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Climate risk for economic activities of the Province of Belluno (NE Italy). II. Sectoral Risk Assessment

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Climate risk for economic activities of the Province of Belluno (NE Italy).
II.Sectoral RIsk Assessment

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1 Foreword

The unprecedented threat of climate change is posing a severe risk for human economic activities, due to the increasing frequency and magnitude of extreme events.

Practitioners in multiple economic sectors, from infrastructural to financial ones, are becoming increasingly more aware of the importance of **climate proofing** in strategic planning and decision-making, to cope with **climate risk**.

Essential information for climate proofing is the assessment of risk to exposed receptors, considering their vulnerability to climate hazards (e.g. floods, heat waves, etc.) in the different combinations of environmental and socio-economic features, within the so-called as social-ecological system.

The dimensions of risk to be considered, according to the IPCC (2012) definitions are:

- **Hazard**, i.e. "*the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources*";
- **Exposure**, defined as the presence of receptors, i.e. "*people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected*" by hazard events;
- **Vulnerability,** i.e. "*the propensity or predisposition to be adversely affected*" by hazard events.

In the Alpine Region, climate change has already shown remarkable effects in terms of temperature rise (2 °C over the last 120 years) at a pace that is as much as twice the global average, with dramatic consequences in terms of glacier retreat and disappearance.

Future projections confirm the past trend and foresee further effects on temperature, seasonality of precipitation, global radiation, relative humidity and frequency/intensity of extreme precipitation and floods (Gobiet et al., 2014). The limited accessibility of mountain areas, due to harsh geomorphological gradients, may exacerbate consequences of extreme events, for example when damaged connections between settlements prevents or slows down the recovery from critical situations.

Recent extreme events in the Belluno Province (eastern Alps at the border between Italy and Austria), such as the disastrous Vaia storm in 2018, provide further evidence of the importance of climate proofing in spatial planning to cope with adverse effects climate change for ordinary and extraordinary management of infrastructures and to grant access to essential public services, i.e. water, electric power, etc.

This working paper presents the second part of results on sectora risks to climatic hazards of a collaborative project between Venice International University (VIU), the Foundation Euro-Mediterranean Centre on Climate Change (CMCC) and Ca' Foscari University of Venice, with the financial support of Enel Foundation.

The main aim of the project was the assessment of multiple risks from climatic hazards in the Belluno Province. The approach adopted herein derives from the **Socio-Economic Regional Risk Assessment** (**SERRA**) method developed by the EU Kulturisk Project (Giupponi et al., 2015). This integrated approach combines accurate spatial risk assessment with socio-economic analysis and valuation, to estimate the potential damages associated with risks of different kind and magnitude. These features made it suitable for the assessment of four key economic sectors of the Belluno Province: summer tourism, the eyewear industry, electricity distribution and winter sports and events.

As previously reported, the **SERRA integrated approach** combines classical spatial risk assessment with socio-economic analysis, enabling the estimation of the damages associated with potential risks of different types and entities (see **Errore. L'origine riferimento non è stata trovata.**), based on the following sequence of steps (Mojtahed et al. 2013):

1. qualitative and quantitative description of the hazards;
2. identification and description of the environment subject to the hazards considered (e.g. urban areas, ecosystems, infrastructures);
3. selection of receptors exposed directly and indirectly to hazards (residential buildings, industrial areas, warehouses, retailers, people, infrastructures, vehicles, etc.);
4. identification of the spatial characteristics of susceptibility, coping and adaptive capacities mapped by means of indicators which are subsequently aggregated into a vulnerability index for each type of receptor;
5. identification of the set of value factors for exposed receptors and their indirect correlations;
6. calculation of the risk from the previous steps;

7. designation of the risk of receptors in the quadrants of the Total Cost Matrix.

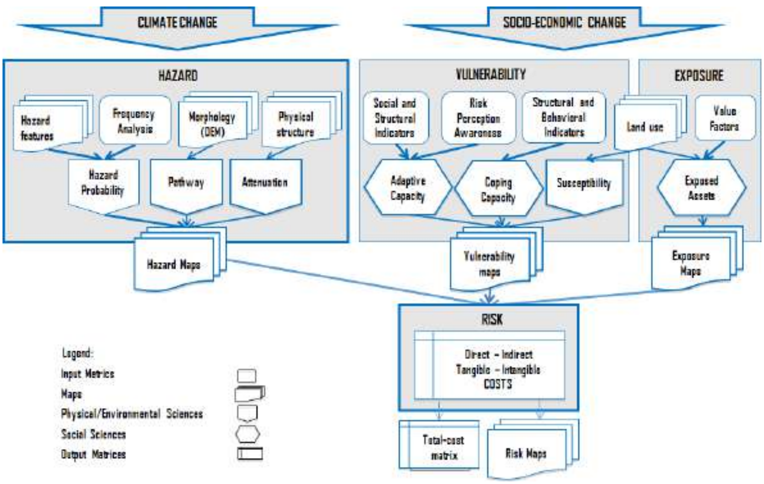

fig. 1-1
General flow-chart of the SERRA methodological framework for risk assessment

This study is based on high-resolution regional climate simulations that represent the most advanced knowledge regarding the climate change expected in Italy. Moreover, it involves the use of spatial indicators based on the local characteristics of the area and on the hazards to be analysed. Such approach follows the conceptual framework proposed by the Intergovernmental Panel on Climate Change (IPCC) in the fifth Assessment Report which, in turn, is in line with the prevailing literature on risk reduction (Disaster Risk Reduction - DRR) (IPCC 2012; 2014b). According to that framework, the three dimensions of risk previously defined (Hazard, Exposure and Vulnerability) are quantified by means of case specific indicators from which the sectoral climate risk indexes are calculated and mapped. This index-based approach is widely used in the literature, furthermore it has been adopted within the Italian National Plan for Adaptation to Climate Change (MATTM, 2017).
The **climate risk indexes** are quantified on the basis of the general formula:

$$Risk = f(Hazard, Exposure, Vulnerability)$$

In this work, the general formula has been implemented with a combination of multiplicative and multi-criteria operators adapted to the four sectors assessed.

The analysis of multiple risks, multiple receptors and multiple climatic scenarios generates a huge number of possible combinations. The current work has opted for a statistical approach, aimed at providing both synthesis by means of averaged results and maps of risk, and also extensive documentation of the various sources of uncertainty and their effects on final results. Therefore, the results are presented as sets of maps (and related statistical summaries), focused on highlighting the diversity of situations within the study area, taking due account of the uncertainty deriving from the different data sources considered, such as the multiplicity of possible future scenarios.

This issue of VIU WPs reports on the results of the the analysis of the exposure of economic activities and vulnerability of local socio-ecosystems and the analysis of climate related risk, the preious reported the assessment of climatic hazards, while a third WP of this series reports on a demonstration study for climate-proofed solutions for local development.

2 Sectoral risk assessments

2.1. Summer tourism

The Belluno tourism system is part of a regional context – the Veneto Region – that ranks fourth in Europe for the number of tourist arrivals and which produces 11.5% of GDP of the regional economy[1].

Tourism represents one of the main sectors of the local economy, and a fundamental driving force to counterbalance historical phenomena such as demographic decline and land abandonment. Its recreational opportunities and the stunning natural landscapes of Dolomitic peaks, make the Belluno Province a very popular tourism destination, in both winter and summer season.

As all the other economic activities related to nature and open spaces, the sector is exposed to short and long-term climatic impacts. Natural disasters can negatively affect the recreational opportunities offered by mountain landscapes, tourist accommodation structures and infrastructures, and also indirectly affect mobility. The geneal SERRA framework has been adapted to the case of summer tourism as reported in Figure 2.1.

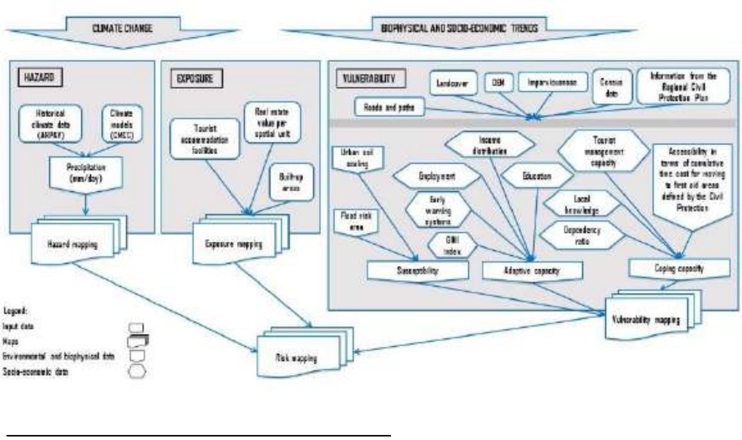

Fig.2-1
Graphical representation of the risk assessment of the summer tourism sector.

[1] Elaborations of Statistical Office of Regione del Veneto on Eurostat data, 2016

In the activities related to the combination of WP from 1 to 4, the climate risk analysis focuses on direct damages to tourist accommodation facilities, by considering possible local variations of hazard, the location of the exposed assets and the vulnerabilities of the social systems.

2.1.1. Climatic hazard

As previously described, the climatic hazard is defined on the basis of the intensity of a selection of indicators and the probability that intense phenomena (defined as extreme or exceptional) will occur within defined time frames, i.e. with various return periods. The intensity of the selected indicators represents the magnitude of the events (hazards) which is combined with physical and structural factors of the exposed assets (exposure) and the local socio-economic factor (vulnerability) through mathematical relationships that express the relative damage of exposed assets as a function of the magnitude of extreme events of different types. Both in the case of the data collected from the ArpaV stations and the climatic variations mapped on the geographical grid points of the climate models, if a significant spatial variability of the variables considered is identified (depending e.g. on geomorphological and biophysical factors), the scattered values are interpolated using trend surfaces. Otherwise, homogeneous values are used over the entire province due to the limited extension of the study area with respect to the spatial dimension of the climatic phenomena considered.

The main type of extreme climatic event of interest for the summer tourism sector is extreme precipitation that can generate floods. This event can lead to inconveniences and safety problems linked to the nature of the emergency (for example, temporarily limiting the accessibility of the civil protection bodies or tourists themselves to the accommodation facilities in the area) and long-term economic impacts (direct impacts on the viability of the structures or indirect effects on the tourist attractiveness of a certain area).

For this sector, the study focuses on the hazard associated with heavy precipitation events that occur in the summer season and can damage building first floor and content. It is expressed in millimetres of rain per day and mapped for a 100-year return period on summer historical data (1981-2010) and on the summer variations produced by the simulations of the COSMO-CLM and EURO-CORDEX models' ensemble mean, considering two time windows (2012-2041, 2036-2065) and two scenarios (RCP 4.5 and 8.5).

In the case of the historical data, an overall linear trend is found, with increasing precipitation intensity values from north-west to south-east, i.e. from the Dolomite peaks of the South-Eastern Alps towards the Prealps bordering the Po Valley. This trend is assumed to be indicative of the current climatic condition:

- based on the information available in terms of the extension of the historical series (sometimes below the conventional period of 30 years), and the location of the stations, on which more complex interpolation methodologies (e.g. ordinary kriging) do not offer significant differences in terms of spatialization;
- in consideration of the nature of the phenomenon itself, typically variable on a regional scale and influenced by the complex orography of the Belluno area;
- as acknowledged by ArpaV reports on annual precipitation[2]

Summer climatic variations calculated on the grid points, are interpolated, and demonstrate:

- a growing linear west to east trend for EURO-CORDEX models' ensemble mean and south to north trend for the COSMO model (2036-2065, RCP8.5);
- a growing linear south-west to north-east trend for EURO-CORDEX models' ensemble mean and south-east to north-west trend for the COSMO model (2036-2065, RCP4.5).

2.1.2. Exposure

Exposure to extreme precipitation events is defined according to the physical characteristics of the tourist facilities and the structural and infrastructural elements of the road networks that ensure accessibility to the area. Specifically, the estimation of the direct damage produced by these events must consider the geolocation of the real estate assets for tourist accommodation (structures with beds, e.g. hotels, bed & breakfasts, hostels, etc.), monetary value per unit of surface area (building or restoration / reconstruction cost), surface area in square meters or land value, as

2 https://www.arpa.veneto.it/arpavinforma/indicatori-ambientali/indicatori_ambientali/clima-e-rischi-naturali/clima/precipitazione-annua/view

well as repair and reconstruction costs defined as a fraction of the total value, subsequently modulated by the vulnerability associated with each type of extreme events. If the exact geolocation of each building is not available, a data downscaling procedure can be carried out on a municipal basis, by dividing the number of tourist accommodation facilities on spatial units of a larger geographical scale proportionally to a subset of tourist facilities, whose geographic coordinates are known (i.e. via OpenStreetMaps). The exposed area is then mapped in terms of square meters as a fraction of the total built-up area.

The exposure map is created by the multiplicative intersection of the exposed surfaces of the buildings by 15% of their monetary value (Molinari et al., 2020) and expressed on a monetary and normalized scale between 0 and 1 (Figure 4 2). In both cases the value 0 indicates the absence of assets exposed to risk for which, regardless of the magnitude of the event and the vulnerability, the result in terms of expected damage (potential risk) is, in any case, zero. In the case of normalized values, the value 1 corresponds to the existing highest value observed. In the case of monetary values, these are attributed to the various assets exposed in relation to the cost of reconstruction or restoration in € per unit of exposed surface.

Data show that Cortina d'Ampezzo exhibits the highest exposure, with property values that tend to be higher than the surrounding areas (Figure 2-2). The estimated potential exposure amount to 427,960,494 € over the whole Belluno Province.

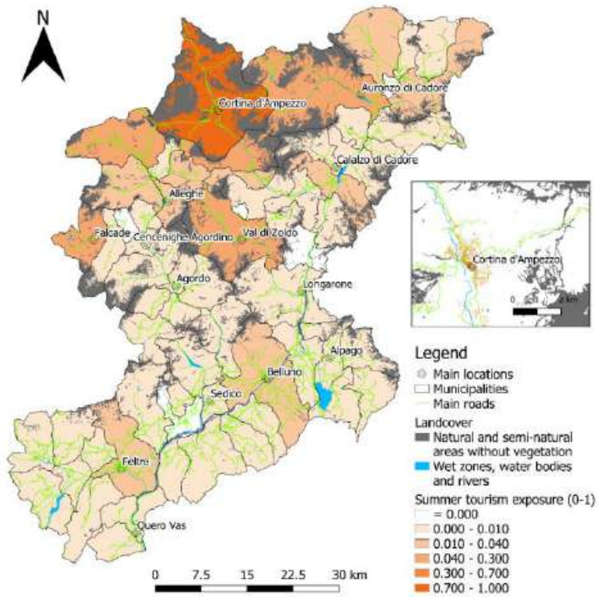

fig. 2-2
Summer tourism exposure at municipality level, normalized between 0 and 1 (left); detail of Cortina d'Ampezzo at 25 m resolution (right); landcover overlaid to highlight those area where exposed assets are typically not present.

2.1.3. Vulnerability

Vulnerability is identified by evaluating three components:

i. **Coping capacity** is the ability of people, organizations and systems, through the use of available skills, resources and opportunities, to face, manage and overcome adverse conditions (IPCC, 2012).

ii. **Adaptive capacity** is the combination of the strengths, attributes and resources available to an individual, community, company or organization that can be used to prepare for and take action to reduce negative impacts, limit damage or exploit positive opportunities (IPCC, 2012).

iii. **Susceptibility** is the probability that the receptors can be potentially damaged by any hazard due to their structural factors, types and charac-teristics (Giupponi et al., 2015).

For the summer tourism sector, the **coping capacity** is interpreted as the possi-bility of promptly intervening to secure the tourist facilities, avoid further damages and therefore guarantee the restoration of the original conditions of the premises in the shortest possible time. Therefore, the minimum travel times necessary to reach each structure are considered, starting from the rescue areas identified in the Pro-vincial Civil Protection Plan, as the timeliness of aid may be limited by the possibly unfavourable geographical location. Socio-economic information such as in-terna-tional tourist stays are also considered, together with the number of available beds in relation to the peak of tourist stays and the number of people belonging to the weakest sections of the population.

The **adaptive capacity**, on the other hand, is expressed as the ability of local tourism systems to implement strategies and measures to prevent damages re-sulting from extreme climatic events, for example through early warning systems, and through proxies of the ability of a population to adapt to exceptional events. Structural socio-economic information such as employ-ment and education levels, the distribution of income in relation to the resident population and the level of social inequality (Gini index) are considered.

For extreme precipitation events, the **susceptibility** (physical aspects) of buildings for tourist use ultimately depends on the morphology of the territory and the sealing of the soil deriving the degree of urbanization and flood risk defined by previous studies (see Table 2-1).

Table 2 1 shows the details of the individual indicators used for the summer tourism sector.

Table 2-1. Vulnerability indicators for summer tourism.

	Indicators	**Motivation and calculation methodology**
Coping capacity	Dependency ratio	A low ratio of dependency of weaker groups on the total population can determine a better capacity of managing critical situations. The ratio is calculated on ISTAT census units (2011): *(population >= 10 years old AND population <= 74 years old) / total population* To avoid outliers, in the census units with total population < 10, the indicator is assumed equal to 1 i.e. maximum coping capacity and minimum vulnerability.
	Tourist management capacity	A high ratio as the proportion of tourist beds over the number of stays during peak season) implies a better management of tourism flows. The ratio is calculated on ISTAT data (2015; 2018) at municipality level: *beds per accommodation facility by ATECO code 55(1,2,3) / seasonal peak of tourists*

	Local knowledge	A high share of international tourists denotes a higher vulnerability due to the lower knowledge of the local context (e.g. communication problems). The ratio is calculated on ISTAT data (2015; 2019) at municipality level: *total population / sum of tourists coming from abroad in the summer season (June to September)*
	Accessibility in terms of cumulative time cost for moving to first aid areas defined by the Civil Protection	Tourism establishments located in remote areas are more vulnerable since they are less easily accessible in case of natural disruption. A cumulative travel cost analysis is carried out at 25 m resolution with the r.cost algorithm of the GRASS plugin available in the processing toolbox of QGIS, using the cost map without railways but unrestricted access to regulated roads for motorized vehicles, and first-aid hotspots as defined in the Civil Protection Plan.
Adaptive capacity	Early warning systems	An extensive presence of early warning systems for extreme precipitation, enhances adaptive capacity. Early warning systems for flooding events are defined in the Civil Protection Plan (boolean).
	Education	High levels of education positively relate to adaptive capacity. The ratio is calculated on ISTAT census units (2011): *people with high school diploma / total population* To avoid outliers, in the census units with total population < 10, the indicator is assumed equal to 1 i.e. maximum adaptive capacity and minimum vulnerability.
	Employment	A higher rate of employment positively relates to adaptive capacity. The ratio is calculated on ISTAT census units (2011): *employed population / total population* To avoid outliers, in the census units with total population < 10, the indicator is assumed equal to 1 i.e. maximum adaptive capacity and minimum vulnerability.
	Income distribution	Spatial income distribution positively relates to adaptive capacity in those areas with highest economic resources. The ratio is calculated on ISTAT data (2017, 2019) at municipality level: *total sum of income across income brackets/total population* Missing records for taxpayers <= 3 (statistical confidentiality) are assumed equal to 0.
	GINI Index	A higher income inequality leads to a lower adaptive capacity. The GINI Index is calculated on ISTAT data (2017), with the function "Gini" of the "ineq" package of R, at the municipality level Missing records for taxpayers <= 3 (statistical confidentiality) are assumed equal to 0.
Susceptibility	Urban soil sealing	Soil sealing due to urbanization increases susceptibility, because of the accumulation of water in urban areas downstream of drainage surfaces. Resampled imperviousness from Copernicus records (2015) at 25 m resolution In case of areas with missing information because of the cloud cover, a value of 0 was assigned after having verified the lack of settlements from earth observation imagery.

	Flood risk area	Susceptible areas to hydrogeological instability, on the basis of the orography that determines surface runoff in the direction of areas subject to water accumulation. A surface runoff analysis is carried out at 25 m resolution using TerrSet, including information of areas at risk of flooding (boolean), according to the Civil Protection Plan and the "Piano di Assetto Idrogeologico" (PAI).

The stack of indicator maps is then aggregated through a multi-criteria analysis, to produce the vulnerability map. To express the relative importance of the various indicators in contributing to the determination of vulnerability, weights are adopted, defined through an expert elicitation exercise carried out with experts of the sector involved in the project. The inherently subjective weight vectors provided by the experts are subject to the analysis of the uncertainty, to quantify the role of such subjectivity on the final results, together with other sources of uncertainty. The normalized indicators are therefore weighted using 9 weight vectors reported.

The multi-criteria aggregation of the indicators is carried out with the OWA methodology which applies a second set of weights to modulate the addictiveness of the aggregation. With such method different risk attitudes of decision makers can be represented with a vector of weights applied to the ordered values of each single pixel of the map: a "risk averse" (or pessimistic attitude) can be represented by giving relatively high weights to those indicators that show relatively bad performances; a "risk taker" (or optimistic attitude) can be expressed by higher weights given to those indicators that perform better; a "balanced" attitude can be expressed by relatively high weights given both to good and bad indicators, with lower weights given to those with average performances. With such approach, an additional element of uncertainty is included in the uncertainty analysis, reflecting the possible variability of the decision-making approach to risk management. Therefore, OWA is applied by considering three risk profiles with corresponding ordered weights, to aggregate coping capacity, adaptive capacity and susceptibility indicators. A total of 27 vulnerability maps are produced, with a normalized scale between 0 and 1. Case 0 indicates a theoretical situation of absence of vulnerability, in which, whatever the entity of the structures or assets exposed and whatever the magnitude of the event, the result in terms of expected damage (potential risk) is zero. On the contrary, the value 1 indicates the situation of maximum vulnerability, in which the climatic event can determine the maximum theoretically possible damage.

The higher values of vulnerability are found in the valleys, flat areas near the hydrographic network, specifically in the areas of Ampezzano, Agordino, Cadore, Valbelluna and Feltrino, with local variability depending on the weighting scheme. Figure 2-3 presents the vulnerability map at 25 m resolution, showing the average trend of all possible combinations of weights and decision-making attitudes.

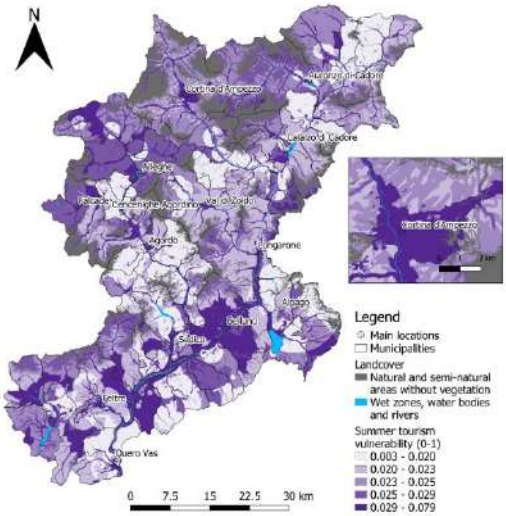

fig. 2-3
Summer tourism vulnerability map to extreme precipitation at 25 m resolution (left); detail of Cortina d'Ampezzo at 25 m resolution (right); average trend of all possible combinations of weights and decision-making attitudes; more vulnerable areas shown with a greater colour intensity; landcover overlaid to highlight those area where exposed assets are typically not present

2.1.4. Risk

The risk analysis is carried out by multiplicative intersection of the hazard, exposure and vulnerability maps, thus obtaining an estimation of the proportion of the total value of the assets exposed at risk. In practice the non-dimensional map of hazard multiplied by the monetary map of exposure generates an estimation of the expected damages, which can be reduced when the vulnerability of the area in which the assets are located is lower than 1. The intermediate products and the results of the risk analysis are reported in tabular and cartographic form, through aggregated representations and descriptive statistics and with the use of metrics that allow communicating the variability and uncertainty of the results.

In the case of summer tourism, 27 historical risk maps are produced, equal to the number of vulnerability maps. Concerning climatic variations, 216 future risk maps are produced by the factorial combination of the 27 vulnerability maps and the 8 hazard maps (the latter in turn given by the combinations of models, scenarios and time windows), under a 100-year return period.

From the stack of risk maps a series of summary maps are then produced to present the average trends and the uncertainty associated with their calculation. The average map and that of the coefficient of variation (CV - percentage of the ratio between standard deviation and mean) are therefore calculated to deliver a concise picture of the results.

In the case of historical risk, the uncertainty depends on the different types and weighting strategies used in mapping the vulnerability. Concerning future climatic risk, the mean maps and the percentage CVs are calculated per each time window (2012-2041, 2036-2065), resulting in total of 4 maps. In this case, the uncertainty depends not only on the different types and weighting strategies used in the mapping of vulnerability, but also on the climate models and on the scenarios considered.

To highlight the areas of the province that present the greatest variations in terms of risk values, the difference between the risk estimated on historical data and that estimated over the 2012-2041 and 2036-2065 time windows is calculated. For communication purposes and display of the information originally assessed at 25 m resolution, average maps are eventually aggregated at the municipality level by sum (Figure 2-4), while the CVs are aggregated by averages (Figure 2-5).

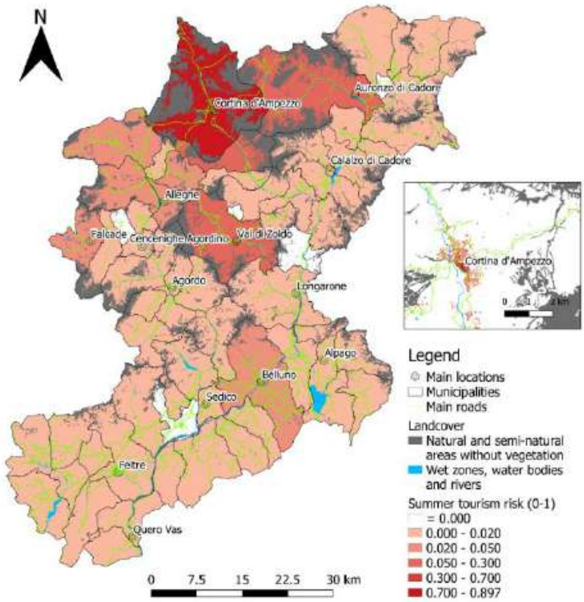

fig. 2-4
Estimated summer tourism climatic risk for extreme precipitation events with a 100-year return period, in the 2036-2065 time window (left); detail of Cortina d'Ampezzo at 25 m resolution (right); normalized spatial pattern between 0 and 1, where 1 corresponds to the maximum risk detected under the risk averse attitude; landcover overlaid to highlight those area where exposed assets are typically not present.

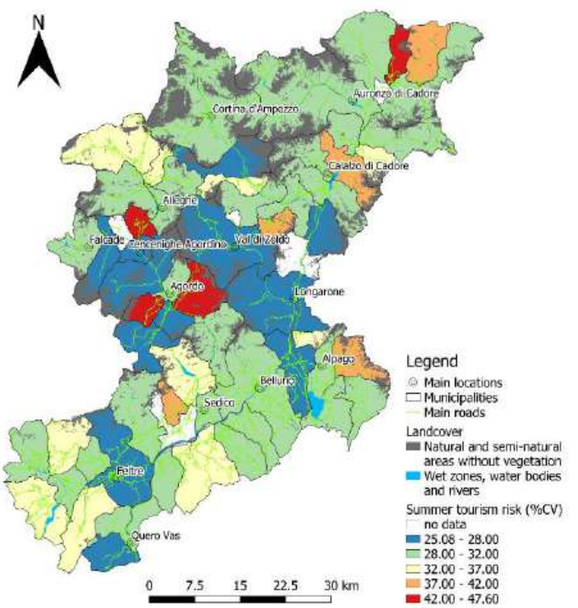

fig. 2-5
Uncertainty of the risk map in **Errore. L'origine riferimento non è stata trovata.**, calculated as percentage of the ratio between standard deviation and mean (CV), in this example by considering multiple indicator weights, risk attitudes, scenarios and models; landcover overlaid to highlight those area where exposed assets are typically not present.

At last, by further aggregating historical and future risk maps over the whole Belluno Province, we found up to about 6.7% increase in climate risk in the 2036-2065 time window, for extreme precipitation events with a 100-year return period (**Errore. L'origine riferimento non è stata trovata.**). Moreover, we found that about 60% of the value of this risk is located in the municipality of Cortina d'Ampezzo.

Table 2-2. Estimated monetary value of climate risk (€/event) for the summer tourism sector in the 2012-2041 and 2036-2065 time windows, over the whole Belluno Province, due to extreme precipitation events with a 100-year return period.

Extreme precipitation						
Risk profiles	2012-2041	Difference with the estimated current risk		2036-2065	Difference with the estimated current risk	
all*	9,642,939 €	363,405 €	3.92%	9,902,107 €	622,572 €	6.71%
balanced	9,694,039 €	365,318 €	3.92%	9,954,545 €	625,824 €	6.71%
risk averse	10,744,128 €	404,892 €	3.92%	11,033,019 €	693,783 €	6.71%
risk taker	8,490,652 €	320,004 €	3.92%	8,718,756 €	548,108 €	6.71%
Range	2,253,476 €	-	-	2,314,262 €	-	-

2.2. Eyewear industry

The Belluno Eyewear District represents the second leading sector of the economy of local communities and consists of the design and production of eyeglass frames, sunglasses, small parts, machinery and production equipment, galvanic treatments, cases and lenses. About 80% of national production is concentrated in this area and the four multinational companies in the district (Luxottica, Safilo, Marcolin, De Rigo) alone account for 70% of the world eyewear market[3].

Interruption of the access to businesses may occur because of

[3] https://www.trevisobellunosystem.com/tvsys/home/archivio-news/13406_distretto-dellocchialeria-bellunese.html

intense climatic events, affecting the infrastructure transport network:

- extreme precipitation that can generate landslides and floods;
- wind gusts that can cause tree fall.

In the activities related to the combination of WP from 1 to 4, the climate risk analysis focuses on indirect damages to the industrial production system of the eyewear industry sector, emerging from impediments to logistics and commuting, by considering possible local variations of hazard, the location of the exposed assets and the vulnerabilities of the social systems, i.e. (i) the geo-positioning and economic importance of the production plants, (ii) the transport infrastructure network for the supply of raw materials and distribution of final products and (iii) the transport infrastructure network for the movement of workers to and from their workplaces.

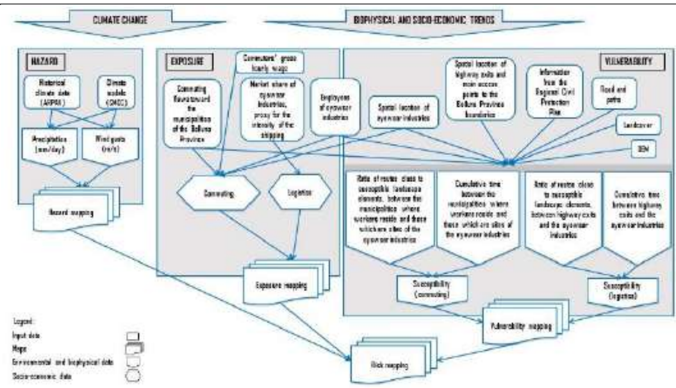

fig. 2-6 Graphical representation of the risk assessment of the eyewear industry sector.

2.2.1. Preliminary survey

We designed a survey to acquire further insights on the past climatic events in the area of Belluno and collect information on the recorded damages. The questionnaire was sent to the eyewear sectorial federation, ANFAO, which accounts about 140 companies in the studied area. The respondent rate is about 5% and therefore, results will be interpreted mostly in a descriptive way, with the sole scope of contributing to the validation of the formal analysis.

The questionnaire was structured in two parts: in part one we collected socio-economic information of the firms and their employees while in part two we asked for past weather-related events and their aftermaths.

The sample is mostly composed by small and medium enterprises, with an average number of 47 employees, and average revenues in 2019 equal to 11 million of €, which is quite representative of the industrial fabric. Interestingly, all the respondents declared that more than 50 % (mix 55%- max 94%) of their employees are commuters, hence validating the relevance of our study on the effects of disruptive events for the commuting phenomenon.

With reference to the period 2015-2020, participants were asked about the number of events with direct and indirect effects on the production activity. About 40% of respondents declared to have suffered damages as a consequence of weather-related events. These events were linked to intense precipitation (1-10 events), snowfalls (2-4 events), wind gusts (1-5 events), floods (2 events), and landslides (2 events).

We asked them to name and describe the worst two events and their economic negative effects of the business activity. Not surprisingly, "Vaia" storm was mentioned as the worst event in the last 5 years, with, on average, 6 days of stop production, due to lack of electricity. This even led to economic losses due to missing deliveries and supplies (up to 150'000€), lack of staff and missed production (up to 150'000€). Moreover, wind gusts phenomena seem to be quite disruptive for the business activity, due to tree falls and consequent damages for the infrastructures and buildings, leading to delays in deliveries and impossibility for the employees to reach the workplace.

These results confirm the severe effects of such events on the local economy and the importance of monitoring them and develop adaptive capabilities for the future. Given the expected increase in the frequency and magnitude of climate events, enterprises need to implement strategies to cope with them and minimize the negative effects. Against this framework, about 30% of respondents declared to have taken an insurance against natural disaster while the rest is considering the possibility of insuring. Moreover, respondents declared to have undertaken some investments to prevent future damages. For instance, concerning lack of electricity, they declared to have purchased power generators and upgraded continuity groups. To avoid damages caused by tree falls, they prune and cut trees adjacent to their structures and infrastructures.

2.2.2. Climatic hazard

The main types of extreme climatic events of interest for the eyewear industry sector are extreme precipitation that can generate landslide and floods, and wind gusts that can cause tree fall, both affecting the transport infrastructure network. These events can lead to long-term economic impacts i.e. indirect effects on economic activities of eyewear industries.

Thus, for this sector, the study focuses on the hazard associated with the following events:

- heavy precipitation, expressed in millimeters of rain per day and mapped for a 100-year return period on annual historical data (1981-2010) and on the annual variations produced by the simulations of the COSMO-CLM and EURO-CORDEX models' ensemble mean, considering two time windows (2012-2041, 2036-2065) and two scenarios (RCP 4.5 and 8.5);
- wind gusts, expressed in meter per second and mapped for a 100-year return period on annual historical data (1981-2010) and on the annual variations produced by the simulations of the COSMO-CLM and EURO-CORDEX models' ensemble mean, considering two time windows (2012-2041, 2036-2065) and two scenarios (RCP 4.5 and 8.5).

In the case of the historical data, an overall linear trend is found, with increasing precipitation intensity values from north-west to south-east, i.e. from the Dolomite peaks of the South-Eastern Alps towards the Prealps bordering the Po Valley. This trend is assumed to be indicative of the current climatic condition:

- based on the information available in terms of the extension of the historical series (sometimes less than the conventional period of 30 years), and the location of the stations, on which more complex interpolation methodologies (e.g. ordinary kriging) do not offer significant differences in terms of spatialization;
- in consideration of the nature of the phenomenon itself, typically variable on a regional scale and influenced by the complex orography of the Belluno area;
- as acknowledged by ArpaV reports on annual

precipitation[4].

In the case of the annual climatic variations calculated on the grid points, these are interpolated, demonstrating:

- a growing linear south-west to north-east trend for EURO-CORDEX models' ensemble mean and north to south trend for the COSMO model (2036-2065, RCP8.5);
- a growing linear south-west to north-east trend for EURO-CORDEX models' ensemble mean and north-east to south-west trend for the COSMO model (2036-2065, RCP4.5).

The linear spatial interpolation is also applied to wind gust historical series and climatic variations but in this case an existing spatial trend is not acknowledged and the produced linear trends are less reliable, although representing the spatial variability of hazard better than a simple average. Moreover, historical series covering at least 20 years are only available for 10 ArpaV weather stations, mostly located in the northern part of the Belluno Province. Concerning variations, EURO-CORDEX models' ensemble mean returns weak increasing trends, up to around 5% while the COSMO model shows negative variations in the northern part of the province (**Errore. L'origine riferimento non è stata trovata.**), even with a wider percentage range.

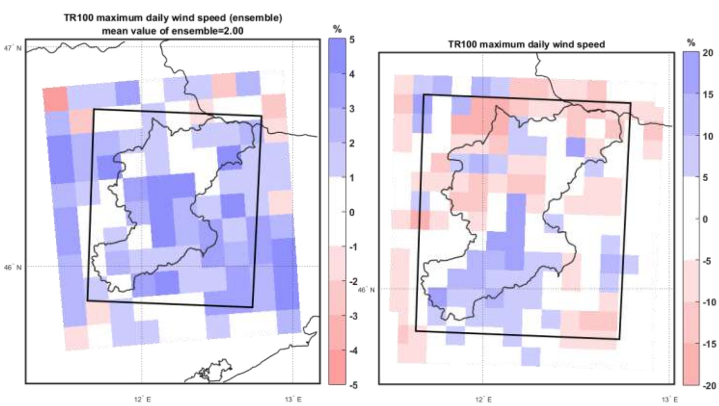

fig. 2-7
Percentage variation of wind gusts for events with a return period of 100 years in the 2036-2065 time window, under the RCP8.5 (CORDEX left; COSMO right).

[4]https://www.arpa.veneto.it/arpavinforma/indicatori-ambientali/indicatori_ambientali/clima-e-rischi-naturali/clima/precipitazione-annua/view

2.2.3. Exposure

Two main dimensions of the eyewear industry sector are well acknowledged to suffer indirect damages from climate hazards: logistics and employees commuting. The interruption of the access to businesses may occur because of intense climatic events affecting the transport infrastructure network. Such events can limit or prevent the accessibility to production sites, affecting product deliveries and workers' access to production plants. Exposed values are therefore located at firm production sites.

The total value of hours worked by employees who do not work in the municipality where they reside (commuters) is used as an estimate for the exposure of **commuting**, in monetary terms.

E=commuters *8 hours of work*11.01 €

with 11.01 € [5]: gross hourly wage, under the ISTAT ATECO code 32 "*altre industrie manifatturiere*" and the category "*operaio*". The number of commuters is estimated at municipality level, by combining Veneto Region geodata on commuting with sector-specific information from ANFAO, including firm addresses and number of employees.

The market share of each firm is used as a proxy for the intensity of the shipping i.e. **logistics**, with higher number of missed transactions in case of climatic extreme event deriving from higher shares. For a monetary estimation the annual revenue from ANFAO data is used with the same rationale, which may overestimate the exposure, but no better information was found to feature logistics in the analyzed sector.

The exposure map is expressed on a monetary and normalized scale between 0 and 1 (Figure 2 8 and Figure 2 9), per individual firm or at municipality level. In both cases the value 0 indicates the absence of assets exposed to risk for which, regardless of the magnitude of the event and the vulnerability, the result in terms of expected damage (potential risk) is, in any case, zero. In the case of normalized values, the value 1 corresponds to the existing highest value observed. In the case of monetary values, these are attributed to the various assets exposed in relation to the business losses in € per day.

The municipalities of Longarone, Sedico, Agordo and Cencenighe Agordino are headquarters of the most important production sites in the Belluno Eyewear District and thus exhibit exposure values that tend to be much higher than the surrounding areas (Figure 2-8 and Figure 2-9). Other clusters of firms can be

5 http://dati.istat.it/index.aspx?queryid=33377

found in Cadore and Basso Feltrino, and in general in the south-eastern half of the Belluno Province. The estimated potential exposure amount to 2,705,280 €/day for logistics and to 872,927.3 €/day for commuting, over the whole Belluno Province.

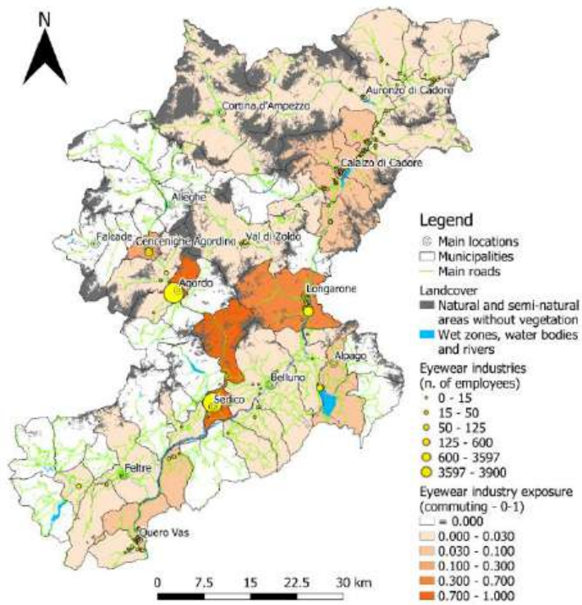

fig. 2-8: Eyewear industry commuting exposure, normalized between 0 and 1, shown together with individual firms represented with a size proportional to the number of employees; landcover overlaid to highlight those area where exposed assets are typically not present.

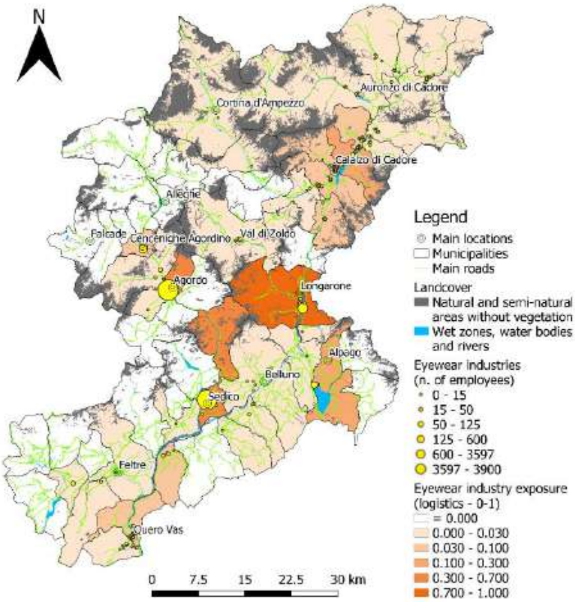

fig. 2-9: Eyewear industry logistic exposure, normalized between 0 and 1, shown together with individual firms represented with a size proportional to the number of employees; landcover overlaid to highlight those area where exposed assets are typically not present.

2.2.4. Vulnerability

As commuting and logistics can be affected by intense climatic events damaging the transport infrastructure network, its morphology clearly plays a major role in defining the landscape susceptibility. Vulnerability is therefore intrinsic to topographic elements (transport infrastructures) connecting sources and destination of goods, raw material and people i.e. business losses, defined multiple spatial locations within and outside the Belluno Province, frame a complex mountain landscape.

In the analysis of commuting for the eyewear industry sector a public dataset from the Veneto Region geodata repository is used, showing the absolute value of commuters per each origin/destination pair (ISTAT codes), where an origin is defined as the municipality in which workers reside while a destination is the municipality where people work.

The number of commuters per each origin/destination pair is compared to the total number of workers in the destination municipality (commuters/tot. number of workers). This ratio is then applied to the number of workers in the eyewear companies, estimated from ANFAO data at municipality level. In this analysis, only firms with more than three workers are considered.

To provide a realistic picture of the commuting phenomenon, only flows of people greater than 10 are considered. As a result, 55 relevant origins are found for the sector, 10 of these are located outside the Belluno Province, and 14 destinations.

A travel-cost analysis is then performed by using the cost map with railways but restricted access to regulated roads for motorized vehicles:

- to compute the cumulative time (in seconds) between the municipalities of origin (those where workers reside) and those of destination (sites of eyewear industries with significant commuting flows, as previously defined);
- to compute the ratio between cells at 25 m resolution close to susceptible areas, i.e. flood and landslide areas (weighted according to the Civil Protection Plan) and wooded areas (weighted on the tree fall probability observed from recent events by tree cover type), and total cells along the routes between origin and destination. The calculation is performed twice for extreme precipitation i.e. for flood and landslide areas, and once for wind gusts i.e. for wooded areas.

The rationale of this travel cost analysis is twofold: (i) estimating the travelling time between origins and destinations; (ii) estimating the percentage of travel exposed to climatic hazards which, in case of extreme events, makes it harder to reach destinations.

The travel-cost analysis outputs, disaggregated by origin/destination pairs, are then weighted on the estimated number of commuters of each route, so as to aggregate the result by destination, i.e. at municipality level.

Concerning logistics, the Belluno Province is classified into 11 clusters, each one accessible through four main routes (one per cardinal point). Routes connect highway exits to the eyewear firms of each cluster through its defined access points. This way of tracing logistic routes is recognized by Confindustria Belluno.

In a similar fashion to the analysis of commuting, another travel-cost analysis is then performed per each firm of each cluster:

- to compute the cumulative time (in seconds) between highway exits and the eyewear firms;
- to compute the ratio between cells at 25 m resolution

close to susceptible areas, i.e. flood and landslide areas (weighted according to the Civil Protection Plan) and wooded areas (weighted on the tree fall probability observed from recent events by tree cover type), and total cells along the routes between highway exits and the eyewear firms. The calculation is performed twice for extreme precipitation i.e. for flood and landslide areas, and once for wind gusts i.e. for wooded areas.

A similar interpretation to commuting holds but in this context the travel distance concerns the time between highway exits and the eyewear firms.

The travel-cost analysis outputs are averaged among the four cardinal points and then among firms, to map the results aggregated at municipality level.

To sum up, the cumulative time to travel from origins and destinations and the percentage of routes close to areas where precipitation may trigger floods or landslides, or wind gusts may knock down trees, represent the three components of **susceptibility** (differentiated by hazard type). As yet, **coping and adaptive capacity** indicators were not included, because those dimensions of vulnerability were considered of secondary relevance for the specific purposes.

The stack of indicator maps is then aggregated through a multi-criteria analysis, to produce a vulnerability map per each combination of hazard and exposed assets. To express the relative importance of the various indicators in contributing to the determination of vulnerability, weights are adopted. The weight vectors provided by the researchers involved in the project are inherently subjective and thus they are included in the analysis of the uncertainty to quantify the role of such subjectivity on the final results, together with other sources of uncertainty. The normalized indicators are therefore weighted using three weight.

The multi-criteria aggregation of the indicators is carried out with the OWA methodology which applies a second set of weights to modulate the addictiveness of the aggregation. With such method different risk attitudes of decision makers can be represented with a vector of weights applied to the ordered values of each single pixel of the map: a "risk averse" (or pessimistic attitude) can be represented by giving relatively high weights to those indicators that show relatively bad performances; a "risk taker" (or optimistic attitude) can be expressed by higher weights given to those indicators that perform better; a "balanced" attitude can be expressed by relatively high weights given both to good and bad indicators, with lower weights given to those with average performances. With such approach, an additional element of uncertainty is included in the uncertainty analysis, reflecting the possible variability of the decision-making approach to risk management. Therefore, OWA is applied by considering 3 risk profiles with corresponding ordered weights, to aggregate coping capacity, adaptive capacity and susceptibility indicators. A total of 9 vulnerability maps is produced per each combination of hazard and exposed asset i.e. extreme precipitation/logistics, extreme precipitation/commuting, wind gusts/logistics and wind gusts/commuting, with a normalized scale between 0 and 1. Case 0 indicates a theoretical situation of absence of vulnerability, in which, whatever the entity of the structures or assets exposed and whatever the magnitude of the event, the result in terms of expected damage (potential risk) is zero. On the contrary, the value 1 indicates the situation of maximum vulnerability, in which the climatic event can determine the maximum theoretically possible damage.

In the case of logistics, vulnerability generally shows an increasing south-to-north trend. For the combination extreme precipitation/logistics, the greatest vulnerability is denoted in the Ampezzano while Cadore/Comelico and Agordino have higher values depending on the adopted weighing scheme. Figure 2 10 presents the vulnerability map to extreme precipitation showing the average trend of all possible combinations of weights and decision-making attitudes. For the combination logistics/wind gusts, the greatest vulnerability is denoted in the Comelico, while Cadore, Ampezzano and Agordino show higher values than the southern part of the Belluno Province.

In the case of commuting, vulnerability generally shows a local pattern, given that main flows of commuters are limited to 14 municipalities but 4 of them host the main production sites. Among these, the greatest vulnerability is denoted in the municipalities of Agordo and Longarone. Figure 2-10 presents the vulnerability map to extreme precipitation, showing the average trend of all possible combinations of weights and decision-making attitudes.

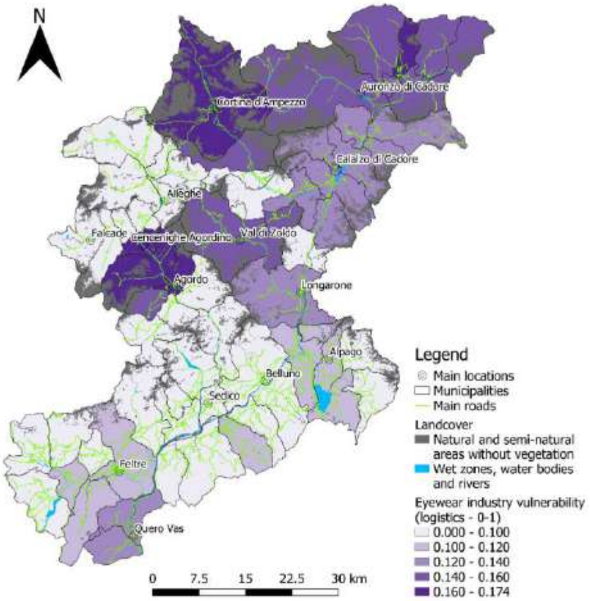

fig. 2-10
Eyewear industry logistic vulnerability to extreme precipitation; average trend of all possible combinations of weights and decision-making attitudes; more vulnerable areas shown with a greater colour intensity; landcover overlaid to highlight those area where exposed assets are typically not present.

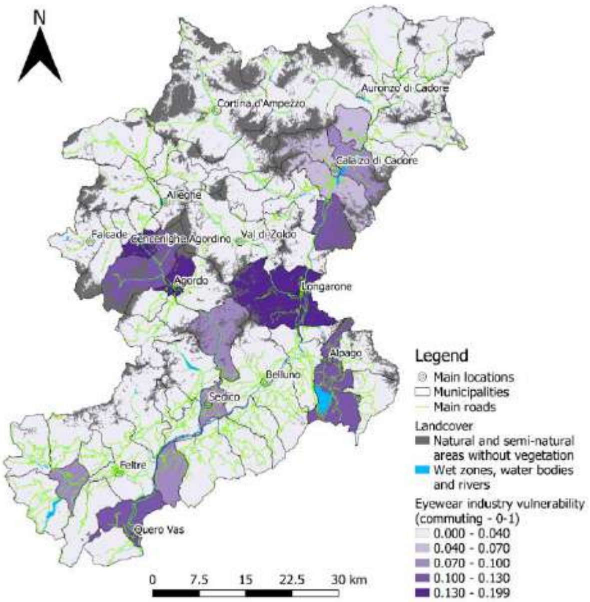

fig. 2.11
Eyewear industry commuting vulnerability to extreme precipitation; average trend of all possible combinations of weights and decision-making attitudes; more vulnerable areas shown with a greater colour intensity; landcover overlaid to highlight those area where exposed assets are typically not present.

2.2.5. Risk

The risk analysis is carried out by multiplicative intersection of the hazard, exposure and the vulnerability maps, thus obtaining an estimation of the proportion of the total value of the assets exposed at risk. In practice the non-dimensional map of hazard multiplied by the monetary map of exposure generate an estimation of the expected damages, which can be reduced when the vulnerability of the area in which the assets are located is lower than 1. The intermediate products and the results of the risk analysis are reported in tabular and cartographic form, through aggregated representations and descriptive statistics and with the use of metrics that allow communicating the variability and uncertainty of the results.

In the case of eyewear industry, 36 historical risk maps are produced, equal to the number of vulnerability maps per each combination of hazard and exposed asset i.e. extreme precipitation/logistics, extreme precipitation/commuting, wind gusts/logistics and wind gusts/commuting, under a return period of 100 years. Concerning climatic variations, 72 future risk maps are produced by the factorial combination of the 9 vulnerability maps and the 8 hazard maps (the latter in turn given by the combinations of models, scenarios and time windows), per each combination of hazard and exposed asset (resulting in a total number of 288 maps) under the 100-year return period.

From the stack of risk maps a series of summary maps are then produced to present the average trends and the uncertainty associated with their calculation. The average map and that of the coefficient of variation (CV - percentage of the ratio between standard deviation and mean) are therefore calculated to deliver a concise picture of the results.

In the case of historical risk, the mean maps and the percentage CVs are therefore calculated, resulting in 2 maps per each combination of hazard and exposed asset. The uncertainty depends on the different types and weighting strategies used in mapping the vulnerability. Concerning future climatic risk, the mean maps and the percentage CVs are calculated per each time window (2012-2041, 2036-2065), resulting in 4 maps per each combination of hazard and exposed asset. In this case, the uncertainty depends not only on the different types and weighting strategies used in the mapping of vulnerability, but also on the climate models and on the scenarios considered. Figure 2 12, Figure 2 13, Figure 2 14 and Figure 2 15 show mean maps and related CVs of both logistics and commuting exposed to extreme precipitation in the 2036-2065 time window.

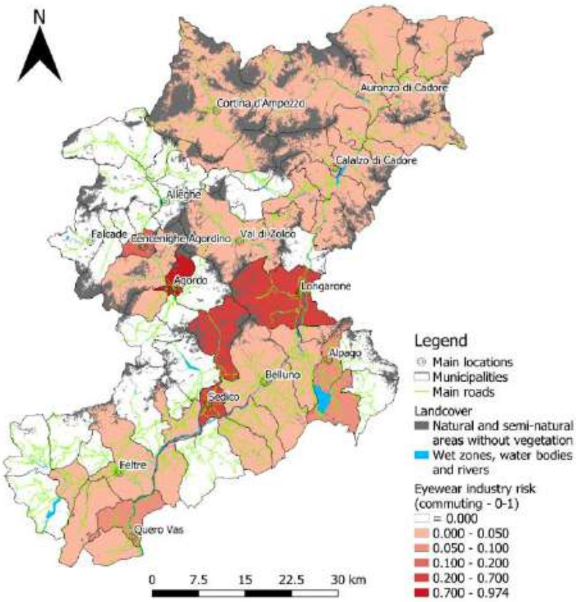

fig. 2-12
Estimated eyewear industry climatic risk for commuting and extreme precipitation events with a 100-year return period, in the 2036-2065 time window; normalized spatial pattern between 0 and 1, where 1 corresponds to the maximum risk detected under the risk averse attitude; landcover overlaid to highlight those area where exposed assets are typically not present.

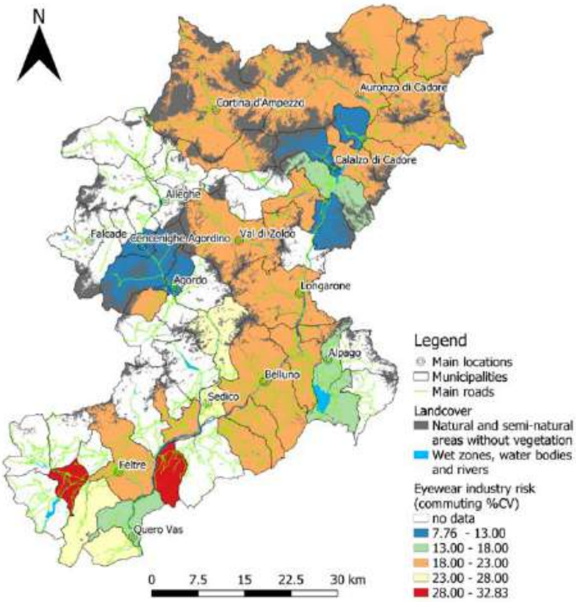

fig. 2-13
Uncertainty of the risk map in **Errore. L'origine riferimento non è stata trovata.**, calculated as percentage of the ratio between standard deviation and mean (CV), in this example by considering multiple indicator weights, risk attitudes, scenarios and models; landcover overlaid to highlight those area where exposed assets are typically not present.

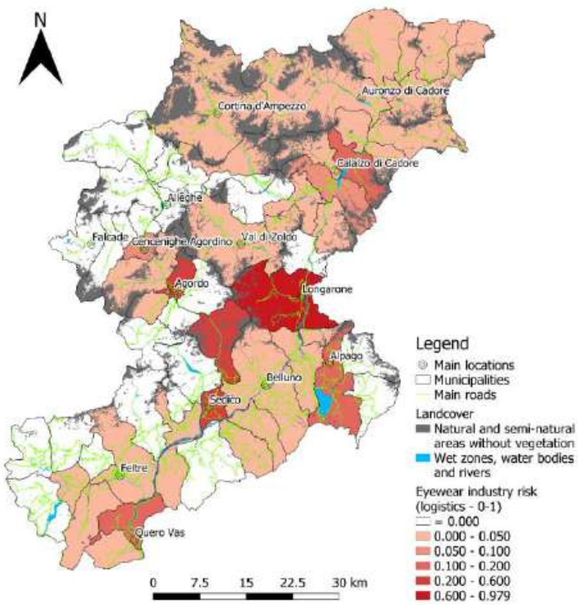

fig. 2-14
Estimated eyewear industry climatic risk for logistics and extreme precipitation events with a 100-year return period, in the 2036-2065 time window; normalized spatial pattern between 0 and 1, where 1 corresponds to the maximum risk detected under the risk averse attitude; landcover overlaid to highlight those area where exposed assets are typically not present.

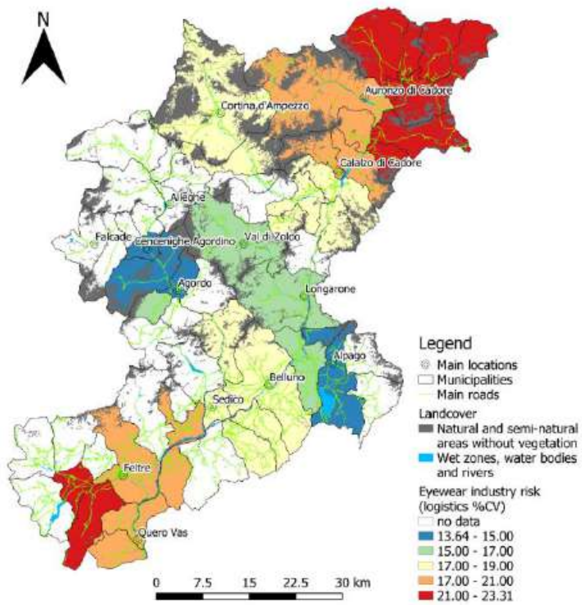

fig. 2-15
Uncertainty of the risk map in **Errore. L'origine riferimento non è stata trovata.**, calculated as percentage of the ratio between standard deviation and mean (CV), in this example by considering multiple indicator weights, risk attitudes, scenarios and models; landcover overlaid to highlight those area where exposed assets are typically not present.

To highlight the areas of the province that present a greatest variations in terms of risk values, the difference between the risk estimated on historical data and that estimated over the 2012-2041 and 2036-2065 time windows is calculated.

At last, by aggregating historical and future risk maps over the whole Belluno Province, we found up to 17.1% increase in the climate risk for extreme precipitation events with a 100-year return period, in the 2036-2065 time window (**Errore. L'origine riferimento non è stata trovata.**). The future risk for wood damages due to wind gusts, is not expected to be higher than that observed in the historical records, although it was found to be about twice the climatic risk of extreme precipitation. The climate risk for logistics was found to be about 2.5 times greater than that of commuting because logistics is estimated on the annual revenue of businesses, as a proxy of the intensity of shipping (as mentioned in Section **Errore. L'origine riferimento non è stata trovata.**). If this assumption is correct, the spatial pattern detected for logistic as well as the aggregated relative variability of risk over time would represent a reliable estimation for the sector, regardless the absolute value of exposed assets.

Table 2-3. Estimated monetary value of climate risk (€/day) for the eyewear industry sector in the 2012-2041 and 2036-2065 time windows, over the whole Belluno Province, due to extreme events with a 100-year return period.

Logistics - Extreme precipitation						
Risk profiles	2012-2041	Difference with the estimated current risk		2036-2065	Difference with the estimated current risk	
all*	139,734 €	9,861 €	7.59%	151,894 €	22,021 €	16.96%
balanced	140,417 €	9,907 €	7.59%	152,637 €	22,127 €	16.95%
risk averse	143,174 €	10,105 €	7.59%	155,630 €	22,561 €	16.95%
risk taker	135,611 €	9,571 €	7.59%	147,415 €	21,374 €	16.96%
Range	7,563 €	-	-	8,215 €	-	-
Commuting - Extreme precipitation						
Risk profiles	2012-2041	Difference with the estimated current risk		2036-2065	Difference with the estimated current risk	
all*	55,635 €	4,077 €	7.91%	60,384 €	8,826 €	17.12%
balanced	55,936 €	4,098 €	7.91%	60,713 €	8,875 €	17.12%
risk averse	57,235 €	4,194 €	7.91%	62,121 €	9,079 €	17.12%
risk taker	53,733 €	3,938 €	7.91%	58,317 €	8,522 €	17.11%
Range	3,502 €	-	-	3,804 €	-	-
Logistics - Wind gusts						
Risk profiles	2012-2041	Difference with the estimated current risk		2036-2065	Difference with the estimated current risk	
all*	307,603 €	1,397 €	0.46%	305,064 €	-1,142 €	-0.37%
balanced	307,398 €	1,396 €	0.46%	304,861 €	-1,141 €	-0.37%
risk averse	315,512 €	1,434 €	0.46%	312,910 €	-1,168 €	-0.37%
risk taker	299,899 €	1,361 €	0.46%	297,421 €	-1,117 €	-0.37%
Range	15,614 €	-	-	15,489 €	-	-
Commuting - Wind gusts						
Risk profiles	2012-2041	Difference with the estimated current risk		2036-2065	Difference with the estimated current risk	

all*	120,852 €	627 €	0.52%	119,825 €	-400 €	-0.33%
balanced	120,772 €	627 €	0.52%	119,745 €	-400 €	-0.33%
risk averse	124,542 €	646 €	0.52%	123,484 €	-411 €	-0.33%
risk taker	117,243 €	608 €	0.52%	116,246 €	-389 €	-0.33%
Range	7,299 €	-	-	7,238 €	-	-

2.3. Electricity distribution

Electricity supply is an essential service that needs to be guaranteed, especially for critical infrastructures such as hospitals, with potential business losses for companies in case of natural disasters that may temporarily affect energy provision. In the Province of Belluno, power grids are owned and managed by e-distribuzione and Terna.

In the activities related to the combination of WP from 1 to 4, the climate risk analysis focuses on direct and indirect damages to the power grids in the Province of Belluno which include, referring to distribution system, HV / MV and MV / LV substations and MV and LV lines. In the analysis the following aspects are considered: local climatic hazard and their future projections, the location of the exposed assets and their vulnerabilities, i.e. the features that may increase or decrease the risk related with a given asset exposed to a given hazard (e.g. overhead infrastructures). This work develops upon a methodological reference document "Assessment of the resilience of the electrical distribution grid: e-distribuzione approach" (2018 AEIT International Annual Conference) and, as a further development, includes consideration of vulnerability and the analysis of future scenarios of climate change. The analysis makes use of data at different level of detail and reports the results at the municipality scale or part of them.

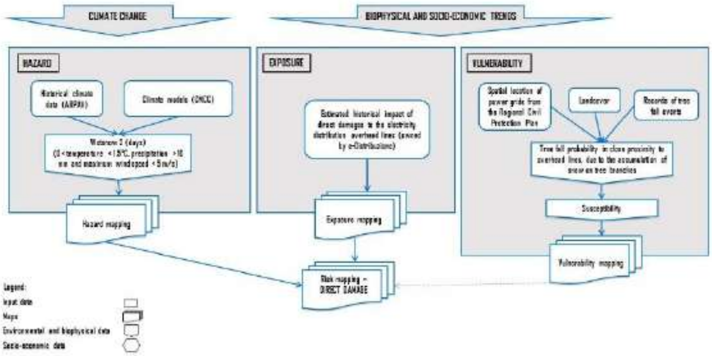

fig. 2-16
Graphical representation of the risk assessment of the electricity distribution sector (direct impacts); the dashed line refers to the first conceptualization of the methodology which includes consideration of vulnerability but, as requested, it was not applied in the final run of the model.

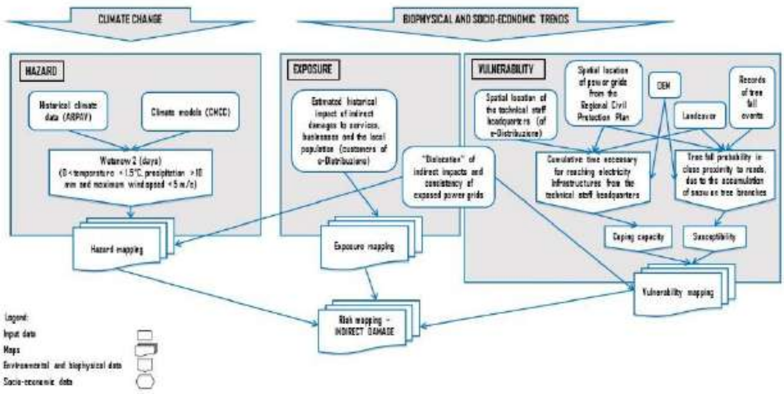

fig. 2-17
Graphical representation of the risk assessment of the electricity distribution sector (indirect impacts).

2.3.1. Climatic hazard

For the sector of electricity distribution, the climatic hazard refers to wet snow events causing heavy ice loads on overhead line conductors and on trees, which may fall on roads (and/or on electrical lines). These events can have direct impacts on distribution grids and indirect impacts to critical services and businesses due to lack of electricity supply.

Ice accretion on the overhead line bare conductors can be estimated by means of a hazard indicator, called "wetsnow", with two possible variants, i.e. wetsnow_01 (number of days with 0 < temperature < 1.5 °C and precipitation > 10 mm) and wetsnow_02 (number of days with 0 < temperature < 1.5°C, precipitation > 10 mm and maximum wind speed < 5 m/s). The second indicator (wetsnow_02, hereafter simply referred to as "wet snow") is closer to commonly adopted analyses of electrical companies and is thus adopted for the risk assessment.

Average data about damages are provided by e-distribuzione and referred to the period 2005-2019, while the historical frequency of wet snow days is calculated by CMCC on Arpa Veneto records for the period 1981-2010. The anomalies are produced by the simulations of the COSMO-CLM and EURO-CORDEX models, considering two time windows (2012-2041, 2036-2065) and two scenarios (RCP 4.5 and 8.5).

The analysis focuses on the winter season (December, January and February) which returns the widest anomaly among all seasons and the best spatial interpolation performance, especially for historical data, showing a statistically significant relationship with the elevation of Arpa Veneto stations.

The analysis is carried out for extreme events with 20, 50, 100 and 150-year return periods but only the 100-year threshold is adopted for risk assessment and mapping, in analogy with the evaluation of the other economic sectors.

In the case of indirect impacts, after consideration of the hazard mapping but before calculating the risk, a further step is necessary to quantify the indirect risk as a function of the "dislocation" of the impact per each return period, by weighting its components on the basis of the consistency of exposed power grids (provided by e-distribuzione). Therefore, the historical hazard and future anomalies are recalculated depending on the municipalities in which the impact originates (including/excluding the administrative unit being analyzed depending on whether there is a network consistency greater than 0). The calculation is iterated per each municipality and return period.

$$IH_{historical\ or\ variation,m,RP} = \frac{\sum_{i=1}^{f} H_{historical\ or\ variation,f,RP} * l_{f,RP}}{\sum_{i=1}^{f} l_{f,RP}}$$

with:

- $IH_{\text{(historical or variation,m,RP)}}$ = indirect value of the mth municipality in the corresponding return period RP
- $H_{\text{(historical or variation,f)}}$ = direct value of the fth municipality which indirectly affects the mth municipality in the corresponding return period RP
- $l_{(f,RT)}$ = exposed length of power grids in the fth municipality for an event occurring under the corresponding return period RP

As an example, assuming a municipality A characterized by a high local hazard (e.g. $H_{(historical,A,100)}$) and, at the same time, a high length of exposed power grids (e.g. $l_{(A,100)}$), together with other municipalities (e.g. B, C and D) in which there is only a minor exposure, all of them indirectly affecting customers of municipality E, the indirect hazard of E ($IH_{(historical,E,100)}$) would mainly depend on municipality A or, in other words, municipalities A and E would share a similar high probability of occurrence of hazardous events. This way, the climate hazard of municipality A (and B, C and D) is dislocated to E.

Concerning historical data, an overall linear trend is found with increasing values from north-west to south-east, i.e. from the Dolomites peaks of the South-Eastern Alps towards the Prealps bordering the Po Valley. This trend is assumed to be indicative of the current climatic condition:

- based on the information available in terms of the extension of the historical series, and the location of the stations, on which more complex interpolation methodologies (e.g. ordinary kriging) do not offer significant differences in terms of spatialization;
- in consideration of the nature of the phenomenon itself, because the indicator is calculated also on a temperature range which strictly depends on the altitude.

Winter climatic variations calculated on the grid points are interpolated, demonstrating a growing linear south-east to north-west trend for both EURO-CORDEX and COSMO models (2036-2065, RCP4.5 and 8.5). Negative values are found in the southern part of the Belluno Province while very weak variations are detected in the central area, i.e. Valbelluna. Hence, historical data and related variations show an evident opposite trend, with a future but slight increase in the number of days of wet snow events, only in the northern part of the Belluno Province.

2.3.2. Exposure

In the case of direct damages to power grids, exposure consists of HV/MV and MV/LV substations, overhead lines with relative supports and underground lines. In the case of indirect damages, services, businesses and the local population are affected by outages and, therefore, they can be considered as the exposed component (hereafter generally referred to as customers). For confidentiality reasons, disaggregated data about the morphology of electricity distribution grids and associated customers cannot be included in the analysis. Exposure is therefore quantified making use of the estimated provided by e-distribuzione, at the municipality level, or at smaller administrative scales (part of current municipalities), according to the methodology described in the abovementioned 2018 AEIT paper (Amicarelli et al., 2018).

At first, expected damages were calculated by comparing their historical magnitude with the estimates for future climatic hazard events. Specifically, direct impacts were assessed through the estimated monetary historical damages to power grids, under 20, 50, 100 and 150-year return period. Such information was used to develop a damage function, for quantifying the increase in the monetary damage output associated with the increase in the frequency of the climatic conditions that determine the individual hazardous event in the winter season, i.e. the average historical number of wet snow days (Figure 2-18).

A strong statistical relationship was found ($R2 = 0.96$) but its interpretation was not consistent with the expected outcome for this sector as the primary target would have been the estimation of the increase in the duration of the individual hazardous event in the future, which cannot be performed with the current state of the art of research in the field. For this reason, both for direct and indirect damages, our methodology switched to a different approach by assuming that the individual hazardous event can be triggered by a day with atmospheric conditions defined by the wetsnow_02 indicator. Hence, multiple wet snow days return multiple hazardous events with potential damage output and their frequency can increase or decrease in the future proportionally with the variation of the hazard indicator.

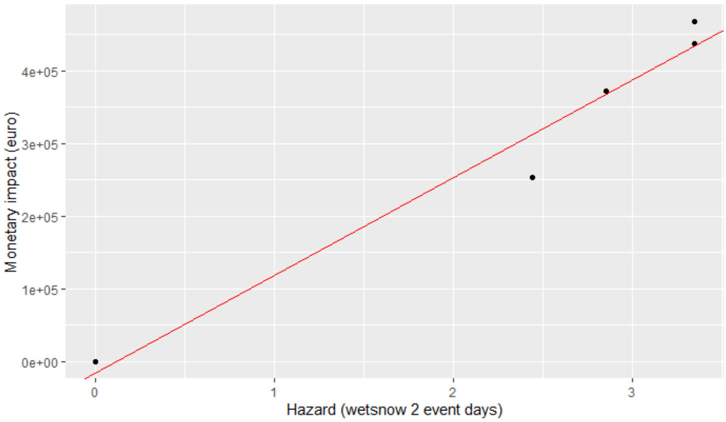

fig. 2-18
: Damage function, for quantifying the increase in the monetary damage output (y-axis) associated with the increase in the frequency of the average historical number of wet snow days (x-axis) in the winter season.

Therefore, in the case of direct damages, the exposure term is represented by the historical monetary damage to power grids estimated in the time span of an individual hazardous event (provided by e-distribuzione). In a similar way, in the case of indirect damages, the exposure term is given, according to ARERA del. 668/18, by the estimated monetary value of the electricity not supplied to disconnected customers (12 € kWh for domestic customers, 54 € kWh for non-domestic customers for an average electricity consumption in the Belluno Province), during outages of a standardized duration (16 h). However, the indirect risk analysis is developed per each combination of voltage level and customer type and a different exposure term is considered per each of them (Table 2-4). Figure 2-19 and Figure 2-20 show the normalized spatial pattern of the electricity distribution exposure to wet snow events 100-year return period, respectively for direct and indirect impacts, the latter taking into account all customer types together. The estimated potential exposure to direct impacts amount to about 30 M€/event and the one to indirect impacts amount to about 15 M€/outage, over the whole Belluno Province.

Table 2-4. Combination of voltage and customer type per consumption band.

<table>
<tr><td rowspan="6">Low voltage (LV)</td><td>Domestic Resident (DRE)</td><td></td><td></td></tr>
<tr><td>Domestic Non-Resident (DNR)</td><td></td><td></td></tr>
<tr><td rowspan="4">Other uses (OU)</td><td>OU up to 1,5 kW</td><td>garages, basements, apartment building services</td></tr>
<tr><td>1,5 < OU <= 10 kW</td><td>coffee shop, small businesses</td></tr>
<tr><td>10 < OU <= 30 kW</td><td>restaurants, medium-sized businesses, small craft businesses</td></tr>
<tr><td>OU over 30 kW</td><td>hotels, restaurants, medium to large-sized businesses, medium-sized craft businesses</td></tr>
<tr><td>Medium voltage (MV)</td><td>Other uses (OU)</td><td></td><td>ski lifts, industrial activities, shopping centers</td></tr>
</table>

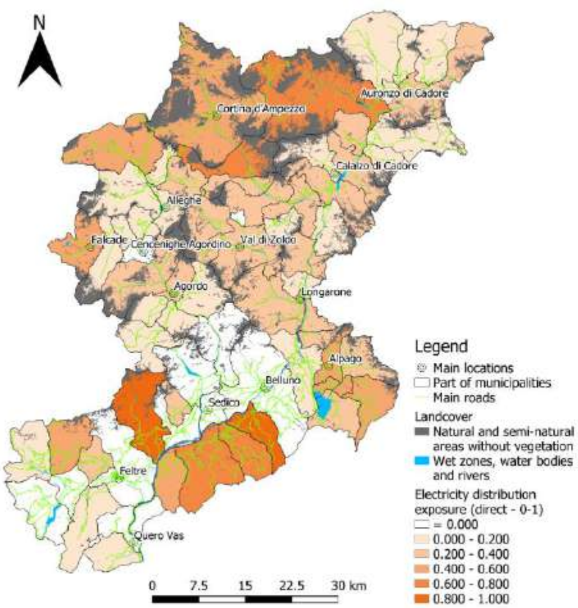

fig. 2-19
Electricity distribution exposure to direct damages, normalized between 0 and 1; elaboration from e-Distribuzione estimated damages for wet snow events with a 100-year return period; landcover overlaid to highlight those area where exposed assets are typically not present.

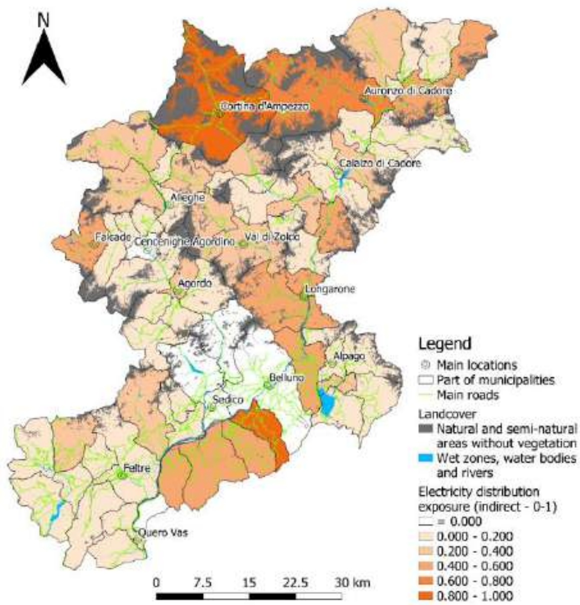

fig. 2-20
Electricity distribution exposure to indirect damages, normalized between 0 and 1; elaboration from e-Distribuzione estimated damages for wet snow events with a 100-year return period; landcover overlaid to highlight those area where exposed assets are typically not present.

2.3.3. Vulnerability

In the case of indirect impacts in the sector of electricity distribution, the coping capacity is defined through an indicator of the remoteness of infrastructures, i.e. the ability of the technical staff of electrical companies to reach damaged lines for recovering the energy supply in case of weather-led electricity outages. The indicator is calculated through the time necessary to reach the elements of the infrastructure from existing maintenance facilities of e-distribuzione. Specifically, a travel-cost analysis is performed by using the cost map without railways but unrestricted access to regulated roads for motorized vehicles, to compute the cumulative time (in seconds) between e-distribuzione facilities and the surrounding areas. This is overlaid with a rasterized product at 25 m resolution of power grids geolocalized from the Civil Protection Plan of the Belluno Province, to calculate the time necessary for reaching electricity infrastructures. The result is then aggregated at the reference administrative level of the assessment to obtain the average remoteness of electricity distribution grids per spatial unit.

Susceptibility depends on the technical features of power grids and on their interactions with territorial features. Since the technical features are not available, electrical lines are analysed through their location and intersection with different types of land cover, focusing on different types of forests. This allows to estimate the tree fall probability:

- in close proximity to overhead lines, due to the accumulation of snow on tree branches;
- in close proximity to roads, due to the accumulation of snow on tree branches, this way preventing the accessibility of the e-distribuzione technical staff to damaged overhead lines.

Specifically, the tree fall probability over overhead lines is calculated as the ratio between:

- the number of cells at 25 m resolution of wooded areas (weighted on the tree fall probability observed from recent events by tree cover type) intersecting electricity distribution grids;
- the total number of cells at 25 m resolution intersecting electricity distribution grids across the Province.

The result is aggregated at the reference administrative level of the assessment to obtain the average tree fall probability over overhead lines per spatial unit, to map susceptibility to direct damages in the proposed methodology[6].

Over the road network, the tree fall probability is calculated as the ratio between:

- the number of cells at 25 m resolution of wooded areas (weighted on the tree fall probability observed from recent events by tree cover type) intersecting a specific path between a maintenance centre and a corresponding municipality within its competence;
- the total number of cells at 25 m resolution intersecting the same specific path.

---

[6] Vulnerability/susceptibility to direct damage was proposed in the first conceptualization of the methodology and used, in a first stage, in the risk analysis but, as requested, it was not applied in the final run of the model, because the tree fall probability over roads cannot be used to modulate the direct risk for overhead lines.

The procedure is iterated over each municipality with the corresponding e-distribuzione facility, i.e. every potential path, to obtain the tree fall probability over the road network at the reference administrative level of the assessment, to map susceptibility to indirect damages.

The adaptive capacity can be recognized in the financial support to structural investments for ameliorating and renovating electrical infrastructures, such as for converting overhead lines with bare conductors to aerial cable ones or to underground lines, preventing in this way potential damages due to the occurrence of the climatic hazards considered. Given the limited surface area of the Belluno Province, and the problems related to the disclosure of sensitive data, adaptive capacity is not considered in the analysis.

In the case of indirect impacts, the stack of indicator maps is then aggregated through a multi-criteria analysis, to produce a vulnerability map. To express the different importance of the various indicators in contributing to the determination of vulnerability, relative weights are adopted. The weight vectors provided by the researchers involved in the project are inherently subjective and thus they are included in the analysis of the uncertainty, to quantify the role of such subjectivity on the final results, together with other sources of uncertainty.

The multi-criteria aggregation of the indicators is carried out with the OWA methodology, which applies a second set of weights to modulate the addictiveness of the aggregation. With such method different risk attitudes of decision makers can be represented with a vector of weights applied to the ordered values of each single pixel of the map: a "risk averse" (or pessimistic attitude) can be represented by giving relatively high weights to those indicators that show relatively bad performances; a "risk taker" (or optimistic attitude) can be expressed by higher weights given to those indicators that perform better; a "balanced" attitude can be expressed by relatively high weights given both to good and bad indicators, with lower weights given to those with average performances. With such approach, an additional element of uncertainty is included in the uncertainty analysis, reflecting the possible variability of the decision-making approach to risk management. Therefore, OWA is applied by considering 3 risk profiles with corresponding ordered weights, to aggregate coping capacity, adaptive capacity and susceptibility indicators. A total of 6 vulnerability maps is produced, with a normalized scale between 0 and 1. Case 0 indicates a theoretical situation of absence of vulnerability, in which, whatever the entity of the structures or assets exposed and whatever the magnitude of the event, the result in terms of expected damage (potential risk) is zero. On the contrary, the value 1 indicates the situation of maximum vulnerability, in which the climatic event can determine the maximum theoretically possible damage. In this sector, vulnerability is assumed to reduce risk up to 30%, hence vulnerability values are then rescaled between 0.7 (minimum value observed for V) and 1 (maximum value) and multiplied by the preliminary estimations of R obtained with the combination of H and E.

In the case of indirect impacts, downstream of the vulnerability mapping but before calculating the risk, a further step is necessary to quantify the indirect risk as a function of the "dislocation" of the impact per each return period, by weighting its components on the basis of the consistency of exposed infrastructures (provided by e-distribuzione). Therefore, the vulnerability is recalculated depending the municipalities in which the impact originates (including/excluding the administrative unit being analyzed depending on whether there is a network consistency greater than 0). The calculation is iterated per each municipality and return period.

$$IV_{m,RP} = \frac{\sum_{i=1}^{f} V_f * l_{f,RP}}{\sum_{i=1}^{f} l_{f,RP}}$$

with:

- 〖IV〗_(m,RP) = indirect value of the mth municipality in the corresponding return period RP
- V_f = direct value of the fth municipality which indirectly affects the mth municipality
- l_(f,RP) = exposed length of power grids in the fth municipality for an event occurring under a specific return period RP

same time, a large length of exposed infrastructures (e.g. l_(A,100)), together with other municipalities (e.g. B, C and D) in which there is only a minor exposure, all of them indirectly affecting customers of municipality E, the indirect vulnerability of E (〖IV〗_(E,100)) would mainly depend on municipality A or, in other words, municipality A and E would share a similar high vulnerability. This way, the vulnerability of municipality A (and B, C and D) is dislocated to E.

All vulnerability maps show an increasing south-to-north trend, both in the case of direct and indirect impacts, with a minor local variability depending on the adopted weighing scheme. Such trend depends on the northernmost half of the Belluno Province whose municipalities are the farthest from the maintenance facilities of e-distribuzione and those with the highest woodland cover (either intersecting overhead lines or the road network). Figure 2-21 shows the vulnerability map to direct impacts, in the proposed methodology, which considers the tree fall probability over overhead lines. Figure 2 22 presents instead the vulnerability map to indirect impacts, showing the average trend of all possible combinations of weights and decision-making attitudes.

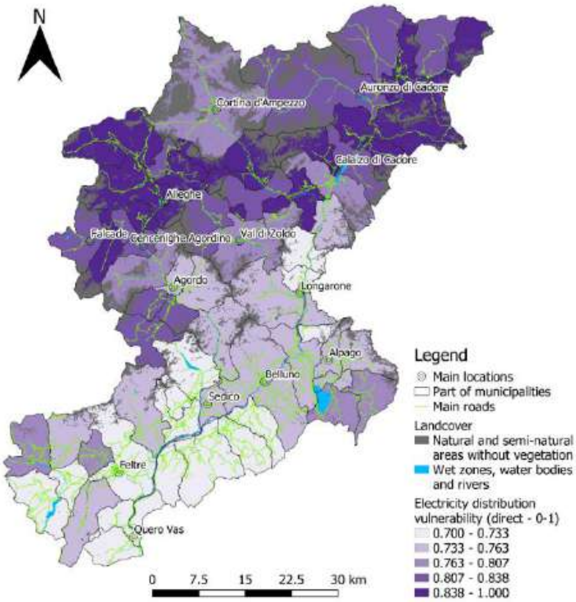

fig. 2-21
Electricity distribution direct vulnerability to wet snow events; more vulnerable areas shown with a greater colour intensity; landcover overlaid to highlight those area where exposed assets are typically not present.

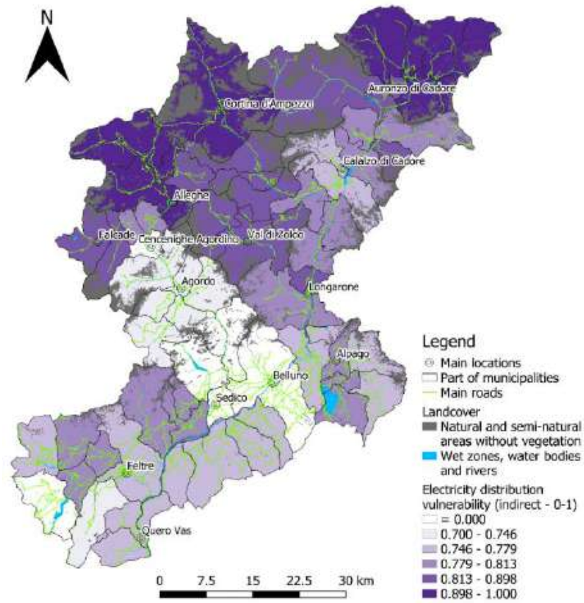

fig. 2-22
Electricity distribution indirect vulnerability to wet snow events, with a return period of 100 years; average trend of all possible combinations of weights and decision-making attitudes; more vulnerable areas shown with a greater colour intensity; landcover overlaid to highlight those area where exposed assets are typically not present.

2.3.4. Risk

The risk analysis is carried out by multiplicative intersection of the hazard, exposure and the vulnerability maps, thus obtaining an estimation of the proportion of the total value of the assets exposed at risk. However, in this sector, the hazard map represents a frequency (days) that is multiplied by the monetary map of exposure to generate an estimation of the expected damages over a time span (winter season), which can be reduced when the vulnerability of the area in which the assets are located is lower than 1. The intermediate products and the results of the risk analysis are reported in tabular and cartographic form, through aggregated representations and descriptive statistics and with the use of metrics that allow communicating the variability and uncertainty of the results.

In particular, the historical risk (Rcurrent) is assessed by multiplying the exposure (Ehistorical) given by the historical damage estimation provided by e-distribuzione, by the historical hazard

(Hhistorical) and the vulnerability (V). The climate risk analysis for the time periods 2012-2041 and 2036-2065 is built upon the historical estimation, by applying the climatic variation (Hvariation) to the historical exposure and the vulnerability component to assess future risk (Rfuture):

$$R_{current} = E_{historical} * H_{historical} * V$$

$$R_{future} = R_{current} \pm (E_{historical} * H_{variation} * V)$$

with:

- $V = 1$ if vulnerability is not considered, in the case of direct damages;
- $V = IV$, $H_{historical} = IH_{historical}$ and $H_{variation} = IH_{variation}$ in the case of indirect damages.

In the case of direct impacts to electricity distribution, 4 historical risk maps are produced, equal to the number of return periods considered. Concerning climatic variations, 32 future risk maps are produced, equal to the 8 hazard maps (the latter in turn given by all combinations of models, scenarios and time windows) per each return period. In the case of indirect impacts to electricity distribution, 24 historical risk maps are produced per each combination given by voltage and customer type per consumption band, equal to the number of vulnerability maps per return period, resulting in a total of 168 maps. Concerning climatic variations, 192 future risk maps are produced by the factorial combination of the 6 vulnerability maps and the 8 hazard maps (the latter in turn given by the combinations of models, scenarios and time windows) processed per each return period, resulting in a total of 1344 maps.

From the stack of risk maps a series of summary maps are then produced to present the average trends and the uncertainty associated with their calculation. The average map and that of the coefficient of variation (CV - percentage of the ratio between standard deviation and mean) are therefore calculated to deliver a concise picture of the results.

In the case of historical direct risk, the calculation of the mean map and the CV is not necessary since the OWA methodology is not applied and, moreover, in the final conceptualization of the methodology, vulnerability is not included[7]. In the case of histor-

[7] Vulnerability/susceptibility to direct damage was proposed in the first conceptualization of the methodology and used, in a first stage, in the risk analysis but, as requested, it was not applied in the final run of the model,

ical indirect risk, the mean maps and the percentage CVs are calculated per each of the 4 return periods and each combination given by voltage and customer type per consumption band, resulting in a total of 56 maps. The uncertainty depends on the different types and weighting strategies used in mapping the vulnerability. Concerning future climatic direct risk, the mean maps and the percentage CVs are calculated per each of the 4 return periods and each time window (2012-2041, 2036-2065), resulting in a total of 16 maps. In this case, the variability depends only on the climate models and on the scenarios. Concerning future climatic indirect risk, the mean maps and the percentage CVs are calculated per each of the 4 return periods, each time window (2012-2041, 2036-2065) and each combination given by voltage and customer type per consumption band, resulting in a total of 112 maps. In this case, instead, the uncertainty depends not only on the different types and on weighting strategies used in mapping the vulnerability, but also on the climate models and on the scenarios considered. Mean indirect risk maps and related CVs of all combinations given by voltage and customer type per consumption band (Table 2-4) are furtherly aggregated in order to provide an overall risk estimation for this sector, resulting in a total of 8 historical risk maps and 16 future climatic risk maps. Figure 2-23, Figure 2-24 and Figure 2-25 show mean maps and the related CV of direct damages to overhead lines due to wet snow events with a 100-year return period, in the 2036-2065 time window. Specifically, Figure 2 23 refers to the proposed methodology, which considers the tree fall probability over overhead lines. Figure 2-24 refers instead to the direct risk without the vulnerability component. Figure 2 26 and Figure 2 27 show the mean map and the related CV of indirect damages to customers due to wet snow events with a 100-year return period, in the 2036-2065 time window.

because the tree fall probability over roads cannot be used to modulate the direct risk for overhead lines.

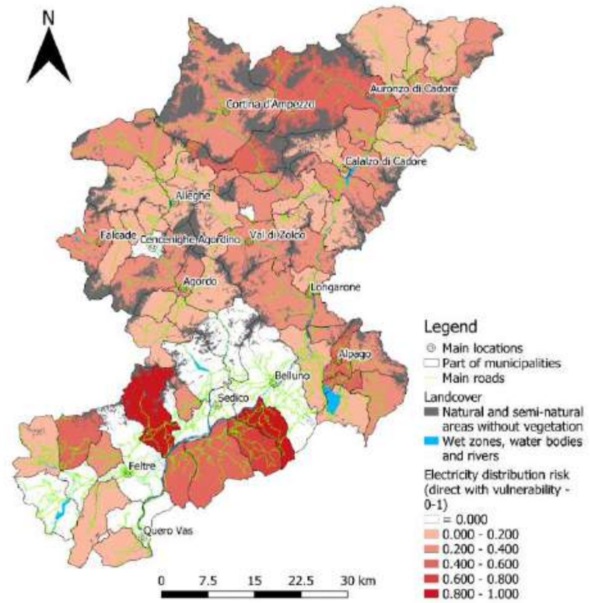

fig. 2-23
Estimated electricity distribution direct climatic risk for wet snow events with a 100-year return period, in the 2036-2065 time window, considering tree fall over overhead lines; normalized spatial pattern between 0 and 1, where 1 corresponds to the maximum risk detected under the risk averse attitude; landcover overlaid to highlight those area where exposed assets are typically not present.

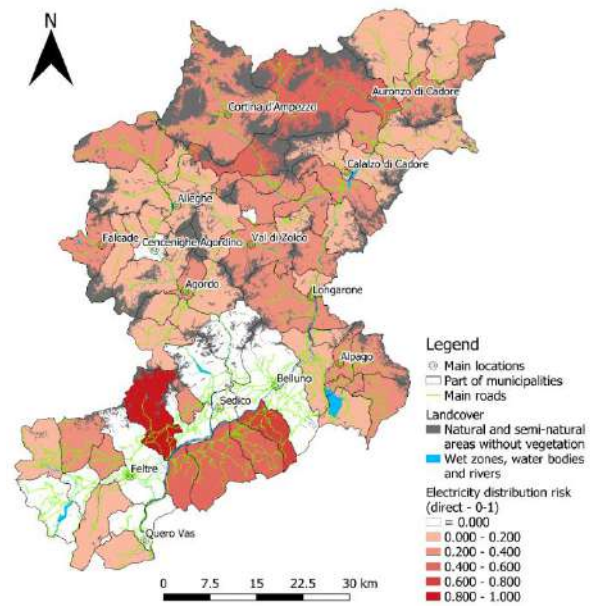

fig. 2-24
Estimated electricity distribution direct climatic risk for wet snow events with a 100-year return period, in the 2036-2065 time window; normalized spatial pattern between 0 and 1, where 1 corresponds to the maximum risk detected under the risk averse attitude; landcover overlaid to highlight those area where exposed assets are typically not present.

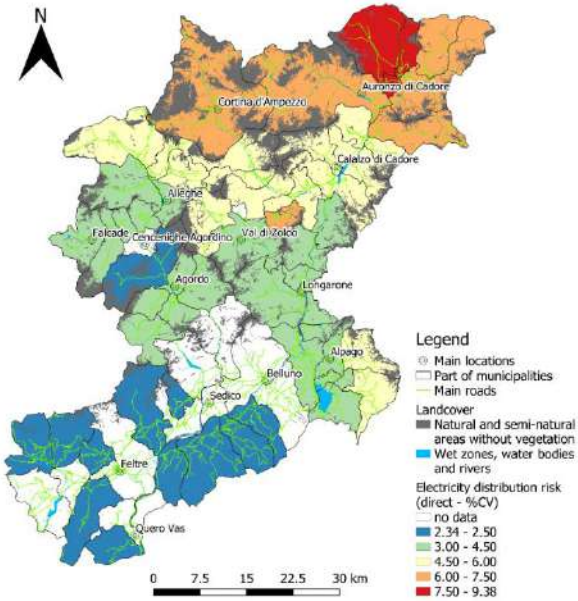

fig. 2-25
Uncertainty of the risk map in Figure xxx, calculated as percentage of the ratio between standard deviation and mean (CV), in this example by considering multiple scenarios and models; landcover overlaid to highlight those area where exposed assets are typically not present.

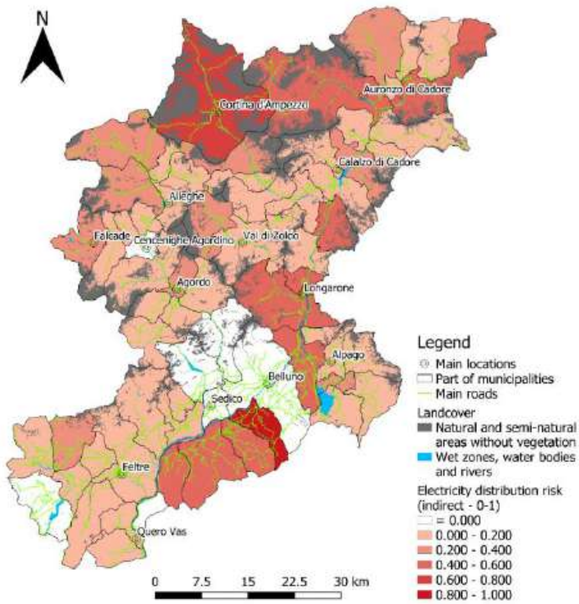

fig. 2-26
Estimated electricity distribution indirect climatic risk for wet snow events with a 100-year return period, in the 2036-2065 time window; normalized spatial pattern between 0 and 1, where 1 corresponds to the maximum risk detected under the risk averse attitude; overall risk among all customer types; landcover overlaid to highlight those area where exposed assets are typically not present.

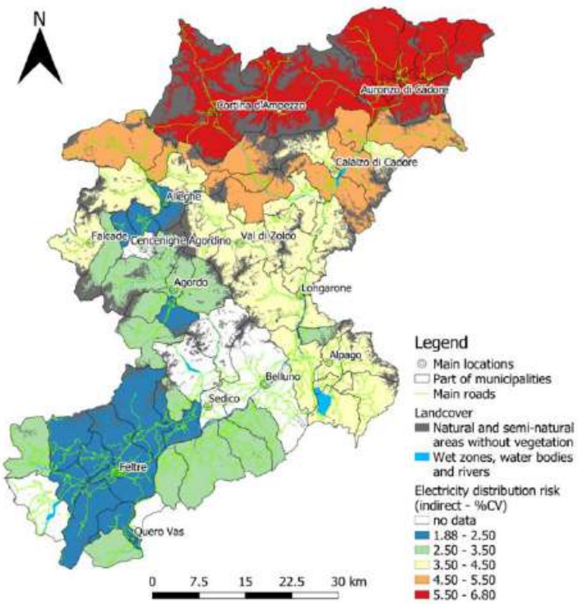

fig. 2-27
Uncertainty of the risk map in Figure xxx, calculated as percentage of the ratio between standard deviation and mean (CV), in this example by considering multiple indicator weights, risk attitudes, scenarios and models; landcover overlaid to highlight those area where exposed assets are typically not present.

To highlight the areas of the Belluno Province that present the greatest variations in terms of risk, the difference between the risk estimated on historical data and that estimated over the 2012-2041 and 2036-2065 time windows is calculated. A slight increase in the number of days of wet snow events, hence in the climate risk, is found only in the northern part of the Belluno Province while a decrease is detected in the southern part.

At last, by aggregating historical and future risk maps over the whole Belluno Province, we found up to 6.2% increase in the direct climate risk and 10.2% increase in the indirect climate risk, for wet snow events in the 2036-2065 time window (Table 2-5). The percentage increase on the estimated current risk is similar between the considered time windows because of the compensatory effect due to the spatial pattern of climate variations.

Table 2-5. Estimated monetary value of climate risk (€/season) for the electricity distribution sector in 2012-2041 and in 2036-2065 over the whole Belluno Province, due to wet snow events with a 100-year return period.

Direct risk – wet snow						
	2012-2041	Difference with the estimated current risk		2036-2065	Difference with the estimated current risk	
	146,724,033 €	8,465,425 €	6.12%	146,801,064 €	8,542,456 €	6.18%
Indirect risk – wet snow						
Risk profiles	2012-2041	Difference with the estimated current risk		2036-2065	Difference with the estimated current risk	
all*	60,198,761 €	4,805,808 €	8.68%	61,015,222 €	5,622,269 €	10.15%
balanced	60,198,761 €	4,805,808 €	8.68%	61,015,223 €	5,622,270 €	10.15%
risk averse	60,517,120 €	4,838,833 €	8.69%	61,342,087 €	5,663,800 €	10.17%
risk taker	59,880,403 €	4,772,784 €	8.66%	60,688,358 €	5,580,739 €	10.13%
Range	636,717 €	-	-	653,728 €	-	-

* all: average maps among risk profiles

2.4. Winter sports and events

Snow cover duration and quality are critical issues for outdoor winter sports and related events, which are threatened by climate change. In this regard, the upcoming Milano-Cortina Olympics of 2026, will take place in the Province of Belluno, with some concerns of the organizing committee of the Winter Olympics (Fondazione Milano-Cortina 2026) on future climatic conditions. In fact, climate change can be responsible for a number of extreme events e.g. floods, landslides, tree fall and temperature increase and might affect snow quality and thus athletes' performance during competitions. In the longer term, climate change may affect more broadly and permanently local communities and businesses and even lead to the abandonment of the ski facilities located below a certain altitude, as already observed in many cases across the Alps.

In the activities related to the combination of WP from 1 to 4, the climate risk analysis focuses on snow making and maintenance along the winter season (November to March), by considering local climatic hazards and their future projections, the location of the exposed assets and their vulnerabilities, i.e. the features that may increase or decrease the risk of a given asset exposed to a given hazard (e.g. geomorphological features).

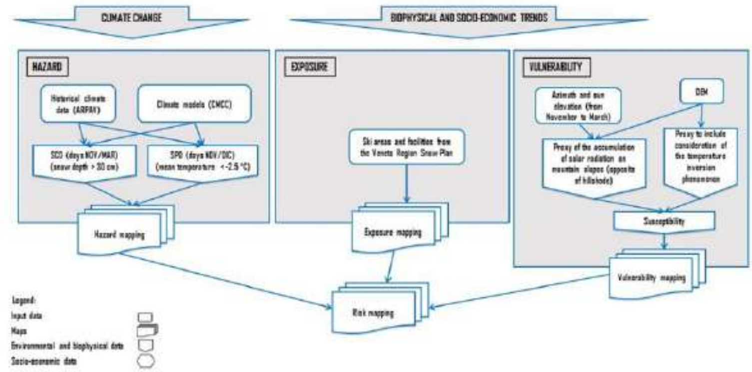

fig. 2-28
Graphical representation of the risk assessment of the winter sports and events sector

2.4.1. Climatic hazard

For the sector of winter sports and events, the climatic hazard refers to the lack of natural snow cover and to temperature increase which may affect the quality of artificial snow. Building upon existing literature and supported by the local experts from ArpaV, we consider two indicators:

- snow cover duration (SCD): number of days from November 1st to March 31st of the following year with snow depth higher than 30 cm;
- snow production days (SPD): number of days from November 1st to December 31st with an average temperature less than -2.5 ° C.

The historical frequency of these indicators is calculated by CMCC on ArpaV records for the period 1981-2010. The variations are produced by the simulations of COSMO-CLM and EURO-CORDEX models' ensemble mean, considering two time windows (2012-2041, 2036-2065) and two scenarios (RCP 4.5 and 8.5). In this sector, rare events are not considered, hence climate variations are not calculated for extreme events with a specific return period. Instead, the analysis focuses on the average trend of future winter seasons that stakeholders will have to face, e.g. for organizing winter sport events.

ArpaV carried out a study on the statistical relationship between temperature gradients and altitude in the Belluno Province. Such relationship was shown to be stronger in the months of November and March in comparison with December, January and February. Consequently, we decided to map SCD and SPD by month so as to improve spatial interpolation performances for hazard mapping. Specifically, in this case:

- historical data are interpolated through a linear regression with a digital elevation model, thus considering only the altitude and not directional trends;
- future climatic variations are mapped through a nonlinear interpolation, by fitting a second order polynomial with two variables, i.e. x and y spatial coordinates, as hazard variations in many cases do not show a linear directional pattern.

In the case of the historical data, interpolated maps show increasing SCD and SPD values with the increase in the altitude. Concerning future SCD climatic variations for EURO-CORDEX models' ensemble mean (2036-2065, RCP4.5 and 8.5), interpolated maps show the greatest and negative values in the northern-central part of the province, decreasing toward north-west and south-east. The same is detected for SPD climatic variations, in this case by considering both COSMO-CLM and EURO-CORDEX models' ensemble mean (2036-2065, RCP4.5 and 8.5).

2.4.2. Exposure

Exposure is given by all state-owned properties ("aree demaniali") in the Belluno Province that include existing ski facilities and slopes and all other areas where new infrastructures for snow-based outdoor winter sports might be built in the future (Figure 2-29). These sites are regulated in the Veneto Region Snow Plan (2013) which defines all the areas ("ambiti territoriali") that meet environmental and landscape protection objectives: protecting soil and biodiversity; reducing anthropogenic pressures; ensuring mobility without increasing vehicular private traffic; raising the competitiveness and the diversification of winter tourism; sustain local communities and their cultural identity.

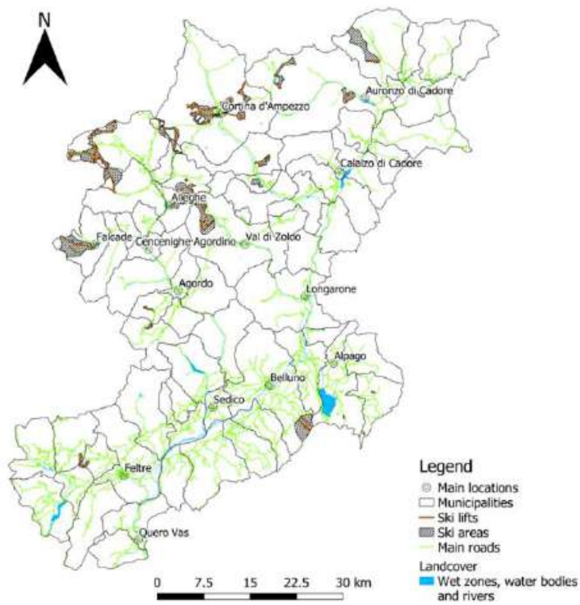

fig. 2-9
State-owned ski areas and existing ski lifts, as defined in the Veneto Region Snow Plan (2013).

2.4.3. Vulnerability

Vulnerability for outdoor winter events mainly depends on **susceptibility** to geomorphological features, which may affect temperatures gradients, hence, the quantity and quality of snow at different altitudes. In order to improve the spatial mapping beyond the mere correlation between snow indicators and the elevation, we identified two suitable indicators: the accumulation of solar radiation on the ski slopes as a function of slope and aspect, through a “hillshade” operator, and a proxy to include consideration of the temperature inversion phenomenon, derived from geomorphological analyses.

Hillshade (or shaded relief) identifies areas less susceptible to climate risk where the snow is not heavily exposed to the sun during the hottest hours of the day. This indicator is calculated for the 15th day of every month between November and March at midday, with an elevation of the sun ranging from 22° and 45° and an azimuth from 172° to 181° (clockwise from North)[8]. Shaded relief

[8] https://www.esrl.noaa.gov/gmd/grad/solcalc/

maps are aggregated to provide average representative values for the reference period.

Temperature inversion (low temperatures at low altitudes) occurring in valleys or depressions in winter months may guarantee the conditions for maintaining the snowpack, hence identifying less susceptible areas to climate risk. This condition is acknowledged by ArpaV to be increasingly frequent in recent years in the Belluno Province. Temperature inversion is mapped through the following steps:

1. the main geomorphological typologies are assessed in the Belluno Province through the r.geomorphons algorithm (Jasiewicz & Stepinski, 2013) of the GRASS plugin available in the processing toolbox of QGIS; it is a pattern recognition-based landform classification algorithm that classifies each grid cell as one of the following ten landform elements: 'flat', 'summit', 'ridge', 'shoulder', 'spur', 'slope', 'hollow', 'footslope', 'valley' and 'depression'; in our study the algorithm is parametrized according to Gruber et al. (2013) which apply the methodology to Alto Adige, a region on the boundaries of the Belluno Province with similar geomorphological features and patterns, showing the best performance at macro-scale in comparison with other landform classification approaches;
2. three of the main geomorphological typologies are filtered out, i.e. summit, ridge and spur which are typically found at higher elevation and a value of zero is assigned as temperature inversion cannot occur;
3. a de-trended digital elevation model is produced with a linear regression of spatial coordinates on the altitude; residuals represent the component of elevation that in this way does not depend on spatial coordinates, i.e. we assume that temperature inversion depends only on the geomorphological typologies and on their local altitude but not on their position within the Belluno Province.
4. the de-trended elevation values not intersecting summit, ridge and spur typologies are inversely normalized, ranging from 0 to 1 where 1 corresponds to the lowest de-trended altitude and temperature inversion is likely to occur under suitable atmospheric condition.

As yet, **coping and adaptive capacity** have been overlooked, because they were considered of secondary relevance for the specific purposes.

The stack indicator maps is then aggregated through a multi-criteria analysis, to produce a vulnerability map. To express the relative importance of the two indicators in contributing to the determination of vulnerability, weights are adopted. The weight vectors provided by the researchers involved in the project are inherently subjective and thus they are included in the analysis of the uncertainty, to quantify the role of such subjectivity on the final results, together with other sources of uncertainty. The normalized indicators are therefore weighted using 3 weight vectors.

The multi-criteria aggregation of the indicators is carried out with the OWA methodology, which applies a second set of weights to modulate the addictiveness of the aggregation. With such method different risk attitudes of decision makers can be represented with a vector of weights applied to the ordered values of each single pixel of the map: a "risk averse" (or pessimistic attitude) can be represented by giving relatively high weights to those indicators that show relatively bad performances; a "risk taker" (or optimistic attitude) can be expressed by higher weights given to those indicators that perform better; a "balanced" attitude can be expressed by relatively high weights given both to good and bad indicators, with lower weights given to those with average performances. With such approach, an additional element of uncertainty is included in the uncertainty analysis, reflecting the possible variability of the decision-making approach to risk management. Therefore, OWA is applied by considering 3 risk profiles with corresponding ordered weights (reported in the methodological annex, Section 4.4.5), to aggregate coping capacity, adaptive capacity and susceptibility indicators. A total of 9 vulnerability maps is produced, with a normalized scale between 0 and 1. Case 0 indicates a theoretical situation of absence of vulnerability, in which, whatever the entity of the structures or assets exposed and whatever the magnitude of the event, the result in terms of expected damage (potential risk) is zero. On the contrary, the value 1 indicates the situation of maximum vulnerability, in which the climatic event can determine the maximum theoretically possible damage. In this sector vulnerability is assumed to increase or decrease risk up to ±15%, hence vulnerability values are then rescaled between 0.85 and 1.15.

Vulnerability map pattern depends on the adopted weighting scheme, showing more vulnerable areas at high elevation, where temperature inversion cannot occur, and/or on mountain slopes exposed to south. Figure 2-30 presents the vulnerability map at 25 m resolution, given by the average trend of all possible combinations of weights and decision-making attitudes.

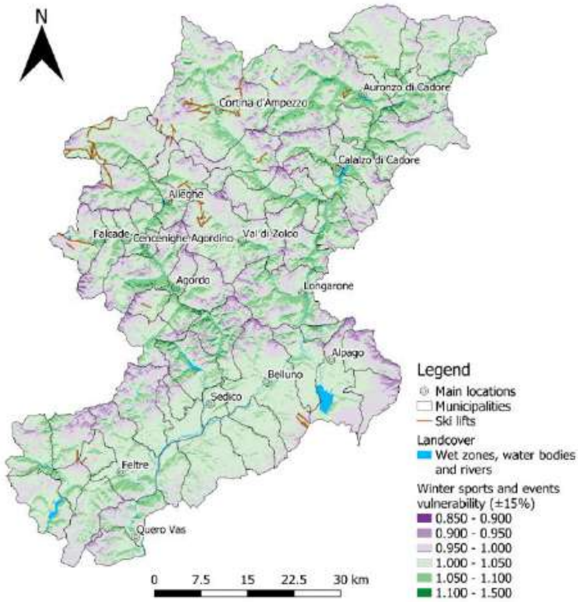

fig. 2-30
Winter sports and events' vulnerability at 25 m resolution; average trend of all possible combinations of weights and decision-making attitudes; more vulnerable areas shown in purple, with a greater colour intensity; green areas instead have suitable geomorphological condition for maintaining the quality of the snowpack.

2.4.4. Risk

The risk analysis is carried out by multiplicative intersection of the hazard and the vulnerability maps, thus obtaining an estimation of the proportion of the total value of the assets exposed at risk. However, in this sector, the hazard map represents a frequency (number of days) that is multiplied by the vulnerability, to generate an estimation of the expected:

- number of days from November 1st to March 31st of the following year with snow depth higher than 30 cm (SCD);
- number of days from November 1st to December 31st with an average temperature less than -2.5 °C (SPD).

The result is masked over exposed ski areas as the exposure map does not provides a monetary damage estimation but only information concerning the location of sites potentially at risk.
The intermediate products and the results of the risk analysis are reported in tabular and cartographic form, through aggregated representations and descriptive statistics and with the use of metrics that allow communicating the variability and uncertainty of the results.

In the case of winter sports and events, 9 historical risk maps are produced, equal to the number of vulnerability maps. Concerning SCD climatic variations, 36 future risk maps are produced by the factorial combination of the 9 vulnerability maps and the 4 hazard maps (the latter in turn given by the combinations of scenarios and time windows). Concerning SPD climatic variations, 72 future risk maps are produced by the factorial combination of the 9 vulnerability maps and the 8 hazard maps (the latter in turn given by all combinations of models, scenarios and time windows).

From the stack of risk maps a series of summary maps are then produced to present the average trends and the uncertainty associated with their calculation. The average map and that of the coefficient of variation (CV - percentage of the ratio between standard deviation and mean) are therefore calculated to deliver a concise picture of the results.

In the case of historical risk, the mean maps and the percentage CVs are calculated, resulting in 2 maps per each hazard indicator (SCD and SPD). The uncertainty depends on the different types and weighting strategies used in mapping the vulnerability. Concerning future climatic risk, the mean maps and the percentage CVs are calculated per each time window (2012-2041, 2036-2065), resulting in 4 maps per each hazard indicator (SCD and SPD). In this case, the uncertainty does not only depend on the different types and weighting strategies used in the mapping of vulnerability, but also on the climate models (the latter only for SPD) and on the scenarios considered. Figure 2 31 and Figure 2 32 present the mean map and the related percentage CV, showing the snow cover duration in the 2036-2065 time window, at 25 m resolution. Figure 2 33 and Figure 2 34 present the mean map and the related percentage CV, showing the number of days with suitable conditions for the production of artificial snow in the 2036-2065 time window, at 25 m resolution.

To highlight the areas of the province that present the greatest variation in terms of risk, the difference between the risk estimated on historical data and that estimated over the 2012-2041 and 2036-2065 time windows is calculated. Figure 2 35 presents the difference map between future (2036-2065 – Figure 2 31) and current (1981-2010) winter sports and events' average risk in terms of snow cover duration (SCD). Figure 4 36 presents the difference map between future (2036-2065 - Figure 2 33) and current (1981-2010) winter sports and events' average risk in terms of days with suitable conditions for the production of artificial snow (SPD).

For communication purposes and display of the information originally assessed at 25 m resolution, average maps are eventually aggregated at the municipality level by sum, while the CVs are aggregated by averages. Figure 4 37 presents the risk map at municipality level, resulting from the aggregation of risk values of Figure 2-31, over ski areas shown in Figure 2 29, and mapped in the related municipalities.

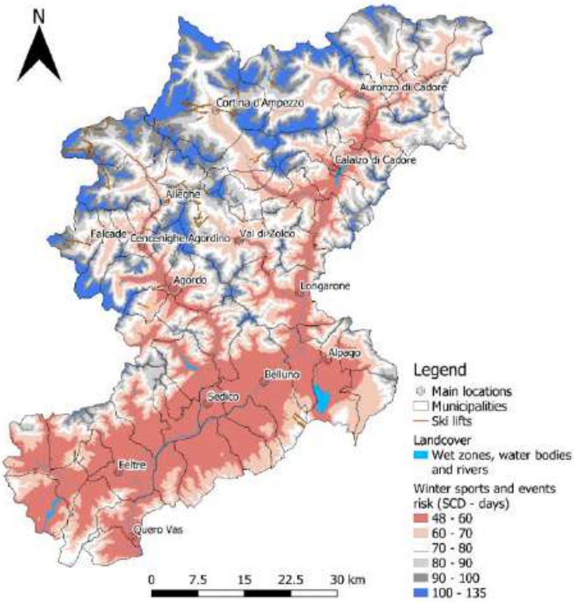

fig. 2-31
Estimated winter sports and events' risk in terms of snow cover duration (SCD) in the 2036-2065 time window, from November to March of the following year, at 25 m resolution.

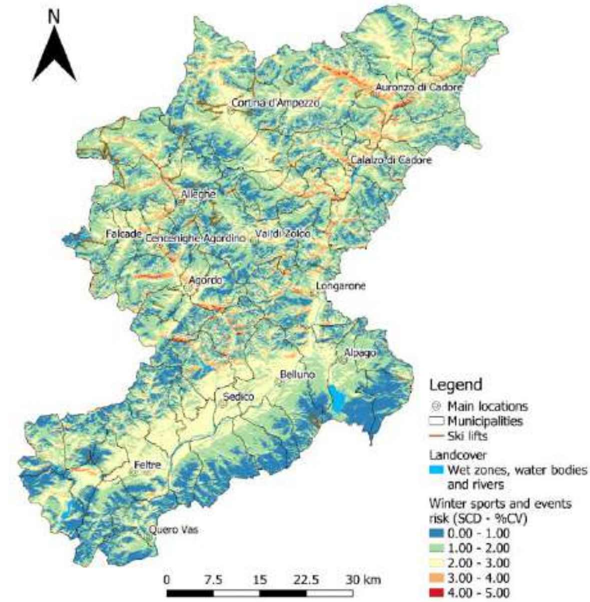

fig. 2-32
Uncertainty of the map in Figure xxx, calculated as percentage of the ratio between standard deviation and mean (CV), in this example by considering multiple indicator weights, risk attitudes and scenarios.

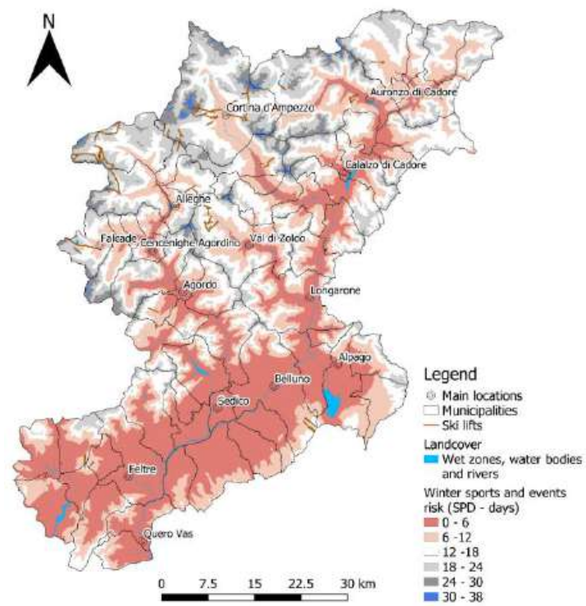

fig. 2-33
Estimated winter sports and events' risk in terms of days in the 2036-2065 time window with suitable conditions for the production of artificial snow (SPD) from November to December, at 25 m resolution.

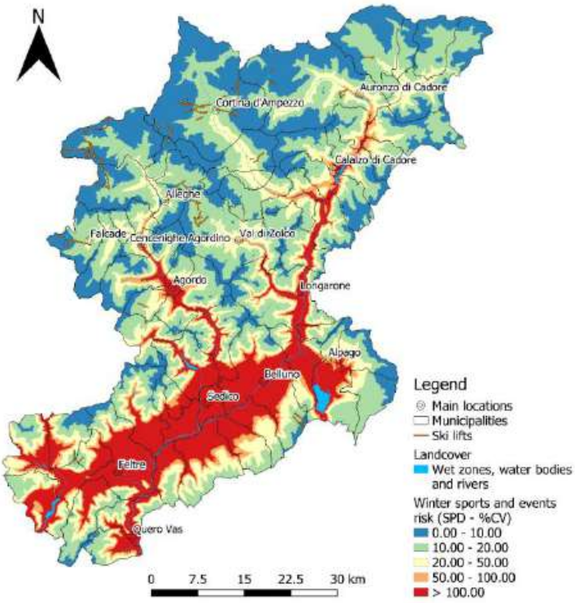

fig.2-34
Uncertainty of the map in Figure xxx, calculated as percentage of the ratio between standard deviation and mean (CV), in this example by considering multiple indicator weights, risk attitudes, scenarios and models.

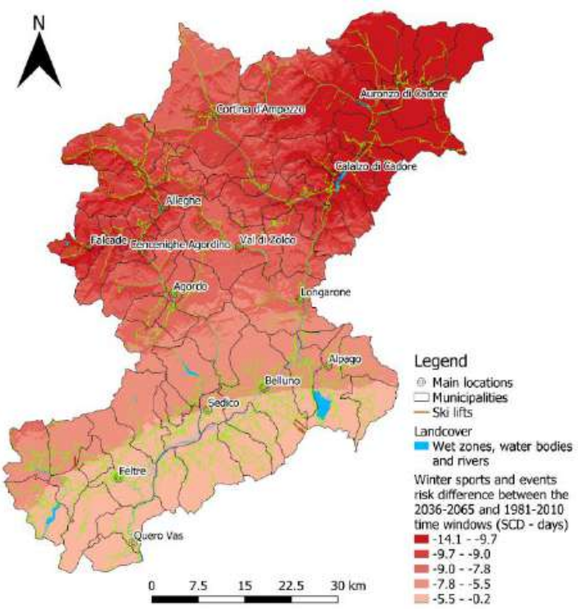

fig. 2-35
Difference map between future (2036-2065 – Figure xxx) and current (1981-2010) winter sports and events' average risk in terms of snow cover duration (SCD), from November to March of the following year, at 25 m resolution.

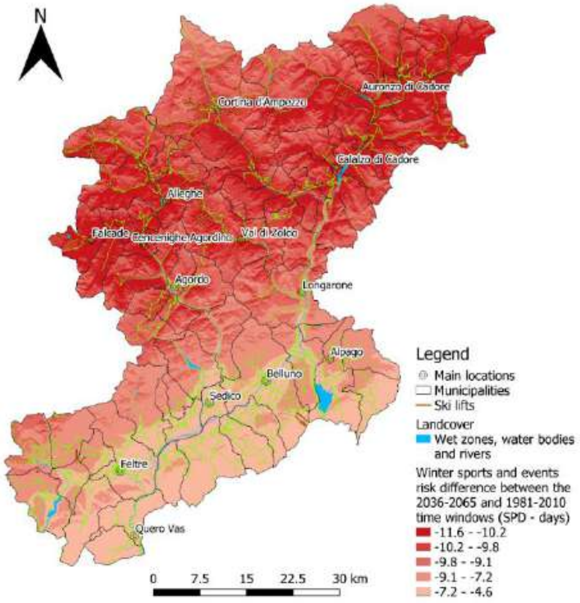

fig. 2-36
Difference map between future (2036-2065 - Figure xxx) and current (1981-2010) winter sports and events' average risk in terms of days with suitable conditions for the production of artificial snow (SPD) from November to December, at 25 m resolution.

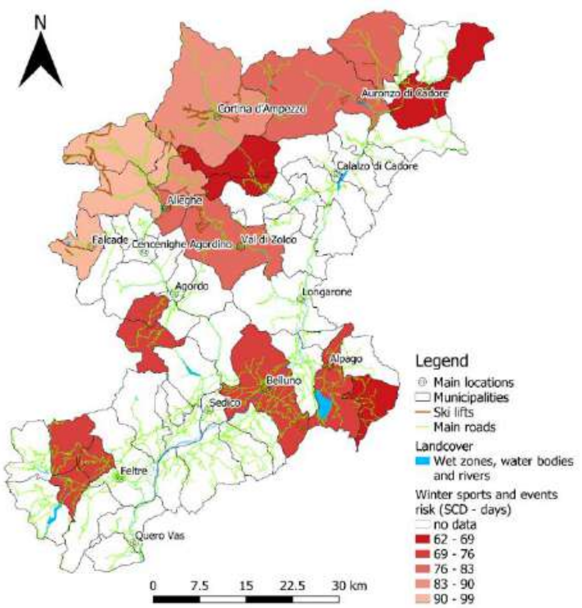

fig. 2-37
Estimated winter sports and events' risk in terms of snow cover duration (SCD) in the 2036-2065 time window, from November to March of the following year, at municipality level; aggregated values over ski areas shown in Figure 2 29, mapped in the related municipalities; average trend resulting from all possible combinations of weights and decision-making attitudes; "no data" refers to municipalities without ski areas, according to the Veneto Region Snow Plan (2013).

By aggregating historical and future risk maps over the ski areas of the whole Belluno Province, we found up to 9.5% decrease in the SCD and 37.9% decrease in the number of SPDs, in the 2036-2065 time window (Table 2-6). Such decreasing trend depends on the hazard variations which are locally stronger in the northern part of the province, where most of the ski facilities are located. We also found a 0.99 Pearson correlation coefficient between risk maps, meaning that the areas of the province with the shortest SCD are also those with the smallest number of effective SPDs. Moreover, both hazard indicators (and related risk maps) correlate with altitude, meaning that ski areas at higher elevation are typically less at risk. Therefore, ski areas at lower altitude and latitude (e.g. Alpe del Nevegal) are likely not to be threatened by medium term climate change (2036-2065) more than they currently are. On the other hand, in the recent history, ski facilities and areas in the northern part of the province were less affected by climate change but future climatic hazards may have significant impacts on the depth and quality of the snowpack, compromising the possibility of organizing future winter sport events and, in general, the sustainability of ski areas. This may occur especially at lower altitudes, although geomorphological condition might locally prevent temperature increase and the snowpack exposure to the sun. At last, as shown in Figure 2-32 and Figure 2-34, the uncertainty of risk related to SPD is much greater than the one of SCD, especially over flat low-altitude areas where the mean value of risk maps tend to zero and consequently the related percentage CV approaches infinity. Nevertheless, it is worth noting that 94% of percentage CV values within ski areas are smaller than 20%, meaning that percentage CV can still be considered a suitable metric to measure value dispersion within these sites.

Table 2-6. Estimated climate risk (days) for the winter sports and events sector in 2012-2041 and in 2036-2065 over the ski areas of the whole Belluno Province, due to the projected future reduction in the snow cover duration (SCD) and the number of days with suitable conditions for the production of artificial snow (SPD).

SCD (November to March)				
Risk profiles	2012-2041	Difference with the estimated current risk	2036-2065	Difference with the estimated current risk

all*	89.44	-4.14	-4.42%	84.65	-8.93	-9.54%
balanced	89.44	-4.14	-4.42%	84.65	-8.93	-9.54%
risk averse	88.92	-4.11	-4.42%	84.16	-8.88	-9.54%
risk taker	89.95	-4.16	-4.42%	85.13	-8.98	-9.54%
Range	1.03	-	-	0.97	-	-
SPD (November to December)						
Risk profiles	2012-2041	Difference with the estimated current risk		2036-2065	Difference with the estimated current risk	
all*	20.34	-5.45	-21.14%	16.01	-9.78	-37.92%
balanced	20.34	-5.45	-21.14%	16.01	-9.78	-37.92%
risk averse	20.24	-5.42	-21.14%	15.93	-9.73	-37.91%
risk taker	20.44	-5.48	-21.14%	16.09	-9.83	-37.92%
Range	0.21	-	-	0.16	-	-

* all: average maps among risk profiles

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