RESIN

SUPPORTING DECISION –
MAKING FOR RESILIENT CITIES

European Climate Risk Typology – Final Report

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1. Executive Summary

This deliverable of the RESIN project presents the European Climate Risk Typology. It builds on previous deliverables released during the project that have described the development of the typology (Hincks et al 2016 and 2017). This deliverable provides readers with details of the typology aims, scope, methodology, outputs and uses. It is of potential value for groups including users looking to better understand the typology before applying it in practice, and for researchers wishing to learn more about how the typology was developed.

1.1 Aim of the typology

We know that climate risk varies, spatially, across Europe's cities and regions. There is real diversity in the factors that shape climate risk in different locations. However, opportunities to visualise and analyse these patterns across the continent, and to understand the climate risk characteristics of specific European cities and regions, are currently limited. This is a barrier to progressing Europe's climate change adaptation and resilience goals. The European Climate Risk Typology aims to address this issue by providing an innovative approach to enhance understanding of climate risk in European cities and regions.

1.2 Typology approach and methodology

In developing the typology, an approach was followed to generate a typology that is methodologically transparent, simple to use, but comprehensive in scope and application. Spatially, the typology is based around Europe's NUTS 3 regions. The NUTS (Nomenclature of Territorial Units for Statistics) (see the Glossary (Appendix 3) for a definition of this term) classification is a hierarchical system that divides Europe into different administrative units[1]. There are 1379 NUTS 3 regions, which have a population between 150,000 and 800,000. NUTS 3 regions are split into those that are predominantly urban, intermediate and predominantly rural based on land use characteristics. Many of Europe's major cities are made up of one or more NUTS 3 region, enabling a cities perspective to be taken.

Conceptually, the typology follows a risk-based approach. Following the latest Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) (IPCC 2014), this approach encompasses climate *hazards* facing Europe's regions and their level of *exposure* and *vulnerability* to these hazards, where vulnerability incorporates *sensitivity* and *adaptive capacity*. The typology methodology involved the selection, cleaning and processing of indicator data specific to these risk domains. A cluster analysis approach was then undertaken to create the climate risk typology that organises Europe's NUTS3 regions into groups that share similar climate risk characteristics.

1.3 Typology output

The outcome of the typology development process was the creation of a two-tier climate risk classification of European cities and NUTS3 regions. These are described as typology classes and sub-classes. Eight typology classes were identified. These are mapped within Figure 1, which presents a screenshot from an online portal developed to house the typology. Each class represents a distinct group of cities and NUTS3 regions that share similar climate risk characteristics (hazard,

[1] Regulation (EC) No 1059/2003

exposure and vulnerability). This map of Europe's typology classes highlights several issues concerning Europe's climate risk 'landscape':

- All of Europe's cities and NUTS3 regions are at risk of climate change, but for different reasons. The typology was not designed to offer a relative ranking of climate risk (from high to low) in order to enable a richer picture of the complex patterns of climate risk across Europe to be developed.
- Considered from the perspective of the European continent, there is real diversity in the climate risk characteristics of its cities and NUTS3 regions.
- Due to the range of socio-economic and biophysical variables that influence climate risk, geography alone cannot adequately explain the spatial patterns revealed by the European Climate Risk typology. In some cases, cities and NUTS3 regions that fall into the same typology class are in very different parts of the continent.

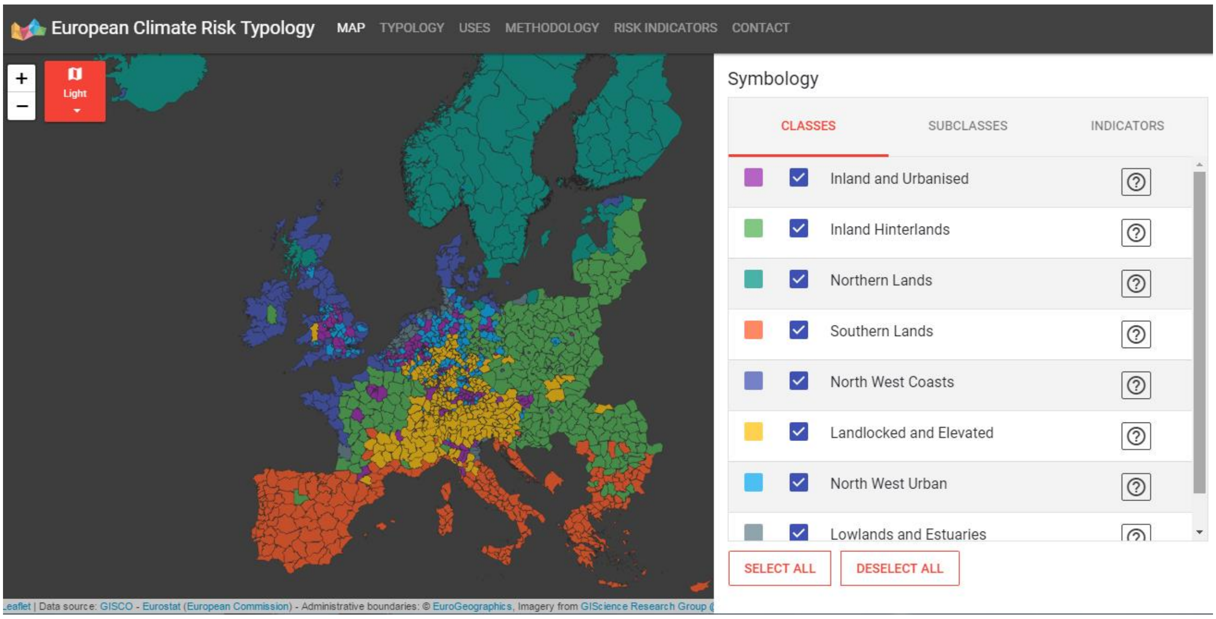

Figure 1: Map of Europe showing the eight typology classes. (Data source: GISCO - Eurostat (European Commission) - Administrative boundaries: © EuroGeographics, Imagery from GIScience Research Group @ University of Heidelberg — Map data © OpenStreetMap)

The second tier of the typology consists of 31 sub-classes. Each of the typology classes is divided into between three and five sub-classes. These identify distinct clusters of NUTS3 regions that sit within each class. The typology sub-classes have been developed in order to enable a more nuanced understanding of climate risk in European cities and NUTS 3 regions to be developed. In regions such as the Mediterranean and Northern Europe, which are dominated by one particular typology class, the sub-classes help to differentiate between their cities and NUTS3 regions on the basis of their climate risk characteristics.

The typology is housed within an interactive online portal that provides data and functionality enabling users to visualise, describe, compare and analyse climate risk in European cities and regions. A wide range of indicator data covering different aspects of climate risk can also be accessed via the online portal.

1.4 Typology Uses and Users

The typology is novel in terms of its scope, coverage and potential utility in climate change adaptation and resilience planning. To date, this is the first time that climate change hazard, exposure and vulnerability layers have been integrated into brought together in a risk-based framework and analysed for the whole of Europe. The typology is an innovative output that provides new perspectives on Europe's climate risk 'landscape', and has the potential to support planners and decision makers working on adaptation at various spatial scales. For example, the typology and its supporting suite of indicators can inform climate change risk assessments and the creation of climate change adaptation and resilience strategies and plans. In addition, the typology presents users with the opportunity to develop networks of cities and regions that share similar climate risk characteristics concerning the hazards they face, and their levels of exposure and vulnerability to these hazards. The typology can also be used in an exploratory way to highlight issues connected to spatial patterns of climate risk across Europe's cities and NUTS3 regions. The typology can therefore be viewed as a decision-aid to support more efficient and effective approaches to assess and adapt to climate risks.

2 Typology background and context

This deliverable of the RESIN project presents the European Climate Risk Typology. It builds on previous deliverables released during the project that have described the development of the typology (Hincks et al 2016 and 2017). This deliverable provides readers with details of the typology aims, scope, methodology, outputs and uses. It is of potential value for groups including users looking to better understand the typology before applying it in practice, and for researchers wishing learn more about how the typology was developed.

2.1 Aims of the typology

Europe's climate is changing rapidly. Projections indicate that significant shifts in temperature and precipitation, and related extreme events such as floods and heat waves, can be expected over the coming decades (EEA 2016, IPCC 2014). Europe's Climate Change Adaptation Strategy (COM 2013-0216 FIN) highlights the need to develop strategies and actions in response. Understanding and responding to the impacts of climate change is now framed in the context of risk (IPCC 2014; Connelly et al 2018). Climate risk varies spatially since it is driven by multiple interacting climatic, biophysical and socio-economic factors. Understanding climate risk from a spatial perspective can therefore inform approaches targeted at adapting and building resilience to climate change.

Although we know that climate risk varies, spatially, across Europe's cities and regions, opportunities to visualise and analyse these patterns and to understand the climate risk characteristics of specific European cities and regions are currently limited. This is a barrier to making progress with Europe's climate change adaptation and resilience goals. The research reported here, undertaken within the RESIN project, addresses this issue via the development of a European Climate Risk Typology (referred to as the typology) for cities and regions. The typology provides an innovative approach to enhancing understanding of climate risk in European cities and regions.

2.2 What is the European Climate Risk Typology?

The first issue to address in establishing the purpose of the typology is to define what is meant by a 'typology'. The term 'typology' has many different meanings and applications in different contexts. However, the following frame of reference is adopted for the RESIN project.

A typology is, '…roughly synonymous with "taxonomy" or "classification", a classification of the phenomenon under study into types, particularly structural types' (Croft, 2003, p.1).

With regard to city-level analysis, it has been suggested that '…typologies are important means to target […] policies and to reveal development patterns; they also provide a reference frame for national and regional policy makers' (Fetner, 2012, p.77).

In this context, the RESIN typology can be viewed as a decision-aid to support more efficient and effective forms of urban adaptation to climate risks. The RESIN typology is not designed to function as an off-the-shelf decision-support system for urban adaptation in its own right. Rather, it is intended to function as a *strategic screening tool* that can be applied within a process of urban adaptation planning to inform tasks including climate change risk assessment, the setting of adaptation objectives and the development of peer-to-peer learning networks.

2.3 A risk-based typology

The RESIN Conceptual Framework (RCF) (Figure 2) positions the RESIN project as following a cyclical approach centred on assessing and reducing climate change risk. The left hand loop captures the 'urban system' and reflects the process by which climate risks are generated and then responded to with the aim of building the resilience of the urban system to future hazards and drivers. The right hand loop reflects the 'adaptation planning system', which follows a process that leads to the development of adaptation objectives and subsequent options that are implemented with the aim of affecting change within the urban system to reduce climate risk and build climate resilience.

Situating the typology within the RCF, it can be positioned along the 'transition path' between the urban system and the adaptation planning system as represented by the two-way arrow in Figure 2. The RCF emphasises that users will often be engaged in a continuous process of evidence-building and iterative learning with regard to understanding and responding to climate change risks. Here, it is notable that the typology offers the means to describe and analyse elements of the urban system concerning features that influence climate risk such as the types of hazards facing a city, the socioeconomic composition of the resident population and economic factors. In doing so, the typology can support the assessment of climate risk and in turn inform the development of strategies and actions to reduce climate risk and build resilience.

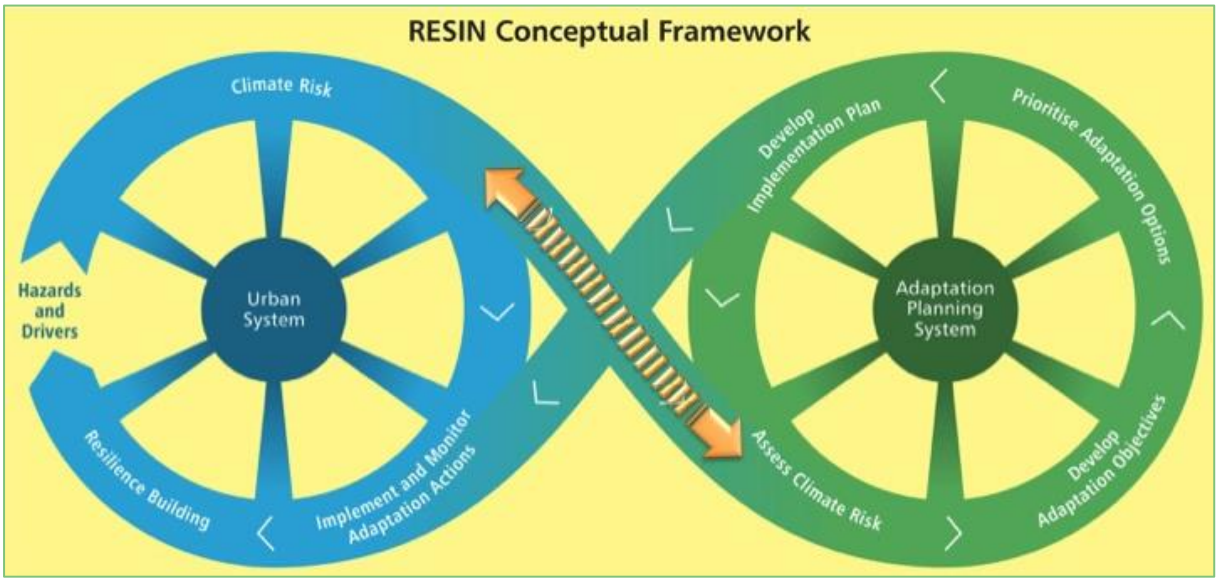

Figure 2: Positioning the typology within the RESIN Conceptual Framework

The RCF is informed by the risk-based approach adopted in the IPCC's AR5. The typology framework follows this risk-based approach and is consequently formed around a set of indicators that reflect the various underlying domains that influence climate risk. The IPCC (IPCC 2014) note that climate risk results from the interaction between three themes: the nature of the climate *hazards* facing cities and the level of *exposure* and *vulnerability* of cities to these various climate hazards (Box 1; Figure 3). Vulnerability is separated into *sensitivity* and *adaptive capacity*. The typology captures the similarities and differences across European cities and regions based on these underlying climate risk domains. Section 3 describes how this analysis was undertaken.

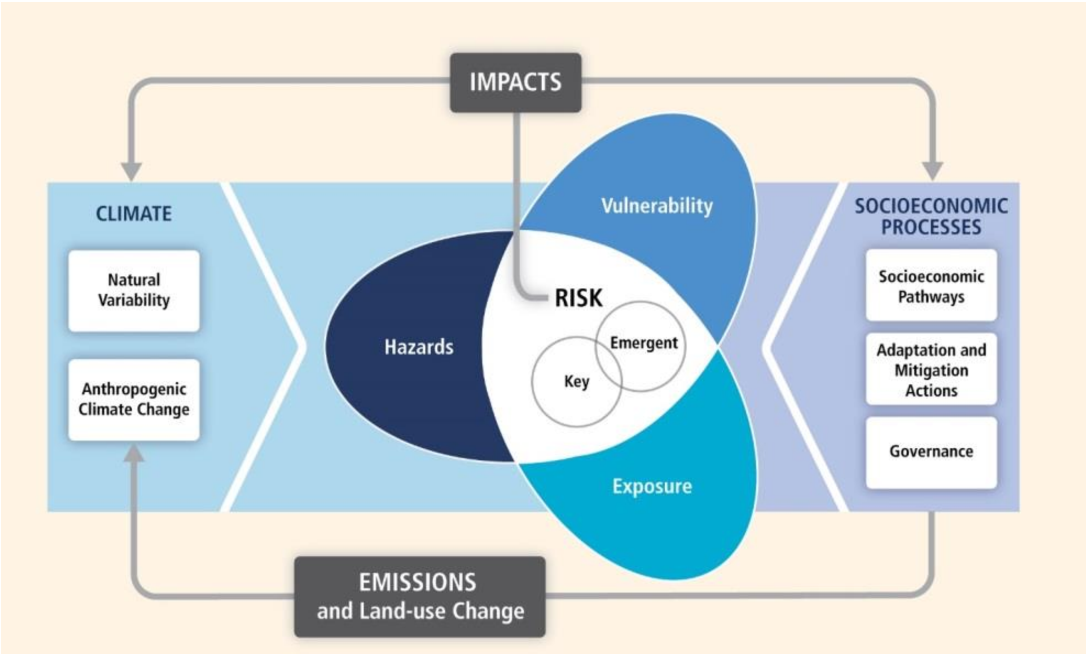

Figure 3: Conceptualization of risk by the IPCC. Source: IPCC 2014a.

- **Risk**: 'Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard.' (IPCC 2014c)
- **Hazard**: '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.' (IPCC 2012)
- **Exposure**: '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.' (IPCC 2014b)
- **Vulnerability**: 'The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.' (IPCC 2014c)
- **Adaptive Capacity**: 'The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.' (IPCC 2014c)
- **Sensitivity**: The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct … or indirect (Adapted from IPCC 2014c)

Box 1: Definitions of the IPCC risk themes (these definitions are taken from the RESIN Glossary, Connelly and Carter 2016).

2.4 Addressing the complexity-usability trade off

A significant challenge facing the development of operational tools such as the typology concerns balancing complexity with usability. The climate risk issues that the typology addresses reflect what Rittel and Webber, (1973) describe as 'wicked problems'. These are policy problems that are embedded in a dynamic socio-environmental context that makes such problems unique and therefore difficult, if not impossible, to solve.

Regarding the typology, the 'wickedness' of the problem is exacerbated by factors including data limitations, the changing nature of the challenges over time and space and the existence of a decision-making context that faces multiple and competing policy rationalities (Rae and Wong, 2012). In seeking to respond to these challenges, the temptation might be to add more data or risk domains to the typology. However, the more processes, characteristics, domains, or data that are integrated into the typology, the more complex the typology becomes. With increasing complexity comes a likely reduction in the usability of the typology in practice (Batty, 2004). Indeed, the 'science first' perspective has led to an 'implementation' or 'usability' gap which limits the influence of scientific data on policy and practice seeking to reduce climate risk (Lemos et al 2012). As noted by Fazey et al (2014), better practice does not necessarily stem from the creation and accumulation of more knowledge: data needs to be useful to the end-users.

The challenge was therefore to integrate sufficient complexity into the typology so as to capture the various processes and interactions that influence climate risk, whilst at the same time retaining the usability of the typology and the data contained within it for practical purposes. In this context, testing different configurations of the typology alongside targeted consultation with stakeholders was needed as a means of ensuring balance between the complexity and usability (see section 5.2).

3 Typology methodology

This section outlines the methodology employed to develop the RESIN typology. The methodology follows an approach that has been developed and refined over the course of the project building on the ideas originally outlined in previous RESIN project working papers (Hincks et al. 2016; 2017). The workflow of the methodology is outlined in Figure 4.

3.1 Pre-Development Stage: Literature review and consultation exercise

The early stages of the typology work undertaken in WP1 revolved around consultation with RESIN partners and evidence-gathering informed by the development of various state-of-the-art reports (Carter at al 2018). This helped to define the scope and purpose of the typology.

A formal workshop-based consultation exercise was conducted with RESIN partners (who were involved in WP1) in November 2015. Further discussions targeted at informing the early stages of typology development were also held with RESIN partners at the project 'kick-off' meeting in Bilbao (May 2015) and at a workshop held in Manchester (September 2015). Iterations of the typology have since been presented to RESIN partners at additional project meetings and at local and international events and conferences (including the 2017 and 2018 Association of European Schools of Planning conferences and the IPCC Cities and Climate Change Scientific Conference in 2018). The aims of these consultation exercises were to gather views about the purpose and function of the typology in relation to the RESIN project and beyond, and to gain feedback on the emerging typology outputs. Key themes raised during these various consultation processes, which informed the development of the typology, were:

Role of the typology

- The typology should function as a decision-aid focused on supporting more efficient and effective adaptation
- The typology should be generic rather than about infrastructure specifically.
- The typology should not be developed for the RESIN project specifically, but for use by European cities and regions more broadly.

Method and output

- The typology should be developed using a methodology that ensures standardisation – e.g. through using statistical procedures.
- Options should be considered for integrating the typology across relevant RESIN work packages.
- Both the output and application of the typology should be intuitive to use for non-experts, comprehensive in its scope and transparent in the methods used to develop the typology.

Significant engagement with relevant individuals from within and beyond the RESIN project took place a later stage in the development of the typology, the testing of a prototype online typology portal, which is outlined in more detail later in this report (see Section 5.2 and Appendix 2).

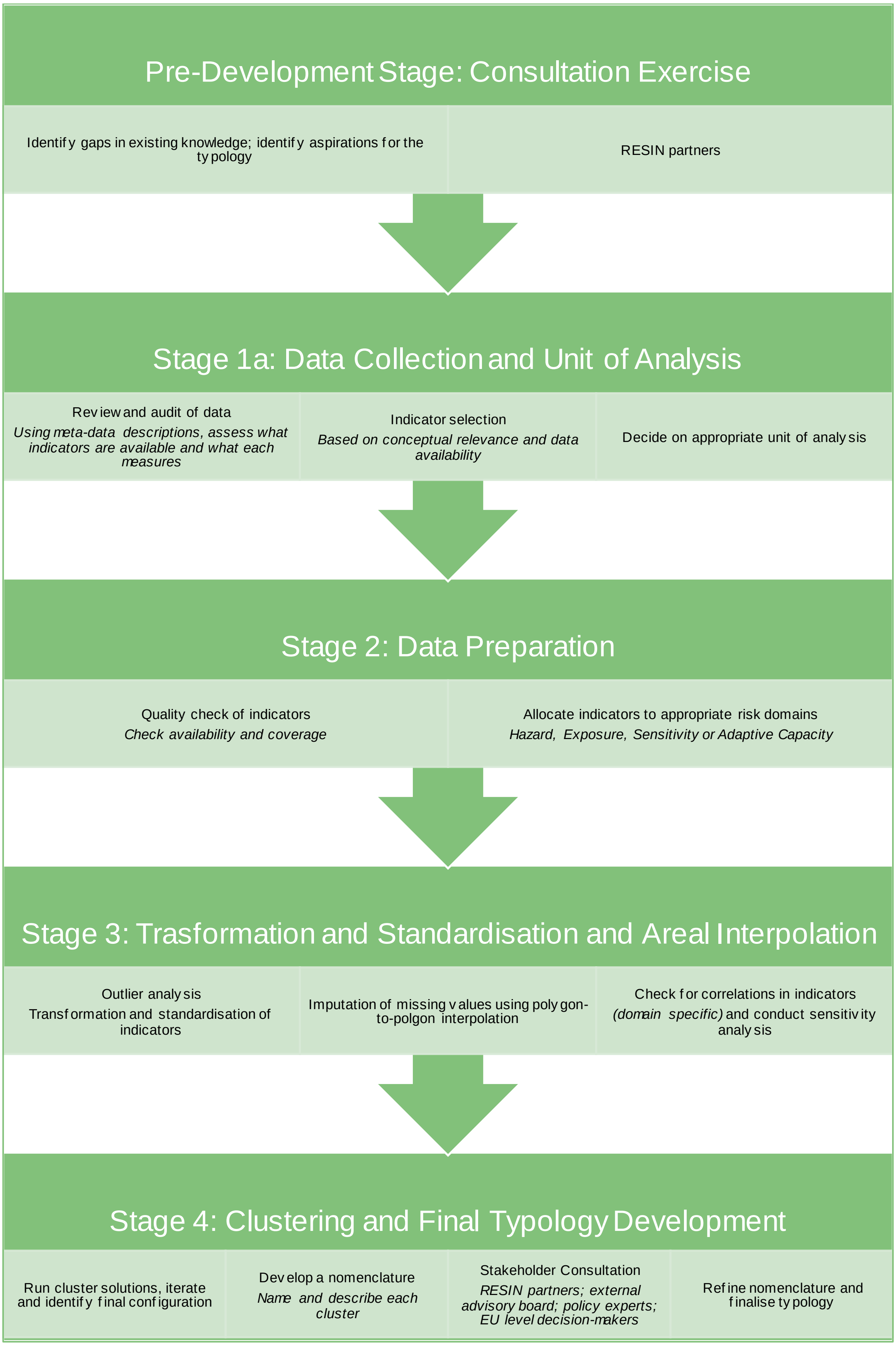

Figure 4: RESIN typology methodology

3.2 Stage 1: Data collection and unit of analysis

The first step in developing the typology involved systematically reviewing existing academic, policy and grey literature on climate risk and its constituent elements (this review is reported in Connelly et al 2016). The literature review focused on the domains of hazard, exposure, sensitivity and adaptive capacity (see the Glossary (Appendix 3) for definitions of these terms) and was undertaken to enable the mapping of individual indicators onto these risk concepts, focusing on the IPCC's AR5. The meta-data files developed for each indicator provide the necessary information to understand how the indicators had been defined and collected and what they were intended to measure in quantitative terms (see Appendix 1 for details of each indicator).

Having identified dominant themes within the literature, the next step involved reviewing and auditing data from a variety of European (e.g. EUROSTAT; Joint Research Council) and international (e.g. NASA; Open Street Map) data repositories. The review was undertaken to identify the availability and quality of potential indicator data across the four climate risk domains that underpin the typology, and to determine their spatial and temporal coverage. A crucial element in this process lay in deciding on an appropriate geographical unit for the typology, and therefore the scale at which indicator data would be developed at, building on the focus of the RESIN project on European cities. The cities covered by Eurostat's Urban Audit framework[2] were initially considered as an option for the typology's geographical unit of analysis. At the time of the research, the Urban Audit city units lacked comprehensive data coverage (see the Glossary (Appendix 3) for a definition of this term) in terms of the scope of the climate risk themes that the typology needed to cover, and there were also gaps in the spatial and temporal coverage of the Urban Audit indicator data that was available. Further, the Urban Audit contained only a selected number of European Cities (around 500), and was therefore not comprehensive in this respect. Further, focusing on cities in isolation from their hinterlands may limit the understanding of the risks facing a particular city or urban area of interest in a broader context.

Taking these limitations into account, the European Commission's NUTS3 classification was selected as the spatial unit to develop the typology around. NUTS3 regions are part of a system that subdivides the economic territory of Europe to support statistical data gathering, socio-economic analysis and the framing of European policies. There are 1379 NUTS3 regions in Europe. NUTS3 regions are a population-based classification system, and contain between 150,000 – 800,000 people. As a result, the density of NUTS3 regions across Europe varies. For example, there are 402 in Germany and 21 in Sweden. The decision to focus the typology at the NUTS 3 scale was taken for several reasons. Firstly, there is a wide availability and coverage of data at the NUTS3 scale which can be used to develop climate risk indicators. In addition, NUTS 3 regions are distinguished according to whether they exhibit land use characteristics that are consistent with the region being Predominantly Urban, Intermediate or Predominantly Rural in nature. This therefore enables the typology to cover the entire continent of Europe, whist allowing cities and urban areas to be isolated. Further, the NUTS 3 scale also enables hinterland regions around cities and rural areas to be considered separately which will have value for certain end users. Depending on the location considered, NUTS3 regions can encompass part or all of a city. For example, there are five NUTS3 regions covering the conurbation of Greater Manchester (in North West England), although the city of Manchester itself forms just one NUTS 3 region. Similarly, a wide range of other cities, including Hamburg, Oslo, Dublin and Krakow, for example, also encompass one NUTS3 region. In other cases cities form the major part but not all of a NUTS 3 region, for example regarding Valencia, Marseille and Rotterdam.

A set of climate risk indicators, covering the domains of hazard, exposure, sensitivity and adaptive capacity, sit at the heart of the typology. Potential indicators were identified by assessing against two

[2] https://ec.europa.eu/eurostat/web/cities/background

criteria: conceptual relevance and technical robustness. This followed a framework of assessment developed by Wong and Watkins (2009):

Conceptual relevance:

- Indicator is consistent with the conceptual risk themes, underpinning the domains of hazard, exposure, sensitivity and adaptive capacity, as identified through the literature review

Technical robustness:

- Availability: available at the chosen spatial unit (i.e. NUTS 3) or it must be available at a scale that allows aggregation to the chosen unit.
- Consistency: clarity in definition and ability to compare across spatial units, potentially over time.
- Transparency: clearly stated specifics as to why the indicator was originally collected and how.
- Continuity: agreed and stated methodologies and routine data collection to enable continuity in the methods and measures used.
- Relevance: intelligence has to be reliable and relevant to the issue concerned.
- Time series: has an appropriate timeframe for measuring the issue of concern

Based on the application of these criteria, and through the data review and indicator (see the Glossary (Appendix 3) for a definition of this term) development process, 81 potential indicators were identified and these were retained for further analysis and/or development. In some cases, due to data availability and time series issues for example, it was not possible to incorporate certain indicators into the process even where these were identified within the literature review as being relevant to the climate risk agenda. Examples include themes related to governance and cultural issues, which have important climate risk implications.

Originally the intention was to use existing indicator data to create the typology. However, due to issues of data coverage and quality, the majority of the indicators were developed within the RESIN project in order to create the typology. With the exception of just two indicators (At Risk of Poverty and Priority Allocations), all of the indicators used within the RESIN typology were subjected to post-collection data processing leading to new or adapted indicators being created at the NUTS 3 level. The climate projection indicators were developed for the RESIN project by Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici (Fondazione CMCC). A set of working definitions and meta-data (see the Glossary (Appendix 3) for a definition of this term) descriptors were developed for each of the 81 indicators. These are outlined in Appendix 1, which provides indicator descriptions, source data and development methodologies. The indicator selection process is discussed in more detail in section 4 of this report.

3.3 Stage 2: Data Preparation

Eight of the 81 indicators initially identified as having relevance to the focus of the risk typology suffered from missing data or were in need of re-aggregation[3] (see the Glossary (Appendix 3) for a definition of this term). These eight indicators are identified in Appendix 1. The indicators needing to be re-aggregated all had data available at the relevant scale but for a geography that had changed since the indicator was first collected (i.e. NUTS 3 2010 rather than NUTS 3 2013). These indicators were identified using the meta-data descriptors available as part of the indicator methodology produced by the supplier (e.g. EUROSTAT). Two techniques for inputting missing data were evaluated as options to use in order to minimise the exclusion of indicators from consideration within the RESIN typology process where possible. The first was a process of single imputation whereby the median

[3] Details to be included on these indicators

(see the Glossary (Appendix 3) for a definition of this term) value of an indicator – defined as the median for all NUTS 3 areas or for the specific country in question – is inputted and used as a proxy (see the Glossary (Appendix 3) for a definition of this term) value for that specific NUTS 3 area that is missing information. This technique was adopted in the RAMSES analysis of key urban vulnerabilities and priority risks (see Tapia et al., 2015). The second was a process of multiple imputations. Unlike the single imputation of the median value, the multiple imputation process requires that imputed values are drawn from many distributions in the available data. The purpose of multiple imputations is to acknowledge that missing data introduces uncertainty because there are a range of possible values that a missing value could take – not only the median. Multiple imputation therefore generates a range of possible values for each piece of missing data. This creates a series of 'complete' sets of data based on 'pooled' results which are generally considered more accurate than those provided by single imputation methods. For instance, say we had an indicator measuring age of population between 15 and 64 containing missing values for some of our spatial units. Rather than using the median, we would compute multiple values from across a distribution range – using a regression model (or another technique) for instance (see Yuan, 2000). This data would then be fitted to the indicator containing the missing values so that predicted values are generated for each unit based on the multiple distributions. These multiple values would then be pooled so that the different distributions are combined to form a new value.

However, both of these methods were identified as having significant limitations when considered in the context of developing the RESIN typology. The single median imputation method is unable to account for the wider context within which the NUTS 3 area sits. For example, should Berlin be missing data for one of the core indicators then we could simply impute the German median to 'plug the data gap'. Although the imputation of the median limits the effects of 'extremes' within the data, it still assumes that the whole of Germany is reflective of the Berlin context. Whilst the multiple imputation method overcomes this limitation to an extent, the success of multiple imputations is dependent on the coverage, quality and relevance of all other variables within the dataset being used to iterate imputed values. Given the variability of data quality and coverage in available datasets, a process of multiple imputations was deemed to have potentially limited application and was not used within RESIN. Similarly, neither the single nor multiple imputation methods were suitable for dealing with indicators where re-aggregation needs to be undertaken from one NUTS 3 framework to another. As a result of these limitations associated with single and multiple imputation methods, an alternative method of areal interpolation was employed as a means of imputing missing values and undertaking re-aggregation. Although the technique does not overcome Modifiable Areal Unit Problems (see the Glossary (Appendix 3) for a definition of this term) or Ecological Fallacy Effects (see the Glossary (Appendix 3) for a definition of this term) (Openshaw, 1984 a,b), it is an acceptable compromise. The technique was employed following initial data cleaning and processing and is described in detail in the following section.

3.4 Stage 3: Transformation, standardisation and areal interpolation

The first task in processing the data for the typology was to identify and remove error-laden values (e.g. due to the incorrect recording of values during the processing of the original data). It was also necessary to identify and record extreme outliers in the indicators early in the process of developing the typology. Many statistical procedures assume a normal distribution (see the Glossary (Appendix 3) for a definition of this term) in the sample of data being subject to analysis. To overcome problems of non-normal distributions, the distribution of each indicator has been assessed using two measures:

- **Skewness**: a measure of the symmetry of a frequency distribution. The curve can be skewed due to outliers which is why outlier detection, data transformation and standardisation are necessary steps in the cleaning and processing of the individual indicators.

- **Kurtosis**: a measure of the peakedness (pointiness) of the data. Again, outliers can accentuate peakedness in different ways.

The Shapiro-Wilks Test for normality was also applied in conjunction with the Skewness and Kurtosis measures as a way of statistically testing for non-normal distributions. In measuring non-normal distributions, transformation and standardisation procedures will be implemented if indicators have a statistically significant non-normal distribution, determined through the Shapiro-Wilks Test, or if the skewness or kurtosis values are measured as being above +1 or below -1. If it is determined that the indicators need to be subjected to transformation and standardisation procedures, there are a range of techniques that can be adopted to help limited skew and kurtosis. These include but are not limited to those techniques listed in Box 2.

Transformation Techniques	**Standardisation Techniques**
- Log transformations (e.g. Log10)	- Z-score standardisation
- Box-Cox transformation	- Range standardisation
- Inverse hyperbolic since	- Inter-decile range standardisation
- Fractional rank and Inverse distribution function	

Box 2: Transformation and Standardisation Techniques for Improving Non-Normal Data Distributions

Testing revealed a preference for the fractional rank and inverse distribution function approach as the transformation technique. A number of standardisation techniques were tested: z-score (see the Glossary (Appendix 3) for a definition of this term); range, and inter-decile range. Range standardisation was adopted in the development of the typology. This combination of fractional rank and inverse distribution transformation in conjunction with range standardisation has been employed elsewhere in typology development (Hincks *et al*, 2018).

In order to address missing data (outlined above) and to enable re-aggregation of data, areal interpolation was adopted where necessary. Areal interpolation (see the Glossary (Appendix 3) for a definition of this term) (applied in the ArcGIS Geostatistical Analyst extension) is a geostatistical interpolation technique that extends kriging theory to normal distributed data averaged or aggregated over polygons (see Logan et al, 2014). The technique enables predictions and standard errors to be made for all points within and between the input polygons which can then be re-aggregated back to a new set of polygons (see the Glossary (Appendix 3) for a definition of this term) (which in this case are NUTS 3 units). The process of aggregating polygonal data is a two-step process. First, a smooth prediction surface for individual points is created from the source polygons, interpreted as a density surface. This prediction surface can then be re-aggregated back to target polygons (see Figure 5 for an illustration). This two-step process is important in that it enables data from one set of polygons (2010 NUTS 3) to be aggregated to another set of polygons (2013 NUTS 3). It can also be used to predict and subsequently impute values for polygons where data is missing. The advantage of this process is that the interpolation prediction takes account of values of surrounding polygons through the creation of a density surface (Krivoruchko *et al*, 2011).

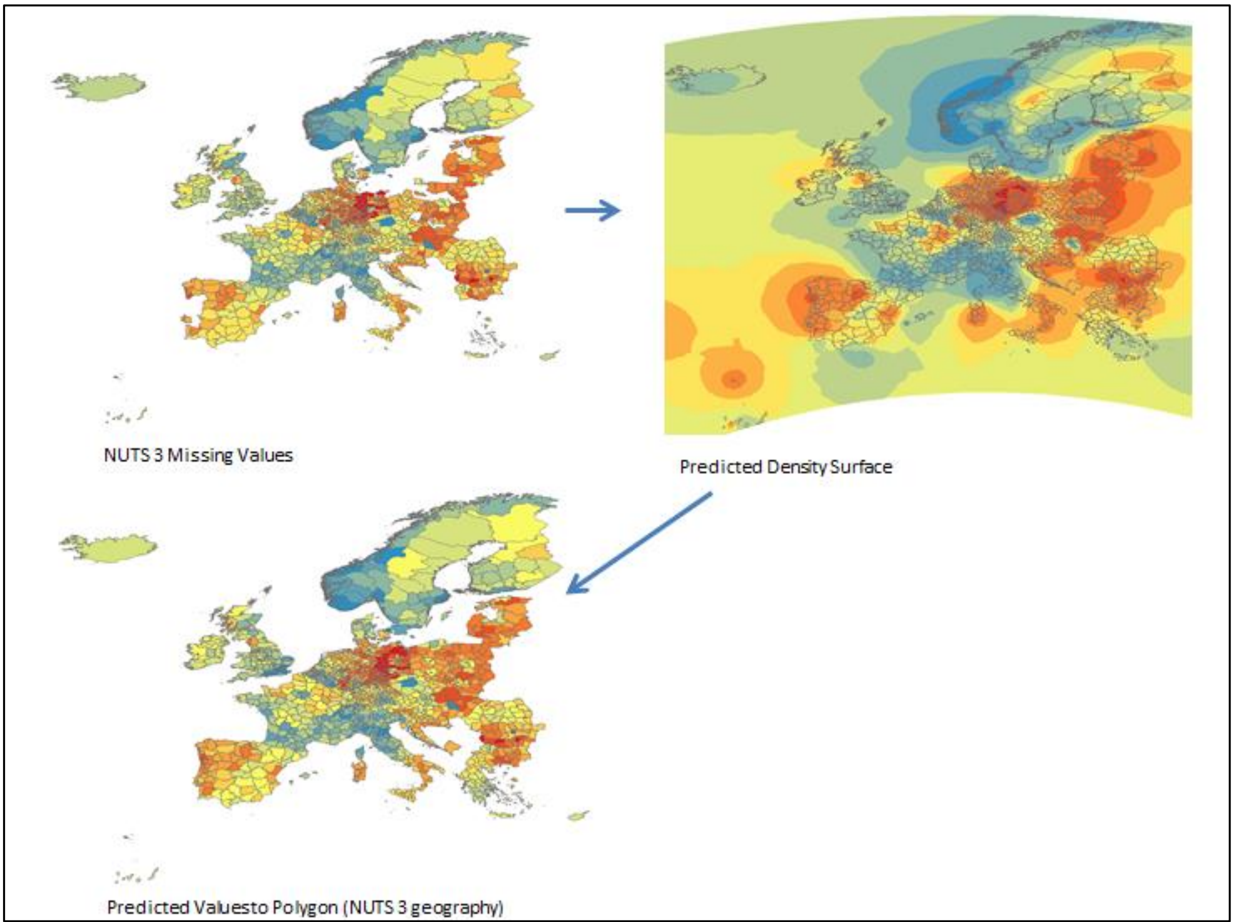

Figure 5: Illustration of polygon-to-polygon re-aggregation/imputation of missing values.

What is areal interpolation?
http://desktop.arcgis.com/en/arcmap/latest/extensions/geostatistical-analyst/what-is-areal-interpolation.htm

Using areal interpolation to perform polygon-to-polygon predictions
http://desktop.arcgis.com/en/arcmap/latest/extensions/geostatistical-analyst/using-areal-interpolation-to-predict-to-new-polygons.htm

The interpolation of indicator data – whether for purposes of re-aggregation or imputation of missing values – is dependent on the accurate specification of predictive models. In ArcGIS, this takes place through what is known as the variography workflow. This is illustrated in Figure 6. The objective is to change the parameters on the right so that most of the blue crosses (empirical covariances) (see the Glossary (Appendix 3) for a definition of this term) fall with the red bars (the confidence intervals) (see Figure 6). When the model is accurately specified, 90% of the blue crosses will coincide with the red bars. In Figure 6, it is clear that the default baseline model is not adequate and requires further processing to improve the fit the model and therefore its accuracy. Areal interpolation was carried out on eight climate risk indicators (identified in Appendix 1) using the k-bessel model.

a) b)

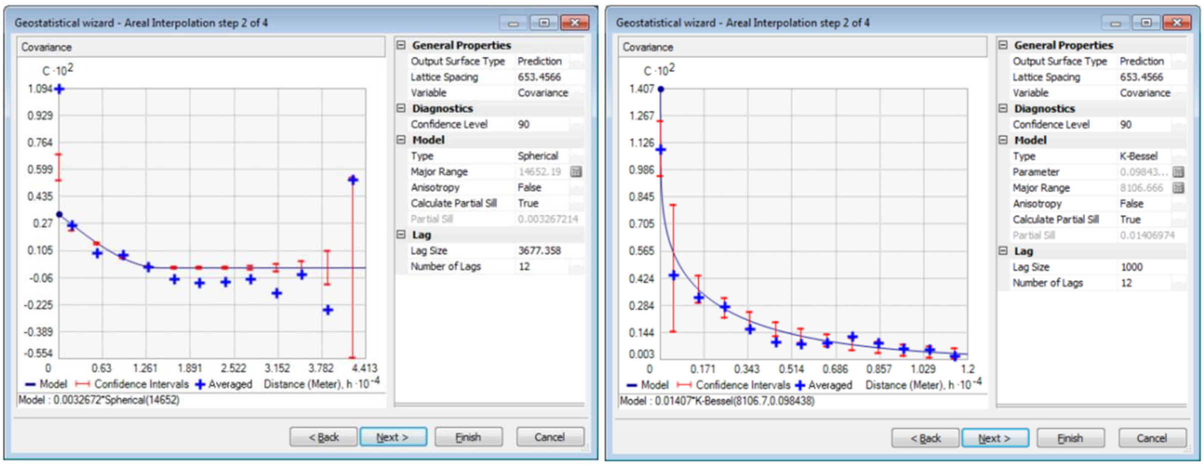

Figure 6: Illustration of poor interpolation model specification (a) and accurate specification (b). The prediction surface represented in Figure 5 is then 'predicted to polygons' which enables the model specification to be tested and missing data imputation verified systematically.

Finally, the transformed, standardised and where necessary, the interpolated indicators were subjected to Pearson's Correlation. This test was performed on indicators within the *same* domain to identify indicators that are excessively correlated (+/-0.9 or greater) (Mooi and Sarstedt, 2011). This adds a necessary step in reducing data redundancy in the final typology. Redundancy in this context relates to the way in which the process or characteristics of one indicator is explained by the composition and structure of another indicator. Therefore, removing redundant indicators will not disadvantage the typology because the characteristics, processes or composition captured by the redundant indicator will be reflected in one of the retained indicators. When an indicator is excessively correlated with one or more indicators then the redundant indicators were removed from any further analysis and the retained indicator reconceptualised to reflect the revised scope of the indicator.

Of the 81 indicators that were originally subjected to the transformation and standardisation procedures, 54 candidate indicators were retained for inclusion in the next stage of the typology development process. The decision as to which indicators should be excluded was taken on a case-by-case basis determined by a combination of measures including outliers, skewness, kurtosis and correlation (Vickers and Rees 2007). Notably, all of the 81 indicators are retained for analysis within the online portal developed to house the typology outputs (described in section 5.1).

3.5 Stage 4: Clustering and typology development

Having cleaned and processed the data and identified those indicators to develop the typology, the next step was to determine the most appropriate method through which to cluster the indicators to identify climate risk typology classes and sub-classes of NUTS3 regions. The logic of cluster analysis is to define groups of objects (i.e. NUTS 3 regions) based on their underlying characteristics, in this case related to climate risk factors. The cluster algorithm seeks to 'minimise within group variations' and to 'maximise between group variations' with the aim of defining homogenous groups of NUTS 3 regions that share climate risk characteristics. There were different clustering methods that could be adopted but the decision as to which was most appropriate was largely dependent on the types of data used to develop the RESIN typology. Table 1 provides a brief summary of three common clustering approaches that were considered for use in the development of the RESIN typology.

Cluster Approach	Description	Data Considerations
Hierarchical Clustering	Hierarchical clustering tends to reflect tree-like structures. Most hierarchical techniques fall into the category of agglomerative clustering. Each object (city) would be represented as an individual cluster. The individual cities are then sequentially merged to form new clusters. Clusters can also be formed through divisive clustering in which all cities are grouped in a single cluster and gradually disaggregated into separate clusters through iteration. Objects are assigned to clusters based on a measure of dissimilarity (distance measures) which include Euclidean, city-block and Chebychev distance. These distance measures need to be set by the analyst.	Hierarchical clustering procedures require data to be in a binary or count form. Scaling of indicators can have significant influences on the outcome of the cluster procedure so care needs to be taken when scales of indicators are different to ensure that standardisation procedures are carried out. The order of cases in the dataset can affect the outcome of the cluster solution because of the way the algorithm identifies, analyses and 'attaches' one object to another. Once objects are 'fused' they remain so. Therefore, multiple iterations should be run of the same cluster solution using randomly ordered data to minimise the effects of case order on the final solution.
K-Means Clustering	K-means clustering is a partitioning method of cluster analysis that uses simple Euclidean distance measures. The process starts by randomly assigning objects (cities) to a number of different clusters. These objects are then reassigned to other clusters to minimise within-group variation – essentially the squared distance from each object to the centre of the associated cluster. The number of clusters is defined by the analyst requiring rounds and rounds of iteration to identify optimum solutions.	K-means clustering requires data to be at the interval or ratio level. Scaling of indicators can have significant influences on the outcome of the cluster procedure standardisation procedures needed to be undertaken. As with hierarchical clustering procedures case order can affect the outcome of the cluster solution Therefore, multiple iterations should be run of the same cluster solution using randomly ordered data to minimise the effects of case order on the final solution.
Two-Step Clustering	Two-step cluster analysis is based on a two-stage procedure. The first follows a similar logic to the k-means algorithm. Based on the results of this procedure, the second stage conducts a modified version of the hierarchical agglomerative clustering similar to the hierarchical approach outlined above. The two-step procedure is attractive in terms of its flexibility and usability especially in instances where there is a mix of data types that would restrict use of either the hierarchical or k-means approaches. Two distance measures are available in two-step procedures: log-likelihood and Euclidean distance. The number of clusters is defined by the analyst.	In two-step clustering, data can take the form of continuous and categorical structures. Scaling of indicators can have significant influences on the outcome of the cluster procedure standardisation procedures needed to be undertaken. As with hierarchical clustering and k-means procedures case order can affect the outcome of the cluster solution Therefore, multiple iterations should be run of the same cluster solution using randomly ordered data to minimise the effects of case order on the final solution.

Table 1: Description of Three Common Clustering Procedures (after Mooi and Sarstedt, 2011)

In this instance, K-means clustering was adopted because all of the indicators were interval or ratio level. K-means clustering is a process for partitioning objects into k centroids that are fixed a priori (MacQueen 1967). In this study, objects (NUTS 3 units) are iteratively reassigned to clusters in an attempt to derive a series of centroids that minimise variation.

$$V = \sum_{x=1}^{k} \sum_{y=1}^{n} (z_x - \mu_y)^2 \quad (1)$$

(where n is the number of clusters and μ_y is the mean centroid of all the points z_x in cluster y (Longley and Adnan, 2016: 381)).

Using IBM SPSS v.22, the 54 candidate indicators selected for inclusion in the cluster analysis (see the Glossary (Appendix 3) for a definition of this term) process were included in the pilot runs to develop the typology classes. One of the limitations of k-means clustering is that case order can affect the outcome of the cluster solution. In an effort to minimise these effects, cluster solutions were rerun using randomly ordered cases units. This exercise was undertaken 1000 times for the 'class' layer and 200 times for each of the 'sub-class' layers (see below). The cluster method was set to 'iterate and classify' with stability being reached once the iteration of centroids between clusters had ceased.

The initial focus of the analysis was on deriving a classification deriving n clusters that would constitute an upper-tier of 'classes' that was constrained by an upper-limit of a maximum of 10 clusters. This upper-tier layer was then further portioned into m_y clusters which formed a second 'sub-class' layer (Gale et al. 2016). This sub-class layer was constrained to an upper-limit of a maximum of five clusters. In developing the 'sub-class' layer, analysis was undertaken of the distributions of each of the newly partitioned datasets. These analyses were used, alongside iterative testing in which separate indicators were included and excluded from the cluster process, to determine which indicators would be retained to define each 'sub-class'. Different sub-classes were comprised of different sample sizes (NUTS 3 units) and were characterised by the dominant features of the class layer. This meant that the explanatory power of certain indicators was reduced through portioning that changed the distribution of the data. Where this was the case, these indicators needed to be excluded from the development of the sub-classes. As an example, Coastal inundation was included in the development of the class layer but its relevance in the definition of sub-classes dominated by landlocked NUTS 3 units was limited and so was excluded. The different configurations of the indicators used in each sub-class definition are reflected in the radial graphs used to profile the different classes and sub-classes.

Another limitation of k-means clustering is that there are no set criteria for defining the optimum cluster solution (Brown 1991). However, there are procedures that can be used to inform decisions as to which solution is optimal. In this study, cluster distances were evaluated using diagnostic statistics. Tukey post hoc tests were calculated to determine whether the distances between cluster centroids for each solution were statistically significant and warranting their retention as separate clusters. The optimum solutions were identified using the within cluster sum of squares (WCSS) statistic, which measures how close objects within each cluster solution are to the centroid indicating cluster homogeneity (Gale et al, 2016: 10). It is not possible to summarise the diagnostic results of the cluster runs given that solutions were generated for 3-10 clusters 1000 times for the classes and 3-5 clusters 200 times for each sub-class solution. However, for reference the optimum class solution minimised the Levene Statistic for the test of homogeneity of variances (3.472, df1 7, df2 1371, .p<.000) with a WGSS of 58.2, df 1371, p<.000).

Having identified the optimum number of clusters, a radial graph for each cluster was created. An example is provided below (Figure 7). Here standardised scores were plotted in relation to the grand mean score for all NUTS3 units in the analysis. Once the optimum class configuration had been identified, the same approach was applied to the development of the lower-tier sub-class solution. Finally, the radial graphs were used to profile individual clusters and to develop names and descriptions for the NUTS3 climate risk classes and sub-classes.

The names and descriptions provide a basic signpost to the dominant characteristics underpinning each climate risk cluster. These names and descriptions opened up to scrutiny by RESIN partners and relevant stakeholders from beyond the project. This was a necessary exercise to ensure that the final cluster solutions for each domain, the descriptions of each cluster, and the associated names resonated with potential users (Kingston et al, 2000). Once these cluster solutions were finalised and sensitivity testing applied to the resultant cluster framework, the final solutions were visualised via an online portal which was developed to house the typology.

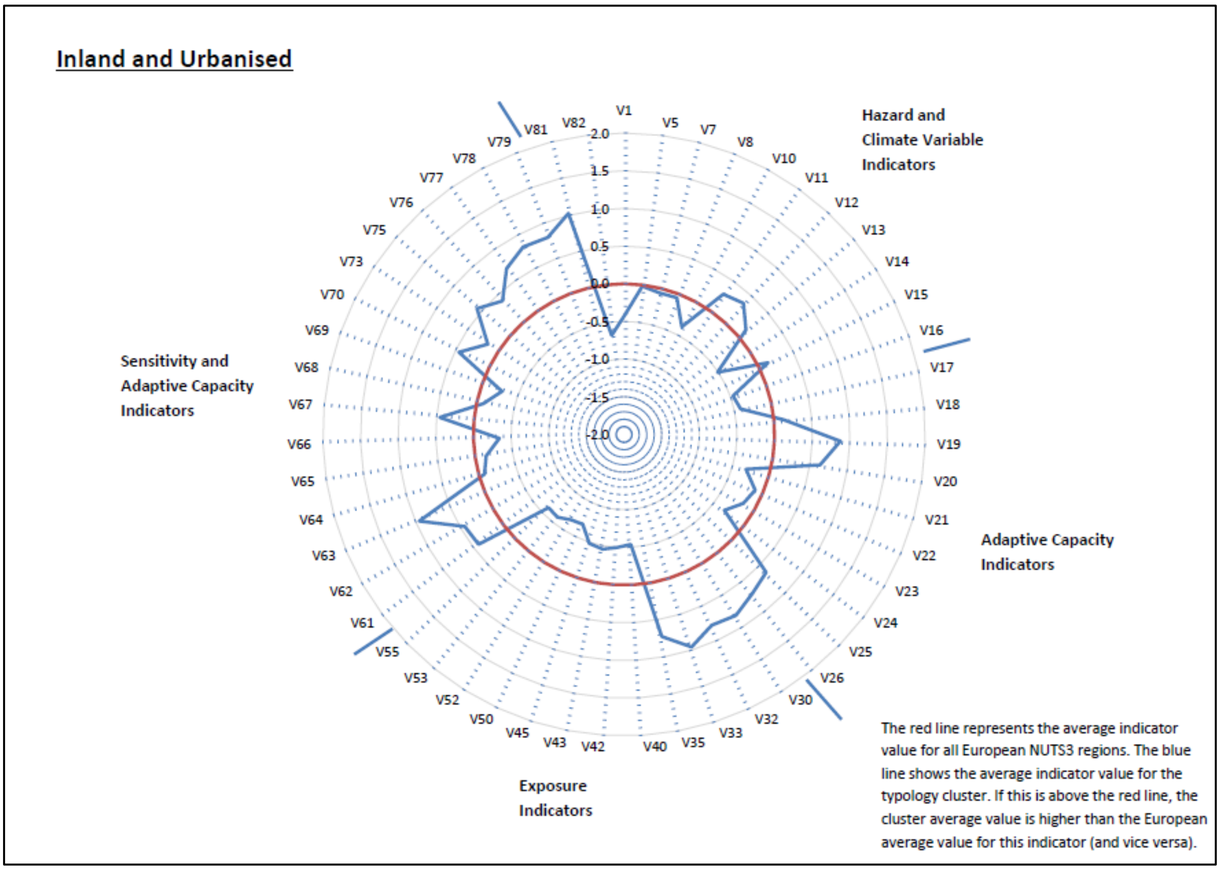

Figure 7: Radial diagram for the 'Inland and Urbanised' climate risk class (indicator details are available on the RESIN typology online portal).

4. Indicator selection

The typology is based around the IPCC AR5 risk-based conceptual framework, which encompasses the themes of extreme weather and climate change hazards, and exposure and vulnerability to those hazards. A key stage in the typology process was to identify, and in many cases create, indicators on these different elements of the risk-based conceptual framework. These indicators, developed at the scale of NUTS3 regions, were used as the basis of the cluster analysis method (described above in section 3.5) that was applied to identify climate risk classes (and sub-classes). This section describes the indicators in more detail as they are central not just to the typology methodology but also to the online portal developed to house the typology which provides users with the ability to explore and visualise the indicator data on an interactive platform.

4.1 Hazard indicators

The IPCC (IPCC 2012: 560) defines hazards as, '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.' Hazards related to extreme weather and climate change generate impacts that in some cases will require adaptation and resilience building in response. Table 2 details five extreme weather and climate change related hazard indicators that were applied within the process of developing the typology. Further details on these indicators, including descriptions of the source data and methodology, are included in Appendix 1.

Indicator	Description
Wildfire hazard	This indicator identifies the proportion of the NUTS 3 region defined as 'burnt areas' according to the 2012 Corine classification. This provides a sense of the extent to which wildfires have been a hazard in the past in the NUTS3 region.
Coastal hazard	This indicator provides data on the % of the total length of the NUTS3 unit coastline (in km) that is exposed to a 1 in 100 year coastal storm surge, and also the % of the total length of the coastline that is exposed to 1 meter sea level rise.
Drought hazard	This indicator utilises the Standardized Precipitation-Evapotranspiration Index (SPEI) at nine month timescales to provide a measure of meteorological drought.
Fluvial hazard	This indicator uses Joint Research Centre (JRC) flood mapping data to show the percentage of the total area of the NUTS3 area that would be prone to flooding in the event of a 1 in 100 year fluvial flood.
Landslide hazard	This indicator draws on NASA's Global Landslide Susceptibility Map, which identifies the potential for landslides across the Earth's surface on a scale from slight to severe. This indicator calculates the proportion of the NUTS3 area that shows moderate (or higher) susceptibility to landslide.

Table 2: Extreme weather and climate change related hazard indicators.

Some climate hazards are not included in the indicators highlighted in Table 2, notably pluvial flooding and heat waves. Although these are important hazards facing a number of European cities and NUTS3 regions, it was not possible within the RESIN project to create Europe-wide indicators for these hazards due to data limitations. However, NUTS3 scale climate change projections related to these two hazards, and others, were included in the list of indicators. These indicators were created specifically to inform the development of the RESIN typology by Fondazione CMCC. The climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX). This is the most comprehensive and up-to-date climate change projections modelling available for the Europe. The analysis was undertaken at a grid square resolution of around 12 km^2 and forced by different global climate models. The approach taken to develop the climate projection indicators for European NUTS3 regions is outlined in a supporting report (Fondazione CMCC 2018).

Table 3 lists the future climate change projection indicators developed for the typology. Indicators were selected to cover a range of temperature and precipitation variables. In particular, indicators were chosen that connect to extreme events, such as heat waves and heavy rainfall events, as such events tend to cause the greatest damages and are therefore especially significant for climate change adaptation and resilience building. The indicators provide climate change projections at the NUTS3 scale for the 2050s, which covers the period 2036-2065, with respect to the control period 1981-2010. Further information on these indicators, including full descriptions and source data, is provided in the typology online portal (and Appendix 1 of this report). In some cases, these climate change projection indicators are directly related to the occurrence of hazard events, for example heat waves. In other cases, the indicators connect to and highlight the potential for hazard events. For example, consecutive dry days, alongside temperature related indicators, identify the potential for drought hazards. Similarly, indicators on projected changes in the number of consecutive wet days and very heavy precipitation days provide insights on the potential occurrence of flood hazards.

The precise nature of future changes to the climate cannot be determined for reasons including uncertainty in future greenhouse gas emissions trajectories, which are a key driver of climate change. This is why a range of climate change projections, underpinned by various greenhouse gas emissions scenarios that account for different future emissions levels, are produced by organizations such as the IPCC. Projections are provided for two IPCC scenarios, RCP 4.5 and RCP 8.5, although for the cluster analysis used to develop the typology, the RCP8.5 scenario is used.

- RCP 4.5 – this is a stabilization scenario where technological change and the implementation of greenhouse gas emissions reduction strategies lead to a future where the most severe impacts of climate change become less likely.
- RCP 8.5 – this is a worst-case climate change scenario with major shifts in temperature and precipitation patterns, and is driven by increasing emissions, high population growth and limited technological innovation.

Taken together, the two scenarios provide an indication of the range of potential changes in temperature and precipitation variables that can be expected over future decades.

Indicator	Indicator Description
Mean temperature	This indicator shows the difference in daily mean temperature between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection).
Maximum temperature	This indicator shows the difference in maximum temperature between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection).
Summer days	This indicator shows the difference in the number of days with a maximum temperature more than 25°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection).
Tropical nights	This indicator shows the difference in the number of nights where the minimum temperature does not drop below 20°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection).
Heat wave days	This indicator shows the difference in the number of days with a maximum temperature of more than 35°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection).
Minimum temperature	This indicator shows the difference in minimum temperature between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection).
Frost days	This indicator shows the difference in the number of days with a minimum temperature of less than 0°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection).
Ice days	This indicator shows the difference in the number of days with a maximum temperature of less than 0°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection).
Total wet-day precipitation	This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the cumulated precipitation for days with precipitation greater than or equal to 1mm.
Consecutive wet days	This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the number of consecutive wet days with precipitation greater than or equal to 1mm.
Heavy precipitation days	This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the number of days with precipitation greater than or equal to 10mm.
Very heavy precipitation days	This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the number of days with precipitation greater than or equal to 20mm.
Consecutive dry days	This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the number of consecutive dry days with precipitation less than 1mm.

Table 3: Climate change projection indicators (for the IPCC RCP 8.5 scenario).

4.2 Exposure indicators

Exposure indicators were needed to develop the typology according to the IPCC's risk-based approach. The IPCC (IPCC 2014a: 123) define exposure as: '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.' Here, exposure can be understood as the extent to which receptors (e.g. people, infrastructure, assets) are located in areas that could be affected by hazards. For the IPCC (and therefore the RESIN typology), exposure is therefore a spatially oriented concept.

The challenge for the typology was to identify indicators, at the NUTS3 region scale, that provide data on the spatial exposure of receptors to different climate change hazards. Initially ESPON project data was considered for this purpose (ESPON 2011). Within ESPON, data on eight 'indicators on exposure to climate stimuli' were developed. The indicators are also variously referred to as relating to 'climate parameters' and 'climate variables'. They include indicators such as change in annual mean temperature and change in annual mean precipitation in winter months. These ESPON indicators do not fit the IPCC's exposure indicator approach. ESPON 'impact' indicators do approximate to the IPCC AR5 definition of exposure and show the extent to which different receptors are projected to be exposed, spatially, to the changing climate in Europe's NUTS 3 areas. However, these indicators are limited in extent and use source information that is now dated.

As there was no readily available recent data at the NUTS3 scale on the exposure of people and infrastructure to weather and climate related hazards, the decision was taken to develop new exposure data to inform the typology. In order to develop the exposure indicators, spatial data was needed for the entire European surface on hazards and also receptors of hazards. This requirement influenced the range of indicators that could be developed. Indeed, it was not possible to develop indicators on exposure to drought, heat waves and pluvial flooding due to a lack of European-scale spatial data on these hazards. However, Europe-wide spatial data on fluvial flooding, coastal and landslide hazards was accessed.

In addition, Europe-wide spatial data on the following 'receptors' was obtained. A particular focus was paid to critical infrastructure given the focus of the RESIN project on this theme. Also critical infrastructure is crucial to quality of life and prosperity in cities and regions and therefore represents and important agenda for climate change adaptation and resilience.

- Population in settlements – using GEOSTAT 1km population grids sourced from EUROSTAT
- Road infrastructure – shapefile of all 'major roads' (see Table 7) sourced from Openstreetmap
- Rail network – shapefile of all rail links (see Table 7) sourced from Openstreetmap
- Transport nodes - shapefile of all transport nodes (see Table 7) sourced from Openstreetmap
- Airports – shapefile sourced from EUROSTAT
- Power plants - shapefile of all power plants (see Table 7) sourced from Openstreetmap
- Ports - shapefile sourced from EUROSTAT
- Hospitals - shapefile of all hospitals (see Table 7) sourced from Openstreetmap

With three hazards and eight receptors, this gave a total of 24 exposure indicators developed specifically for the RESIN project in order to inform the creation of the typology. Further information on these indicators, including full descriptions and source data, is provided in Appendix 1.

4.3 Vulnerability Indicators

The identification of vulnerability indicators for the typology was supported via a literature review (Connelly and Carter 2018). This was one element of the process of selecting indicators to incorporate within the process of developing the typology. However, beyond their conceptual relevance, indicators also had to be suitable for use at the NUTS 3 level and meet data quality, availability and coverage criteria to be used to underpin the development of the typology. As noted in the typology methodology discussion above, the general indicators identified here were further refined following statistical work to exclude, for example, highly correlated indicators. Some were therefore excluded, although this section details the wider range of vulnerability indicators that link to understanding this aspect of climate risk.

In order to keep the vulnerability indicator review manageable, and given the wide range of cross-referencing between studies, a shortlist of eight vulnerability assessments and one standardised vulnerability indicator set was selected for further analysis based on expert judgement. These assessments were used to compile lists of generic indicators that could potentially be used in the final typology. It should be noted that the identification of generic indicators for sensitivity and adaptive capacity may be problematic in certain situations as there is some consensus over the factors that drive sensitivity to floods and heat, whereas there is little consensus when considering drought (Schauser et al. 2010; Carter et al. 2012). Additionally, the typology utilises the IPCC's AR5 definition of risk where vulnerability is comprised of sensitivity and adaptive capacity. Whilst many pre-2015 climate change impact and adaptation studies use concepts based on the earlier vulnerability-driven perspective, the definitions for sensitivity and adaptive capacity are similar which renders them comparable (See Connelly et al. 2018). Further, vulnerability cannot be measured directly and thus all indicators are an approximation. End-users should be made aware of the caveats around indicator completeness and undertake more detailed local assessments before formulating policies and actions.

What drives sensitivity?

The IPCC's approach separates vulnerability into sensitivity and adaptive capacity. Sensitivity to (or susceptibility to harm from) climate change is driven by several issues. These can be the *personal characteristics* of the population, characteristics of *physical and economic assets*, and issues which affect the *broad functioning of the city system* (Swart et al. 2012). For example, it is generally recognised the older and younger people are more affected during heatwaves and floods, and therefore indicators relating to age can give a useful insight into the broad trends in these areas. In addition to the personal characteristics of the population, economic assets (or lack thereof) can also enhance sensitivity. Building on these examples, Table 4 provides an overview of the generic climate change sensitivity indicators identified in the literature review.

References	Broad Sensitivity Indicator	Applicable Hazard	Category	Brief description
(Tapia et al. 2015)	Ozone/particulate matter concentration	Heatwave	Functioning	Increases in air pollution, measured through ozone and particulate matter concentration, increase during periods of hot weather. However, more research is needed to establish the relationship (Ffoulks et al. 2017)
(Tapia et al. 2015)	Price of domestic water	Drought	Functioning	The price of domestic water may influence a city's sensitivity to drought i.e. if the price is high, then the city is more sensitive. This indicator is not be used in the RESIN set
(Cutter 2003; Kazmierczak and Cavan 2011; Swart et al. 2012; Tapia et al. 2015)	Lone households (inc. single parent; pensioners)	All	Population	Some studies use this indicator for sensitivity. However, it also connects to social networks that enable people to respond to and recover from an extreme weather event. For the RESIN indicator set, this is adaptive capacity.
(Cutter 2003; Kazmierczak and Cavan 2011; Swart et al. 2012)	Deprivation/poverty (e.g. unemployment rate)	All	Population	Some studies use deprivation/poverty for adaptive capacity as it can affect people's response and recovery from extreme weather events. However, for the RESIN indicator set, this is considered sensitivity.
(Cutter 2003; Kazmierczak and Cavan 2011; Tapia et al. 2015; cf Climate Just 2014)	International foreigners (e.g. non-EU; recent immigrants; ethnic minorities)	All	Population	Some studies use this indicator for sensitivity.
(Cutter 2003; Kazmierczak and Cavan 2011; Swart et al. 2012; Climate Just 2014; Tapia et al. 2015; Mayors Adapt n.d.)	Young age (e.g. aged 0 – 4)	All	Population	Young people's health may be more affected by an extreme weather event such as a heatwave or flood.
(Cutter 2003; Kazmierczak and Cavan 2011; Swart et al. 2012; Climate Just 2014; Tapia et al. 2015; Mayors Adapt n.d.)	Old age (e.g. over 65, over 75)	Floods / Heatwave	Population	Older people are more susceptible to harm during extreme weather events.
(Tapia et al. 2015)	Health (e.g. deaths/year < 65 from illness)	All	Population	Those in poor health are more susceptible to harm during extreme weather events.
(Cutter 2003; Tapia et al. 2015; Mayors Adapt, n.d.)	Population density	All	Population	Population density can indicate the proportions of people that may be at risk in a city and can be compared with other cities.
(Cutter 2003; Tapia et al. 2015; Mayors Adapt n.d.)	Population growth rate	All	Population	This demographic may indicate that a city will have more people who are susceptible to harm from extreme weather events.

Table 4. Common sensitivity indicators identified in selected literature

Following the gathering of relevant data at NUTS3 level and the application of statistical tests, including for correlation (as described in the typology methodology section above) some indicators were excluded. In the final typology, it was agreed that the typology should try to include dynamic indicators of age to show potential changes in an aging population that could enhance sensitivity to climate change in the future. The final list of sensitivity indicators for the RESIN project is shown in Table 5. Further details on these indicators are included in Appendix 1.

Indicator Name	Short Indicator Description
Total population living in urban areas /area in km2	Population density measures the concentration of individuals living in a particular spatial unit. Population density may be considered in tandem with hazard indicators relating to temperature and heatwaves as population density (which can be used as a proxy for the density of the built environment) may indicate more intense urban heat island effects.
% change in population density in NUTS3 unit between 2017-2050	This indicator shows the projected Change in Total Population and NUTS 3 Density. Increasing population and density will interact with the effects of climate change and may render a NUTS 3 region more sensitive to the effects of climate change.
% change in population through migration in NUTS3 unit between 2017-2050	This indicator shows the % change in population through migration in NUTS3 unit between 2017-2050. Decreases in migration, when combined with other population indicators such as age, may indicate that there is an aging population.
% change in population less than 15 years in NUTS3 unit between 2017-2050	This indicator shows how the % of population under 15 may change between 2017 and 2050. This indicator could be considered in the context of heat and flood indicators.
% change in population more than 70 years in NUTS3 unit between 2017-2050	This indicator shows projected change in population more than 70 years. Older age is a high confidence sensitivity indicator across a range of hazards.
Soil Moisture Stress	Sensitivity to drought also includes a measure of soil moisture stress. When soil moisture is depleted, e.g. through reduced precipitation, this lack of soil moisture inhibits the effective functioning of natural and managed ecosystems.
Water Consumption Pressure (2030)	This indicator shows future water consumption pressure. Drought occurs not only because of natural processes, but also because of pressures on the demand for water by users. Water consumption can be increased by a number of factors including a dense population and a period of hot and dry weather.
At Risk of Poverty (ARoP)	This indicator shows those living in a household with an 'equivalised disposable income' below 60 % of the national median, after taxes and social transfers (ESPON 2013). This is the European definition of poverty.

Table 5. Sensitivity indicators included in the typology

What drives adaptive capacity?

There is a robust debate on the conceptualisation of adaptive capacity and how it should be measured which led to Schauser et al. (2010) observing that this is the ‘most challenging aspect of the vulnerability definition provided by the IPCC’. Adaptive capacity indicators may differ depending on whether one is looking at individuals or at regional/national levels. Given the NUTS 3 focus of the RESIN climate risk typology, we examined adaptive capacity at higher spatial scales.

Some influential studies have divided adaptive capacity into the constituent components of ability, awareness and action (Swart et al. 2012) or the ability to respond, prepare and recover (Kazmierczak and Cavan 2011; Climate Just 2014; CLUVA 2011). The ESPON project used a number of determinants of adaptive capacity to reflect the dimensions of ‘awareness’, ‘ability’ and ‘action’ identified by the EEA (See Box 3 for an explanation of terminology).

AWARENESS: in order to recognise that adaptation to a changing climate is needed, a city and its people need to recognise the problem. This could be phrased as the following questions: Does a city encourage awareness building? Does a city recognise the problem and perceive that something needs to be done about it?

ABILITY: a city needs to have enabling factors in order to progress adaptation. Such factors include technological capability or the ability of citizens to cope with a hazard. This can be phrased as the following question: Is a city equipped to address the problem of climate change?

ACTION: refers to factors crucial for the adaptation measures to take place. This can be phrased as a question such as ‘What constraints are placed on a city that wishes to implement adaptive actions?’

Terms adapted from (Schröter et al., 2004 and Swart et al. 2012).

Box 3: Explanation of adaptive capacity themes.

The generic adaptive capacity indicators identified within the literature are outlined in Table 6. Following the sourcing of suitable NUTS3 level data and statistical processes, as described in the methodology section above, the final set of indicators was identified and is shown in Table 7. These indicators are described in more detail within Appendix 1.

References	Generic Adaptive Capacity Indicator	Determinant	Brief description
(Swart et al. 2012; ESPON 2011; Tapia et al. 2015)	Education (e.g. qualified to Level 5; proportion educated to degree level or above)	Knowledge and Awareness	Higher levels of education may be positively correlated with awareness and perception of climate change as an issue.
(Swart et al. 2012; ESPON 2011; Tapia et al. 2015)	Awareness of climate change	Knowledge and Awareness	Surveys indicating the awareness of climate change directly may be useful in tracking climate change awareness.
(Swart et al. 2012; ESPON 2011; Tapia et al. 2015)	Risk perception	Knowledge and Awareness	Indicators that show the perception of risk amongst citizens may be useful as a proxy for how citizens understand climate risk.
(Swart et al. 2012)	Built environment and infrastructure (e.g. road density)	Infrastructure	The denser the road network, the more likely that alternative routes may be found in order to keep a city functioning.
Swart et al. 2012; ESPON 2011)	Innovation & Technology (e.g. investment in R&D; number of patents)	Technology	Technology and innovation are important in helping a city to adapt to climate change e.g. investment in new flood technologies or building technologies that can help to mitigate heat.
(Swart et al. 2012; ESPON 2011)	Hospital beds available	Infrastructure	The number of hospital beds available in a city may indicate the capacity to cope with increased numbers of hospital admissions during an extreme weather event.
(Swart et al. 2012; ESPON 2011)	GDP per capita/ disposable household income	Economic Resources	Income is important in helping a city, and its citizens, to adapt to climate change and to cope with extreme weather events.
(Swart et al. 2012; ESPON 2011)	Insurance penetration	Economic Resources	The availability and take-up of insurance may be regarded as financial means to help citizens cope with extreme weather events.
Swart et al. 2012; ESPON 2011; Tapia et al. 2015)	Social capital (e.g. trust in government; political participation; equity)	Institutions	Higher levels of social capital (as measured through the trust and cooperation) can help cities to cope with extreme weather events. However, it should be noted that private adaptation may be hindered by a reliance on collective responses (Paul et al. 2016).
Swart et al. 2012; ESPON 2011; Tapia et al. 2015)	Actual adaptation at the city/national level (e.g. existence of an adaptation strategy)	Institutions	City government commitment to adapting to climate change can be measured through the existence of an adaptation strategy to guide actions.

Table 6. Common categories denoting adaptive capacity. The cited literature refers to urban/regional assessments and not adaptive capacity at the individual level.

Indicator Name	Short Indicator description
% of total employment in NUTS1 unit	This indicator shows the employment-population balance. The ratio of jobs to people can be an important indication of economic concerns within an area.
Length of major road network in NUTS3 unit	This indicator shows the length of major road network in NUTS3 unit. Major roads are defined as ‘Highways’ and include ‘motorway’, ‘trunk’, ‘primary’, ‘secondary’ and ‘tertiary’ segments of the network. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality.
Length of railway network in NUTS3 unit	Length of railway network in NUTS3 unit. The rail network was sourced from open street map (2017) and includes standard gauge rail, subways, trams and light rail segments of the network. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality.
Density of major road intersections per km2 of the NUTS3 unit	This indicator shows the density of major road intersections per km2 of the NUTS3 unit. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality.
Density of transport nodes per km2 of the NUTS3 unit	This indicator shows the density of transport nodes per km2 of the NUTS3 unit. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality.
Number of airports per head of population in the NUTS3 unit	This indicator shows the number of airports per head of population in the NUTS3 unit. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality.
Number of ports per head of population in the NUTS3 unit	This indicator shows the number of ports per head of population in the NUTS3 unit. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality.
Number of hospitals per head of population in the NUTS3 unit	This indicator shows the number of hospitals per head of population in the NUTS3 unit. The ability for the population to access hospitals and other medical units during an extreme weather event is of paramount importance.
Number of power plants per head of population in the NUTS3 unit	This indicator shows the power plants per head of population in the NUTS3 unit. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality.
Fixed broadband coverage	This indicator shows fixed broadband coverage. Social media is becoming an increasingly common way of sharing risk information and warnings. Therefore, access to decent broadband is important in order to support the adaptive capacity of a given area.
Next Generation Access (NGA) - broadband	Next Generation Access (NGA) are access networks which consist wholly or in part of optical elements and which are capable of delivering broadband access services with enhanced characteristics (such as higher throughput) as compared to those provided over already existing copper networks. Increasing population densities, for example, are thought to indicate a need for faster broadband access in the future.

Number of patent applications to the EPO per 1000 population in the NUTS3 unit	This indicator shows the number of patent applications to the European Patent Office per 1000 population. Technology and innovation are important in helping a city to adapt to climate change e.g. investment in new flood technologies or building technologies that can help to mitigate heat.
% of total urban area in NUTS3 unit that is classified as green space (2012 data)	This indicator shows the % of total urban area in NUTS3 unit that is classified as green space (2012 data). There is robust evidence that green spaces can help city's resilience to the effects of climate change and extreme weather events.
Priority Allocations (Euros, 2013 - 2015)	This indicator refers to the amount of Euros received in a NUTS3 region.
Change in % of total urban area in NUTS3 unit that is classified as green space (2009-2012 data)	This indicator shows the change in % of total urban area in NUTS3 unit that is classified as green space (2009-2012 data). There is robust evidence that green spaces can help city's resilience to the effects of climate change and extreme weather events.
% of total land in the NUTS3 unit that is covered by continuous and/or discontinuous urban fabric (2012 data)	This indicator shows the built-up urban area based on CORINE data. This includes continuous urban fabric (more than 80% of the land is covered by artificial surface cover), discontinuous urban fabric (where 50% - 80% of the land is covered by artificial surface cover) and industrial, commercial and transport units.
Change in % of total land in the NUTS3 unit that is covered by continuous and/or discontinuous urban fabric (2012 data)	This indicator shows the change in the % of the built-up urban area based on CORINE data. This includes continuous urban fabric (more than 80% of the land is covered by artificial surface cover), discontinuous urban fabric (where 50% - 80% of the land is covered by artificial surface cover) and industrial, commercial and transport units.

Table 7. Final set of adaptive capacity indicators as included in the typology

5 The European Climate Risk Typology

5.1 The typology online portal

The typology is housed in an online portal, which can be accessed at www.european-crt.org**.** The typology online portal aims to support adaptation and resilience strategy, planning and action by offering users the means to visualise, describe, compare and analyse climate risk in European cities and regions. This section describes how the portal was developed and outlines its main contents and features.

Technical aspects of the online portal

The typology web application has been developed as a typical Informing Planning Support System (PSS). Its target audience consists of a wide spectrum of end users including planners, public sector employees, researchers and policy makers, in addition to others who are interested in obtaining climate risk information related to European cities and regions. The aim of this application is to provide climate risk data and spatial information through a simple to use Graphical User Interface (GUI), which helps users to interpret the information quickly and easily. The GUI of this application follows well known industry standards. In particular it is designed using the look and feel of Material Design developed by Google, which is the look and feel selected for the entire RESIN project. The application allows sight impaired users to interact with it since it incorporates assistive technologies.

Developing the geospatial data element of the application was a challenge since the level of interactivity needed (i.e. short response times) demanded the volume of the data to be kept to a level that allows a meaningful map to be drawn on the web page but at the same time enable fast user queries. The choropleth map (see the Glossary (Appendix 3) for a definition of this term) rendered on the web page is displayed using the Leaflet web mapping library which is considered currently a state-of-the-art library by the geospatial industry. The geospatial data are provided in the form of GeoJSON, which means that the actual vector data with all the class, sub-class and indicator values are downloaded and rendered on the fly. The application architecture has been designed in such a way that by the end of the project an optimization will be attempted to use the browser's IndexedDB to cash the geospatial data to minimize the time needed initially for the map to appear on screen.

The application architecture has been developed as a Single Page Application (SPA), which means that its html skeleton is downloaded once and all changes on it due to user's actions are rendered by the browser on the client machine using JavaScript and JSON data accordingly. The application uses a one-way flow of data utilising the JavaScript library Vue.js which provides a Model–View–View-Model (MVVM) architecture. Therefore, all GUI elements of the application follow the MVVM standard except the tooltip displayed on the map. The JavaScript code follows the ECMAScript 5 capabilities and is fully object oriented making extensive use of MVVM. The source code of the application is open source and is provided through GitHub in the url:

https://github.com/resin-crt/european-crt-website

The online portal user interface

The GUI of the online portal has been designed with visuals as its central focus point. A map is displayed on the web page occupying its entire real estate allowing the user to initially view the entire European continent drawn as a choropleth map. The user can change the background map to their preferred look and feel, including various options including between light, dark, roads, physical, terrain and satellite backgrounds. A collapsible panel displayed on the right side of the page (over the map) shows to the user the initial state of the application (which is referred to as the symbology state). The application has been designed to allow the user to interact with the portal contents through the symbology axon and the information axon, which form two collapsible panels that are mutually exclusive. The user is initially presented with the 'Symbology panel' which allows them switch between the typology classes and sub-classes, and also the climate risk indicators. Each time a user changes the view in the symbology panel the choropleth map is redrawn. Therefore, a user can see the classes of the typology and switch on/off classes to view their spatial patterns. The same level of interactivity is possible for the sub-classes. The user can also select indicators from the symbology panel. All indicators are grouped into the domain where they belong (ie: hazard, exposure, sensitivity, adaptive capacity). Only one indicator can be selected at once, allowing it to be drawn on the map. The GUI provides accordion panels that display detailed information for all classes, sub-classes and indicators.

When a user hovers with a mouse over the map a tooltip is displayed showing information for the current NUTS 3 region, which is the one that the mouse is hovering over. The tooltip is drawn as a semi-transparent white rectangle on which the name of the region is displayed as well as its climate risk typology class and sub-class. When a user clicks on a NUTS3 region, the region is selected and remains so until the user decides to click on another region. Once selected, information related to the region is provided including the name of the selected region, its class and sub-class and tables including all of the climate risk indicators for the region. The tables are interactive displaying the name of the indicator, its value, unit and z-score. The z-scores are statistical values used to classify the region and can have positive or negative values depending on whether the value is above or below the European average. Each indicator name is displayed as a link which allows the user to expand a panel dedicated to each indicator. In this panel the user can get more information about the indicator as well as see a visual representation of the region's indicator value in relation to the rest of the European regions. Descriptive statistics for each particular indicator are also displayed. The typology classes, sub-classes and climate risk indicators are now described in more detail.

5.2 A collaborative approach

The development of the typology has been collaborative and informed by inputs from within and beyond the RESIN project. A key point of engagement on the typology came with a consultation process on a prototype of the typology online portal. This sought to evaluate and improve the usability and application of the portal and the information contained within it. The consultation employed a mixed-methods approach and engaged a range of stakeholders. Appendix 2 includes a summary of the key points raised during the consultation and the actions taken in response. As a result of the consultation, several changes were made to the prototype in order to strengthen the content and usability of the online portal. Appendix 2 also lists the individuals involved in the consultation process.

5.3 Typology classes and sub-classes

The typology consists of two 'tiers', which are described as typology classes and sub-classes. The portal presents users with the opportunity to understand and map the typology classes and sub-classes, and where relevant position their city or NUTS3 region of interest within Europe's climate risk landscape. The cluster analysis process described in the methodology section above resulted in eight typology classes being identified. These are mapped within Figure 8, which presents a screenshot from the online portal, and described in Table 8. Each class represents a distinct group of cities and NUTS3 regions that share similar climate risk characteristics based on the indicators (hazard, exposure and vulnerability) developed to underpin the typology.

The map of Europe's typology classes highlights several issues concerning Europe's climate risk 'landscape':

- All of Europe's cities and NUTS3 regions are at risk of climate change, but for different reasons. The typology does not offer a relative ranking of climate risk (from high to low), and as a result provides a richer picture of the complex patterns of climate risk across Europe.
- There is real diversity in the climate risk characteristics of Europe's cities and NUTS3 regions.
- Due to the range of socio-economic and biophysical factors that influence climate risk, geography alone cannot adequately explain the spatial patterns revealed by the typology. In some cases, cities and NUTS3 regions that fall into the same typology class are in very different parts of the continent, although they nevertheless share similarities (statistically) across a range of climate risk indicators.
- Certain areas of Europe, particularly the Mediterranean and Northern Europe, are dominated by one typology class. Correspondingly, certain countries in these areas (e.g. Sweden and Portugal) only include one typology class.
- Some countries contain a number of typology classes. For example, the UK has six, France seven and Germany seven.

In areas where there is a concentration of smaller NUTS3 regions (such as Germany) there will tend to be greater variation in typology classes simply due to the sheer number of units in which indicators like population, infrastructure and climate characteristics will introduce scope for greater statistical variation. Where there are larger regions (such as in Sweden), a greater geographical area is covered by the same trends (e.g. population is not given the opportunity to vary or exposure to flood events is smoothed across a larger space). This is linked to what is known as the modifiable areal unit problem (Forheringham and Wong 1991).

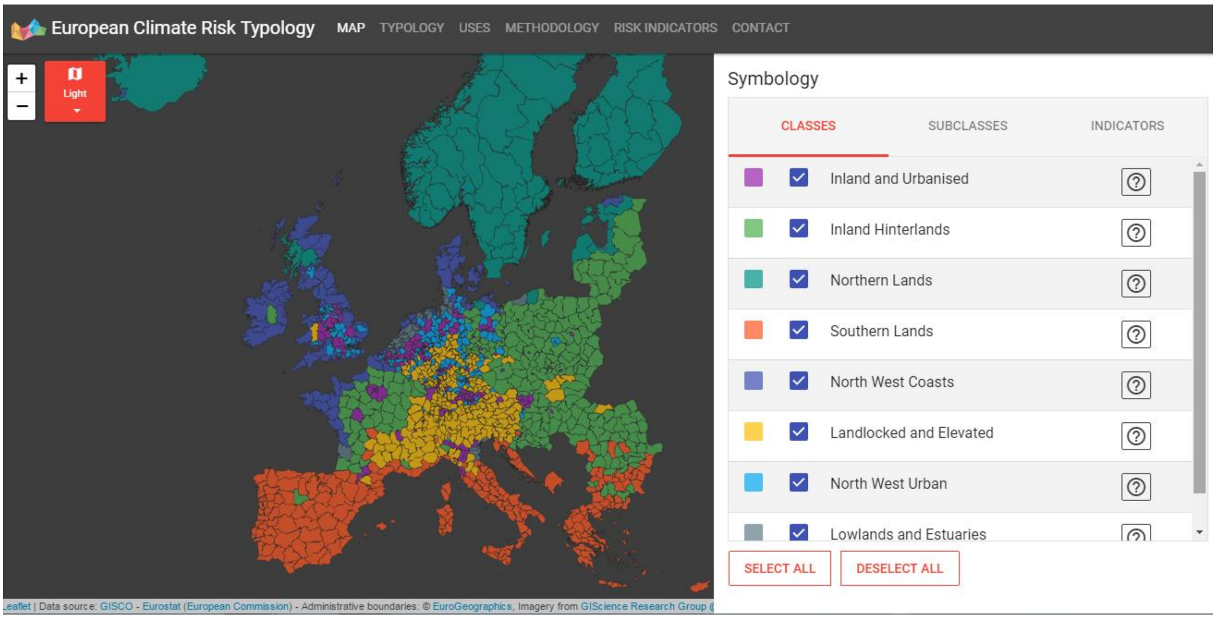

Figure 8: Map of Europe showing the eight typology classes. (Data source: GISCO - Eurostat (European Commission) - Administrative boundaries: © EuroGeographics, Imagery from GIScience Research Group @ University of Heidelberg — Map data © OpenStreetMap)

The second tier of the typology consists of 31 sub-classes. Each of the typology classes is divided into between three and five sub-classes. These identify distinct clusters of cities and NUTS3 regions that sit within each class. The sub-classes have been developed as an element of the typology in order to enable a more nuanced understanding to be developed of climate risk in European cities and NUTS 3 regions. In regions such as the Mediterranean and Northern Europe, which are dominated by one typology class, the sub-classes help to differentiate between cities and NUTS3 regions on the basis of their climate risk characteristics. This is demonstrated in Figure 9, which provides a screenshot from the portal showing the typology sub-classes. In areas of Europe where a higher number of typology classes are present, such as the UK, France and Germany, the sub-classes highlight the significant diversity of cities and NUTS3 regions in terms of their climate risk characteristics. For example Germany with seven typology classes, has 27 sub-classes. Conversely Sweden, with one typology class, has four sub-classes. The sub-classes are described in Table 9. The descriptions highlight the sub-class geography and the key issues that distinguish the sub-class from others in the same class. Where climate risk indicator themes are not highlighted in these descriptions, they are generally at a level around the average for the cities and NUTS 3 regions in the same class. It is important to emphasise the importance of exploring the indicators within the typology portal in order to gain an understanding of the climate risk characteristics sub-classes and their constituent cities and NUTS 3 regions.

Typology Class	Key Words
Inland and Urbanised	Central and western Europe, major cities, inland, fluvial flooding, affluent and innovative, high critical infrastructure provision.
Inland Hinterlands	Eastern Europe and central France, multiple climate hazards, exposure to fluvial flooding, peri-urban and rural, relatively low GDP (in a European context), low projected migration.
Northern Lands	Northern Europe, coastal hazard exposure, cool and wet, projected increase in very heavy rainfall events, affluent and dynamic, high projected migration.
Southern Lands	Mediterranean, increasingly hot and dry, landslides and coastal hazards, relatively low critical infrastructure provision, economic challenges (from a European perspective).
North West Coasts	Atlantic and North Sea coasts, areas of high population density, high exposure to coastal hazards but not to other climate hazards, projected increases in migration.
Landlocked and Elevated	Alpine and central European mountains and uplands, high landslide and fluvial flooding exposure, projected increase in very heavy rainfall, dense transport infrastructure, relatively affluent and innovative.
North West Urban	North west Europe, predominantly inland, urbanised, relatively low hazard exposure, projected increase in very heavy rainfall, GDP and employment prospects above European average.
Lowlands and Estuaries	Low lying and estuarine locations, high exposure to fluvial flooding and coastal hazards, good critical infrastructure provision, relatively strong economies.

Table 8: Typology class names and key words.

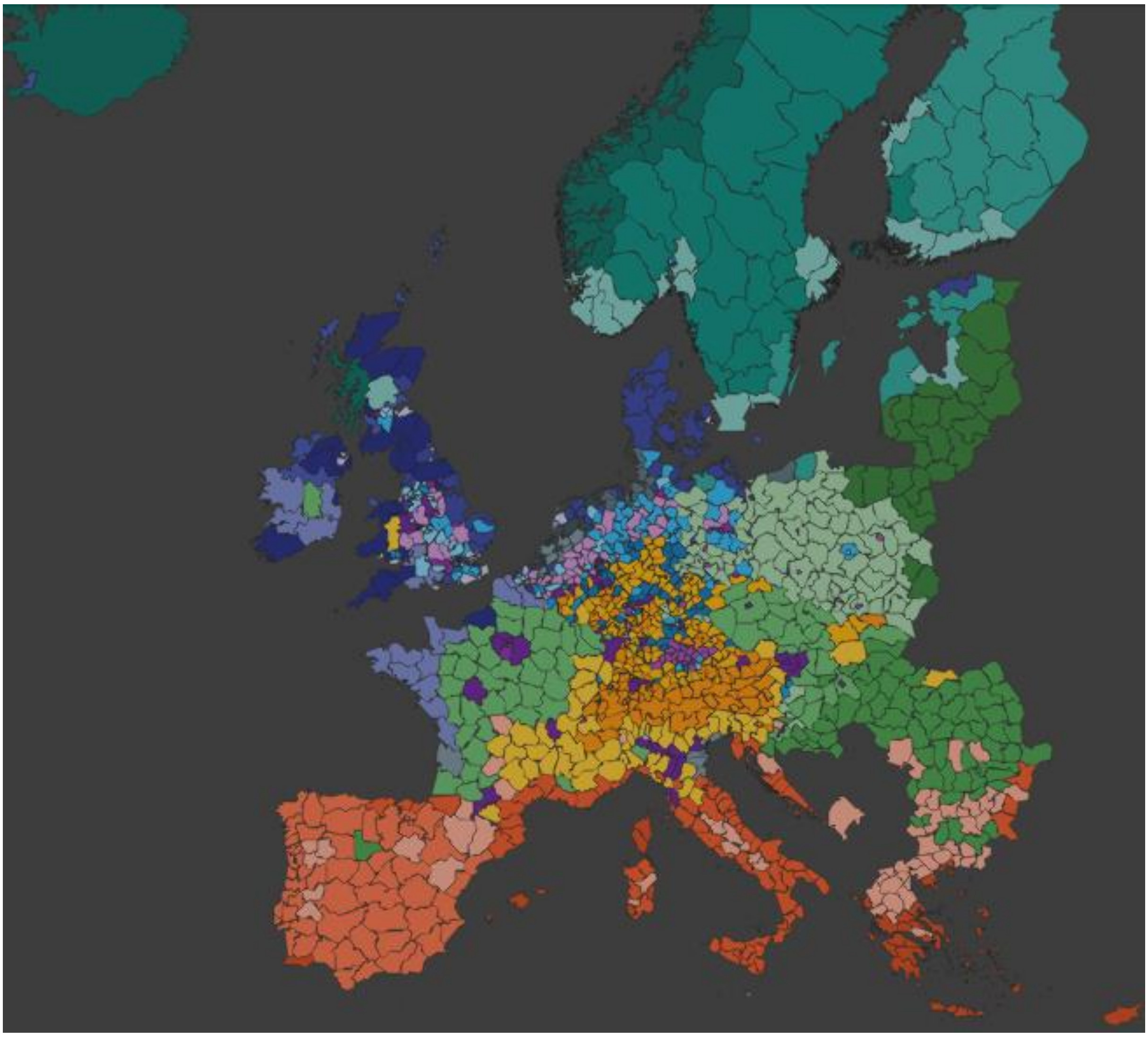

Figure 9. Map showing typology sub-classes. (Data source: GISCO - Eurostat (European Commission) - Administrative boundaries: © EuroGeographics, Imagery from GIScience Research Group @ University of Heidelberg — Map data © OpenStreetMap)

Typology Sub-Class	Key Words (N.B. these highlight principal geographic characteristics and the main differences between the sub-class and the class it sits within)
Inland and Urbanised 1	Cities and their hinterlands; higher landslide hazard and related exposure of transport infrastructure; higher wildfire hazard; becoming warmer and drier; greater soil moisture stress and pressure on water resources; higher projected change in total population, migration and the number of older and younger people; more patent applications.
Inland and Urbanised 2	Capital cities and key urban centres; higher fluvial flood hazard; fewer projected continuous wet days; fewer projected heat wave days; lower exposure of transport infrastructure to landslides; higher urban population density; higher numbers of people at risk of poverty; economically stronger.
Inland and Urbanised 3	German and Polish cities; projected to become warmer and wetter; lower soil moisture stress and pressure on water resources; higher exposure of people and transport infrastructure to fluvial flooding; shorter road and rail networks; lower broadband coverage; lower projected change in total population; higher ratio of jobs to people.
Inland and Urbanised 4	Hinterlands surrounding major cities; lower fluvial flooding and landslide hazard and related exposure of people and transport infrastructure; higher drought and wildfire hazard; lower projected increase in heat and rainfall related extremes; slower pace of urban development; more stable population numbers; lower economic performance.
Inland Hinterlands 1	Baltic states and north east Poland; lower incidence of landslides and fluvial flooding and related exposure of people and transport infrastructure; projected to become wetter but with fewer high temperature extremes; higher urban population density; higher proportion of urban green space; lower projected change in population; lower economic performance.
Inland Hinterlands 2	South eastern Europe; higher landslide and wildfire hazard; projected to become warmer and drier; higher exposure of people and transport infrastructure to flooding and landslide; lower provision of transport infrastructure; higher urban population density; lower urban green space cover; lower performance on economic indicators.
Inland Hinterlands 3	Widely dispersed with particular concentrations in France and Czech Republic; higher landslide hazard and exposure of transport infrastructure to this hazard; higher critical infrastructure provision (including transport and broadband coverage); higher projected change in total population; stronger economic performance.
Inland Hinterlands 4	Dominated by Poland; higher fluvial flood hazard; projected to become wetter with fewer high temperature extremes; lower exposure of transport infrastructure to landslides; higher transport infrastructure density; lower urban population density; higher proportion of built up land in urban areas; higher GVA.

Northern Lands 1	Dominated by Norway; coastal and mountainous; higher landslide and coastal hazard and related exposure of people and transport infrastructure; lower fluvial flooding hazard and exposure; lower wildfire hazard; projected to become wetter; lower road infrastructure density; higher critical infrastructure provision; higher economic performance; higher projected change in total population.
Northern Lands 2	Sweden, south eastern Norway and Lapland; higher fluvial flooding hazard and related exposure of people and transport infrastructure; higher drought and wildfire hazard; lower projected increase in the number of continuous dry days; lower exposure of people and transport infrastructure to coastal hazard; higher proportion of people at risk of poverty; higher economic performance.
Northern Lands 3	Finland and the Baltic coast; lower fluvial flooding, coastal, drought and landslide hazard; projected to become warmer and drier; lower exposure of people and transport infrastructure to landslide, fluvial flooding and coastal hazard; lower critical infrastructure provision; lower projected change in total population; lower economic performance.
Northern Lands 4	Major Scandinavian cities; higher fluvial flood hazard; higher coastal hazard and related exposure of people and transport infrastructure; projected to become warmer and drier but with more extreme rainfall events; higher density of transport infrastructure; higher broadband coverage; higher proportion of built up urban area; higher projected change in older and younger people and migration; higher economic performance.
Southern Lands 1	Mediterranean islands; lower fluvial flooding hazard and related exposure of people and transport infrastructure; higher exposure of transport infrastructure to coastal flooding; higher landslide hazard; projected to become warmer and drier; lower road and rail length; higher number of ports and airports per head of population; lower proportion of people at risk of poverty; higher projected change in numbers of older and younger people; higher projected increase in total population.
Southern Lands 2	Mediterranean coastline; hills and mountains; higher coastal hazard; higher exposure of people and infrastructure to coastal flooding and landslides; projected to become wetter; higher proportion of built up urban area; higher road and rail length and number of transport nodes; higher broadband provision; higher projected change in total population and numbers of older and younger people; stronger economic performance.
Southern Lands 3	Iberian Peninsula; diverse landscapes; higher fluvial flooding and related exposure of people and transport infrastructure, higher drought and wildfire hazard; lower landslide hazard; lower exposure to coastal and landslide hazard; projected to become warmer and drier; higher road and rail length; higher proportion of people at risk of poverty; higher receipt of EU priority allocations funding; lower projected change in population via migration; higher economic performance.
Southern	Widely dispersed across Europe; inland; mountainous; higher fluvial flood hazard and related exposure of people and transport infrastructure; lower coastal hazard and related

Lands 4	exposure of people and infrastructure; projected to become warmer and wetter; lower critical infrastructure provision; lower projected change in total population and numbers of younger and older people; lower economic performance.
North West Coasts 1	British Isles; rural, coastal and upland areas; higher fluvial flooding, wildfire and landslide hazard; projected to be cooler with less extreme rainfall events; exposure of people and transport infrastructure higher for fluvial flooding and landslides but lower for coastal hazards; lower water consumption pressure; longer and less dense transport networks; higher broadband coverage; higher proportion of people at risk of poverty; lower projected change in migration.
North West Coasts 2	North Sea coast and much of Denmark; urbanised; higher fluvial flood hazard; lower landslide hazard; higher exposure of people and critical infrastructure to fluvial flooding and coastal hazard but lower exposure to landslides; projected to become warmer and wetter; higher provision of critical infrastructure; higher number of patent applications.
North West Coasts 3	Scottish Islands; coastal; lower fluvial flooding, wildfire and coastal hazard; higher landslide hazard; lower exposure of people and infrastructure to fluvial flooding but higher exposure to landslides; lower soil moisture stress and projected water consumption pressure; projected to be cooler and wetter; lower road and rail infrastructure lengths and densities; higher critical infrastructure provision; lower proportion of built up urban area; lower patent applications
North West Coasts 4	North west Atlantic coasts; peri-urban and rural areas; higher fluvial flooding hazard; higher exposure of people and infrastructure to fluvial flooding but lower exposure to coastal hazard; projected to become warmer and drier; higher soil moisture stress and projected water consumption pressure; higher road and rail lengths; lower critical infrastructure provision; lower urban population densities and proportion of urban built up area; higher projected change in older people; higher patent applications.
North West Coasts 5	Major coastal cities; lower fluvial flooding, wildfire and landslide hazard; lower exposure of people and infrastructure to fluvial flooding and landslide hazard but higher exposure to coastal hazard; higher water consumption pressure; denser transport infrastructure; higher broadband provision; higher projected change in population and numbers of older and younger people; higher urban population density and proportion of built up urban area.
Landlocked and Elevated 1	North side of the Alps; higher fluvial flooding and landslide hazard; projected to become wetter with fewer high temperature extremes; higher exposure of people and critical infrastructure to fluvial flooding and landslide hazard; higher broadband coverage; higher projected change in population and numbers of older and younger people; higher GVA.
Landlocked and Elevated 2	Dominated by upland areas in Germany; lower fluvial flooding and landslide hazards and related exposure of people and transport infrastructure; projected to become wetter; lower road and rail lengths but with higher road intersections and transport nodes; higher proportion of urban green and built up area; lower projected change in older and younger

	people and migration.
Landlocked and Elevated 3	South side of the Alps and French upland areas; higher wildfire hazard; projected to become warmer and drier; higher soil moisture stress and projected water consumption pressure; higher projected change in the number of young people and migration; longer but less dense transport networks; lower broadband provision; lower employment-population balance; lower GVA.
North West Urban 1	Dominated by Germany; lower fluvial flooding hazard; higher landslide hazard; projected to become wetter; lower exposure of people and transport infrastructure to fluvial flooding; higher exposure of transport infrastructure to landslides; lower urban population density and proportion of green and built up urban area; lower projected change in total population and numbers of old and young people; higher economic performance.
North West Urban 2	Widely dispersed across different countries; higher landslide hazard; projected to become warmer and drier; lower exposure of people and transport infrastructure to fluvial flooding but higher exposure to landslides; higher broadband provision; lower urban population density; lower change in green and built up urban area; higher proportion of people at risk of poverty; higher projected change in total population and the number of old and young people; lower economic performance.
North West Urban 3	Cities in Germany and south east England; higher fluvial flood hazard; lower landslide hazard; higher exposure of people and transport infrastructure to fluvial flooding but lower exposure to landslides; higher change in urban green and built up area; lower projected change in total population.
North West Urban 4	Industrial cities in the UK and Germany; lower fluvial flooding, landslide and drought hazard; lower projected increase in wet and very wet days; higher soil moisture stress and projected water consumption pressure; lower exposure of people and transport infrastructure to fluvial flooding and landslide hazard; higher broadband provision; higher urban population density and proportion of green and built up urban area; higher projected change in total population and older and younger people; higher employment-population balance.
Lowlands and Estuaries 1	Cities, particularly in the Netherlands and on the Baltic coast; higher drought hazard; lower projected increase in summer days and heatwave days; higher exposure of people and rail network to coastal hazard; shorter but more dense transport infrastructure networks; higher broadband coverage; higher urban population density and urban green cover; higher proportion of people at risk of poverty; higher employment-population balance.
Lowlands and Estuaries 2	Northern German coast; lower fluvial flooding, drought and wildfire hazard; higher coastal hazard; projected to become wetter; lower water projected water consumption pressure; lower road and rail length; higher density of transport infrastructure; higher broadband provision; lower urban population density; lower proportion of urban green and built up land cover; higher urban green and built up change; lower projected change

	in total population, migration and numbers of older and younger people; lower economic performance.
Lowlands and Estuaries 3	Widely dispersed; some cities; higher fluvial flooding and wildfire hazard; lower coastal and drought hazard; projected to become warmer and drier; higher projected water consumption pressure; higher exposure of people to fluvial flooding; lower exposure of people and rail network to coastal hazard; longer road and rail length; higher number of hospital sites per 1000 people; higher projected change in total population, migration and numbers of older and younger people; higher number of patent applications.

Table 9: Typology sub-class names and key words.

5.4 Climate risk indicators

In addition to housing and presenting the opportunity to visualise the typology classes and sub-classes, the online portal also contains a range of data on the climate risk indicators that underpin the typology. The 81 climate risk indicators are a significant output of the work undertaken to develop the typology. The indicators represent a valuable resource that can support climate change adaptation and resilience responses in Europe. Although the original intention was to use existing indicator data, it became apparent during the RESIN project that this was not going to be possible due to data quality, coverage and availability issues. Consequently, aside from two indicators, all of the other indicators used within the development of the typology were subjected to post-collection data processing leading to new or adapted indicators being created at the NUTS 3 level.

The online portal contains data on the 81 climate risk indicators including:

- A description of the indicator creation method and source data
- A range of statistical data on the indicators
- Maps visualising the indicator values for Europe's NUTS3 regions.

Reviewing the typology indicators can help to determine the factors that are driving climate risk in a particular European city or NUTS3 region, or more broadly typology classes and sub-classes. In addition to the ability to map the indicators, a range of descriptive, map-based and statistical data is provided within the typology online portal to support this process. This includes a z-Score, which gives an initial hint as to whether the theme addressed by each indicator represents an issue of concern. If the z-Score is above zero, this highlights that the indicator value for the NUTS3 region lies above the average for all European NUTS3 regions. A z-score below zero demonstrates that the indicator value is below the European average. The higher (or lower) the z-Score, the further the value for the NUTS3 region is away from the European average. Depending on the indicator considered, a high z-Score may be positive from the perspective of climate risk (e.g. high GVA is a positive indicator of adaptive capacity), whereas in other situations a high z-Score is negative in this respect (e.g. where the indicator concerns the proportion of road infrastructure exposed to fluvial flooding).

The indicator maps on the online portal (e.g. Figure 10) are produced using the z-scores. Figure 10 shows a screenshot from the online portal that maps the fluvial flood hazard indicator. This map (the likes of which is available for all of the 81 climate risk indicators) provides a quick impression of the European cities and regions that are above (red colour) and below (green colour) the average for Europe in terms of the potential occurrence of flood hazards.

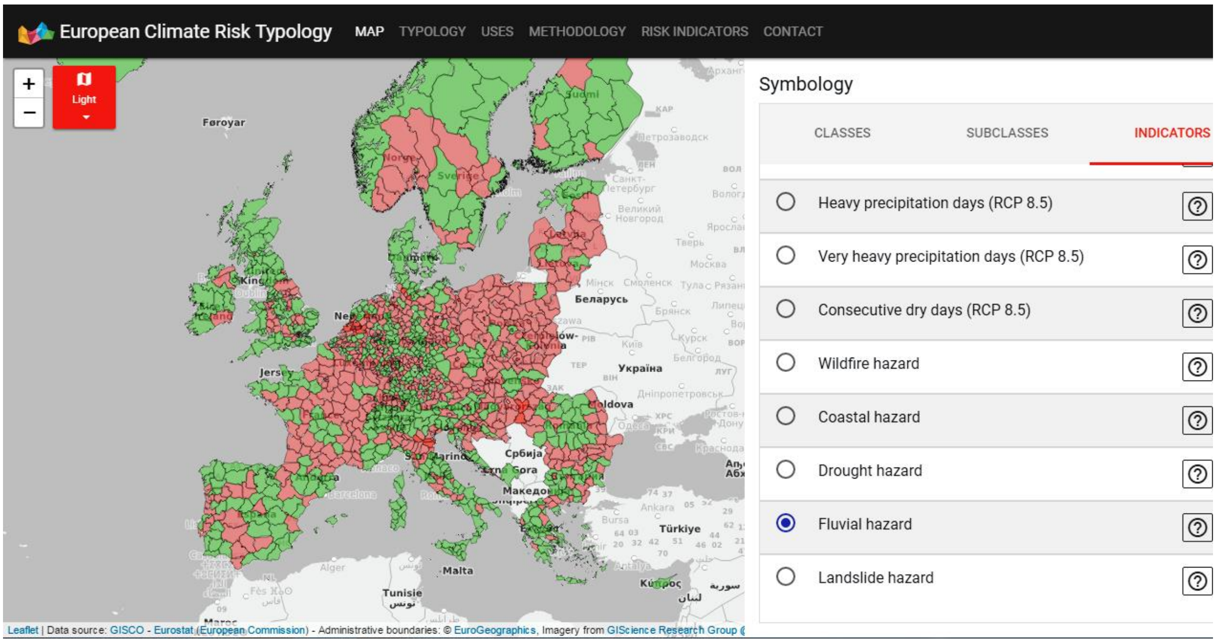

Figure 10: Fluvial flood hazard indicator map (in this case the dark red regions are those with the greatest potential to be affected by flood hazards, whereas the green regions have the least potential to be affected by flood hazards). (Data source: GISCO - Eurostat (European Commission) - Administrative boundaries: © EuroGeographics, Imagery from GIScience Research Group @ University of Heidelberg — Map data © OpenStreetMap)

5.5 Integration with RESIN project outputs

The typology functions as a *risk-based* tool that can inform climate change adaptation and resilience planning processes. Consequently, there are clear connections between the typology and other outputs produced within the RESIN project, specifically the IVAVIA tool and the e-Guide, which are also focused on this agenda. Options to link the typology with the RESIN Adaptation Options Library were explored. It was identified that it was not useful to operationalise the connection with adaptation options in the library as it was difficult and, in some cases, not possible to link, spatially, the options to the typology classes and sub-classes. However, the typology may be able to support the selection of adaptation options in some cases, particularly where the focus is at larger spatial scales (e.g. cities) by highlighting key drivers of climate risk to address. For example, the typology indicators can provide a first indication of exposure and vulnerability themes to target adaptation options towards.

The RESIN IVAVIA tool

The IVAVIA (impact and vulnerability analysis of vital infrastructures and built up areas) tool provides guidance on how to prepare, gather, and structure data for a risk-based climate change vulnerability assessment, to quantify and combine vulnerability indicators, to assess risk and to present outcomes.

The typology has a role to play in supporting the application of the IVAVIA tool in practice. A link to the typology is provided on the landing page for the IVAVIA tool: https://resin.iais.fraunhofer.de/ivavia/

Specific modules in the IVAVIA process at which the typology, and specifically the climate risk indicator data underpinning the typology, could be used are:

Module 0: Systematically selecting hazards and stressors – the typology incorporates indicator data on the climate hazard profile of European cities and NUTS3 regions that can help to inform hazard identification.

Module 1: Preparing the vulnerability assessment – the indicator data underpinning the typology covers climate hazard, exposure and vulnerability themes that can support the IVAVIA risk assessment process.

Module 2: Developing impact chains – the typology indicators may in some cases be helpful for IVAVIA users during the development of impact chains, for example when determining hazard-exposure combinations to focus on and when identifying impact chain indicators.

Module 3: Identifying and selecting indicators – the typology incorporates a series of vulnerability indicators, covering sensitivity and adaptive capacity themes, that can assist users complete this element of the IVAVIA process by identifying factors that are driving vulnerability to climate hazards.

When using the typology indicators within the IVAVIA process, it will be important to take time to review the supporting data (descriptive and statistical) provided within the typology online portal to develop an understanding of whether and how the indicator data could be used as part of the IVAVIA risk assessment. Issues related to spatial scale are especially important to consider. The typology indicators relate to the NUTS3 scale. With over 1300 NUTS3 regions in Europe, the spatial scale varies considerably. A single NUTS3 region may cover part of a densely populated city, or a much larger area where urban settlements are more widely dispersed. The typology indicators can be particularly useful where the IVAVIA tool is focused at larger spatial scales (e.g. cities, regions). Conversely, the typology is of less value to an IVAVIA user where the focus is on specific asset (e.g. a power station or railway line) or smaller area within a city (e.g. a particular district or neighbourhood).

The RESIN e-Guide

The e-Guide is a decision support system available as a web application. It can be accessed at: http://e-guide.resin.itti.com.pl/. It provides guidance and functions to users undertaking climate change adaptation planning processes. The e-Guide is organised into 4 phases:

1. Assess climate risk
2. Develop adaptation approaches
3. Prioritise adaptation options
4. Develop implementation plan

The typology has a role to play during the first of these phases; assess climate risk. This phase includes two steps, determining climate threats and context, which the typology can support. Regarding the first of these steps, the indicator data that underpins the typology provides planners and decision makers with information on the threat of and exposure to climate-related hazards, and also future climate change projections in their city or NUTS3 region of interest. Concerning context, the typology incorporates several indicators that can be used as a source of data on non-climate related trends within the city, such as population projections. The typology and the e-Guide are linked via a data sharing platform that enables e-Guide users to access the typology's climate risk indicator data and import them directly into the workspace of the e-Guide. Although the indicator data can be accessed directly in this way, it is recommended that e-Guide users also refer to the typology online portal for further information and visualisations on the indicators.

6 Using the typology

The typology has been developed to support policy makers, practitioners and researchers in better understanding and responding to climate change risks. Through the process of developing and testing the typology, which has involved input from potential end users from within and beyond the RESIN project, several key uses and users of the typology have been identified. These are described below. The typology portal contains several use cases to guide the application of the typology in practice.

6.1 Typology uses

The key functions of the typology can be summarised as:

Awareness raising

Using the online portal, the typology and supporting indicators can help to visualise, communicate and raise awareness of climate risk amongst different stakeholder groups. Applied in this way, the typology could be used in the early stages of an adaptation planning process to generate commitment for adaptation and resilience action.

Description

The typology can be used to describe and enhance understanding of the climate risk characteristics, relating to hazard, exposure, vulnerability and adaptive capacity, of European cities and NUTS3 regions. The typology classes and sub-classes, and supporting radial diagrams, provide users with a brief description of the underlying climate risk characteristics of their city or region. These characteristic can be explored in greater detail via the indicators that the typology is developed around. Also, the visualisation of climate risk classes and sub-classes provided through the typology online portal enables a strategic perspective on spatial patterns of climate risk to be taken. Indeed, the typology provides an overview of Europe’s climate risk landscape.

Risk assessment

Looking beyond its high level descriptive function, the typology (and particularly the supporting climate risk indicators) could be used to inform a more in-depth climate change risk assessment. As the typology indicators are provided at the NUTS 3 scale, which may been too course a spatial scale for some risk assessments, and some climate risk themes are not covered within the typology (e.g. exposure to heat waves and pluvial flooding), local data will generally be needed to supplement that provided via the typology in order to undertake a risk assessment.

Strategy and plan development

The typology can inform the development of climate change adaptation and resilience strategies and plans. The typology output and the underlying indicators can help to guide decisions on particular climate risk themes that could be usefully investigated in more detail (e.g. related to prominent hazard, exposure or vulnerability themes) within processes to develop adaptation and resilience strategies and plans. This may be particularly helpful where capacity and resources to support urban adaptation and resilience activity are limited as the typology can help to target resources to particular areas of need or opportunity. However, it is important to note that the typology should not be used to take adaptation and resilience decisions, and should be viewed as one tool that can support this process.

Baselining

The typology provides a 'snapshot' of climate risk in European NUTS3 regions based on the climate and socio-economic indicator data available at the time of its development. The indicator underpinning the typology is dynamic, and the climate risk indicator values will evolve over time influenced by factors including socio-economic change and improvements in research techniques. If the cluster analysis approach were to be re-run in the future using an updated set of indicators, this could in turn result in a different set of typology outcomes. However, this also highlights that the typology could be used to monitor climate risk over time. The risk 'snapshot' (or baseline) produced within the RESIN project therefore provides the opportunity to assess changes in climate risk across the European landscape over time.

Network development

The typology groups European cities and NUTS3 regions together according to their climate risk characteristics, as defined through the indicators used to develop the typology. Cities and NUTS3 regions that fall into the same class, or sub-class, share similar climate risk characteristics. The typology can therefore be used to help develop peer-to-peer networks between urban areas that face similar risk profiles in order to encourage sharing of learning, experience and practice.

6.2 Typology end users

The typology will be most useful for two main user groups operating at different spatial scales:

- Regional, national and European planners and decision-makers
- City and urban planners and decision makers

Regional, national and European planners and decision-makers

Given that the typology operates at the scale of NUTS3 regions, it has a role to play informing adaptation and resilience strategy, planning and decision making at larger spatial scales. European (and global level) organisations including the European Commission, European Environment Agency, Global Covenant of Mayors, national agencies and governing bodies and regional level agencies and governing bodies have the potential to benefit from the typology. The strategic perspective of European, national and regional climate risk 'landscapes' that the typology provides can support organisations such as these in progressing their adaptation and resilience objectives.

Urban planners and decision makers

Cities and urban areas are increasingly developing climate change adaptation and resilience strategies. In some cases this is driven by legislation and in others where the imperative to adapt to climate change is recognised, perhaps due to previous experience of extreme weather events. The typology is of potential value to urban decision makers who are looking to better understand and/or develop responses to reduce extreme weather and climate risk. The typology can support this process in several ways, although the value of the typology in this respect will depend on factors including the size of the city and existing levels of knowledge and awareness on climate risk issues. Smaller urban areas that form part of a NUTS3 region, or those cities and urban areas that already have significant knowledge and data on climate change risk, will benefit less from the typology. The typology is of particular value to larger cities and urban areas that cover one or more NUTS3 region, especially where knowledge and data on climate risk is at a relatively low level. Further, the typology can assist signatories to the Global Covenant of Mayors for Climate and Energy, specifically in the preparation of the required 'Risk and Vulnerability Assessment' which is subsequently used to inform a 'Sustainable Energy and Climate Action Plan.'

Other potential users

Although the RESIN project has focused particularly on cities, and this is the scale that adaptation and resilience strategies and actions are currently most prominent, peri-urban and rural regions are also facing climate risks. Given that the typology output (and the indicator data) covers the whole of Europe, it can also support adaptation and resilience strategy and action in peri-urban and rural regions. In addition, the typology can assist researchers and students working in this field as it provides a new way of visualising and analysing climate risk in Europe. It also demonstrates and describes methodological developments related to the creation and use of climate risk indicators at the European scale. Further, other stakeholders including infrastructure providers, insurance brokers and consultants may also benefit from the typology and the data and insights that it contains.

6.3 Typology caveats

Several caveats connected to the typology and its indicators must be acknowledged when using this tool in practice.

Spatial scale

The typology indicators relate to the NUTS3 region scale. The density of NUTS3 regions across Europe differs from place to place, and their spatial scale varies considerably. A single NUTS3 region may cover part of densely populated city or a larger area where urban settlements are more widely dispersed. For example, five NUTS3 regions cover Greater Manchester whereas only one covers Greater Dublin. Such variations need to be considered when interpreting and utilising the indicator data. Ultimately, the indicators are most valuable in supporting a strategic screening process to determine which climate threats need to be investigated in more detail as part of a wider adaptation planning process.

Indicator gaps

The typology indicators were developed for a particular function; to create a typology using a cluster analysis method that groups European cities and NUTS3 regions into classes and sub-classes that share similar climate risk characteristics. It was not possible to gather or develop indicator data to incorporate within the typology on all aspects of climate risk due to issues of data quality, access and availability. As a result, issues that are potentially important in determining climate risk are not covered within the typology indicator set. For example, indicators on the exposure of people and infrastructure to heat stress are not provided. Further, indicators covering themes including governance approaches and cultural attitudes are not represented, yet will have important implications for climate risk and related responses. This highlights that although the indicators available within the typology online portal can usefully support climate risk assessment and response, they should not be relied upon exclusively.

Outlier cities and NUTS3 regions

The typology classes will usefully explain the climate risk characteristics of the majority of NUTS3 regions that fall within them. However, there will always be outliers that do not immediately appear to fit in. Here, the typology sub-classes are helpful as they further distinguish NUTS3 regions in terms of their underlying climate risk characteristics, although there may also be outliers at this scale of the typology.

The influence of the typology methodology

Typology development is both a science and an art underpinned by conceptual orientations, user requirements and indicator availability and coverage. As Gale et al (2016: 2) note, “These influences impact upon the subjective choices and predilections of the classification builder, guiding the methodological approaches undertaken to produce a usable classification”. Whilst decisions in developing the RESIN typology were taken to maximise the robustness of the outcome, the typology is essentially a product of the choices made during its development. Had different decisions been made in the choice of input data; data transformation and standardisation procedures; clustering methods; and approaches for describing the underlying structure of the classification (e.g. radials and descriptions, the typology could have taken a different form to the one produced here. However, this feature of typology development should not detract from the merit and robustness of the RESIN typology given the extent to which it differentiates features of risk across Europe at varying levels of granularity.

7 Typology benefits and innovations

Looking beyond the value of the typology for planners and decision makers working on climate change adaptation and resilience issues, this output of the RESIN project offers wider benefits and innovations.

7.1 Moving towards a risk-based typology

Risk sits at the heart of the IPCC's climate change adaptation and resilience agenda. Consequently, the decision was taken to position risk as the guiding concept underpinning the typology, and the RESIN project more broadly. Here, the IPCC's most recent risk framework, contained in AR5 (IPCC 2014), was adopted. This distinguishes the typology from other European-scale spatially oriented research outputs and decision support tools that focus on climate change adaptation and resilience, which are often based on distinct elements of the risk framework.

For example, the European Environment Agency's Urban Vulnerability Map Book[4] focuses on the mapping of different indicators linked to vulnerability to climate change hazards. In some cases the Map Book enables indicators to be overlaid, for example those related to vulnerability and hazard. The ESPON Climate project (ESPON 2011) focuses at the NUTS3 region scale and classifies regions according to levels of vulnerability. This report also includes a hazard based classification of Europe's NUTS3 regions, and provides various maps of the exposure of settlements and infrastructure to hazards. However, the ESPON Climate project applies climate change projection and socio-economic data that is now dated. Also, the ESPON Climate project does not provide a typology of climate risk as has been developed within RESIN. Further, both ESPON and the Urban Vulnerability Map Book use terminology contained in the IPCC's 4th Assessment Report, which has now been superseded (Connelly at al 2018).

A more recent European funded project, RAMSES, involved a climate risk analysis of European cities (Tapia et al 2015). This study took the 571 cities in Europe's Urban Audit database as its unit of analysis, and applied the IPCC's most recent risk-based framework (IPCC 2014). The output of this research is a quartile-based ranking of the Urban Audit cities according to the risk posed by different climate change hazards. Consequently, there are some similarities with the RESIN climate risk typology, particularly concerning the risk framework adopted. However, the focus on Urban Audit cities within RAMSES means that it provides a partial view of this issue from a European perspective.

The RESIN typology complements and takes forward existing work on climate risk at the European scale.

- The typology provides, for the first time, a classification of European cities and NUTS3 regions into different climate risk classes (and sub-classes).

- The typology is one of the first large scale research outputs to apply the IPCC's most recent climate risk framework in practice (IPCC 2014), and provides a useful test bed for this leading global framework. Although the framework has been applied to create a climate risk typology at the NUTS 3 scale, it is a generic approach and could be applied at a range of other scales (e.g. city districts or neighbourhoods).

[4] https://climate-adapt.eea.europa.eu/knowledge/tools/urban-adaptation/my-adaptation

- The typology provides a comprehensive and integrated view of the different elements of the risk framework, covering hazards, and exposure and vulnerability to hazards.

7.2 Broadening perspectives of climate risk

Existing European scale climate change risk and vulnerability assessments tend to distinguish cities and regions according to the degree of risk and vulnerability to hazards that they face, from high to low. This provides a useful insight into locations where risk and/or vulnerability is high. However, this approach may divert attention away from locations where risk and/or vulnerability is low. Climate change is an all-encompassing issue, spatially, and all cities and regions should ultimately develop strategies and responses to reduce risk and increase resilience. Further, highlighting certain cities or regions as being 'riskier' than others may also have unintended consequences, for example discouraging inward investment and the realisation of development aspirations. The RESIN typology was not designed to assess climate risk on a relative scale, and as a result highlights that all cities and regions are at risk from extreme weather and climate change, but for different reasons. In doing so it provides a starting point for developing adaptation and resilience strategies and responses in locations across Europe.

7.3 A comprehensive spatial picture of climate risk patterns

One of the key advances offered by the RESIN typology is the opportunity to visualise spatial patterns of climate change risk across the European continent. Indeed, the typology is the first tool that enables this to be done in an interactive way. This has clear potential benefits for adaptation and resilience planning and strategy development at larger spatial scales. The typology operates at the NUTS3 scale, which in a number of (but not all) cases align with the administrative boundaries of cities. As a result, users can develop an understanding of climate risk in their city of interest and then also look at the climate risk characteristics of their surrounding hinterland regions. Given that some climate change impacts and risks are generated beyond city boundaries (for example related to flooding and water shortages), and should therefore be responded to at the scale of watersheds and wider bio-regions, the typology can usefully help to widen the spatial perspective of climate risk. This may be necessary in order to respond to broader systemic risks, for example where transport links between urban centres and their commuter hinterlands may be impacted by extreme weather. Enabling this hinterland perspective can also help to demonstrate the need for coordinated adaptation approaches across administrative boundaries. Indeed, the city may not necessarily be the scale at which adaptation and resilience strategies should always be developed. The typology also highlights that in certain locations there are clusters of NUTS 3 regions that fall within the same typology class or sub-class. In these situations, broader regional scale adaptation and resilience strategies may be appropriate, or at least necessary as a complement to city-scale strategies.

7.4 Acknowledging the diversity of climate risk

The spatial picture of climate risk provided by the typology highlights the diversity of this issue across Europe. It is clear, therefore, that adapting and building resilience to climate change in cities and regions is a multi-faceted exercise. Cities and regions show considerable differences in the socio-economic and biophysical factors that drive climate risk, although the RESIN typology does identify climate risk classes (and sub-classes) of cities and regions. The two-tier nature of the typology enables different layers of granularity to be observed concerning Europe's climate risk patterns.

Building on the IPCC's climate risk framework, the typology provides the opportunity to break down the drivers of climate risk within cities and regions. This clarifies that adapting and building resilience to climate change is not a 'one-size-fits-all' endeavour. Extreme weather and climate change hazards, and factors influencing exposure and vulnerability to hazards, vary considerably between cities and regions. Although standardised processes can support adaptation and resilience planning and strategy development, such as the IVAVIA and e-Guide developed within the RESIN project, the typology demonstrates that the issues these processes grapple with are diverse and location dependant.

7.5 Typology online portal functionality

A key benefit of the typology, in comparison to other existing research and data outputs in this field, is the online portal developed to house and provide access to the typology and its supporting indicators. Specific benefits include:

- All of the typology indicator data is publically available and accessible via the online portal. This is not the case for related outputs including those developed by RAMSES or ESPON, which do not provide easy access to supporting indicator data.
- Where other online data portals do exist, for example the European Environment Agency's Urban Vulnerability Map Book, the capacity for users to access data for specific cities and regions is limited. The RESIN online portal goes beyond the visualisation of spatial patterns of risk and vulnerability to provide data and resources that can support adaptation strategy and action in European cities and regions.

These aspects and functions of the online portal increase its utility for end users. Taken together with the other benefits and innovations outlined above, the typology can be viewed as a valuable addition to the resources available to individuals and organisations looking to progress climate change adaptation and resilience objectives in Europe.

8 Appendices

Appendix 1: Indicators for the European Climate Risk Typology

Indicator Name	Unit	Indicator Details	Indicator description	Indicator Source Data and Approach	Indicator used in clustering	IPCC AR5 Risk Domain
Mean Temperature (RCP 4.5)	°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	Mean temperature is a globally recognised and standardised climate indicator. This indicator shows the difference in daily mean temperature between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). Projected change in daily mean temperature is not itself a climate change hazard. However, this indicator and the supporting statistical data (the Z-Score) can be used to enhance understanding of how the climate of the NUTS3 area is projected to change over the coming decades.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Mean Temperature (RCP 8.5)	°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP8.5 scenario.	Mean temperature is a globally recognised and standardised climate indicator. This indicator shows the difference in daily mean temperature between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5 scenario). Projected change in daily mean temperature is not itself a climate change hazard. However, this indicator and the supporting statistical data (the Z-Score) can be used to enhance understanding of how the climate of the NUTS3 area is projected to change over the coming decades.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP8.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	Yes	Hazard
Maximum Temperature (RCP 4.5)	°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	Maximum temperature is a globally recognised and standardised climate indicator. This indicator shows the difference in maximum temperature between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5 scenario). Projected change in maximum temperature is not itself a climate change hazard. However, this indicator and the supporting statistical data (the Z-Score) can be considered alongside other high temperature related indicators (e.g. heat wave days) to demonstrate how high temperature related hazards may evolve in the NUTS3 area over the coming decades.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Maximum Temperature (RCP 8.5)	°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP8.5	Maximum temperature is a globally recognised and standardised climate indicator. This indicator shows the difference in maximum temperature between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). Projected change in maximum temperature is not itself a climate change hazard.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP8.5 greenhouse	Yes	Hazard

		scenario.	However, this indicator and the supporting statistical data (the Z-Score) can be considered alongside other high temperature related indicators (e.g. heat wave days) to demonstrate how high temperature related hazards may evolve in the NUTS3 area over the coming decades.	gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.		
Summer Days (RCP 4.5)	Number of days with maximum temperature more than 25°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	This indicator shows the difference in the number of days with a maximum temperature more than 25°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). The 25°C temperature threshold for summer days is a globally recognised and standardised climate indicator. The supporting statistical data (the Z-Score) provides further information on this indicator in the context of the NUTS3 area. Although the summer days threshold of 25°C does not pose a threat to the majority of people and infrastructure, it can be considered alongside other heat-related indicators to better understand projected changes in temperature and related hazards in the NUTS3 area.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Summer Days (RCP 8.5)	Number of days with maximum temperature more than 25°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP8.5 scenario.	This indicator shows the difference in the number of days with a maximum temperature more than 25°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5 scenario). The 25°C temperature threshold for summer days is a globally recognised and standardised climate indicator. The supporting statistical data (the Z-Score) provides further information on this indicator in the context of the NUTS3 area. Although the summer days threshold of 25°C does not pose a threat to the majority of people and infrastructure, it can be considered alongside other heat-related indicators to better understand projected changes in temperature and related hazards in the NUTS3 area.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP8.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	Yes	Hazard
Tropical Nights (RCP 4.5)	Number of days with minimum temperature more than 20°C during the night	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	This indicator shows the difference in the number of nights where the minimum temperature does not drop below 20°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). The 20°C temperature threshold for tropical nights is a globally recognised and standardised climate indicator. The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of tropical nights is a potentially significant issue for the NUTS3 area. The tropical nights indicator is used by the European Environment Agency who note that their occurrence is a crucial factor influencing the degree of health impacts associated with high temperatures in urban areas. The level of risk to people in the NUTS3 area from tropical nights (and associated heat wave days) will depend on factors including the proportion of elderly and young people in the population, groups who are particularly susceptible to harm from high temperatures. Indicator data on these factors is available within the typology portal.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Tropical Nights (RCP 8.5)	Number of days with minimum	Difference between the 2036–2065	This indicator shows the difference in the number of nights where the minimum temperature does not drop below 20°C between the 1981-2010 period (observed baseline) and the 2036-2065 period	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European	No	Hazard

	temperature more than 20°C	period and the 1981–2010 period for the IPCC RCP8.5 scenario.	(future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5 scenario). The 20°C temperature threshold for tropical nights is a globally recognised and standardised climate indicator. The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of tropical nights is a potentially significant issue for the NUTS3 area. The tropical nights indicator is used by the European Environment Agency who note that their occurrence is a crucial factor influencing the degree of health impacts associated with high temperatures in urban areas. The level of risk to people in the NUTS3 area from tropical nights (and associated heat wave days) will depend on factors including the proportion of elderly and young people in the population, groups who are particularly susceptible to harm from high temperatures. Indicator data on these factors is available within the typology portal.	domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP8.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.		
Heat Waves (RCP 4.5)	Number of days with maximum temperature more than 35°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	This indicator shows the difference in the number of days with a maximum temperature of more than 35°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). There is no universal standard definition for a heat wave, although they are generally regarded as periods of extremely high temperature that exceeds a certain threshold (which varies depending on location and sector being considered) for a set number of days. Heat waves can negatively impact on people, ecosystems and infrastructure. The severity of impacts will depend on factors including the degree to which they are exposed to high temperatures and their vulnerability to this hazard. Vulnerability to heat waves is influenced by factors including the proportion of elderly and young people in the population and the extent of green space cover in urban areas. Indicator data on both of these factors is available within the typology portal. The severity and duration of the heat wave will also influence levels of associated risks. The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of heat waves is a potentially significant issue for the NUTS3 area.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Heat Waves (RCP 8.5)	Number of days with maximum temperature more than 35°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP8.5 scenario.	This indicator shows the difference in the number of days with a maximum temperature of more than 35°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5 scenario). There is no universal standard definition for a heat wave, although they are generally regarded as periods of extremely high temperature that exceeds a certain threshold (which varies depending on location and sector being considered) for a set number of days. Heat waves can negatively impact on people, ecosystems and infrastructure. The severity of impacts will depend on factors including the degree to which they are exposed to high temperatures and their vulnerability to this hazard. Vulnerability to heat waves is influenced by factors including the proportion of elderly and young people in the population and the extent of green space cover in urban areas. Indicator data on both of these factors is available within the typology portal. The severity and duration of the heat wave will also influence	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP8.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	Yes	Hazard

			levels of associated risks. The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of heat waves is a potentially significant issue for the NUTS3 area.			
Minimum Temperature (RCP 4.5)	°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	Minimum temperature is a globally recognised and standardised climate indicator. This indicator shows the difference in minimum temperature between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). Projected change in minimum temperature is not itself a climate change hazard. However, this indicator and the supporting statistical data (the Z-Score) can be considered alongside other low temperature related indicators (e.g. frost days and ice days) to demonstrate how low temperature related hazards may evolve in the NUTS3 area over the coming decades.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Minimum Temperature (RCP 8.5)	°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP8.5 scenario.	Minimum temperature is a globally recognised and standardised climate indicator. This indicator shows the difference in minimum temperature between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5 scenario). Projected change in minimum temperature is not itself a climate change hazard. However, this indicator and the supporting statistical data (the Z-Score) can be considered alongside other low temperature related indicators (e.g. frost days and ice days) to demonstrate how low temperature related hazards may evolve in the NUTS3 area over the coming decades.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP8.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Frost days (RCP 4.5)	Number of days with minimum temperature less than 0°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	This indicator shows the difference in the number of days with a minimum temperature of less than 0°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). The 0°C temperature threshold for frost days is a globally recognised and standardised climate indicator. The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of frost days is a potentially significant issue for the NUTS3 area. The number of frost days is decreasing across Europe, and the impacts of this shift may be positive or negative depending on the location being considered and related factors including the nature of dominant industries and land uses.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Frost days (RCP 8.5)	Number of days with minimum temperature less than 0°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP8.5 scenario.	This indicator shows the difference in the number of days with a minimum temperature of less than 0°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5 scenario). The 0°C temperature threshold for frost days is a globally recognised and standardised climate indicator. The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of frost days is a potentially significant issue for the NUTS3 area. The number of frost days is decreasing across Europe, and the impacts	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP8.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period	No	Hazard

			of this shift may be positive or negative depending on the location being considered and related factors including the nature of dominant industries and land uses.	1981-2010.		
Ice Days (RCP 4.5)	Number of days with maximum temperature less than 0°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	This indicator shows the difference in the number of days with a maximum temperature of less than 0°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). The 0°C temperature threshold for ice days is a globally recognised and standardised climate indicator. The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of ice days is a potentially significant issue for the NUTS3 area. The number of ice days is decreasing across Europe, and the impacts of this shift may be positive or negative depending on the location being considered and related factors including the nature of dominant industries and land uses.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Ice Days (RCP 8.5)	Number of days with maximum temperature less than 0°C	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP8.5 scenario.	This indicator shows the difference in the number of days with a maximum temperature of less than 0°C between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection). The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5 scenario). The 0°C temperature threshold for ice days is a globally recognised and standardised climate indicator. The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of ice days is a potentially significant issue for the NUTS3 area. The number of ice days is decreasing across Europe, and the impacts of this shift may be positive or negative depending on the location being considered and related factors including the nature of dominant industries and land uses.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP8.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	Yes	Hazard
Total Wet-Day Precipitation (RCP 4.5)	Cumulated precipitation for days with precipitation greater than or equal to 1mm	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	Total wet-day precipitation is a globally recognised and standardised climate indicator. This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the cumulated precipitation for days with precipitation greater than or equal to 1mm. The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). Projected change in total wet day precipitation is not itself a climate change hazard. However, this indicator and the supporting statistical data (the Z-Score) can enhance understanding of how the climate of the NUTS3 area is projected to change over the coming decades.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Total Wet-Day Precipitation (RCP 8.5)	Cumulated precipitation for days with precipitation greater than or equal to 1mm	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP8.5 scenario.	Total wet-day precipitation is a globally recognised and standardised climate indicator. This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the cumulated precipitation for days with precipitation greater than or equal to 1mm. The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5 scenario). Projected change in total wet day precipitation is not itself a climate change hazard. However, this indicator and the supporting statistical data (the Z-Score) can	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP8.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with	No	Hazard

			enhance understanding of how the climate of the NUTS3 area is projected to change over the coming decades.	respect to the control period 1981-2010.		
Consecutive Wet Days (RCP 4.5)	Number of consecutive wet days with precipitation greater than or equal to 1mm	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	Consecutive wet days is a globally recognised and standardised climate indicator. This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the number of consecutive wet days with precipitation greater than or equal to 1mm. The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). Projected change in consecutive wet days is not itself a climate change hazard. However, this indicator and the supporting statistical data (the Z-Score) can enhance understanding of how the climate of the NUTS3 area is projected to change over the coming decades. Considering this indicator alongside other related indicators can support this process. For example, where consecutive wet days are projected to increase, in addition to increases in heavy and very heavy precipitation days, this indicates that flood hazards may become more common within the NUTS3 area.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Consecutive Wet Days (RCP 8.5)	Number of consecutive wet days with precipitation greater than or equal to 1mm	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP8.5 scenario.	Consecutive wet days is a globally recognised and standardised climate indicator. This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the number of consecutive wet days with precipitation greater than or equal to 1mm. The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5 scenario). Projected change in consecutive wet days is not itself a climate change hazard. However, this indicator and the supporting statistical data (the Z-Score) can enhance understanding of how the climate of the NUTS3 area is projected to change over the coming decades. Considering this indicator alongside other related indicators can support this process. For example, where consecutive wet days are projected to increase, in addition to increases in heavy and very heavy precipitation days, this indicates that flood hazards may become more common within the NUTS3 area.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP8.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	Yes	Hazard
Heavy Precipitation Days (RCP 4.5)	Number of days with precipitation greater than or equal to 10mm	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	Heavy precipitation days is a globally recognised and standardised climate indicator. This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the number of days with precipitation greater than or equal to 10mm. The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). Where the frequency of heavy precipitation days is projected to increase, this indicates that flood hazards may also increase (although flooding is driven by multiple other factors including land use change). The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of heavy precipitation days is a potentially significant issue for the NUTS3 area.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Heavy Precipitation Days (RCP 8.5)	Number of days with precipitation greater than or	Difference between the 2036–2065 period and the 1981–	Heavy precipitation days is a globally recognised and standardised climate indicator. This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the number of days with precipitation greater than or equal to 10mm. The future projection is developed for a high	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by	Yes	Hazard

	equal to 10mm	2010 period for the IPCC RCP8.5 scenario.	greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5 scenario). Where the frequency of heavy precipitation days is projected to increase, this indicates that flood hazards may also increase (although flooding is driven by multiple other factors including land use change). The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of heavy precipitation days is a potentially significant issue for the NUTS3 area.	different global climate models. The simulations taken into account are obtained according to the IPCC RCP8.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.		
Very Heavy Precipitation Days (RCP 4.5)	Number of days with precipitation greater than or equal to 20mm	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	Very heavy precipitation days is a globally recognised and standardised climate indicator. This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the number of days with precipitation greater than or equal to 20mm. The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). Where the frequency of very heavy precipitation days is projected to increase, this indicates that flood hazards may also increase (although flooding is driven by multiple other factors including land use change). The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of very heavy precipitation days is a potentially significant issue for the NUTS3 area.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Very Heavy Precipitation Days (RCP 8.5)	Number of days with precipitation greater than or equal to 20mm	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP8.5 scenario.	Very heavy precipitation days is a globally recognised and standardised climate indicator. This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the number of days with precipitation greater than or equal to 20mm. The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5 scenario). Where the frequency of very heavy precipitation days is projected to increase, this indicates that flood hazards may also increase (although flooding is driven by multiple other factors including land use change). The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of very heavy precipitation days is a potentially significant issue for the NUTS3 area.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP8.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	Yes	Hazard
Consecutive Dry Days (RCP 4.5)	Number of consecutive dry days with precipitation less than 1mm	Difference between the 2036–2065 period and the 1981–2010 period for the IPCC RCP4.5 scenario.	Consecutive dry days is a globally recognised and standardised climate indicator. This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the number of consecutive dry days with precipitation less than 1mm. The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 4.5 scenario). The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of consecutive dry days is a potentially significant issue for the NUTS3 area.	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into account are obtained according to the IPCC RCP4.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.	No	Hazard
Consecutive Dry Days (RCP 8.5)	Number of consecutive dry days with precipitation less than	Difference between the 2036–2065 period and the 1981–2010 period for	Consecutive dry days is a globally recognised and standardised climate indicator. This indicator shows the difference between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection) in the number of consecutive dry days with precipitation less than 1mm. The future projection is developed for a high greenhouse gas emissions scenario (the Intergovernmental Panel on Climate Change	Climate analysis was performed using CORDEX regional climate model (RCM) simulations available over the European domain (EURO-CORDEX) with a resolution of 0.11 degrees (about 12 km) and forced by different global climate models. The simulations taken into	Yes	Hazard

	1mm	the IPCC RCP8.5 scenario.	(IPCC) Representative Concentration Pathway (RCP 8.5 scenario). The statistical data provided for this indicator (the Z-Score) can be used to better understand whether change in the number of consecutive dry days is a potentially significant issue for the NUTS3 area.	account are obtained according to the IPCC RCP8.5 greenhouse gas emissions scenario. Climate anomalies were evaluated over the period 2036-2065 with respect to the control period 1981-2010.		
Wildfires	%	% of total area of the NUTS3 unit covered by burning	This indicator identifies the proportion of the NUTS 3 region defined as 'burnt areas' according to the 2012 Corine classification. This provides a sense of the extent to which wildfires have been a hazard in the past in the NUTS3 region.	Corine land cover data (2012) was used to identify the percentage of land in each NUTS 3 area that is classified as 'burnt areas'.	Yes	Hazard
Coastal Hazards	%	% of total length of NUTS3 unit coastline in km that is exposed to a 1 in 100 year coastal storm surge and 1 meter sea level rise	% of total length of NUTS3 unit coastline in km that is exposed to a 1 in 100 year coastal storm surge and exposed to 1 meter sea level rise.	GTSR (Global Tide and Surge Reanalysis) is an analysis of storm surges and extreme sea-levels based on hydrodynamic modelling (Muis *et al*, 2016). GTSR covers the entire world's coastline and provides estimates of extreme sea-levels values based on the period 1979-2014. The dataset is based on the application of two global hydrodynamic models: GTSM to simulate storm surges [Verlaan et al., 2015], and FES2012 to simulate tides [Carrere et al. 2012]. Surge levels were modelled by forcing GTSM with 10m wind speed and atmospheric pressure from the ERA-Interim climate reanalysis [Dee et al., 2011]. Total water levels are calculated by superimposing tides and surges. The 1-in-100 year sea level was estimated by fitting a Gumbel extreme value distribution to the annual maxima. The water levels included over 12,000 locations along the coastline defined as a centroid of the DIVA segments database.	Yes	Hazard
Drought Hazard	N°		The EEA has defined drought as a natural phenomenon reflecting, 'a sustained and extensive occurrence of below average water availability' (EEA 2009: 11). Droughts are defined differently according to whether they are meteorological, hydrological, agricultural, environmental or socio-economic. This indicator utilises the Standardized Precipitation-Evapotranspiration Index (SPEI) at nine month timescales, and therefore provides a measure of meteorological drought. A SPEI measure below 0 reflects a region where precipitation over a nine-month period is below the European average. A measure above 0 reflects a region where precipitation over a nine-month period is above the European average.	This indicator is derived using a global gridded dataset of the Standardized Precipitation-Evapotranspiration Index (SPEI) at nine month timescales. These were extracted from a netcdf format for each from 1970 to 2017 from the SPEI Global Drought Monitor (http://spei.csic.es/map/maps.html#months=1#month=7#year=2018). The extracted files were converted to raster format. The rasters were averaged in ArcGIS 10.4 across the sample to derive an average of the drought trends over time.	Yes	Hazard
Fluvial Hazard	%	% of NUTS3 area prone to flooding in the event of a 1 in 100 year fluvial flood	This indicator shows the percentage of the total area of the NUTS3 area that would be flooded in the event of a 1 in 100 year fluvial flood. Fluvial flooding occurs when watercourses (rivers, streams) overflow and inundate the surrounding area. The statistical data provided for this indicator (the Z-Score) can be used to better understand whether fluvial flooding is a significant issue for the NUTS3 area. Also, this indicator can be considered alongside others included in the typology portal that show the extent of exposure of people and	This indicator uses the Joint Research Council's (JRC) depiction of flood prone areas in Europe for flood events with 100-year return period. Cell values indicate water depth (in m). The raster was intersected with polygonised NUTS 3 units to calculate the total NUTS 3 area with susceptibility flooding on a 1-in-100 year return (http://data.jrc.ec.europa.eu/colle	Yes	Hazard

			infrastructure to fluvial flooding in the NUTS3 area.	ction/id-0054).		
Landslide Hazard	%	% of NUTS3 area that shows moderate (or higher) susceptibility to landslide	This indicator and the supporting statistical data (the Z-Score) can be used to better understand whether landslide hazard is a significant issue for the NUTS3 area. The key factor that influences landslide susceptibility is the presence of steep slopes. Others include bedrock and soil characteristics, deforestation and the presence of roads. Heavy rainfall can often trigger landslides. The typology portal includes an indicator on projected changes to the occurrence of very heavy rainfall days in NUTS3 areas. This can be used alongside the landslide hazard indicator, and also other indicators related to the exposure of people and infrastructure to landslides, to better understand this hazard in the NUTS3 area.	This indicator draws on NASA's Global Landslide Susceptibility Map, which identifies the potential for landslides across the Earth's surface on a scale from slight to severe. This indicator calculates the proportion of the NUTS3 area that shows moderate to higher susceptibility to landslide (https://pmm.nasa.gov/precip-apps)	Yes	Hazard
Population in settlements exposed to fluvial flooding	%	% of total population in settlements of NUTS3 unit exposed to 1 in 100 year fluvial flood	Fluvial flooding occurs when watercourses (rivers, streams) overflow and inundate the surrounding area. This indicator shows the percentage of the total population of the NUTS3 area living in settlements that would be exposed to flooding in the event of a 1 in 100 year fluvial flood. This indicator does not highlight the specific elements of the population living in settlements that would be affected in the event of a flood. Further, it does not account for flood defences that may protect certain locations. More localised flood risk assessments would therefore be needed to establish which specific locations would be exposed if a 1 in 100 year fluvial flood occurred. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether the exposure of populations living in settlements to fluvial flooding is a significant issue for the NUTS3 area.	This indicator was derived by intersecting 1km GEOSTAT population grids (https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat) with 1km GHS settlement grids (https://ghsl.jrc.ec.europa.eu/ghs_smod.php) in ARCGIS 10.4 to derive a measure of population living in settlements. This ratser layer was then intersected with the Joint Research Council's (JRC) depiction of flood prone areas in Europe for flood events with 100-year return period in which cell values indicate water depth (in m). The measure of population living in settlements and exposed to fluvial flooding was transformed into a rate based on the total population living in the NUTS 3 area, calculated from the 1km GEOSTAT population to ensure consistency between the numerator and denominator.	Yes	Exposure
Population in settlements exposed to coastal hazards	%	% of total population in settlements of NUTS3 unit exposed to a 1 in 100 year coastal storm surge and 1 meter sea level rise	This indicator shows the proportion of the total population of the NUTS3 area living in settlements located in areas that are potentially exposed to coastal hazards. Coastal hazards include sea level rise (1 metre above current levels) and susceptibility to storm surge. This indicator does not highlight the specific elements of the population living in settlements that would be affected should these coastal hazards occur. Further, it does not account for defences that may protect certain locations from coastal hazards. More localised flood risk assessments would therefore be needed to establish which specific locations would be exposed in the event of coastal hazards occurring. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether the exposure of populations living in settlements to coastal hazards is a significant issue for the NUTS3 area.	This indicator was derived by intersecting 1km GEOSTAT population grids (https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat) with 1km GHS settlement grids (https://ghsl.jrc.ec.europa.eu/ghs_smod.php) in ARCGIS 10.4 to derive a measure of population living in settlements. This indicator was intersected with the 1 metre sea level rise inundation area defined by CReSIS (www.cresis.ku.edu/content/research/maps). GTSR (Global Tide and Surge Reanalysis) is an analysis of storm surges and extreme sea-levels based on hydrodynamic modelling (Muis et al, 2016). GTSR covers the entire world's coastline and provides estimates of extreme sea-levels values based on the period 1979-2014. The dataset is based on the application of two global hydrodynamic	Yes	Exposure

				models: GTSM to simulate storm surges [Verlaan et al., 2015], and FES2012 to simulate tides [Carrere et al. 2012]. Surge levels were modelled by forcing GTSM with 10 mps wind speed and atmospheric pressure from the ERA-Interim climate reanalysis [Dee et al., 2011]. Total water levels are calculated by superimposing tides and surges. The 1-in-100 year sea level was estimated by fitting a Gumbel extreme value distribution to the annual maxima. The water levels included over 12,000 locations along the coastline defined as a centroid of the DIVA segments database. The measure of population living in settlements and exposed to coastal flooding was transformed into a rate based on the total population living in the NUTS 3 area, calculated from the 1km GEOSTAT population grid.		
Population in settlements exposed to landslide	%	% of total population of the NUTS3 area living in settlements located in areas that show moderate (or higher) susceptibility to landslide	This indicator shows the percentage of the total population of the NUTS3 area living in settlements located in areas that are susceptible to landslide hazard. This indicator and the supporting statistical data (the Z-Score) can be used to better understand whether exposure of population in settlements to landslides is a significant issue for the NUTS3 area. The key factor that influences landslide susceptibility is the presence of steep slopes. Others include bedrock and soil characteristics, deforestation and the presence of roads. Heavy rainfall can often trigger landslides. The typology portal includes an indicator on projected changes to the occurrence of very heavy rainfall days in NUTS3 areas.	This indicator was derived by intersecting 1km GEOSTAT population grids (https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat) with 1km GHS settlement grids (https://ghsl.jrc.ec.europa.eu/ghs_smod.php) in ARCGIS 10.4 to derive a measure of population living in settlements. This indicator was intersected with the proportion of the NUTS3 area that shows moderate to higher susceptibility to landslide derived from NASA's Global Landslide Susceptibility Map (https://pmm.nasa.gov/precip-apps). The measure of population living in settlements and exposed to landslides was transformed into a rate based on the total population living in settlements in the NUTS 3 area, calculated from the 1km GEOSTAT population grids (https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat)	Yes	Exposure
Road infrastructure exposed to fluvial flooding	%	% length of major road in NUTS3 unit exposed to 1 in 100 year fluvial flood	Fluvial flooding occurs when watercourses (rivers, streams) overflow and inundate the surrounding area. This indicator shows the percentage of the total length of road infrastructure in the NUTS3 area (major roads and major road intersections) that would be exposed to flooding in the event of a 1 in 100 year fluvial flood. This indicator does not highlight the specific elements of road infrastructure that would be affected in the event of a flood. Further, it does not account for flood defences that may protect certain stretches of road infrastructure. More localised flood risk assessments would therefore be needed to establish which specific infrastructure elements would be exposed if a 1 in 100 year fluvial flood occurred. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether fluvial flooding	The road network was sourced from open street map (2017). Major roads are defined as 'Highways' and include 'motorway', 'trunk', 'primary', 'secondary' and 'tertiary' segments of the network. The road network was intersected in ArcGIS 10.4 with the Joint Research Council's (JRC) depiction of flood prone areas in Europe for flood events with 100-year return period. Cell values indicate water depth (in m). (http://data.jrc.ec.europa.eu/collection/id-0054). The measure of road infrastructure exposed to	Yes	Exposure

			to road infrastructure is a significant issue for the NUTS3 area.	fluvial flooding was transformed into a rate based on the total length of road infrastructure in the NUTS 3 area.		
Rail network exposed to fluvial flooding	%	% length of rail network in NUTS3 unit exposed to 1 in 100 year fluvial flood	Fluvial flooding occurs when watercourses (rivers, streams) overflow and inundate the surrounding area. This indicator shows the percentage of the total length of the rail network in the NUTS3 area that would be exposed to flooding in the event of a 1 in 100 year fluvial flood. This indicator does not highlight the specific elements of the rail network that would be affected in the event of a flood. Further, it does not account for flood defence infrastructure that may protect certain stretches of rail line. More localised flood risk assessments would therefore be needed to establish which specific elements of the rail network would be exposed if a 1 in 100 year fluvial flood occurred. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether fluvial flooding to the rail network is a significant issue for the NUTS3 area.	The rail network was sourced from open street map (2017) and includes standard gauge rail, subways, trams and light rail segments of the network. The rail network was intersected in ArcGIS 10.4 with the Joint Research Council's (JRC) depiction of flood prone areas in Europe for flood events with 100-year return period. Cell values indicate water depth (in m). (http://data.jrc.ec.europa.eu/collection/id-0054). The measure of rail infrastructure exposed to fluvial flooding was transformed into a rate based on the total length of rail infrastructure in the NUTS 3 area.	Yes	Exposure
Road infrastructure exposed to coastal hazards	%	% length of major road network in NUTS3 unit exposed to a 1 in 100 year coastal storm surge and 1 meter sea level rise	This indicator shows the proportion of the total length of road infrastructure in the NUTS3 area (major roads and major road intersections) that is located in areas that are potentially exposed to coastal hazards. Coastal hazards include sea level rise (1 metre above current levels) and susceptibility to storm surge. This indicator does not highlight the specific elements of the road infrastructure that would be affected should these coastal hazards occur. Further, it does not account for defences that may protect certain road infrastructure from coastal hazards. More localised flood risk assessments would therefore be needed to establish which specific infrastructure elements would be exposed in the event of coastal hazards occurring. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether the exposure of road infrastructure to coastal hazards is a significant issue for the NUTS3 area.	The road network was sourced from open street map (2017). Major roads are defined as 'Highways' and include 'motorway', 'trunk', 'primary', 'secondary' and 'tertiary' segments of the network. Calculated as intersections in ArcGIS Network Analyst using open street map road data (2017). The road network was intersected with the 1 metre sea level rise inundation area defined by CReSIS (www.cresis.ku.edu/content/research/maps). GTSR (Global Tide and Surge Reanalysis) is an analysis of storm surges and extreme sea-levels based on hydrodynamic modelling (Muis et al, 2016). GTSR covers the entire world's coastline and provides estimates of extreme sea-levels values based on the period 1979-2014. The dataset is based on the application of two global hydrodynamic models: GTSM to simulate storm surges [Verlaan et al., 2015], and FES2012 to simulate tides [Carrere et al. 2012]. Surge levels were modelled by forcing GTSM with 10 mps wind speed and atmospheric pressure from the ERA-Interim climate reanalysis [Dee et al., 2011]. Total water levels are calculated by superimposing tides and surges. The 1-in-100 year sea level was estimated by fitting a Gumbel extreme value distribution to the annual maxima. The water levels included over 12,000 locations along the coastline defined as a centroid of the DIVA segments database. The measure of road infrastructure exposed to coastal flooding was transformed into a rate based on the total length of road infrastructure in the NUTS	Yes	Exposure

				3 area.		
Road infrastructure exposed to landslide	%	% of the total length of road infrastructure in the NUTS3 area located in areas that show moderate (or higher) susceptibility to landslide	This indicator shows the percentage of the total length of road infrastructure in the NUTS3 area (major roads and major road intersections) that is located in areas that are susceptible to landslide hazard. This indicator and the supporting statistical data (the Z-Score) can be used to better understand whether exposure of road infrastructure to landslides is a significant issue for the NUTS3 area. The key factor that influences landslide susceptibility is the presence of steep slopes. Others include bedrock and soil characteristics, deforestation and the presence of roads. Heavy rainfall can often trigger landslides. The typology portal includes an indicator on projected changes to the occurrence of very heavy rainfall days in NUTS3 areas.	The road network was sourced from open street map (2017). Major roads are defined as 'Highways' and include 'motorway', 'trunk', 'primary', 'secondary' and 'tertiary' segments of the network. The road network was intersected in ArcGIS 10.4 with the proportion of the NUTS3 area that shows moderate to higher susceptibility to landslide derived from NASA's Global Landslide Susceptibility Map (https://pmm.nasa.gov/precip-apps). The measure of road infrastructure exposed to landslides was transformed into a rate based on the total length of road infrastructure in the NUTS 3 area.	Yes	Exposure
Rail network exposed to coastal hazards	%	% length of rail network in NUTS3 unit exposed to a 1 in 100 year coastal storm surge and 1 meter sea level rise	This indicator shows the proportion of the total length of the rail network in the NUTS3 area (major roads and major road intersections) that is located in areas that are potentially exposed to coastal hazards. Coastal hazards include sea level rise (1 metre above current levels) and susceptibility to storm surge. This indicator does not highlight the specific elements of the rail network that would be affected should these coastal hazards occur. Further, it does not account for defences that may protect certain elements of the rail network from coastal hazards. More localised flood risk assessments would therefore be needed to establish which parts of the rail network would be exposed in the event of coastal hazards occurring. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether the exposure of the rail network to coastal hazards is a significant issue for the NUTS3 area.	The rail network was sourced from open street map (2017) and includes standard gauge rail, subways, trams and light rail segments of the network. The rail network was intersected with the 1 metre sea level rise inundation area defined by CReSIS (www.cresis.ku.edu/content/research/maps). GTSR (Global Tide and Surge Reanalysis) is an analysis of storm surges and extreme sea-levels based on hydrodynamic modelling (Muis et al, 2016). GTSR covers the entire world's coastline and provides estimates of extreme sea-levels values based on the period 1979-2014. The dataset is based on the application of two global hydrodynamic models: GTSM to simulate storm surges [Verlaan et al., 2015], and FES2012 to simulate tides [Carrere et al. 2012]. Surge levels were modelled by forcing GTSM with 10 mps wind speed and atmospheric pressure from the ERA-Interim climate reanalysis [Dee et al., 2011]. Total water levels are calculated by superimposing tides and surges. The 1-in-100 year sea level was estimated by fitting a Gumbel extreme value distribution to the annual maxima. The water levels included over 12,000 locations along the coastline defined as a centroid of the DIVA segments database. The measure of rail infrastructure exposed to coastal flooding was transformed into a rate based on the total length of rail infrastructure in the NUTS 3 area.	Yes	Exposure
Rail network exposed to landslide	%	% of the total length of the rail network in the NUTS3	This indicator shows the percentage of the total length of the rail network in the NUTS3 area that is located in areas that are susceptible to landslide hazard. This indicator and the supporting statistical data (the Z-Score) can be used to better understand whether exposure of the rail network to landslides is a significant issue for the NUTS3	The rail network was sourced from open street map (2017) and includes standard gauge rail, subways, trams and light rail segments of the network. These were intersected in ArcGIS 10.4 with the proportion of the NUTS3	Yes	Exposure

		area that is located in areas that show moderate (or higher) susceptibility to landslide	area. The key factor that influences landslide susceptibility is the presence of steep slopes. Others include bedrock and soil characteristics, deforestation and the presence of roads. Heavy rainfall can often trigger landslides. The typology portal includes an indicator on projected changes to the occurrence of very heavy rainfall days in NUTS3 areas.	area that shows moderate to higher susceptibility to landslide derived from NASA's Global Landslide Susceptibility Map (https://pmm.nasa.gov/precip-apps). The measure of rail infrastructure exposed to landslides was transformed into a rate based on the total length of rail infrastructure in the NUTS 3 area.		
Transport nodes exposed to fluvial flooding	%	% of total number of transport nodes in NUTS3 unit exposed to 1 in 100 year fluvial flood	Fluvial flooding occurs when watercourses (rivers, streams) overflow and inundate the surrounding area. This indicator shows the percentage of the total number of transport nodes in the NUTS3 area that would be exposed to flooding in the event of a 1 in 100 year fluvial flood. Transport nodes include tram, rail and bus stations, airports and ports. This indicator does not highlight specific transport nodes that would be affected in the event of a flood. Further, it does not account for flood defence infrastructure that may protect certain transport nodes. More localised flood risk assessments would therefore be needed to establish which transport nodes would be exposed if a 1 in 100 year fluvial flood occurred. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether fluvial flooding to transport nodes is a significant issue for the NUTS3 area.	Transport nodes were derived from Open Street Map (2017) and included 'airports', 'bus stations', 'bus steps' ferry terminals' 'railway stations/halts' and 'tram stops'. These were intersected with the Joint Research Council's (JRC) depiction of flood prone areas in Europe for flood events with 100-year return period in which cell values indicate water depth (in m). The measure of transport nodes exposed to fluvial flooding was transformed into a rate based on the total number of transport nodes in the NUTS 3 area.	Yes	Exposure
Transport nodes exposed to coastal hazards	%	% of total transport nodes in NUTS3 unit exposed to a 1 in 100 year coastal storm surge and 1 meter sea level rise	This indicator shows the percentage of the total number of transport nodes in the NUTS3 area that are located in areas that are potentially exposed to coastal hazards. Coastal hazards include sea level rise (1 metre above current levels) and susceptibility to storm surge. Transport nodes include tram, rail and bus stations, airports and ports. This indicator does not highlight the specific transport nodes that would be affected should these coastal hazards occur. Further, it does not account for defences that may protect certain transport nodes from coastal hazards. More localised flood risk assessments would therefore be needed to establish which specific transport nodes would be exposed in the event of coastal hazards occurring. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether the exposure of transport nodes to coastal hazards is a significant issue for the NUTS3 area.	Transport nodes were derived from Open Street Map (2017) and included 'airports', 'bus stations', 'bus steps' ferry terminals' 'railway stations/halts' and 'tram stops'. The intersections were intersected with the 1 metre sea level rise inundation area defined by CReSIS (www.cresis.ku.edu/content/research/maps). Transport nodes were intersected in ArcGIS Network Analyst using open street map road data (2017). The road network was intersected with the 1 metre sea level rise inundation area defined by CReSIS (www.cresis.ku.edu/content/research/maps). GTSR (Global Tide and Surge Reanalysis) is an analysis of storm surges and extreme sea-levels based on hydrodynamic modelling (Muis et al, 2016). GTSR covers the entire world's coastline and provides estimates of extreme sea-levels values based on the period 1979-2014. The dataset is based on the application of two global hydrodynamic models: GTSM to simulate storm surges [Verlaan et al., 2015], and FES2012 to simulate tides [Carrere et al. 2012]. Surge levels were modelled by forcing GTSM with 10 mps wind speed and atmospheric pressure from the ERA-Interim climate reanalysis [Dee et al., 2011]. Total water levels are calculated by superimposing tides and	Yes	Exposure

				surges. The 1-in-100 year sea level was estimated by fitting a Gumbel extreme value distribution to the annual maxima. The water levels included over 12,000 locations along the coastline defined as a centroid of the DIVA segments database. The measure of transport nodes exposed to coastal flooding was transformed into a rate based on the total number of transport nodes in the NUTS 3 area.		
Transport nodes exposed to landslide	%	% of total number of transport nodes in NUTS3 area located in areas that show moderate (or higher) susceptibility to landslide	This indicator shows the percentage of the total number of transport nodes in the NUTS3 area that are located in areas that are susceptible to landslide hazard. Transport nodes include tram, rail and bus stations, airports and ports. This indicator and the supporting statistical data (the Z-Score) can be used to better understand whether exposure of transport nodes to landslides is a significant issue for the NUTS3 area. The key factor that influences landslide susceptibility is the presence of steep slopes. Others include bedrock and soil characteristics, deforestation and the presence of roads. Heavy rainfall can often trigger landslides. The typology portal includes an indicator on projected changes to the occurrence of very heavy rainfall days in NUTS3 areas.	Transport nodes were derived from Open Street Map (2017) and included 'airports', 'bus stations', 'bus steps' ferry terminals' 'railway stations/halts' and 'tram stops'. These were intersected in ArcGIS 10.4 with the proportion of the NUTS3 area that shows moderate to higher susceptibility to landslide derived from NASA's Global Landslide Susceptibility Map (https://pmm.nasa.gov/precip-apps). The measure of transport nodes exposed to landslides was transformed into a rate based on the total number of transport nodes in the NUTS 3 area.	Yes	Exposure
Airports exposed to fluvial flooding	%	% of total number of airports in NUTS3 unit exposed to 1 in 100 year fluvial flood	Fluvial flooding occurs when watercourses (rivers, streams) overflow and inundate the surrounding area. This indicator shows the percentage of the total number of airports in the NUTS3 area that would be exposed to flooding in the event of a 1 in 100 year fluvial flood. This indicator does not highlight specific airports that would be affected in the event of a flood. Further, it does not account for flood defence infrastructure that may protect certain airports. More localised flood risk assessments would therefore be needed to establish which airports would be exposed if a 1 in 100 year fluvial flood occurred. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether fluvial flooding to airports is a significant issue for the NUTS3 area.	Airport nodes were sourced from the GISCO repository (Eurostat 2013). The nodes were intersected with the Joint Research Council's (JRC) depiction of flood prone areas in Europe for flood events with 100-year return period in which cell values indicate water depth (in m). The measure of airports exposed to fluvial flooding was transformed into a rate based on the total number of airports in the NUTS 3 area.	No	Exposure
Airports exposed to coastal hazards	%	% of total number of airports in NUTS3 unit exposed to a 1 in 100 year coastal storm surge and 1 meter sea level rise	This indicator shows the percentage of the total number of airports in the NUTS3 area that are located in areas that are potentially exposed to coastal hazards. Coastal hazards include sea level rise (1 metre above current levels) and susceptibility to storm surge. This indicator does not highlight the specific airports that would be affected should these coastal hazards occur. Further, it does not account for defences that may protect certain airports from coastal hazards. More localised flood risk assessments would therefore be needed to establish which specific airports would be exposed in the event of coastal hazards occurring. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether the exposure of airports to coastal hazards is a significant issue for the NUTS3 area.	Airport nodes were sourced from the GISCO repository (Eurostat 2013). The nodes were intersected with the 1 metre sea level rise inundation area defined by CReSIS (www.cresis.ku.edu/content/research/maps). GTSR (Global Tide and Surge Reanalysis) is an analysis of storm surges and extreme sea-levels based on hydrodynamic modelling (Muis et al, 2016). GTSR covers the entire world's coastline and provides estimates of extreme sea-levels values based on the period 1979-2014. The dataset is based on the application of two global hydrodynamic models: GTSM to simulate storm surges [Verlaan et al., 2015], and FES2012 to simulate tides [Carrere et al. 2012]. Surge levels were modelled by forcing GTSM with 10 mps wind speed	No	Exposure

				and atmospheric pressure from the ERA-Interim climate reanalysis [Dee et al., 2011]. Total water levels are calculated by superimposing tides and surges. The 1-in-100 year sea level was estimated by fitting a Gumbel extreme value distribution to the annual maxima. The water levels included over 12,000 locations along the coastline defined as a centroid of the DIVA segments database. The measure of airports exposed to coastal flooding was transformed into a rate based on the total number of airports in the NUTS 3 area.		
Airports exposed to landslide	%	% of total number of airports in NUTS3 unit located in areas that show moderate (or higher) susceptibility to landslide	This indicator shows the percentage of the total number airports in the NUTS3 area that are located in areas that are susceptible to landslide hazard. This indicator and the supporting statistical data (the Z-Score) can be used to better understand whether exposure of airports to landslides is a significant issue for the NUTS3 area. The key factor that influences landslide susceptibility is the presence of steep slopes. Others include bedrock and soil characteristics, deforestation and the presence of roads. Heavy rainfall can often trigger landslides. The typology portal includes an indicator on projected changes to the occurrence of very heavy rainfall days in NUTS3 areas.	Airport nodes were sourced from the GISCO repository (Eurostat 2013). These were intersected in ArcGIS 10.4 with the proportion of the NUTS3 area that shows moderate to higher susceptibility to landslide derived from NASA's Global Landslide Susceptibility Map (https://pmm.nasa.gov/precip-apps). The measure of airports exposed to landslides was transformed into a rate based on the total number of airports in the NUTS 3 area.	No	Exposure
Power plants exposed to fluvial flooding	%	% of total number of power plants in NUTS3 unit exposed to 1 in 100 year fluvial flood	Fluvial flooding occurs when watercourses (rivers, streams) overflow and inundate the surrounding area. This indicator shows the percentage of the total number of power plants in the NUTS3 area that would be exposed to flooding in the event of a 1 in 100 year fluvial flood. This indicator does not highlight specific power plants that would be affected in the event of a flood. Further, it does not account for flood defence infrastructure that may protect certain power plants. More localised flood risk assessments would therefore be needed to establish which power plants would be exposed if a 1 in 100 year fluvial flood occurred. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether fluvial flooding to power plants is a significant issue for the NUTS3 area.	Power plant facility locations were sourced from Enipedia, (open street map) and does not distinguish between different types of power generation (e.g. coal, renewable). The powerplants were intersected with the Joint Research Council's (JRC) depiction of flood prone areas in Europe for flood events with 100-year return period in which cell values indicate water depth (in m). The measure of powerplants exposed to fluvial flooding was transformed into a rate based on the total number of plants in the NUTS 3 area.	No	Exposure
Power plants exposed to coastal hazards	%	% of total number of power plants in NUTS3 unit exposed to a 1 in 100 year coastal storm surge and 1 meter sea level rise	This indicator shows the percentage of the total number of power plants in the NUTS3 area that are located in areas that are potentially exposed to coastal hazards. Coastal hazards include sea level rise (1 metre above current levels) and susceptibility to storm surge. This indicator does not highlight the specific power plants that would be affected should these coastal hazards occur. Further, it does not account for defences that may protect certain power plants from coastal hazards. More localised flood risk assessments would therefore be needed to establish which specific power plants would be exposed in the event of coastal hazards occurring. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether the exposure of power plants to coastal hazards is a significant issue for the NUTS3 area.	Power plant facility locations were sourced from Enipedia, (open street map) and does not distinguish between different types of power generation (e.g. coal, renewable). The nodes were intersected with the 1 metre sea level rise inundation area defined by CReSIS (www.cresis.ku.edu/content/research/maps). GTSR (Global Tide and Surge Reanalysis) is an analysis of storm surges and extreme sea-levels based on hydrodynamic modelling (Muis et al, 2016). GTSR covers the entire world's coastline and provides estimates of extreme sea-levels values based on the period 1979-2014. The dataset is based on the application of two global hydrodynamic	No	Exposure

				models: GTSM to simulate storm surges [Verlaan et al., 2015], and FES2012 to simulate tides [Carrere et al. 2012]. Surge levels were modelled by forcing GTSM with 10 mps wind speed and atmospheric pressure from the ERA-Interim climate reanalysis [Dee et al., 2011]. Total water levels are calculated by superimposing tides and surges. The 1-in-100 year sea level was estimated by fitting a Gumbel extreme value distribution to the annual maxima. The water levels included over 12,000 locations along the coastline defined as a centroid of the DIVA segments database. The measure of powerplants exposed to coastal flooding was transformed into a rate based on the total number of plants in the NUTS 3 area.		
Power plants exposed to landslide	%	% of total number of power plants in NUTS3 unit located in areas that show moderate (or higher) susceptibility to landslide	This indicator shows the percentage of the total number of power plants in the NUTS3 area that are located in areas that are susceptible to landslide hazard. This indicator and the supporting statistical data (the Z-Score) can be used to better understand whether exposure of power plants to landslides is a significant issue for the NUTS3 area. The key factor that influences landslide susceptibility is the presence of steep slopes. Others include bedrock and soil characteristics, deforestation and the presence of roads. Heavy rainfall can often trigger landslides. The typology portal includes an indicator on projected changes to the occurrence of very heavy rainfall days in NUTS3 areas.	Power plant facility locations were sourced from Enipedia, (open street map) and does not distinguish between different types of power generation (e.g. coal, renewable). These were intersected in ArcGIS 10.4 with the proportion of the NUTS3 area that shows moderate to higher susceptibility to landslide derived from NASA's Global Landslide Susceptibility Map (https://pmm.nasa.gov/precip-apps). The measure of powerplants exposed to landslides was transformed into a rate based on the total number of plants in the NUTS 3 area.	No	Exposure
Ports exposed to fluvial flooding	%	% of total number of ports in the NUTS3 unit exposed to 1 in 100 year fluvial flood	Fluvial flooding occurs when watercourses (rivers, streams) overflow and inundate the surrounding area. This indicator shows the percentage of the total number of ports in the NUTS3 area that would be exposed to flooding in the event of a 1 in 100 year fluvial flood. This indicator does not highlight specific ports that would be affected in the event of a flood. Further, it does not account for flood defence infrastructure that may protect certain ports. More localised flood risk assessments would therefore be needed to establish which ports would be exposed if a 1 in 100 year fluvial flood occurred. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether fluvial flooding to ports is a significant issue for the NUTS3 area.	Port nodes were sourced from the GISCO repository (Eurostat 2013). The nodes were intersected with the Joint Research Council's (JRC) depiction of flood prone areas in Europe for flood events with 100-year return period in which cell values indicate water depth (in m). The measure of ports exposed to fluvial flooding was transformed into a rate based on the total number of ports in the NUTS 3 area.	No	Exposure
Ports exposed to coastal hazards	%	% of total number of ports in the NUTS3 unit exposed to a 1 in 100 year coastal storm surge and 1 meter sea level rise	This indicator shows the percentage of the total number of ports in the NUTS3 area that are located in areas that are potentially exposed to coastal hazards. Coastal hazards include sea level rise (1 metre above current levels) and susceptibility to storm surge. This indicator does not highlight the specific ports that would be affected should these coastal hazards occur. Further, it does not account for defences that may protect certain ports from coastal hazards. More localised flood risk assessments would therefore be needed to establish which specific ports would be exposed in the event of coastal hazards occurring. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether the exposure of ports to coastal hazards is a significant issue for the NUTS3 area.	Port nodes were sourced from the GISCO repository (Eurostat 2013). The nodes were intersected with the 1 metre sea level rise inundation area defined by CReSIS (www.cresis.ku.edu/content/research/maps). GTSR (Global Tide and Surge Reanalysis) is an analysis of storm surges and extreme sea-levels based on hydrodynamic modelling (Muis et al, 2016). GTSR covers the entire world's coastline and provides estimates of extreme sea-levels values based on the period 1979-2014. The dataset is based on the application of	No	Exposure

				two global hydrodynamic models: GTSM to simulate storm surges [Verlaan et al., 2015], and FES2012 to simulate tides [Carrere et al. 2012]. Surge levels were modelled by forcing GTSM with 10 mps wind speed and atmospheric pressure from the ERA-Interim climate reanalysis [Dee et al., 2011]. Total water levels are calculated by superimposing tides and surges. The 1-in-100 year sea level was estimated by fitting a Gumbel extreme value distribution to the annual maxima. The water levels included over 12,000 locations along the coastline defined as a centroid of the DIVA segments database. The measure of ports exposed to coastal flooding was transformed into a rate based on the total number of ports in the NUTS 3 area.		
Ports exposed to landslide	%	% of total number of ports in NUTS3 unit located in areas that show moderate (or higher) susceptibility to landslide	This indicator shows the percentage of the total number of ports in the NUTS3 area that are located in areas that are susceptible to landslide hazard. This indicator and the supporting statistical data (the Z-Score) can be used to better understand whether exposure of ports to landslides is a significant issue for the NUTS3 area. The key factor that influences landslide susceptibility is the presence of steep slopes. Others include bedrock and soil characteristics, deforestation and the presence of roads. Heavy rainfall can often trigger landslides. The typology portal includes an indicator on projected changes to the occurrence of very heavy rainfall days in NUTS3 areas.	Port nodes were sourced from the GISCO repository (Eurostat 2013). These were intersected in ArcGIS 10.4 with the proportion of the NUTS3 area that shows moderate to higher susceptibility to landslide derived from NASA's Global Landslide Susceptibility Map (https://pmm.nasa.gov/precip-apps). The measure of ports exposed to landslides was transformed into a rate based on the total number of ports in the NUTS 3 area.	No	Exposure
Hospitals exposed to fluvial flooding	%	% total number of hospitals in the NUTS3 unit exposed to 1 in 100 year fluvial flood	Fluvial flooding occurs when watercourses (rivers, streams) overflow and inundate the surrounding area. This indicator shows the percentage of the total number of hospitals in the NUTS3 area that would be exposed to flooding in the event of a 1 in 100 year fluvial flood. This indicator does not highlight specific hospitals that would be affected in the event of a flood. Further, it does not account for flood defence infrastructure that may protect certain hospitals. More localised flood risk assessments would therefore be needed to establish which hospitals would be exposed if a 1 in 100 year fluvial flood occurred. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether fluvial flooding to hospitals is a significant issue for the NUTS3 area.	Hospital locations were sourced from open street map (2017) as 'points of interest'. The hospitals were intersected with the Joint Research Council's (JRC) depiction of flood prone areas in Europe for flood events with 100-year return period in which cell values indicate water depth (in m). The measure of hospitals exposed to fluvial flooding was transformed into a rate based on the total number of hospitals in the NUTS 3 area.	No	Exposure
Hospitals exposed to coastal hazards	%	% total number of hospitals in the NUTS3 unit exposed to a 1 in 100 year coastal storm surge and 1 meter sea level rise	This indicator shows the percentage of the total number of hospitals in the NUTS3 area that are located in areas that are potentially exposed to coastal hazards. Coastal hazards include sea level rise (1 metre above current levels) and susceptibility to storm surge. This indicator does not highlight the specific hospitals that would be affected should these coastal hazards occur. Further, it does not account for defences that may protect certain hospitals from coastal hazards. More localised flood risk assessments would therefore be needed to establish which specific hospitals would be exposed in the event of coastal hazards occurring. Nevertheless, this indicator and the supporting statistical data (the Z-Score) can be used to better understand whether the exposure of hospitals to coastal hazards is a significant issue for the NUTS3 area.	Hospital locations were sourced from open street map (2017) as 'points of interest'. The nodes were intersected with the 1 metre sea level rise inundation area defined by CReSIS (www.cresis.ku.edu/content/research/maps). GTSR (Global Tide and Surge Reanalysis) is an analysis of storm surges and extreme sea-levels based on hydrodynamic modelling (Muis et al, 2016). GTSR covers the entire world's coastline and provides estimates of extreme sea-levels values based on the period 1979-2014. The dataset is based on the application of two global hydrodynamic	No	Exposure

				models: GTSM to simulate storm surges [Verlaan et al., 2015], and FES2012 to simulate tides [Carrere et al. 2012]. Surge levels were modelled by forcing GTSM with 10 mps wind speed and atmospheric pressure from the ERA-Interim climate reanalysis [Dee et al., 2011]. Total water levels are calculated by superimposing tides and surges. The 1-in-100 year sea level was estimated by fitting a Gumbel extreme value distribution to the annual maxima. The water levels included over 12,000 locations along the coastline defined as a centroid of the DIVA segments database. The measure of hospitals exposed to coastal flooding was transformed into a rate based on the total number of hospitals in the NUTS 3 area.		
Hospitals exposed to landslide	%	% of total number of hospitals in NUTS3 unit located in areas that show moderate (or higher) susceptibility to landslide	This indicator shows the percentage of the total number of hospitals in the NUTS3 area that are located in areas that are susceptible to landslide hazard. This indicator and the supporting statistical data (the Z-Score) can be used to better understand whether exposure of hospitals to landslides is a significant issue for the NUTS3 area. The key factor that influences landslide susceptibility is the presence of steep slopes. Others include bedrock and soil characteristics, deforestation and the presence of roads. Heavy rainfall can often trigger landslides. The typology portal includes an indicator on projected changes to the occurrence of very heavy rainfall days in NUTS3 areas.	Hospital locations were sourced from open street map (2017) as 'points of interest'. These were intersected in ArcGIS 10.4 with the proportion of the NUTS3 area that shows moderate to higher susceptibility to landslide derived from NASA's Global Landslide Susceptibility Map (https://pmm.nasa.gov/precip-apps). The measure of hospitals exposed to landslides was transformed into a rate based on the total number of hospitals in the NUTS 3 area.	No	Exposure
Population density	Ratio	Total population living in urban areas /area in km2	This indicator shows the ratio of numbers of people per kilometre in a given NUTS3 area as a measure of population density. Population density measures the concentration of individuals living in a particular spatial unit. Population density may be considered in tandem with hazard indicators relating to temperature and heatwaves as population density (which can be used as a proxy for the density of the built environment) may indicate more intense urban heat island effects (Swart et al. 2012). On the other hand, where dense urban populations are supported by good infrastructure and resources, their climate resilience may be increased (Blake et al. 2011)	This indicator was derived by intersecting 1km GEOSTAT population grids (https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat) with 1km GHS settlement grids (https://ghsl.jrc.ec.europa.eu/ghs_smod.php) in ARCGIS 10.4 to derive a measure of population living in settlements.	No	Vulnerability - Sensitivity
Change in population density	%	% change in population density in NUTS3 unit between 2017-2050	This indicator shows the percentage change in population density (number of people/area (km) in a given NUTS3 unit between 2017 and 2050. Increasing population and density will interact with the effects of climate change and may render a NUTS 3 region more sensitive to the effects of climate change. For example, increased density may interact with high temperatures to increase the urban heat island (UHI) effect. Increased population may put pressure on resources in order to devise strategies for dealing with the effects of climate change.	Change in NUTS 3 population was calculated based on projections of total population sourced from Eurostat (proj_13rpms3). This was used to calculate a NUTS 3 level density measure for 2017 and 2050 which was then used to calculate change in population density of NUTS3 areas between over the period. N.B. There was missing data for this indicator which was addressed via an areal interpolation approach (see sections 3.1.3 and 3.1.4).	No	Vulnerability - Sensitivity
Migratory population change	%	% change in population through migration in NUTS3	This indicator shows the percentage change in population through migration in NUTS3 unit between 2017-2050. Areas with diverse populations have been shown to be spatially coincidental with areas of surface water flooding in certain cities where diversity was comprised of	Change in NUTS 3 population owing to migration was calculated based on projections of migration-based population change sourced from Eurostat (proj_13rdbims3). N.B. There	Yes	Vulnerability - Sensitivity

		unit between 2017-2050	ethnic minorities, private rental and population density (Kazmierczak and Cavan 2011). There have also been a limited number of studies that have examined the interaction between linguistaclly diverse communities and increased impacts from extreme weather events (e.g. Yardley et al. 2011; Hansen et al. 2013). There is, therefore, some debate in the literature over the extent to which a population with a high number of recent migrants may indicate increased sensitivity to extreme weather events and climate change (e.g. Cutter 2003; Tapia et al. 2015). Decreases in migration, when combined with other population indicators such as age, may indicate that there is an aging population.	was missing data for this indicator which was addressed via an areal interpolation approach (see sections 3.1.3 and 3.1.4).		
Population change – children	%	% change in population less than 15 years in NUTS3 unit between 2017-2050	This indicator show projected change in population less than 15 years as a percentage between 2017 and 2050. This indicator could be considered in the context of heat and flood indicators. Children and babies may be more sensitive during heat waves but there is less evidence about the significance of child deaths during heat waves (Swart et al. 2012). Children are also emotionally impacted upon after a flood and may lose out due to instable place of residence and education (Walker et al. 2010; Mallett & Etzel 2018). Additionally, this indicator may be considered alongside Projected Change in Population over 70 in terms of understanding the age-dependency. For example, if there is a projected decrease in the younger population combined with a projected increase in the older population, there may be differential effects in terms of the impacts of climate change e.g. more sensitivity to heat (ESPON 2011).	Change in NUTS 3 population under 15 years was calculated based on projections of population change sourced from Eurostat (proj_13rdbims3). N.B. There was missing data for this indicator which was addressed via an areal interpolation approach (see sections 3.1.3 and 3.1.4).	Yes	Vulnerability - Sensitivity
Population change in older people	%	% change in population more than 70 years in NUTS3 unit between 2017-2050	This indicator shows projected change in population more than 70 years as a percentage between 2017 and 2050. The relationship between age and heatwaves is well-evidenced. It has been found that even a 1°C increase in temperature can negatively affect the mortality of older people (Bunker et al. 2016) and over 70, 000 excess deaths in the 2003 European heatwave where age distribution affected mortality (Robine et al. 2009). This association has been demonstrated in several climatic contexts such as Sweden (Rocklöv & Forsberg 2009), Russia (Barriopedro et al. 2011), France (La Tertre et al. 2006) There are a number of reasons for this. There are several reasons for this. Older people, for example, may have pre-existing health conditions which heighten their vulnerability during a heatwave, particularly respiratory conditions (Kovats & Kristie 2006; Rocklöv & Forsberg 2009). Older people may also be socially isolated which can additionally heighten their vulnerability to heatwaves (Toulemon and Barbieri 2008; Semenza et al., 1996, 1999). That said, there is some discrepancy over the precise age when, for example, mortality during a heatwave begins to be significant. For example, Kovats and Hajat (2006, cited in Swart et al. 2012) found that mortality was pronounced in the over-75's and not significant between 65 and 74. Similarly, older people are more sensitive to the effects of flooding due to a number of reasons (Tapsell et al. 2002). Often, they are socially isolated or tend to live in properties that are sensitive to floods. For this reason, old age is often correlated with increased sensitivity to flood (see Green et al. 1994; Climate Just 2014). However, this relationship has been shown to be pronounced in rural, coastal areas (Oven et al. 2012). This means that older age is a high confidence indicator across a range of hazards. That said, there is some discrepancy over the precise age when, for example, mortality during a heatwave begins to be significant. For example, Kovats and Hajat (2006, cited in Swart et al. 2012) found that mortality was pronounced in the over-75's and not	Change in NUTS 3 population aged 70 years and over was calculated based on projections of population change sourced from Eurostat (proj_13rdbims3). N.B. There was missing data for this indicator which was addressed via an areal interpolation approach (see sections 3.1.3 and 3.1.4).	Yes	Vulnerability - Sensitivity

			significant between 65 and 74. Owing to data availability, this indicator shows over-70s.			
Employment-population balance	%	% of total employment in NUTS1 unit	This indicator shows the employment-population balance. The ratio of jobs to people can be an important indication of economic concerns within an area. When thinking about the way that the employment-population balance works in a given area, there may be particular interactions with climate resilience. For example, where there are more jobs than people (e.g. central London) this may indicate a high number of commuters, which may put pressure on a city's resources, particularly its transport infrastructure, to deal with extreme weather events. In addition, there may be issues with getting supporting people to fill vacant jobs (e.g. in a hospital) during an extreme weather event when existing staff cannot travel (Description to be enhanced in the future).	This indicator was calculated as total employment in the NUTS 3 area as a percentage of in the NUTS1 unit in which it falls (nama_10r_3empers). The data was missing for Switzerland so the economic activity rate of the permanent resident population aged 15 and above by canton, in 2016 (T 40.02.03.02.03) was used.	Yes	Vulnerability - Adaptive Capacity
Length of major road networks	Km	Length of major road network in NUTS3 unit	This indicator shows the length of major road network in kilometres in a NUTS3 unit. Major roads are defined as 'highways' and include 'motorway', 'trunk', 'primary', 'secondary' and 'tertiary' segments of the network. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality. Where road length is higher than average in a NUTS 3 area, this may signal that there is redundancy in the road network and alternative routes can be found. This is also important from an emergency management point of view as during an extreme event, alternative means of providing key services and moving people may be found.	The road network was sourced from open street map (2017). Major roads are defined as 'Highways' and include 'motorway', 'trunk', 'primary', 'secondary' and 'tertiary' segments of the network.	Yes	Vulnerability - Adaptive Capacity
Length of railway network	Km	Length of railway network in NUTS3 unit	Length of railway network in NUTS3 unit. The rail network was sourced from open street map (2017) and includes standard gauge rail, subways, trams and light rail segments of the network. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality. Where rail length is higher than average in a NUTS 3 area, this may signal that there is redundancy in the rail network and alternative routes can be found. This is also important from an emergency management point of view as during an extreme event, alternative means of providing key services and moving people may be found.	The rail network was sourced from open street map (2017) and includes standard gauge rail, subways, trams and light rail segments of the network.	Yes	Vulnerability - Adaptive Capacity
Density of major road intersections	Ratio	Density of major road intersections per km2 of the NUTS3 unit	This indicator shows the density of major road intersections per km2 of the NUTS3 unit. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality. Where there are more road intersections than the EU average in a NUTS 3 area, this may signal that there is redundancy in the road network and alternative routes can be found. This is also important from an emergency management point of view as during an extreme event, alternative means of providing key services and moving people may be found.	Major roads are defined as 'Highways' and include 'motorway', 'trunk', 'primary', 'secondary' and 'tertiary' segments of the network. The intersections are calculated in ArcGIS Network Analyst using open street map road data (2017).	Yes	Vulnerability - Adaptive Capacity
Density of transport nodes	Ratio	Density of transport nodes per km2 of the NUTS3 unit	This indicator shows the density of transport nodes per km2 of the NUTS3 unit. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality. Where there are more transport nodes than the EU average in a NUTS 3 area, this may signal that there is redundancy in the overall transport network and alternative routes/modes of travel can be found.	Transport nodes were derived from Open Street Map (2017) and included 'airports', 'bus stations', 'bus steps' ferry terminals' 'railway stations/halts' and 'tram stops'. Taxis, airports and ports were excluded here.	Yes	Vulnerability - Adaptive Capacity

			This is also important from an emergency management point of view as during an extreme event, alternative means of providing key services and moving people may be found.			
Airports per head of the population	Ratio	Number of airports per head of population in the NUTS3 unit	This indicator shows the number of airports per head of population in the NUTS3 unit. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality. Where there are more transport nodes than the EU average in a NUTS 3 area, this may signal that other airports can help to provide alternative routes/modes of travel. This is also important from an emergency management point of view as during an extreme event, alternative means of providing key services and moving people may be found.	Airport nodes were sourced from the GISCO repository (Eurostat 2013). These were weighted by population data sourced from EUROSTAT (demo_r_d3dens).	Yes	Vulnerability - Adaptive Capacity
Ports per head of the population	Ratio	Number of ports per head of population in the NUTS3 unit	This indicator shows the number of ports per head of population in the NUTS3 unit. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality. Where there are more ports than the EU average in a NUTS 3 area, this may signal that there is redundancy and alternative routes/methods of moving goods around can be found.	Port nodes were sourced from the GISCO repository (Eurostat 2013). These were weighted by population data sourced from EUROSTAT (demo_r_d3dens).	Yes	Vulnerability - Adaptive Capacity
Hospital sites per head of the population	Ratio	Number of hospital sites per head of population in the NUTS3 unit	This indicator shows the number of hospital sites per head of population in the NUTS3 unit. The ability for the population to access hospitals and other medical units during an extreme weather event is of paramount importance. Where there are lower than average numbers of hospital sites per head of the population, this may indicate that an area will experience intense pressure in ensuring that the population receive necessary medical support during, for example, a flood or a heatwave.	Hospital site locations were sourced from open street map (2017). These were weighted by population data sourced from EUROSTAT (demo_r_d3dens).	Yes	Vulnerability - Adaptive Capacity
Number of powerplants per head of the population	Ratio	Number of power plants per head of population in the NUTS3 unit	This indicator shows the power plants per head of population in the NUTS3 unit. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality. If there are more powerplants in a NUTS3 area than the EU average, this may mean that alternative ways of providing energy to a given population may be found.	Power plant facility locations were sourced from Enipedia and does not distinguish between different types of power generation (e.g. coal, renewable). These were weighted by population data sourced from EUROSTAT (demo_r_d3dens).	Yes	Vulnerability - Adaptive Capacity
Fixed broadband coverage	%	Fixed broadband coverage	This indicator shows fixed broadband coverage. This indicator is a measure of adaptive capacity since social media is becoming an increasingly common way of sharing risk information and warnings, as well as assisting in the recovery process during an extreme weather event. Therefore, access to decent broadband is important in order to support the adaptive capacity of a given area. There may be more locally specific measures available that will give a greater insight into what this indicator is measuring e.g. % of population with access to a smart phone, and so on. Definitions of fixed broadband used here are as follows: - A household has DSL coverage if it is a telephone exchange area fully enabled for DSL. - A household has VDSL coverage if it is close enough to a VDSL-enabled cabinet or exchange to get a high-speed broadband signal. - A household has FTTP coverage if it can be connected now to a fibre service without requiring the construction of new fibre infrastructure. - A household has WiMAX coverage for broadband if it can receive at least 2Mbps downstream from	This is a measure of the coverage of overall fixed broadband according to country/technology definitions at NUTS 3 level. The measure of fixed broadband was transformed into a rate based on the total number of households in the NUTS 3 area.	Yes	Vulnerability - Adaptive Capacity

			an existing service without requiring the construction of new WiMAX infrastructure. - A household has cable modem coverage if it can be connected now to a broadband service without requiring the construction of new cable TV network infrastructure. - A household has DOCSIS 3.0 coverage if it can be connected now to a DOCSIS 3.0 service.				
Next Generation Access (NGA) - broadband	%	Next Generation Access (NGA) - broadband	This indicator shows Next Generation Access (NGA) provision which has been sourced from Point Topic's European Broadband Markets Service. NGA represents access networks which consist wholly or in part of optical elements and which are capable of delivering broadband access services with enhanced characteristics (such as higher throughput) as compared to those provided over already existing copper networks. In most cases NGAs are the result of an upgrade of an already existing copper or co-axial access network .Next Generation Access (NGA) provision has been variable across Europe dependent on a country's need. Essentially NGA provides the infrastructure to allow superfast broadband speeds of up to 100MB. Increasing population densities, for example, are thought to indicate a need for faster broadband access in the future. Therefore, given the reliance on social media for weather, risk and crisis information, superfast broadband may increase an area's adaptive capacity. Low NGA provision may indicate that policies should be put in place to prioritise NGA provision in the future.	This is a measure of the coverage of overall next generation broadband according to country/technology definitions at NUTS 3 level. The measure of next generation broadband was transformed into a rate based on the total number of households in the NUTS 3 area.	No		
Patent applications to the EPO	Ratio	Number of patent applications to the EPO by priority year per 1000 population in the NUTS3 unit	This indicator shows the number of patent applications to the European Patent Office per 1000 population. Technology and innovation are important in helping a city to adapt to climate change e.g. investment in new flood technologies or building technologies that can help to mitigate heat. The ability of a country or urban area to invest in technological solutions, is thought to be an indicator of its adaptive capacity (ESPON 2011; Swart et al. 2012; Acosta et al. 2013). Therefore, number of patents per year is used as a proxy indicator reflecting this issue. Ideally, the availability of adaptation solutions would be a direct indicator; however, such data is not typically collected on a city-by-city basis.	The number of patents at NUTS 3 level was averaged from 2008 to 2012. This was defined as nominal GDP in billion euros. Using the total population in the NUTS 3 region in 2011, the EPO applications were weighted per 1000 people in the NUTS 3 unit (demo_r_d3dens). N.B. There was missing data for this indicator which was addressed via an areal interpolation approach (see sections 3.1.3 and 3.1.4).	Yes	Vulnerability - Adaptive Capacity	
Urban area classified as green space	%	% of total urban area in NUTS3 unit that is classified as green space (2012 data)	This indicator shows the percentage of total urban area in NUTS3 unit that is classified as green space (2012 data). There is robust evidence that green spaces, such as parks, trees and gardens, can help city's resilience to the effects of climate change and extreme weather events (EEA 2016). Green spaces can have a cooling effect during periods of hot temperatures. In addition, green spaces can help to infiltrate stormwater and potentially reduce the rate of water runoff during a precipitation event so that excess water does not reach the sewarage system. Therefore, the higher the percentage of green space, the higher an area's potential adaptive capacity might be. This indicator can also be considered alongside percentage total change in green space since an existing lack of green space, combined with a decreasing trend, may signal to city planners that more should be done in terms of increasing urban greening.	Derived from Corine (2012) landcover and defined as the total area of green space as a percentage of total urban area (km2). The indicator was derived using 1km GHS settlement grids (https://ghsl.jrc.ec.europa.eu/ghs_smod.php)	Yes	Vulnerability - Adaptive Capacity	
Priority allocation funding	%	Priority Allocations (Euros, 2013 - 2015)	This indicator refers to the amount of Euros received in a NUTS3 region as part of the priority allocations and expenditure on EU projects. This is a proxy indicator that may indicate increased levels of technology and innovation access which could enhance the adaptive capacity of a given NUTS3 area.	Derived according to total priority allocations in 2013 and 2014 in million euros per NUTS 3 area as a percentage of all allocations made over the period (EU regio) (http://ec.europa.eu/regional_policy/en/policy/evaluations/data-for-	Yes	Vulnerability - Adaptive Capacity	

				research/).			
GVA	Euro	GVA at basic prices per head of population (2012-2015 data)	Gross Value Added (GVA) is defined as output value at basic prices less intermediate consumption valued at purchasers' prices. GVA is calculated before consumption of fixed capital. The resources that a city has can be a good indicator of a city's sensitivity in terms of extreme weather events and climate change. If a city has a lower than average GVA, then it may have be more susceptible to damage from all types of extreme weather events. A city with low resources may not be able to adequately address climate change adaptation due to other pressures. he statistical data provided for this indicator (the Z-Score) can be used to better understand whether (lack of) resources is a potentially significant issue for the NUTS3 area.	GVA data was sourced from EUROSTAT (nama_10r_3gva) except Switzerland which was sourced from Knoema (https://knoema.com/nama_r_e3gdp/gross-domestic-product-gdp-at-current-market-prices-by-nuts-3-regions?geo=1027030-switzerland). N.B. There was missing data for this indicator which was addressed via an areal interpolation approach (see sections 3.1.3 and 3.1.4).	Yes	Vulnerability - Adaptive Capacity
Change in total green space	%	Change in % of total urban area in NUTS3 unit that is classified as green space (2009-2012 data)	This indicator shows the change in percentage of total urban area in NUTS3 unit that is classified as green space (2009-2012 data).There is robust evidence that green spaces can help city's resilience to the effects of climate change and extreme weather events (Swart et al. 2012). Green spaces can help to absorb runoff during a flood. Green spaces can also help to reduce temperature due to evapotranspiration effects. Therefore, this indicator should be considered alongside hazards relating to flood and heat. A decreasing trend in green space, compared to the European average, may indicate increased sensitivity to the effects of these hazards and may signal to city planners that more should be done in terms of increasing urban greening.	Change in Corine (2009-2012) green space area measured as percentage of total urban area (km2). The indicator was derived using 1km GHS settlement grids (https://ghsl.jrc.ec.europa.eu/ghs_smod.php)	Yes	Vulnerability - Adaptive Capacity
Urban Land cover	%	% of total land in the NUTS3 unit that is covered by continuous and/or discontinuous urban fabric (2012 data)	This indicator shows the built up urban area based on CORINE data. This includes continuous urban fabric (more than 80% of the land is covered by artificial surface cover), discontinuous urban fabric (where 50% - 80% of the land is covered by artificial surface cover) and industrial, commercial and transport units. There is robust evidence that the amount of artificial areas, such as buildings and other structures, intensifies heat and can exacerbate the urban heat island (UHI) effect (EEA 2012). This will make an area more sensitive to the effects of high temperatures and heatwaves	Corine (2012) continuous and discontinuous urban fabric as a percentage of total NUTS 3 area (km2). The indicator was derived using 1km GHS settlement grids (https://ghsl.jrc.ec.europa.eu/ghs_smod.php)	Yes	Vulnerability - Adaptive Capacity
Change in landcover	%	Change in % of total land in the NUTS3 unit that is covered by continuous and/or discontinuous urban fabric (2012 data)	This indicator shows the change in the % of the built up urban area based on CORINE data. This includes continuous urban fabric (more than 80% of the land is covered by artificial surface cover), discontinuous urban fabric (where 50% - 80% of the land is covered by artificial surface cover) and industrial, commercial and transport units. There is robust evidence that the amount of artificial areas, such as buildings and other structures, intensifies heat and can exacerbate the urban heat island (UHI) effect. This will make an area more sensitive to the effects of high temperatures and heatwaves. An increasing trend in built-up areas that is above the European average may indicate that a city is increasing in its sensitivity to high temperatures and heatwaves.	Change in Corine (2009-2012) continuous and discontinuous urban fabric as a percentage of total NUTS 3 area (km2). The indicator was derived using 1km GHS settlement grids (https://ghsl.jrc.ec.europa.eu/ghs_smod.php)	Yes	Vulnerability - Adaptive Capacity
Soil Moisture Stress	N°	Soil Moisture Stress	This indicator shows soil moisture stress which helps to measure sensitivity to drought. When soil moisture is depleted, e.g. through reduced precipitation, this lack of soil moisture inhibits the effective functioning of natural and managed ecosystems. The EEA use information on soil moisture content as a proxy for agricultural droughts (see Cammalleri and Vogt 2015). This indicator can be used in tandem with historic drought and projected water consumption in order	Raster layer sourced from the Joint Research Council's 'Water Portal'. The raster cells record the average number of days in a year on which soil moisture levels are not sufficient to meet the vegetation water demand at a 5x5km resolution.	Yes	Vulnerability - Sensitivity

			to give an overall sense of the risk of drought to a NUTS 3 region. If soil moisture stress is higher than the European average, then a NUTS 3 region may be more sensitive to drought.			
Water Consumption Pressure	N°	Water Consumption Pressure (2030)	This indicator shows future water consumption pressure in 2030. Drought occurs not only because of natural processes, but also because of pressures on the demand for water by users, e.g. households (EEA 2018). Water consumption can be increased by a number of factors including a dense population and a period of hot and dry weather. It is important to understand the potential water consumption pressure in order to understand the risk of drought (in combination with soil moisture stress and historic instances of drought. If water consumption is higher than the EU average, policy makers may want to consider 'softer' measures to reduce user demand in greater detail.	Raster layer sourced from the Joint Research Council's 'Water Portal'. The raster cells record the annual total consumptive water using a baseline land use projection for 2030 from the LUMP model. The resolution of the raster is 5x5km. It is measured as a unit of $mm/25km^2$.	Yes	Vulnerability - Sensitivity
At Risk of Poverty	%	At Risk of Poverty (ARoP)	This indicator shows those living in a household with an 'equivalised disposable income' below 60 % of the national median, after taxes and social transfers (ESPON 2013). This is the European definition of poverty. This indicator is a proxy for deprivation. Those living in deprived areas may be more sensitive to climate change because of poor accommodation and an inability to prepare for an extreme event e.g. lack of insurance (ClimateJust 2014)	This indicator is deprived form the Territorial Dimension of Poverty and Social Exclusion in Europe study (https://www.espon.eu/sites/default/files/attachments/TIPSE_Draft_Final_Report.pdf). The draws on the unadjusted at Risk of Poverty Rate composite TiPSE map based on before housing costs. The indicator was manually digitised to reflect the five ranges used in the TiPSE report.	Yes	Vulnerability - Sensitivity

Appendix 2: Prototype portal consultation

The typology portal consultation received a broad range of comments from consultees these are grouped around (1) Navigation (2) Understanding the data and (3) Using the portal in practice.

1. Navigation around the portal

The consultation gathered feedback on how users interacted with and navigated the portal. This included enquiring into the visual legibility of the interface (e.g. colour coding, labelling, overall organisation, accessibility) and the pathways followed by users (e.g. How do they navigate to particular parts of the portal? What are common routes and / or obstacles to using these routes?). Consultation input on this theme was used in order to improve the user experience of the portal.

2. Understanding the data contained within the portal

A key usability aspect of the portal concerned the presentation of data on the typology classes/sub-classes and supporting indicator data so that it makes sense to users. The consultation involved questions around terminology, language, typology titles and descriptions, data organisation and level of detail. Consultation input on this theme helped to strengthen the approach to the presentation and interpretation of the data on the portal.

3. Using the portal in practice

Beyond the usability of the portal and the clarity of the data contained within it, we were interested in identifying potential applications of the typology and its supporting portal in practice. The consultation opened a wider discussion with stakeholders around how the portal could inform their work and who else may be able to benefit from using the typology. Here the aim was to gain input help improve the impact and future legacy of the typology beyond the end of the RESIN project.

Theme	Issues	Suggested improvements	Comments and responses
Navigation	Class descriptions need to be more appealing and readable.	• Highlight the main indicators that of each class in bold font • Separate the text into smaller sections with sub-headings • Use bullet points • Add pictures to visualize the hazards • Give examples of what hazards look like	• Key words of classes will be given when user hovers over the title. • The information button will provide details of highlighted keywords • Finding images would be too difficult for every class as it may detract from the detailed description and reduce the characterization.
Navigation	The selection and de-selection of regions is not intuitive	• Have a tutorial message to indicate that region will stick • Provide a more intuitive way to deselect e.g. by clicking on another region	• Issue to be addressed in new interaction flow. • Clicking on the map after selecting a region will select new region
Navigation	Map appearance, colours, and base map selection	• Option to turn on and off labels, eg the names of the NUTS (depending of the zoom) • Provide clearer country borders to help identify regions • Colour gradation is potentially misleading and, in some cases, hard to distinguish.	• The existing base maps are the most intuitive to import • Previous research indicates the value of different colours on maps • Colour choice somewhat constrained by the number of classes and the number of colours distinguishable to the naked eye.
Navigation	Different user starting points e.g. class vs one NUTS3 region Difficulty in finding classes and sub-classes.	• Ensure a tutorial provides the user with training examples to get started. • Map the classes only once a class is selected. • Ensure that it is easy to select a region and then select the class to see where the region fits in.	• Decided to have the landing page as a map as this is a good way to draw users in. • Difficulty in finding classes will be addressed by new layout with list of classes immediately available
Navigation	Finding descriptive information about classs and indicators is not intuitive	• Indicators: description window should appear when you go over the names, not the number • Class: information should be provided by clicking on the class name	• Numbers have been removed from indicator list • Hovering over the class name will provide a short summary. Clicking on the side '?' will provide more details. • Indicator and class view aligned with same navigation
Navigation	Difficult to identify region for people with less geographical experience	Include search field for region	• Users will be able to select specific cities or highlight urbanised NUTS3 regions.
Navigation	Separation of indicators and group information	Put the radial diagrams in the same place as the indicators and class names.	• The interface has changed to ensure that information is more integrated.
Navigation	Interface comments	Various interface comments were made on the prototype version to revise bugs.	• All bugs have been addressed • A new action flow has been created where hovering shows information. • The right hand side panel will remain open.
Navigation	Map interface	• Buttons related to map visualisation need to be separated from content-related buttons	• Addressed through change in layout. • All visualisation tabs moved onto map

		• Separate the tabs in different boxes with headers e. g how map is displayed, detailed info	
Navigation	Landing page	• Provide a separate landing page with an image of the map rather than the map itself. • This could stop users from only focusing on their region.	• This remains under consideration.
Navigation	Difficulty reading general text pages.	• Highlight some words within the text • Change typography, colours, and sizes • Use bullet points with links or collapsed menus for more info	• Testing versions were holding pages only. • All text editing and stylistic comments will be addressed. • Current sub-headings to be rephrased as questions (e.g. 'What can the typology do?')
Navigation	User tutorial is needed	• Provide a separate user tutorial • Provide text bubbles to show through a potential flow.	• A series of tool tips will be displayed when the map is first accessed. • Create a tutorial. Include both a help button to return to the tutorial, and also the option to skip it
Navigation	Consider potential need for translation	Keep the level of text relatively low	This is not feasible. Text pages could be translated but not the map interface.
Navigation	Constraints on certain browsers and use on mobile devices and tablets.	User constraints need to be explicitly stated up-front.	Browser check to be implemented when a user accesses the portal.
Navigation	Comparing across more than one region.	Provide the ability to compare two NUTS3 regions.	• This is a good suggestion which will be explored in the future as an extra feature.
Navigation	Provide a data export function.	Provide the ability for users to select a region and download the associated indicator information.	• A download button will be provided as part of the information panel (to download class, descriptions, indicators, radial diagrams for a selected region) • The potential for being able to select all or multiple regions as a zip file will be explored.
Understanding the data	Naming of the classes	• Use numbers to denote classes and sub-classes.	• Naming to be revisited in connection to naming sub-classes. • Some adjustment to existing class names will be made to avoid loaded terms e.g. 'Southern states'.
Understanding the data	More guidance needed for user interpretation	• Connect classes and sub-classes to example good practice case study cities e.g. Covenant of Mayors. This will assist networking aims of the portal. • Provide examples of how the portal might be used. • Provide use case examples around the indicators and their communication.	• Use cases are under-development for different scales of users. • Examples of good practice are too much to include in each class. • Provide a separate page that provides good practice examples and links to existing resources. Show different uses and spatial scales (eg how could a city use it?)
Understanding the data	Cluster approach is not always intuitive (e.g. 'outliers' that don't fit their class name).	• Provide more guidance on how to interpret the classes • Show methodology and	• Separate methodology section will be provided. • More detail to be given on

		reasoning behind this particular approach (in methodology page) • Perhaps make reference to surprises in the (extended) description of a group • Comment on anomalies arising from the methodology (e.g. positive scores relating to coastal hazards for areas not near the coast).	interpreting clusters in the methodology. • Make an FAQ section that will address queries such as outliers and other anomalies.
Understanding the data	Use of indicators with different temporal dimensions is not clear.	• Clearly present the metadata, source, and methodology for each indicator • Clearly indicate temporal dimension, and make sure names are accurate (eg 'Mean temperature' should be named 'difference in daily mean temperature between the 1981-2010 period (observed baseline) and the 2036-2065 period (future projection)' or 'Δ mean t°'). • Give an explanation on how indicators were chosen with reference to any obvious omissions.	• Indicators description list to be presented like classes to ease interpretation • A short one line summary, will be provided when a user hovers over an indicator. The side question mark can be clicked for detailed explanation, including data sources • The indicator description box will highlight caveats • Units for each indicator will be included.
Understanding the data	Meaning of z-scores is not clear	• Provide a better explanation of z-scores • Perhaps instead of the z-score there could be more of a qualitative understanding 'Very high', 'high', 'similar' etc.	• Z-scores will be presented with a clearer discussion of their interpretation in the methodology. • An easy explanation of z-scores will be presented in tool tip
Understanding the data	Radial diagrams require more guidance	• Annotate the diagram to guide user in reading it • Clearly label what the points below / above line mean • Indicators need to be labelled more clearly and grouped together more clearly. • Show only the extreme indicators in the diagram to give a better sense of the class. • Investigate highly correlated indicators and use them to tell a story for the user • Use bar charts with European average as line in the middle	• Radial diagrams could be created depending on user needs. This is complex therefore static versions will be presented. • Present diagrams embedded in a box about a class as PDF or PNG. • Investigate interactive PDFs to allow easier labelling / annotation. • Use arrows to point to min / max z-scores. Can annotate these to link with key words for each class / sub-class • Space for additional information in margins could be created.
Understanding the data	Presentation of raw values for z scores	• Go for a mixed approach with raw value where available and	• Raw values will be made available

		z-scores (with text interpretations e.g. far above/below EU average) for other regions where raw values are not available.	• Unavailable values will be marked as N/A with explanation in methodology FAQs
Understanding the data	Methodology	• Include a table that compares the RESIN typology with others (e.g. RAMSES and ESPON) in order to make the differences clear. • Different users require different levels of information. Create a detailed methodology for e.g. researchers and a 'lite' methodology for municipalities.	• Methodology summary with link to full methodology download will be provided. • Include a list of FAQs to respond to common concerns • There will be detailed and 'lite' versions of the methodology. A comparison to other tools will be available in the extended version.

Table 10: Consultee comments on navigation and understanding the data in the prototype web portal.

The following users and uses for the typology and online portal were identified:

Identified end-users:

- European Environment Agency, Covenant of Mayors (both for supporting vulnerability/risk assessment and also their twinning programme) and the UNISDR Making Cities Resilient Campaign.
- Students and researchers working on climate change risk and adaptation topics

Identified uses:

- The typology cannot be relevant for all spatial levels and tasks so there should be a focus on those areas where the links are strongest, which include strategic planning and adaptation strategy development, and scoping out risk themes to concentrate on locally.
- The portal may be used for positioning reasons, for example using the indicators to justify a proposal for a new policy.
- The typology could be used to support Strategic Environmental Assessment processes.

People involved in the consultation

Name	Affiliation
Birgit Georgi	Independent Consultant (previously at the European Environment Agency)
Jean-Marie Cariolet, Morgane Colombert	Ecole des Ingenieurs de la Ville de Paris
Daniel Luckarath, Erich Rome	Fraunhofer
Helen Telfer, Matt Ellis, Jill Holden, David Hodcroft	Greater Manchester Combined Authority
Aleksandra Kazmierczak, Julia Peliekis, Lea Kleinenkuhen	European Environment Agency, ICLEI, Covenant of Mayors
Vera Rovers, Peter Bosch	TNO
Maddalen Mendizabal Zubeldia, Carolina Cantergiani De Carvalho	Tecnalia
Linda Mathe, Markus Dubeilzig	Siemens
Eva Streberova	City of Bratislava
Marie Gantois	City of Paris
Attendants at Stakeholder Dialogue Workshops, Bilbao	
Attendants at the ICLEI World Congress, Montreal	

Table 11: People involved on the Typology consultation.

Appendix 3: Glossary

Term	Definition	Source
Adaptive capacity	The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences	IPCC 2014a
Aggregation	Aggregation refers to the combination of related categories, usually within a common branch of a hierarchy, which serves to provide information on a broader level rather than only according to the individual observations.	Eurostat 2015
Areal interpolation	In most GIS literature, areal interpolation specifically means the reaggregation of data from one set of polygons (the source polygons) to another set of polygons (the target polygons). For example, demographers frequently need to downscale or upscale the administrative units of their data. If population counts were taken at the county level, a demographer may need to downscale the data to predict the population of census blocks. In the case of large-scale redistricting, population predictions may be needed for a completely new set of polygons.	ESRI GIS Dictionary
Choropleth Map	A thematic map in which areas are distinctly colored or shaded to represent classed values of a particular phenomenon.	ESRI GIS Dictionary
Cluster analysis	A statistical classification technique for dividing a population into relatively homogeneous groups. The similarities between members belonging to a class, or cluster, are high, while similarities between members belonging to different clusters are low. Cluster analysis is frequently used in market analysis for consumer segmentation and locating customers, but it is also applied to other fields.	ESRI GIS Dictionary
Covariance	A statistical measure of the linear relationship between two variables. Covariance measures the degree to which two variables move together relative to their individual mean returns.	ESRI GIS Dictionary
Coverage	Coverage, is the extent to which the real, observed population matches the ideal or normative population. A population is the domain from which observations for a particular topic can be drawn. Under-coverage results from the omission of units belonging to the target population, while over-coverage occurs due to the inclusion of elements that	Eurostat 2015

	do not belong to the target population. For instance, for causes of death statistics, all deaths of residents occurring in a given year should be covered. However, information about residents dying abroad might not be included in all countries (resulting in under-coverage), and deaths of non-residents might be included (resulting in over-coverage).	
Ecological Fallacy	The assumption that an individual from a specific group or area will exhibit a trait that is predominant in the group as a whole.	ESRI GIS Dictionary
Exposure	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.	IPCC 2014
Hazard	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.	IPCC 2012.
Hazard	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard. Note that in the context of climate change risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur.	Adapted from IPCC 2014
Indicator	quantitative, qualitative or binary variable that can be measured or described, in response to a defined criterion	ISO 13065:2015, 3.27
Median	The middle value of a group of numbers.	Eurostat 2015
Meta-data	Information that describes the content, quality, condition, origin, and other characteristics of data or other pieces of information. Metadata for spatial data may describe and document its subject matter, how, when, where, and by whom the data was collected, availability and distribution information, its projection, scale, resolution, and accuracy, and its reliability with regard to a particular standard. Metadata consists of properties and documentation. Properties are derived from the data source (for example, the coordinate system and projection of the data), whereas documentation is entered by a	ESRI GIS Dictionary

	person (for example, keywords used to describe the data).	
Modifiable Areal Unit Problem (MAUP)	A challenge that occurs during the spatial analysis of aggregated data in which the results differ when the same analysis is applied to the same data, but different aggregation schemes are used. MAUP takes two forms: the scale effect and the zone effect. The scale effect exhibits different results when the same analysis is applied to the same data, but changes the scale of the aggregation units. For example, analysis using data aggregated by county will differ from analysis using data aggregated by census tract. Often this difference in results is valid: each analysis asks a different question because each evaluates the data from a different perspective (different scale). The zone effect is observed when the scale of analysis is fixed, but the shape of the aggregation units is changed. For example, analysis using data aggregated into one-mile grid cells will differ from analysis using one-mile hexagon cells. The zone effect is a problem because it is an analysis, at least in part, of the aggregation scheme rather than the data itself.	ESRI GIS Dictionary.
Nomenclature of territorial units for statistics (NUTS)	A hierarchical system for dividing up the economic territory of the European Union. NUTS 1 refers to major socio-economic regions; NUTS 2 refers to basic regions for the application of regional policies; NUTS 3 refers to small regions for specific diagnoses.	Adapted from Eurostat 2016.
Normal distribution	A theoretical frequency distribution of a dataset in which the distribution of values can be graphically represented as a symmetrical bell curve. Normal distributions are typically characterized by a clustering of values near the mean, with few values departing radically from the mean. There are as many values on the left side of the curve as on the right, so the mean and median values for the distribution are the same. Sixty-eight percent of the values are plus or minus one standard deviation from the mean, 95 percent of the values are plus or minus two standard deviations and 99 percent of the values are plus or minus three standard deviations.	ESRI GIS Dictionary
Polygons	On a map, a closed shape defined by a connected sequence of x,y coordinate pairs, where the first and last coordinate pair are the same and all other pairs are unique.	ESRI GIS Dictionary
Proxy	Indirect measure or sign that approximates or represents a phenomenon in the absence of a direct measure or sign.	The Business Dictionary.

Sensitivity	The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct … or indirect	IPCC 2014a
Standard deviation	The most widely used measure of dispersion of a frequency distribution. It is equal to the positive square root of the variance.	Eurostat 2015
Z-score:	A statistical measure of the spread of values from their mean, expressed in standard deviation units, where the z-score of the mean value is zero and the standard deviation is one. In a normal distribution, 68 percent of the values have a z-score of plus or minus 1, meaning they lie within one standard deviation of the mean. Ninety-five percent of the values have a z-score of plus or minus 1.96, meaning they lie within two standard deviations of the mean, 99 percent of the values have a z-score of plus or minus 2.58. Z-scores are a common scale on which different distributions, with different means and standard deviations, can be compared.	ESRI GIS Dictionary

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