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RESIN

SUPPORTING DECISION – MAKING FOR RESILIENT CITIES

Work Package 1 Final Report: Concepts and Approaches

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Table of Contents

Executive Summary

The goal of Work Package 1 (WP1) was to establish a coherent framework of concepts and approaches linked to understanding and responding to extreme weather and climate change risks in urban areas, with a particular focus on critical infrastructure. In doing so, Work Package 1 helped to structure and guide work undertaken across the RESIN project. The themes addressed and outputs produced within WP1 are broad in scope, and are therefore relevant beyond the RESIN project in other situations where climate change adaptation and resilience goals are being pursued.

WP1 involved three core tasks:

Task 1.1: The preparation of seven state-of-the-art reports, and a glossary, on key topics related to the RESIN project. The state-of-the-art reports covered the following topics:

- Urban critical infrastructure systems.
- Adaptation, resilience and disaster risk reduction – concepts, definitions and application.
- Weather and climate hazards facing European cities.
- Vulnerability assessment – definitions, indicators and existing assessment methods.
- Undertaking climate risk assessments – definitions, approaches and methods.
- Adaptation approaches – characterising, assessing and prioritising towards implementation.
- Decision support.

Task 1.2: The development of the RESIN Conceptual Framework.

Task 1.3: The creation of a European Climate Risk Typology.

Risk is central to leading climate change adaptation and resilience frameworks, such as the one produced by the Intergovernmental Panel on Climate Change (IPCC). Due to its prominence in this field, climate risk was identified as the guiding theme underpinning the RESIN project, and connects the various tasks and outputs that are described within this WP1 report. This mirrors the shift from vulnerability towards risk-based adaptation and resilience approaches driven forward by the Intergovernmental Panel on Climate Change. WP1 outputs, including the state-of-the-art report on this theme (Connelly et al 2016) and a related paper published on this topic (Connelly et al 2018), help to clarify and better understand the implications of this significant development for the adaptation and resilience agendas.

The European Climate Risk Typology, produced within WP1, can also support the transition towards risk-based climate change adaptation and resilience approaches. The typology provides a new classification of European cities and regions into different climate risk classes (and sub-classes) which can be interrogated via an interactive and user-friendly online portal. It can be used to enhance understanding of, and response to, climate change risk in European cities and NUTS 3 regions. Climate change is projected to intensify over the coming decades. However, the capacity of planners and decision makers to respond to related challenges is in some cases limited by a lack of knowledge and resources. Here, the typology can provide a valuable input and can help to progress the achievement of Europe's climate change adaptation and resilience goals.

1. Introduction

European cities and urban areas, and the critical infrastructure assets and networks that serve them, are at risk from current and projected extreme weather events and related changes to the climate. There is a growing recognition that developing strategies and implementing actions focused on adapting and building resilience to the changing climate is needed in response. The EU Strategy on Adaptation to Climate Change (COM/2013/0216 final), which was adopted in 2013, positions this agenda closer to the mainstream of policy and planning and cities are increasingly taking on this challenge. However, the development and implementation of climate change adaptation strategies and actions is a challenging task for cities and urban areas, although there are some recognised leaders in this field from within and beyond Europe (Carter 2011, EEA 2016). The adaptation actions that have been implemented have tended to be mostly incremental and focused on proximate causes, with limited evidence of transitions and transformational change taking place (Wise et al 2014). The adaptation planning process can be demanding for individuals and organisations tasked with leading the response to climate change, as they are faced with multiple competing demands on their time and resources. Consequently, there is a need for standardised approaches to support the development of urban adaptation strategies. These issues set the context for the RESIN project, which aims to develop standardised approaches to help city administrators, urban infrastructure operators and other related stakeholders develop adaptation strategies that can enhance urban climate change resilience.

The goal of WP 1 was to establish a coherent framework of concepts and approaches linked to understanding and responding to extreme weather and climate change risks in urban areas, with a particular focus on critical infrastructure. In doing so, WP1 structured and guided work undertaken across the RESIN project. The themes addressed and outputs produced within WP1 are broad in scope, and are therefore relevant beyond the RESIN project in other situations where climate change adaptation and resilience goals are being pursued.

WP1 involved three core tasks, which are summarised in Table 1:

> **Task 1.1:** The preparation of seven state-of-the-art reports, and a glossary, on key topics related to the RESIN project.
>
> **Task 1.2:** The development of the RESIN Conceptual Framework.
>
> **Task 1.3:** The creation of a European Climate Risk Typology.

The overarching theme that links the WP1 tasks, and the outputs of the RESIN project more broadly, is climate risk. This theme is covered in Section 2. Section 3 then reports on Task 1.1, which constituted the preparation of seven state-of-the-art reports and a project glossary. Section 4 reports on Task 1.2 and the RESIN Conceptual Framework. Section 5 then describes the European Climate Risk Typology. The typology development process, output and uses are covered within this section. This is the largest section of the report, which reflects the greater allocation of time and resources to this task within WP1. Section 6 provides a conclusion that summarises the key outcomes and learning that has emerged from WP1 of the RESIN project. This deliverable, D1.5, is the concluding report of WP1 and refers to all other deliverables produced within WP1. No other RESIN deliverable is dependent on D1.5.

WP1 outputs	Overarching goals	Main research methods	RESIN project contribution
State of the art reports (x7) D1.1	• Positioning RESIN within the wider climate change adaptation and resilience agenda • Identifying research gaps and opportunities	• Literature review	• Ensuring that RESIN is 'up-to-date' • Informing partners on relevant topics linked to RESIN • Supporting development of WP 1,2,3 and 6
Glossary D1.2	• Identifying and defining key terms	• Literature review	• Providing clear definitions of key terms • Encouraging consistent application of key terms across the project
RESIN Conceptual Framework (RCF) D1.3	• Clarifying concepts underpinning RESIN and highlighting linkages between them • Establishing project scope and boundaries	• Literature review • Workshop with RESIN partners • RESIN partner questionnaire • WP1 partner workshop	• Providing a framework to structure and connect work across RESIN • Guiding and supporting activity in the WPs
European Climate Risk Typology D1.4	• Understanding and visualising Europe's climate risk 'landscape' • Broadening perspectives of climate risk • Promoting more effective adaptation and resilience policy and action	• Literature review • RESIN partner questionnaire and workshops • Consultation process • Statistical data methods • Website development and testing	• Supporting the development of other RESIN outputs, particularly IVAVIA (WP2) and the e-Guide (WP6)

Table 1: Overview of WP1 outputs

2. A risk-based approach

Climate risk is the guiding theme underpinning the RESIN project. Urban areas face risks from a range of hazards and drivers, yet the focus of the RESIN project is on those risks linked to the changing climate. Risk is central to leading climate change adaptation and resilience frameworks such as the one produced by the Intergovernmental Panel on Climate Change (IPCC), which is visualised in Figure 1 (IPCC 2014a), and sits at the heart of their most recent assessment report on climate change impacts, adaptation and vulnerability (Burkett et al. 2014, Connelly et al 2018). Due to its prominence in this field, and because the concepts linked to climate risk (which include hazard, exposure and vulnerability) are relatively well defined, the RESIN project took this theme as its starting point.

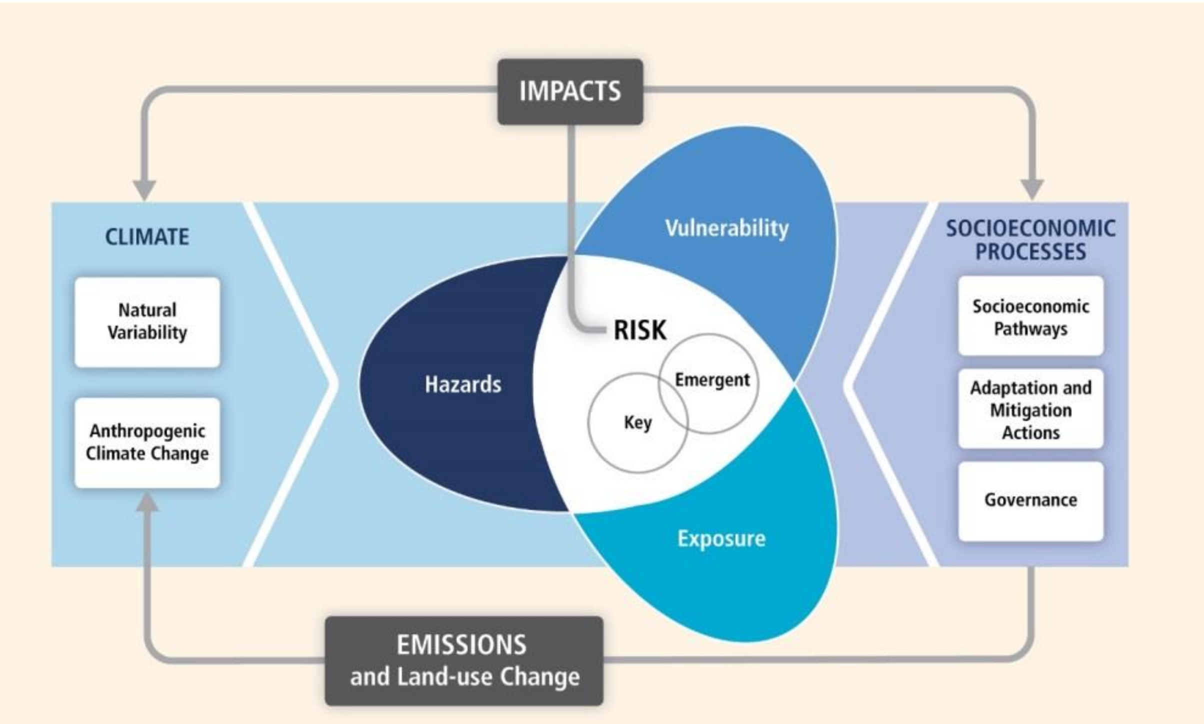

Figure 1: Conceptualization of risk by the IPCC. Source: IPCC 2014a.

Risk can be understood as a function of weather and climate hazards, the degree to which a receptor (e.g. people and infrastructure) is exposed to a hazard and the vulnerability of the receptor to the hazard should it be exposed to it (see Figure 1). Vulnerability is broken down into sensitivity and adaptive capacity themes. These constituent elements of the risk framework are defined in Box 1. It is notable that the IPCC's conceptualisation of risk also highlights the influence of climate and socio-economic processes on risk. Climate risks therefore arise as a result of climate and non-climate drivers and hazards interacting with and impacting on vulnerable receptors within an urban system. The emergence of risks may in turn initiate an adaptation planning process aimed at risk reduction and building climate resilience.

In certain cases, climate change may generate opportunities as well as risks within urban systems. For example, a warming climate may enable new businesses to develop, and higher temperatures may reduce the need for space heating in some areas. However, in the majority of cases, climate change will have negative implications for urban areas, particularly when the indirect effects of climate change in other regions and countries are considered (Foresight 2011). It is also notable that climate change can act as a multiplier, and worsen the impact of other drivers and stressors on urban systems. For example, higher temperatures may exacerbate health problems in some urban areas.

- **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 et al 2016).

3. Task 1.1 – Concepts and approaches

Seven state-of-the-art reports were prepared as part of WP1, and alongside a glossary were the key deliverable of Task 1.1 (of WP1). Originally six state-of-the-art reports were planned. However, a seventh report was added as a voluntary deliverable on the topic of climate change risk and risk assessment as this was felt to be an important theme that was missing from the original list of planned reports. The reports had several broad aims:

- To provide the RESIN partners with details on current thinking relating to the main project issues and themes.
- To inform the work of WPs 1, 2, 3 and 6, which each have at least one report that covers themes that connect closely to their aims and scope.
- To inform the development of the RESIN Conceptual Framework (Task 1.2).
- To provide a resource to build climate change adaptation and resilience awareness and capacity amongst relevant stakeholders beyond the RESIN project.

The definitions included within the reports were used to build the project glossary, which is another deliverable of T1.1. This aimed to provide clear boundaries around, and definitions of, key concepts and terms sitting at the centre of the RESIN project. Also, the glossary helped to ensure that these concepts and terms were consistently applied by the project partners.

The RESIN state-of-the-art reports provide overviews of specific themes linked to the field of urban climate change adaptation and resilience, and to the objectives and outputs of the RESIN project In doing so they acted as a resource for RESIN partners to support the development of project outputs. Looking beyond RESIN, the reports will have wider relevance within policy maker, practitioner and research communities.

A number of RESIN partners were involved in preparing, reviewing, and presenting the key findings of the the state-of-the-art reports.

Table 2 below highlights the reports prepared within this task. The table also indicates responsibility for their preparation and review.

The first two reports are definitional and help to set out the meaning, scope and boundaries of the RESIN project. These are:

- Urban critical infrastructure systems (Rome et al 2015, D1.1, Report 1)
- Adaptation, resilience and disaster risk reduction – concepts, definitions and application (Nassopolous et al 2015, D1.1, Report 2)

Three further reports are aimed at understanding and assessing the extreme weather and climate change challenges that cities and urban areas face. These are:

- Weather and climate hazards facing European cities (Carter et al 2015, D1.1, Report 3)
- Vulnerability assessment – definitions, indicators and existing assessment methods (Connelly et al 2015, D1.1, Report 4)
- Undertaking climate risk assessments – definitions, approaches and methods (Connelly et al 2016a, separate voluntary RESIN deliverable, Report 7)

The final two reports set the context for acting on the various assessments to develop and implement responses to reduce risk and build resilience. These are:

- Adaptation approaches – characterising, assessing and prioritising towards implementation (Abajo at al 2015, D1.1 Report 5)
- Decision support (Wijnmalen et al 2015, D1.1 Report 6)

D1.1 report theme	Report lead author (and supporting authors)	Report reviewers
Report 1: Urban critical infrastructure systems (Rome et al 2015)	Fraunhofer (with support from UNIMAN and Siemens DE)	UNIMAN; Siemens
Report 2: Adaptation, resilience, and disaster risk reduction – concepts, definitions and application (Nassopolous et al 2015)	EIVP	UNIMAN; Tecnalia
Report 3: Weather and climate hazards facing European cities (Carter et al 2015)	UNIMAN	UNIMAN; TNO
Report 4: Vulnerability assessment – definitions, indicators and existing assessment methods (Connelly et al 2015)	UNIMAN (with support from Fraunhofer)	UNIMAN; Fraunhofer
Report 5: Adaptation approaches – characterising, assessing and prioritising towards implementation (Abajo at al 2015)	Tecnalia (with support from EIVP)	UNIMAN; TNO
Report 6: Decision support (Wijnmalen et al 2015)	TNO	UNIMAN; EIVP
Report 7: Undertaking climate risk assessments – definitions, approaches and methods (Connelly et al 2016a)	UNIMAN	TNO, Fraunhofer, Tecnalia

Table 2: State of the art reports produced within the RESIN project.

The RESIN state-of-the-art reports can therefore be viewed as an integrated package, as clarified within Figure 2. A further contribution of the reports was to inform the development of the RESIN conceptual framework, which is described in the following section.

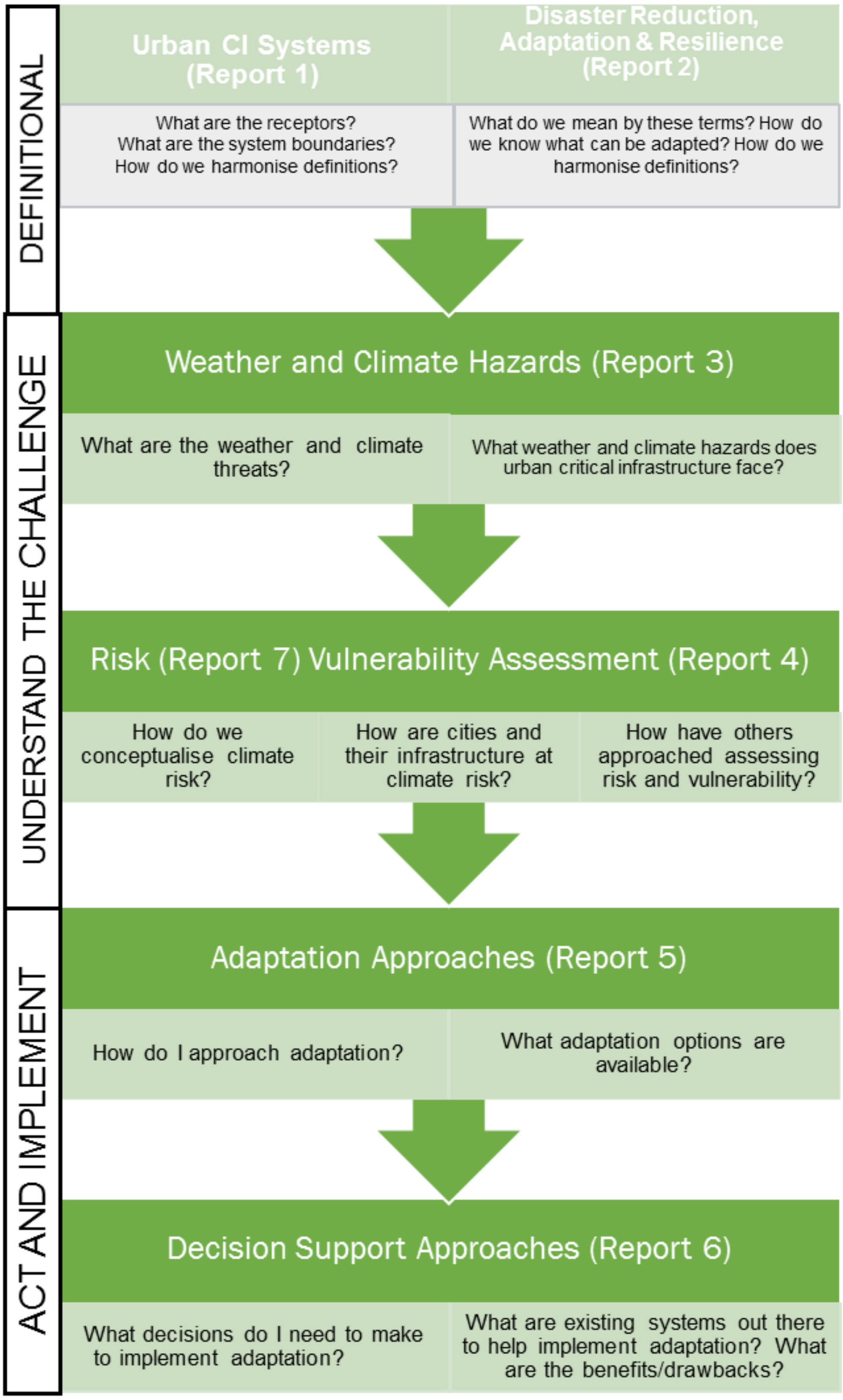

Figure 2: Visualising the connections between the RESIN state-of-the-art reports.

4. Task 1.2 – RESIN Conceptual Framework

The RESIN Conceptual Framework (RCF) has been designed to guide and support the RESIN project and the various tasks being undertaken within it. The RCF is the principal output of Task 1.2 (of WP1) and is documented in D1.3 (Carter et al 2016). The RCF was developed based on inputs (via questionnaires, workshops and discussions) from the RESIN partners at various points in the first phase of the project. The creation of the RCF therefore followed an iterative and collaborative process to develop a framework that adopts a multi-disciplinary perspective.

The RCF outlines the key concepts, and the connections between them, that structure the RESIN project. These key concepts, and others linked to urban climate change adaptation and resilience, are defined within the RESIN Glossary (Connelly et al 2016, deliverable D1.2) which was a further output of WP1. The RCF positions the RESIN project within the field of urban climate change adaptation and resilience. It also highlights the practical nature of the project and its ultimate aim of building the resilience of European cities to the changing climate. This is exemplified by the involvement of four case study cities as RESIN project partners, who are working to progress the achievement of adaptation and resilience objectives. The main objectives of the RCF are:

- To clarify key RESIN project concepts and identify the principal relationships between them.
- To provide a high level overarching context for the project to operate within.
- To inform and complement the RESIN project work packages and their related tasks.

The RCF focuses on urban climate change adaptation and resilience. Adaptation and resilience are complementary processes that can aid urban areas in preparing for, coping with and responding to challenges (and potential opportunities) posed by the changing climate. Adaptation strategies and actions are developed and implemented in response to climate risks, building the climate resilience of urban systems. More specifically, and connecting to the overarching goals of the RESIN project, the thematic scope of the RCF encompasses:

- Urban systems, with critical infrastructure forming the key sub-system of interest sitting within a complex and interconnected urban system.
- Climate change as the principal ‘driver of change’, whilst recognising that climate change is one of multiple interacting hazards and drivers on urban systems.
- The provision of decision support for adapting and building the resilience of cities and their critical infrastructure to risks associated with extreme weather and climate change.

The RCF (Figure 3) builds on these themes and positions the RESIN project as following a cyclical approach centred on assessing and then 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.

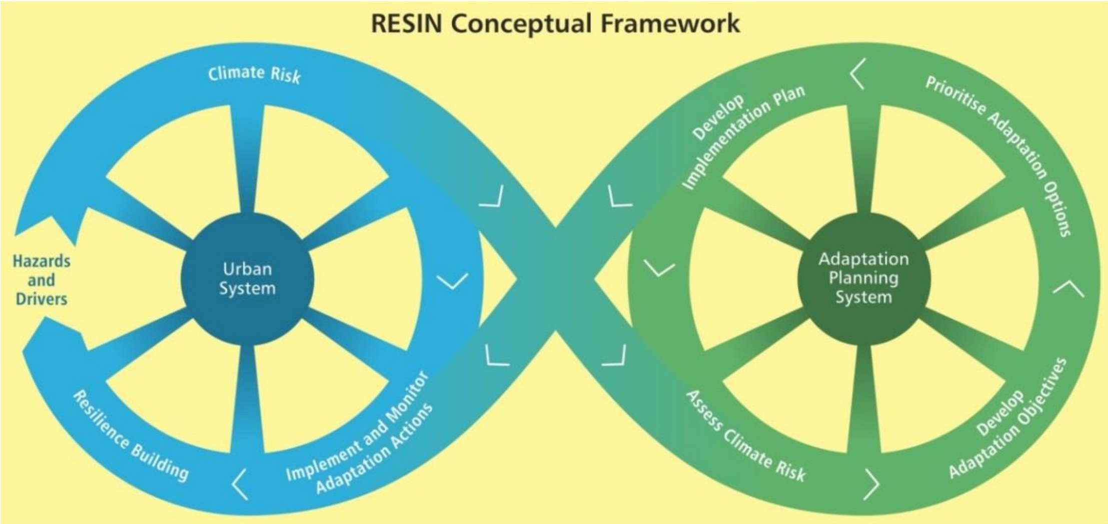

Figure 3: The RESIN Conceptual Framework.

Processes to adapt to climate change and build urban climate resilience may be on-going due to heightened awareness of risks because of research studies and/or previous experience of climate hazards. It is not expected that every city would come to this process without prior knowledge of adaptation planning. A city may already have worked through stages of the adaptation planning process and may have generated some learning on climate risks and the implementation of adaptation options. The anticipated outcome(s) of the adaptation planning process is, rather, an implementation plan to progress targeted actions that build climate resilience within the urban system and constituent sub-systems. It is here that the adaptation planning cycle connects into the urban system cycle for a second time. The implementation (and subsequent monitoring) of actions, if effective, increases the resilience of the urban system to potential future hazards.

The RCF also emphasises that adaptation and resilience are not simply end-goals to be achieved within urban areas. Adaptation and resilience building are on-going and evolving processes that can incrementally transform urban areas towards a better adapted and more resilient state. The RCF can be viewed as a continuous feedback loop where learning generated by experience and/or heightened awareness of climate risks starts or continues an adaptation planning process which then leads to the implementation of actions to lessen future risks by building urban resilience. This emphasises that an urban adaptation process may span decades, which places requirements on stakeholders engaged in the process regarding issues such as the documentation of the adaptation process and monitoring results in order encourage continuity and learning. The RCF also emphasises that the connection between the risk and response loops lies at the heart of the RESIN project.

The RCF is primarily focused on supporting the RESIN project, the key goal of which is to assist cities and urban areas in adapting and becoming more resilient to climate change. A number of other conceptual frameworks exist that have been designed specifically to support adaptation and resilience. These generally cover similar issues linked to the assessment of risk, including climate change hazard, exposure, vulnerability and adaptive capacity. The RCF aims to complement and not compete with these existing frameworks. The RCF reflects the emphasis of the RESIN project on supporting the development and implementation of actions to build the resilience of urban areas to climate change. Other projects and initiatives with a focus on adaptation and resilience may benefit from the RCF and its approach to connecting the urban system with the process of adaptation planning.

5. Task 1.3 – European Climate Risk Typology

5.1. Introducing the typology

We intuitively understand that spatial patterns of climate risk exist across Europe, but we have not yet developed a way of analysing and visualising these patterns. The RESIN European Climate Risk Typology addresses this issue and identifies European cities and regions that share similar characteristics concerning factors that drive climate risk. Following the IPCC's risk-based approach, the factors underpinning the typology include the hazards faced by cities and regions, and their levels of exposure and vulnerability to these hazards. The typology offers the opportunity to better understand and respond to climate risk.

Situating the typology within the RCF positions it along the 'transition path' between the urban system and the adaptation planning system as represented by the two-way arrow in Figure 4. 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 issues that influence climate risk such as the types of hazards facing a city, the socioeconomic composition of the resident population and economic factors. The typology can in turn inform the development of strategies and actions to reduce climate risk and build resilience.

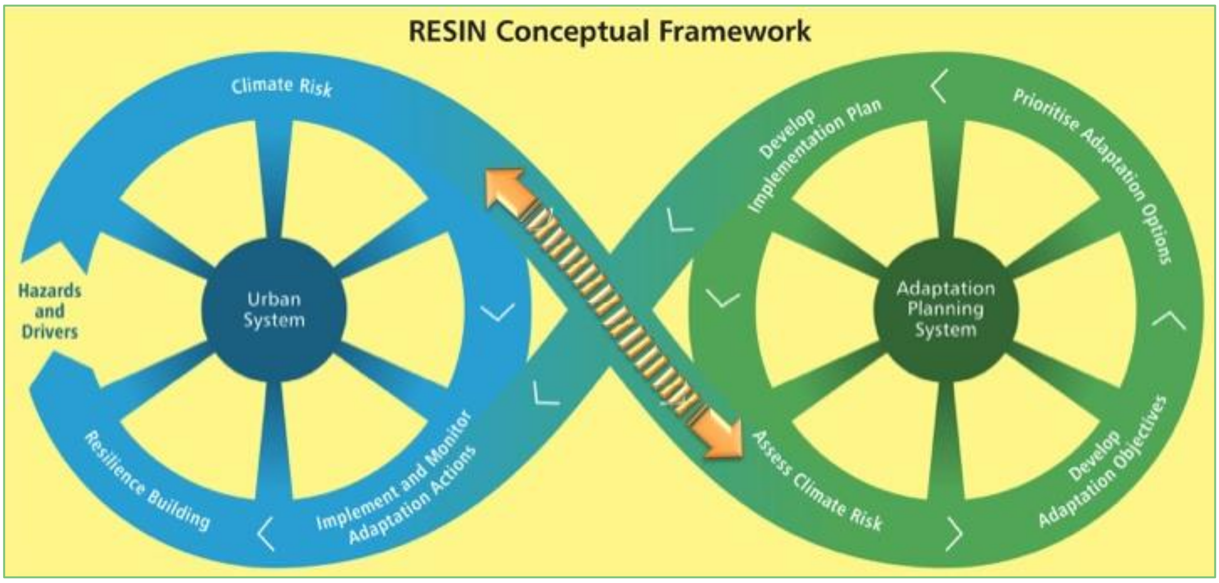

Figure 4: Positioning the Typology within the RESIN Conceptual Framework.

The typology operates at the scale of European NUTS3 regions, which are defined as 'small regions'. The NUTS3 scale was selected as the spatial unit for the typology as this allowed it to cover the entire continent of Europe, enabling cities and urban areas to be identified within this wider European landscape. 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. As a result, a range of socio-economic data is reported at the NUTS3 scale, which was utilised to create indicators to develop the typology.

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. 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. The NUTS 3 region scale therefore enables certain cities to be identified, whilst also allowing hinterland regions around cities, and rural areas, to be considered.

5.2. Developing the typology

The basis of the typology is a suite of climate risk indicators covering hazard, exposure and vulnerability themes, where vulnerability is separated into sensitivity and adaptive capacity. Box 1 includes definitions of these terms, which are also covered in the RESIN glossary (Connelly et al 2016, deliverable D1.2). 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. In total, data was gathered and developed on 81 indicators at the NUTS3 level. Examples of these indicators are included in Table 3. Further details on the indicators, including selection approach, full descriptions, source data and development methods, is included in the typology final report (Carter et al 2018, deliverable D1.4).

Risk theme	Number of indicators	Indicator examples
Hazard	31	Heat wave days (projected) Consecutive dry days (projected) Very heavy precipitation days (projected) Fluvial flood hazard (current)
Exposure	24	Road infrastructure exposed to fluvial flooding Rail network exposed to coastal hazard Settlements exposed to landslide
Sensitivity	10	GVA per head of population Change in population over 70 years (2017-2050) Proportion of population at risk of poverty
Adaptive capacity	16	Number of hospitals per head of population Broadband coverage % of urban area that is classified as green space

Table 3: European climate risk typology indicators.

The indicators were used as the basis of a cluster analysis method that was applied to identify climate risk classes and sub-classes for all of Europe's NUTS 3 areas. The 81 indicators were subjected to data transformation and standardisation procedures in order to address issues such as inputting missing values, removing excessively correlated indicators and overcoming problems of non-normal distributions (see Carter et al 2018 (D1.4) for descriptions of these processes). 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). Following the application of these transformation and standardisation procedures, 54 indicators were retained for inclusion in the next stage of analysis. However, all of the 81 indicators were retained for use within the online portal developed to house the typology outputs.

Having identified those indicators to be retained and used to develop the typology, the next step was to determine the most appropriate method through which to cluster the indicators to develop climate risk classes and sub-classes. The logic of cluster analysis is to define groups of objects (in this case NUTS 3 regions) based on their underlying characteristics. There are different clustering methods that could have been adopted to complete this task, with the decision as to which was the most appropriate largely influenced by the types of data that were used to develop the typology. In this instance, K-means clustering was adopted because all of the variables were interval or ratio level (see Carter et al 2018 (D1.4) for a description of this clustering approach as undertaken within the RESIN project).

5.3. The typology output

An online portal has been developed to house the typology output and the indicators that underpin it. The online portal is interactive and provides data and functionality enabling users to visualise, describe, compare and analyse climate risk in European cities and regions. The online portal can be accessed at: www.european-crt.org

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 5, which presents a screenshot from the online portal. Each class represents a distinct group of cities and NUTS3 regions that share similar climate risk characteristics (hazard, exposure and vulnerability). The online portal names and describes each class.

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 will find themselves in very different parts of the continent.
- 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 show more diversity and 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, which introduces scope for greater statistical variation in indicators such as population, infrastructure and climate variables. 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 (Fotheringham and Wong 1991).

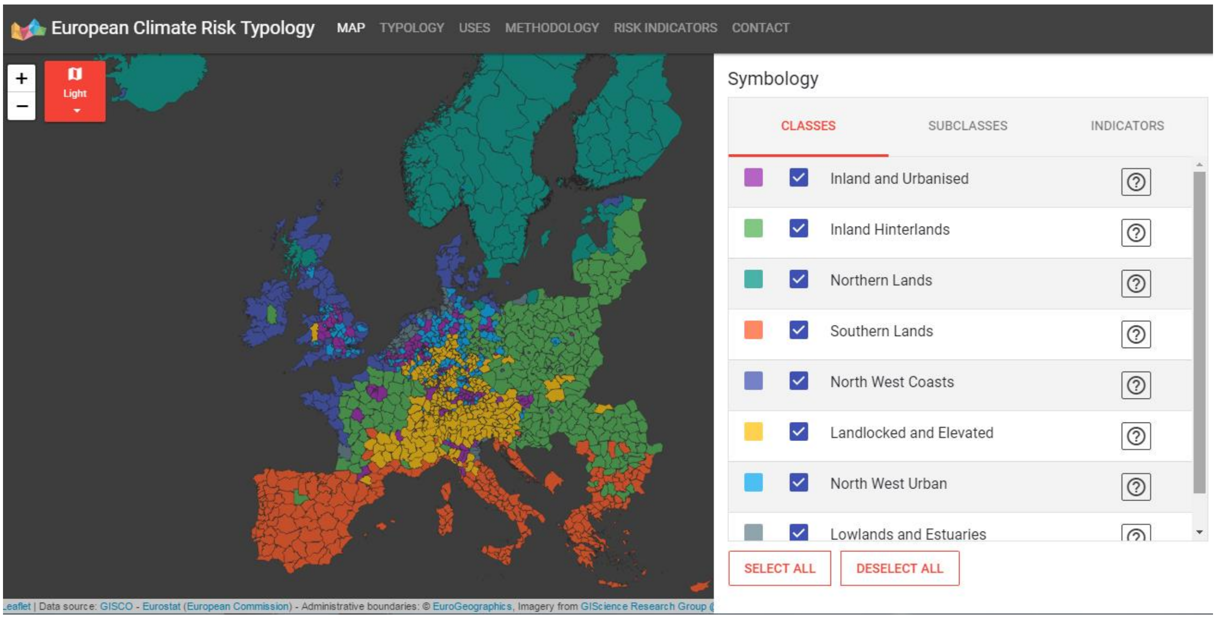

Figure 5: Map of Europe showing the eight typology classes. (Data source: GISCO - Eurostat (European Commission) - Administrative boundaries: © EuroGeographics, Imagery from GIScience Research Group @ University of Heidelberg — Map data © OpenStreetMap)

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. Figure 6 shows a screenshot from the typology online portal of the 31 sub-classes. The online portal includes names and descriptions for each sub-class. In regions such as the Mediterranean and Northern Europe, which are dominated by one particular typology class, the sub-classes help to differentiate between NUTS3 regions on the basis of their climate risk characteristics. 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 diversity of NUTS3 regions in terms of their climate risk characteristics. For example Germany, with seven typology classes, has 27 sub-classes. Conversely Sweden, with one class, has four sub-classes.

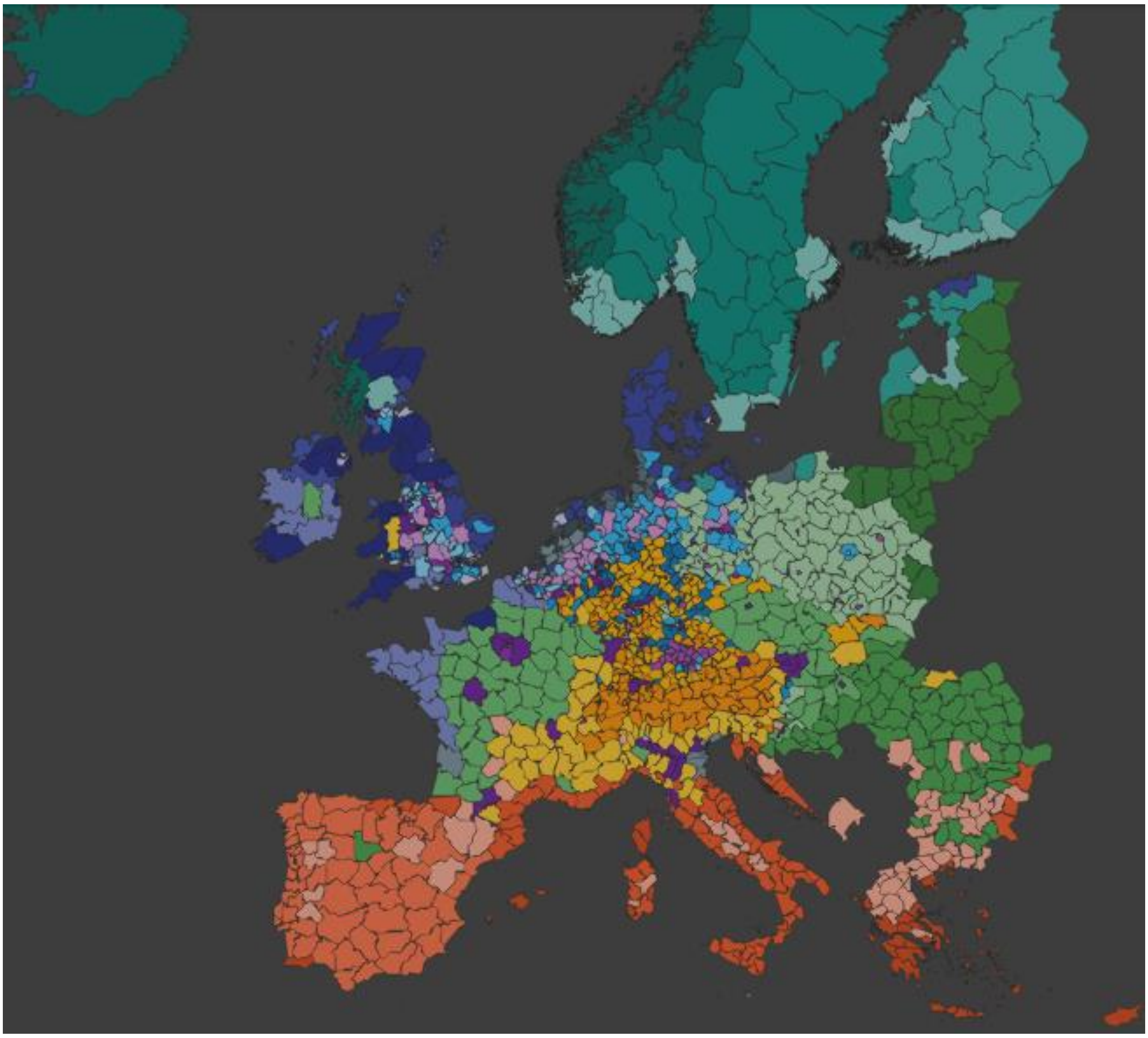

Figure 6: Map showing typology sub-classes. (Data source: GISCO - Eurostat (European Commission) - Administrative boundaries: © EuroGeographics, Imagery from GIScience Research Group @ University of Heidelberg — Map data © OpenStreetMap)

A radial graph was created for each typology class and sub-class. An example is provided below for the Inland and Urbanised typology class (Figure 7). Here standardised scores for the different indicators are plotted in relation to the grand mean score for all NUTS3 units in the analysis. The radial graphs, which are accessible via the online portal, enable a quick overview to be gained on the key drivers of climate risk in the typology classes and sub-classes.

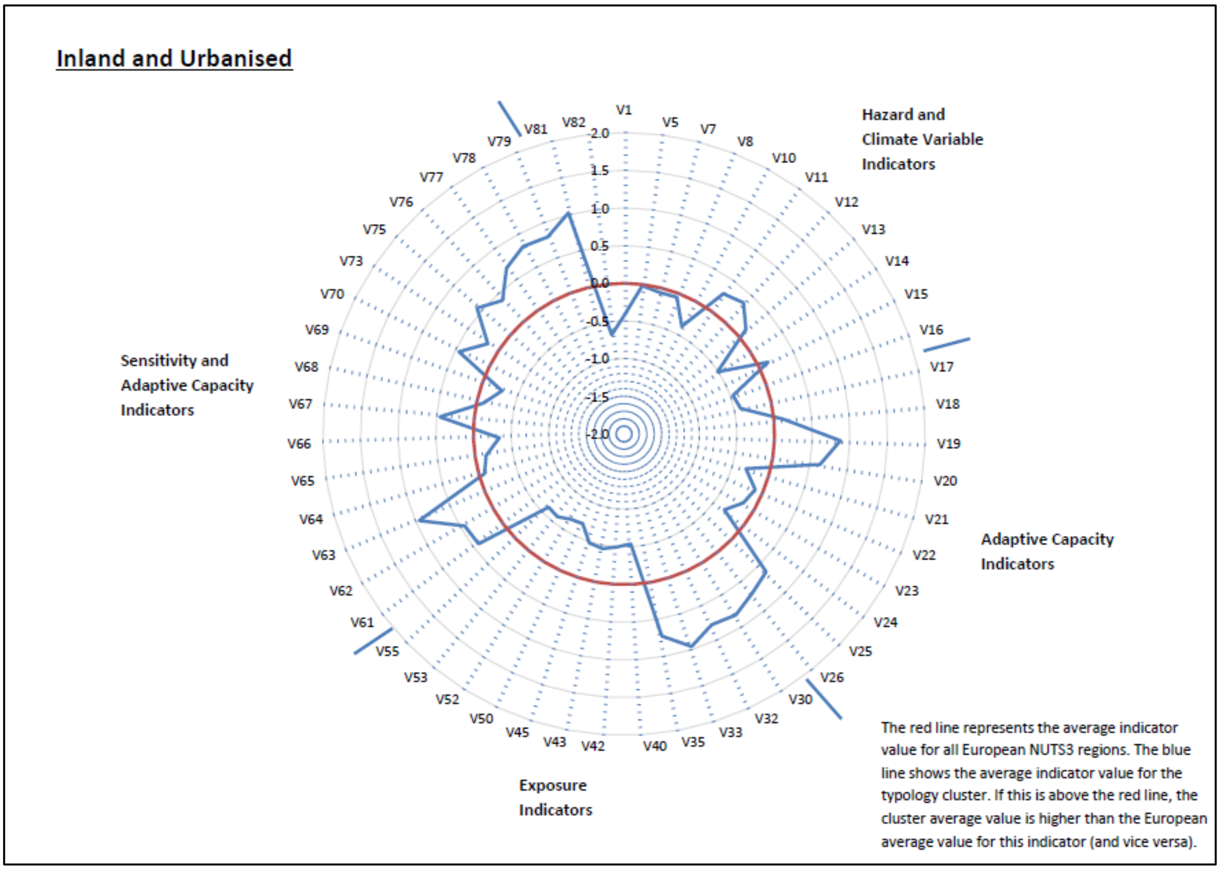

Figure 7: Radial graph for the 'Inland and Urbanised' climate risk class (the radial graphs are explained in more detail in the typology online portal).

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. Indeed, the 81 climate risk indicators are a significant output of the work undertaken to develop the typology. Although the original intention was to use existing indicator data, it became apparent that this was not going to be possible due to data quality, coverage and availability issues. As a result, the majority of the indicators incorporated within the process of developing the European Climate Risk Typology were created specifically for this purpose, and were therefore not previously available at the NUTS3 region scale. Indeed, all of the hazard and exposure indicators are new, as are the majority of the sensitivity and adaptive capacity indicators. The indicators therefore represent a valuable new resource that can support climate change adaptation and resilience responses in Europe, for example by informing climate change risk assessments and supporting the development of adaptation and resilience plans and strategies.

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.

Figure shows a screenshot from the online portal that maps the fluvial flood hazard indicator. This map 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. It also enables specific cities and regions to determine their relative level of fluvial flood hazard in comparison to others in Europe. Similar maps are available for all of the 81 climate risk indicators. As a result, a wide range of indicator data covering different aspects of climate risk can also be accessed via the online portal and used to support climate change risk assessments and the development of adaptation and resilience strategies and plans.

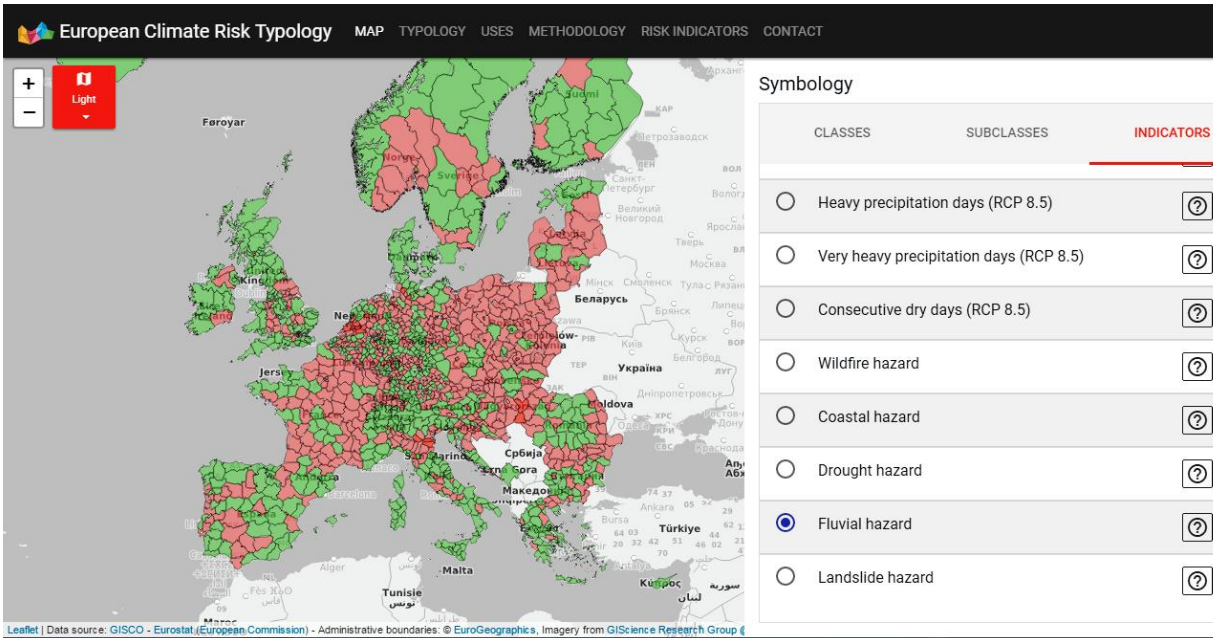

Figure 8: Fluvial flood hazard indicator map. (Data source: GISCO - Eurostat (European Commission) - Administrative boundaries: © EuroGeographics, Imagery from GIScience Research Group @ University of Heidelberg — Map data © OpenStreetMap)

In addition, the typology presents users with the opportunity to find cities and regions that share similar climate risk characteristics concerning the hazards they face, and their levels of exposure and vulnerability to these hazards. This can encourage mutual learning. Ultimately, the typology can be viewed as a decision-aid to support more efficient and effective approaches to assess and adapt to climate risks.

5.4. Using the typology

The European Climate Risk Typology has been developed to support policy makers, practitioners and researchers in better understanding and responding to climate change risks. The process of developing and testing the typology, which has involved input from potential end users from within and beyond the RESIN project, has identified several key uses and users of the typology. Uses for the typology include:

- Description: the typology can be used to describe the climate risk characteristics, relating to hazard, exposure and vulnerability, of European cities and NUTS3 regions.
- 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.

- 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.
- Baselining: The typology provides a 'snapshot' of climate risk in European cities and NUTS3 regions based on the climate and socio-economic indicator data available at the time of its development.
- Strategic planning and decision making: A key benefit of the typology, and the indicator data underpinning the typology, is in supporting the development of climate change adaptation and resilience strategies and plans.
- Network development: The typology can be used to help develop networks between urban areas that face similar risk profiles in order to encourage sharing of experience and practice.

Based on these uses, the European Climate Risk Typology will be particularly useful for two main groups:

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

Although the RESIN project has focused particularly on cities, and it is at this scale that adaptation and resilience strategies and actions are currently most prominent, it is clear that peri-urban and rural regions are also facing climate risks. Given that the typology (and 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 working in this field due to its novel approach to visualising and analysing climate risk in Europe. Further, other stakeholders including infrastructure providers, insurance brokers and consultants may also benefit from the typology and the data and insights that it contains.

5.5. Integrating the typology within RESIN outputs

The European Climate Risk 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 topic.

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, particularly through the provision of indicators. A link to the typology is provided on the landing page for the IVAVIA tool: https://resin.iais.fraunhofer.de/ivavia/

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 organises the right hand loop of the RCF into 4 phases:

- Assess climate risk
- Develop adaptation approaches

- Prioritise adaptation options
- Develop implementation plan

The typology has a role to play during the first of these phases, assess climate risk, again through the provision of indicators to inform the risk assessment. 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. 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.

5.6. Typology caveats

Several caveats connected to the European Climate Risk Typology indicators must be acknowledged when using this tool in practice.

- Spatial scale: The typology and its supporting indicators relate to the NUTS3 region scale, which needs to be considered when interpreting and utilising the outputs. For example, it is clear that the indicators are most valuable in supporting a strategic screening process to determine which climate threats to investigate in more detail as part of a more comprehensive adaptation planning process.
- Indicator gaps: The typology indicators were developed for a particular function; to create a typology that clusters European cities and NUTS3 regions into groups that share similar climate risk characteristics. The indicator list is not exhaustive. For example, indicators covering themes including governance approaches and cultural attitudes are not represented, yet will have important implications for climate risk and related responses. Although the indicators available within the typology online portal can usefully support climate risk assessment and response, they should not be relied upon exclusively.
- A 'snapshot' of climate risk: The indicators underpinning the typology are dynamic, and indicator values will evolve over time influenced by factors including socio-economic change and improvements in research techniques. It is therefore important to recognise that the typology provides a current 'snapshot' of climate risk based on available data.
- 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.
- The influence of the typology methodology: The typology is ultimately a product of a specific methodology. A different methodology would have produced a different typology output. However, significant effort was made to select the most appropriate and robust cluster analysis approach to develop the typology.

5.7. 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.

Moving towards a risk-based typology

Risk sits at the heart of the IPCC's influential climate change adaptation and resilience agenda. Consequently, the decision was taken to position risk as the guiding concept underpinning the European Climate Risk Typology, and the RESIN project more broadly. Here, the IPCC's most recent risk framework, contained in their 5th Assessment Report (IPCC 2014a), was adopted. The typology complements and takes forward existing work on climate risk at the European scale in several ways.

- The typology provides, for the first time, a classification of European cities and regions into different climate risk classes (and sub-classes).
- The typology applies the IPCC's most recent climate risk framework in practice (IPCC 2014a), and provides a useful early test bed for this leading global framework. Although the framework has been applied at 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).
- The typology provides a comprehensive and integrated view of the different elements of the risk framework, covering hazards, and exposure and vulnerability to hazards.

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 European Climate Risk 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.

A comprehensive spatial picture of climate risk patterns

One of the key advances offered by the RESIN European Climate Risk 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 (particularly cities and NUTS3 regions, or clusters of NUTS3 regions). Further, the typology enables users to develop an understanding of climate risk in their city of interest whilst also looking at the climate risk characteristics of 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. Indeed, this emphasises that the city may not necessarily be the scale at which adaptation and resilience strategies should 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.

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 that can help to manage this complexity. The two-tier nature of the typology enables different layers of granularity to be observed concerning Europe's climate risk patterns. 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 often diverse and location dependant.

Typology online portal functionality

A key benefit of the RESIN European Climate Risk 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 aspects and functions of the online portal that increase its utility for end users include:

- Users can easily find cities and regions that share their climate risk characteristics, which can encourage network development and mutual learning.
- All of the typology indicators are publicly available and accessible via the online portal.
- 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.

Taken together with the other benefits and innovations outlined above, the RESIN European Climate Risk 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.

6. Conclusion

WP1 helped to structure and guide the RESIN project, whilst also developing outputs that can support climate change adaptation and resilience strategy and action more widely. A key continuing theme running through WP1, and the RESIN project, was climate risk. This mirrors the shift from vulnerability towards risk-based adaptation and resilience approaches driven forward by the IPCC. WP1 outputs, including the state-of-the-art report on this theme (Connelly et al 2016) and a related paper published on this topic (Connelly et al 2018), help to clarify and better understand the implications of this significant development for the adaptation and resilience agendas.

The European Climate Risk Typology, produced within WP1, can also support the transition towards risk-based climate change adaptation and resilience approaches. The typology provides a new classification of European cities and regions into different climate risk classes (and sub-classes) which can be interrogated via an interactive and user-friendly online portal. It can be used to enhance understanding of, and response to, climate change risk in European cities and NUTS 3 regions. Climate change is projected to intensify over the coming decades. However, the capacity of planners and decision makers to respond to related challenges is in some cases limited by a lack of knowledge and resources. Here, the typology can provide a valuable input and can help to progress the achievement of Europe's climate change adaptation and resilience goals.

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