Horizon 2020 Programme
Instrument: Research & Innovation Actions, Capability project: Security

Realising European ReSILiencE for Critical INfraStructure

RESILENS

Start date of project: 2015-04-30
Duration: 36 months

Development of the Methodological Framework of the European Resilience Management Guidance (ERMG)

Deliverable details	
Deliverable number	**3.1**
Revision number	**0.1**
Author(s)	**UoW**
Due date	**29 July 2016**
Delivered date	**29 July 2016**
Reviewed by	**Irish Water/ Factor Social**
Dissemination level	PU/RE/CO
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The research leading to these results has received funding from the European Union's Horizon 2020 Research and Innovation Programme, under Grant Agreement no 653260

Contributing Partners	
1.	**TCD**
2.	**FhG**
3.	**FAC**
4.	**MTRS**
5.	**SfJE**

EXECUTIVE SUMMARY

This deliverable combines the findings from the literature overview and practice experiences (WP1) with the various methodological elements underpinning the developed Critical Infrastructure (CI) Resilience Management Toolkit (WP2) to advance a methodological framework/set of principles for the European Resilience Management Guideline (ERMG) based on requirement lists, processes and methods/measures. This framework also reflects a critical engagement with existing International and EU Risk Assessment Guidance and the UNISDR urban resilience scorecards, as well as their ongoing evaluation.

The deliverable proceeds in five key parts. After situating this deliverable within the context of the work plan, and specifically WP3, we illuminate some critical challenges for developing a methodological framework for assessing resilience; why this needs to undertaken in relation to critical infrastructure; and, further unpack how the RESILENS approach extends existing standards and approaches to of risk management (as best represented by ISO 3100).

We then progress to an overview of all tools produced by the RESILENS project within WP2; focussing on the details of methods utilised, the rationale for this approach, as well as reflecting on the limitations and advantages of the given method and in particular, articulating how the tools move beyond the current state of the art. This process of aligning gaps and capabilities will inform the development of the draft ERMG. After drawing together this range of methodological approaches utilised in the RESILENS tools the penultimate section reflects and critically assesses the methodologies and ideas underpinning the RESILENS tools, how they compare to other approaches currently in use, identifying areas for further work and how these understandings will shape the ERMG.

The final section describes the foundation of the methodological framework through a sequence of complementary tools and their relevance to the formulation of the ERMG. Furthermore, it outlines a set of important principles which need to be adopted if we are to successfully move towards a CI resilience (CIR) approach; the need to move beyond complex, technical and specialist understandings of resilience that are often time and resource intensive that limits their wider applicability between organisations and wider sectors. Here we propose that the RESILENS approach to advancing the EMRG takes a simple, non-specialised semi-qualitative approach, using appropriate numeric measures of largely quantitative data that are constructed through collaboration amongst stakeholders. Such collaboration builds a shared understanding of social and organisational capacities and capabilities for resilience, allowing a deeper exploration of difference resilience foci, including contextual considerations and the systems connections, linkages and dependencies.

Contents

1. Introduction

Overview of the RESILENS project

Critical Infrastructure (CI) provides essential functions and services that support societal, economic and environmental systems at national and European scales. As disasters and crises, both natural and man-made, become more commonplace, the need to ensure the resilience of CI so that it is capable of withstanding, adapting and recovering from disruptive events, is paramount. Moving resilience from a conceptual understanding to applied, operational measures that integrate best practice from the related realm of vulnerability assessment and risk management is the focus of the RESILENS project. RESILENS will develop a European Resilience Management Guideline (ERMG) to support the practical application of resilience to all CI sectors. Accompanying the ERMG will be a Resilience Management Matrix and Audit Toolkit (ReMMAT) which will enable CI systems (encompassing assets and organisations) to have their level of resilience quantitatively and qualitatively indexed. This toolkit is outlined in this Deliverable report. The developed toolkit will allow for the quantitative analysis of the resilience of the systems at different spatial scales (urban, regional, national and trans-boundary), which can then be iteratively used to direct users to aspects of their systems where resources could be concentrated in order to further improve their resilience levels. The ERMG and RESILENS resilience management methods will be tested and validated through stakeholder engagement, table-top exercises and three large scale pilots (transport CI, electricity CI and water CI). The ERMG and accompanying resilience methods will be hosted on an interactive web based platform - the RESILENS Decision Support Platform (RES-DSP). The RES-DSP will also host an e-learning hub that will provide further guidance and training on CI resilience.

Overall, RESILENS will aim to further advance the state of the art in CI resilience management and intends to increase and optimise the uptake of resilience measures by CI stakeholders.

Overview of Work Package 3

WP3 is initially concerned with analysing outputs from WP1 and WP2 and considering approaches taken to achieve CI resilience (CIR) as the basis for providing a methodological framework for developing an initial generic draft ERMG, integrating and advancing the SOTA in relation to resilience management and risk assessment. Both generic resilience management and sector specific resilience management will be addressed taking account of the need for consistent use of agreed terminology.

The development of the ERMG is an iterative process of incorporating different considerations, approaches and methodologies; these include the adapted European Risk Assessment Guideline and relevant supporting tools, standardized approaches and learning opportunities, as well as the different methodologies developed through the CONOPs. The

draft ERMG will be subject to sector specific table top testing also involving the RESILENS Advisory Board and providing outputs to refine the ERMG.

The ERMG content will inform the interactive web based RESILENS Decision Support Platform (RES-DSP) which will host the ERMG and resilience management matrix and audit toolkit. RESILENS outputs on the RES-DSP will provide standardised terminology recommendations and integration of methodological approaches derived and taken from risk assessment and resilience management across various CI sectors operators, incident responders and other end users.

The final ERMG and the RES-DSP, addressing the needs and requirements of CI end-users, will be formulated in coordination with WP2 and WP3 task leaders to ensure methods and tools are correctly addressed. Inputs will also be taken from the findings of the evaluation and validation undertaken by sector specific pilot demonstrations in WP4 as well as input from CONOPS and harmonisation actions based on the outcomes of WP5, emphasising how these guidelines advance the SOTA.

Overview of Task 3.2 and Deliverable 3.1

The aim of this task is to formulate a sequential methodological framework for all of the proposed approaches, methods and processes within RESILENS, which will act as a conceptual pathway for the development of the ERMG and also the navigation through other project outputs. This process begins by reflecting on the purpose of a methodological framework, the emerging methodological considerations illuminated in the state of the art and gap analysis, and their relevance for methods that advance CIR (in RESILENS WP1).

Fundamental to this work was a detailed analysis of all tools produced within WP2 This was done to reflect on their respective methodological and epistemological underpinnings, as well as to critique the rationale of the proposed approach, including their appropriateness in comparison to alternative methodologies and how the chosen approach will advance beyond the current state of the art. Following a brief comparison of the proposed approaches against existing best practice and guidance, this task aims to compose a collective framework of methodologies for all RESILENS tools, as well as a series of methodological principles for how this will be translated into the ERMG.

This task acts as a bridge from the tools initially developed in WP2 to their wider application across the RESILENS project. Within the boundaries of WP3, Task 3.2 connects these tools by providing broader methodological principles for the formulation of the ERMG, with the wider aim of considering how RESILENS move beyond the existing state of the art to facilitate the operationalising of resilience.

2. Advancing a Methodological Framework for the ERMG

In this deliverable we advance a methodological framework, for use in structuring the EMRG, as well as for understanding the methodological underpinnings and sequencing of developed tools. In doing so we draw upon the wide ranging literature and practice reviews from WP1 and WP2, which reflect upon the methodological approaches to enhancing resilience across sectors. The State-of-the-Art (SOTA) as outlined with D1.1, highlighted the ongoing transition from a more limited critical infrastructure protection (CIP) to a more holistic and forward-thinking, critical infrastructure resilience (CIR). Key to this approach has been the conceptualisation of CI as system of systems, operating in a complex and uncertain context, which necessitates transformational approaches and tools that promote resilience enhancement, based upon social and organisational factors, adaptability and ongoing learning. D1.2 reflected upon the experiences and practice of existing CI stakeholders, which in turn informed the gap analysis in D1.3. The gap analysis detailed ways to extend beyond the current SOTA. Furthermore, WP2 has built upon this approach through the steps and stages approach, as proposed in D2.1 and the range of resilience enhancing tools described in D2.2 and D2.3.

In simple terms the methodological framework seeks to specify 'what' we are aiming for in advancing the ERMG framework (i.e. to enhance CIR) and the methodologies - the 'how' – we will deploy including the range of methods, tools etc. Thus the role of this task is to highlight the most appropriate sequence of methods to use from previous risk assessment and resilience management approaches across different CIs and stakeholders, as well as to select and combine them into a workable schema tailored to perform selected functions in an optimal way. Accordingly, the methodological framework (i.e. the range and combination of methods) needs to evolve and will be re-defined and refined throughout the process through testing and the views of key stakeholders. This will be undertaken in WP4.

Methods for Assessing Risk and Resilience

In recent years, and across numerous disciplines, many indices and frameworks have been developed which seek to standardise methods of assessing the properties of resilience, including CIR[1]. However, as one commentator observed, 'in general, these measures employ different definitions of resilience, they are constructed using dissimilar constituents (indicators or variables), they are utilised for different purposes – and as a result they ultimately measure different things. Even a basic exploration of what might

[1] For example see: Bruneau et al., 2003; O'Rourke, 2007; Fisher and Norman, 2010; Bakkensen et al., 2016.

constitute a measure (or index) of resilience, for example, reveals the difficulty in establishing a measure that is both accurate and 'fit for purpose''.[2]

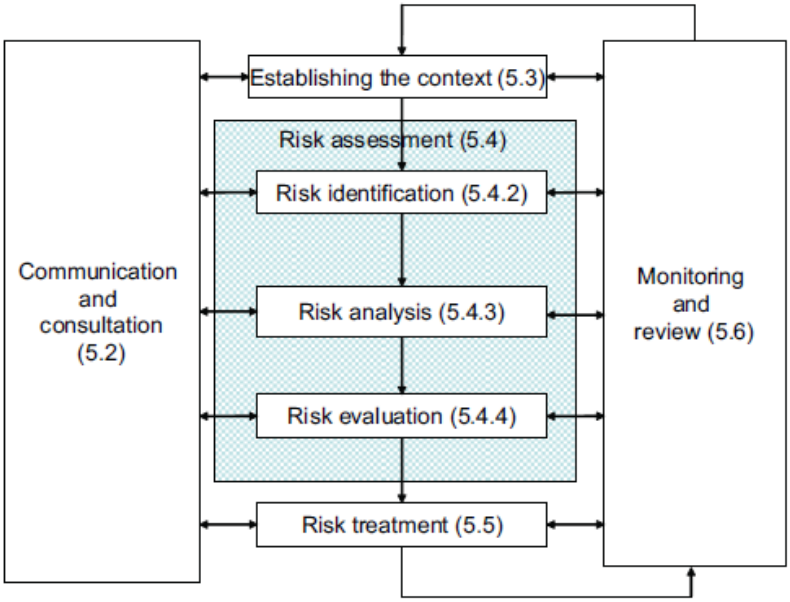
Whilst there is no agreed international measurement approach for resilience and CI resilience, there is broad agreement on *why* we need to measure it; to *characterise* resilience in context and articulate what it requires to implement, to *raise awareness* amongst individuals with the potential to contribute to resilience, to provide transparency for the *allocation of resources* for resilience, to *build resilience* as a means to address disruptive challenges and finally to *monitor policy performance*.[3]

In part, such ideas are addressed in existing risk management standards and guidance that currently assist CI providers and operators in seeking to reduce their exposure to risk. Notably, risk assessment matrices are often used by CI stakeholders (For detailed appraisal of how RESILENS is drawing on such measures see D1.3 and D2.1), typically based upon the approach outlined by the ISO31000 family of risk management standards, which advocate a risk-based process and understands risk as *'the effect of uncertainty on objectives'*.[4] Such an approach views risk management as a step-by-step process and provides a universal blueprint for its practice. As the World Bank notes, ISO31000 provides a 'universal paradigm' for risk management which is sufficiently broad to be used across sectors and contexts[5]

See Fig.2.1, below for ISO 31000's Risk Management Process:

[2]Prior and Hagmann, 2013, p.4; see also Hinkel, 2011
[3]Prior and Hagmann, 2013; Coaffee and Lee, 2016
[4] International Organization for Standards, 2009
[5] World Bank, 2012

Fig.2.1 – ISO 31000 Risk Management Process



ISO 31000 is a 'foundation document' for international risk management practice, acting as a universal standard for ensuring that risks are addressed in a similar manner across countries and industries.[6]Others have noted that this necessary broadness for application across many sectors means that it often fails to capture context-specific issues which are particularly important for resilience; this over-standardization can all too often promote a 'rigidity-trap' which limits adaptability and flexibility.[7]However, ISO31000 *is not* an approach for addressing resilience on its own, rather a way of preparing and responding to known risks; an approach which RESILENS seeks to extend through an examination and reflection upon system components which contribute to resilience through a cycle of prepare, prevent, protect, respond and recover, and the blending of these with risk management steps from ISO31000 (see D2.1 for further details of this approach).

A more nuanced approach to risk management is given by the European Commission's (2010) "Risk Assessment and Mapping Guidelines for Disaster management" paper, which advocates a semi-quantitative risk assessment approach, based upon some principles from the ISO 31000 series, and which aims to build a common European approach to risk management:

'The main purpose of these guidelines is to improve coherence and consistency among the risk assessments undertaken in the Member States at national level in the prevention,

[6] Little et al., 2012
[7] Rogers, 2013

preparedness and planning stages and to make these risk assessments more comparable between Member States. Coherent methods for national risk assessments will support a common understanding in the EU of the risks faced by Member States and the EU, and will facilitate co-operation in efforts to prevent and mitigate shared risks, such as cross-border risks.'[8]

Expanding upon ISO 31000 and incorporating relevant EU regulations including those related to flooding and critical infrastructure, the European Guidelines advocates the use of a risk matrix linked to a disaster management cycle and stresses the importance of 'common terminology' and 'shared understanding of concepts'. The guidelines also make the case for a multi-hazards and multi-risk approach and for wider consideration of potential cross-border impacts and multi-risk events. Within this context, it acknowledges that risk management is a multi-actor process and that the use of spatial risk mapping is essential to supporting this work. These understandings have informed the key principles underpinning the RESILENS tool development (for a detailed appraisal of this see D2.1, D2.2 and D2.3).

Within the associated context of disaster risk reduction, many have noted the intrinsic advantage of simple standards in promoting compliance and improved working, as opposed to quantitative, metrics; *'where general principles and quality standards are superior to metrics is in the flexibility they retain when applied across variegated local contexts.'*[9] However, there is also acknowledgement that whilst standards offer some additional flexibility, where they are insufficiently contextual they can create a 'rigidity trap' of over-standardisation that limits effective practice. This echoes some of the findings of WP1, which noted the importance of local context to resilience approaches, including social and organisational factors, but which were often overlooked as a result of the widespread emphasis on physical robustness, quantitative measures and 'locked-in' existing practices. By contrast, the RESILENS understanding of resilience sees it as an ongoing process that seeks to understand and adapt to the complexities of change and disruption, moving beyond the technical process of risk management and risk assessment and embrace the wider dimensions of resilience for assessing, quantifying or implementing the resilience of CI.

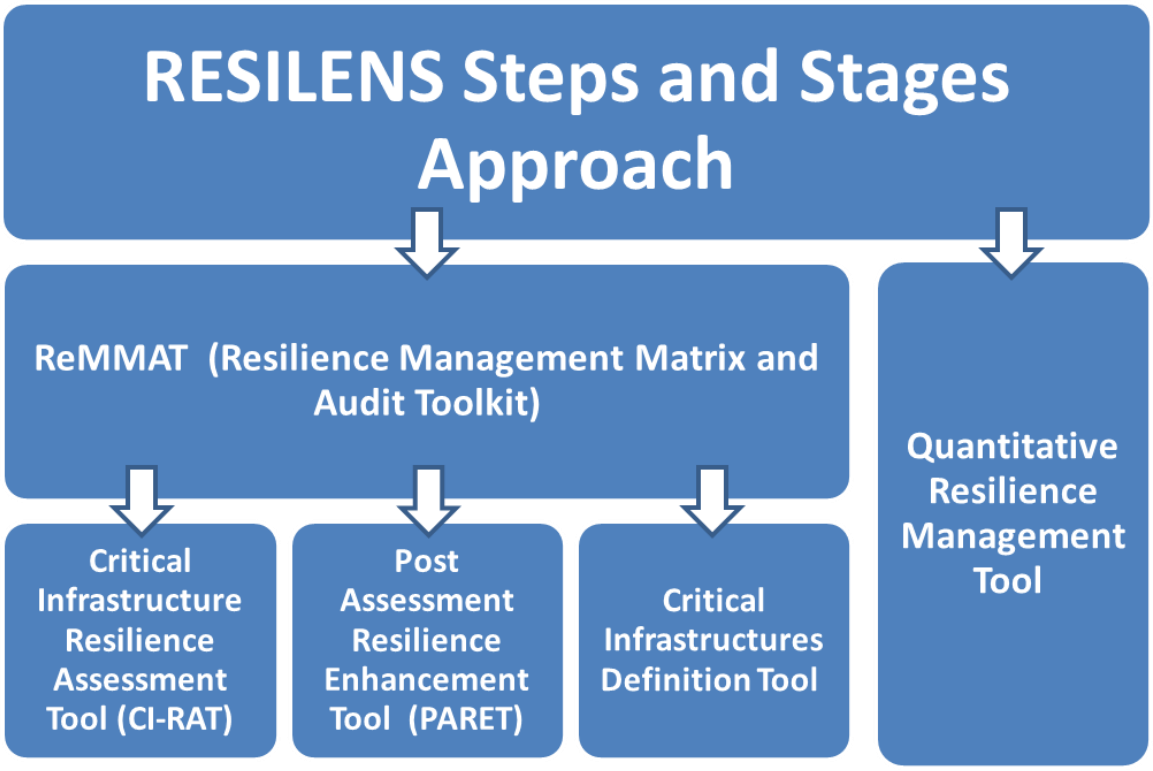
[8] European Commission, 2010, p.6.
[9] Rogers, 2013

3. Methodologies Underpinning the RESILENS Developed Tools

The aim of this section is to provide an analytical overview of all tools produced by the RESILENS project within WP2. This will focus on the details of methods utilised, the rationale for this approach, as well as reflect on the limitations and advantages of the given method and in particular, articulate how the tools move beyond the current state of the art. This process of aligning gaps and capabilities will then be used to inform the development of the draft ERMG.

As part of Task 3.2 we assessed the methodologies underpinning RESILENS tools (summarised in Table 3.1) – further details of which can be found in D.2.1, 2.2 and 2.3. Fig.3.1, below shows how the proposed tools are organised within the RESILENS project.

Fig.3.1. – Organisation of RESILENS Tools



RESILENS Steps and Stages Approach - A process oriented analytical resilience assessment approach based on resilience dimensions

This simple, process orientated approach to resilience assessment adopted by RESILENS builds on the widely applied and understood ISO standards for risk management, enhanced through the consideration of resilience for use in the complex systems of critical infrastructure. By using resilience management and analysis dimensions (e.g. resilience cycle phases, resilience domains, technical resilience capabilities, etc.),

combined with risk management steps from ISO 31000, the approach informs a process of resilience assessment of the systems under investigation. This extends traditional risk management and analysis approaches to reflect wider system resilience properties, rather than simply considering scenario specific risks. It also does it in a way that will be familiar to many within the CI industry, being grounded in well-used standards.

As such, different resilience dimensions can be adopted according to the use context. A flexible nesting of qualitative and quantitative approaches allows for the consideration of overall risk assessment measures as well as of single or multiple resilience dimensions including resilience properties, criteria or qualities, resilience phases or stages, resilience domains as well as technical and societal resilience capabilities. The possibility of using additional resilience dimensions in the future ensures flexibility.

ReMMAT (Resilience Management Matrix and Audit Toolkit)

The web based RESILENS resilience management matrix and audit toolkit (ReMMAT) is a combination tool of complementary methods, encompassing a suite of functionalities developed in WP2 and is designed to operate in logical progression as a "single functioning unit" to achieve the overall goal of providing a resilience assessment function, resulting in the scoring of the resilience level of the CI system evaluated. In addition to this, the resilience evaluation function of the toolkit also provides an indication of the most relevant stages of the resilience cycle that the CI operators can focus on, as a means to further improving their resilience levels. The ReMMAT also contains an audit tool aimed at providing guidance to the CI operators on the interpretation of their obtained resilience scores, how to use the scores, and to support the incorporation of organisational, societal and political considerations for developing implementable resilience enhancement strategies. In addition, a GIS visualisation of the resilience of investigated CI assets or systems is provided in the ReMMAT toolkit which is linked to the resilience scores, and supports the CI operator/owners understanding of the spatial resilience status of the different investigated assets in their CI system.

The Critical Infrastructure Resilience Assessment Tool (CI-RAT) (presented in D2.2)is the main resilience assessment tool in the toolkit. This digitised semi-quantitative assessment tool is what comprises and is referred to as the ***Resilience Management Matrix Tool*** in the RESILENS toolkit. In addition to the overall score provided for the investigated CI, drilled down scores on specific CI components, stages and domains which may be of particular interest to the CI operator can also be obtained from the matrix tool results.

The CI-RAT is devised to provide critical infrastructure operators with a way to evaluate the resilience of their infrastructure, according to the project's resilience concept. This

approach is based on three key resilience management steps: (1) The processes taking place prior to the disruption – *prepare, prevent and protect*; (2) The processes taking place during the disruption – *mitigate, absorb, adapt* and (3) The processes taking place after the disruption – *respond, recover and learn*. The tool provides a scorecard in which a semi-quantitative assessment is performed in relation to a variety of measured items. It enables assessment of resilience based on each of the operator's three resilience management steps and their components.

The digitised CI-RAT approach used in the toolkit is based upon the widely-used UNISDR Disaster Resilience Scorecard for Cities, which uses a self-assessment process that is widely understood, relatively simple, flexible and hence can be adapted contextually. One criticism of the scorecard approach is that it can be time consuming. To overcome this, the resilience management steps developed in the project (D.2.1) are converted into three 'requisites' in the assessment tool, which simplifies the process and makes the components of the assessment bespoke to the CI sector. Each of the three requisites includes secondary fields called 'components', each of which includes 'items measured' together with succinct descriptions. The assessment of each item is based on 'six assessment criteria', classified from 5 to 0, with 5 representing the fullest achievement of the criteria and 0 representing the least achievement. This approach allows individual CI operators/owners to focus on specific aspects of CI or their own priorities within the defined system.

Given the potential resource limitations of CI operators, CI-RAT adopts a semi-quantitative approach. This allows CI operators/owners to draw upon quantitative measurements where available, to make informed estimates and to draw together both the quantitative and qualitative measures, which the SOTA report (D.1.1) identified as critical to move forward traditional approaches to risk assessment (see D2.1 for further details). Together these provide operators/owners with a situational picture of the resilience of their systems and sub-systems, represented by a numerical score, in a manner that is straight-forward and easy to use.

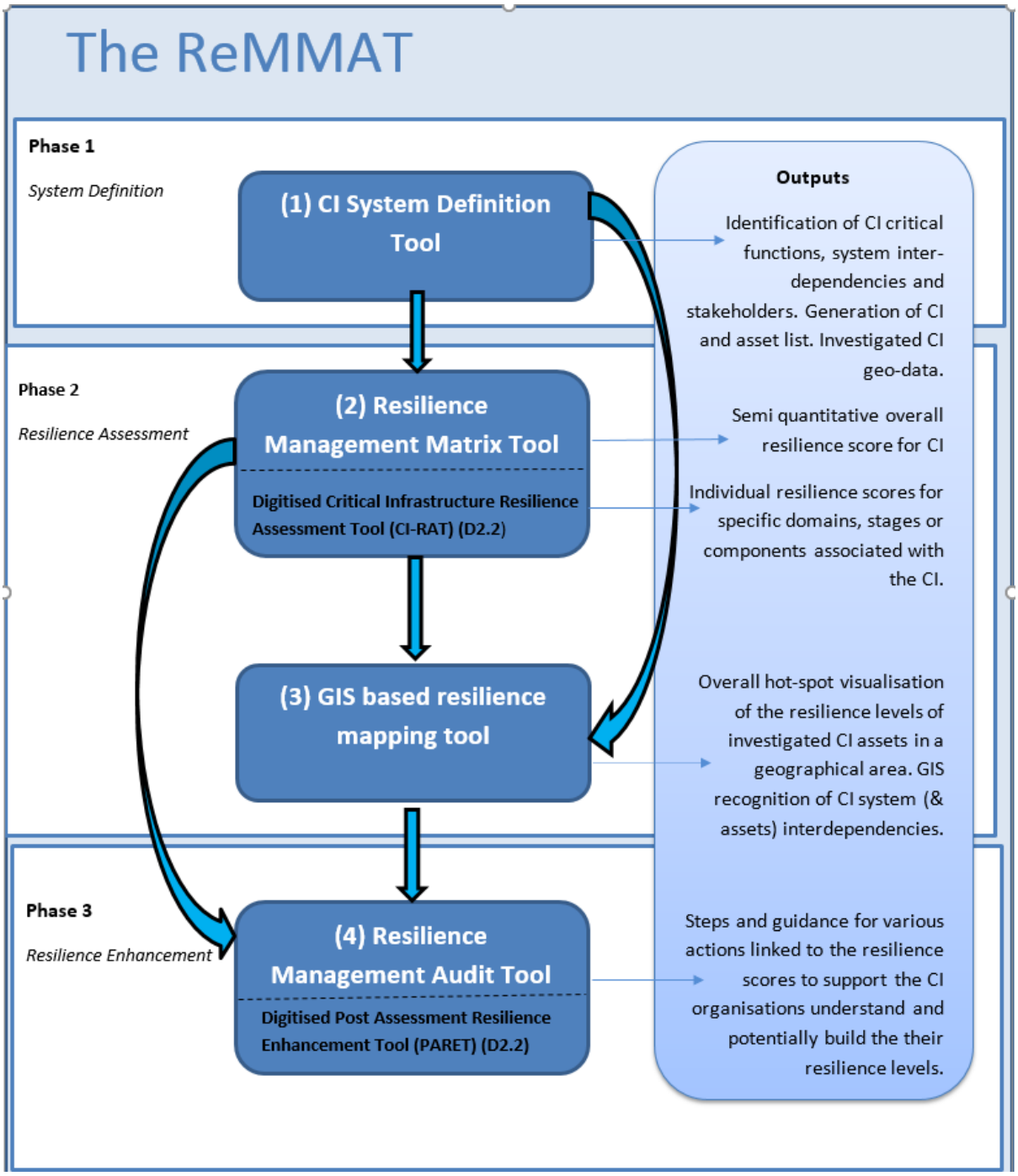
To facilitate an understanding of the obtained resilience scores, resilience concepts and how these affect the CI operations, an additional functionality is provided for in the toolkit via a qualitatively-based methodology audit tool associated with the matrix tool. The Post Assessment Resilience Enhancement Tool (PARET) presented in D2.2 was adopted and digitised for use in the toolkit to provide an audit function. This tool will be applied across each of the stages of the resilience components, stages and domains identified in the Matrix tool and contain steps and guidance for potential organisational actions that can be applied to help build the resilience of the investigated CI system or of a particular asset. The digitised qualitative support tool developed and presented in Task 2.3 was therefore further refined to meet this goal and is referred to as the ***Resilience***

management audit tool. The aim of this tool is to provide CI providers with an understanding of the significance of resilience scores obtained through the use of the matrix tool, and thus provide opportunities for organisational learning. To do this it assists users to interpret what the scores mean, and how to use the scores as a basis to improve the resilience knowledge of their CI operation, as well as supporting the development of strategies to enhance the resilience levels of their CIs.

There is a potential limitation that if used independently the matrix tool could allow CI operators to simply focus upon individual components up the "pre-defined resilience scale" without any context as to its relation to other components or the implications of external factors on the resilience components. In order to address this concern, the audit tool requires users to further reflect upon into their responses, prioritise specific system functions, reflect upon contextual concerns and evaluate organisational responses in a qualitative manner. The audit tool component of the toolkit therefore also incorporates steps which call for the identification of cross linkages of the different resilience items with other components to which they are related. Accordingly, the impact of external societal, political and situational considerations can be incorporated to understand the impacts upon specific resilience components, as well as providing a wider evaluation of the CI system.

Thus the combination of the two tools, qualitative using the audit and quantitative from the matrix tool, working in tandem will deliver a more holistic resilience approach, identified in WP1 as key to advancing practice. An overview of the different component tools and their respective outputs in the ReMMAT are shown in Figure 3.2.

Figure 3.2. An overview of the Resilience Management and Matrix toolkit (ReMMAT)



The combination of a semi-quantitative methodologically backed resilience scoring tool was selected for use in the RESILENS project since this would provide a tangible output which most CI operators/owners (who usually have a technical background) can relate to. Supporting this assessment output, an in-depth qualitative method was employed since the analysis of the resilience scores will depend on the particular situational and

subjective organisational human considerations which will be required for any decision making process related with intended resilience improvement actions in the CI.

Furthermore, prior to the use of the resilience assessment tool of ReMMAT, a ***CI system definition tool*** is available in the toolkit. The CI system definition tool aims to identify the scope and boundaries of the CI systems to be evaluated (including level of coverage), providing a description of systems, an identification of the critical assets and functions of the CI, as well as highlighting potential interdependencies and existing trans-boundary relationships with other CIs.

The outputs of the REMMAT are further enhanced by a **GIS based resilience mapping tool** (Mapping tool) which provides a visualisation function linked to the outputs of the Matrix tool, utilising the obtained score to provide a hot-spot indication of the resilience levels of investigated CI assets or systems in a given geographical area. The Mapping tool is intended to assist the CI operators/owners obtain a better overview of the resilience of their systems and a clearer understanding of potential impacts of disruptions of evaluated critical assets, as well as aid an overview visualisation of any available system interdependencies associated with the evaluated CI.

Quantitative Resilience Management Tool

Where the ReMMAT toolkit uses a semi-quantitative self-assessment method to assess resilience, the purpose of the Quantitative Resilience Management Tool developed in the project andput forward in D2.2, is to provide quantitative evaluation of systems through their resilience 'domains' that that complements the other toolkit approaches, further helps to define the system at to reduce subjectivity.

The quantitative tool approach considers both those characteristics of the system resilience that cannot be mathematically evaluated and those that can be quantified by means of numerical indicators. This methodology advances on existing approaches, which only manage either subjective assessments, or numerical indicators, resulting in an incomplete estimation of the holistic concept of resilience.

This tool allows the minimisation of the subjectivity of the assessment, as well as analysis of the evolution of the system resilience over time. The conceptual framework is designed to determine partial resilience scores, namely, (i) the resilience associated with each state, i.e., resilience in preparation, prevention and protection, resilience of response, and resilience of recovery, and (ii) the resilience associated with each level of study, i.e., the physical, the operational and the organizational levels..

The main difficulties of this methodology are;

1. The identification of the most relevant indices and characterisations (I&C) describing the system, given that a complete scrutiny of all the I&C is impractical. The larger the number of I&C included, the more difficult and time consuming the tool will be.

2. The selected I&C should not overlap information, in order to avoid the consideration of the same aspects several times, overweighting their importance.

3. The numerical evaluation of the characteristics in an objective manner.

4. The selection of the most suitable weights to combine the selected I&Cs.

A chromatic scale is used for the sake of simplicity, as it allows a straightforward identification of the weaknesses and strengths of the system.

The methodology guarantees the following requirements;

(a) Simplicity of the method, allowing its application by primary users.

(b) General approach, enabling its application to different type of systems.

(c) Scalable, guaranteeing its validity for systems with different complexities.

Although not contained in the web-based toolkit, the quantitative resilience quantitative methodology is expected to be applied by CI operators who are interested in specifically applying such approaches for the assessment of the resilience of their (mainly technical) CI assets or systems. The quantitative tool might therefore not sit alongside the component ReMMAT tools, but is important nonetheless.

A Methodological Sequence

Within the context of the RESILENS project which promotes a variety of different methodological approaches, a methodological framework is primarily about the sequence of approaches used. Accordingly, Figure 3.2 illustrates the RESILENS tool process through a flow diagram.

Mirroring the risk management approach of ISO31000, the first phase of the RESILENS tools resilience evaluation and enhancement processes involves defining the system context, including the critical functions and assets, assisted by the ReMMAT and potentially supplemented by the Quantitative tool. Where the SOTA and Gap analysis noted that such a process could be hampered by differing understandings of risk and resilience, a role emerges for the ERMG to provide common terminology and concepts to this work. The second phase of the RESILENS approach diverges from convention risk management approaches by allowing the user to asses resilience through a semi-qualitative self-assessment matrix, hosted by the ReMMAT that provides different scores and indicators for different aspects and domains of resilience. This tool also provides hot-spot visualisation of interdependencies through the GIS mapping function. Once again there is potential for the ERMG to supplement this work by providing more

detailed guidance on the assessment criteria. Finally, the audit function of the ReMMAT allows users to further investigate and reflect upon key resilience criteria, with the ERMG potentially providing signposting to further bespoke learning.

Together these different tools, components and functionalities provide a holistic, one-box approach to enhancing CIR based upon a common approach, shared understanding of resilience and with an understanding of potential outcomes across a range of domains and spatial scales, that can be readily actioned by CI operators. The operation of the toolkit as a single functional unit will limit any confusion associated with the use of multiple tools and can be used as a "one stop" toolkit for the CI user; see Table 3.1, below, for a summary of the individual tools purpose, methods and user benefits.

Table 3.1 – Summary of RESILENS Tools

TOOL	Purpose	Method	Benefits
Steps and Stages Approach	Process orientated resilience approach for the RESILENS project, based on analysis of resilience dimensions.	Extended risk management approach (adapted from ISO 31000).	Flexibility and simplicity.
ReMMAT	Resilience management matrix and audit toolkit for critical infrastructure.	Various.	Multi-sector, flexible approach.
Matrix tool component (CI-RAT)	Critical infrastructure resilience assessment.	Semi-quantitative, check-list	Simplicity. Incorporates both quantitative and qualitative measures.
Audit tool component (PARET)	Post-assessment, resilience audit and enhancement.	Qualitative	Allows interpretation and prioritisation of CI-RAT outcomes, as well as more general reflection, focus on contextual concerns and organisational learning.
Quantitative Resilience Management Tool	Provides a comparable and replicable measure of CI resilience.	Quantitative	Allows system definition, benchmarking and comparative measures.

4. Critical Reflections on Existing and Proposed Methodologies

The purpose of this penultimate section is to reflect and critically assess the methodologies and ideas underpinning the RESILENS tools, how they compare to other approaches currently in use, identifying areas for further work and how these understandings will shape the ERMG.

As we illuminated in D.1.1 and D.1.3, a number of generalised observations can be made about the methods currently in use for calculating resilience, principally the absence of standard approaches, with a number of highly-complex, technical and sector specific methods adopted. These often, overly quantitative, approaches are thus highly infrastructure specific and limit cooperation between sectors, as well as leaving social or organisational approaches too often overlooked.[10]Finally, it could be argued that there is too little organisational learning. This was characterised as the limitations of critical infrastructure protection (CIP) approaches, highlighted by recent disruptive events, cascade failures and in particular the vulnerabilities of 'cyber physical systems'. More broadly, CIP is characterised by its focus upon single domain, highly technical, single sector approaches and often limited spatial scales, typically leading to attempts to enhance the physical characteristics of CI sites. Within this context, RESILENS seeks to move beyond traditional notions of CIP, towards critical infrastructure resilience (CIR), which addresses the ongoing need for resilience processes to ideally be both multi-scalar and multi-dimensional, through advancing such a 'fit for purpose' assessment framework. This is premised upon thinking and acting strategically and in so doing, drawing in a wide range of related stakeholders into a collective and collaborative effort where technical elements are fused with social and organisational requirements.

Increasingly, there is evidence of a growing global interest in the assessment of resilience with a number of core ideas emerging that provide a relatively consistent set of largely quantitative approaches (mainly for cities but increasingly for critical infrastructure) to develop their resilience strategies and assess how prepared or exposed they are to varying threats. Whilst quantitative indices and indicators provide an important tool for decision makers by reducing complexity in measuring progress and setting priorities, many technical and conceptual issues remain unresolved, there validity for enhancing resilience is often not substantiated by empirical evidence[11].

Approaches such as the 4Rs, which uses robustness, redundancy, resourcefulness, rapidity as key performance indicators, have attempted to broaden approaches beyond technical measures, but their quantitative focus remains. Similarly the use of matrix

[10]Chang, 2009; Cutter et al., 2010; Winderl, 2014; Coaffee and Lee, 2016.
[11]Cutter, 2008;

methods has advanced this approach through the integration of new indices and dimensions for resilience. However, there is a suggestion that these approaches can be normative, discourage necessary adaption and lead to the focussing of resources on 'easy wins' rather than the more holistic conception of resilience that RESILENS seeks to promote. Many of the existing indices exhibit significant shortcomings in terms of robustness and problems in relation to the aggregation of data to different scales. Existing assessment frameworks serve to simplify an inherently complex resilience process, often as a result of time and resource pressures, and thus often only 'measure' relative resilience (for example one neighbourhood versus another) rather than the risks faced and capacity to cope in any one area (absolute resilience)[12]. As other have noted:

'*While an index of overall system performance has utility for comparative purposes, communities are complex systems that perform many functions for which aggregation may obscure relevant results.*'[13]

Moreover the current assessment processes, given their bias towards quantitative indicators and to parameterisation, often using arbitrary indicators and associated weighing to create an amalgam of several core indicators; more recent empirical testing of these indicators, has shown highly variable success in promoting resilience.[14] Further, the use of such indicators is often a complicated and time consuming task and 'assumes an in-depth knowledge of the way particular behaviours, structures, policies, etc. contribute to the resilience of the entity under examination'.[15] It also assumes appropriate data is readily available and consistent for the system to be assessed across a defined geographical area. Overall, greater importance should be placed upon context, scale and risk specificity in any measurement of resilience.

The limitations of these predominantly quantitative approaches have led to the development of more flexible approaches, that utilise self-assessment and can be used with differing available data, such as 'scorecards'. The most prominent of these is the UNISDR scorecard for cities (10 sections, includes 82 measures and is 56 pages long) which requires considerable commitment and resources for initial completion, notwithstanding that this will become a periodic exercise as urban resilience is seen as something to work towards with the scorecard expected to highlight improvements through a new public management framing and indicates the high degree of professionalization and information management required[16].

[12]Prior and Hagmann, 2013
[13]Bakkensen et al., 2016, p.17
[14]Bakkensen et al., 2016
[15]Prior and Hagmann, 2013
[16]Coaffee and Lee, 2016

Perhaps worryingly such approaches can privilege a prescriptive blue-print or one size fits all model of assessment, implicitly tied to furthering growth and development, and embedding local need within a broader national context. Conversely, whilst the assessment of resilience has been heavily influenced by quantitative approaches to risk assessment often associated with material aspects of resilience, there has been a recent shift towards approaches that promote more holistic approaches to the development of assessment frameworks and indices (such as RESILENS).

Whilst many existing assessment 'tools' provide a broad and scalable baseline measure of resilience that might be of interest to policy makers, and indeed further illuminate the requirements for CIR, they are currently developed at a level of abstraction that does not fully account for context. It is therefore an issue of the combinational, dynamic and evolutionary nature of CIR that requires measurement – a task perhaps better undertaken through a mixed method approach involving quantitative and qualitative measures to study the impacts of infrastructure disruption in situ – and to combine this with a generalised framework or index of resilience that provides a relative aggregated picture of exposure to disruption. Notably it is often difficult to 'quantify resilience in absolute terms without any external reference with which to validate the calculations' and that 'baseline indicators provide the first 'broad brush' of the patterns of resilience within and between places and the underlying factors contributing to it'. Here 'a second step is a more detailed analysis within jurisdictions to assess place-specific capacities in each of these areas (social, economic, institutional, infrastructure, community) and the development of fine-tuned and local appropriate mechanisms for enhancing disaster resilience'. [17]

Existing resilience assessment approaches therefore need modifying to enable recognition of capacities and capabilities in addition to physical risks. They need to avoid silo thinking, capture perspectives of a range of stakeholders, better represent interrelationships between different aspects of resilience and, capture the multiple scales at which resilience can be encapsulated. Capturing key resilience performance indicators in an ongoing holistic way to address current and future infrastructure challenges, as the RESILENS tools seek to do, is a critical task but is by no means an easy one, especially given the lack of an agreed international measurement approach.

[17] Cutter et al 2010, p.18

Evaluating a Scorecard Approach to Resilience

The ability to respond to natural shock events and to improve Disaster Risk Reduction (DRR) is emphasised in a number of resilience indices and frameworks developed by global organisations such as the United Nations Office for Disaster Risk Reduction under their International Strategy for Disaster Reduction (UNISDR). A number of core principles have underpinned this work and feed through into the UNISDR resilient cities campaigns – seen as a key comparator for FCT 15 Research Actions. Such formalisation and prescription for assessing city resilience is evidenced by the 'Disaster Resilience Scorecard for Cities' to measure the preparedness of cities to cope with shocks. Here the aim is to support public policy decision-making and create a set of standardised tools and approaches to the business of resilience making. In such approaches, the core aim of reducing underlying risk factors through an ethic of prevention feeds into the building of institutional capacity to ensure risk identification, assessment and monitoring are core components of this approach as is the building of a culture of safety through understanding and awareness, knowledge transfer, innovation and education.

In this approach, local priorities are self-assessed by municipalities using a Local Government Self-Assessment Tool for Disaster Resilience scorecard (UNISDR, 2012) which assesses cities and municipal authorities' preparedness for disaster against ten 'essential' criteria. As preparation for this work, the UNISDR approved scorecard facilitates the setting of local baselines and the identification of gaps by local authorities grading each of their ten 'essentials' against 82 separate indicators measuring the degree of resilience and necessitating systematic adoption of resilience codes of governance practice to provide such level of detail.

Within this context, the initial findings of EU-funded 'Managing Urban Risks in Europe: implementation of the City Disaster Resilience Scorecard (U-SCORE)' project[18] are highly relevant to the development and adoption of the ReMMAT (especially the matrix tool component) approaches. A number of observations can be drawn from the UNISDR report 'U-SCORE: Lessons learned from conducting self-assessments on disaster risk reduction at the local level in Europe' based upon stakeholder experiences of using the standard UNISDR scorecard criteria (rather than the adapted version developed by RESILENS in the ReMMAT matrix tool)[19].

[18] U-SCORE was launched in 2015 to pilot the UNISDR Disaster Resilience Scorecard in cities across Europe. These were: Amadora and Lisbon, Portugal; Salford and Stoke-on-Trent, UK; and Jonkoping and Arvika, Sweden, whilst the project also engaged the Portuguese National Authority for Civil Protection, the Swedish Civil Contingencies Agency, the UK Cabinet Office and Department for Communities and Local Government.

[19] These observations are also drawn from the Greater Manchester (GM) report 'Greater Manchester's baseline measurement of the current level of disaster resilience measured against the draft "Disaster Resilience Scorecard for Cities"' and supported by stakeholder interviews conducted by the University of Warwick.

Foremost amongst the comments, was a concern that the process was both time and resource intensive. However, it was also noted that this process of collaboration was actually more important than any numeric outcomes generated. Critical to this was a collaborative approach to completion of scorecard entries, based upon, broad multi-stakeholder workshops, with sector-led discussions and expert practitioners contributing to individual sections, all validated by the multi-stakeholder group. It was adjudged that this engagement process had 'promoted a broad understanding of contributors to resilience' amongst participants and 'enabled stronger and more comprehensive' relationships to between stakeholders who have previously been disengaged, e.g. the gas industry. Similarly, it was noted that the process of completion had broadened many stakeholders understanding of resilience, promoted inter-agency discussion and learning, as well as fostered better relationships with wider agencies. This highlights the critical importance of how the tools engage stakeholders, rather than simply the factors it asks them to consider.

In addition to being time consuming participants highlighted a number of further limitations of the scorecard around the difficulty capturing the 'connections, linkages and dependencies' of systems, and in particular the social and organisational factors which are key to RESILENS transformational understanding of resilience. Similarly, they noted furthers challenge around CI and the variations in ownership of assets (including data) between public and private, or even between private companies with competing interests. Potentially such issues around the control of assets could be reviewed through the audit function of the ReMMAT.

Conclusions from the U-SCORE project regarding the use of a self-assessment scorecard noted that 'resilience cannot be an accurate predictive science' and that the strength of the scorecard-approach was in helping to build capacity to 'resist, absorb, accommodate and recover', rather than to eliminate risks altogether. Further, that the scorecard was only the beginning of an 'ongoing process' which required 'regular monitoring and reporting'. Particularly relevant to the ERMG and RESILENS e-learning resource, it was found that by giving stakeholders examples of successful case-studies, applicable to the different essential/criteria, it had helped build 'stakeholder buy-in' and generated better completions. Finally, it was noted that the scorecard was often poor at capturing local and contextual information, for instance where 'work arounds' to particular problems existed; making the RESILENS toolkit contextually appropriate will be a critical challenge going forward.

5. Methodological Principles for the ERMG

As outlined within the introduction, the wider purpose of this deliverable is to identify the requirements of the ERMG, as well as how it will be deployed, including a collective approach to tool development and to highlight some overarching principles for going forward.

The methodological foundation of RESILENS, is based upon a flexible nesting of quantitative and qualitative approaches, and bespoke self-assessment processes using semi-qualitative measures that allow users to tailor their resilience enhancement according to their own system needs. Key to this is the sequence of methods outlined in Section 3, which begins with the establishing of the system context and allows users to focus upon their own resilience priorities. The priority of the ERMG will be to enhance this process, allowing flexible and context-specific engagement with the most appropriate criteria or essentials, with tailored organisational learning. Thus the intended purpose of the RESILENS ERMG is to provide a flexible approach to building resilience which can be used by a single CI sector (or ideally a wide combination of CI sectors) and as an infrastructure management approach to enhance the infrastructure preparedness to be potential disruptions to their core services within a locality.

Within this context, the preceding sections of this report have included a number of important reflections, which highlight the need to move towards a critical infrastructure resilience (CIR) approach. This also builds upon the EC's "Risk Assessment and Mapping Guidelines for Disaster management" requirement for 'common terminology', 'shared understanding of concepts', and understanding of potential cross-border impacts and multi-risk events.

More widely the shift towards CIR requires the development of more *proactive* approaches based upon greater foresight and the move towards a *socio-technical* understanding of the system. Such a holistic approach requires integrated governance, moving beyond a single-sector focus and incorporates both top-down and bottom-up approaches.CIR therefore requires engagement and collaboration between wider stakeholders, the inclusion of social, organisational and behavioural factors, and the promotion of ongoing learning and innovation. To do this successfully, there is a need for a simple usable approach with appropriate measures and guidelines.

This understanding highlights a critical challenge for the ERMG; whether to provide a more mandatory standard or a more advisory form of guideline? If we are to reflect upon the best methodological approach for the ERMG, it is important to make a number of observations. Foremost, it has been repeatedly identified that an understanding of local context is critical to both resilience and risk management approaches, however D1.3 identified how standards often struggle to capture the flexibility required to

operationalise the principles of CIR. Similarly the format of a standard tends to be either too specific, limiting its applicability, or, too general, making it vague. Accordingly, there is consensus across the consortium of the need for a guideline approach, which should present a systematic yet flexible means of operationalising the resilience management process developed under RESILENS. The RESILENS project therefore adopts a "guideline approach" instead of that of a standard for the ERMG. This involves the development of a number of key principles, with recognition of the unique and individual factors that impacts on their implementation in organisations, using our stakeholder organisations from water, energy and transport as case studies.

Stakeholder consultations, contained within D1.2 and D2.1, also yielded some important considerations for the ERMG, particularly around the need to articulate a simple process of resilience evaluation and audit. CI operators were especially interested in issues of viability and value for money, thus demonstrating financial benefits for approach and interventions, including time investments of organisations, was critical. By implication, methods that were overly time intensive, would not be used and thus a more appropriate ERMG format would allow them to select and concentrate on their particular area of interest. Related to this issue, once again it was highlighted how important context is to both CI and wider resilience enhancement, particularly for the consideration of social and organisational factors. Finally, any approach should be easily repeatable and based upon a standard process and terms.

Finally, the critique of proposed methods also uncovered a number of key principles for the ERMG. Foremost, was the need to move beyond complex, technical and specialist understandings of resilience; not only are such approaches overly time and resource intensive, but the high-degree of professionalization limits their wider applicability between organisations and wider sectors. More damningly, they are typically reliant on inconsistent data that is used to build arbitrary indicators. By contrast the RESILENS ERMG approach should take a simple, non-specialised semi-qualitative approach, using numeric guidance measures of largely quantitative data that is constructed through collaboration amongst stakeholders. Such collaboration builds a shared understanding of social and organisational capacities and capabilities for resilience. Furthermore, the proposed ERMG will also allow for a deeper exploration of difference resilience foci, including contextual considerations and the systems connections, linkages and dependencies. The developed ERMG will therefore serve as the principal mechanism which CI operators interested in improving their resilience of their systems can apply.

Given these requirements, it seems highly appropriate that the RESILENS ERMG is centred upon the stages and phases approach outlined in D2.1 (which is, itself, based upon the widely adopted ISO standard) but as a simple and logical way to extend existing risk management to encompass resilience within CI. This promotes an

understanding that the ERMG is a process, which takes users through a variety of bespoke tools, learning opportunities and signposts towards key sources of guidance, with the aim of enhancing the resilience of the CI system. Together, these understandings provide a clear direction of travel for the development of the ERMG and some key principles for getting there.

6. Summary and Next Steps

As a conclusion to this work, it is important to take on board the critique of methodologies utilised by the RESILENS tools and reflect upon the implicit advantages and disadvantages proposed, as well as considering how the suite of tools complements each other. The overarching steps and stages approach builds upon the known ISO standards and provides a well-understood rationale, with flexibility and simplicity. More widely, the suite of tools contained within the ReMMAT provides variety of methods and approaches that are suitable to different sectors, scales and systems. In addition to this, the Quantitative tool developed by the RESILENS project offers benchmarking and comparison. However, it is the components tools of the ReMMAT that are considered as essential to the RESILENS methodology; the scorecard format of the matrix tool (digitised CI-RAT) provides a simple approach utilising quantitative and qualitative data, whilst the audit tool (digitised PARET) allows further reflection and focus upon contextual concerns and organisational learning.

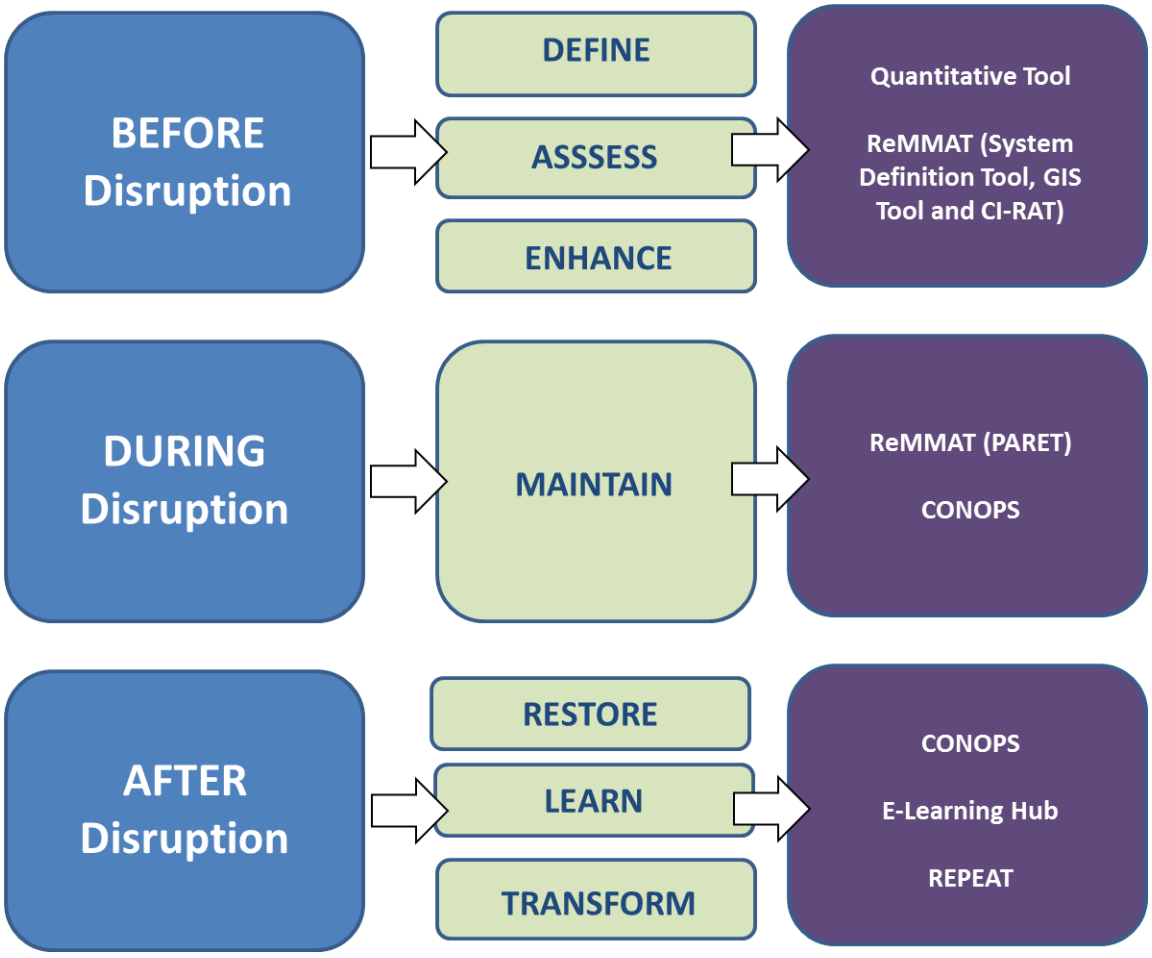
Going forward, this report highlights a number of issues for the development of the ERMG; foremost, is that the developed ERMG will provide important guidance on the terminology, concepts, relevant stages and steps associated with resilience management in CI. It will identify and contextualise resilience concepts in a form which can be easily adopted by CI operators to support their resilience management goals. The ERMG will further act as a sign post to the useful resilience evaluation and enhancement tools which could be implemented by the CI operators.

Regarding the use of the developed tools along with the developed ERMG, the understanding that the process of completing the resilience assessment and audit, typically in collaboration with other stakeholders, can often be more fruitful than simply the outcomes or scores generated should be noted. Thus a key challenge for future Tasks will be to attempt to capture this understanding. Similarly, there needs to be further clarification of the role of stakeholders, both internal and external to CI organisations, within the RESILENS process. Finally, a key challenge will be to evaluate the ‘validity’ and effectiveness of the different criteria in promoting resilience.

The ERMG provides a comprehensive guide to resilience within the CI sector, providing not only a common understanding of concepts, but also directs users to resources which can enhance their resilience. Critical in this is the sequencing of the toolkit, which will be informed by the ERMG through the use of steps and stages/essential criteria to guide CI users to the most appropriate methods for enhancing CIR; the RESILENS process begins by establishing the context of the system or system, before evaluating its resilience using the essential criteria and reflecting upon the spatial consequences using the GIS

mapping tool, before conducting a deeper examination of resilience priorities using the audit functions. Within this process the ERMG both foregrounds critical information and common understandings, but also provides bespoke signposting to learning and further guidance through RESILENS tools (including the CONOPS approach being developed in WP5), and proposed training resources which allow users with different resilience interests and priorities to engage with this wider resilience process at different stages. This is highlighted in Figure 6.1.

Figure 6.1 – ERMG Signposting



The development of a draft ERMG will be continued through Task 3.3, with subsequent work-packages carrying out table-top testing and further iterative refinement of the document.

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This document draws from the collected work of WP1 and WP2; consequently only supplementary references are listed below.

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