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The evaluation is:

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- The content is not related to general outcomes as dissemination and communication
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Web Based Tool for incident probability forecasting

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1 Executive summary

This document corresponds to the description of deliverable D5.4 *Web Based Tool for incident probability forecasting* which is actually a software module. It is an extension of previous work developed and described in deliverable D5.3. Therefore, this report references to the documents where the design of forecasting is made. It also references to previous deliverables, and the extension proposal of the tool:

- Design of forecasting:
 - Deliverable D4.4 v2 Forecast modules definition, and
 - Milestone MS8 Modelling of Forecasting Modules,
- Previous deliverables:
 - Deliverable D5.3
 - Deliverable D5.5
- Extension proposal:
 - RAIN - Proposal for task extension - Extension of Web Tool functionalities

Incidents, defined for electrical grids, telecommunications and land transport networks, are analysed at two levels:

- *global level* where impact at the regional level or geographical area analysed¹ is assessed, and
- *local level* where the focus is on the impact on each of the components of the electrical grid, telecommunications or land transportation network.

Probability of failure is assigned to each component as function of its properties, the characteristics of the Extreme Weather Event (EWE) considered, and geographical information. This local information is then integrated to obtain the global incident probability and impact.

A module that computes the **incident probabilities of different network components and global incidents** was developed and integrated in the webtool. This first version of the webtool fully complies with the risk decision framework developed within RAIN project and it has been adapted to the data available for its application to the Alpine case study (Val Canale incident).

The tool has been extended and modified up to a level that two differentiated modules on the electrical analysis have been defined: one for the electrical connectivity analysis approach, and a second one for the load flow computation approach², which is more closely related to electrical engineering analysis. Both modules are complementary.

¹ Regional level refers to the region analysed. It can be at the municipality, county, region, national or international levels.

² Approaches described below.

An open, test version of the webtool will be available online³ for potential end-users, stakeholders, policy makers, researchers or anyone interested in critical infrastructure protection against extreme weather events. First demonstration videos are already publicly available on Youtube⁴.

The source code of the webtool is publicly available at the rain-fp7 repository⁵ on the development platform Github.

Finally, one of the main remarks about development and usability of this kind of tools is the importance of the data gathering process: meteorological measurement stations, updated infrastructure component inventory, updated geological information. Therefore, investment in measurement acquisition and on field studies is highly recommended.

³ At the time of this report, the tool is not available publicly. The exact link to it will be available in the RAIN website <http://rain-project.eu/> and within the RAIN LinkedIn group.

⁴ <https://youtu.be/gM6Ugu0Fjo8?list=PLPBl6rsXvRsCxbg-QMYoYsAdlrya92joZ>

⁵ <https://github.com/grupoiaia/rain-fp7>

2 Incident probability forecasting

Incident is considered as the impact of the Extreme Weather Event on the infrastructure. In all cases, incidents are analysed at two levels:

- **Global or macroscopic level:** impact at the regional level is assessed. This analysis includes not only the (direct) repercussions on the elements of the infrastructure (repairing, replacing) but also the indirect effects of the incident.
- **Local or microscopic level:** the focus is on the impact on the elements of the electrical grid, telecommunications or land transportation network. Only direct consequences are assessed.

The definition of incident is slightly different depending on the infrastructure and its indirect consequences may also differ:

- **Electrical incident:** power supply disruption or blackout. Direct consequences considered are the damage on electrical elements of the grid. Indirect repercussions include loss of productivity in the industrial sector, impact on other utility providers (e.g telecommunications or water distribution system), public transportation, or attention to vulnerable people.
- **Telecommunications incident:** disruption on the telecommunications service. Direct consequences: damage on the antennas and base stations. Indirect: impact on the access to emergency call centres, financial transaction problems, for instance.
- **Road incident:** loss of connectivity between two points in the region connected by road. Direct consequences: damage on road elements (bridges, tunnels) or road segments, also blocking of segments (that have to be cleaned). Indirect: isolation of regions, increase of the repairing times of other affected infrastructures (difficulties to reach affected points), increase in evacuating times (in case medical attention is needed, for instance), etc.
- **Railway incident:** loss of connectivity between two points in the region connected by train. Direct consequences: damage on railway elements (bridges, tunnels) or track segments, also blocking of segments (that have to be cleaned). Indirect: in combination to road incidents it may lead to complete region isolation.

Incident probability is assessed as follows:

1. **Principal failure modes** of the **individual elements** of the infrastructure considered (e.g. communication towers, bridges, transmission lines) are obtained per EWE: the main physical features and variables that determine the probability of failure by different channels (or failure modes) and EWE intensities are first identified for each component and meteorological threat. For instance: for heavy precipitation, impact on bridges is through increase in river flow that may cause scour, but impact on the electrical transmission towers is through landslides.
2. **Probabilities of occurrence** of the **trigger event(s)** or **exceedance of threshold of the failure mode** (river flow or landslide in the proposed examples) are assessed.

In some cases, these probabilities are computed at the scale of the region (global). Then, **susceptibility maps** with local information about the impact of this global probability on each specific point (x,y) are also used. For instance: landslide occurrence depends on the geological properties of the ground that can be condensed (as an approximation) in a susceptibility map.

3. Using the **weighting methodology** developed within the project (defined in the *Element failure weighting methodology* subsection below), the **relative importance** of the various factors affecting the **status of each element** (building material, age of the element, maintenance status, etc.) is determined by a Delphi panel composed by a group of experts. In some specific cases, **fragility curves** are available (for instance, damage probability for transmission towers as function of wind speed), that allows the tool has a more precise dependence on the event intensity (see Figure 5).
4. **Failure probabilities of individual elements** are computed as a combination of the information obtained as:
$$P_{\text{elementfailure}} = \text{status.prob} * \text{probability.trigger} (* \text{susc.prob}),$$
where, `status.prob` is the failure probability of the element itself derived from the weighting methodology or fragility curves, `probability.trigger` is the probability of the trigger event obtained at point 2, and optionally the susceptibility (local information tuning of the probability of the trigger) `susc.prob` can be also used.
5. **Incident probability** is computed combining the failure probabilities of each individual element of the infrastructure and the topological and operational information of the infrastructure considered. For example, damage on a bridge of a road may not imply a road incident (considered as loss of connectivity) if an alternative route between the two points considered exists. To assess this probability, different approaches (based on Bayesian networks or Monte Carlo simulations) are followed depending on the infrastructure and the available data (see subsections below).

With the incident probabilities obtained, **consequences** are computed:

1. **Direct costs** can be assessed using the failure probabilities of individual elements and the data on their repairing or replacement costs.
2. **Indirect costs** are assessed considering the incident probability and its consequences.

Examples per infrastructure are provided below.

2.1 Element failure weighting methodology

Dragados has developed for RAIN an Excel sheet as instrument of component vulnerability assessment by experts. In it the different **infrastructure components** (e.g. bridges or electrical pylons) are grouped into clusters that can be later given a **failure probability** when impacted by an **extreme weather event**⁶. This methodology can be used by itself or it can be used as complementary to fragility curves when those exist.

This spreadsheet presents a survey made by:

- A multilevel list compounded by:
 - A Chapters / Fields level,
 - A Questions level, and
 - An Answers level;
- A weighting process;
- A clustering and failure probability determination process; and
- An evaluation process.

A Delphi panel contributes to all the steps of the process:

1. Chapter definition and weighting,
2. Questions definition and weighting,
3. Answers definition and weighting,
4. Failure probability determination, and
5. Evaluation process.

The whole process depends on the type of infrastructure and the weather event analysed. Therefore, it needs to be tailored in each case.

2.1.1 Multilevel list

In order to facilitate the usage of the sheet, it is divided into hierarchic levels.

The first level is the Chapters / Fields one. It corresponds to a list of the general, main topics to consider related to the infrastructure component. (Example: General for a bridge.)

The Questions level is the second one. Each Chapter has its own, specific questions related to the EWE being considered. The questions may change among various EWEs considered for the same infrastructure. (Example: Bridge material within the general Chapter.)

The Answers level is the third and last one. It consists of the possible answers to the Questions of each Chapter. It is adapted to the region and type of infrastructure analysed. (Example: Masonry,

⁶ Described in detail in document "RAIN WP6 - Methodology for provision of inputs for Risk Assessment framework".

concrete, steel, Mix Steel-Concrete as possible Answers within the Building material Question within the structure Chapter.)

2.1.2 Weighting process

Once the Chapters, Questions and Answers are defined, a weight is assigned to each chapter, question and answer.

As described in the document aforementioned, the first level is weighted with values between 1 and 10. A weight of 1 point represents that this particular field does not have importance considering the selected extreme weather event. Therefore, a value of 10 points indicates that this particular field presents a significant importance or relevance considering the selected EWE.

The Questions in the second level also have a range of values between 1 and 10. However, in this case the values are associated with the importance of each Question regarding to a combination of both, structure and event. The higher the value is; the higher importance has that particular element when it is affected by the studied EWE.

Finally, the third level corresponds with the Answers to the Questions. In this case, the way to develop the weighting process is different, due to this, in the following lines are defined the required steps, in order to develop this weighting process.

An example of levels definition and weighting is provided in Figure 1 for the vulnerability of bridges to fluvial flooding. Two Chapters are shown (General and Piers) weighted with an importance of 8.25 and 9.5, respectively. For each chapter, a series of questions are provided (from 1.1 to 1.9 for General, and from 2.1 to 2.7 showed for Piers). Each answer is given a weight (7.25 for question 1.1, or 5 for question 1.9). Then, two answers are shown per each question (in the document up to 7 different answers are considered). Each answers has its value and weight (for question 1.1: answer a) "0 to 10" with a weight of 1, and answer b) "10 to 20" with a weight of 1.375).

To compare the various aspects analysed, i.e. all the answers per question, the questions per chapter and the chapters among them, the answers are standardised so that their weight ranges from 1 to 10.

8.25 1.- General		a)	b)		
1.1	7.25 Active life	0 to 10	1	10 to 20	1.375
1.2	5 Bridge materials	Concrete	1	Masonry	4
1.3	4.75 Time from last inspection	0 to 2	1	2 to 4	2
1.4	9.25 Bridge defects (in piers, buttress, deck, etc.)	Structural defects (low)	1.375	Structural defects (High)	3
1.5	5 Design Lifetime	25	3	50	1.75
1.6	4.5 Bridge typology	Slab	2.5	Beam	2.75
1.7	7.5 Relation between free height of the bridge (H) and the stream depth (Y)	H / Y < 1	3	1 < H / Y < 3	1.5
1.8	4 Bridge length	< 50 m	1	50 m - 100 m	1.75
1.9	5 Aggressive environment	I	1	Iia	2

9.5 2.- Piers		a)	b)		
2.1	7.5 Pier shape	Rounded	1	Not rounded	2.75
2.2	5.75 Pier placement / Straight or bend stream	Centre / Straight	2.25	etween centre and outside bank / Ben	3
2.3	6 Minimum bridge span length inside the stream	< 10 m	3	10 m - 30 m	2
2.4	10 Foundation typology	Shallow	2	Deep	1
2.5	5 Pier material	Concrete	1	Masonry	2.5
2.6	4.25 Number of piers	< 3 piers	1	> 3 piers	1.775
2.7	4.25 Number of piers inside the stream	< 30 %	1	30 % - 60 %	2
2.8	8 Pier and foundation countymeasures (fabric and section)	Yes	1	No	3

8 1.- Structure		a)	
1.1	4 Building Material	Lattice	1
1.2	2 Height/Voltage Level	EHV	1
1.3	8 Foundation	Concrete auger or caisson	1
1.4	6 Type of Tower	Type E Tower (Dead End or Terminal Tower and Angle over 60o)	1
1.5	6 Guyed	Yes	1
1.6	5 Function	Terminal	1
1.7	3 Distance between pylons (span)	up to 200m	1
1.8	3 Clearance distance from earth to line. Compliance with the EN 50431.1 Deviation (%)	Yes	1
1.9	3 Conductors - Type and area/cross section (generalised size)	1 (small)	1
1.10	2 Number of Conductors per phase	One	1
1.11	2 Conductors order	Horizontal	1
1.13	2 Insulation String	Single	4
1.14	4 Number of Circuits per pylon	Single	1

Figure 1. Example of expert’s evaluation (weighting) of relevant variables regarding the vulnerability of bridges to fluvial flooding. See text for details. Bottom: Same approach applied to electrical pylons related to landslide.

2.1.3 Clustering and failure probability determination process

A clustering of the infrastructures which could have the same response facing an EWE is performed. Creating clusters allows to reduce dramatically the number of final infrastructure component scores to which a failure probability will have to be provided.

To clusterize the components, the range of possible scores per infrastructure component has to be obtained, i.e. the maximum and minimum score values have to be assessed.

The score per component results from the sum of the scores obtained per each question:

- Each question has a value that is the product of the weight of the question times the weight of the chapter (e.g. in Figure 1, question 1.1 would have a weight of 8.25 x 7.25 = 59.81).
- The score of the question given an answer is obtained as the product of the question value and the standardised value (1 to 10) of the answer chosen.

Therefore, to get the range of values per question we need to assess its value (59.81) and multiply it by the lowest and highest standardised answer values

The scores from all questions are added up and a minimum and a maximum scoring values are obtained. Any infrastructure analysed will have a score between these two values.

This range of scores is split in as many clusters as the experts consider relevant. In the example shown in Figure 2, six clusters are considered. On the left panel, the clusters are defined: the percentage range of scores considered per cluster number and the corresponding values are shown.

Once the infrastructure components have been clustered, each cluster will have different probabilities of failure related to the EWE intensity.

In order to identify the probabilities of failure, three EWE intensities have been considered (low, medium, high). In the example shown in Figure 2, four possible failures are taken into account: -No Failure, -Operational Failure, -Partial failure, and -Full failure.

Bridge Clustering	%Range		Value Range		
	min	max	min	max	
Best	Cluster 1	0	10	1951.55	3267.05
	Cluster 2	10	30	3267.05	5898.06
	Cluster 3	30	40	5898.06	7213.56
	Cluster 4	40	70	7213.56	11160.06
	Cluster 5	70	90	11160.06	13791.07
Worst	Cluster 6	90	100	13791.07	15106.57

Low Intensity			
No failure	Operational F.	Partial F.	Full F.
0.9	0.05	0.04	0.01
0.79	0.08	0.1	0.03
0.68	0.1	0.15	0.07
0.55	0.15	0.2	0.1
0.4	0.2	0.25	0.15
0.25	0.25	0.3	0.2

Figure 2. Example of clustering of infrastructure components and expert's evaluation of the failure probabilities per cluster and intensity level (low intensity shown in this capture only). See text for details.

2.1.4 Evaluation process

The last step of the process consists in characterising the infrastructure elements present in the region of interest. The panel of experts answers the questions of the sheet. These answers are translated into a score per each element and classified into its corresponding cluster.

An example of the evaluation of a bridge is provided in Figure 3.

1.- General	Option	Value	3.- Buttress		
1.1	a	59.81	3.1	b	62.50
1.2	d	134.06	3.2	b	40.63
1.3	a	39.19	3.3	b	40.63
1.4	a	205.09	3.4	a	66.41
1.5	b	180.47			
1.6	c	53.83	4.- Deck		
1.7	c	61.88	4.1	b	131.15
1.8	a	33.00	4.2	b	28.69
1.9	a	41.25			
2.- Piers			5.- Joints		
2.1	a	71.25	5.1	b	4.69
2.2	c	54.63	6.- River		
2.3	b	313.50	6.1	a	195.41
2.4	b	95.00	6.2	b	609.34
2.5	a	47.50	6.3	b	71.69
2.6	a	40.38	6.4	b	62.44
2.7	a	40.38	6.5	a	60.13
2.8	b	760.00	6.6	a	57.81
			6.7	a	485.63
TOTAL					4148.32
Cluster					Cluster 2

Figure 3. Example of evaluation of a bridge in relation to river flooding. Answers provided by the experts (a, b, c, d...) for each specific element (for instance, for each bridge) are translated into values according the weights. All values are summed to obtain the TOTAL score of the element. From this value, the bridge is classified as Cluster 2 type.

2.2 Electrical Approaches

To assess the failure probabilities of the electrical grid, two different approaches are proposed and used.

As described at the beginning of the section, the main physical features and variables that determine the probability of failure for different channels (or failure modes) and event intensities are first identified for each component and meteorological threat. Figure 4 shows a partial example for windstorm: elements affected by the EWE are highlighted (Turbine and Lines & towers shown in this case), their static and dynamic variables that may modify the response of these elements are detailed, and the failure modes quoted.

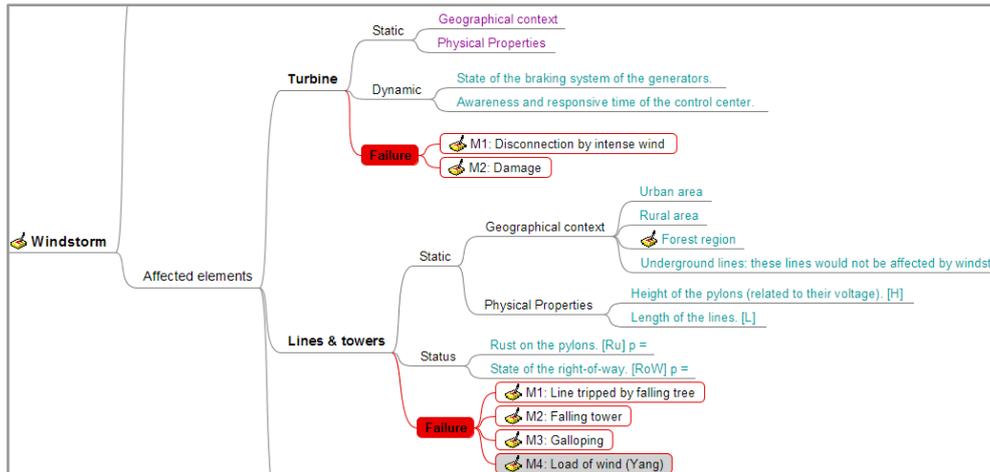


Figure 4. Example of failure modes analysis for electrical components under windstorms. Physical contextual variables are identified (as the type of area surrounding the power lines) and the different failures modes.

Then, using the *weighting methodology* described above, the relative importance of each factor is determined. The tool may have a more precise dependence on the event intensity when fragility curves are available of the infrastructure related to the EWE studied are available. An example is shown in Figure 5 for the damage probability for transmission towers as function of wind speed.

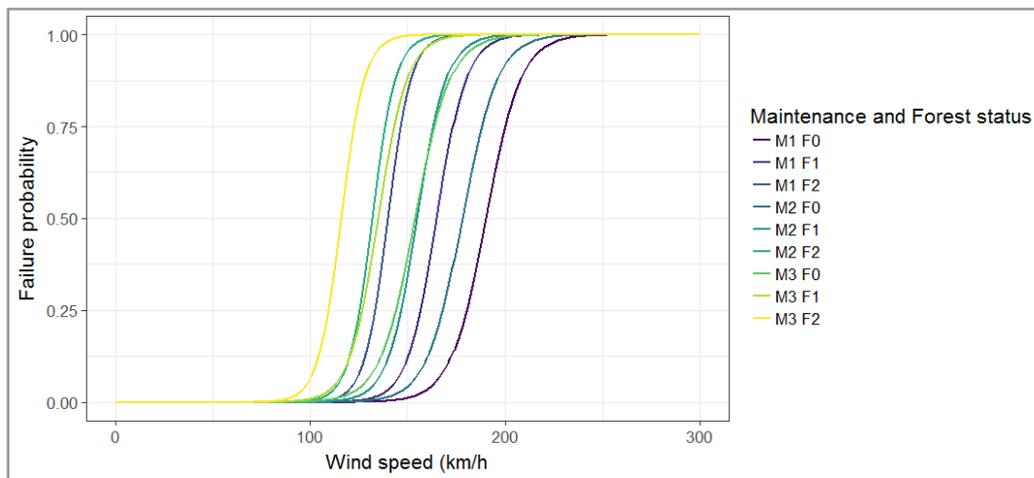


Figure 5. Fragility curves of line segments as function of the maintenance and forest status used in the Finnish case study. Three maintenance status are considered: good (1), regular (2), bad (3). For forest, only two status are considered: good (1) and bad (2), and also no forest (0).

Once the basic elements have been identified and their properties have been defined, depending on the available and accessible data on the electrical grid one of the two approaches described in the following are used: the connectivity analysis or the load flow computations.

2.2.1 Connectivity analysis

In this approach, electrical connectivity between energy sources (generators or high-voltage lines) and specific consumption points (electrical stations) is studied.

The analysis consists on checking whether the electrical path(s) from the energy source(s) available in the region to the consumption point(s) of interest have been affected by the EWE and its impact or not. If all the paths have been affected at some point, the energy supply at the consumption point(s) is disrupted.

To assess the probability of disconnection of a consumption point, i.e. a blackout in the region it feeds, the connectivity information is mapped to a Bayesian Network (BN) to compute the electrical failure or blackout probability. In this BN:

- Physical components (line segments, stations) are represented by graph nodes,
- Topological information is represented as
 - Joint probability nodes that correspond to grouping various other nodes with AND or OR logical operators, and
 - Links among nodes (directed edges).

The failure probabilities of the basic elements are obtained from the weighting tables or fragility curves and the properties of the EWE.

It has to be taken into account that some elements in an electric grid are redundant (like parallel line segments) and therefore all of them have to fail to get a failure of that element. In other cases the elements are arranged in series (like towers in a line segment), there if one of the elements fails, all the segment fails.

Left panel of Figure 6 shows an example of the electrical model used in this approach: two transmission lines crossing a valley (darker green lines) and the distribution lines (lighter green lines) together with the series of stations these lines are connected to. A particular consumption point and the two energy sources of the region are highlighted. Right panel of the figure shows the corresponding BN for this scenario: top node represents the probability of failure of the consumption point, right below the failure probability of the OR joint node for the paths feeding the station and the failure probability of the stations at the consumption point itself, and as we go at lower and lower nodes we look at elements closer and closer to the energy sources⁷.

⁷ See the Example section for a detailed description of the structure of these Bayesian networks.

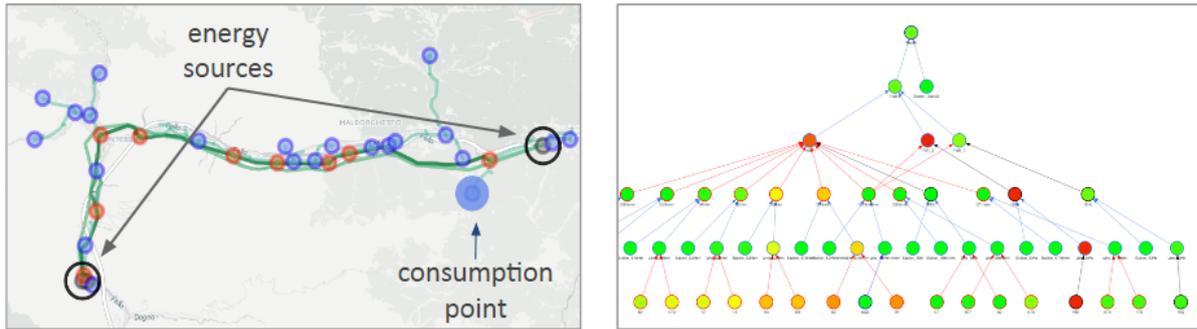


Figure 6. Left: electrical grid model used in the connectivity approach. Stations (circles) and transmission lines (lines) are shown as well as the consumption point of the region of interest. Right: Bayesian network used in the connectivity approach to assess the probability of blackout in an electrical station given the failure probabilities of each element considering a specific EWE. Failure probability increases from green to red.

This approach can be implemented with information of the topology of the electrical grid and its distribution in electrical stations, but without having more information than the voltage levels of the lines. This analysis does not allow an actual contingency study at the electrical level (the specific electrical model of the grid would be needed) and therefore electrical effects due to the action of electrical protections triggered by the first consequences of the EWE on the grid cannot be accounted for. On the other side, the analysis can be performed without having access to sensitive data of the critical infrastructure.

2.2.2 Load flow computations

In this case, an electrical load flow analysis is performed, i.e. a numerical computation of flow of electric power in a grid. This analysis was developed in T4.5 and its implementation in T5.4, then, a description is already available in deliverables D4.4 v2 and D5.3.

This approach is based on performing a load flow analysis on a number of electrical scenarios generated from Monte Carlo simulations considering the failure probabilities of the various elements of the grid. It is a more realistic approach from an engineering point of view, as it allows, for instance, the implementation of electrical protections. It also allows quantifying the real impact in terms of lost load (energy not supplied to the customers) and estimating the duration of the effects using empirical approach described also in D4.4.

Load flow computation analysis, however, requires sensitive data from energy providers. Since the access to these data was not possible for the case analyses in RAIN project, simplified model cases have been analysed to show capabilities of this approach (see Figure 7 where the standard IEEE 14-bus electrical model is used over a city map to demonstrate the functionalities of the tool)

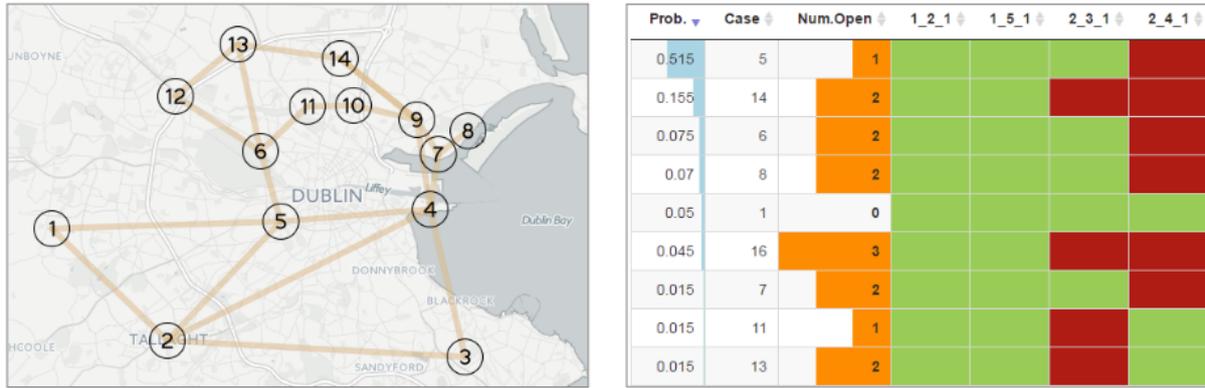


Figure 7. Left: IEEE 14-bus electrical model with geographical context used in the Load flow computation approach. Right: Monte Carlo generated electrical scenarios. Each scenarios includes a number of operative (green) and unavailable (red) lines.

2.3 Land Transportation Approaches

The inclusion of land transportation analysis in the webtool was not foreseen in the DOW. As consequence of the task extension proposal approved⁸, this part has been also included in the webtool.

The approaches followed for the road and railway studies are based on the connectivity analysis presented for the electrical grid and on the work of the transportation experts in the RAIN project (specially in the definition of critical elements, failure probabilities, etc.). These approaches are detailed in the following subsections.

2.3.1 Road transportation

Road connectivity in this approach is defined as the possibility to go from a specific point (A) in the region of interest to another point (B) using any of the main roads (motorways/autoroute, A-road/national routes). Non-primary roads could be also considered.

The analysis consists on checking whether the path(s) from A to B have been affected by the EWE and its impact or not. If all the paths have been affected at some point, the communication by road is interrupted.

To assess the probability of disconnection, the road geographical information (intersection(s), critical elements, etc.) is mapped to a Bayesian Network (BN). This BN is defined by:

- Physical components (road segments potentially affected by the EWE, vulnerable elements like bridges) are represented by graph nodes,

⁸ Document: RAIN - Proposal for task extension - Extension of Web Tool functionalities.

- Topological information is represented as
 - Joint probability nodes that correspond to grouping various other nodes with AND or OR logical operators, and
 - Links among nodes (directed edges).

Like in the electrical approach, failure probabilities of the basic physical elements are obtained from the weighting tables or fragility curves and the properties of the EWE.

Some road segments may be redundant like road segments between two intersections of main roads. In these cases, all road segments between these two intersections must fail to *break* road connectivity. If only one road connects two intersections, if a segment or element of the road fails, connectivity is lost.

2.3.2 Railway transportation

Railway connectivity is defined as the road connectivity described before: possibility to go from point A to point B.

Railway disconnection may have two origins:

- Physical failure of the track,
- Failure of the electrical supply.

For the physical failure of the track, the same approach as for the road transportation is followed. Power supply is analysed in terms of electricity connectivity between energy sources and the train stations (or the electrical feeding points of the train track).

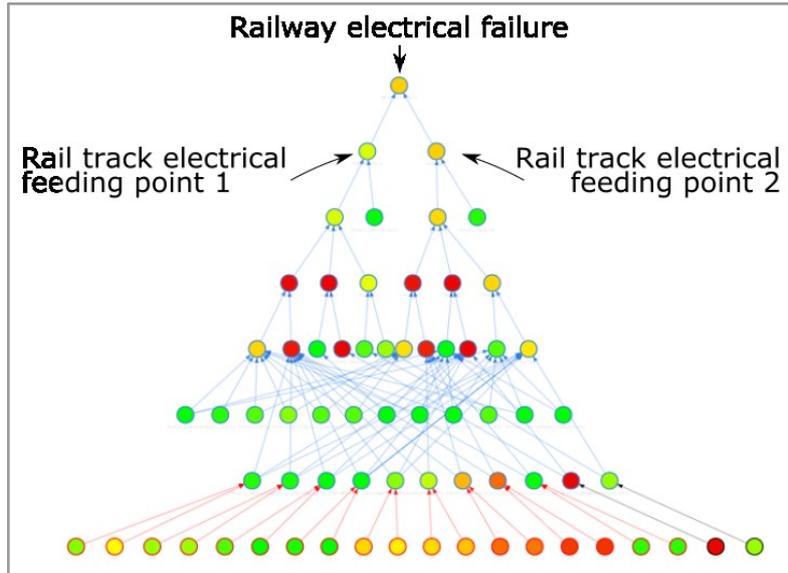


Figure 8. Example of the Bayesian network for railway failure due to electricity supply disruption. Two electrical feeding points are identified and considered in this case.

3 Webtool implementation

The incident probability forecasting modules for electrical analysis and land transportation have been integrated to the webtool. Their visualization within the tool, the reporting of the results and the data requirements for implementation of the tool for a specific case are described in this section.

Screenshots of the main page of the webtool are shown in Figure 9: top panel displays the connectivity approach module for the electrical analysis, bottom panel shows the load flow computation approach. In both cases shown and for all the modules of the app (including also the land transportation module), the app is responsive (perfectly functional when used on mobile devices), as demonstrated in the inset.

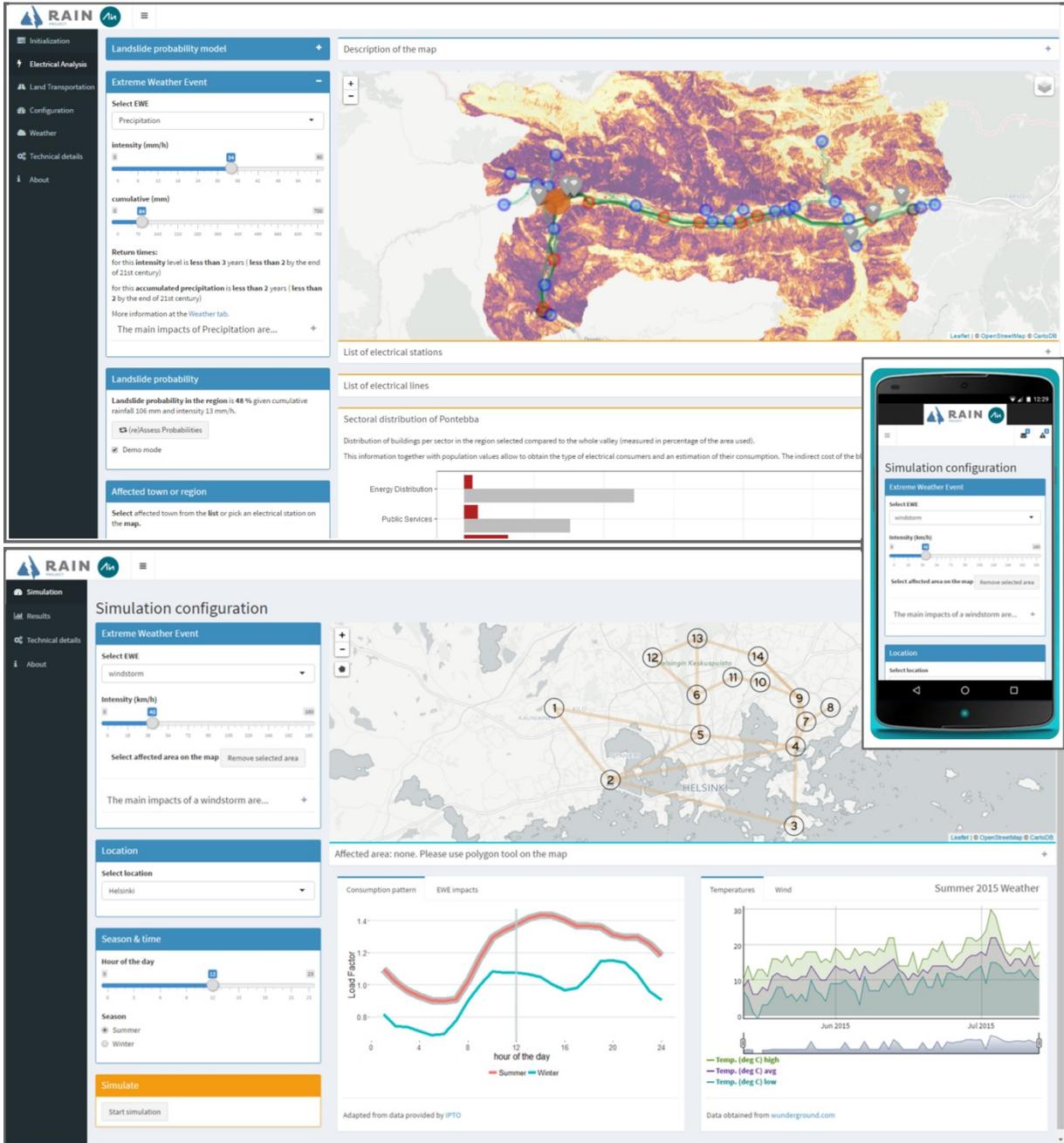


Figure 9. Screenshots of the main page of the webtool for the Connectivity approach applied to the Alpine case study (top) and the Load flow computation approach applied to the Finnish case study (bottom). Inset shows the responsiveness of the webtool: it works well on mobile devices.

3.1 Results reporting

Depending on the module used to analyse each case, the reporting of the results slightly differs:

- The results for **land transportation** and the **electrical connectivity** approaches are displayed as shown in Figure 10. The Bayesian network with the failure probabilities per component is shown as well as the risk profile corresponding to posterior failure probabilities for the riskiest elements analysed (left panels of the figure). On the right panel, the consequences (economical and societal) are displayed as function of the promising preventive investment scenarios to be considered.



Figure 10. example of the consequences assessment in the Connectivity approach webtool. Left panel shows the Bayesian network automatically generated to assess the probability of a blackout in a region and the risk profile (the posterior failure probabilities of the critical elements given a blackout in the region). Right panel shows the economical and societal consequences.

- The results for the electrical **Load flow computation** approach can be more detailed: the actual amount of lost load (power not supplied to customers), electrical impacts (over/under voltages, overloads...) can be considered as well as the impact of the action of electrical protections. An example of parts of the reports that can be obtained is shown in Figure 11. Recovery times can be better estimated also (see Figure 12).

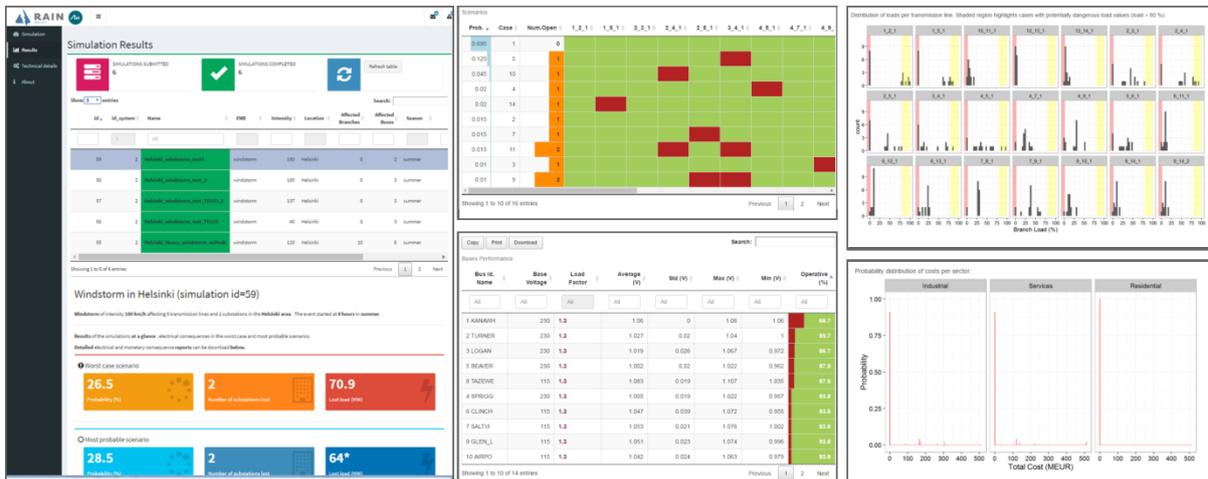


Figure 11. Examples of the simulation results and analysis in the Load flow computation approach. Given the nature of the approach, it allows to assess the actual amounts of lost load, electrical impact per element of the grid, customers affected, its economical consequences, etc. Left panel shows the summary of the results for the various EWEs analysed. Central panel shows the electrical cases generated through Monte Carlo simulations and its consequences on the electrical substations. Right top panel shows the electrical consequences on the lines of the grid and on the bottom the probability distribution of costs per sector is shown.

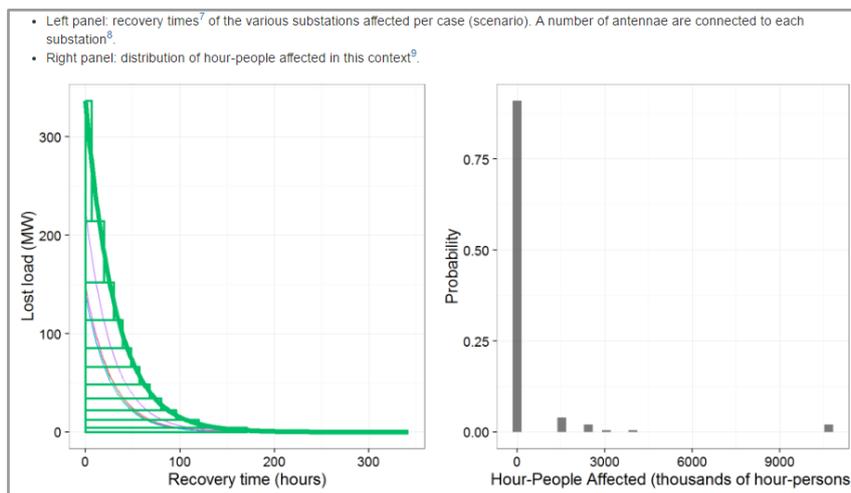


Figure 12. Example of the assessment of the impact on the telecommunications network. The main failure mode is related to lost of energy supply and recovery time of such connectivity.

3.2 Data requirements

To implement the webtool to other case studies, a series of data is required:

- Geographical information:
 - Extreme weather events to consider.
 - Susceptibility map in relation to that specific weather threat.

- Infrastructure information:
 - Electrical and land transportation elements to be considered and their properties (e.g. for electrical transmission towers, their foundations, their maintenance status).
 - Failure modes in relation to the weather threat considered (e.g. towers under heavy precipitation may fail due to landslide).
 - Geographical information of the electrical and land transportation elements (e.g. coordinates of the electrical towers).
 - Relationship among elements (e.g. which towers belong to a specific electrical line, which electrical stations are lines connected to, electrical lines feeding train stations).
 - Reparation and replacement costs of the elements (e.g. high voltage pylon reparation 12.000 €/pylon, replacement 40.000 €/pylon).
 - Possible preventive or mitigation measures: elements affected, cost of the measure, expected improvement (e.g. install bored piles peripheral to the foundation of the pylon improves by 25 % and costs 12.000 €).

- Societal context information:
 - Population distribution (geographically).
 - Sectoral distribution of customers (for each geographical area, or more specifically, for each area fed by a distribution substation).

4 Example: Italian Alps - Val Canale

The Italian case study of heavy precipitation at Val Canale in 2003 is used as a working example of the webtool.

4.1 Electrical analysis

In this case, the electrical model of the region is not available. Therefore, the connectivity analysis approach is used. Once the various electrical elements have been identified, the BN is generated for the consumption points of interest.

Here, we focus on three electrical stations that feed most of the population of the valley: Pontebba, Valbruna, and Camporosso. See table below for the population data (obtained from OSM⁹):

People max	People min	Town
1215	1043.38	Pontebba
763	297.45	Valbruna
4253	3270.56	Camporosso

Failure probabilities for each element of the network are defined per EWE joining the information obtained from the Delphi panels, the properties of the EWE studied, and the most probable failure modes per element. For example, in the case of heavy precipitation in a mountainous region, the most probable failure mode for electrical towers is landslide affecting them. The different probabilities are joined in a Bayesian approach to finally obtain the damage probabilities.

Figure 13 shows the schema of how the BN are built:

⁹ Openstreetmap.

1. Electrical failure (blackout) in a region occurs when **all** the consumption points feeding the region fail (or **a number of them** to consider partial blackouts).
2. A number consumption points (electrical stations) are considered.
3. An electrical failure at these points may arise from a failure of the electrical station at the consumption point itself **or** due to a problem in energizing the station through the electrical paths available.
4. A number of paths to energize the station are possible, and they **all** need to fail¹⁰ in order to cut the power supply to the consumption point (i.e. for the *Paths* node to fail).
5. Each path is split into stations and lines that compose it. A failure happens when either stations **or** lines fail.
6. All electrical stations involved in a path are grouped and **any** of them has to fail to get a failure of the system.
7. All electrical lines involved in a path are grouped and **any** of them has to fail to get a failure of the system.
8. Each line is composed by a number of independent segments that **all** of them need to fail, in order to cause damage.
9. Each segment is composed by towers (not shown in Figure 13) and **any** of them has to fail to get a failure of that line.

¹⁰ We assume that the rest of the power grid is robust and stable enough to allow this. Proving this would require detailed electrical simulations at national level, including power exchange with neighbouring countries.

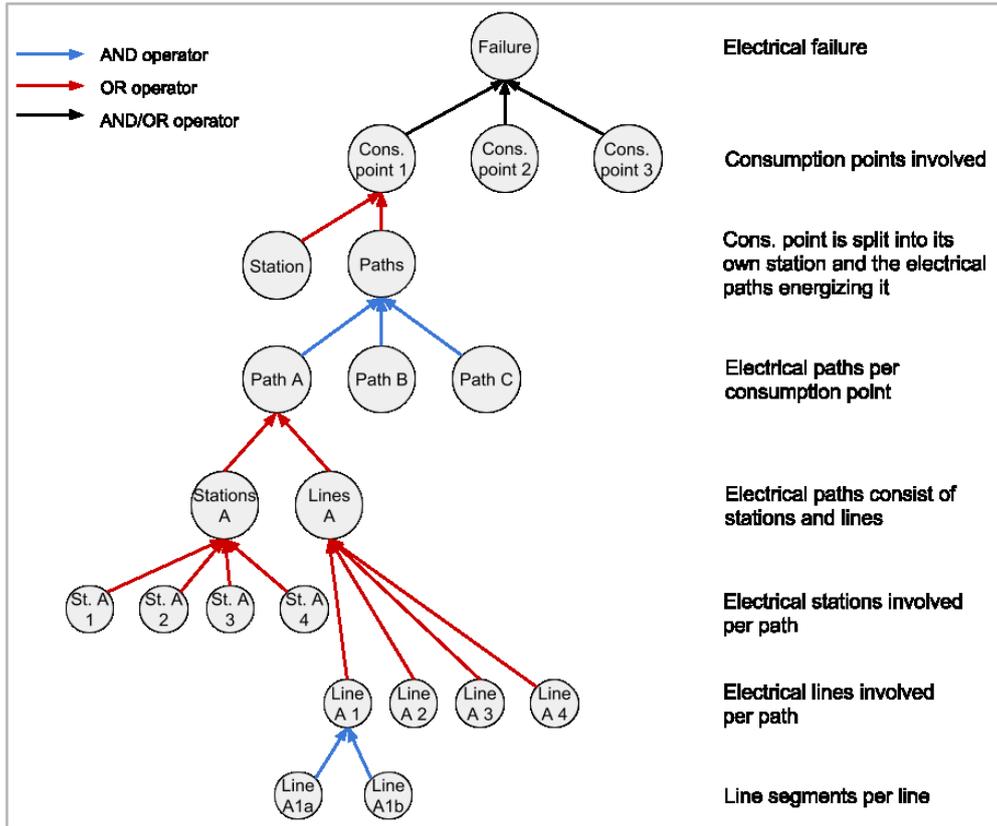


Figure 13. Schema of how the Bayesian Network used to assess the probability of a blackout at a number of consumption points (electrical stations) is generated. Description and details used in WP6 for the Alpine and Finnish case studies.

The critical components identified can be analysed individually (see Figure 14). Their properties or maintenance status can be analysed, or modified for what-if scenario studies.

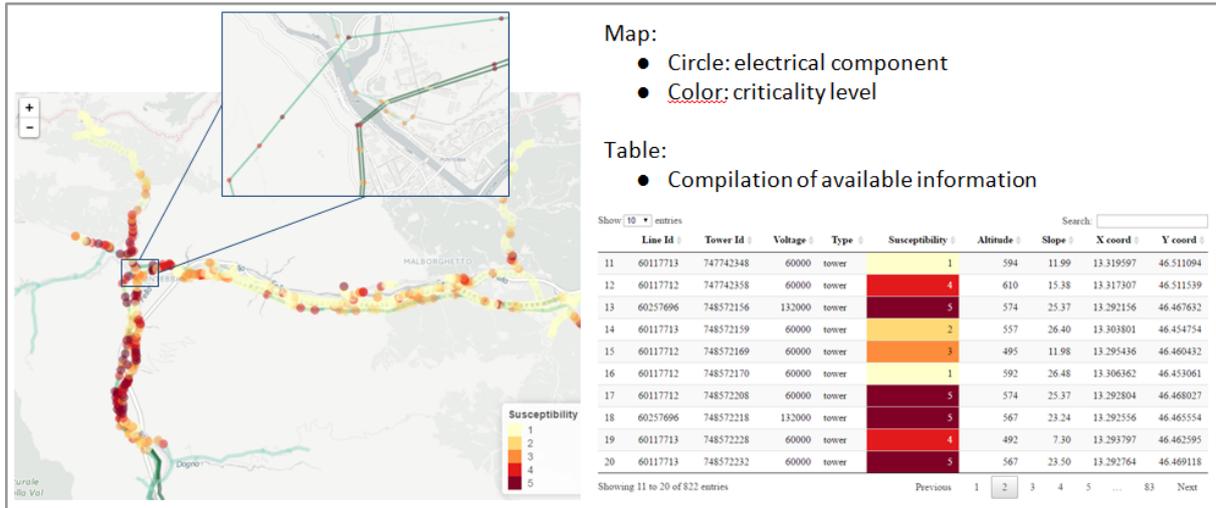


Figure 14. Identification of critical components given a specific EWE. Each element is shown on the map (left), listed in the table (right) and their properties are shown for analysis.

The social structure is obtained from OSM (see Figure 15). For each region fed by an electrical station, buildings are classified as function of their type into:

- Residential,
- Services,
- Industry,
- Public services,
- Energy distribution elements,
- Others.

Population is obtained from residential buildings occupation estimation also available in OSM.

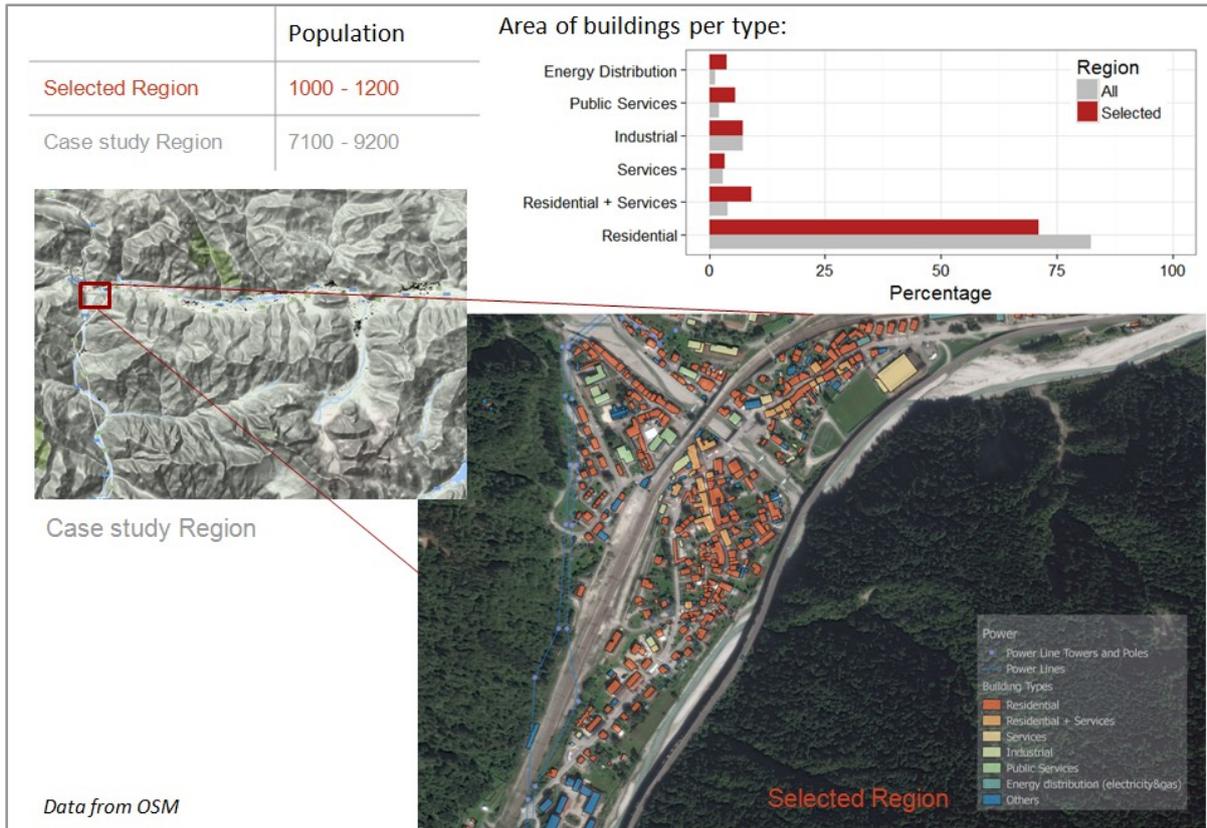


Figure 15. Identification of social structure in Pontebba region (Alpine case study). Data from Openstreetmap (OSM) allows to identify the type of building in the region of interest and extract the population. This information is used to assess monetary and social impacts.

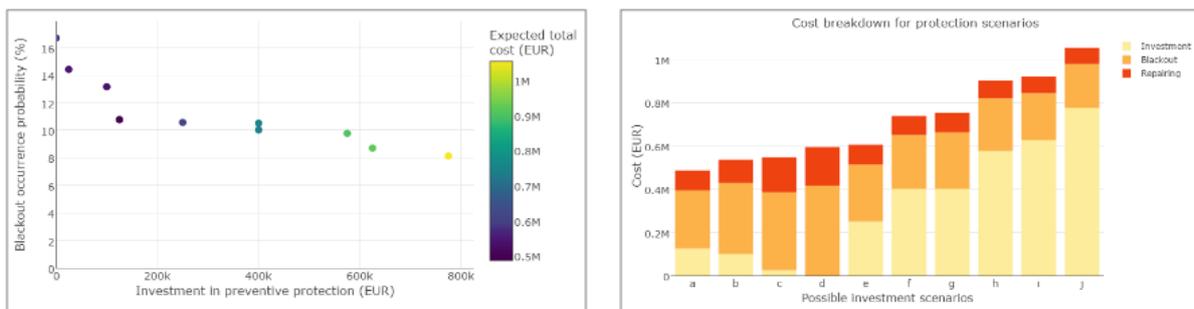


Figure 16. Left: blackout probabilities as function of investment in preventive protection measures. Colorscale shows the expected total cost (considering the new-Bernoullian utility function). Right: cost breakdown (investment, direct, and repairing costs) for the 10 best investment scenarios.

4.2 Land transportation

The two main roads and the railway crossing the valley are considered:

- Via nazionale SS13, and
- Autostrata A23,
- Railway.

Failure of the **road infrastructure** is considered to depend on the damage on bridges and on road segments (Figure 17):

- Bridges. Two failure modes are taken into account:
 - Basic failure probability: its intrinsic failure probability.
 - Scour failure probability: related to the specific EWE considered (heavy precipitation) that causes an increase in the flow rates in the river that may eventually cause scour of the bridge. This analysis has been provided by RODis.
- Road segments. These elements may be damaged by landslides, in particular, landslides blocking the road. This analysis has been provided also by RODis.

Regarding the **railway failure**, two failure modes are considered:

- Bridge failure. The same modes as for road infrastructure are taken into account:
 - Basic failure probability.
 - Scour failure probability (analysis provided by RODis).
- Electricity supply. Trains may stop working in case of energy supply disruption if they are electrical and no back-up diesel machines are available. In such case, a connectivity electrical analysis (as described before) is performed considering as consumption points the electrical stations from which the train track is fed (shown in Figure 18).

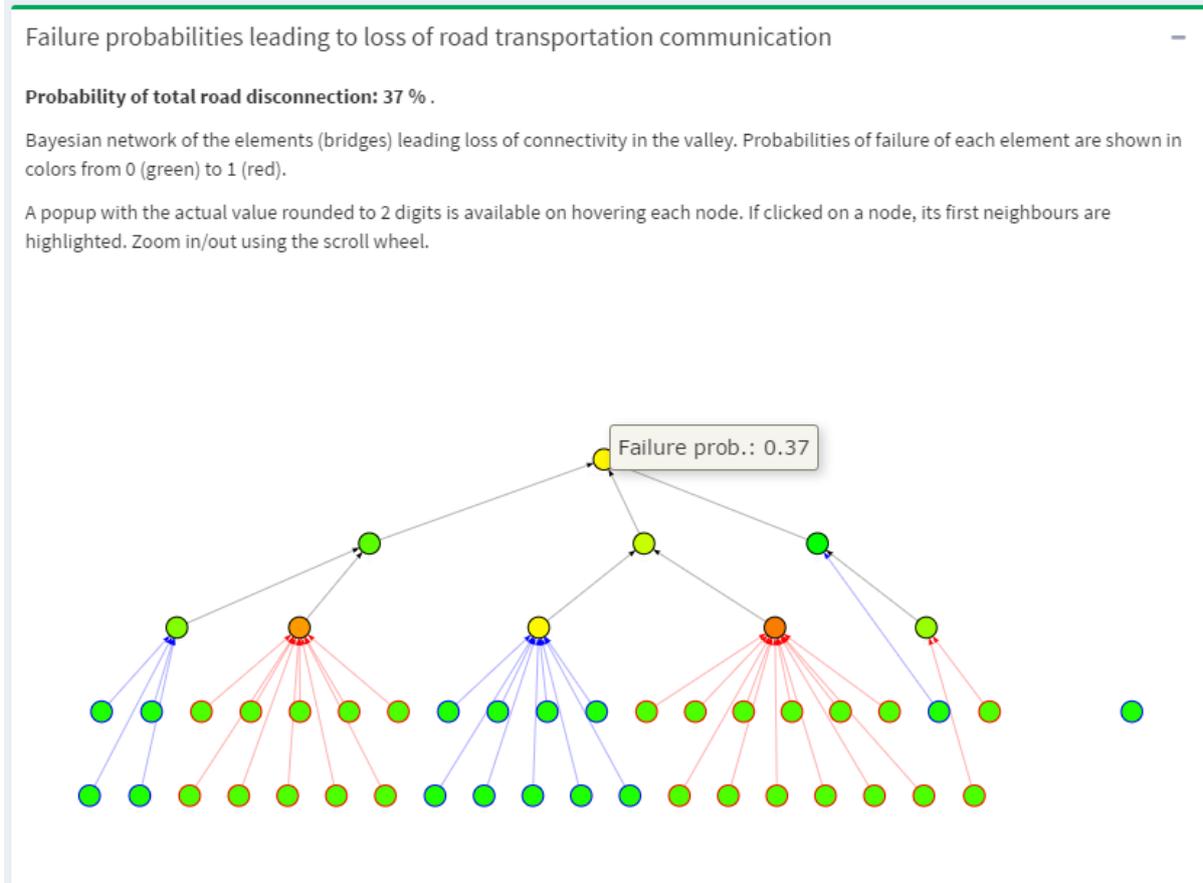


Figure 17. : Bayesian network to assess road connectivity disruption due to an EWE (top node). The infrastructure elements (bridges, road segments) are displayed in the two bottom rows. The AND and OR joints probabilities are represented as nodes with several edge inwards.

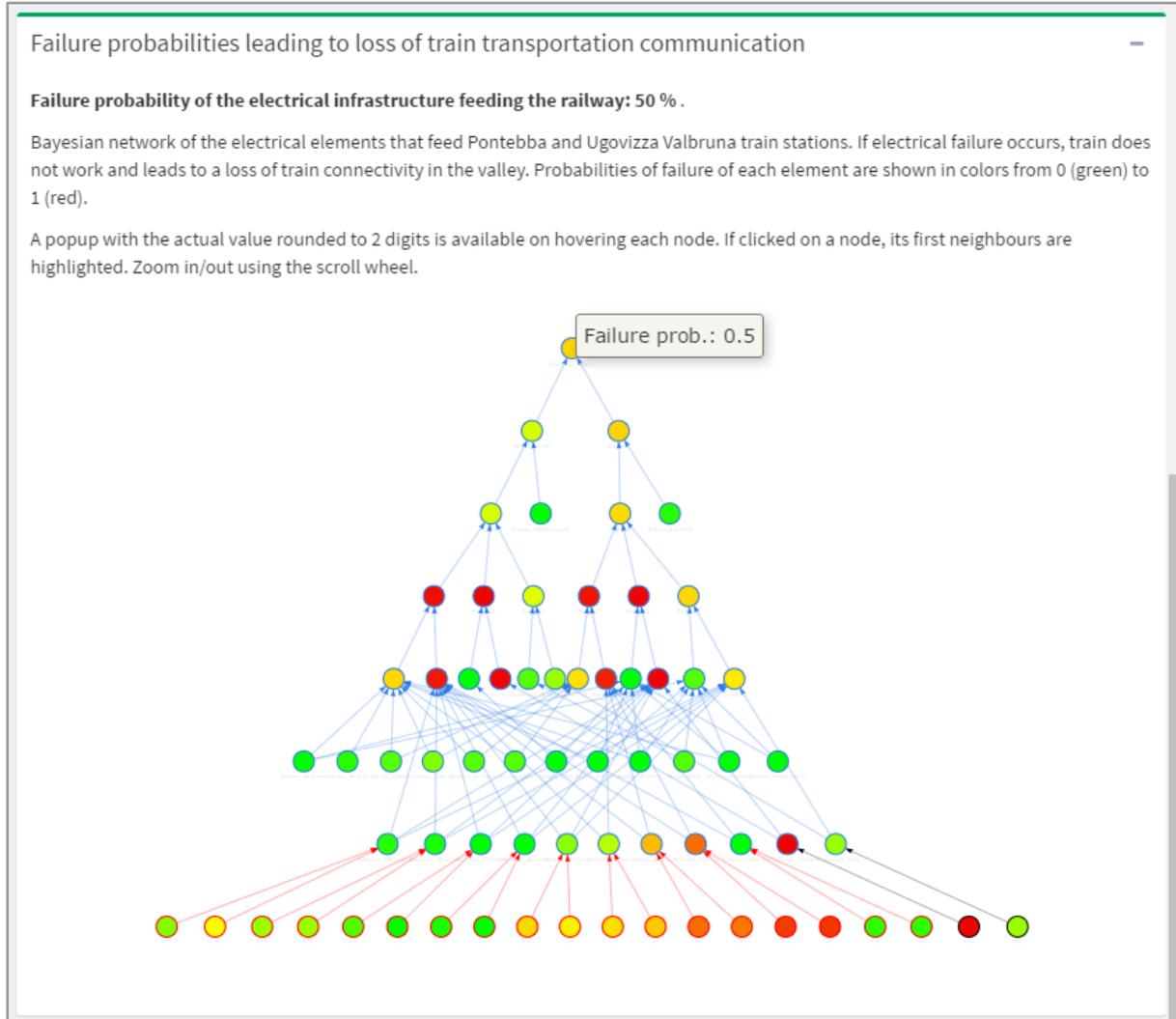


Figure 18. Bayesian network to assess the probability of disruption of electricity supply to the rail track (top node). Two feeding stations (nodes in the second row of the image) are considered.

5 Conclusions

The module described in this deliverable (incident probability forecasting) completes the web tool for risk assessment and decision support under the extreme weather events. The tool integrates expert knowledge and engineering models for component vulnerability assessment (Delphi panel results and fragility curves).

The final tool is ready to be used, but it requires some input data for its application in use cases. The gathering of information is the main obstacle to a precise study. In the case of lack of information, assumptions or guesses are used, but those undermine the quality of the results obtained. The required data for a proper analysis are described in this document.

The tool is successfully applied to the project use cases, but is constrained by data quality. For instance:

- Meteorological data can be not precise enough (due to geographical resolution) to describe highly located extreme events (like heavy precipitation in Val Canale case), making it impossible to identify, track or forecast these events.
- Susceptibility maps. The geological composition of the terrain changes with time and specially after each landslide. Updated maps would increase the quality of the results.
- Access to Electrical & telecommunication inventory data is restricted to infrastructure owner. In this study only the location is available (to public data sources). Expert knowledge was used to make the best guesses about the properties/characteristics of the elements, but relevant data (as elements age and status) cannot be evaluated.
- Similarly, Costs of replacement/repairing are better known by the infrastructure owner. The relative costs are fundamental for leading to one or other solution in the computation of “best action(s) for protection investment”. In the study carried on, values provided from the infrastructure partner were used, but they can severely change from one country to another, or even among regions.

Therefore, one of the main remarks to take into account to work in vulnerable areas is the need to gather information: meteorological measurement stations, updated infrastructure component inventory, updated geological information. Investment in measurement acquisition and on field studies is highly recommended.

As a final remark, even when the methodology and tool developed are useful and had a very good reception (by possible end users as infrastructure managers or policy makers) in the conferences and dissemination events, a final complete validation with a real use case scenario in which infrastructure owners as well as local agents are involved to provide data, support, and specific knowledge about the local context, could take advantage of and show all the potential of the tool.