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VULNERABLE ELEMENTS AND RISK ASSESSMENT

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D2.1 Review of transboundary areas

WP No.	WP02 – Extension of the intervention area		
Status (Final- F; Draft - D)	F	Dissemination level (Public; Restricted; Confidential)	Restricted

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Keywords	European region, transboundary, extreme weather events, wildfires, industries, nuclear power plants, vulnerability
Brief description	The primary goal of this deliverable is to identify transnational areas where the VERA project can be applied, extending beyond the pilot cases (e.g., Portugal-Spain and Spain-France). This entails conducting a comprehensive analysis of hazards in European cross-border regions, considering georeferenced data on extreme weather events, the location of industrial infrastructure, nuclear power plants, and wildfires, as well as the vulnerability of the European population.

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Index

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Acronyms

CLC	Corine Land Cover
DII	Drought Impact Index
ECHO	European Civil Protection and Humanitarian Aid Operations
EDO	European Drought Observatory
EEA	European Environment Agency
EFFIS	European Forest Fire Information System
ESSL	European Severe Storms Laboratory
ESW	European Severe Weather
ESWD	European Severe Weather Database
EWE	Extreme Weather Event
EWEI	Extreme Weather Events Index
GIS	Geographic Information System
HH	Heavy Hail
HI	Normalized Hazard Index
HR	Heavy Rain
HS	Heavy Snowfall/Snowstorm
HWI	Heat Wave Index
IA	Industrial Area
MODIS	Moderate Resolution Imaging Spectroradiometer
NPP	Nuclear Power Plant
NUTS	Nomenclature of Territorial Units for Statistics
PFP	Potential Flood Prone
PVI	People Vulnerability Index
SPI	Standard Precipitation Index
SW	Severe Wind gusts
TA	Thermal Anomaly
TO	Tornado
UCPM	Union Civil Protection Mechanism
VIIRS	Visible Infrared Imaging Radiometer Suite
VERA	Vulnerable Elements and Risk Assessment
VESPRA	Vulnerable Elements in Spain and Portugal and Risk Assessment
WP	Work Package

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1. Introduction

Natural disasters, such as floods and wildfires, often have transboundary impacts, affecting multiple countries simultaneously. For instance, large-scale floods in river basins can impact several nations downstream, causing widespread damage and displacement (Alfieri et al., 2020). Similarly, wildfires, particularly in regions with shared ecosystems like the Mediterranean, can cross borders and exacerbate regional environmental and health challenges (Turco et al., 2019). Furthermore, the effects of nuclear or industrial accidents are not confined by national boundaries. The Fukushima Daiichi nuclear disaster in 2011 had far-reaching consequences, with radioactive contamination detected across various countries (Hirose, 2020). Industrial accidents, such as the Seveso disaster in 1976 and the Bhopal gas tragedy in 1984, also highlight the potential for cross-border environmental and public health impacts (Eskenazi et al., 2018).

The lack of joint preparation and coordinated response mechanisms can significantly increase damage and complicate recovery efforts. Collaborative frameworks and transnational cooperation are essential for effective disaster risk reduction and management. Studies have shown that coordinated disaster preparedness and response can mitigate impacts and expedite recovery (Baubion, 2013). Enhanced international cooperation, including sharing resources, information, and best practices, is critical for building resilience against such multifaceted threats.

The VESPRA project, developed within the Directorate-General for European Civil Protection and Humanitarian Aid Operations - Union Civil Protection Mechanism (UCPM-2020-PP-AG), aimed to improve risk management mechanisms, focusing on the border area between Spain and Portugal, and addressing wildland fires, industrial and nuclear accidents, and extreme weather risks. As part of VESPRA, a GIS-based platform called the VESPRA platform (VESPRA, 2024) was created to improve management and enable continuous updates.

The VERA (Vulnerable Elements and Risk Assessment) project builds on VESPRA, intending to improve and expand the VESPRA platform to other regions and borders in the European Union. In this scope, VERA's WP2 (Expansion of the Intervention Area) focuses on defining pilot cases (Task 2.2) and studying cross-border areas (Task 2.1) where the platform could be implemented. Task 2.1, in particular, involves identifying transnational areas beyond the pilot cases that could face various threats, such as extreme weather events, industrial and nuclear accidents, and wildfires, and assessing their suitability for transnational intervention.

2. Objective

This deliverable presents the activities of Task 2.1, which aims to identify additional areas where the results of the VERA project, including the GIS web-based platform and methodologies, can be applied beyond the pilot cases.

The methodology used to identify and select the transboundary areas is explained and applied, with the results presented and the most relevant areas identified. Finally, a conclusive summary is provided along with some recommendations.

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3. Methodology for selecting transboundary areas

This section outlines the approach and datasets used to identify transnational areas suitable for applying the results and findings of VERA. Given that the VESPRA platform serves as the basis for the initial assessment, we considered the hazards already integrated into the platform for pinpointing cross-border regions where the platform could potentially be utilized. These hazards include those associated with extreme weather events (EWE), nuclear power plants, industrial facilities, and wildfires. Additionally, population density was considered relevant information for selecting the areas.

3.1 Hazard indexes estimation and mapping

The first step of the approach was to define transboundary areas. Based on the protocol established between Spain and Portugal on mutual assistance in border areas (Ministerio de Asuntos Exteriores Unión Europea y Cooperación, 2019), a buffer of 25 km was considered on either side of the borders for all European countries (Figure 1). It should be noted that all European transboundary areas were considered, including special administrative areas such as Vatican City (Italy), San Marino (Italy), Gibraltar (UK), and Melilla (Spain).

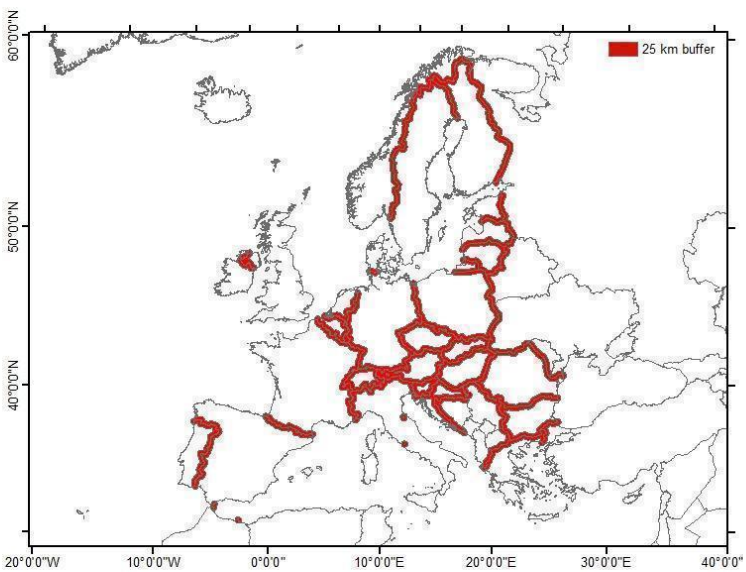

Figure 1. European Union countries' borders and cross-border regions within a 25 km buffer on either side of the borders (shown in red) (Eurostat, 2021).

The hazard indexes for various types of threatening events were calculated and mapped. The Nomenclature of Territorial Units for Statistics (NUT), level III, was used for mapping the European NUTS III regions and applying spatial clips for the different hazards. Data on the occurrence, coverage, and indexes for several extreme weather events were combined for the European NUTS III transnational regions within a 25 km buffer zone. Additionally, the locations of nuclear power plants (NPP) and industrial areas (IA), along with the wildfire danger levels related to thermal anomalies (TA), were aggregated at the same spatial level. Subsequently, individual hazard values for each

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NUTS III bordering region were normalized using Eq. 1, so that a hazard index for each NUTS III bordering area had values ranging from 0 to 1.

$$HI_j\ (-) = \frac{\frac{Hazard_j}{Area_j}}{max\left\{\frac{Hazard_j}{Area_j}\ : j = 1, n\right\}} \qquad \text{Eq. 1}$$

Where:

$Hazard_j$	Hazardous event aggregated over or associated with the j-th specific European NUTS III bordering region
$Area_j$	Area of the j-th specific European NUTS III bordering region
HI_j	Normalized Individual Hazard Index associated to the j-th specific European NUTS III bordering region
n	Total number of European NUTS III bordering regions

After estimating and mapping the normalised individual hazard index for each particular addressed hazard, a combined hazard index was calculated and mapped. For this, an unweighted average index was computed according to Eq. 2, where i represents each of the four types of hazards: 1) Extreme Weather Events; 2) Nuclear Power Plants; 3) Industrial areas; and 4) Wildfires. Here, j denotes the resolution level, which in this stage of the analysis refers to European NUTS III regions within the 25 km bordering buffer.

$$Combined\ hazard_j\ (-) = \frac{\sum_{i=1}^{i=4} Hazard\ Index_{i,j}}{max\left\{\sum_{i=1}^{i=4} Hazard\ Index_{i,j}\ : j = 1, n\right\}} \qquad \text{Eq. 2}$$

Where:

$Hazard\ Index_{i,j}$	Normalized i-th hazard index associated with the j-th specific European NUTS III bordering region
n	Total number of European NUTS III bordering regions

Finally, to better understand the potential hazards that could affect people across borders, we examined the population distribution in the European NUTS III transnational regions within a 25 km buffer zone. This included looking at the total population as well as the number of people under 5 years old and over 65 years old. It is important to note that we didn't normalize the dataset for this parameter.

3.2 Datasets and data manipulation

Several datasets were compiled with information about extreme weather events, nuclear power plant locations, industrial area coverage, and wildfire danger. For extreme weather events, short-duration meteorological variables were selected, namely: Heavy Rain (HR), Heavy Snowfall/Snowstorm (HS), Heavy Hail (HH), Severe Wind (SW), and

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Tornado (TO). Moreover, long-duration weather events were also considered, such as Potential Flood Prone (PFP), Heat Wave Index (HWI) and Drought Impact Index (DII).

Population density data was also included. This section describes the datasets used and presents the obtained maps of Europe. In Table 1 a summary of the type of data gathered is shown.

Table 1. Type of datasets used for the analysis of transboundary areas.

Type of information	Author (year) or Database (period)	Type of data	Domain	Resolution
NUTS III regions	Eurostat (2021)	Polygon	Europe	-
European countries borders	Eurostat (2020)	Polygon	Europe	-
Heavy rain (HR)	ESW (2020 - 2023)	Point	Europe	-
Heavy snow/ Snowstorm (HS)	ESW (2020 – 2023)	Point	Europe	-
Heavy hail (HH)	ESW (2020 - 2023)	Point	Europe	-
Severe wind (SW)	ESW (2020 - 2023)	Point	Europe	-
Tornado (TO)	ESW (2020 - 2023)	Point	Europe	-
Potential flood-prone (PFP)	EEA (2021)	Polygon	Europe	-
Heatwave index (HWI)	EEA (2022)	Polygon	Europe	NUTS III
Drought impact index (DII)	EEA (2022)	Polygon	Europe	NUTS II
Nuclear power plants (NPP)	ArcGIS Hub (2024)	Point	Europe	-
Industrial areas (IA)	Planas et al. (2023)	Polygon	Europe*	> 1 ha
Wildfire danger / Thermal anomalies (TA)	EFFIS (2024)	Raster	Europe	1 km
Burnt areas	EFFIS (2024)	Raster	Europe	1 km
Population	Eurostat (2021)	Raster	Europe	NUTS III

*Except Russia
European Severe Weather (ESW); European Environment Agency (EEA); European Forest Fire Information System (EFFIS)

3.2.1 Extreme weather events

Europe has experienced several extreme weather events of different natures. These events are related to one or more meteorological variables. They can be immediate events (e.g., intense rainfall of short duration) or events of long duration (e.g., drought for years). For the period from 2020 to 2023, a selection of short-duration extreme weather events has been made, highlighting their diverse nature and geographical distribution. These events include:

- Heavy rain (HR)
- Heavy snowfall/snowstorm (HS)
- Heavy hail (HH)
- Severe wind (SW)
- Tornado (TO).

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Long-duration weather events have diverse and complex impacts, making them challenging to assess. This complexity arises from the varied nature of Europe's geography and the range of meteorological variables involved. Therefore, several long-duration events occurring across Europe have been selected and evaluated based on their impact. The selected events are:

- Potential flood prone (PFP)
- Heat wave index (HWI)
- Drought impact index (DII).

After analysing short duration EWE data (point-type data), the following conclusions were reached: they came from non-systematic observations, the area affected was unknown and only one geographical coordinate was available, the distribution was closely related to the position of the settlements and in many cases the borders are in remote unpopulated areas. Therefore, to ensure that no crucial information that could affect the overall results was overlooked, a first density analysis was conducted at the NUTS III level, rather than just considering bordering areas. Normalized information, per weather event, was provided based on the application of Eq. 1 but considering complete NUTS III areas.

In the following sections the distribution of the different types of events and the normalized results obtained considering all NUTS III regions in Europe are presented for each EWE considered.

Heavy rain (HR)

Heavy rain is a highly impactful and damaging type of adverse weather phenomenon. In the VERA project, HR was defined based on the event reporting criteria of the ESW database as described by the European Severe Storms Laboratory (ESSL, 2019) (details about these criteria can be found in the Annex). Data downloaded from the ESW database for the period 2020 – 2023 are presented in Figure 2. The heavy rain accumulation events for each NUTS III region are displayed in Figure 3.

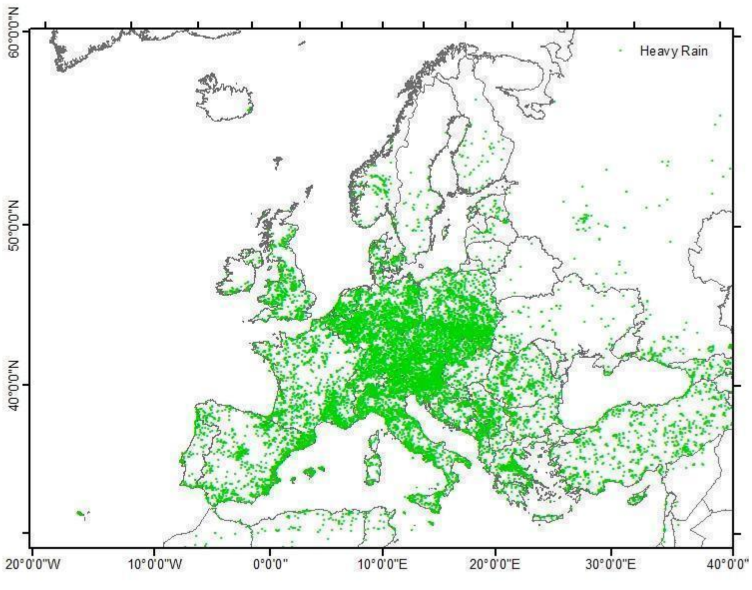

Figure 2. Heavy rain events in Europe (2020 - 2023).

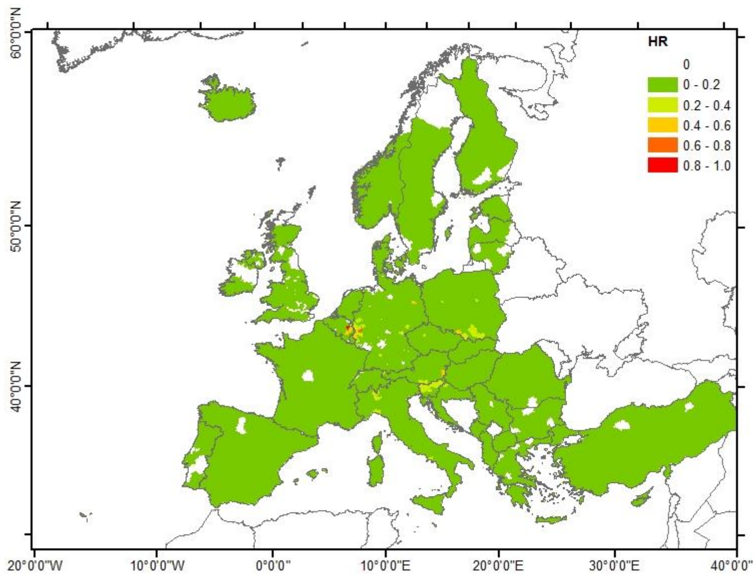

Figure 3. Normalized heavy rain accumulated events for each NUTS III region (2020 - 2023).

Heavy Snowfall/Snowstorm (HS)

Heavy snow (or snow grains) and/or snowstorms are phenomenon which can close a large city entirely. Here it is defined as an event where snow falls in an amount that causes - or is capable of causing - important disruptions of daily life and/or considerable material or economic damage. Specific criteria are defined by (ESSL, 2019). In Figure 4 heavy snowfall/snowstorm accumulation events in Europe from 2020 to 2023 are shown. The normalized heavy snowfall/snowstorm events for each NUTS III region are shown in Figure 5.

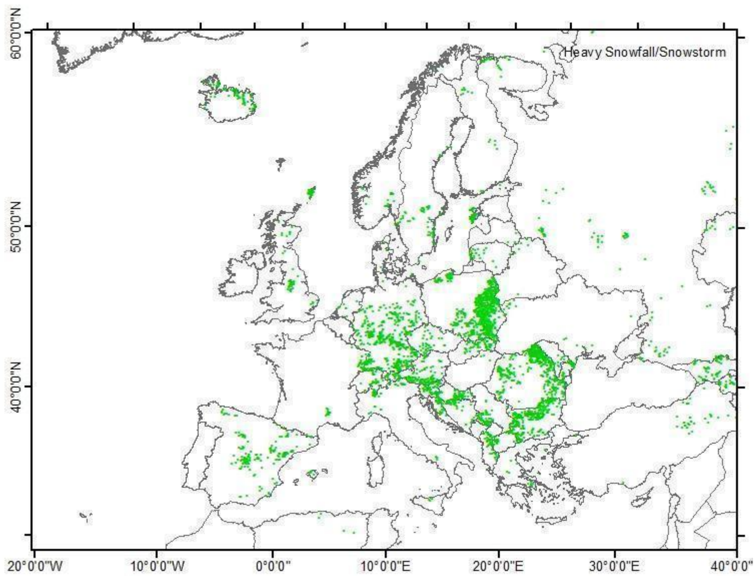

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Figure 4. Heavy snowfall/snowstorm events in Europe (2020 - 2023).

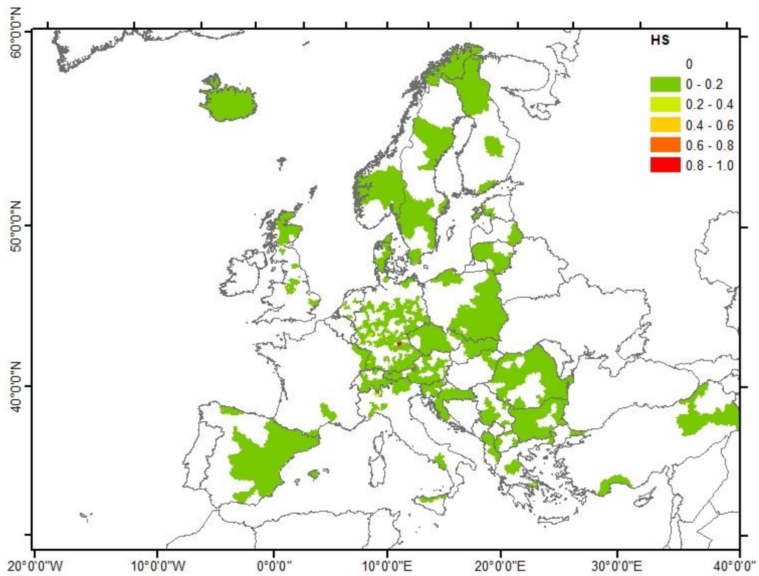

Figure 5. Normalized heavy snowfall/snowstorm accumulated events for each NUTS III region (2020 - 2023).

Heavy hail (HH)

Heavy hail is a meteor capable of causing severe damage locally. In this project, it has been defined as the falling of hailstones having a diameter (in the longest direction) of 2.0 centimetres or more and/or smaller hailstones that form a layer of 2.0 cm thickness or more on flat parts of the earth's surface (ESSL, 2019) (details about these criteria can be found in the Annex). In Figure 6 heavy hail accumulation events in Europe from 2020 to 2023 are shown. The normalized heavy hail accumulated events for each NUTS III region are shown in Figure 7.

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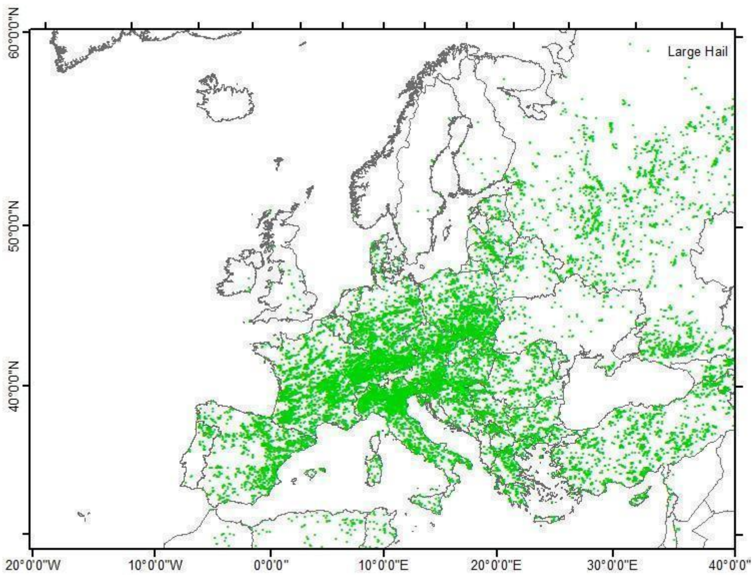

Figure 6. Heavy hail events in Europe (2020 – 2023).

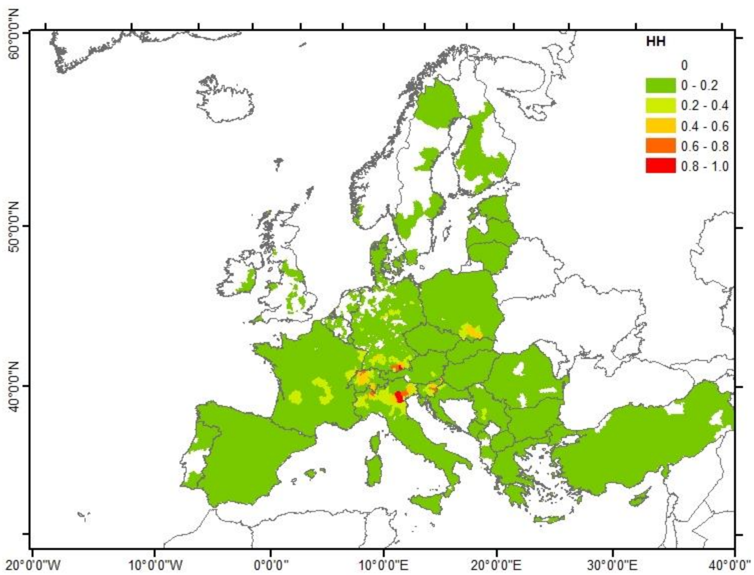

Figure 7. Normalized heavy hail events for each NUTS III region (2020 - 2023).

Severe wind gusts (SW)

A severe wind gust can cause serious damage to infrastructure. It is considered a gust measured to have a speed of at least 25 m/s or one doing such damage that a wind speed of 25 m/s or higher is likely to have occurred (ESSL, 2019) (details about these criteria can be found in the Annex). In Figure 8, severe wind events in Europe from 2020 to 2023 are shown. The normalized heavy hail accumulated events for each NUTS III region are shown in Figure 9.

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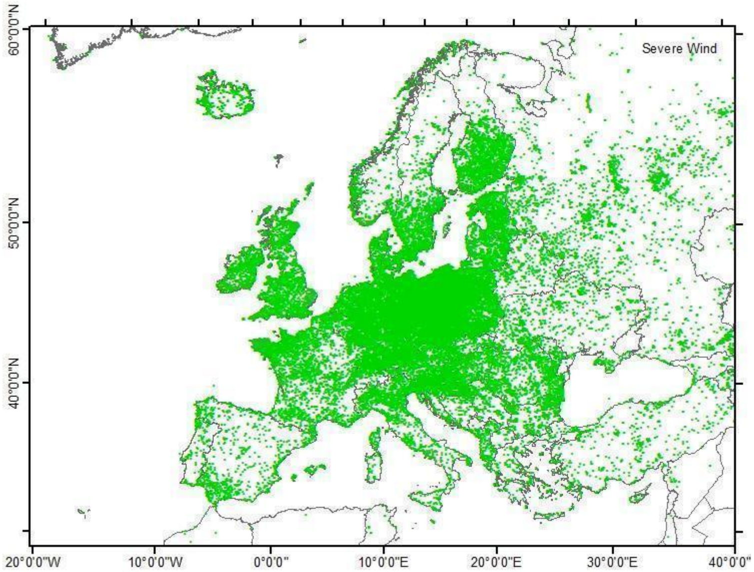

Figure 8. Severe wind events in Europe (2020 - 2023).

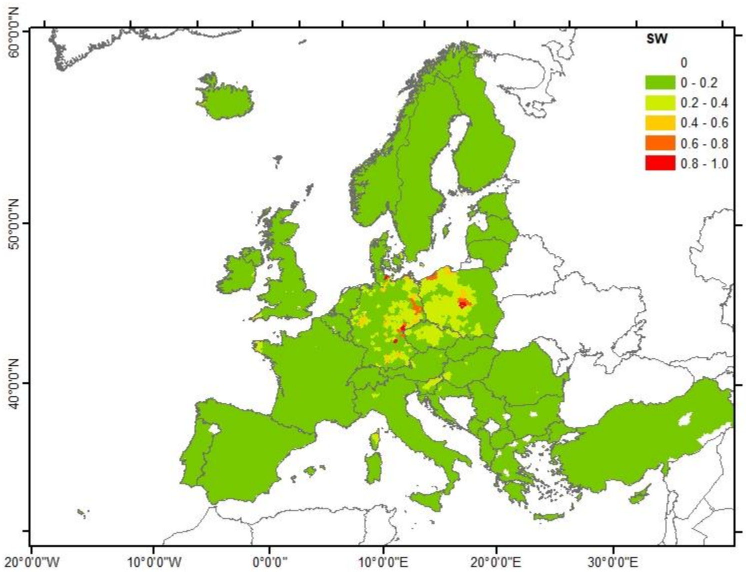

Figure 9. Normalized severe wind accumulated events for each NUTS III region (2020 - 2023).

Tornado (TO)

A tornado or waterspout (above water) is a vortex typically between a few metres to a few kilometres in diameter, extending between a convective cloud and the earth's surface, that may be visible by condensation of water and/or by material (e.g., water, in case of a waterspout) that is lifted off the earth's surface (details about these criteria

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can be found in the Annex). Tornadoes are not very common in Europe, but there are areas where they appear more frequently and can cause serious damage. Events in Europe from 2020 to 2023 are shown in Figure 10. Normalized tornado accumulated events for each NUTS III region are shown in Figure 11.

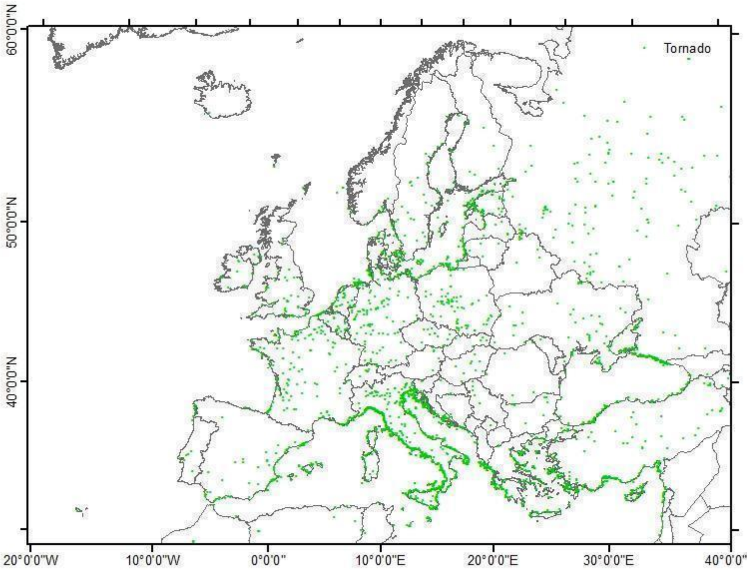

Figure 10. Tornado events in Europe (2020 - 2023).

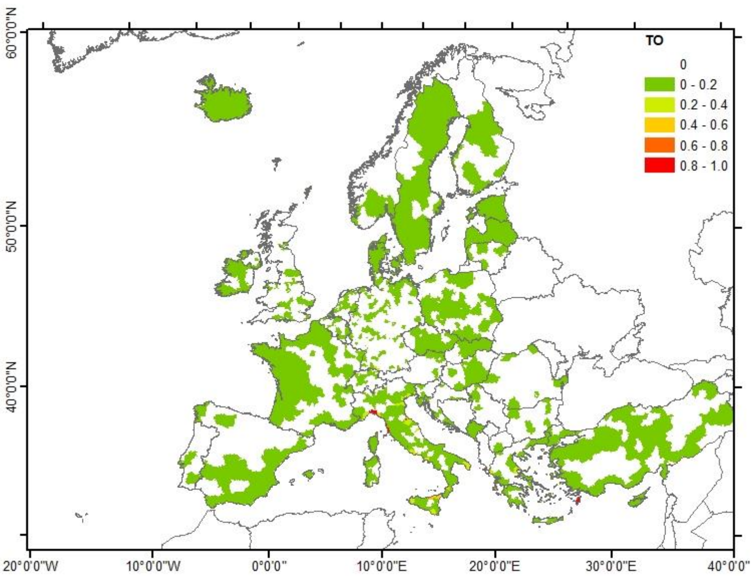

Figure 11. Normalized tornado accumulated events for each NUTS III region (2020 - 2023).

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Potential flood prone (PFP)

Potential flood prone areas in Europe are shown in Figure 12, based on data from the European Floods Database (EEA, 2019). Normalized potential flood prone areas for each NUTS III region are shown in *Figure 13*.

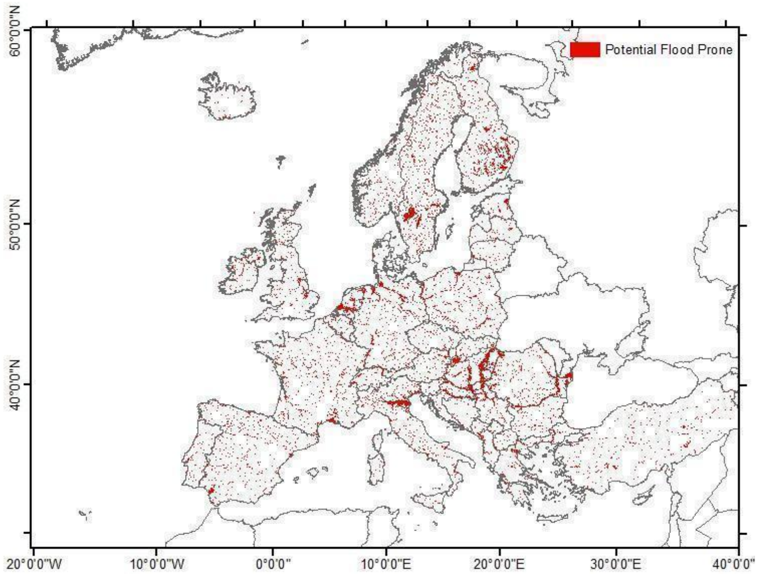

Figure 12. Potential flood prone areas in Europe (EEA, 2019).

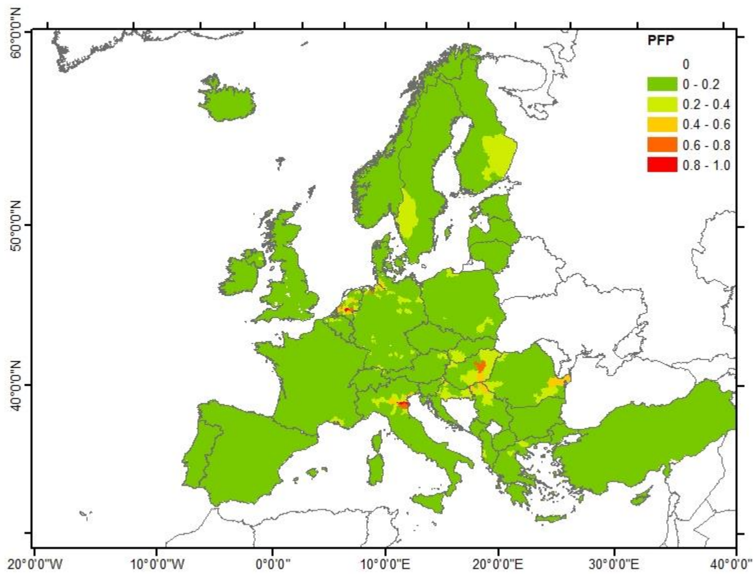

Figure 13. Normalized potential flood prone areas coverage for each NUTS III region (2020 - 2023).

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Heat wave index (HWI)

Heat waves are the greatest direct climate-related health threat to the European population (Kovats and Hajat, 2008). Climate change coupled with an ageing population and increasing urbanization across Europe means that many vulnerable people will be exposed to high temperatures, particularly in southern and central Europe (Watts et al., 2019). High temperatures can cause heat stress, which increases the risk of death from heat exhaustion and heat stroke. They also have other indirect health effects, such as worsening mental health. Overall, heat waves are estimated to have caused around 90% of deaths attributable to extreme weather and climate events in Europe over the last four decades.

Based on the map produced by the European Environment Agency on trends in the incidence of heat-related mortality during the period 2000-2020 in Europe (EEA, 2022), a normalized index of heat wave incidence in different European regions has been generated (Figure 14).

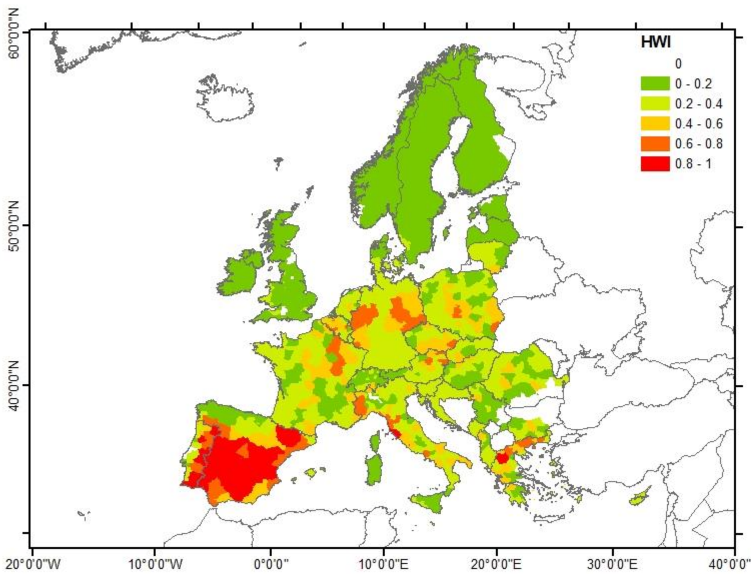

Figure 14. Normalized heat wave index (HWI) for each NUTS III region (2020 – 2023).

Drought impact index (DII)

Drought is a condition resulting from a prolonged lack of precipitation, leading to various impacts such as water scarcity for human consumption, agriculture, forestry, and industry. Several indices and maps have been developed to assess drought, including the Standardized Precipitation Index (SPI) and the European Drought Observatory (EDO) for Europe. In this study, a Drought Impact Index (DII) has been created based on data from the European Environment Agency (EEA, 2017) (see Figure 15).

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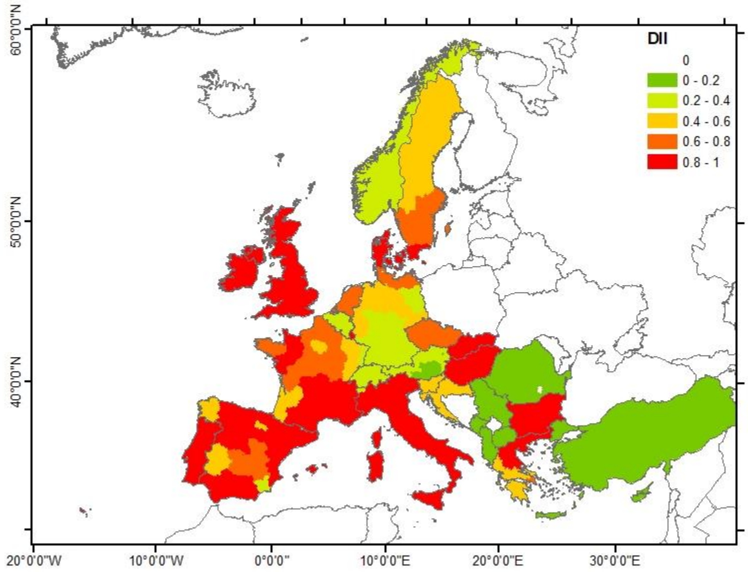

Figure 15. Drought Impact Index (DII) for each NUTS II region (EEA, 2017).

Extreme weather events index (EWEI)

A combined Extreme Weather Events value for each region (EWE_j) was estimated as a weighted sum (see Eq. 3). The weights assigned to each event were established based on expert knowledge from the VERA consortium.

$$EWE_j = 0.20 \times HWI_j + 0.20 \times HR_j + 0.10 \times HS_j + 0.10 \times HH_j + 0.15 \times SW_j + 0.10 \times TO_j + 0.10 \times PFP_j + 0.05 \times DII_j \quad \text{Eq. 3}$$

Then, a normalized Extreme Weather Events Index ($EWEI_j$) (Figure 16) was estimated for each NUTS III region by considering the maximum combined Extreme Weather Events value within the European Union (see Eq. 4).

$$EWEI_j = \frac{EWE_j}{max\,\{EWE_j : j = 1..n\}} \quad \text{Eq. 4}$$

Where:

$EWEI_j$ Normalized Extreme Weather Events Index for the j-th specific European NUTS III region (values: 0..1)

EWE_j Combined Extreme Weather Events value for each area of the j-th specific European NUTS III region

n Total number of European NUTS III regions

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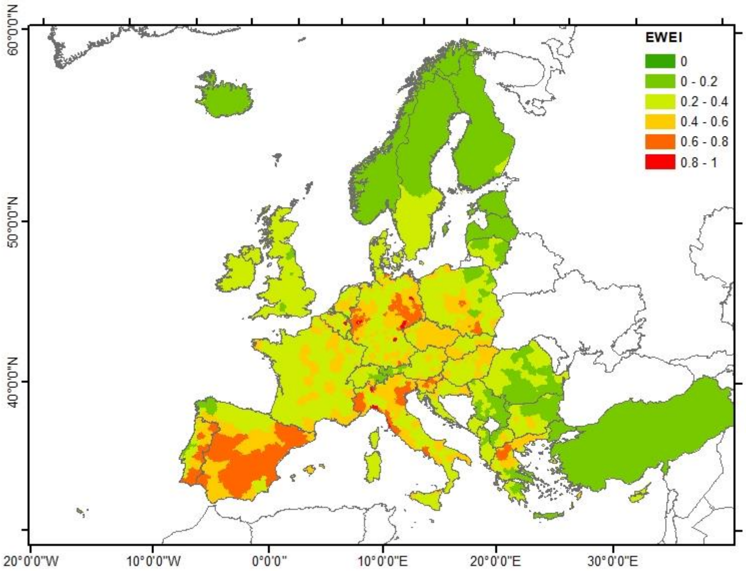

Figure 16. Extreme Weather Events Index for each NUTS III region as defined according to Eq. 4.

After analyzing Figure 16, it is clear that certain areas in Europe experience extreme weather events (EWE) more frequently. Based on the previously presented individual hazards, the Iberian Peninsula stands out due to its susceptibility to droughts and heat waves. Additionally, Belgium, the Netherlands, and certain regions in Germany are prone to EWEs related to heavy rainfall and floods. Eastern Germany and Poland are particularly susceptible to severe wind events, contributing to a higher EWEI in those areas.

3.2.2 Nuclear power plants

Nuclear power plant locations were obtained from an open and collaborative dataset (ArcGIS Hub, 2024), which includes more than 100 facilities worldwide. It should be noted that this dataset is the only open-source resource providing worldwide geospatial information about nuclear power plants in operation and may not contain the most updated information. Figure 17 shows the locations of nuclear power plants within a 30 km buffer zone around the facilities and their gross power (MW) in the European region.

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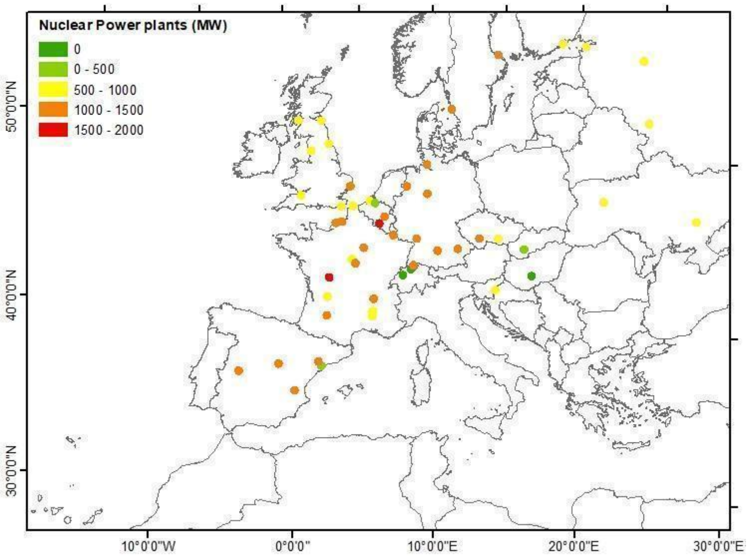

Figure 17. Location of nuclear power plants in Europe with a 30-km buffer zone around them, and their gross power (MW) (ArcGIS Hub, 2024).

In the European Union, there are approximately 55 facilities in operation, utilising different types of reactors, including boiling water, carbon dioxide gas-cooled, fast breeder, heavy water gas-cooled, heavy water moderated, light water graphite, pressurised heavy water, pressurised water, and very high-temperature reactors (ArcGIS Hub, 2024). Many European Union countries utilize nuclear facilities to produce energy. Among them, France has the highest number of nuclear power plants, totalling 14, followed by the United Kingdom with 7 facilities. Germany, according to the accessed dataset, has 6 facilities, but they are currently not in operation.

3.2.3 Industrial areas

The industrial areas map (Figure 18) was extracted from the OpenStreetMap (OSM) dataset (March 2023 version), considering the tag "landuse = industrial". This was filtered to keep only polygons greater than 1 ha, as described by Planas et al. (2023). Although no validation study was conducted to evaluate the accuracy of this methodology (for example, through visual comparison with satellite images), representative results can still be obtained for the purpose of this work.

The Corine Land Cover (CLC) product was not used because it does not have a specific category for industrial installations. CLC includes category 1 (Artificial Surfaces) subdivided into four sub-classes, one of which includes industrial units (1.2-Industrial, commercial, and transport units). Thus, industrial activities cannot be separated from commercial units.

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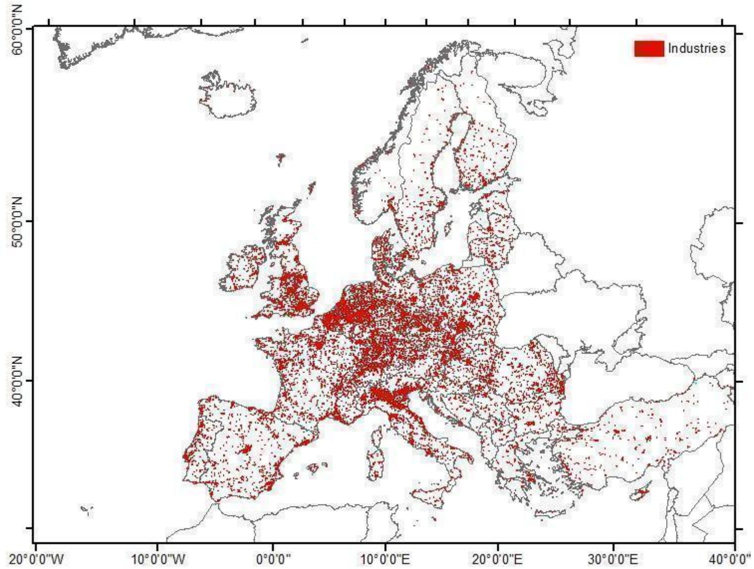

Figure 18. Industrial areas in Europe based on OpenStreetMap data set (2023 version) considering the tag landuse = industrial (Planas et al., 2023)*.*

The United Kingdom, Germany, Belgium and The Netherlands are highly industrialized countries in Europe. Additionally, regions within several countries, such as Northern France, Northern Italy, Northern and Eastern Spain, and Western Portugal, also represent significant industrial clusters.

More specifically, the Rhine-Ruhr region in Western Germany is highly industrialized and populated. In Italy, industrial activity is concentrated near northern cities like Milan, Turin, Bologna, Verona and Venice. In the UK, industrial zones include Central Scotland, Durham and Northumberland, Lancashire and West Yorkshire, The Midlands, and areas near London. France has industrial areas around major cities (e.g., Paris, Lyon, Bordeaux, Strasbourg), while Belgium is notably industrialized, particularly in Antwerp, Ghent and Dunkirk. The Netherlands has an important industrial cluster in the Rotterdam area.

3.2.4 Wildfires

A dataset provided by the European Forest Fire Information System (EFFIS) was used in this study, specifically the wildfire danger map. This map was deemed the most pertinent index for this study because it focuses solely on the wildfire hazard. It is derived from the observed frequency of thermal anomalies (MODIS/VIIRS), and the ranking is performed based on the expected association with wildfires, with lower rankings for other types of vegetation fires, such as agriculture fires. A detailed description of this parameter, ranging from 0 to 1, as well as the methodology used to obtain it, is described by Oom et al. (2020), Oom et al. (2022), Oom et al. (2022a), San Miguel et al. (2017), and San-Miguel-Ayanz et al. (2018). Figure 19 shows the spatial distribution of wildfire danger based on thermal anomalies. The representativeness of the anomaly map (Figure 19) concerning wildfire danger can be observed by comparing it with a map of fires larger than 30 hectares recorded since 2000, as presented in *Figure 20*.

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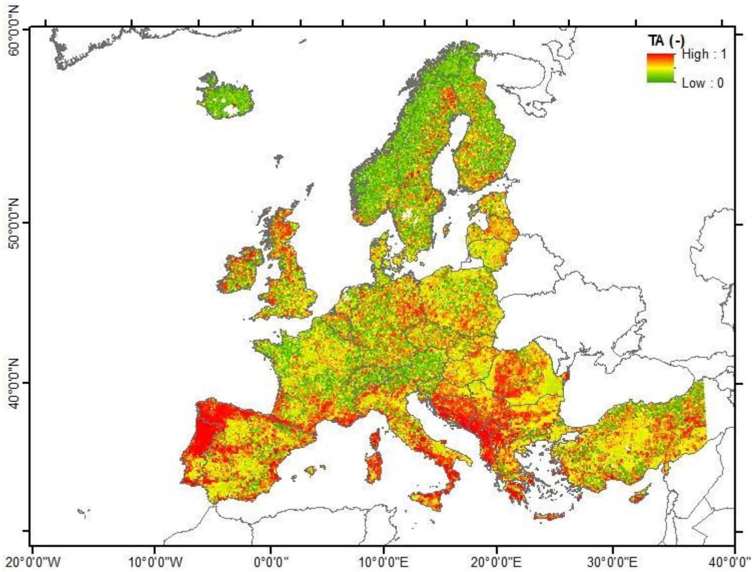

Figure 19. Danger by wildfire thermal anomalies in Europe (EFFIS, 2024).

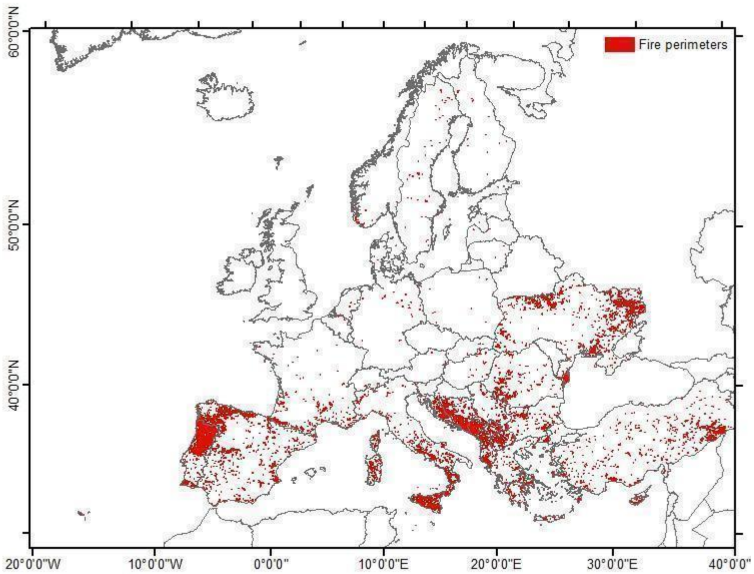

Figure 20. Burnt areas from fire events of 30 hectares or larger using MODIS satellite imagery (EFFIS, 2024).

A strong correlation between the two variables represented on the maps (Figures 19 and 20) is evident, with Mediterranean areas showing a higher historical record of both fires and thermal anomalies, particularly in the northwest of the Iberian Peninsula, southwest Italy, and the eastern coast of the Balkan Peninsula.

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3.2.5 Population

The population distribution (by NUTS III) for the year 2023 in the European Union was provided by Eurostat (Eurostat, 2021). It includes the usual residential population, i.e., those who have lived in their place of usual residence for a continuous period of at least 12 months before the reference date, or those who arrived in their place of usual residence during the 12 months before the reference date to stay there for at least one year. The total population distribution by NUTS III is presented in Figure 21. The population of individuals under 5 years old by NUTS III is shown in Figure 22, while Figure 23 illustrates the population of individuals over 65 years old by NUTS III.

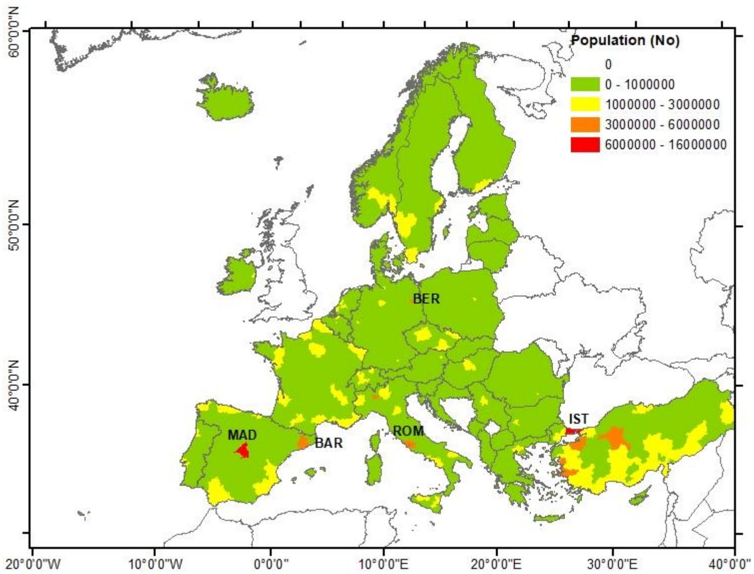

Figure 21. Population distribution (total) by NUTS III for the year 2023 in the European Union (Eurostat, 2021).

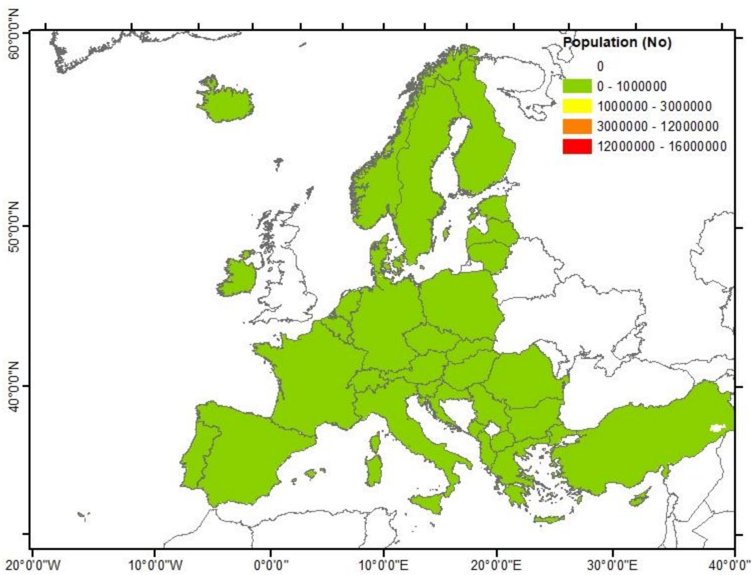

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Figure 22. Population distribution (< 5 years) by NUTS III for the year 2023 in the European Union (Eurostat, 2021).

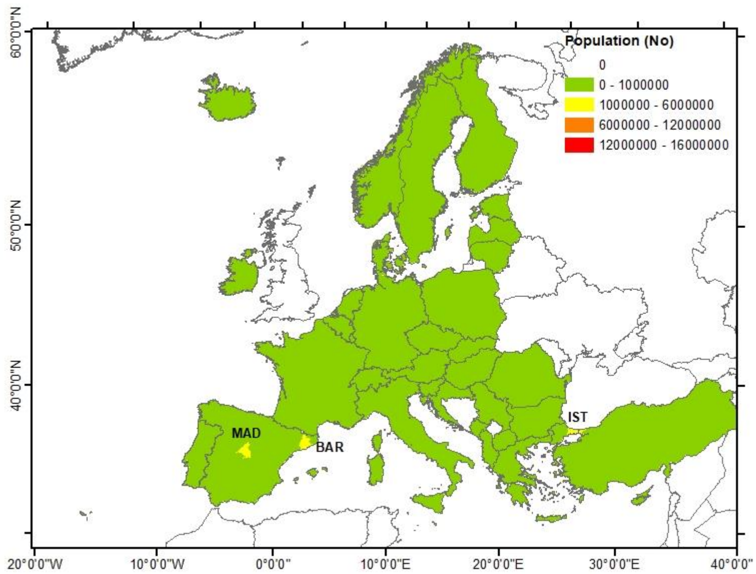

Figure 23. Population distribution (> 65 years) by NUTS III for the year 2023 in the European Union (Eurostat, 2021).

In 2023, the total population per NUTS III, varied between 370,287 and 646,588 inhabitants, with the highest number being observed in Istanbul - IST (> 6,000,000), followed by Madrid - MAD (> 6,000,000), and Barcelona (3,000,000 < pop < 6,000,000) (Figure 21). Figure 21 illustrates that most of population resides in major European cities such as Istanbul (IST), Madrid (MAD), Rome (ROM), and Berlin (BER). The population under 5 years old varies, on average, between 18,127 and 36,620, with all NUTS III regions having values lower than 1,000,000 (Figure 22). Additionally, the population over 65 years old varies, on average, between 72,161 and 95,030, with Istanbul (IST), Madrid (MAD) and Barcelona (BAR) recording a population between 1,000,000 and 6,000,000 (Figure 23).

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4. Selection of Transboundary Areas

The previously collected and processed data served as the foundation for identifying transboundary areas susceptible to being affected by extreme weather events, nuclear and industrial accidents, and wildfires. A 25 km buffer was applied to these various hazards, which were mapped according to normalized indexes.

4.1 Potentially affected areas

The following figures depict the European NUTS III transboundary regions that could potentially be affected by various hazards, based on the estimated EWEI (Figure 24), the locations of the nuclear power plants (Figure 25), coverage of industrial areas (Figure 26), and wildfire danger (Figure 27). Additionally, Tables 2 to 5 display the ranking of NUTS III bordering areas in the European Union in terms of extreme weather events, nuclear power plants, industrial areas, and wildfires.

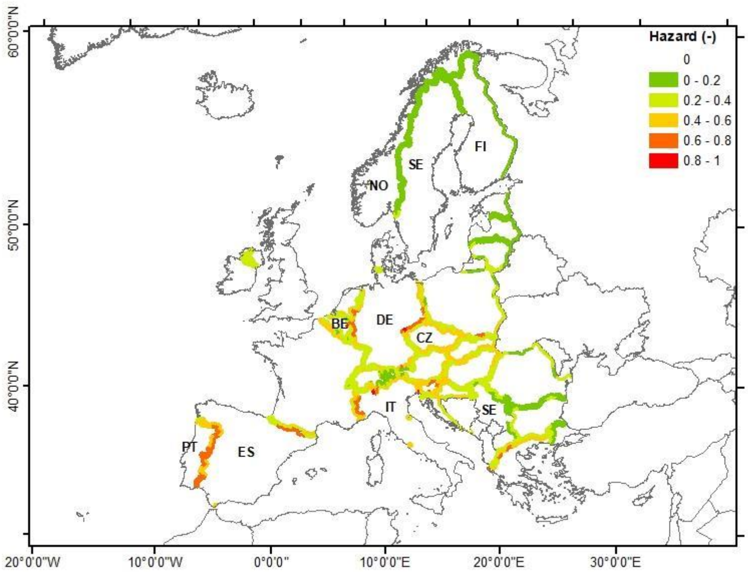

Figure 24. Extreme Weather Events Index (EWEI) for transboundary areas in Europe.

Analysing Figure 24, the EWEI ranged between 0 (Pirotska oblast, Servia - SE) and 1 (Zwickau, Germany - DE), with an average value of 0.36 and a standard deviation of 0.17. The highest value of EWEI (i.e., 1) is observed at the Germany-Czech Republic (DE-CZ) border, while the lowest values (EWEI < 0.2) were mainly found at the borders of northern European countries such as Norway-Sweden and Sweden-Finland.

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Table 2. Ranking of NUTS III bordering areas in the European Union according to the Extreme Weather Events Index (EWEI). 1st: highest hazard; 10th: lowest hazard. DE – Germany; BE – Belgium; IT – Italy.

Rank	EWEI		
	Value	Country	NUTS III
1st	1.00	DE	Zwickau
2nd	0.99	BE	Arr. Liège
3rd	0.90	DE	Vogtlandkreis
4th	0.88	IT	Gorizia
5th	0.85	IT	Varese
6th	0.79	DE	Düren
7th	0.76	DE	Rhein-Kreis Neuss
8th	0.73	DE	Sächsische Schweiz-Osterzgebirge
9th	0.73	DE	Dresden, Kreisfreie Stadt
10th	0.72	DE	Euskirchen

The European country with the highest number of top EWEI values along the border was Germany (DE), followed by Italy (IT) and Belgium (BE) (Table 2). However, examining which borders exhibited high values on both sides, it is evident from Figure 24 that the Portugal-Spain (PT-ES) border showed the highest overall values (0.6 < EWEI < 0.7), particularly in the eastern region of Portugal.

Regarding the nuclear power plants hazard in Figure 25, values ranged between 0 (in several European NUTS III bordering areas) and 1 (in Aargau, Switzerland - CH), with an average value of 0.02 and a standard deviation of 0.08. Despite the large area that could be affected in the event of a nuclear accident, the European borders potentially most impacted by the activity of nuclear power plants include France-Belgium (FR-BE), France-Switzerland (FR-CH), France-Germany (FR-DE), Belgium-The Netherlands (BE-NL), Belgium-Luxembourg (BE-LU), Netherlands-Germany (NL-DE), Switzerland-Germany (CH-DE), Czech Republic-Austria (CZ-AT), Slovakia-Hungary (SK-HU), Slovenia-Croatia (SI-HR), and Croatia-Bosnia and Herzegovina (HR-BA). The highest recorded value at the Switzerland-Germany (CH-DE) border.

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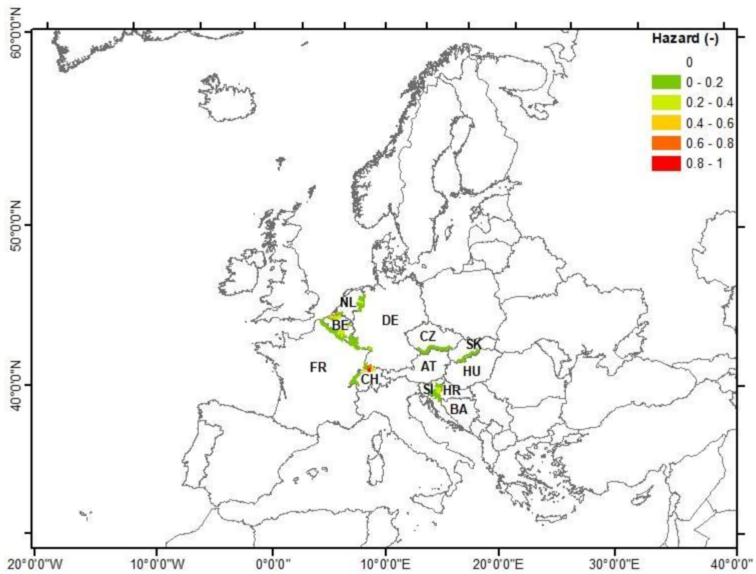

Figure 25. Normalized nuclear power plant hazard index along transboundary areas in Europe.

The European country with the highest number of top values for nuclear power plant hazards was Belgium (BE), followed by The Netherlands (NL), Switzerland (CH), Germany (DE), and Slovenia (SI) (Table 3). The Switzerland-Germany (CH-DE) border exhibited the highest overall values (0.6 < hazard < 1) on both sides (i.e., northern region of Switzerland – CH) (Figure 25).

Table 3. Ranking of NUTS III bordering areas in the European Union according to the nuclear power plants location. 1st: highest hazard; 10th: lowest hazard. CH – Switzerland; DE – Germany; NL – The Netherlands; SI – Slovenia; BE – Belgium.

Rank	Nuclear power plants		
	Value	Country	NUTS III
1st	1.00	CH	Aargau
2nd	0.72	DE	Waldshut
3rd	0.50	NL	Zeeuwsch-Vlaanderen
4th	0.44	NL	Overig Zeeland
5th	0.37	SI	Posavska
6th	0.37	BE	Arr. Waremme
7th	0.36	CH	Basel-Landschaft
8th	0.34	BE	Arr. Mechelen
9th	0.33	BE	Arr. Sint-Niklaas
10th	0.33	BE	Arr. Dinant

The industrial normalized hazard index ranged between 0 (in several European NUTS III bordering areas) and 1 (Milan, Italy – IT), with an average value of 0.06 and a standard deviation of 0.02. Across Europe, the industrial hazard index was predominantly between 0 and 0.2 for more than 90% of NUTS III.

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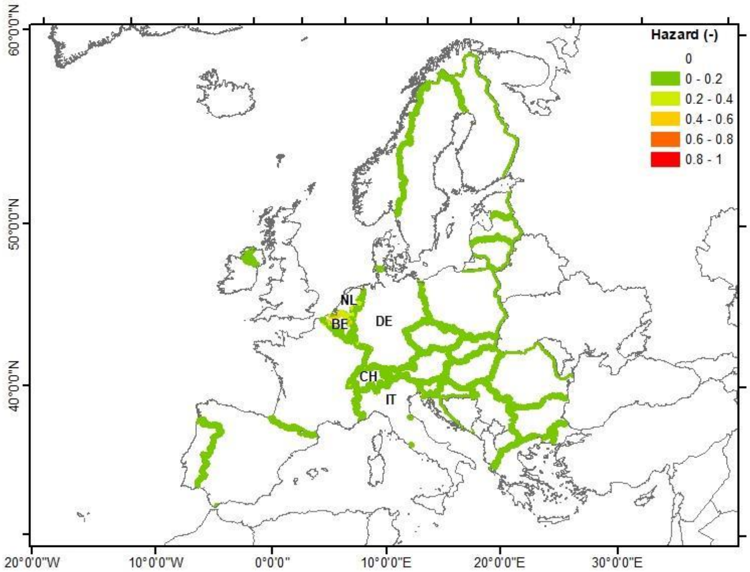

Figure 26. Normalized industrial areas hazard index along transboundary areas in Europe.

Table 4. Ranking of NUTS III bordering areas in the European Union according to industrial areas location. 1st: highest hazard; 10th: lowest hazard. IT – Italy; NL: The Netherlands; DE – Germany; CH – Switzerland.

Rank	Industries		
	Value	Country	NUTS III
1st	1.00	IT	Milano
2nd	0.81	NL	Delfzijl en omgeving
3rd	0.76	DE	Emden, Kreisfreie Stadt
4th	0.59	BE	Arr. Antwerpen
5th	0.56	CH	Basel-Stadt
6th	0.51	BE	Arr. Kortrijk
7th	0.51	BE	Arr. Sint-Niklaas
8th	0.50	DE	Flensburg, Kreisfreie Stadt
9th	0.46	IT	Monza e della Brianza
10th	0.46	BE	Arr. Gent

The European country with the highest number of top values for industrial hazards in transboundary areas is Belgium (BE), followed by Germany (DE), Italy (IT), The Netherlands (NL), and Switzerland (CH) (Table 4). The Belgium-Netherlands (BE-NL) border exhibited the highest overall values, ranging from 0.2 to 0.6, particularly in the north-eastern region of Belgium (BE) (Figure 26).

The wildfire hazard index ranged between 0 and 1, with *Médio Tejo*, Portugal (PT) recording the highest value. The average value was 0.51, with a standard deviation of

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0.19. The highest values were observed in the Mediterranean borders (e.g., Portugal-Spain border, PT-ES), while the lowest were found in the northern European border countries (e.g., Norway-Sweden border, NO-SE).

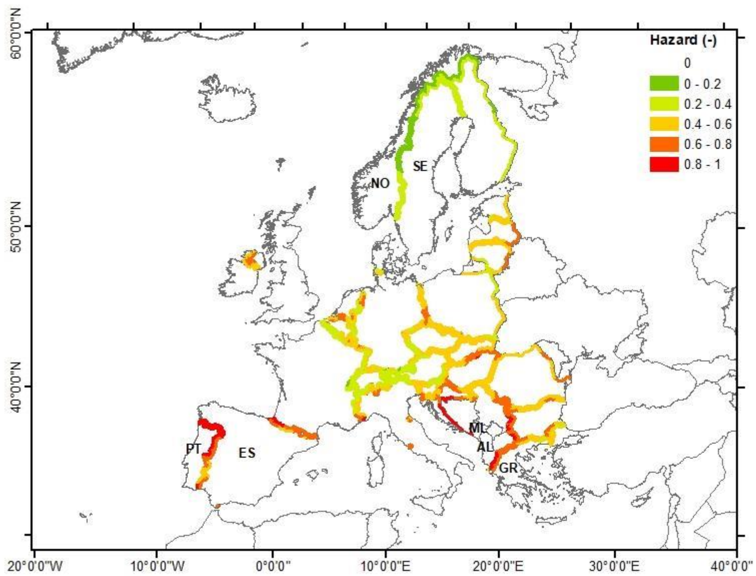

Figure 27. Normalized wildland fire hazard index along transboundary areas in Europe.

Portugal (PT) had the highest number of top values for wildfire hazards in bordering areas, followed by Spain (ES), Montenegro (ME), and Albania (AL) (

Table 5). Notably, the borders between Portugal and Spain (PT-ES), Bosnia and Herzegovina and Croatia (BA-HR), and Greece and Albania (GR-AL) exhibited the highest overall values, with hazards exceeding 0.6 (Figure 27).

Table 5. Ranking of NUTS III bordering areas in the European Union according to wildfires hazard. 1st: highest hazard; 10th: lowest hazard. PT – Portugal; ES – Spain; ME – Montenegro; AL – Albania.

Rank	Wildfires		
	Value	Country	NUTS III
1st	1.00	PT	Médio Tejo
2nd	0.99	ES	León
3rd	0.99	PT	Ave
4th	0.99	PT	Alto Minho
5th	0.99	PT	Cávado
6th	0.99	PT	Alto Tâmega
7th	0.99	ME	Crna Gora
8th	0.99	AL	Vlorë
9th	0.99	PT	Douro
10th	0.98	ES	Ourense

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The results from the cross-border areas potentially affected by different hazards indicate that the distribution of these areas depends on the specific hazard being analyzed. Transboundary areas across almost all of Europe may be affected by EWE (Figure 24), industrial hazards (Figure 26), and wildfires(Figure 27). However, hazards related to nuclear power plants are primarily located in central European transboundary areas, such as Belgium (BE), The Netherlands (NL), Switzerland (CH), and Germany (DE) (Figure 25).

4.2 Combined hazards

To identify the transboundary areas with a higher potential for using the VERA platform, an averaging approach was used to account for different types of hazards across European transboundary areas (see Eq. 2). Figure 28 shows the combined hazard index for European NUTS III transboundary regions within a 25 km border buffer. Tables 62 and 7 provide the ranking of NUTS III bordering areas in the European Union based on the quantified index. Table 6 also details individual hazard values, while Table 7 presents the top 10 positions for single hazard.

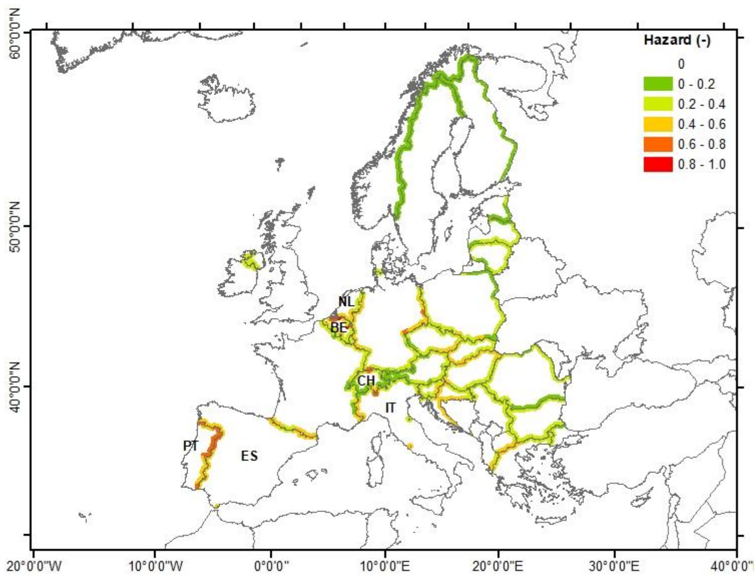

Figure 28. Combined Hazards Index for NUTS III within the 25 km bordering buffer.

The combined hazard index ranged between 0 (Pohjois-Pohjanmaa, Finland - FI) and 1 (Milan, Italy – IT), with an average value of 0.34 and a standard deviation of 0.15. Belgium (BE) had the highest number of top values for combined hazard index in bordering areas, followed by Italy (IT), Switzerland (CH), The Netherlands (NL) and Portugal (PT) (Table 6).

Table 6. Ranking of NUTS III bordering areas in the European Union according to the Combined Hazards Index. Single hazards values are also included. 1st: highest hazard; 10th: lowest hazard. IT – Italy; BE – Belgium; CH – Switzerland; NL: Netherlands; PT – Portugal. EWEI: Extreme Weather Events Index; NPP: Nuclear Power Plant.

Rank	Combined hazards	Individual hazards values

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	Value	Country	NUTS III	EWEI	NPP	Industries	Wildfires
1st	1.00	IT	Milan	0.50	0.00	1.00	0.76
2nd	0.86	BE	Arr. Antwerpen	0.38	0.32	0.59	0.69
3rd	0.81	BE	Arr. Liège	0.99	0.21	0.28	0.39
4th	0.80	CH	Aargau	0.24	1.00	0.09	0.52
5th	0.75	BE	Arr. Mechelen	0.43	0.34	0.34	0.65
6th	0.75	BE	Arr. Sint-Niklaas	0.35	0.33	0.51	0.56
7th	0.75	NL	Overig Zeeland	0.27	0.44	0.45	0.59
8th	0.73	IT	Varese	0.85	0.00	0.19	0.67
9th	0.72	IT	Monza e della Brianza	0.46	0.00	0.46	0.78
10th	0.70	PT	Algarve	0.72	0.00	0.01	0.94

Milan (IT) and Aargau (CH) were the only NUTS III regions in the top 10 combined hazards ranking to achieve the maximum hazard value (i.e., 1), respectively, for industries and nuclear power plants (Table 7). Algarve, Portugal (PT) was the only region not ranked in the top 10 for any individual hazard. Moreover, no regions with high wildfire hazard rankings appeared in the combined hazard top 10 (Table 7).

Table 7. Ranking of NUTS III bordering areas in the European Union according to the Combined Hazards Index together with single hazards Top 10 position for each NUTS III region ranked for the combined hazards. 1st: highest hazard; 10th: lowest hazard. IT – Italy; BE – Belgium; CH – Switzerland; NL: Netherlands; PT – Portugal. EWEI: Extreme Weather Events Index.

Rank	Combined hazards			Individual hazards – Top 10	
	Value	Country	NUTS III	Rank	Hazard
1st	1.00	IT	Milan	1st	Industries
2nd	0.86	BE	Arr. Antwerpen	4th	Industries
3rd	0.81	BE	Arr. Liège	2nd	EWEI
4th	0.80	CH	Aargau	1st	Nuclear power plants
5th	0.75	BE	Arr. Mechelen	8th	Nuclear power plants
6th	0.75	BE	Arr. Sint-Niklaas	7th 9th	Industries Nuclear power plants
7th	0.75	NL	Overig Zeeland	4th	Nuclear power plants
8th	0.73	IT	Varese	5th	EWEI
9th	0.72	IT	Monza e della Brianza	9th	Industries
10th	0.70	PT	Algarve	-	-

The results also showed that the bordering regions with high individual hazard index values – such as IT-CH for extreme weather events, BE-NL for industrial areas and nuclear power plants, and PT-ES for wildfires) (Figures 24-27) – had combined hazard values exceeding 0.6. In contrast, most European bordering areas recorded combined hazard index values below 0.6, suggesting that at least two of the considered hazards (i.e., extreme weather events, nuclear power plants, industrial areas, or wildfires) are relatively low (< 0.2) in these regions.

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4.3 People vulnerability

To assess the impact on different age groups within the specified buffer regions, the vulnerability of people to the combined hazards was analysed using the People Vulnerability Index (PVI) (Eq. 5). This index provides insights into how different segments of population are affected by various hazards. The PVI for European transboundary areas within a 25 km buffer was quantified using Eq. 5, where j denotes the resolution level and k represents each of the three population age ranges: 1) total population; 2) individuals under 5 years old; and 3) individuals over 65 years old.

$$PVI_{j,k}\,(-) = \frac{Combined\ hazards_j \times Pop_{j,k}}{max\{Combined\ hazards_j \times Pop_{j,k}\ : j = 1..n\,; k = 1..3\}} \quad \text{Eq. 5}$$

Where:

$Combined\ hazards_j$ Normalized combined hazards estimated using Eq. 2 within the j-th specific European NUTS III bordering region

$Pop_{j,k}$ Population for the k–th age range (i.e., total, 5 < years old, and > 65 years old) within the j-th specific European NUTS III bordering region

n Total number of European NUTS III bordering regions

Figures 29-31 illustrate the People Vulnerability Index (PVI) based on the total population, individuals under 5 years old, and individuals over 65 years old, respectively, for European NUTS III transnational regions within a 25 km border buffer. Furthermore, Tables 8-10 show the ranking of NUTS III bordering areas in the European Union according to the quantified index.

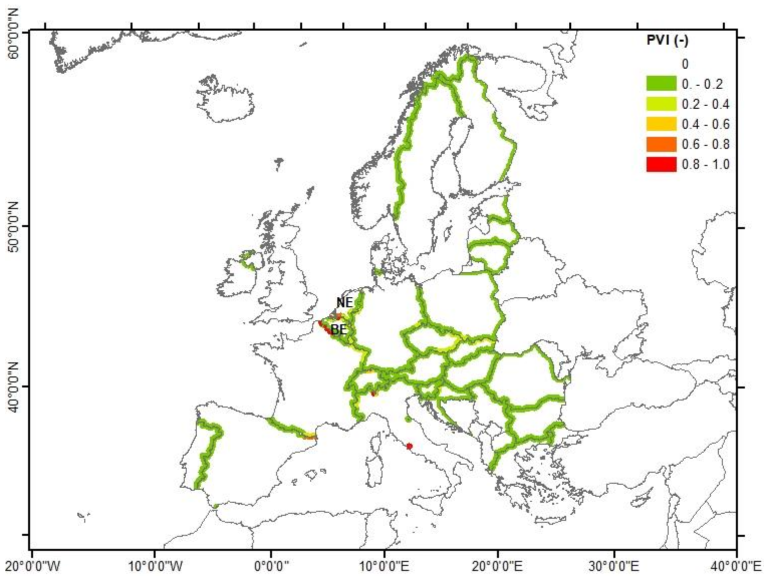

Figure 29. PVI for NUTS III within the 25 km bordering buffer (total population).

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The PVI based on the total population recorded an average value of 0.07 with a standard deviation of 0.11. The highest PVI for the total population and individuals over 65 years old was found in Roma (IT) (Figure 29 and Figure 31), where the main hazards include EWEI, industrial hazards and wildfires (Table 8 and Table 10). For individuals under 5 years old, the highest PVI was observed in Nord (FR) (Figure 30). Italy (IT) had the highest number of top PVI values for both the total population and individuals over 65 years old (Table 8 and Table 10). For individuals under 5 years old, Italy (IT), Switzerland (CH), and The Netherlands (NL) each recorded the same number of top values (2 each) (

Table 9). Analysing the results between countries, it is evident that the Belgium-Netherlands (BE-NL) border showed the highest overall values (PVI > 0.4) (Figures 29-31).

Table 8. Ranking of NUTS III bordering areas in the European Union according to the PVI considering population (total) together with single hazards Top 10 position for each NUTS III region ranked for the combined hazards. 1st: highest hazard; 10th: lowest hazard. IT – Italy; BE – Belgium; FR - France; ES – Spain; CH – Switzerland; NL: Netherlands. EWEI: Extreme Weather Events Index. NPP: Nuclear Power Plants.

Rank	PVI			Individual hazards values				
	Value	Country	NUTS III	EWEI	NPP	Industries	Wildfires	Population (total)
1st	1	IT	Roma	0.56	0.00	0.13	0.69	0.71
2nd	0.97	IT	Varese	0.85	0.00	0.19	0.67	0.53
3rd	0.88	BE	Arr. Antwerpen	0.38	0.32	0.59	0.69	0.41

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4th	0.87	FR	Nord	0.42	0.05	0.18	0.32	1.00
5th	0.72	ES	Girona	0.39	0.00	0.02	0.71	0.68
6th	0.60	NL	West-Noord-Brabant	0.30	0.12	0.38	0.63	0.41
7th	0.57	CH	Aargau	0.24	1.00	0.09	0.52	0.28
8th	0.48	CH	Zürich	0.38	0.26	0.09	0.48	0.41
9th	0.45	IT	Como	0.69	0.00	0.09	0.79	0.27
10th	0.42	NL	Zuid-Limburg	0.64	0.00	0.41	0.43	0.27

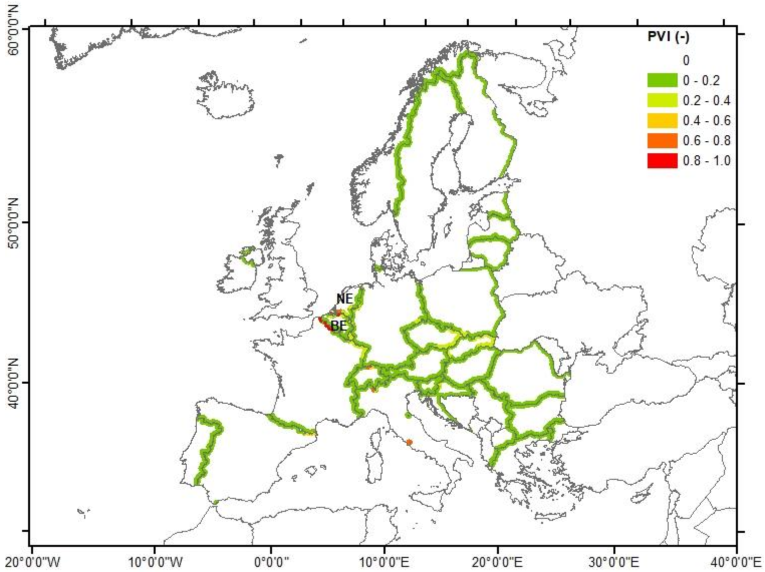

Figure 30. PVI for NUTS III within the 25 km bordering buffer (< 5 years).

Table 9. Ranking of NUTS III bordering areas in the European Union according to the PVI considering population (< 5 years) together with single hazards Top 10 position for each NUTS III region ranked for the combined hazards. 1st: highest hazard; 10th: lowest hazard. FR: France; BE: Belgium; IT: Italy; NL: Netherlands; CH – Switzerland; ES: Spain; CZ: Czech Republic. EWEI: Extreme Weather Events Index. NPP: Nuclear Power Plants.

Rank	PVI			Individual hazards values				
	Value	Country	NUTS III	EWEI	NPP	Industries	Wildfires	Population (< 5 years)
1st	1.00	FR	Nord	0.42	0.05	0.18	0.32	1.00
2nd	0.99	BE	Arr. Antwerpen	0.38	0.32	0.59	0.69	0.41
3rd	0.74	IT	Varese	0.85	0.00	0.19	0.67	0.35

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4th	0.73	IT	Roma	0.56	0.00	0.13	0.69	0.45
5th	0.62	NL	West-Noord-Brabant	0.30	0.12	0.38	0.63	0.37
6th	0.60	CH	Aargau	0.24	1.00	0.09	0.52	0.26
7th	0.58	ES	Girona	0.39	0.00	0.02	0.71	0.48
8th	0.51	CH	Zürich	0.38	0.26	0.09	0.48	0.38
9th	0.40	CZ	Moravskoslezský kraj	0.48	0.00	0.08	0.43	0.38
10th	0.39	BE	Arr. Turnhout	0.23	0.00	0.20	0.66	0.33

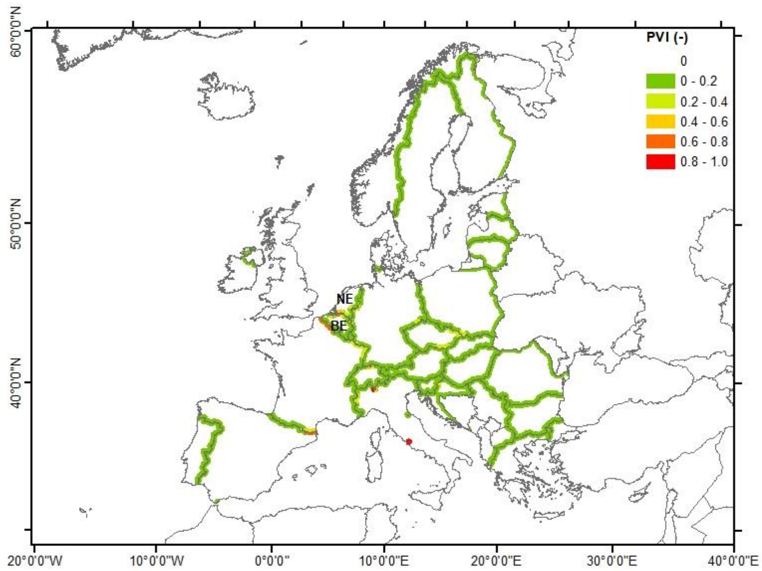

Figure 31. PVI for NUTS III within the 25 km bordering buffer (> 65 years).

Table 10. Ranking of NUTS III bordering areas in the European Union according to the PVI considering population (> 65 years) together with single hazards Top 10 position for each NUTS III region ranked for the combined hazards. 1st: highest hazard; 10th: lowest hazard. IT – Italy; BE – Belgium; FR - France; ES: Spain; NL: Netherlands; CH – Switzerland. EWEI: Extreme Weather Events Index.

Rank	PVI			Individual hazards values				
	Value	Country	NUTS III	EWEI	NPP	Industries	Wildfires	Population (> 65 years)
1st	1.00	IT	Roma	0.56	0.00	0.13	0.69	0.88
2nd	0.99	IT	Varese	0.85	0.00	0.19	0.67	0.68

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3rd	0.76	BE	Arr. Antwerpen	0.38	0.32	0.59	0.69	0.43
4th	0.71	FR	Nord	0.42	0.05	0.18	0.32	1.00
5th	0.62	ES	Girona	0.39	0.00	0.02	0.71	0.71
6th	0.52	NL	West-Noord-Brabant	0.30	0.12	0.38	0.63	0.44
7th	0.47	NL	Zuid-Limburg	0.64	0.00	0.41	0.43	0.38
8th	0.47	IT	Como	0.69	0.00	0.09	0.79	0.35
9th	0.45	CH	Aargau	0.24	1.00	0.09	0.52	0.28
10th	0.37	CH	Zürich	0.38	0.26	0.09	0.48	0.38

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5. Conclusions

The main purpose of this deliverable was to identify transboundary intervention areas where the VERA project can be applied beyond the pilot cases (i.e., Portugal-Spain, Spain-France). To achieve this, a combined hazard index and a population vulnerability index were developed based on extreme weather events, industrial and nuclear power plant locations, wildfires, and population datasets.

The findings indicate that the following transboundary European regions may be impacted by various events: extreme weather for the Portugal-Spain border, nuclear power plants for the Switzerland-Germany border, industrial activities for the Belgium-Netherlands border, and wildfires for the Portugal-Spain border. However, when the results are analysed using the combined hazard index and the population vulnerability index, the regions along the Italy-Switzerland and Belgium-Netherlands borders emerge as potential areas for transnational intervention where the VERA project can be implemented.

In brief, this report outlined potential areas for cross-border intervention in the VERA project beyond the initial pilot cases. By using a combined hazard index and a population vulnerability index, the analysis identified the borders potentially most impacted by natural and technological events, as well as human activities. The results emphasize the need to prioritize the Italy-Switzerland and Belgium-Netherlands regions as key sites for future interventions based on VERA outcomes. This will enable focused efforts to improve resilience against these challenging hazards in Europe.

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6. References

Alfieri, L., Lorini, V., Hirpa, F.A., Harrigan, S., Zsoter, E., Prudhomme, C., Salamon, P., 2020. A global streamflow reanalysis for 1980–2018. J. Hydrol. X 6, 100049. https://doi.org/10.1016/j.hydroa.2019.100049

APP, (Asian Preparedness Partnership), 2021. Estimation of wind speed. Beaufort scale [WWW Document]. URL https://app.adpc.net/resources/beaufort-scale-on-conditions-at-land/ (accessed 7.7.24).

ArcGIS Hub, 2024. World Nuclear Power Plant 2023 [WWW Document]. URL https://hub.arcgis.com/datasets/622055e631ce4098a6d4a960eac431be/explore (accessed 2.27.24).

Baubion, C., 2013. OECD Working Papers on Public Governance No. 23 OECD Risk Management: Strategic Crisis Management, OECD Working Papers on Public Governance.

EEA, (European Environmental Agency), 2022. Drought impacts on public water supply and water quality for two drought severity levels [WWW Document]. URL https://www.eea.europa.eu/data-and-maps/figures/trends-in-heat-related-mortality (accessed 7.6.24).

EEA, (European Environmental Agency), 2019. European Flood Database [WWW Document]. URL https://www.eea.europa.eu/data-and-maps/data/external/european-floods-database (accessed 7.6.24).

EEA, (European Environmental Agency), 2017. Drought impacts on public water supply and water quality for two drought severity levels [WWW Document]. URL https://www.eea.europa.eu/data-and-maps/figures/drought-impacts-on-public-water (accessed 7.6.24).

EFFIS, 2024. European Forest Fire Information System EFFIS [WWW Document]. URL https://forest-fire.emergency.copernicus.eu/ (accessed 6.19.24).

Eskenazi, B., Warner, M., Brambilla, P., Signorini, S., Ames, J., Mocarelli, P., 2018. The Seveso accident: A look at 40 years of health research and beyond. Environ. Int. 121, 71–84. https://doi.org/10.1016/j.envint.2018.08.051

ESSL, 2019. European Severe Storms Laboratory [WWW Document]. URL https://www.essl.org/cms/european-severe-weather-database/reporting/ (accessed 7.6.24).

Eurostat, 2021. NUTS regions [WWW Document]. URL https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/nuts#nuts21 (accessed 4.11.24).

Eurostat, 2020. Administrative boundaries at country level [WWW Document]. URL https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/countries (accessed 4.10.24).

Funded by the European Union
Grant Agreement: UCPM/2023/101140339

Hirose, K., 2020. Atmospheric effects of Fukushima nuclear accident: A review from a sight of atmospheric monitoring. J. Environ. Radioact. 218, 106240. https://doi.org/10.1016/j.jenvrad.2020.106240

Kovats, R.S., Hajat, S., 2008. Heat stress and public health: A critical review. Annu. Rev. Public Health 29, 41–55. https://doi.org/10.1146/annurev.publhealth.29.020907.090843

Ministerio de Asuntos Exteriores Unión Europea y Cooperación, 2019. Protocolo adcional entre el Reino de Espana y la República Portuguesa sobre ayuda en zonas fronterizas, hech en Valladoid el 21 de noviembre de 2018, adoptado en los términos del articulo 8 del Protocolo sobre cooperación técnica y assistencia mutua en ma.

Nachtnebel, H.-P., 2003. Studienblätter der Gewässerkunde, Hydrometrie und Hydroinformatik.

Oom, D., de Rigo, D., Pfeiffer, H., Branco, A., Ferrari, D., Grecchi, R., Artés-Vivancos, T.., Houston Durrant T., Boca, R.., Maianti, P., Libertá, G., San-Miguel-Ayanz, J., et a.l., 2022a. Pan-European wildfire risk assessment EUR 31160 EN, Publications Office ofthe European Union, Luxembourg, 2022. https://doi.org/10.2760/9429

Oom, D., de Rigo, D., Pfeiffer, H., San-Miguel-Ayanz, J., Grecchi, R., Durrant, T.H., Libertà, G., Artes-Vivancos, T., Boca, R., Maianti, P., Branco, A., Ferrari, D., Oom, D., de Rigo, D., Pfeiffer, H., San-Miguel-Ayanz, J., Grecchi, R., Durrant, T.H., Libertà, G., Artes-Vivancos, T., Boca, R., Maianti, P., Branco, A., Ferrari, D., 2020. Developing the European wildfire risk assessment (WRA). In: Atlas of the Human Planet 2020. Publications Office of the European Union, Luxembourg. https://doi.org/https://purl.org/INRMM-MiD/z-QW8I46GC

Oom, D., de Rigo, D., San-Miguel-Ayanz, J., Artes-Vivancos, T., Boca, R., Branco, A., Campanharo, W.A., Grecchi, R., Houston Durrant, T., Ferrari, D., Libertà, G., Maianti, P., Pfeiffer, H., 2022b. Wildfires. https://doi.org/10.5281/zenodo.6045338

Planas, E., Paugam, R., Àgueda, A., Vacca, P., Pastor, E., 2023. Fires at the wildland-industrial interface. Is there an emerging problem? Fire Saf. J. 141. https://doi.org/10.1016/j.firesaf.2023.103906

San-Miguel-Ayanz, J., Costa, H., Rigo, D. de, Libertà, G., Vivancos, T.A., Durrant, T., Nuijten, D., Loffer, P., Moore, P., 2018. Basic criteria to assess wildfire risk at the pan-European level. Jt. Res. Cent. 294–305.

San Miguel, J., Chuvieco, E., Handmer, J., Moffat, A., Montiel-Molina, C., Sandahl, L., 2017. Climatological Risk: Wildfires. Sci. Disaster Risk Manag. 2017Knowing Better Losing Less 294–335.

Turco, M., Jerez, S., Augusto, S., Tarín-Carrasco, P., Ratola, N., Jiménez-Guerrero, P., Trigo, R.M., 2019. Climate drivers of the 2017 devastating fires in Portugal. Sci. Rep. 9, 1–8. https://doi.org/10.1038/s41598-019-50281-2

VESPRA, 2024. Vespra – vulnerable elements in spain and portugal and risk assessment [WWW Document]. URL https://vespra.org/ (accessed 6.19.24).

Funded by the European Union
Grant Agreement: UCPM/2023/101140339

Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Boykoff, M., Byass, P., Cai, W., Campbell-Lendrum, D., Capstick, S., Chambers, J., Dalin, C., Daly, M., Dasandi, N., Davies, M., Drummond, P., Dubrow, R., Ebi, K.L., Eckelman, M., Ekins, P., Escobar, L.E., Fernandez Montoya, L., Georgeson, L., Graham, H., Haggar, P., Hamilton, I., Hartinger, S., Hess, J., Kelman, I., Kiesewetter, G., Kjellstrom, T., Kniveton, D., Lemke, B., Liu, Y., Lott, M., Lowe, R., Sewe, M.O., Martinez-Urtaza, J., Maslin, M., McAllister, L., McGushin, A., Jankin Mikhaylov, S., Milner, J., Moradi-Lakeh, M., Morrissey, K., Murray, K., Munzert, S., Nilsson, M., Neville, T., Oreszczyn, T., Owfi, F., Pearman, O., Pencheon, D., Phung, D., Pye, S., Quinn, R., Rabbaniha, M., Robinson, E., Rocklöv, J., Semenza, J.C., Sherman, J., Shumake-Guillemot, J., Tabatabaei, M., Taylor, J., Trinanes, J., Wilkinson, P., Costello, A., Gong, P., Montgomery, H., 2019. The 2019 report of The Lancet Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate. Lancet 394, 1836–1878. https://doi.org/10.1016/S0140-6736(19)32596-6

Wussow, G., 1922. Untere Grenze dichter Regenfälle. Met. Z 39, 173–178.

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Annex

European Severe Weather Database (ESWD) criteria

Heavy rain

There are two criteria for heavy rain, according to ESSL (2021), which both refer to 24h (a single day) period.

- 1) rain falling in such large amounts that an extreme impact occurs with significant damage;

Any event must accomplish a minimum of one condition of this list to be considered as an extreme impact event into the heavy rain list at the European Severe Weather Database (ESWD) used as data reference source:

- Important streets have become impassable
- Rail, tram or subway transport is disrupted
- Multiple structures or their basements have been flooded
- Landslides have occurred, which caused significant damage to structures or vegetation
- Fire department have come into action multiple times

These impacts may however not be caused by:

- Flooding along rivers
- Flooding owing to a combination of thaw and rain
- Falling rocks to which the rainfall may have contributed

If traffic accidents occur due to water on a street (e.g., because of aquaplaning), but the street is still passable, this is not considered an extreme impact.

- 2) no damage is known but precipitation amounts observed are exceptional for the region in question.

For unknown damage events that count on extreme rainfall measurement, the reference network uses to verify the event the extreme precipitation criterion of Wussow (1922) and Nachtnebel (2003), which requires a precipitation amount of P (mm) fallen during a period of t (minutes)to meet the following criteria:

$$P \geq 2\sqrt{5t} \quad \text{Eq. 8}$$

It is required that 1/2 hour < t < 24 hours.

Visually, it can be understood taking into account the events that its precipitation amount, for a known time between 30 min and 24 h, overpasses the Figure 32 red line.

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Rain measurements of less than 25 mm are not reported to the ESWD, even for shorter intervals than ½ hour.

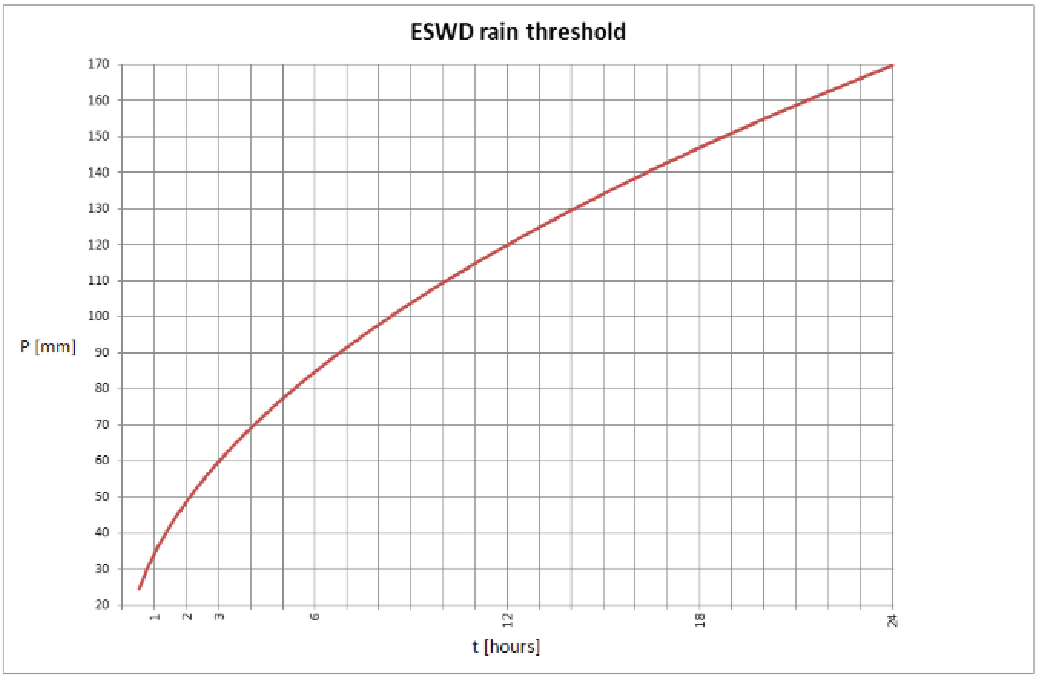

Figure 32. Precipitation thresholds for ESWD reports type 2 (ESSL, 2021).

Heavy Snowfall/Snowstorm

Any event must accomplish a minimum of one condition of the following list to be considered as an extreme impact event into the heavy snowfall list at the European Severe Weather Database (ESWD) used as data reference source.

- Important streets have become impassable, or have been closed as a precaution to avoid accidents
- Rail, tram or subway transport is disrupted
- An airport had to be closed for multiple hours
- Widespread damage was done to trees
- Power outages that are caused by multiple failures of power lines
- Structures are damaged, e.g. because of collapsing roofs (only in as far as it was caused mostly by a single snowfall event rather than snow accumulating over a long period)

These are not impact-related criteria:

- Observations of large snow accumulations
- Isolated traffic accidents due to slipperiness
- Isolated personal injuries due to slipperiness

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Heavy hail

Any event must accomplish a minimum of one of the two conditions of this list (ESSL, 2021) to be considered as an extreme impact event into the large hail list at the European Severe Weather Database (ESWD) used as data reference source:

- Diameter: a hailstone diameter of 2.0 cm or larger must have been measured, or the damage that was caused suggests that this has been the case. The hailstone diameter is the diameter that it has at the moment it impacts the earth's surface or another object. Hailstones that freeze together at a later moment do not count for this criterion.
- Layer thickness: a layer of hail of at least 2.0 cm thickness on a flat surface must have been measured, or the resulting damage suggests this to have been the case. Hail that has accumulated locally by a stream of water, by wind, or any other way do not count for the criterion

Severe wind gusts

A severe wind gust is considered a gust measured to have a speed of at least 25 m/s or one doing such damage that a wind speed of 25 m/s or higher is likely to have occurred (ESSL, 2021). Any event must accomplish trespassing or indirectly accomplish the mentioned threshold as a condition to be considered as an extreme impact event into the severe wind gusts list at the European Severe Weather Database (ESWD) used as data reference source. No distinction is made between wind gusts occurring in association with deep, moist convection, and those occurring in its absence.

For indirect estimations the well-known Beaufort scale can be used (Figure 33), and reports are compiled when observed damages are equal or overpassing the storm category (10):

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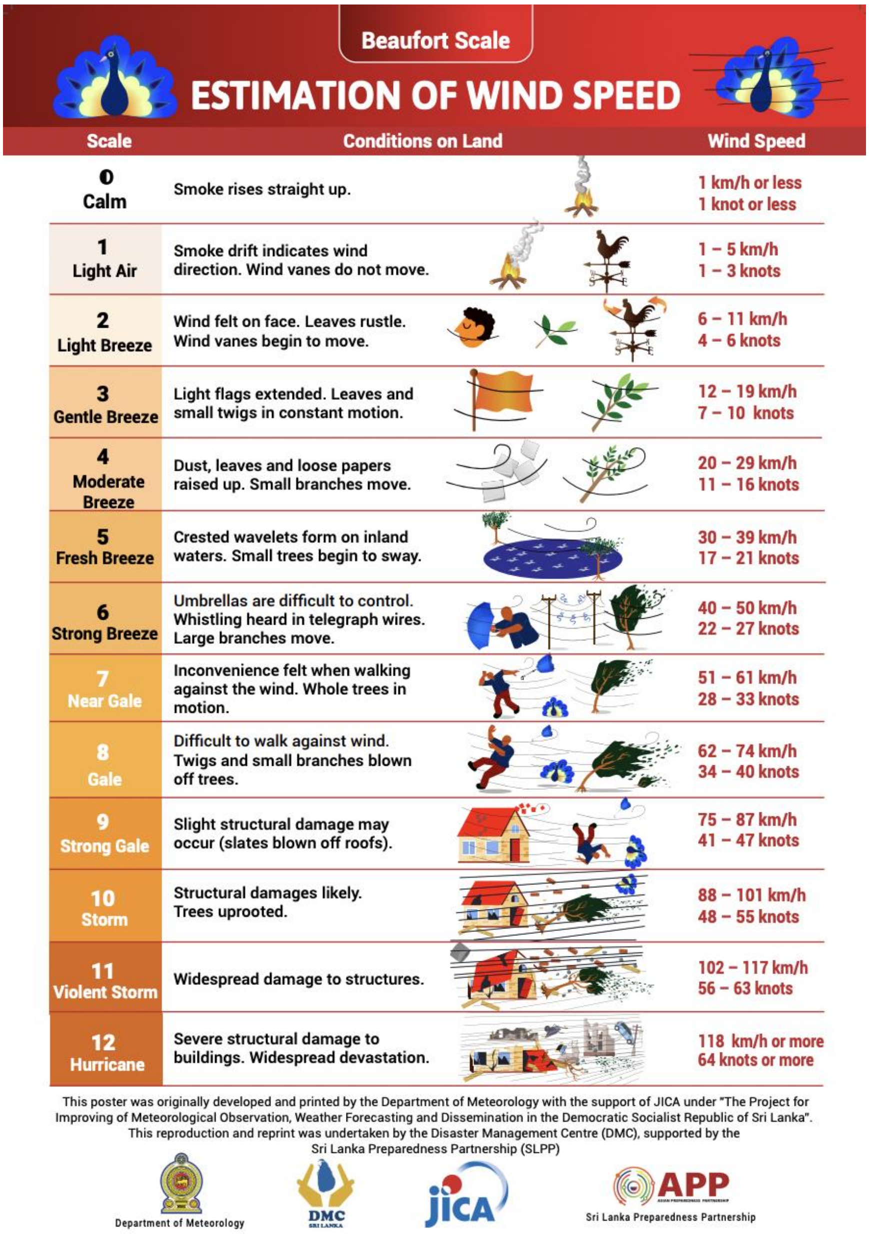

Figure 33. Beaufort scale for indirect estimations of wind speed impact (APP, 2021).

Tornado

Any event must accomplish the following criterion (ESSL, 2021) to be considered as an extreme impact event into the tornado list at the European Severe Weather Database (ESWD) used as data reference source:

The definition of a tornado includes only those events in which it is deemed probable that wind speeds of at least 25 m/s occurred. When an observation of a tornado is made that includes the sighting of a funnel cloud reaching the earth's surface, or a sighting of a funnel cloud aloft with an attendant circulation near the earth's surface, it is assumed that wind speeds of 25 m/s are occurring in the vast majority of cases. This means that such an event must be reported as a tornado.

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