Vulnerability of **Energy** and **Telecom** Infrastructures to Extreme Weather Events

A Risk Assessment Tool

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Outline

- **Extreme Weather Events**
  - Impact on the Electric & Telecom infrastructures
  - Threats & protection measures
- **Contingency analysis ⇔ meteorological threats**
  - Electrical simulations
  - Impact evaluation
- **Risk Assessment Tool**
- **Summary**

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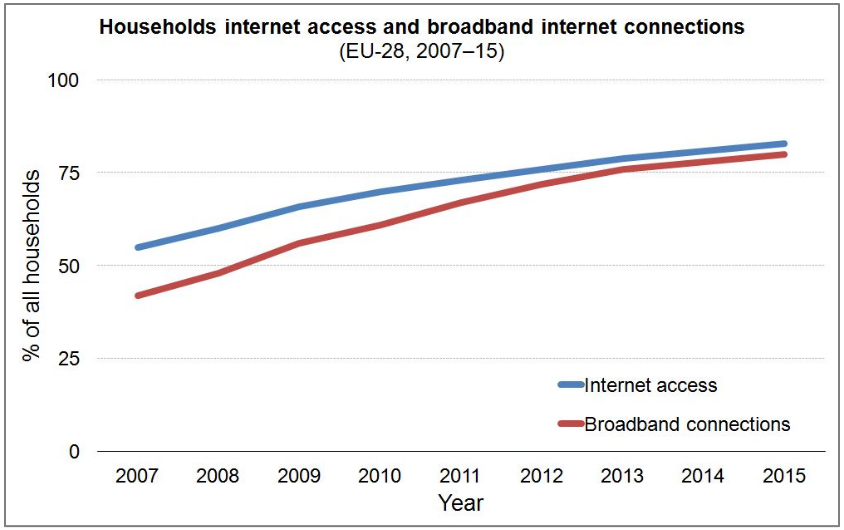
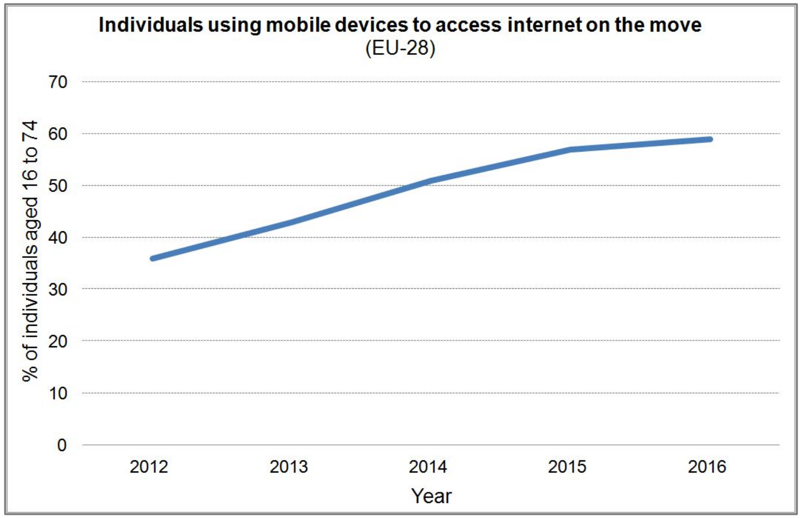
EWE impact on E & Telco Infrastructures

In the coming years

- more EWEs,
- more E & Telco dependent,
- more complex grid operation.





Eurostat (2016)

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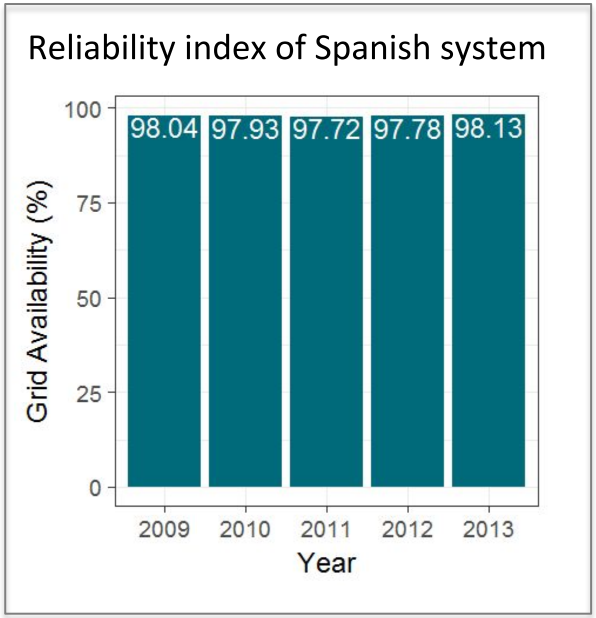
EWE impact on E & Telco Infrastructures

European power grids are

- **robust** and **reliable**, but still
- vulnerable to **extreme weather events**.

Telecommunication networks are

- **redundant**, but
- electricity dependent.



Adapted from REE (2013)

In this work, we present a **methodology** based on bayesian networks to

- identify their **weak points** linked to **specific weather threats**,
- assess the expected economical & social **impact**, and
- propose **protection measures**.

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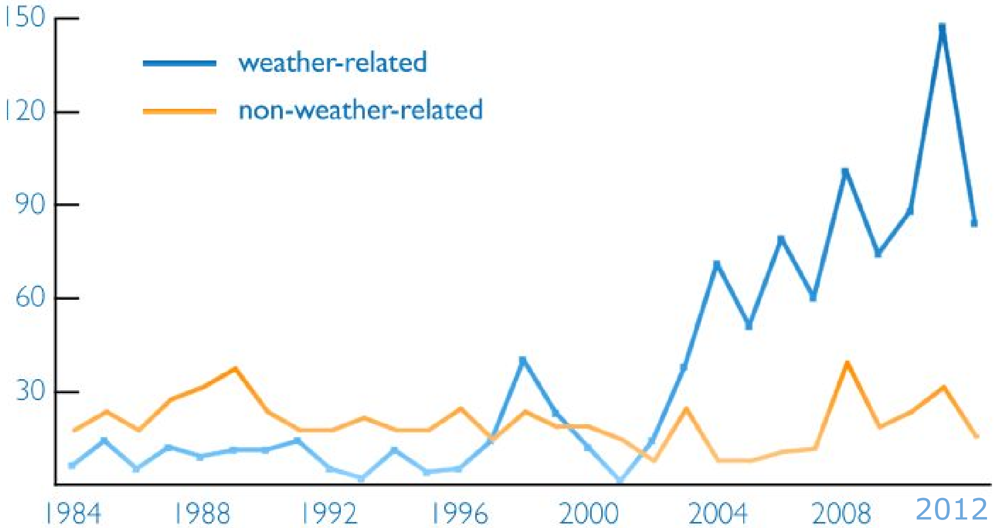
EWE impact on Electrical Infrastructures

Number of **power outages per year** in the U.S.



Kenward & Raja, Climate Central report (2014)

Effects of **tropical storm Delta**
Canary Islands (Spain), 2005

Foro contra la incineración de Tenerife (2005)

EWE impact on Electrical Infrastructures

Some European examples with number of **affected customers**, and **indirect damage** to other infrastructures:

- **Heavy snow/wind storms** in Poland (Nov. 2004):
  600k customers, fresh water supply, 25 tramway traction lines
- **Windstorm** Gudrun/Erwin (Sweden, Feb. 2005):
  663k customers affected (82k up to 7 days after), telco
- **Tropical Storm** Delta (Canary Islands, Spain, Nov. 2005):
  300k customers (20k 4 days after), water supply affected
- **Freezing rain** (Slovenia, Jan. – Feb. 2014):
  250k customers for days, rail transportation, roads, telco, water supply

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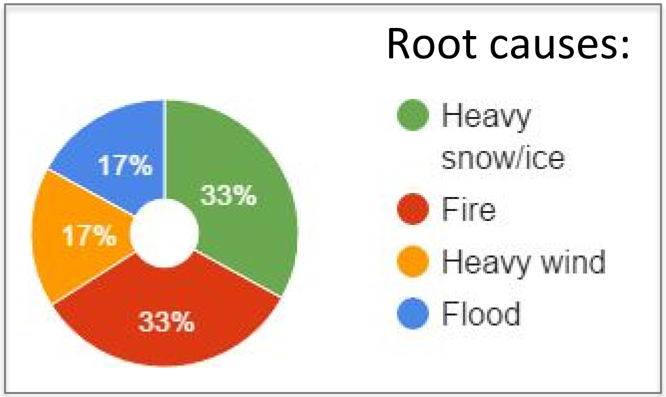
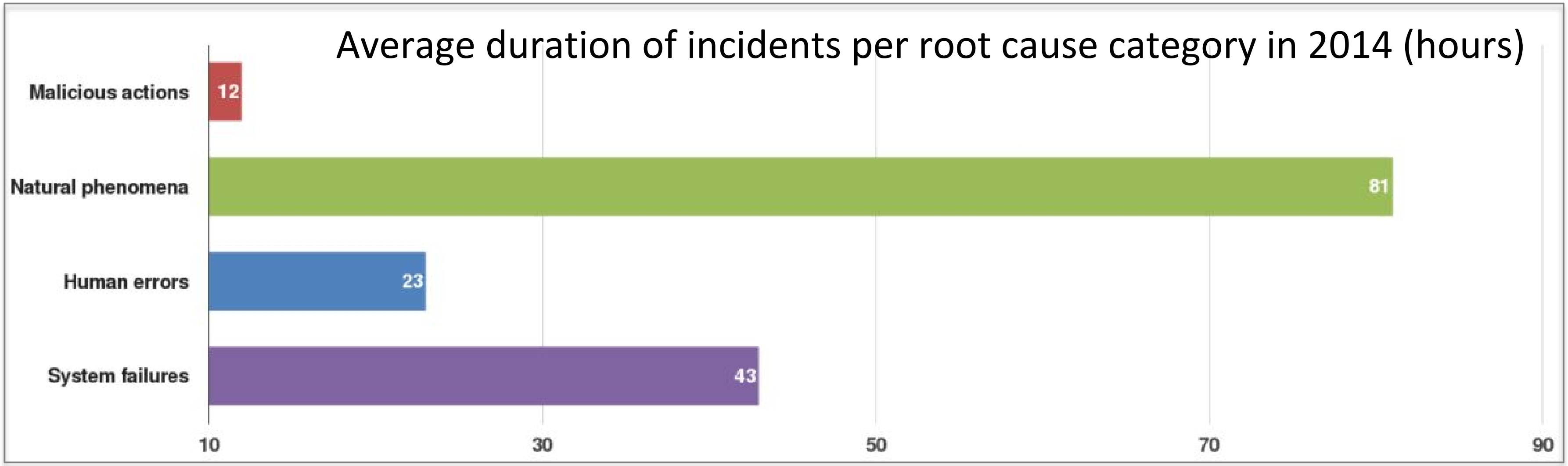
EWE impact on Telco Infrastructures

In Europe:

- **8%** of large incidents **directly** caused by **natural phenomena** during 2015
  (6% in 2014, 14% in 2013)
- indirect effect through **power cuts**:
  13% during 2014 (26% in 2013)
- **Longest recovery times**: 55 hours
  (average 2012-2015)





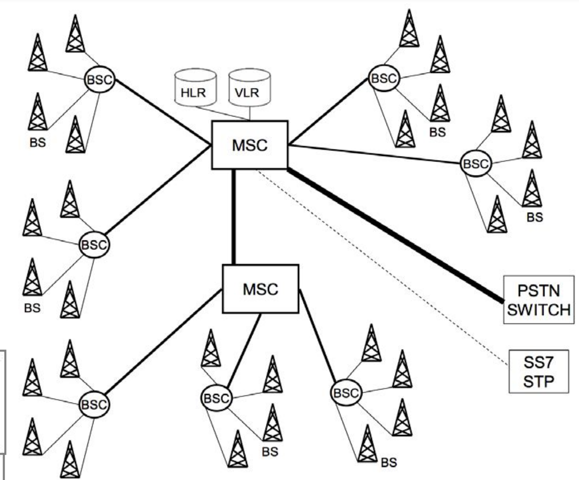
ENISA Annual Incident Reports 2014

Threats & protection measures

a. An overall **description** of the two Critical Infrastructures (CI) **elements** is provided.
b. The CI elements and their (weather related) **threats** are identified.
c. A first scheme of **interdependencies** with other CI is provided.

Telecommunications network

Network elements are characterized and their vulnerability related to specific EWEs identified in RAIN is assessed.



Telco network structure

(Snow and Weckman 2013)

	Outside Plants	End Offices	Central Offices	Aerial lines	Underground lines	RF/Sat links	Base Stations	MSC	BSC
Lightning	High	Mid	Low	Mid	Low	High	High	Mid	Low
Windstorms	High	Mid	Low	High	Low	High	High	Mid	Low
Ice/snow storms	High	Mid	Low	High	Low	High	High	Mid	Low
Flash floods	High	Mid	Low	Mid	Low	Mid	High	Mid	Low
Extreme cold	Low	Low	Low	Low	Low	Low	Low	Low	Low
Extreme heat	Mid	Low	Low	Low	Low	Mid	Mid	Low	Low
Wild fires	High	Mid	Low	High	Low	High	High	Mid	Low
Sand storms	High	Mid	Low	Mid	Low	High	High	Mid	Low

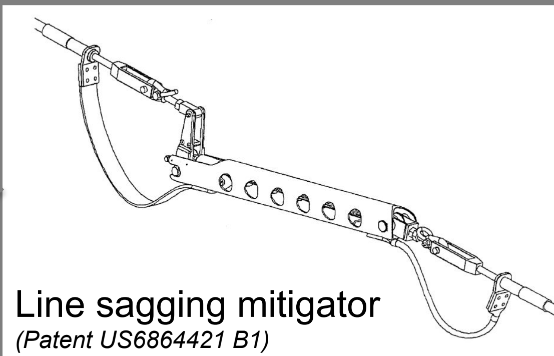
Threat assessment per weather threat and network element

Threats & protection measures

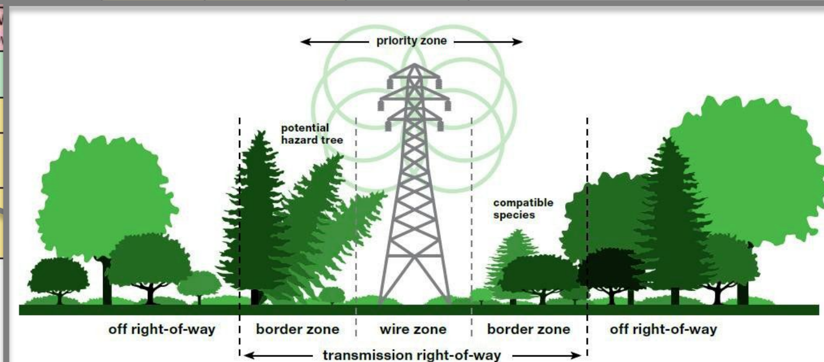
Preventive and **mitigation protection elements** and **methods** to protect **critical E & TC equipment** against damage from EWEs are reviewed.

PREVENTION									
	Lightning	Windstorms	Ice/snow storms	Flash floods	Extreme cold	Extreme heat	Wild fires	Sand storms	Seasonal drought
Generators (housed)									
Generators (wind / PV)	• Graded lightning protection • Lightning rods • Grounding	Wind Brakes: • Tip brakes (aerodynamic) • Mechanical braking system	• Winterization procedures. Wind • Blade anti icing systems: blade active heating, passive hydrophobic coating		Wind • Overproduction: breaking systems			PV • Minim of expos • Polym Encapsu • Forced	
Lines and Pylons		• Right-of-way maintantenance • Tower inspections and maintenance • Wind-induced oscillations (gallop, flutter) • Stockbridge damper:	• Line monitoring (LMO) • Protection against ice: - Passive - Active coatings - Mechanical - Thermal		• Tower inspections • Maintenance	• Line sagging: - Static and dynamic re-rating - Real time monitoring - SLiM			
Xformers	• Walls and covers	• Walls and covers	• Walls and covers	• Elevation platforms	• Walls and covers	• W co			
Sw / Breakers									
Relays									
SCADA & telecom									
Voltage control devs									

Preventive protection measures in electric infrastructures.



Line sagging mitigator
(Patent US6864421 B1)



Transmission right-of-way *(ConEdison)*

Contingency analysis

- part I

electrical contingency analysis ⟺ specific meteorological threats

- part II

holistic impact evaluation

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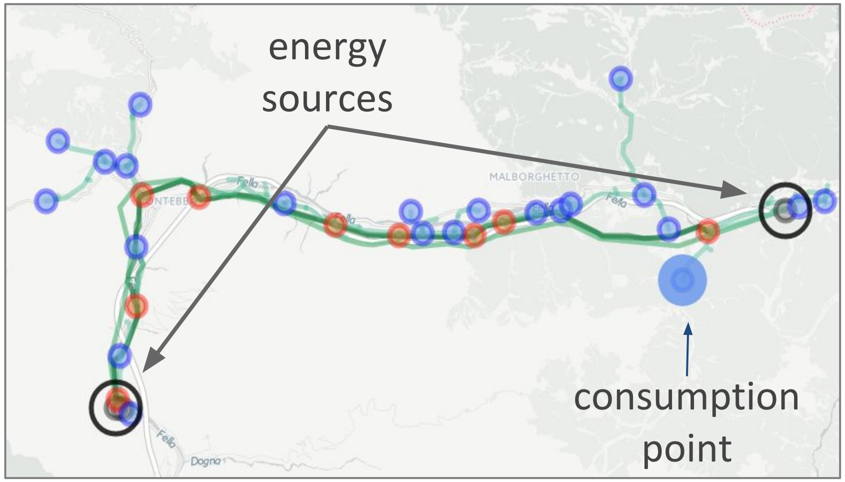
Electrical simulations

a) Connectivity analysis

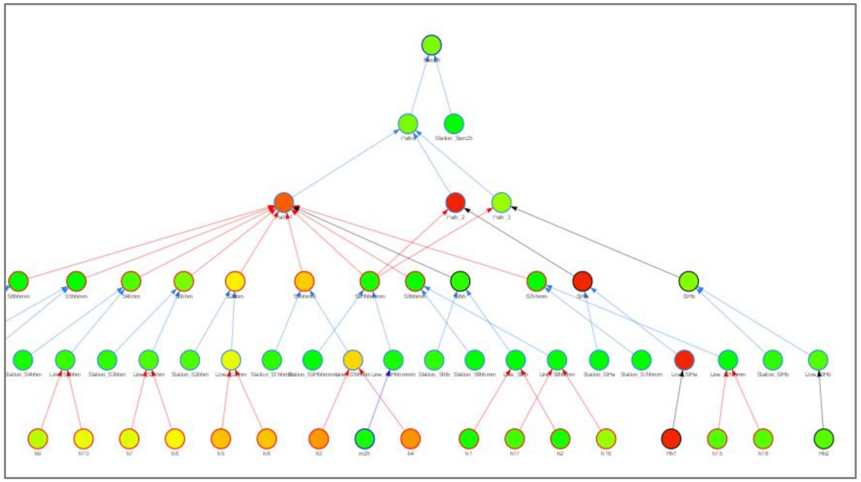
Electrical **connectivity** between **energy sources** (generators or high-voltage lines) and specific **consumption points** (electrical stations).

Bayesian network used to assess **probability** of disconnection, i.e. **blackout**.

Possible to implement **without sensitive data** of the critical infrastructure.



Electrical grid
Stations (circles), transmission lines (lines)



Part of the Bayesian Network
Failure probabilities increase from green to red

Electrical simulations

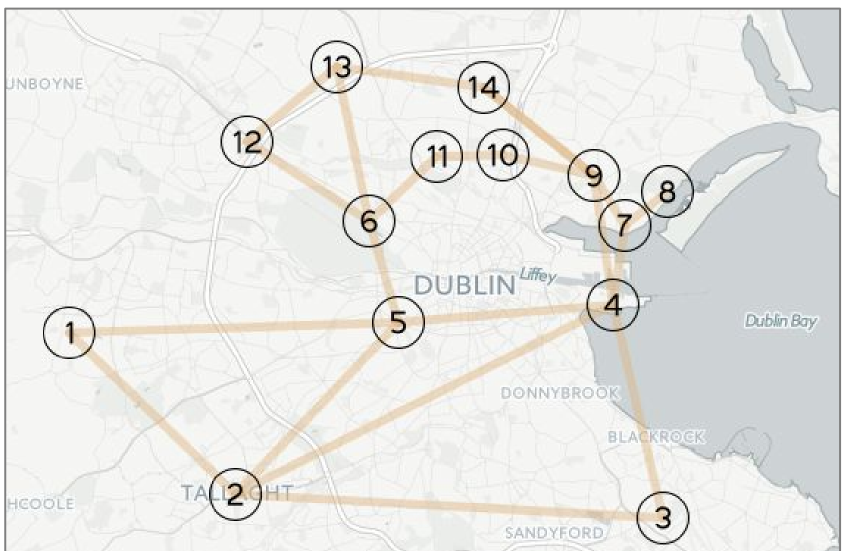
b) Load flow computations

Electrical **load flow** analysis* can be performed when an **electrical model** of the grid is available. More **realistic approach** from an engineering point of view.

Monte Carlo simulations to generate electrical scenarios.

It **requires sensitive data** from energy providers.

*Numerical computation of flow of electric power in a grid.



IEEE 14-bus electrical model
with geographical context

Prob.	Case	Num.Open	1_2_1	1_5_1	2_3_1	2_4_1
0.515	5	1				
0.155	14	2				
0.075	6	2				
0.07	8	2				
0.05	1	0				
0.045	16	3				
0.015	7	2				
0.015	11	1				
0.015	13	2				

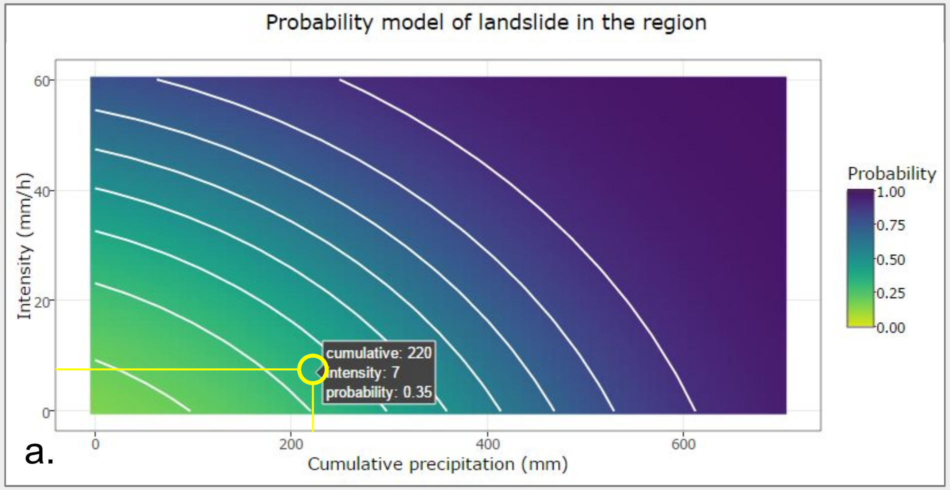
Electrical scenarios generated
Operative (green) or unavailable (red) lines

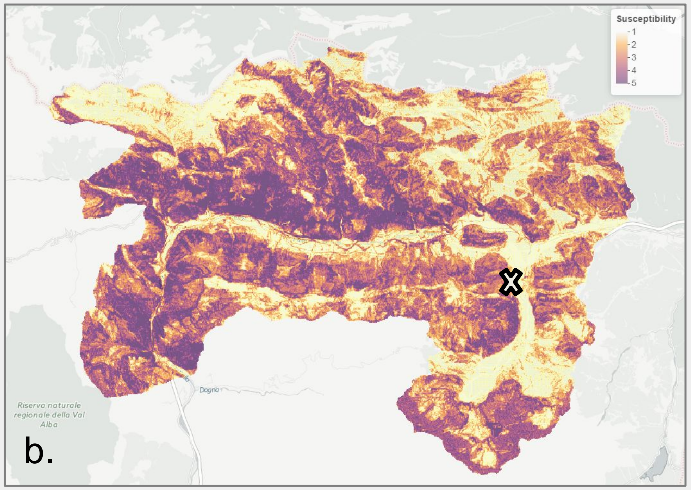
Electrical simulations

In both cases, **failure probabilities** for each **element** of the network are defined per **EWE**

Use case: **heavy precipitation** at Val Canale Alpine region

a. Landslide probability in the region given EWE properties (intensity and cumulative).
b. Susceptibility of landslide at each specific location.





P(landslide in x,y)=P(landslide in x,y | landslide in zone)* P(landslide in zone)

c. Status of the element.

P(pylon falling over | landslide in location x,y)

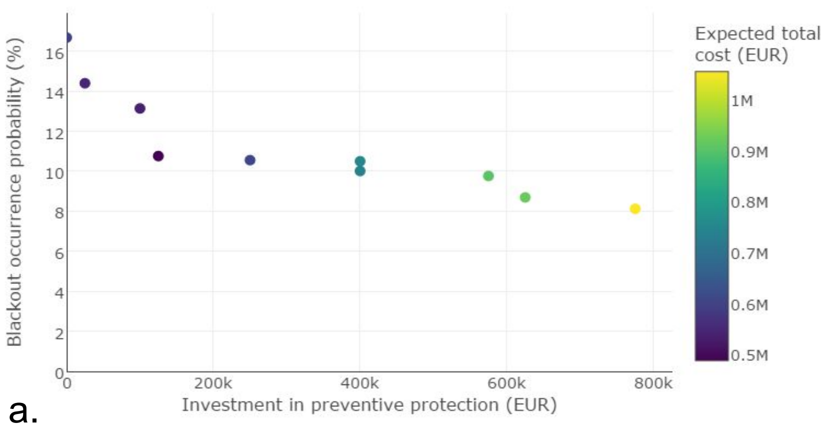
Impact evaluation

- **Economic consequences** of a blackout or lost load and **number of consumers** affected are assessed.
- **What-if scenarios** where **protection or mitigation engineering measures** are applied are considered.
- **Engineering measures** for each **element** of the network are defined per **EWE**.

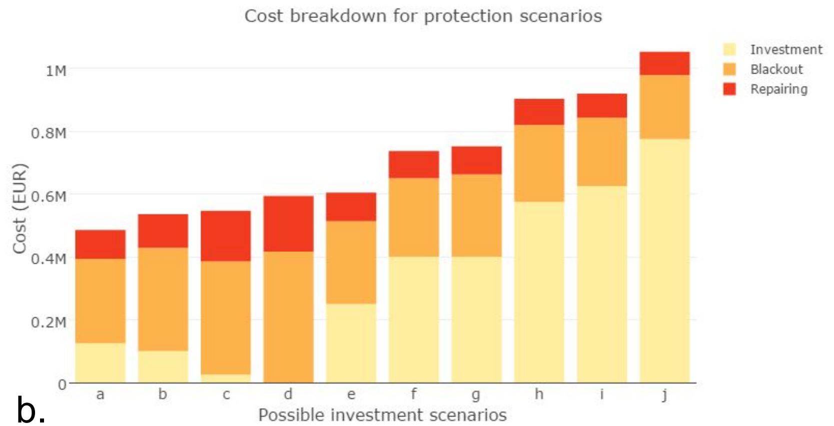
Use case: **heavy precipitation**

a. Probability **occurrence blackout** as function of **investment** in preventive protection.

b. Cost breakdown per protection scenario: **repairing** (direct), **blackout** (indirect), **investment costs**.



a.

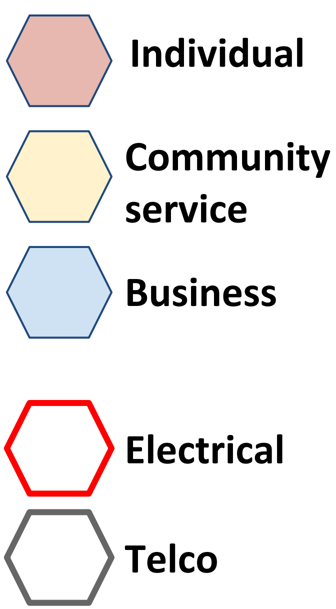


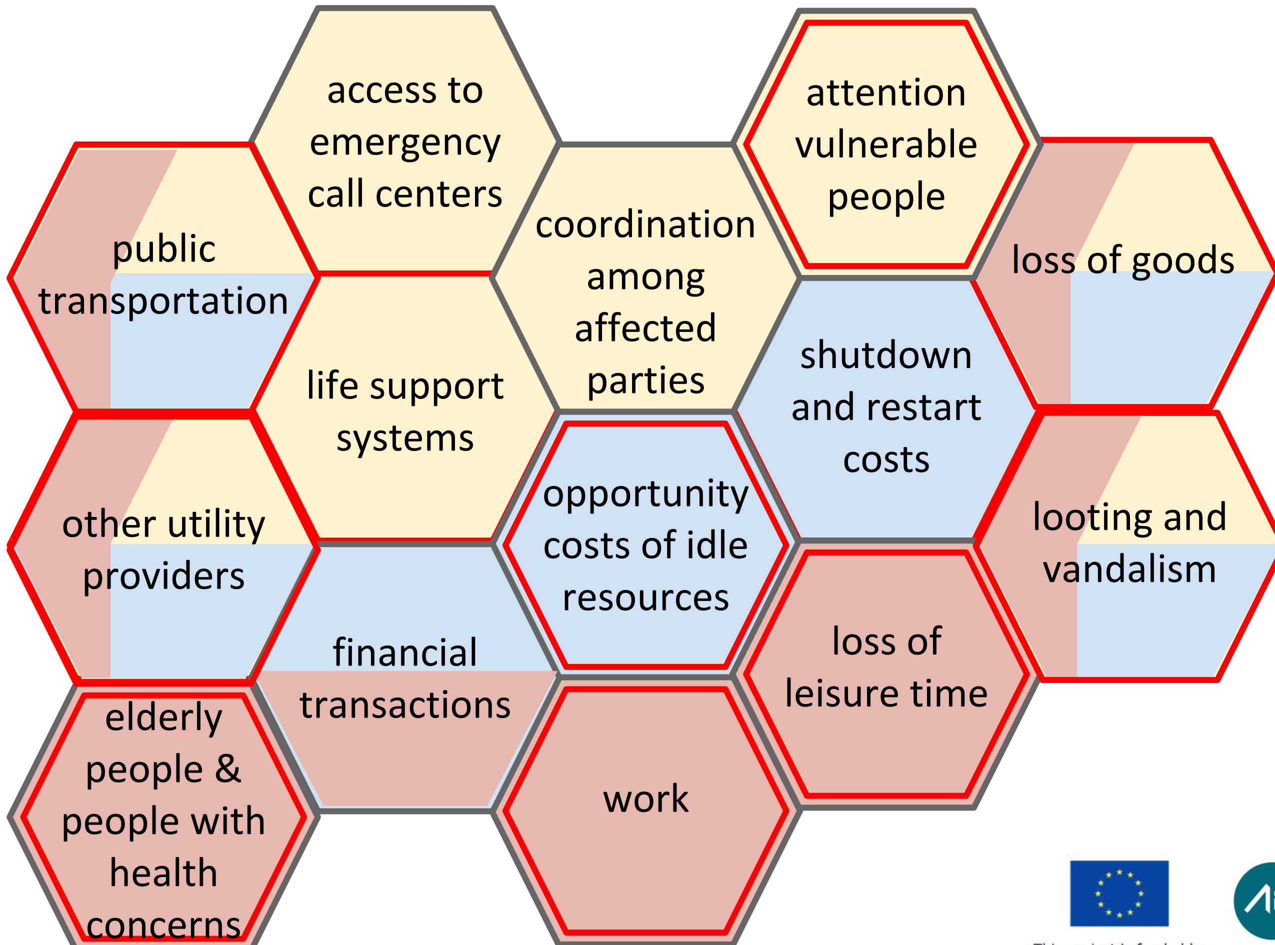
b.

Impact evaluation

The analysis of the impact on **specific activities** per **sector** and infrastructure helps to assess **social costs**.

Qualitative social effects due to electrical or telco failure
Based on Munasinghe & Sanghvi (1998)





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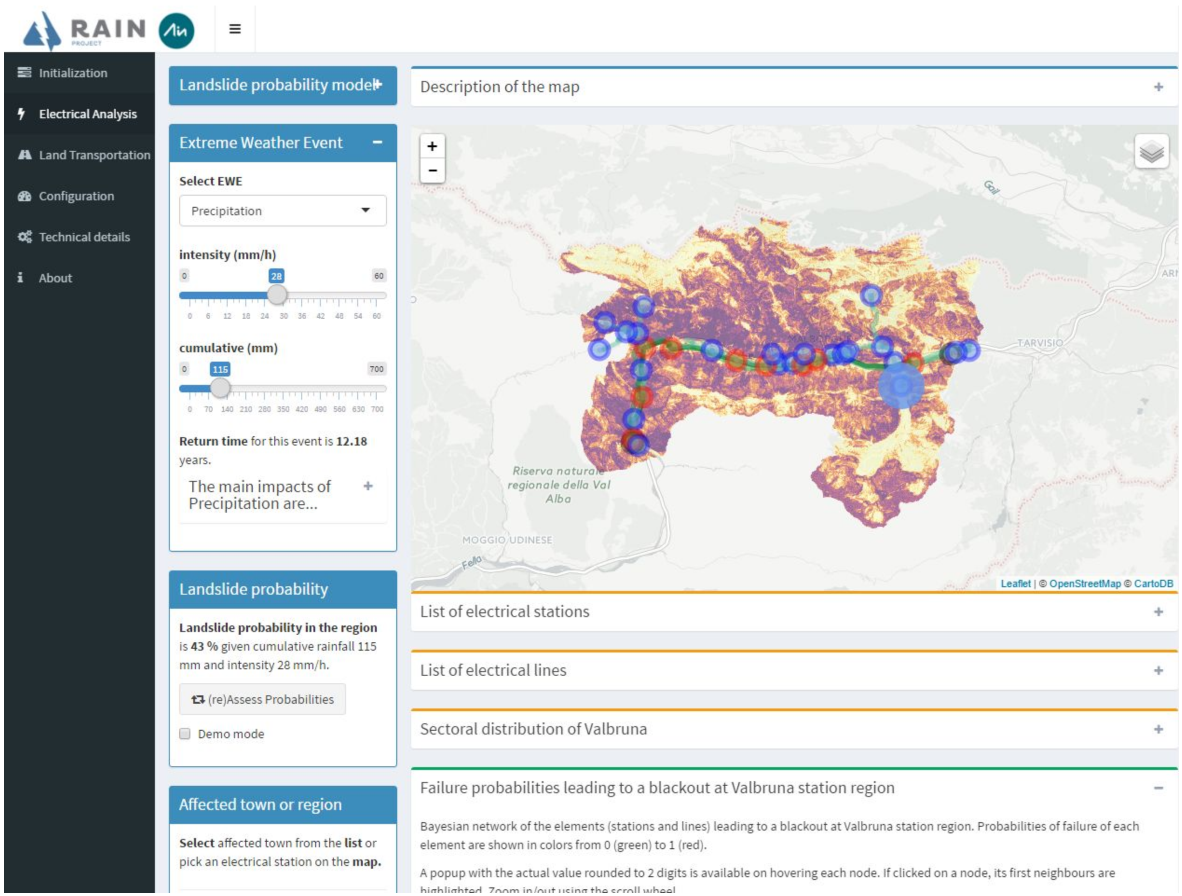
Risk Assessment Tool

A **webtool** has been developed within RAIN project to help owners, stakeholders, policy makers to choose the best protection option.



Snapshot of the main page of the webtool

Demo videos: https://youtu.be/gM6Ugu0Fjo8?list=PLPBI6rsXvRsCxbg-QMYoYsAdIrya92joZ

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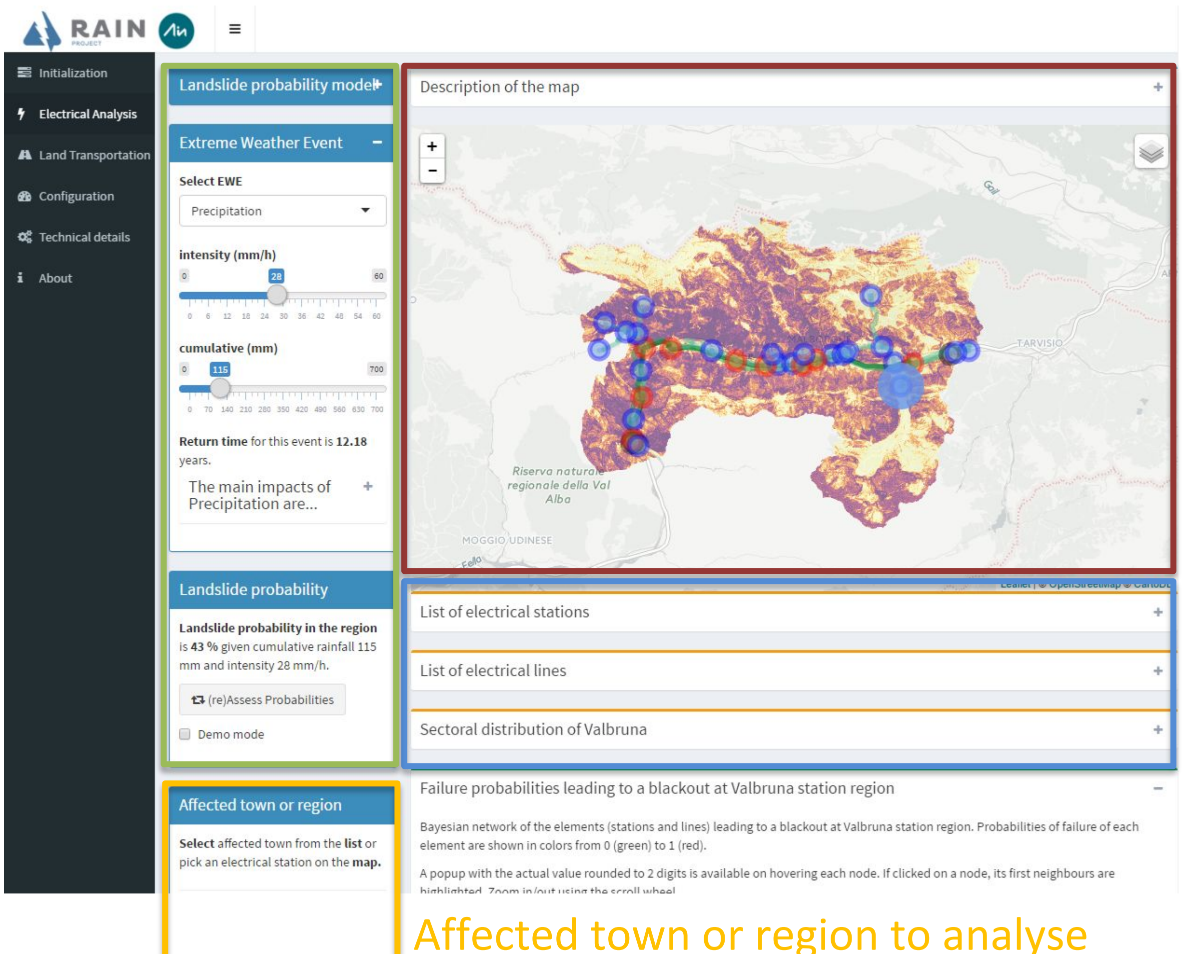
Risk Assessment Tool

Properties of the EWE to analyse
EWE chosen, intensity…
Landslide probability given that specific EWE



Map of the region studied
Electrical grid (lines) and substations (circles) are shown.

Properties of the infrastructure
Lists with information of the various elements

Affected town or region to analyse

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Summary

The **risk assessment tool** presented allows a

reproducible workflow

that integrates **weather threats** and **physical context**

to estimate the **social impact** described by specific markers,

useful for **decision support** (in planning and operation) and

the analysis of **what-if scenarios**.

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RAIN Project

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GRUPO AIA

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