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Climate change adaptation mainstreaming through strategic environmental assessments. An in-depth analysis of environmental indicators from spatial plans in Friuli Venezia Giulia Region (Italy)

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ABSTRACT

Climate change adaptation, CCA henceforth, is nowadays a shared concern, deeply investigated and advocated by international research and political organisations. However, both CCA implementation and its monitoring and evaluation (M&E) are challenges yet to be properly addressed. From a spatial planning perspective, local plans are the land-use-oriented tools with the highest potential to enhance CCA operativity. Strategic Environmental Assessment (SEA) is also acknowledged to be a key instrument to integrate climate change concerns and hence, to monitor and evaluate climate change (CC) risks and CCA efforts. This study addresses two hypotheses, i.e., i) indicators included in SEAs' spatial plans may be used at the service of CCA M&E, ii) the full extent of indicators can be captured by multi-level planning analyses. To this aim, this study provides an in-depth analysis, through a multi-step systematic categorization, of the indicators used within the SEA of regional and municipal plans in the Friuli Venezia Giulia Region (Italy). This study brings novelty in the SEA research field by bridging the climate risk theoretical principles to the methodological approach for analysing SEAs' indicators, which are classified within the risk function frame. Key insights come from the metrics, the indicators' explicitness for CCA, and the indicators' extent into the climate risk function. Finally, the paper paves the way for further research of CC- and CCA-related indicators in both spatial planning and other public sectors to support CCA mainstreaming through SEAs.

1. Introduction

Climate change (CC) is considered one of the most threatening issues nowadays, leading to the increase in both severity and frequency of hazards, e.g. heatwaves and heavy storms, and impacts, e.g., sea level rise, floods, and droughts, that can cause significant human and economic impacts and losses (IPCC, 2022).

The importance of climate change adaptation (CCA) is globally recognized as a response to current and foreseen climatic stimuli and impacts, to minimise and avoid harms, and exploits beneficial opportunities (IPCC, 2022). Its relevance has grown over time due to the ineffective mitigation initiatives and the necessity to address the evident increase of climate and meteorological impacts (IPCC, 2022). Aware of the main aim to achieve long-term CCA, the protection of human settlements and well-being from climate-related impacts also requires immediate effective short-term CCA objectives and actions, leading to the shared need to, first, achieve their implementation, and, consequently, monitoring and evaluating (M&E) them (Olazabal and Ruiz De Gopegui, 2021). In this sense, the UN, OECD, and EU are key international players who repeatedly stated the necessity to address this challenge. Especially the UN, with the Sustainable Development Goals (SDGs), aims to globally track CCA implementation through SDGs' targets, namely 3.D, 11, and 13, at least. Additionally, CCA M&E is recognized as an important step in the process of CCA and requested in the 2015 Paris Agreement under Art.7 §9(d).

Since most of the CCA efforts and benefits are provided at the local scale (Ayers, 2010), which is the scale where most actions are implemented on the ground and where governments and actors are most pressured to invest in them (Olazabal and Ruiz De Gopegui, 2021), the regional, metropolitan, and municipal scales are considered as

Abbreviations: CC, Climate change; CCA, Climate change adaptation; FVG, Friuli-Venezia Giulia; M&E, Monitoring and Evaluating; SEA, Strategic Environmental Assessment.

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fundamentals for addressing CCA, especially within the spatial planning field (Birkmann et al., 2010). Regional, metropolitan, and municipal plans (e.g. city master plans, regional landscape protection plans) are thus the spatial and land-use-oriented tools with the highest potential to integrate and mainstream CC concerns and CCA measures (Runhaar et al., 2018).

The Strategic Environmental Assessment (SEA) is also acknowledged to be a key instrument for integrating CC concerns and M&E CCA issues into spatial plans (Ledda et al., 2021; Wende et al., 2012). The ultimate objective of SEA in spatial planning is to promote sustainable development and management of cities and land by ensuring that environmental considerations associated with human wellbeing (including climate-related issues) inform the drafting of, e.g., spatial policies, land use plans, and place-based programmes (Geneletti, 2016).

Among the most prominent challenges towards CCA integration and mainstreaming, including in SEAs, there is the development of robust approaches to M&E the extent, progress, and effectiveness of CCA implementation (Goonesekera and Olazabal, 2022), as well as of other CC-related aspects depicting, e.g., CC risks and impacts. This includes the definition of ad hoc indicators tailored to assess components of climate-related risks (e.g., hazards, vulnerabilities, exposures), their effects (e.g., areas or assets degraded due to climate impacts), and to M&E the implementation and effectiveness of CCA measures incorporated into the spatial plans (Ledda et al., 2021).

Academic scholarship of the CCA field confirms that CCA M&E is a challenge yet to be effectively addressed (e.g., Leiter, 2021; Goonesekera and Olazabal, 2022). This goes unparallel with the more active on-field knowledge production by the practitioners working in the development and CCA-oriented cooperation system (e.g. Bours et al., 2015, Rai et al., 2019, Posas 2021, OECD, 2010, Leiter, 2021). Likewise, the knowledge gap in the SEA field concerning CCA has been investigated hitherto in a very limited set of academic papers (do Nascimento Nadruz et al., 2018; Ledda et al., 2021; Mascarenhas et al., 2015; Prathaithep, 2021; Wende et al., 2012; Posas, 2011; Enríquez-de-Salamanca et al., 2017; Larsen et al., 2012).

Aware of these gaps, this study tests two main hypotheses together, which are:

- Environmental concerns and current instruments (i.e., SEAs) for its policy integration can help in carrying the CCA cause – as a driver for CCA implementation within spatial planning – into the policy arena and decision-making processes (i.e., in this case the plan-making process). Hence, this paper tested the hypothesis that indicators included in SEAs of spatial plans may be used at the service of CCA M&E and potentially provide the premises to better consider and integrate CCA into SEAs and as ultimate goal into the plans.
- The multi-level governance of CCA in spatial planning highlights the need to investigate the whole hierarchy of plans enforced in a specific area. Hence, this paper addressed the hypothesis that it is necessary to focus on multiple governance scales when analysing CC- and CCA-related issues and, especially, environment-oriented indicators.

To this end, this study provides an in-depth analysis and classification of the indicators used within the SEA of a number of spatial plans at the regional (i.e., 2 plans/SEAs) and municipal scale (i.e., 9 plans/SEAs) in Friuli Venezia Giulia Region (Italy). The analysis focused on indicators that can explicitly be useful or implicitly be relevant to M&E:

- the possible implications of planning decisions and future development trajectories on climate risks and impacts (e.g., indicators associated with a change of land assets that can result in a change of risk or that can act as a stressor exacerbating climate impacts);
- the integration and implementation of CCA measures aimed at climate risk reduction/impact mitigation (e.g., by enhancing adaptive capacity of communities, by reducing exposure and/or sensitivity).

This paper builds the methodological approach for the in-depth analysis and classification of indicators (deeply explained in Section 4) using multiple criteria, including the risk function (also called in this paper as risk equation), considering in the equation: hazards, impacts, sensitivity and adaptive capacity – combined together forms the vulnerability – exposure, and stressors.

Results (Section 5) show the indicators that are identified and classified according to the adopted criteria. Discussion (Section 6) and conclusions (Section 7) build on critical aspects of the indicators, addressing research gaps with a peculiar attention on the CCA mainstreaming through SEAs and highlighting limitations and possible follow ups.

2. State of the art: on the monitoring and evaluation of climate change adaptation and the role of strategic environmental assessments

CCA implementation measurement and tracking, including the provision of clear metrics, is fundamental to assess the short-term effectiveness and pave the way for long-term sustainability of these endeavours. M&E has been viewed as an integral part of CCA planning (Feldmeyer et al., 2019) and the current increase of CCA-oriented funding obliges both CCA-related scholars and practitioners to M&E in an effective and shared way (UNEP, 2023).

Academic literature and grey literature (e.g., working and policy papers, policy documents and reports, and policy and programming guidelines) are still progressing unparalleled. The latter category, mostly coming from the development and CCA-oriented cooperation field, has been more active due to its on-field knowledge production (Bours et al., 2015, Rai et al., 2019, Posas 2021, OECD, 2010, Leiter, 2021). In general, literature on assessing CCA progress has so far been predominantly focused on the level of projects and communities (Bours et al., 2015; Rai et al., 2019), where the development cooperation approach, so-called MERL – acronym of monitoring, evaluation, reporting, and learning –, is predominant. Certainly, local CCA-related plans and strategies have been analysed for their inner contents and qualities (Olazabal et al., 2019). CCA planning is typically depicted in the form of a policy cycle that includes M&E (Leiter, 2021) but it is still rarely examined so that "there is scant empirical evidence of how local governments are completing the CCA planning cycle by monitoring or evaluating their efforts" (Scott and Moloney, 2022, p.1).

Shifting the attention from the climate to the environmental research field, in the long-standing narrative of Environmental Policy Integration (Jordan and Lenschow, 2010), where the current narrative of Climate Policy Integration builds on, attempts of CCA mainstreaming have been made with environmental-related instruments such as SEAs (Ledda et al., 2020; Serra et al., 2022; Prathaithep, 2021; Wende et al., 2012; Enríquez-de-Salamanca et al., 2017). Larsen et al. (2012) asserted that SEAs can allow mainstreaming climate issues into (spatial) plans and can provide technical basis to ensure strategic environment-driven actions. Concerning the specific aspect of CC- and CCA-related indicators in the SEAs' spatial plans, to our knowledge, no academic paper provides an in-depth analysis of SEAs' indicators to analyse the extent and typologies of indicators that can M&E climate risks/impacts and/or CCA implementation.

In the European Union, the macro-regional context where this study is framed, spatial plans at all local scales (i.e. regional, metropolitan, country, provincial, municipal, site-specific) are in fact among the plans and policies that are required to undergo an environmental assessment, through the SEA, before they are adopted.[1] Also, the European Commission remarks the need to consider climate impacts in implementing spatial planning policies,[2] with SEA recognized to be a suitable instrument for integrating climate considerations given that CC impacts are closely related to and interlinked with the environment, biodiversity, and ecosystems, as well as with human wellbeing and development. Actually, there are countries in Europe attempting to support the integration of climatic aspects into SEA processes and the monitoring phase, by providing guidelines that include the definition of possible indicators to use to M&E CCA, among others, e.g., Ireland, UK, Scotland, the Netherlands, Belgium (Scottish Government, 2009; Willekens et al., 2011; Mäkinen et al., 2018). In Italy, this systemic approach has been lacking and environmental concerns in SEAs' M&E frameworks have been framed into a simplified classification, the Context-Process-Contribute (translated from the Italian *Contesto-Processo-Contributo*) tryptic (see ISPRA[3]). This approach simplifies the M&E endeavours and does not allow to effectively measure the CCA implementation in terms of outcomes and impacts because they are aggregated within the 'Contribute' label with the outputs. Therefore, thorough frameworks in SEAs, but not only, are necessary to be set up and tested to effectively M&E CCA implementation.

3. Research context

3.1. Climate change adaptation policies and plans in Italy

Concerning the progress of CCA policies, strategies, and plans that are relevant for the case study, CCA is a very recent topic in the Italian policy framework. After the 2015 CCA national strategy, the Italian Minister of Environment and Energy Security elaborated the CCA national plan only in very recent times, which was finally approved at the end of 2023 (MASE, 2024) after a dedicated SEA process.[4] CCA is also somewhat addressed via the Sustainable Development Strategy[5] (2022). Among the several instruments proposed and fostered, the CCA Italian plan provides indications and measures relevant for integrating CCA into a number of sub-national policy and decision-making processes - including spatial planning. The annexes I and II of the CCA national plan clearly provide recommendations about the employment of the climate risk function at the service of SEAs' M&E framework. The CCA Italian plan also states the responsibility of the regional level to integrate and implement both the national sustainable development strategy and the national CCA plan's measures and indications into the regional policy and planning framework. To this aim very few Italian Regional Authorities already have a dedicated plan or strategy that addresses CCA - the FVG Region has not yet approved any regional CCA strategy or plan. Concerning municipal governments in the FVG region, which should address CCA and M&E the CCA progress within the plans and policies for which they are responsible, very few seem to concretely encompass these issues. For example, despite not being legally binding, only 9 local authorities[6] have elaborated the Covenant of Mayors' Sustainable Energy and Climate Action Plan.

3.2. Spatial planning and environmental instruments in the FVG region

The Friuli Venezia Giulia (FVG) Region is located in the north-eastern part of Italy, bordering Slovenia (east) and Austria (north). It is a geomorphologically heterogeneous area, including the alpine region, a hilly karst area, a floodplain in which most people live, and a coastal area overlooking the North Adriatic Sea with an important coastal lagoon ecosystem.

Due to its geographical location and complex orography, the climate profile is varied and characterised by weather extremes (projected to become more frequent due to climate change, see ARPA FVG, 2018 for more information). These extremes include significant annual amounts of precipitation in certain areas, intense rainfall events alternating with periods without precipitation, and high summer temperatures (see ARPA-FVG, 2023 for more details), which may occasionally result in floods, drought, wildfires, and thermal discomfort periods, among others. In addition, due to the characteristics of the southern plain and coastal areas predominantly below sea level, the expected future rise of sea level, unless not significant such as in other areas, will likely have large impacts if no actions are taken.

In the FVG Region the activities related to spatial planning are carried out on a hierarchy basis, as ruled in the Italian legislative context. The Regional Authority takes care of developing the regional master plan, which sets out the regional development objectives and strategies, and the regional landscape plan, which focuses on landscape and cultural heritage preservation and valorisation aspects. At the subordinate level, Municipalities develop their municipal master plan. There are no intermediate authorities between the Region and the Municipalities with tasks in this discipline, thus there are no intermediate-scale spatial plans, confirming the FVG Region as a unique case in Italy.

Concerning the regional level, the current spatial plan in force still is the one from 1978 (called "*Piano Urbanistico Generale Regionale*") since the new one (called "*Piano di Governo del Territorio*"), despite having been approved in 2013, has not yet entered into action due to the need for further revisions before being operatively adopted. The regional landscape plan (called "*Piano Paesaggistico Regionale*") instead was recently approved and has been in force since 2018. As regards the municipal level, only a few municipalities have developed new master urban plans, or substantially reviewed the existing ones, in recent years, which were required to undergo the SEA process (mandatory from 2006 according to Italian legislation). The majority remain with outdated plans and progressively update them through a myriad of small plan reviews, which often are not required to be subject to a SEA given the small environmental impacts they foresee to have. This recurring practice, which is generalised at Italian level (Di Ludovico and Fabietti, 2018), may lead to uncontrolled cumulative and larger impacts due to the progressive addition of small changes that are not assessed nor monitored for their environmental impacts. Hence, the opportunity for integrating environmental considerations, including CCA, into the municipal plans through SEAs is not yet fully exploited.

4. Methods and materials

This work proposes a first attempt of a systematic multi-step identification, analysis, and categorization of indicators based on a desk-based review of SEA documents. It focuses on both the hierarchical levels of spatial planning instruments currently in force in the FVG region: the regional spatial plans and the municipal urban plans. Accordingly, it analyses the SEAs of the regional master plan of 2013[7] and the regional landscape plan of 2018, and of some municipal urban

[1] Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment

[2] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52009DC0147

[3] https://annuariodev.isprambiente.it/it/frontpage

[4] Here the SEA of the CCA national plan (Italy): https://va.mite.gov.it/it-IT/Oggetti/MetadatoDocumento/964576

[5] Here the Sustainable Development Italian Strategy: https://www.mase.gov.it/sites/default/files/archivio/allegati/sviluppo_sostenibile/ALL1_SNSvS_2023_Strategia_e_allegati.pdf

[6] The local authorities in the FVG Region with a SECAP are: Trieste, Duino-Aurisina, Savogna, Pradamano, Meduna, Lignano, Latisana, Udine, Castelnovo, Azzano Decimo.

[7] The regional spatial plan of 2013, even though it has not yet entered into legal force for institutional and technical reasons, is selected for the analysis because the one from 1978, which still is in force, has not undergone the SEA process.

plans that are selected according to the following criteria to limit the sample. First, the timespan selected for the data sourcing is from 2012 until 2023. Second, the municipalities selected have at least 10,000 inhabitants, except plans adopted after 2018 to conform with the regional landscape plan, for which this criterion is not applied. This is to restrict the analysis to more recent urban plans that potentially have more chances to integrate CCA aspects due to: i) the exponential increase of CCA attention over the past 15 years (IPCC, 2022; UNEP, 2023), and especially after Paris COP21 in 2015 and ii) because mid to large-sized municipalities have more technical and human resources than smaller ones to promote innovative aspects in the decision-making processes and planning instruments (Araos et al., 2016). According to these criteria, nine urban plans are considered in this study, namely those of the following municipalities (in parenthesis the year of adoption): Udine (2012), Latisana (2012), Ronchi dei Legionari (2012), Trieste (2015), Muggia (2015), Pordenone (2020), Azzano Decimo (2022), Sagrado (2023), Codroipo (2023). See Annex 4 and Fig. 1 for a general and geographical contextualization.

As a first step, the identification of the potentially relevant indicators to M&E CC- and CCA-related issues starts by building on these questions:

- Does the indicator explicitly mention/refer to any climate-related risk issue or adaptation process/outcome? Even if not explicit, does the indicator have an implicit relevance to any of the aforementioned aspects?

For the first question, we inspired on the broad categorization of CCA-oriented indicators provided by the Climate Change Expert Group paper (Vallejo, 2017) into indicators addressing climate risks (including climate hazards, climate impacts, exposure, and vulnerability/adaptive capacity), adaptation processes (implementation of strategies/policies/measures relevant for the adaptation purpose) or outcomes (the results of implementation). To identify the explicitness of SEAs indicators, a list of CCA- and CC-related keywords was defined. The latest CC technical reports of the FVG regional agency for the environmental protection (ARPA-FVG, 2018, 2023) are the main sources for building this list. Due to a lack of policy- and governance-related keywords in these reports, it was added a second step for the keyword research in the ARPA-FVG website[8] where certain spatial-oriented tools are mentioned and may serve to promote CCA (see Annex 1 for the list of keywords).

For the second question, the inclusion of indicators whose relationship with CC- and CCA-related issues is not explicit is to capture all the possible indicators that may somewhat have a relevance to monitor them, even if they were not purposely built with this aim. For example, an indicator measuring the share of forest area, even if not formulated within or explicitly linked to any CC- or CCA-related monitoring framework, may be considered relevant to track climate-related risks (e.g., measuring the extent or reduction of forest cover can provide insights on a component influencing the actual erosion/landslide risk or its trend) or adaptation progresses (e.g., an increase of forest cover as a result of afforestation programmes that may provide adaptation benefits) (Mäkinen et al., 2018). While the method for identifying the explicit indicators is based on keyword analysis, the identification of this second type of indicators implied several iterative rounds of discussion among the researchers involved in this study to reach a decision about their relevance or not, and consequently about their inclusion into the 'implicit indicators' dataset.

While explicit and implicit indicators are identified and collected from SEAs, they are classified according to a specifically developed set of criteria and categorizations to depict their role in terms of M&E either positive or negative aspects of CC- and CCA-related issues. These criteria/categories were inspired and based on - with some adjustments - the ones proposed in the EEA report "Indicators for adaptation to climate change at national level - Lessons from emerging practice in Europe" (Mäkinen et al., 2018). A complete overview of the criteria/categories used for classifying the indicators is provided in Annex 2.

The first criterion is related to the main aspect that they seek to target or to which they are relevant: climate risks, climate impacts, or CCA (including adaptation processes and outcomes).

The second concerns the target 'object' to M&E, i.e.: state, intervention, or effect of intervention; where 'State' refers to the current contextual condition (i.e., baseline); 'Intervention' refers to the action or measure employed aiming at producing an output; 'Effect of intervention' refers to the outcome or impact resulting from the action/measure implementation (i.e., deviation from the baseline). When the indicator is associated with an adaptation intervention, two further (sub)classifications are applied. One concerns the classification per typology of intervention addressed, i.e., Hard measures involving physical transformations that can be 'Green-blue' (nature-based or ecosystem-based), 'Grey' (human-engineered - mostly impermeable - artefacts), or 'Hybrid' when the previous two are combined; Soft measures involving (non-physical) policy initiatives. The other seeks to categorise them by the aim to 'minimise' or 'avoid' the risk/impact (Davidse et al., 2015), hence clarifying the CCA ultimate purpose. In case of impossibility to define the indicators with one of the previous two options, they are classified as 'ND' (not definable).

The third criterion implies the categorization of indicators in terms of relatedness with the climate/climate-related hazard or impact they address (explicitly or implicitly), e.g., heatwaves, flooding, drought, etc. In case of an indicator related to a general measure with a broad scope and multiple possible links, it is classified as 'multi-impact'. The fourth relates to the sector (e.g., built environment, water natural ecosystems, etc.) the indicator applies to. 'Generic' is the category used when it is not possible to relate the indicator to a specific territorial sector. Finally, the fifth and last criterion applied to categorise the indicators concerns the 'climate risk function' extent and is described in Table 1 and whose interrelations are visualised in Fig. 2. This criterion applies on the indicator's targeted component among the ones considered as determinants of risk and is based on the common IPCC risk components - hazard, vulnerability, and exposure, also used by Mäkinen et al. (2018), with the addition of the 'stressors' category - the latter category sometimes is included as an element indirectly linked to risk such as in the EU-RESIN project[9]. In the context of CC, 'risk' is the result of dynamic interactions between (climate-related) hazards with the exposure and vulnerability (i.e., a combination of sensitivity and adaptive capacity components) of the affected systems/assets/elements to the hazards. All these three components may change over time and space due to socio-economic changes (i.e., natural, unintended, or deliberate changes) and human decision-making (e.g., risk management strategies) (Reisinger et al., 2020). Citing an example from Reisinger et al. (2020), "the risk from flooding to human and ecological systems is caused by the flood hazard (the frequency and/or magnitude of flood events), the exposure of the system affected (e.g. topography, or infrastructure in the area potentially affected by flooding) and the vulnerability of the system (e.g. design and maintenance of infrastructure, existence of early warning systems)" (pp. 11–12).

5. Results

The process of identification of explicit or potentially relevant (i.e., implicit) CC- and CCA-related indicators identified 251 out of a total of 589 (see Annex 3) in the analysed SEAs. 22 indicators were detected as explicit, based on the systematic keyword identification, while the other 229 are considered implicitly (potentially) relevant to M&E CCA (e.g., measures that can mitigate specific climate risks) or other CC-related

[8] www.arpa.fvg.it

[9] https://iclei-europe.org/projects/?RESIN-RESIN_-_Climate_Resilient_Infrastructures_and_Cities_&projectID=Yh4Z1i8J

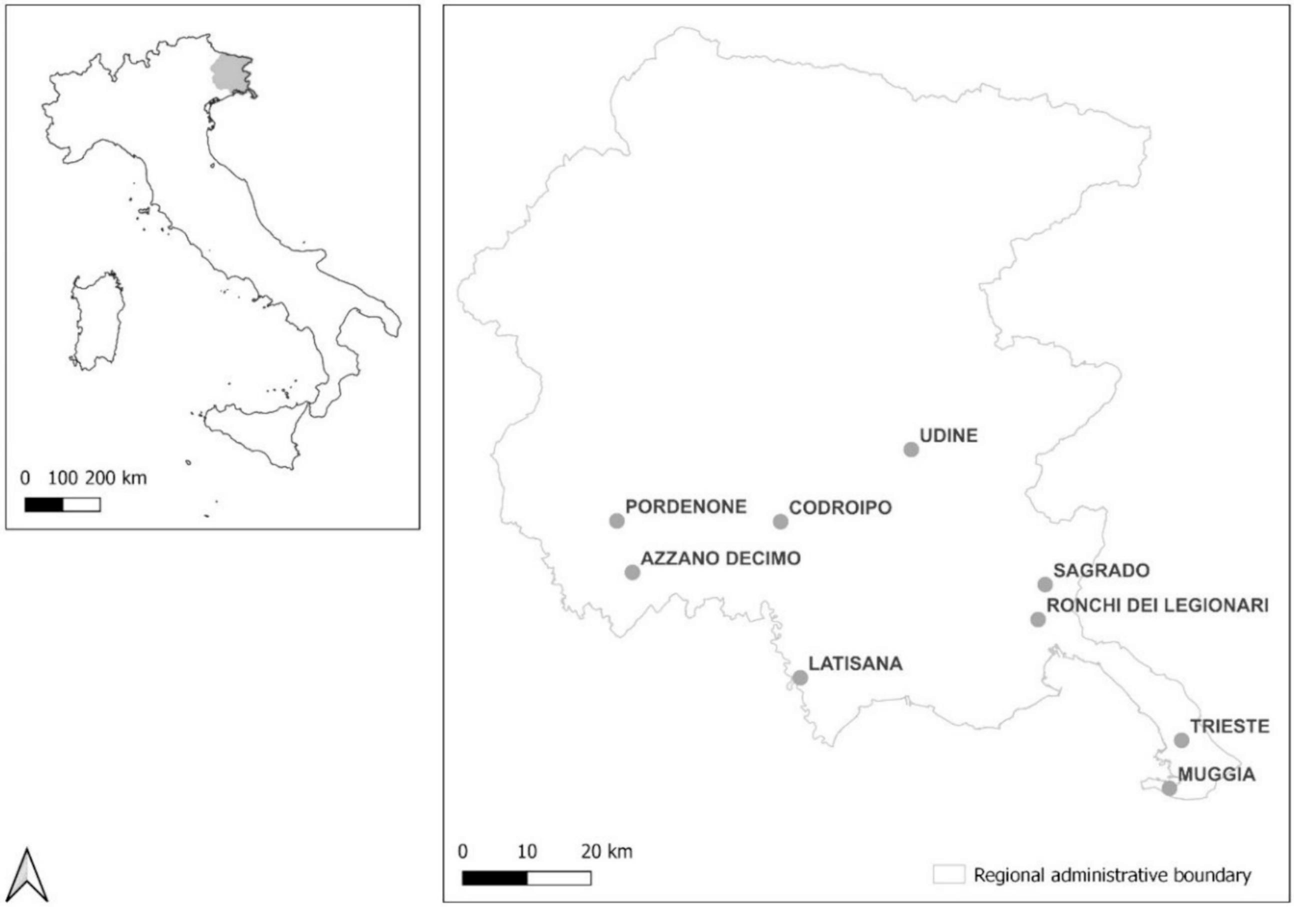

Fig. 1. Geographical overview of FVG Region and the nine municipalities investigated (Made by the Authors).

Table 1
Description of the types of indicators for each element of the risk function (IPCC, 2022, Luckerart et al. 2018).

Indicators for	Description
Hazards	Indicators that assess the potential occurrence of a climate-induced physical event (e.g. heavy rainfall) 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
Sensitivity (Vulnerability*)	Indicators that target the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. Often addressing intrinsic properties of an object resulting in susceptibility to a risk source.
Adaptive Capacity (Vulnerability*)	Indicators that assess the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.
Exposure	Indicators that assess the presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected.
Stressors	Indicators that monitor a change or trend that is not directly linked to climate issues but that may exacerbate the climate vulnerability.

* Vulnerability is defined as the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity and (lack of) capacity to adapt.

aspects (e.g., physical or non-physical elements influencing the vulnerability/risk to climate impacts). Table 2 provides an overview of the SEAs contribution in terms of number of indicators, most recurrent CCA-related interventions – when present, most recurrent indicators identified, and most recurrent metrics or units of measurement. Both the regional plans contributed the most in terms of number of indicators, but only providing 3 CCA-explicit indicators. They similarly address CCA through green-oriented measures for the sake of ecological continuity. Among the municipalities investigated, the SEAs providing CCA-related indicators are Pordenone's, Udine's, Azzano Decimo's, and Muggia's. Pordenone's SEA is the largest contributor with 35 indicators, including 9 explicit ones.

Concerning the metrics, the majority of the indicators (see Fig. 3) present simple metrics and units of measurement aiming at detecting: number of (N°)[10] items/inhabitants/interventions (33.9 %), surfaces (27.5 %), percentages (13.1 %), lengths (7.5 %). The last 18 % out of the total contains limited examples of metrics measuring volumes of river waters or potable water, densities of pollutants in the air, energy production and provision, litres of water flows in pipelines, and currency (€) for funding CCA projects. Also, three non-quantitative approaches are identified, which are the dichotomous 'Yes/No' used for tracking legislative and policy progresses (e.g., laws approval or adoption), the 'spatial' identification of land uses, and the 'qualitative' status of ecological value of ecosystems (i.e. in danger, bad, moderate, good, excellent) or for the state of progress of CC-related plans (i.e., Covenant of Mayors' Sustainable Energy and Climate Action Plan).

Concerning the general extent within the climate risk and adaptation spectrum (see Fig. 4a), the indicators are mainly shared between two categories, i.e., 'adaptation' (44.2 %) and 'risk' (54.3 %). Few are the indicators that can monitor 'impacts' (1.5 %), which are, e.g., 'Hydrogeologic-impacted surfaces' and 'Surfaces impacted by wildfires'. As examples of indicators that were identified as relevant for M&E

[10] N° is used as a symbol for number counting

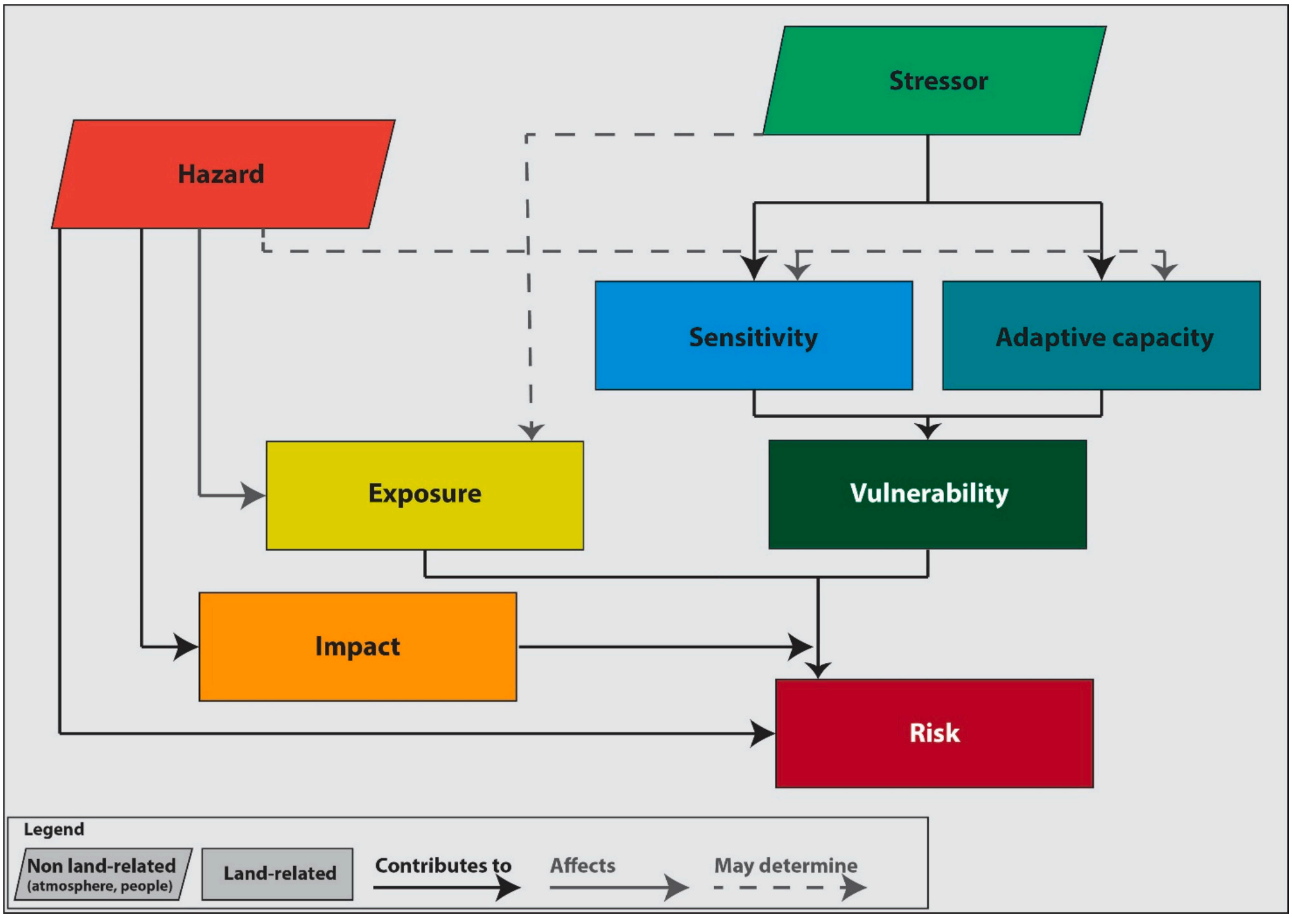

Fig. 2. Interrelations between the climate risk components (Made by the Authors, adapted from Lückerath et al., 2018).

Table 2
Overview of the SEAs indicators' CCA-relatedness.

Source	N° of CC- and CCA-related indicators	N° of CC- and CCA-related explicit indicators	Most recurrent CCA-related intervention(s), when present	Most recurrent indicator(s)	Most recurrent metric(s) / unity(ies) of measurement
SEA Regional master plan (2013)	46	3	Mitigation/compensation of green-oriented measures	Ecological pressure; Land use; Infrastructure; Soil sealing	Qualitative; Spatial; km; ha
SEA Regional landscape plan (2018)	64	3	Ecological connectivity protection/ enhancement	Green areas; Interventions; Land use	Ha; N°; spatial
SEA master plan Trieste (2015)	13	0	/	Atmosphere pollutants concentration	Pg/m^3
SEA master plan Udine (2012)	20	1	Green interventions	Green and blue interventions; (different) land use percentage out of total municipal area	N°; %
SEA master plan Pordenone (2020)	35	9	Green buffer zones and green urban areas	(Different type of) Measures implemented	N°
SEA master plan Muggia (2015)	18	3	/	/	m^2
SEA master plan Latisana (2012)	6	0	/	/	%
SEA master plan Codroipo (2023)	4	0	/	/	%
SEA master plan Azzano Decimo (2022)	27	3	Water pipeline implementation (Grey); Urban green areas/forestry (Green-blue)	Pipeline length; green surfaces, measures implemented	m or km; m^2 or ha; N°
SEA master plan Ronchi dei Legionari (2012)	4	0	/	/	%
SEA master plan Sagrado (2023)	14	0	Waterbeds re-naturalization; Agricultural land rehabilitated (Green-blue)	Soil sealed; Land use, Energy production/consumption	Ha; spatial; kW

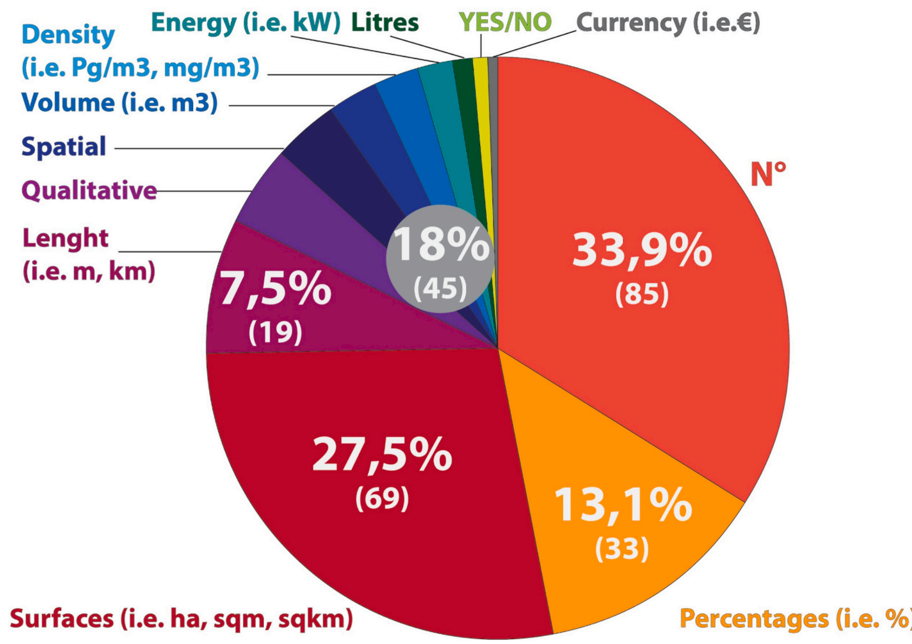

Fig. 3. Metrics and units of measurement (in percentage and, in brackets, the number counting of each type).

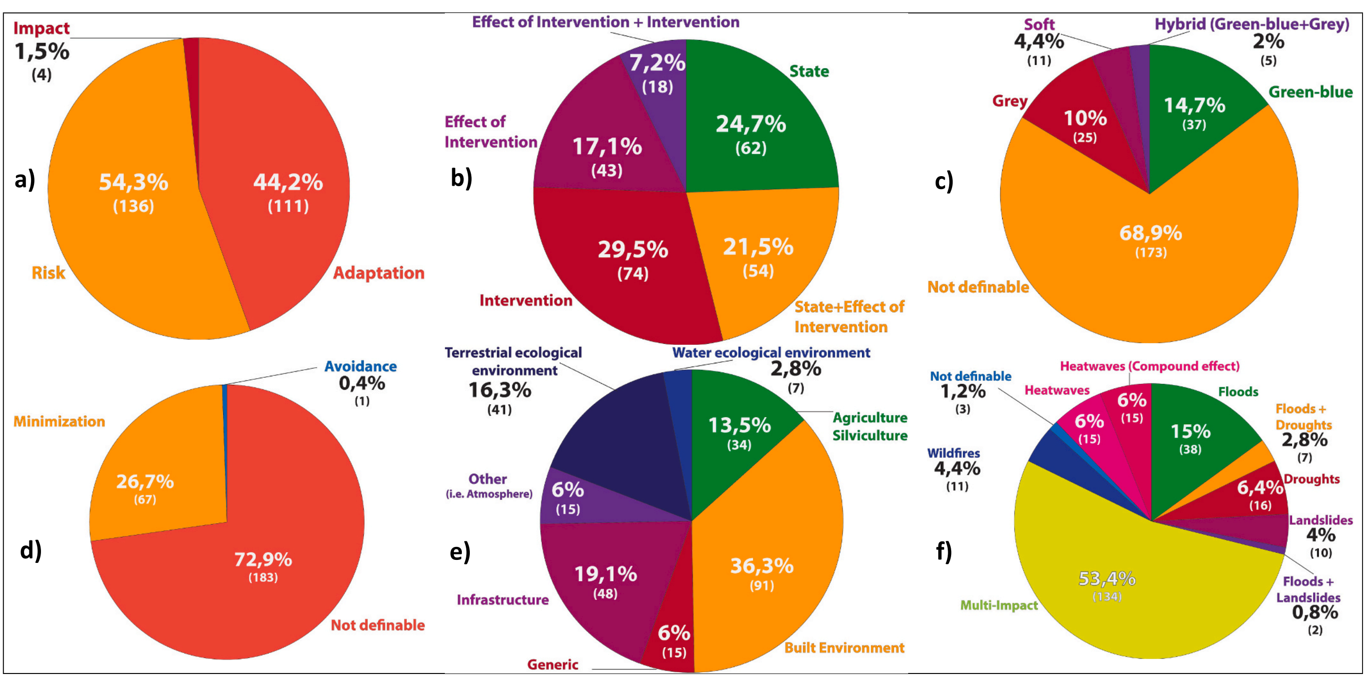

Fig. 4. a) General aim of the indicators; b) Type of indicators in the State-Intervention-Effect tryptic; c) Type of CCA measures; d) Type of risk reduction; e) Type of target sector; f) Type of climate hazard/impact addressed (in percentage and, in brackets, the number counting of each type).

'adaptation' advancements, here are listed: 'Urban green space increase', 'Rural connectivity area', 'Rules and laws for local development and environmental quality maintenance', and 'Removal or relocation of buildings and people from high flood risk areas'. As examples of 'risk' indicators, here are listed: 'Soil sealing', 'Built volumes in hydrogeological risk areas', and 'New built-up area'.

The indicators were also classified according to the object that they can monitor, meaning if they aim to address the state of current conditions, a specific intervention, or the effect of an intervention – it was also possible that an indicator can overlap by addressing two out of the three categories (see Fig. 4b). In order of presence, the indicators were categorised as: i) Intervention (29.5 %), ii) State (24.7 %), iii) State + Effect of intervention (21.5 %), iv) Effect of intervention (17.1 %), and v) Effect of intervention + Intervention (7.2 %). Here below a list of indicators exemplifying the labels:

- for 'Interventions', e.g.:
  - 'Number of new infrastructures constructed',
  - 'Rules and laws for the agroforestry practices' (Number of), and
  - 'Mitigation measures on urbanised or soil sealed surfaces';
- for 'State', e.g.:
  - 'Land use',

  - 'Ecological value',
  - 'Resident population', and
  - 'Potable water consumption per capita';
- for "State + Effect of intervention', e.g.:
  - 'Railroad infrastructure density',
  - 'Resident population in medium flood risk areas',
  - 'Number of buildings with low energy efficiency' and
  - 'Urban green area (total and per capita)';
- for 'Effect of intervention', e.g.:
  - 'Variation of urban green areas',
  - 'Pollution concentration reduction',
  - 'New soil sealed', and
  - 'Metres of terraces rehabilitated';
- for Effect of intervention + Intervention', e.g.:
  - 'Implementation of new pipelines',
  - 'New urban forestry',
  - 'Water buffer zones for flood-proofing', and
  - 'Mitigation measures on impacted ecological corridors'.

Regarding the type of CCA interventions that the indicator is aiming to monitor (Fig. 4c), most of the indicators were not definable (68.9 %) as related to states or context conditions. The other 31.1 % of indicators involving the definition/implementation of measures were categorised instead as: 'Green-blue' (14.7 %), 'Grey' (10 %), 'Soft' (4.4 %), and 'Hybrid' (2 %).

The categorization of indicators based on the type of the CCA intervention, aiming at either minimising or avoiding climate risks/ impacts, resulted as 'Minimising' (26.7 %) and as 'Avoiding' (0.4 %). Most of the indicators were not definable in this categorization (see Fig. 4d). Among the 'Minimising' indicators there are, e.g., 'Biodiversity enhancement in grassland and bushland', 'Number of hydraulic risk reduction interventions', and 'Hard measures for flood risk reduction'. Among the 'Avoidance' indicators, there is 'Removal or relocation of buildings and people from high flood risk areas'.

As regards the target sectors (Fig. 4e), the indicators are mainly calibrated for the artificial and urbanised areas, with the categories 'Built environment' and 'Infrastructure' at 36.3 % and 19.1 % respectively, for a total of 55.4 %. 'Terrestrial ecological environment' accounts for 16.3% and 'Agriculture and silviculture' for 13.5 % of the total. 'Water ecological environment' indicators are 2.8 %, while the 'Other' category – including indicators for atmospheric concerns (e.g., levels of Ozone, CO_2, CH_4, PM10) – accounts for 6 %. Finally, the 'Generic' label gathers all indicators with no specific target sector, potentially applicable everywhere and targeting all the land and/or water environments, e.g., 'Interventions for hydraulic risk reduction', 'Status of progress of covenant of mayor and SECAP', 'Rules and laws for vulnerability mitigation', and 'Rehabilitation interventions for landslides'.

In terms of CC-related hazards and impacts (Fig. 4f), the four most addressed are 'Floods' with 15 %, 'Heatwaves' (including both heatwaves and the compound effect of heatwaves and pollution) with 12 %, and 'Droughts' with 6.4 %. 'Wildfires' is present with 4.4 % and 'Landslide' (landslide risk and hydrogeological risks in general) is present in a dedicated manner with 4 % and in an integrated manner in the categories 'Landslide + flooding' with 0.8 %. Most of the indicators were labelled in the 'Multi-impact' category (53.4 %).

Here below a list of indicators exemplifying the most accounted labels for hazards and impacts:

- for 'Floods', e.g.:
  - 'Risk assessments of flood, drought, health, earthquake',
  - 'New pipelines implementation', and
  - 'Removal or relocation of buildings and people from high flood risk areas';
- for 'Drought's, e.g.:
  - 'Population with potable water accessibility',
  - 'Percentage of water leaks in the pipelines', and
  - 'Potable water consumption per capita';
- for 'Heatwaves', e.g.:
  - 'Interventions for the energy efficiency by retrofitting buildings',
  - 'Electric energy production from public buildings from renewable sources'
  - 'Number of buildings with low energy efficiency', and
  - 'Pollution concentration: PM10, NOX, CO';
- for 'Wildfires', e.g.:
  - 'Surfaces impacted by wildfires',
  - 'Surfaces per year recovered from spontaneous reforestation', and
  - 'Biodiversity enhancement in grassland and bushland';
- for 'Landslides' and 'Landslides + Floods', e.g.:
  - 'Hydrogeologic-impacted surfaces',
  - 'Rehabilitation interventions for landslides', and
  - 'Number of falls and landslides';
- for 'Multi-impact', e.g.:
  - 'Urban green areas' increase',
  - 'Pressure from railroads to protected areas',
  - 'Potential new soil sealed due to urbanisation', and
  - 'Percentage of inhabitants with accessibility to green spaces (300m)'.

Lastly, regarding the climate risk variables (See Fig. 5), the indicators were gathered and classified in the following labels:

- 'Sensitivity', with the 75.4 %, e.g.:
  - 'Urban green areas',
  - 'Interventions against the forestland spread', and
  - 'Compensation for the ecological network's impacts';
- 'Stressors', with the 14.7 %, e.g.:
  - 'Touristic flows: income and presences',
  - 'Percentage of population exposed to PM10 concentration' and
  - 'Inhabitants with no access to wastewater pipeline';
- 'Adaptive capacity', with the 4.4 %, e.g.:
  - 'Rules and laws for vulnerability mitigation' (Number of),
  - 'Status of progress of covenant of mayor and SECAP' and
  - 'Recommendations and guidelines to avoid soil sealing';
- 'Exposure', with the 2 %, i.e.:
  - 'Removal or relocation of buildings and people from high flood risk areas' (Number of),
  - 'Built volumes in hydrogeological risky areas', and
  - 'Resident population in high flood risk areas';
- 'Hazard', with the 0.5 %, i.e.:

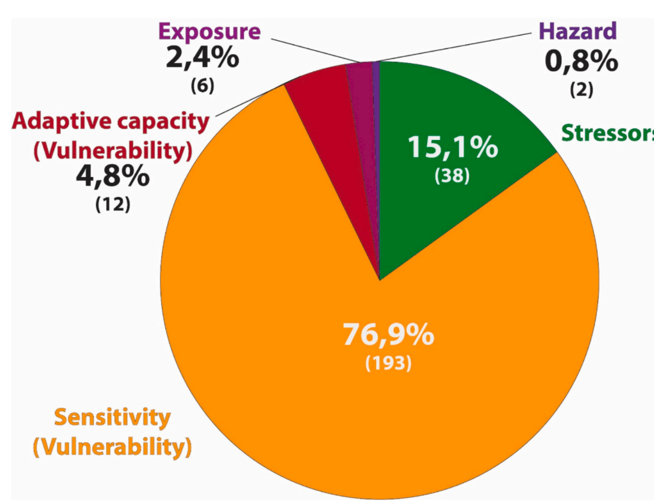

Fig. 5. Climate risk extent of indicators (in percentage and, in brackets, the number counting of each type).

◦ 'Number of falls and landslides'.

5.1. A focus on the CCA-explicit indicators

The explicit indicators for CCA and climate risk M&E (see Annex 5) - i.e., 22 out of 251, less than 10 % - were identified through matching a series of selected keywords relevant for defining the explicitness to CC- and CCA-related issues (see Annex 1 for the complete list) with the ones provided in the indicator formulation. The matching keywords in the identified 22 indicators are:

- Landslide
- Hydrogeological/Hydraulic/Flood/Fluvial (associated with) risk/security/defence
- Stormwater management (in relation to urban pluvial floods)
- Hydric security (in relation to droughts)
- CC resilience and adaptation
- (Climate) Vulnerability
- Wildfires
- Covenant of Mayors

Most of the indicators aim at monitoring interventions to be designed or measures to be implemented, which are evaluated through the simple metric of N°. This item counting is also employed for monitoring the inhabitants living in risky areas. Some indicators aim to monitor the surfaces (e.g., ha or square km) of the implemented measures. Volume of built areas is also considered for one indicator, while the progress of a climate-related plan (i.e., SECAP's Covenant of Mayors) is tracked in qualitative terms.

Concerning the general aim of the indicators, most of the identified data was gathered and classified into the 'Adaptation' label, meaning that they target CCA action and implementation (i.e. 15 out of 22 indicators). Five indicators were labelled as 'Risk' oriented and just two were categorised as 'Impact' related (i.e., 'Surfaces impacted by wildfires', 'Hydrogeological-impacted surfaces').

Regarding the State-Intervention-Effect of intervention tryptic, the explicit indicators were mainly categorised as 'Intervention' (15 out of 22) – one indicator was categorised with the double labelling 'Intervention + Effect'. Exclusivity to 'State' and 'Effect of intervention' was assigned just to two (i.e., 'Surfaces impacted by wildfires- and 'Number of falls/landslides') and one (i.e., 'Variation of number of landslides in the Landslide register'), respectively. Finally, the double labelling 'State + Effect of intervention' was assigned to four indicators (e.g., 'Resident population in high flood risk areas').

Most indicators, when categorised according to the type of hazard/impact they address, are assigned to 'Flood' (16 out of 22); three of them are also related to 'Droughts' and two to 'Landslide'. 'Landslide'-dedicated indicators are three, i.e., 'Number of falls and landslides', 'Rehabilitation interventions for landslides', and 'Variation of number of landslides in the Landslide register' – also framed into the broad umbrella of hydrogeological risks. One indicator addresses 'Wildfires' and two are not definable, as set for policy or legislative purposes.

As regards the target sectors, most of the explicit indicators (13) are labelled as 'generic', meaning that they can be employed into several sectors. Eight indicators address the 'Built environment' sector and one is dedicated to 'Terrestrial ecological environment', i.e., 'Surfaces impacted by wildfires'.

The explicit indicators aiming at monitoring CCA interventions mainly concern the 'Grey' type (8), e.g., 'Grey stormwater management (interventions)'. The 'Green-blue' type accounted for two indicators, e.g., 'Water buffer zones for flood-proofing', just like the 'Hybrid' type, e.g., 'Interventions for hydraulic risk reduction'. The indicators addressing 'Soft' measures were three, e.g., 'Risk assessments of flood, drought, health, earthquake'.

In terms of CCA interventions' ultimate purpose, nine indicators were classified as 'Minimization', one as 'Avoidance', i.e., 'Removal or relocation of buildings and people from high flood risk areas', while twelve were not definable.

Finally, the indicators' targeted components of the climate risk determinants showed the preponderance (12) of 'Sensitivity'-oriented indicators, e.g., 'Hydraulic risk interventions' and 'Rehabilitation interventions for landslides'. As for 'Exposure', the indicators gathered were five, e.g., 'Resident population in low flood risk areas'; as for 'Adaptive capacity' the indicators were four, e.g., 'Design of rules and laws for hydrogeological risk reduction'; and last, for 'Hazard', only one indicator fit into this type, i.e., 'Number of falls and landslides'.

6. Discussion

This paper aimed at finding SEAs environmental indicators supporting CC- and CCA-related issues in spatial plans. To this end, it tested two main hypotheses that were confirmed by the evidence of the results, which can lead now to the following assertions:

- indicators included in SEAs of spatial plans can be explicitly used at the service of CC risk and CCA M&E and can provide the premises to better consider and mainstream CCA into SEAs and as ultimate goal into spatial planning instruments.
- when analysing environmental indicators in a spatial planning context, it is necessary to address the enforced plans (i.e., their related SEAs) at multiple scales (at least regional and municipal) to include the full extent of indicators and capture the possible interdependencies in relation to CCA integration in M&E schemes.

A key aspect of the research lies in the investigation of the elements of the climate risk function (i.e., hazard, sensitivity and adaptive capacity for the overall vulnerability, exposure, stressor) that are targeted by the identified indicators. All indicators fit into the equation with a preponderance of sensitivity-oriented indicators. Few indicators aim at M&E exposure, adaptive capacity, and stressors; just one aims at monitoring hazards. Despite the sharp discrepancy between sensitivity and the other variables, which is a context-sensitive point of discussion, this work showed a possible use of the climate risk equation lens for the sake of analysing the extent of inclusion of CC- and CCA-related aspects into M&E schemes of SEAs. Also important, within the set of sensitivity-oriented indicators there are two complementary approaches, one that can monitor the sensitivity improvement, the other its worsening. The prevalence of spatial and biophysically-oriented sensitivity indicators over socio-political and institutional elements, which are the main elements on which the adaptive capacity relies, is in line with the findings of Dupuits et al. (2024), who recognize this aspect as a limitation of CCA monitoring systems and call for integrating more indicators to monitor the changes in the adaptive capacity of human groups (e.g., knowledge, capacities, empowerment).

Another context-sensitive issue that arose relates with the spectrum of hazards and impacts that the identified indicators aim or potentially aim to address. Most of the indicators have a multi-impact general attention (e.g., heat and stormwater; heat and drought; heat, flood, and drought) and when specific to one source of harm, they mainly tackle water-related issues, i.e., (river and pluvial) floods, droughts, landslides. Heatwaves and wildfires are also tackled. Coastal floods, storm surges, sea level rise, wind gusts and tornadoes, and vector-borne diseases are not addressed, despite being mentioned in the regional CC risk assessments (ARPA-FVG, 2018, 2023). For some hazards (e.g., seal level rise, vector-borne diseases), this could depend on the fact that they are not seen as imminent hazards, thus they are not accounted for within the rather limited timeframe for which the planning objectives are defined, especially at the municipal scale. This is a recurrent gap in spatial planning, where short-term objectives and benefits are almost always preferred to those that are achieved only in the longer term, such as in CCA planning (Bours et al., 2015).

Concerning the metrics employed and the effectiveness of CCA M&E, here the discussion includes two trade-offs, yet to be fully solved, i.e.: simplicity vs. complexity (Sugoni et al., 2023), and generalisation vs context-specificity (Di Ludovico and Fabietti, 2018; Mascarenhas et al., 2015). These issues are typical of the M&E field, but specific considerations from the analysed CCA-relevant indicators can be formulated. All the metrics employed are very simple, cost-efficient, and easy to use, hence, facilitating civil servants and practitioners. Yet, some indicators are barely helpful for CCA effectiveness evaluation. Can indicators such 'Water buffer zones for flood-proofing' or 'Design of rules and laws for hydrogeological risk reduction' help asserting on the CCA effectiveness? This question shifts the attention to the opposite side of the spectrum, hence, to the complexity and context-specificity of the indicators, which are cost- and skills-demanding but necessary in line with the CCA inner complexities. Actually, there is no standard metric or one single and internationally recognized indicator framework for M&E CCA. Several are the reasons for this lack, *in primis*, the inherent uncertainties and evolving conditions of the climate. In addition, "finding a common understanding about which indicators are useful and which data best underpin them to measure the progress towards goals and objectives is often seen as a challenging and time-consuming process" (Mäkinen et al., 2018, p.18), and this seems especially true for indicators that should evaluate effectiveness rather than simply tracking implementation. Another worth-to-mention reason is the fact that many plans still do not recognize CCA as a priority, and this mirrors the lack in the SEA's M&E phase. Although addressed in plans, there are cases where CCA inclusion in the monitoring phase remains neglected (e.g., similarly to what found by Longato et al. (2021) for the ecosystem service concept). However, independently from the context-specific reasons, this study confirmed the tendency to use general indicators and related metrics which, even if not specifically formulated for M&E CCA, can capture – to some extent – CC- and CCA-related aspects, sometimes working as proxy outcome indicators. This does not always imply that the identified indicators are of good quality for M&E these issues. In general, a good-quality indicator can be defined as an indicator that is Specific, Measurable, Achievable, Relevant, and Timely (i.e., the key elements of the "S.M.A.R.T." listing (e.g.; Maxwell et al., 2015)), but especially when it comes to CCA-oriented indicators, several criticalities for their development arise.

Concerning the different extent of inclusion of CC- and CCA-related indicators in the analysed SEAs, this may depend on different factors. One could be due to the specificity of spatial planning frameworks that are often disciplined by a hierarchy of plans. Consequently, CCA considerations in the supra-ordinate plans, to which the subordinate plans need to conform with, could influence CCA integration in the municipal ones. Since in the FVG case only the regional landscape plan of 2018 requires the conformation of subordinate municipal plans, some of them that were approved or substantially revised after 2018 may have been stimulated more than the less recent ones to include CCA considerations (i.e., Azzano Decimo's and Pordenone's plans above all). However, this is not always true (i.e., Sagrado's and Codroipo's plans). To this regard, bottom-up local demand, from both the community and practitioners, for CCA integration seems to constitute one of the most important drivers – building on Mascarenhas et al.' (2015) assertions relating instead to environmental aspects. This could be especially true in Pordenone, which is considered an example of innovative planning (e.g., Pultrone, 2021) and stands for being the case in which the integration of CCA-related aspects seems greater with the highest number of CC- and CCA-related indicators, including explicit ones, among the municipalities analysed. Another factor possibly influencing the integration of CC- and CCA-related indicators and their quality may be the case that (some of) the reviewed plans can have flaws in terms of quality or conformance with SEA good practices and/or supra-ordinate plans (e.g., poor attention or conformance to CCA-related aspects along the whole SEA process, from objectives to actions' definitions, among others). Consequently - through a cascading effect - also the elaboration of SEA indicators may have suffered from these shortcomings in those plans showing a lower degree of integration.

Reflecting on the limitations of this research, there is room for improvement from several perspectives. Despite the limitations of available data, this study paved the way for analysing M&E schemes and related indicators within SEAs aiming at enhancing mainstreaming of CCA into spatial plans. The methodology can be replicated (or further adapted) and used as a stepping stone for further theoretical and analytical progress. Building on the current set of methods, others can be added, i.e., interviews with practitioners of several regional departments, including environmental agencies, and focus groups with technicians that are in charge of developing SEAs and monitoring schemes. Also, the research scope of the case study could be widened, i.e., including the SEAs of other sectoral plans and policies that are relevant to CCA (e.g., air quality plan, water management plan, one health strategy, waste management plan, etc), EU-Operative Programmes (e.g., EAFRD, ERDF, CF, etc), and Environment and Climate regional agencies' M&E schemes. Finally, internal (i.e., within the same spatial plan/related SEA) and external (i.e., between supra-ordinate and subordinate spatial plans/related SEAs) coherence in the nexus objectives-actions-indicators should be further assessed to identify drivers and criticalities for the integration and mainstreaming CCA in spatial planning decisions.

7. Conclusions

The increasing recognition of the necessity to integrate CCA in our society's response to CC has led to the need for making targeted, justified, effective, and cost-efficient decisions in several policy sectors, including spatial planning. In this context, the M&E phase plays an important role in the adaptation policy cycle, and SEAs are considered a key instrument for integrating CC- and CCA-related considerations and for M&E the associated issues (e.g., CC risks and impacts, CCA implementation progresses).

This study aimed to demonstrating that current environmental instruments, i.e., SEAs, can help in carrying the CCA cause into the spatial policy arena, aligning environmental policy integration with climate policy integration. The in-depth analysis of 589 indicators from 11 SEAs, 2 from regional spatial plans and 9 from municipal spatial plans, led to the detection and categorization of 251 CC- and CCA-related indicators, even if only a small number can be considered as indicators explicitly built to M&E these issues. With this evidence, the paper argues that indicators included in SEAs of spatial plans may be used at the service of CC risk and CCA M&E. Another key point of assertion relates with the necessity to focus on multiple governance scales, especially the regional one hitherto neglected, when analysing CCA indicators, and, specifically, environment-oriented indicators in SEAs.

This study employed an analytical approach for indicators' analysis and categorization that brought novelty in the SEA field. One of the (novel) analytical lenses that was used for classifying the indicators is the climate risk function (IPCC, 2022). Despite the limited number of CCA-explicit indicators and possible flaws in terms of quality and conformance in the analysed SEAs' indicators, this lens helped in categorizing the 251 CCA-related indicators to M&E the risk elements, i.e. hazard, susceptivity, adaptive capacity, exposure, and stressor.

The multi-step analysis paved the way for further investigation in the SEA field. The methodology can be replicated and used as a stepping stone for further theoretical and analytical progress. From the practitioners' perspective, this study provides a complete methodology that can potentially be used by SEA professionals for analysing and further refining SEA indicators, possibly enhancing the knowledge base to support the mainstreaming CCA into spatial planning frameworks.

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Declaration of competing interest

The Authors declare that they have no conflict of interest. Also, the Authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eiar.2024.107650.

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