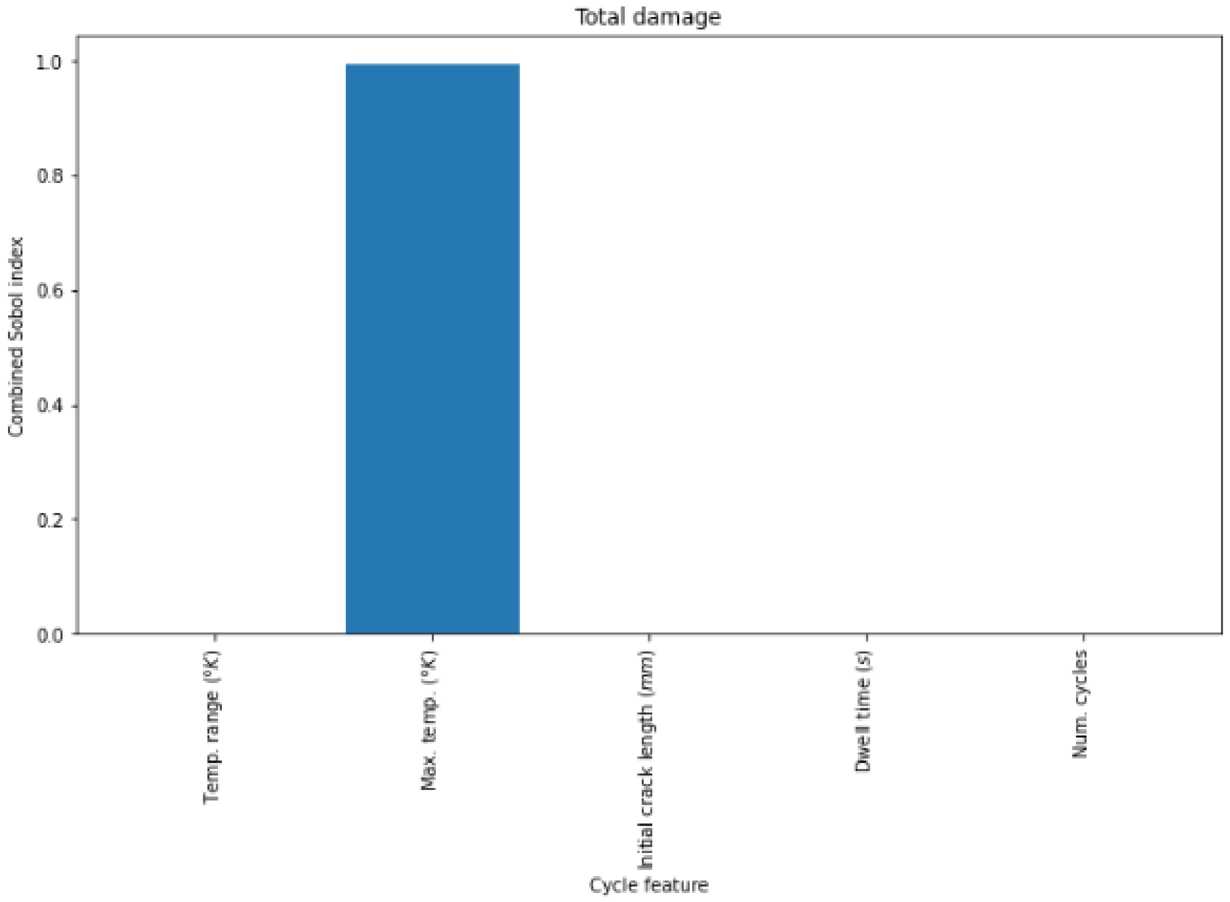
- Soil conditions strongly influence underground cable temperatures.





Conclusions so far

- The probability of underground low voltage asset failure can be simulated through the use of a probabilistic framework.
- Electric vehicle usage can cause a threefold increase in peak current in underground low voltage cables.
- Soil conditions strongly influence underground cable temperatures.
- Greater demand leads to higher cable temperatures, which can lead to increased cable joint damage.



QUESTIONS & ANSWERS

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Please contact us if you have any questions or would like to arrange a one-to-one briefing about our innovation projects

Interactive learning tool

LV Predict

A visualisation tool to predict the damage in underground low voltage cables across the Electricity North West region.

Select the cable type:

Three-core polymeric insulated waveform cable (95mm² solid a...

Select the soil type:

Peat

Drag the following sliders to change the values:

Cable Depth (m):

0.4 0.6 0.8 1

Initial Crack Length (mm):

0.01 0.25 0.5 0.75 1

Number of Customers:

10 20 40 80 160

Electric Vehicle (%):

0 20 100

Soil Temperature (°C):

0 3 6 9 12

Daily Rainfall (mm):

0 2 4 6 8

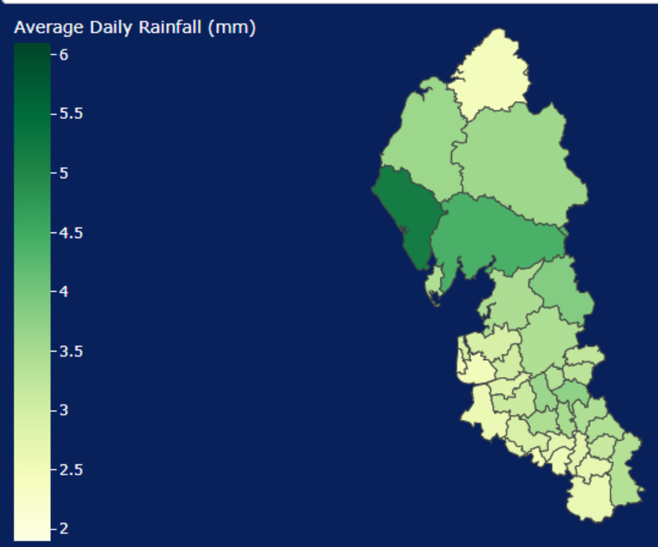
☑ Model Dynamic Heating?

Soil properties and rainfall across the North West region

The soil type, soil properties, and average rainfall vary across the North West. Use the dropdown to explore how these properties vary in the region. Click to select these properties for the model.

Select a map:

Average Daily Rainfall



The buried cable and joint

Different cable types are buried at different depths across the region. Use the sliders on the left to modify the cable type and cable burial depth.

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https://lv-predict.fnc.digital

Additional Slides

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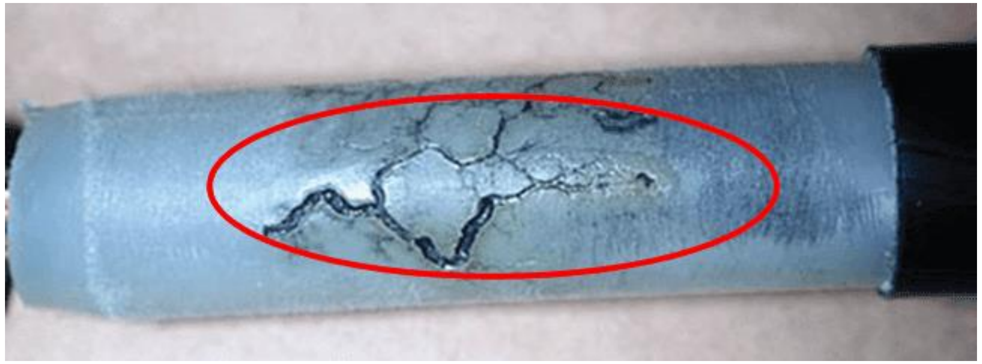
Electrical-driven degradation

- Voltages in LV cables is generally too low to cause significant damage to the cables and / or joints.

- While unlikely due to the low voltages, a literature review found that water ingress could lead to electrical-based degradation via heating and evaporation of the water, leading to damage in the conductors.



Chemical-based degradation

- Most chemical-based degradation mechanisms are not credible for underground LV cables and joints.

- However, thermally-induced degradation of mechanical properties is possible at high temperatures.
  - The likelihood of this occurring becomes significant when temperatures exceed 75°C, and when the operating life reaches 20 years.

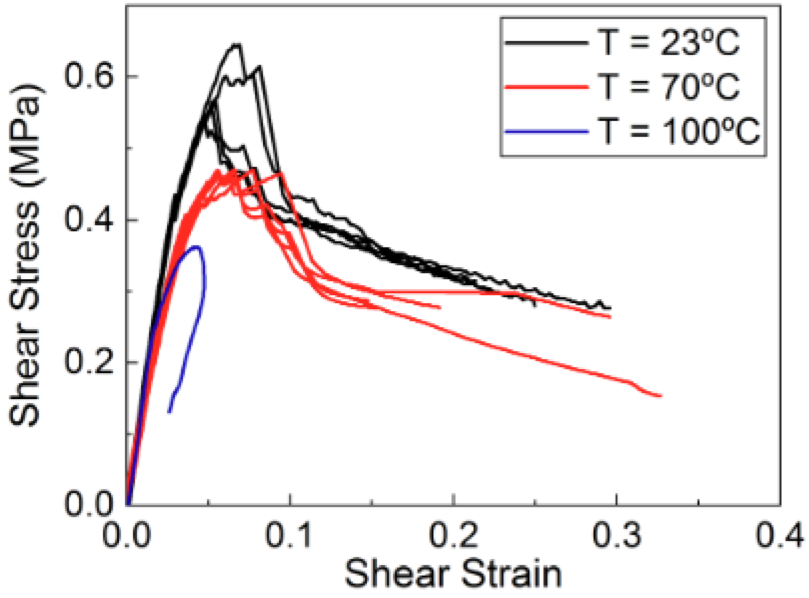
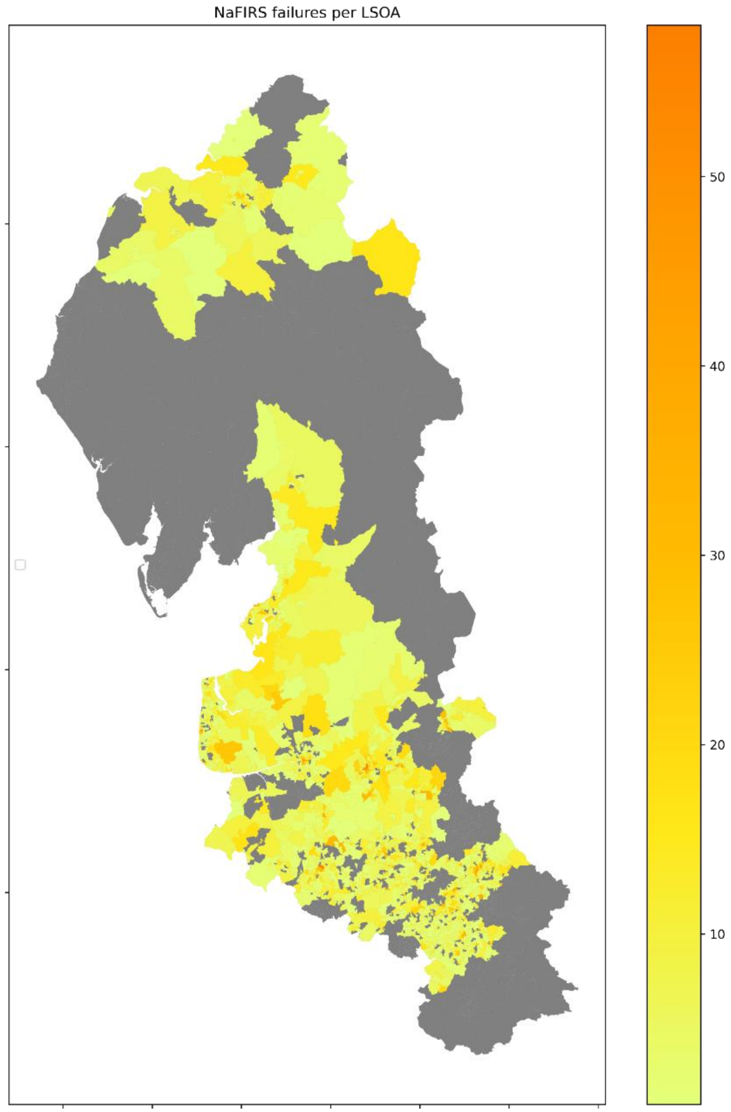


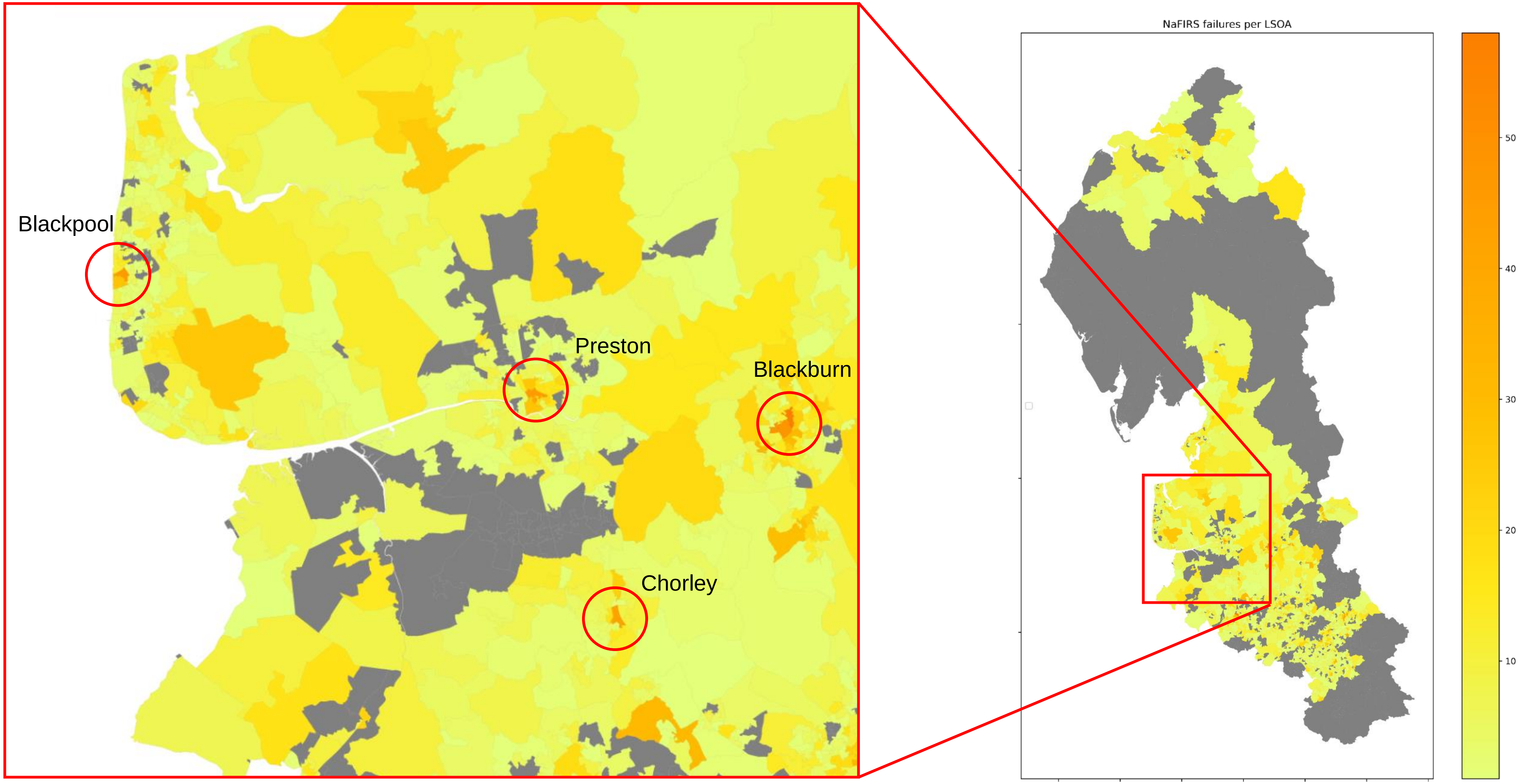
FIGURE 6 Stress–strain curve of unaged samples under different temperatures [Colour figure can be viewed at wileyonlinelibrary.com]

Recorded failure data

- Recorded failure data was analysed to understand trends for the failure of LV assets.
- The most common cause of failure is due to "deterioration due to ageing or wear (excluding corrosion)".
- Failure data showed higher failure rates in more densely populated locations, even when failures are normalised by household density.
- Top 5 highest daily failure counts coincide with dates of "severe weather events" according to the Met Office.



Recorded failure data: population density



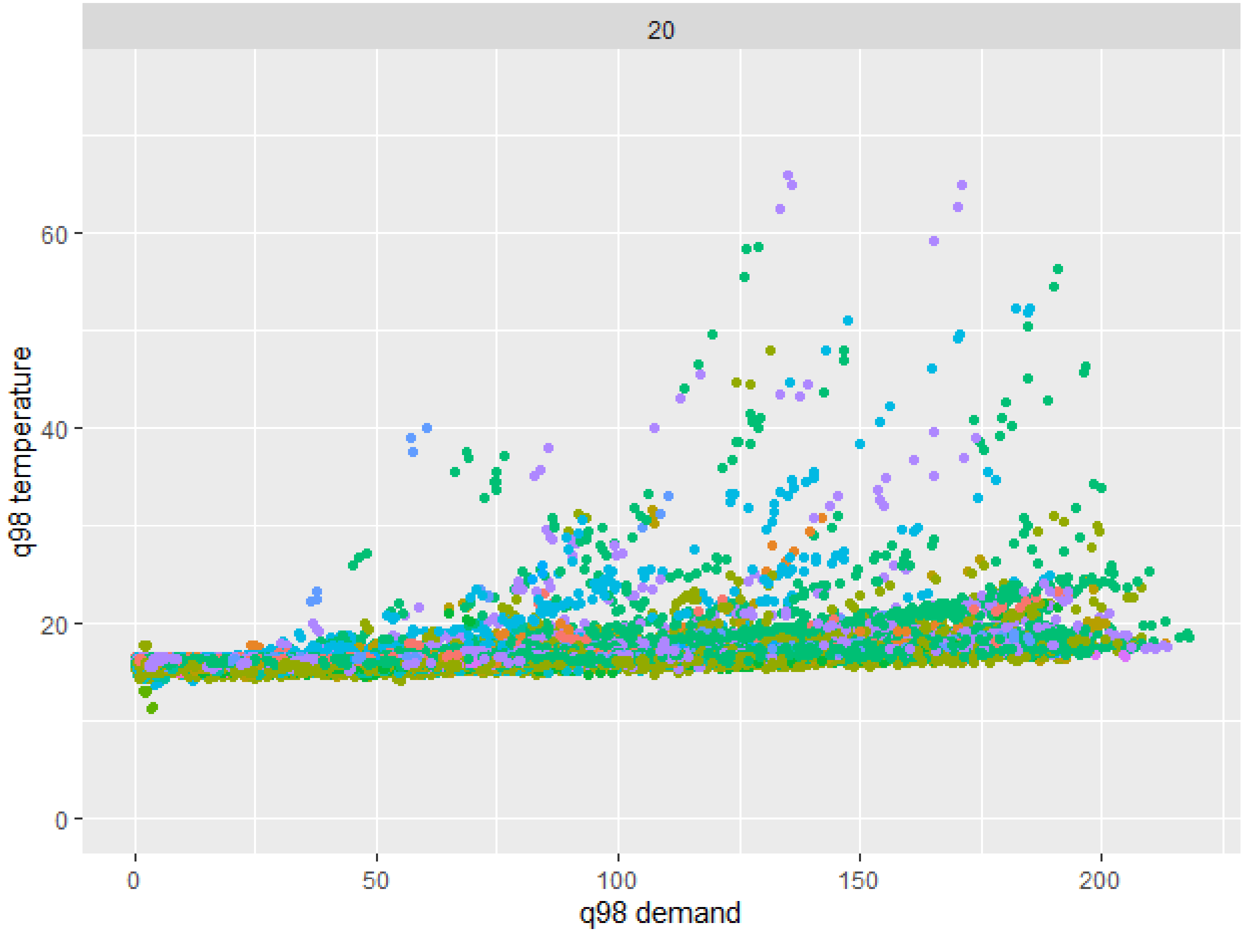
Recorded failure data: weather events

- Top 5 highest daily failure counts coincide with dates of “severe weather events”, according to the Met Office.

Failure Count	Precipitation (mm)	Date	Weather event
174	13.3	09/02/2020	Storm Ciara (8-9th Feb)
141	15.0	28/07/2019	Between “record breaking heatwave” (25th Jul), and “torrential downpours” (30-31st Jul)
125	24.2	20/01/2021	Storm Cristoph (18-20th Jan)
120	1.0	26/08/2020	Day after Storm Francis (25th Aug)
117	26.8	19/01/2021	Storm Cristoph (18-20th Jan)

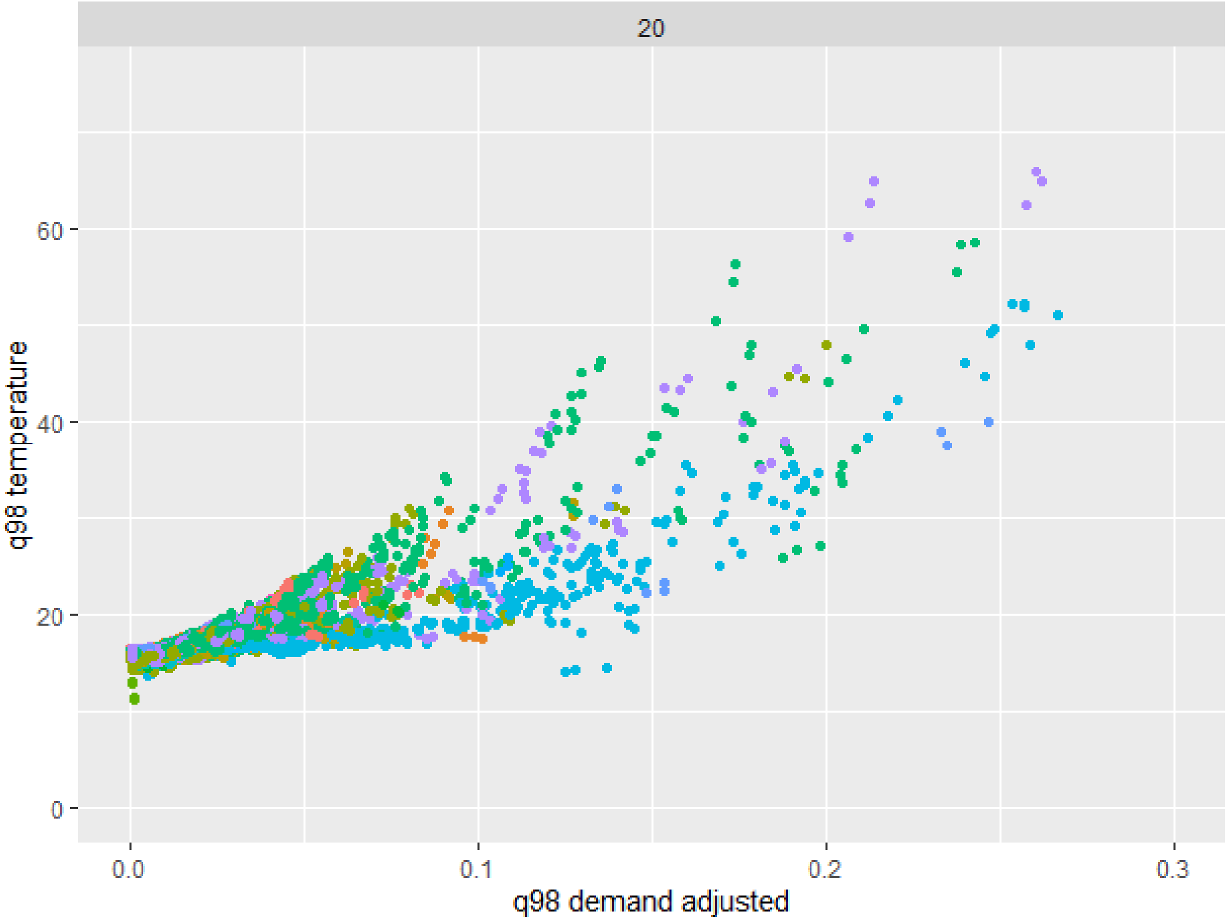
Temperature model

- The relationship with high demands and high temperatures is very “noisy”.



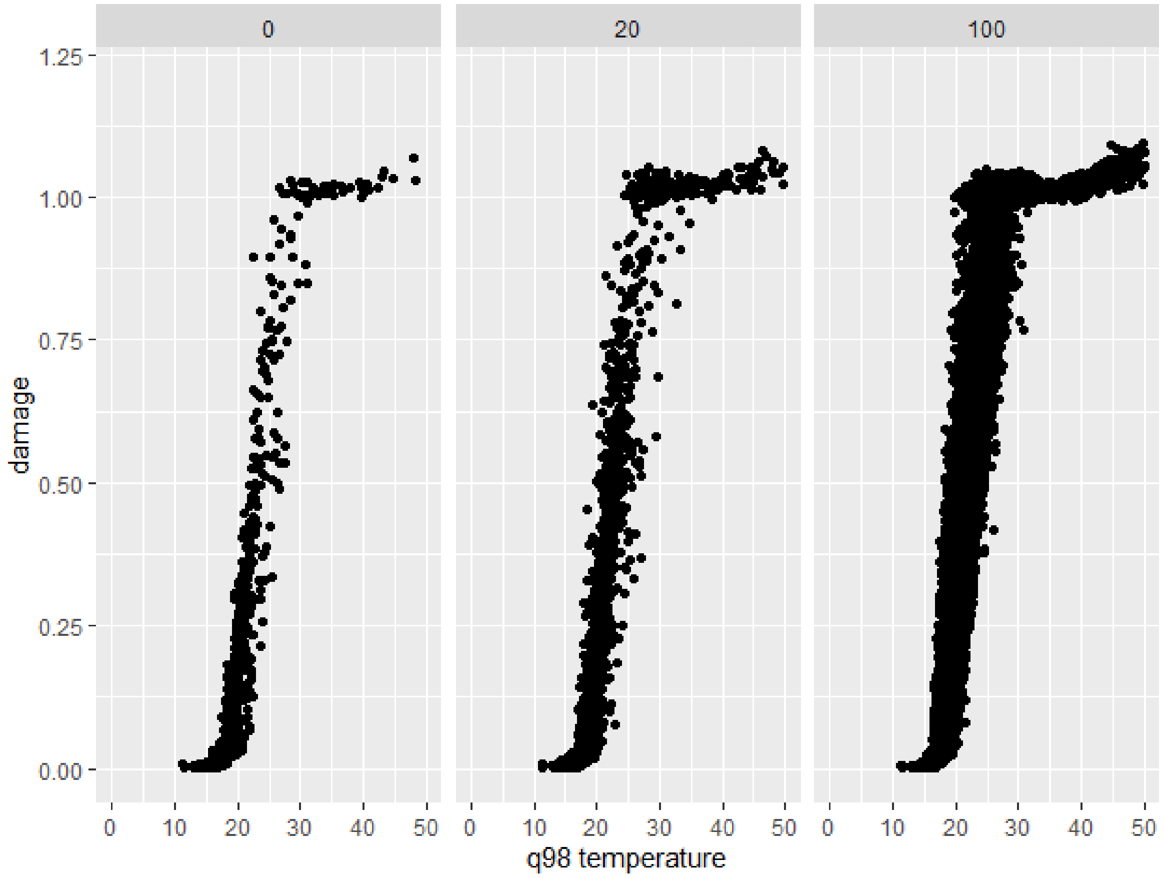
Temperature model

- The relationship with high demands and high temperatures is very “noisy”.
- A clearer pattern is seen when accounting for electrical and thermal resistance.



Damage model

- A strong relationship exists between high temperatures and total annual damage.



Electric vehicle charging