The **CLIMSAVE** Project

Climate Change Integrated Assessment Methodology for Cross-Sectoral Adaptation and Vulnerability in Europe

Report on assessment of vulnerability across Europe and the identification of vulnerability hotspots

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SEVENTH FRAMEWORK PROGRAMME

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0. Preface

The aim of this deliverable is to document a methodology for identifying hotspots of vulnerability that could be implemented within the CLIMSAVE Integrated Assessment Platform (IAP). The methodology builds on previous work in the CLIMSAVE Project. In Deliverable 5.1 a framework for assessing vulnerability to climate and socio-economic change was developed[1]. This framework, based on a wide survey of relevant literature, considers the impacts of both exogenous and endogenous pressures on a human-environment system, which could be a physical location (e.g. city, village, river valley, country) or a sector (e.g. agriculture, forestry, health). As a result of impacts, decision-makers could decide to mitigate (i.e. reduce the pressures) or adapt (i.e. take action so that in the future the vulnerability to the impacts of climate and socio-economic change is lower). Importantly, the framework developed in Deliverable 5.1 shows that the capacity to cope with exogenous and endogenous pressures, as well as the capacity to adapt, depend on the availability of five capitals: natural capital, human capital, social capital, financial capital and manufactured capital.

Deliverable 4.1 then reviews methodologies for assessing "adaptive capacity" and "coping capacity" and how they may be implemented within the CLIMSAVE IAP[2]. In D4.1 vulnerability is conceptualised in terms of the prospect of suffering a decline in well-being due to impacts that cannot be avoided given the available resources. Coping capacity is defined as the ability to deal with climate changes (including variability and extremes) as they happen. Adaptation is defined as the means of enhancing coping capacity and reducing vulnerability to future climate change; adaptive capacity as the ability to carry out such adaptation.

This deliverable describes the implementation of the coping capacity method as described in Deliverable 4.1 within the vulnerability framework described within Deliverable 5.1. Some modifications have been made in order to operationalise their implementation within the vulnerability screen of the IAP which enables users to map vulnerability hotspots for a selection of ecosystem services indicators (described in Section 2.3).

1. Introduction

Policy-makers and other stakeholders need to better understand the future impacts of climate change and the related vulnerability of human and environmental systems (Harley 2008). Current adaptation policy and practice is often myopic, focused on improving the ability to cope with current climate variability and on 'climate proofing' against short-term changes in climate risks (Brooks et al. 2011). Longer-term vision is needed and integrated assessment models combined with scenario analysis, such as in the CLIMSAVE project, represent one way of facilitating this. One of the main goals of adaptation is to reduce future vulnerability to hazards associated with climate change, taking account of possible socio-economic changes, and indicators are needed both to monitor progress in adaptation (process-based or upstream indicators) and to measure the effectiveness of adaptation (outcome-based or downstream indicators). Identification of vulnerability hotspots is an important form of outcome indicator, identifying where the important vulnerabilities lie and helping stakeholders to consider ways in which they might be addressed. Vulnerability is influenced by a wide range of factors - social, economic, political, cultural and environmental - and vulnerability indicators need to reflect this, while remaining feasible to calculate and implement.

[1] http://www.climsave.eu/climsave/doc/Report_on_Vulnerability_Framework.pdf
[2] http://www.climsave.eu/climsave/doc/Report_on_the_adaptive_capacity_methodology.pdf

Many attempts have been made to measure vulnerability at different scales, combining measures of exposure with measures of adaptive capacity under different scenarios at the global (e.g. Yohe et al. 2006; Brenkert and Malone 2005) and regional scales (e.g. Tate et al. 2010; Emrich and Cutter 2011). Assessments may be based on observations of recent severe events (e.g. Yohe and Tol 2002; Brooks et al. 2005), on surveys of experts (e.g. Alberini et al. 2006), or on indices justified on a mix of theoretical and empirical grounds (e.g. Metzger and Schröter 2006). Broadscale methods are useful for global assessments of mitigation, but their low resolution limits their usefulness as a guide to regional or local adaptation policy (Harley et al. 2008; Jones et al. 2010); Brooks et al. (2011) stress that the appropriate vulnerability indicators may differ between broadscale assessments of the number of vulnerable people and the value of vulnerable assets, and local analysis of policy options.

Füssel (2007) distinguishes between 'end-point' and 'start-point' interpretations of vulnerability. The former represents the (expected) net impacts of a given level of global climate change, taking into account feasible adaptations. The latter is more concerned with reducing internal socio-economic vulnerability to any climatic hazards. Both are considered within CLIMSAVE where the IAP can be used to assess adaptation to future climate change; the amount of adaptation that can be implemented within a scenario being determined by available adaptive capacity, which was identified by Füssel as a characteristic of the end-point approach. But equally, CLIMSAVE considers social adaptation and how the vulnerability of societies can be reduced by including socio-economic factors in the methodology for vulnerability assessment. Thus, one innovation in CLIMSAVE is seeking to strike a balance between these paradigms, integrating natural and social science perspectives, combining a risk-hazard approach with political economy considerations.

It is generally recognised that vulnerability is multidimensional and differential, varying across physical space and among and within social groups (Vogel and O'Brien 2004). However, few studies have focused on the vulnerability of particular sectors to climate and socio-economic change, and cross-sectoral approaches are rarely used. A sectoral approach to vulnerability assessment is set out in the framework proposed by Villagran de Leon (2006), but cross-sectoral interactions are not explicitly included. O'Brien et al. (2004) focused on three sectors, but did not examine cross-sectoral impacts. An indirect cross-sectoral approach to vulnerability assessment is described by Schröter (2009) who investigated vulnerability of several sectors to changes in ecosystem services resulting from a combination of climate and land-use changes. Cross-sectoral interactions can be considered via integrated modelling, as in the RegIS integrated assessment in the UK (Holman et al. 2005 a and b), examining impacts of regional climate change and socio-economic change on flooding, agriculture, water resources and biodiversity in East Anglia and north-west England. An important aim of CLIMSAVE has been to advance the treatment of cross-sectoral interactions in vulnerability assessment.

The CLIMSAVE approach is similar to the concept adopted in the A-Team project (Schröter et al. 2004; Metzger and Schröter 2006; Metzger et al. 2008) which constructed an index formed of 12 indicators underpinning 6 determinants of 3 components of adaptive capacity. The future values of the indicators were projected using estimated relationships between the indicators and GDP and population. CLIMSAVE differs in two main ways. Firstly, the theoretical justification is different, rather than focusing on "adaptive capacity" the CLIMSAVE approach is grounded in the concept of "coping capacity". Coping Capacity is a concept grounded in a five-capitals model of resource availability, with a clear focus on developing indices that reflect how individuals within society would be able to cope at the moment a crisis is revealed: how much of which capitals do they have to draw on? This directly addresses the critique noted by Schröter et al. (2004) in which the stakeholders were ambivalent regarding the A-Team index, accepting it as a first attempt to capture the regional context in which they make decisions, but with reservations regarding the choice of indicators used as components of the index, and because the adaptive capacity of individuals is not captured by the index. A further difference with the CLIMSAVE method is that we have addressed this potential ambivalence by drawing directly on stakeholder input, using scenario-specific projections of the capitals developed by stakeholders in participatory workshops. Furthermore, our projections are tied directly to the socio-economic scenarios, rather than driven by deterministic correlations with GDP and population changes (Schroter et al. 2004). The indicator variables used by the CLIMSAVE approach are selected to have a greater focus on individuals; for example personal savings and income are used rather than GDP. Taking account of these factors ensures the CLIMSAVE method is delivering something new and not solely focusing on either individual- or national-scale adaptive capacity. Instead our context remains firmly that of regional long-term planning, and we highlight the different factors influencing the ability to cope with the combined impacts of climate and socio-economic change across multiple sectors.

2. Method

2.1. The CLIMSAVE vulnerability index

The CLIMSAVE vulnerability hotspot approach aims to assess the spatially-explicit impacts of future scenarios on human wellbeing. To do so it breaks vulnerability down into three key elements: (i) the severity of the impact itself; (ii) the level of adaptation in place through specific management options to reduce the impact; and (iii) the extent to which humans are able to draw on their available resources (both tangible and societal) to cope with the impacts that remain: "coping capacity". Locations where the level of impact following adaptation is greater than society's ability to cope are considered vulnerable.

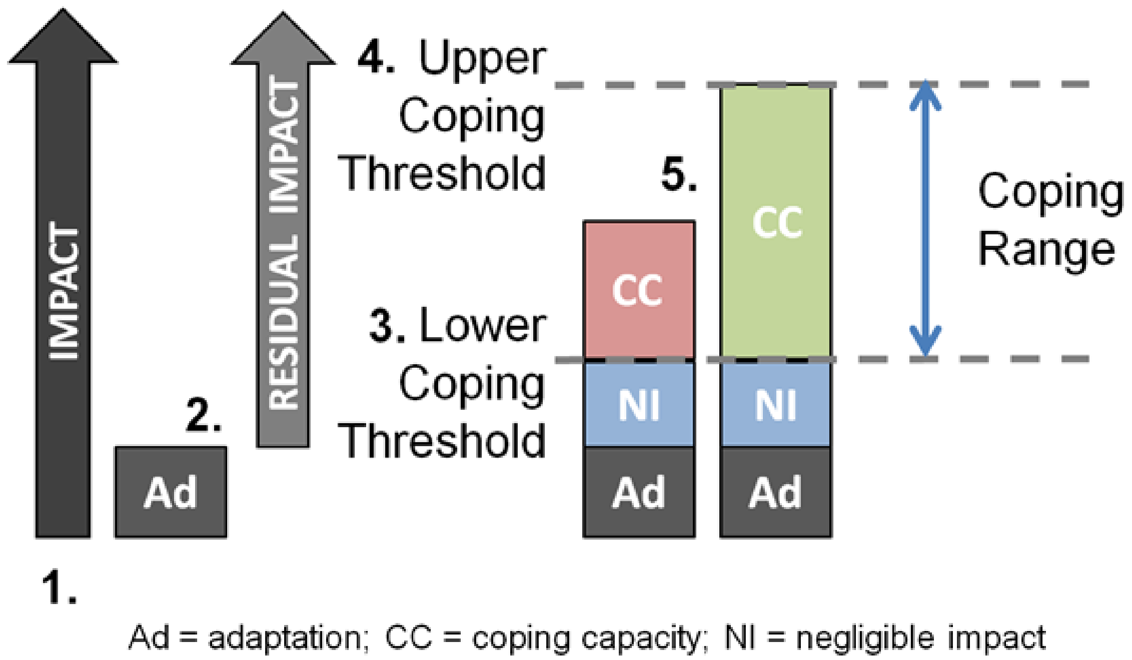


Figure 1: Schematic overview of the CLIMSAVE vulnerability approach.

Figure 1 illustrates how these elements are combined using output from the CLIMSAVE Integrated Assessment Platform (IAP). Impact is modelled using the IAP integrated modelling framework that includes models for a wide-range of sectors including urban development, agriculture, forestry, water provision, flooding and biodiversity. The user is able to map impacts for each of these sectors under a wide range of future scenarios by customising climate projections and socio-economic scenarios (1). Adaptation is represented within the IAP as a series of sliders which allow the user to modify the socio-economic scenario variables (for example, increasing the level of flood defence). Adaptive capacity changes with the socio-economic scenario and this is reflected by the different ranges within which it is possible to move the slider within different scenarios. The resultant impact following adaptation is termed "residual impact" (2). It is this impact that has the potential to affect human well-being. The extent to which well-being is affected depends on three further factors. The first, termed the "lower coping threshold" is the level of residual impact below which the impacts on human well-being can be considered negligible (3). This could reflect, for example, very small puddles or pooling resulting from flood water overtopping a dam. The second, termed the "upper coping threshold" is the level of residual impact above which there is no way that a society, no matter how resource rich, could cope without impacts on human well-being. Areas with impacts above this threshold will therefore always be vulnerable (4). Between the two thresholds is the "coping range", any residual impact within this range is referred to as a "significant residual impact" as it has the potential to contribute to vulnerability. Within this range vulnerability is determined by the available coping capacity. Coping capacity reflects the available resources, both tangible and societal, that are available to a particular society and in the CLIMSAVE project these are split into four capitals: human, social, financial and manufactured. A fifth capital stock, natural capital, is not included in our index because it is represented directly by the biophysical modelling within the IAP. Areas with greater capital coping capacity can endure greater impacts with some only becoming vulnerable once the upper coping capacity threshold is reached (5).

2.2. Quantifying coping capacity

Developing an index of coping capacity is challenging as there is a wide range of contributing political, social, economic and technological resources that could contribute to reducing the severity of impacts on human well-being. It would be impossible to measure all of them, and determine exactly how they combine and interact to influence the human capacity to cope with specific impacts. However, at a general level, the principal determinant of coping capacity, at whatever geographical or social scale, is access to the capital stocks: areas with more capital are expected to be better able to cope.

2.2.1. *Selecting indicator variables*

Twenty-three potential indicator variables (Table 1) were identified representing the four capitals. These potential indicators were analysed based on five guiding principles: (i) appropriateness, there must be a clear conceptual tie between the variables and the capital that they are used to represent; (ii) open access, the data used must be freely accessible within the public domain; (iii) independence, the selected variables must have a low correlation with the other selected indicator variables; (iv) fixed asset, resource stocks were preferred over flows and rates; and (v) spatial resolution, fine spatial resolution datasets were preferred over those at the country scale.

Eight variables were finally selected; two representing each capital (Table 1). These included four at the NUTS 2 level and four at the NUTS 0 level. All datasets were freely available and the majority of datasets were available from Eurostat (http://appsso.eurostat.ec.europa.eu), however, World Bank and Eurobarometer datasets were also used. For human capital, "life expectancy" and "tertiary education" were selected as they had the lowest correlation with the other variables considered (r=0.26) and clearly represented two key aspects of human capital: the health and education of the population. Social capital was the only capital for which no suitable high-resolution dataset was identified. Furthermore, the available datasets were mostly highly correlated. "Income inequality" and "help when threatened" were selected as they had the lowest correlation of all variables (r=-0.36) and represented two key aspects of social capital: inequality and community support. Furthermore, "help when threatened" correlated well with corruption perception, trust and volunteering metrics ($r \geq 0.62$) suggesting that the variable also represents other elements of social capital related to trust. Financial capital variables also showed high inter-correlations, and all variables, except "net household savings rate", had correlations ≥ 0.6. "Household income" was chosen as an indicator of financial capital because it reflects the general wealth of the population at a local scale, is available at the NUTS 2 level and correlates highly with national wealth (r=0.91 with GDP). "Net household savings rate" was selected, despite being a rate rather than a stock variable, as it had the lowest correlation with "household income" and reflected a conceptually different aspect of financial capital: potential long-term financial reserves. Manufactured capital variables were chosen to reflect two aspects of manufactured capital. The World Bank's "produced capital" variable describes the total sum of physical capital and urban land per capita, whilst "transport" data from Eurostat reflects infrastructure (road, rails and navigable inland waterways) that might be drawn upon to cope with a crisis. Transport data were standardised by area since standardising by population disproportionately privileged areas with low populations such as the Scottish islands. Transport and produced capital variables had a very low correlation with one another (r=-0.02). The correlation matrix for all variables is shown in Appendix A.

Table 1: Dataset overview showing the variables considered during the indicator analysis. The eight selected variables are marked with a tick (✓) .

	Variable	Spatial	Data Source	✓
Human	Life Expectancy	NUTS2	Eurostat	✓
	Tertiary Education	NUTS2	Eurostat	✓
	Longterm Unemployment	NUTS2	Eurostat	
	HRST (Human resources in Science and technology)	NUTS2	Eurostat	
Social	Income Inequality	NUTS0	Eurostat	✓
	Help when threatened	NUTS0	Eurobarometer	✓
	At-risk-of-poverty	NUTS0	Eurostat	
	Corruption Perception	NUTS0	Transparency International	
	Trust	NUTS0	Eurobarometer	
	Volunteering	NUTS0	Eurobarometer	
Financial	Household Income	NUTS2	Eurostat	✓
	Household Financial Assets	NUTS0	Eurostat	
	Household saving rate	NUTS0	Eurostat	
	Net household savings rate	NUTS0	Eurostat	✓
	Financial Assets (% of GDP)	NUTS0	Eurostat	
	Net Foreign Assets	NUTS0	World Bank	
	Net National Assets	NUTS0	World Bank	
	GDP	NUTS2	Eurostat	
Manufactured	Transport (Density)	NUTS2	Eurostat	
	Transport (Area)	NUTS2	Eurostat	✓
	Transport (Pop)	NUTS2	Eurostat	
	Produced Capital	NUTS0	World Bank	✓
	Construction	NUTS2	Eurostat	

Eurostat: http://appsso.eurostat.ec.europa.eu
Eurobarometer (2005): http://ec.europa.eu/public_opinion/archives/ebs/ebs_223_en.pdf
Transparency international (2011): http://cpi.transparency.org/cpi2011/in_detail/
World bank: http://data.worldbank.org/data-catalog/wealth-of-nations

2.2.2. *Standardising indicator variables*

To create variables to represent each of the four capitals the paired indicator variables were combined. To do this, standardisation was required. However, relationships between indicator variables and high and low levels of capital are not linear. For example, a 5% increase in tertiary education from 0 to 5% would have a significantly greater impact on human capital than an increase from 45 to 50%. Furthermore, some of the socio-economic scenarios reflect futures where conditions are considerably different from the present. As such, standardisation cannot simply use existing European extreme values; instead plausible 'absolute' maxima and minima for the 2050s were determined based on descriptions of the CLIMSAVE socio-economic scenarios and expert judgement. To account for non-linearity, different functional forms relating an indicator to its standardised index were used, determined using expert judgement drawn from a fuzzy approach. For each variable, the expert group was asked to sketch a distribution curve linking real values of the indicator to a conceptual five class classification from very low to very high (Appendix B). The experts were then asked to use this to define breakpoints between the five classes. The experts were given freedom to modify their graphs and breakpoints until they were happy with them and were able to refer to the present day distribution of the dataset for guidance. Capital values for baseline conditions were calculated as an average of the paired indicator values.

2.2.3. *Changing capitals with socio-economic scenarios*

The CLIMSAVE IAP focuses on four socio-economic storylines (Kok et al. 2013) and covers two time steps (from baseline to the 2020s and from the 2020s to the 2050s). During the creation of the storylines, stakeholders were asked to state how each of the four capitals would change qualitatively for each time step. They were asked to determine whether the capital would increase, decrease or stay the same and whether or not this change was “moderate” or “high”. A sliding scale was developed to translate the stakeholder-determined changes into increases and reductions in the indicator variables. For changes from baseline to the 2020s, a stakeholder-classified “moderate” change was reflected by a shift of a single class (either positive or negative) reflecting the stakeholder classification. A “high” change was reflected by a two-class shift. For changes from the 2020s to the 2050s these shifts were doubled in weight reflecting the length of the time period being double that from the baseline to the 2020s. As such a moderate change from the 2020s to the 2050s was reflected by a two-class shift, and a “high” change by a four-class shift. This created a 13 class system with baseline (0) in the centre and classes from -6 to +6 on either side (Figure 2).

The quantification of each indicator in each of these classes was undertaken with reference to expert judgements on the plausible ‘absolute’ maximum and minimum values for each indicator. A systematic approach was then put in place that created limits between which each indicator variable was standardised for each of the classes. The following steps explain the methodology for positive changes, negative changes follow the same method, but inverted. First, it was decided that the upper limit for a “high” change” in the 2020s should be set to the absolute maximum value for the 2020s (class 2+ in Figure 2). A “moderate” change was set to half way between this value and baseline (class 1+ in Figure 2). Second, it was decided that the lower limit should not be outside the range set by the current distribution at baseline within the 2020s scenario; instead the lower limit was set to 50% of the current distribution for a “high” change (class 2+) and halfway between this and baseline for a “moderate” change (class 1+). Third, for changes between the 2020s and 2050s it was decided that the 2050s maximum would be reached following a “high” change in the 2050s even if no change had occurred from baseline to the 2020s. This meant that the upper limits for classes 4 to 6 were set to the absolute maximum; the upper limit for class 3 was set to the midpoint between the limit for class 2 and class 4. Finally, it was determined that data would only be outside the current distribution following particularly extreme or consistent changes (class 4 or above) and that the dataset would only move beyond the 2020s maximum most extreme scenario (where a “high” change in the 2020s followed a “high” change in the 2050s). This set the lower limits for classes 4 and 6. The lower limits for classes 3 and 5 were set to half way between these limits and the limit below. Figure 2 shows the impact of the approach on the distributions of two very different indicators. Once each pair of indicator variables had been transformed using the limits of the appropriate class they were then averaged to capital variables. The advantage of the approach is in its relative simplicity. By adding together shifts between the two time blocks it easily allows cumulative changes to be represented – including situations where the direction of change is different.

- 6+
  - ➔ Max : 2050s max
  - ➔ Min : 2020s Max
- 5+
  - ➔ Max : 2050s max
  - ➔ Min : midpoint of Current max and 2020s max
- 4+
  - ➔ Max : 2050s max
  - ➔ Min : Current Max
- 3+
  - ➔ Max : midpoint of Current max and 2020s max
  - ➔ Min : Current Min + 0.75(Current Max – Current Min)
- 2+
  - ➔ Max : 2020s max
  - ➔ Min : midpoint of current distribution
- 1+
  - ➔ Max : (2020s Max + Current Max)/2
  - ➔ Min : Current Min + 0.25(Current Max – Current Min)
- 0
  - ➔ Max: Current Max
  - ➔ Min: Current Min
- 1-
  - ➔ Max : (Current Min + 0.75(Current Max – Current Min)
  - ➔ Min : (Current Min + 2020s Min)/2
- 2-
  - ➔ Max : midpoint of current distribution
  - ➔ Min : (2020s Min)
- 3-
  - ➔ Max : (Current Min + 0.25(Current Max – Current Min)
  - ➔ Min : (2020s Min + 2050s Min)/2
- 4-
  - ➔ Max : (Current Min)
  - ➔ Min: 2050s Min
- 5-
  - ➔ Max : midpoint of Current min and 2020s min
  - ➔ Min: 2050s Min
- 6-
  - ➔ Max : 2020s Min
  - ➔ Min: 2050s Min

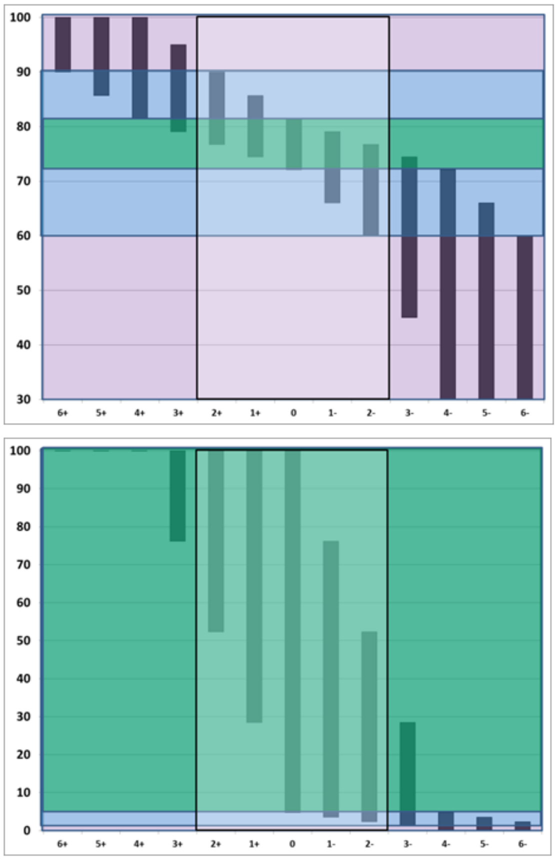


Figure 2: The sliding scale used to create a flexible coping capacity system.

2.2.4. *Calculating coping capacity*

Coping capacity was calculated as the unweighted average of the values of the four capitals for any given scenario. For baseline this was the raw baseline capitals, and for the scenarios it was the average of the sliding-scale classes that reflected the stakeholder-selected changes in the capital values. For display on the IAP the continuous coping capacity variables were broken down into six classes with reference to their overall distributions across the scenarios.

2.3. Calculating vulnerability

As described in Figure 1 vulnerability is a result of the combination of residual impact, the upper and lower coping thresholds and coping capacity. Six ecosystem service (ES) indicators were selected from the IAP to represent a cross-section of ecosystem services categories. Two indices were selected for provisioning and cultural services and one each for regulating and supporting services. The six indicators were: (i) a food index (provisioning); (ii) the water exploitation index (provisioning); (iii) a flood index (regulating); (iv) a biodiversity index (supporting); (iv) a landscape intensity index (cultural; reflecting the negative consequences of land use intensification for broader environmental quality and human well-being; and (vi) a landscape diversity index (cultural; reflecting the role of land use diversity in supporting landscape aesthetics). The detail of these indices is explained in the results (Section 3.4).

For each of these indices upper and lower coping thresholds were chosen in consultation with sectoral experts and the modellers responsible for each variable. The thresholds for the food index were, for example, based on the daily calories required for males (this being greater than the value for women), with a lower coping threshold of 2500 and an upper coping threshold of 0.01. This means that coping begins when the projected impact drops below 2500. Unlike adaptive capacity, coping is conceptualised as being the immediate response of individuals within the society once the threat has been identified (i.e. "we are not going to have enough food - what can be done?"). As such, coping doesn't allow for any long-term research or manufactured solutions, but could reflect the application of existing research or produced capital. In the food example, coping might include: using human capital by enduring the health implications of poorer nutrition or applying appropriate skills (cooking/ preserving/ foraging); using social capital by pooling reserves and societal self-rationing; drawing on financial capital to import food from elsewhere or purchase technological solutions; drawing on manufactured capital including available technology (refrigerators/ freezers/ food processors) and transport networks to access other resources; or a combination of any of these.
For each index the coping range and significant residual impact proportion are then calculated (Equation 1 and 2). In this methodology vulnerability is defined as occurring in areas where the significant residual impact, as a proportion of the coping range, is greater than the coping capacity. By implementing this methodology a vulnerability index is calculated for each ES index at the grid cell level (Equation 3).

Equation 1: Coping Range = Upper Coping Threshold – Lower Coping Threshold

Equation 2: Significant Residual Impact = Residual Impact – Lower Coping Threshold

Equation 3: Vulnerability Index = Significant Residual Impact / Coping Range

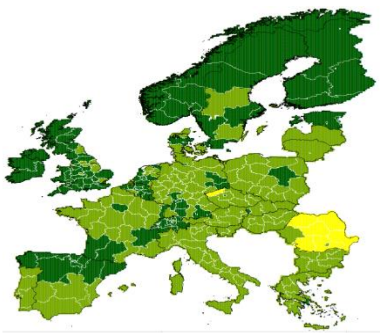
These variables are then used to classify all areas into four classes: (i) "not vulnerable, negligible impact": where residual impact is less than the lower coping threshold; (ii) "not vulnerable, coping": where the significant residual impact is less than the coping capacity; (iii) "vulnerable, not coping": where the coping capacity is not great enough to deal with the significant residual impact; and (iv) "vulnerable, impossible to cope": where the residual impact is greater than the upper coping threshold. Summary statistics, in terms of the total vulnerable area and number of vulnerable people are calculated at the European scale using the two vulnerable classes and summing the area and population of cells identified as vulnerable. Furthermore, cross-sectoral aggregate vulnerability is calculated by counting for each cell the number of sectors that are vulnerable.

The CLIMSAVE IAP provides an opportunity to explore the four socio-economic scenarios combined with a range of climate scenarios. Five global climate models (GCMs) chosen to represent the range of uncertainty in future climate are included within the IAP. These models (CSMK3, HadGEM, MPEH5, IPCM4 and GFCM21; Appendix C) can each be run with high, medium or low climate sensitivity and any of the four SRES emissions scenarios (A1, B1, A2, B2). In this analysis the four socio-economic scenarios were run under each GCM twice, first, with a "high emissions scenario" where SRES scenario A1 was selected with "high" climate sensitivity and, second, for a "low emissions scenario" where SRES scenario B1 was selected with "low" climate sensitivity. This resulted in a total of 40 combined climate and socio-economic scenarios. The spatial pattern was mapped for each scenario and the number of vulnerable people (VP) and total vulnerable area (VA) was recorded; the 2050s timeslice was used in all cases.

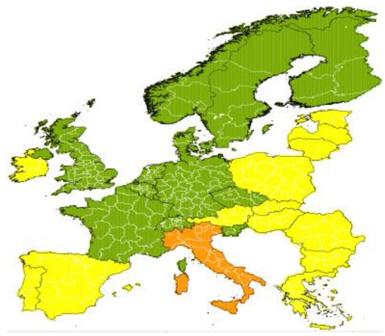
3. Results

3.1. Capitals

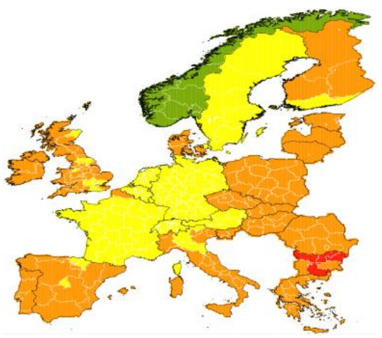
The European capital maps generally reflect expected patterns. Human capital (Figure 3a) is high across the majority of Europe, reflecting the fact that life expectancy is generally very high (72-82 years) and the majority of countries have high levels of tertiary education (14-36%). As such, of all the capital stocks available for coping, human capital is the most widespread resource consistently available at a high level. The healthy, well educated population of Europe is one of its greatest potential resources for coping with climate impacts.



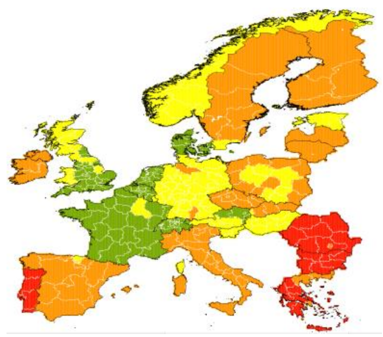
(a) HUMAN
(life expectancy[N2] and tertiary education[N2])



(b) SOCIAL
(income inequality[N0] and help when threatened [N0])



(c) FINANCIAL
(household income [N2] and household savings rate[N0])



(d) MANUFACTURED
(transport (area)[N2] and produced capital[N0])

Class	Standardised Index Value
Very High	> 0.8
High	0.6-0.8
Medium	0.4-0.6
Low	0.2-0.4
Very Low	< 0.2

Figure 3: Baseline capital estimates for Europe.

Compared with human capital, the maps of social capital (Figure 3b) suggest a more varied picture of Europe. Areas with higher levels of capital (northern and central Europe) have "high" rather than "very high" social capital and larger areas, particularly in the east and south, have moderate and low levels of social capital. Italy stands out with low social capital. This is a result of Italy having a particularly low value for "help when threatened", 18% compared to a European average of 46%, and a relatively high inequality index (ranking 11th highest of 26 countries). Whilst the choice of indicator is bound to have an impact on the patterns highlighted in the datasets, particularly when datasets such as opinion surveys are used, it is important to remember that the "help when threatened" variable correlated well with other indicators such as corruption perception, trust and volunteering. Italy, for example, had the fourth lowest ranking for corruption perception, and ranked 10/28 and 11/27 for participation and trust. It is also important to remember, that although presented on the IAP as a classified map for clarity, that the capital (and coping capacity) variables are continuous. As such whilst Italy was the only country to fall beneath the 0.4 threshold Portugal, Hungary, Romania, Greece and Spain all had social capital values ≤ 0.45.

The financial capital map (Figure 3c) shows a pattern of moderate and low capital for Europe with northern and central Europe having relatively higher financial capital than the majority of eastern and southern Europe along with much of the United Kingdom and Ireland. NUTS 2 areas containing key cities are also apparent as higher points within their national context (London, Madrid, Milan, Helsinki). Whilst the spatial pattern of financial capital appears reasonable, a first interpretation may be that the categories assigned present a relatively pessimistic picture of the financial capital in Europe, and a different map than that expected with reference to GDP (Appendix D). When considering this point it is important to remember that these maps are designed to be baseline inputs into a system that must be able to cover a range of potential conditions that could take place between now and the 2050s. A classification of "low" financial capital is, therefore, low with respect to a potential future where in the most affluent areas income quadruples from their current values (from a current EU maximum of 26,325€ to 100,000€) and net household savings more than double (from 9,500€ to 25,000€). It is also important to note that the variables selected are focused on the household level at which coping would take place. Furthermore, by including household savings, a variable that specifically does not correlate with GDP, we are able to consider aspects of financial capital that can be brought into play when coping becomes necessary. Norway, for example, is flagged as particularly high due to having the greatest net household savings (9,500€/capita).

The manufactured capital map (Figure 3d) indicates that the highest capital stocks are in France, Belgium, Switzerland, Denmark, the Netherlands and southern England, locations traditionally recognised for their high density transport infrastructure. Conversely, the lowest manufactured capital stocks are in Portugal, Romania, Bulgaria and Greece, areas with both very low transport density and produced capital stocks. This overall trend matches well with the infrastructural capital maps produced by Greiving et al. (2011) (Appendix E), who use indices for road network density, sustainable water use and hospital beds, which highlight low values in southern Europe, particularly Portugal, Spain, Italy and Greece. The Greiving maps differ, however, with eastern nations, particularly Finland, Latvia and Lithuania, highlighted as having some of the highest infrastructural capacities, but these countries have low manufactured capital in Figure 3d. The main differences here are the inclusion of produced capital within the CLIMSAVE manufactured capital index, and Greiving's inclusion of sustainable water use and hospital beds. When developing manufactured capital as a component of coping capacity we looked to "produced capital" to provide an indication of total physical assets (machinery, equipment, structures and urban land) and the infrastructure variable as a measure of both the connectedness of the physical assets and as routes to cope with impacts by moving populations. An investigation of the data suggests that areas such as Latvia and Lithuania, whilst relatively rich in terms of infrastructure (ranking 12th and 13th out of 27) are relatively poor in terms of overall physical assets (ranking 23rd and 24th, respectively). Conversely, locations such as Ireland and Finland, which rank high for produced capital (6th and 10th, respectively) suffer from having lower manufactured capital due to their low transport infrastructure densities. In the Greiving maps, Ireland and Finland must have comparably high values for sustainable water resource infrastructure and hospital bed provision that compensate for the low density of transport infrastructure.

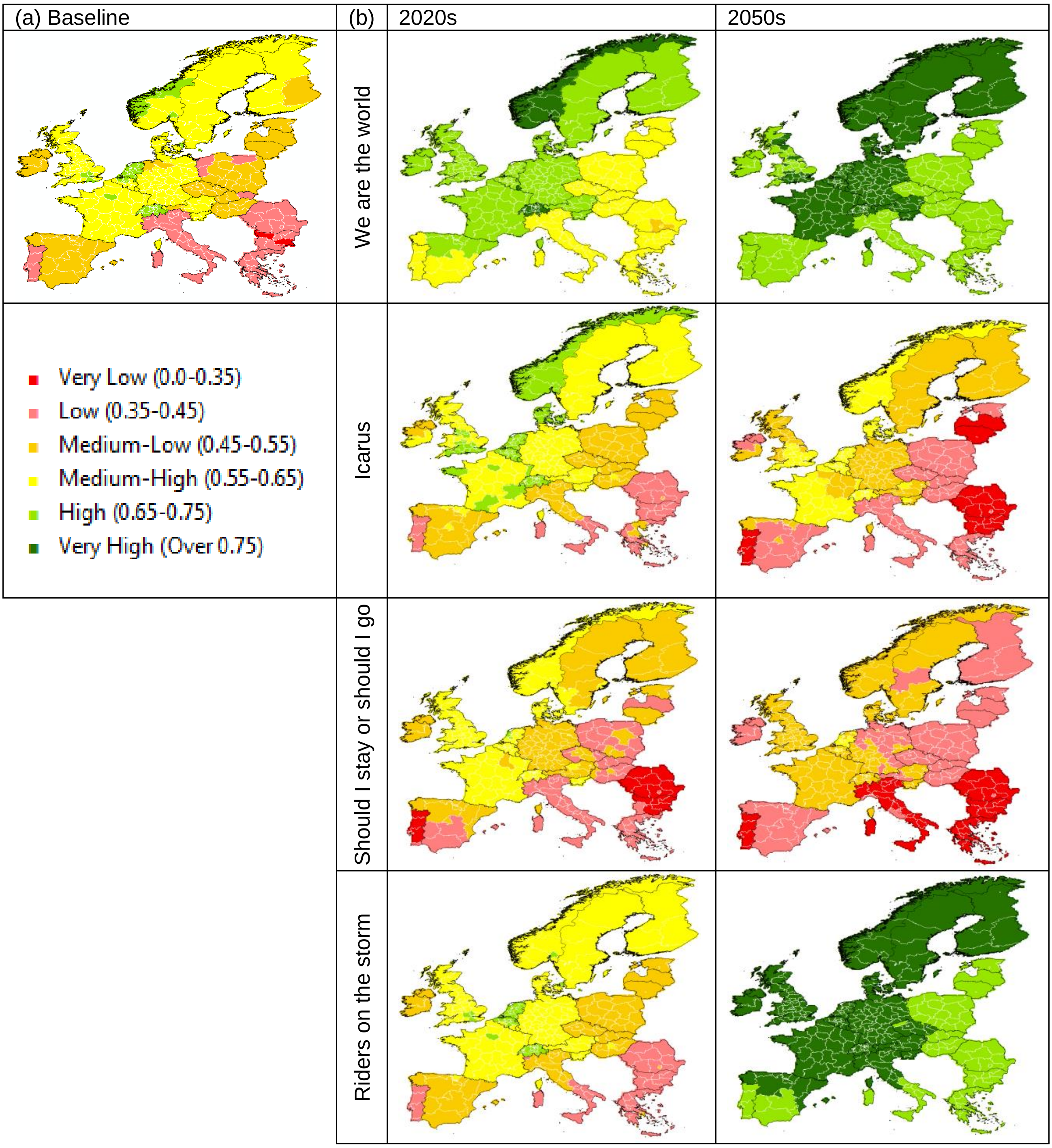
3.2. Coping capacity

At baseline, the CLIMSAVE map of coping capacity looks reasonable (Figure 4a). The majority of Europe has a medium level of coping capacity reflecting the fact that in general Europe has a reasonable level of capital to deal with crises, and that there is considerable scope for coping capacity to both increase and decrease with changes in its socio-economic future. The differentiation in classes between high- and low-medium identifies key differences between northern and central Europe, where coping capacity is generally higher, and southern and eastern Europe where coping capacity is lower. In terms of extremes, only two sub-regions of Bulgaria map out as "very low" and there is significant room for improvement in all countries, with only Netherlands and Switzerland, north-western Norway and the cities of London, Paris, Oslo and Brussels standing out as having high coping capacity. These distributions broadly reflect the map of adaptive capacity identified in other index-based projects (Schröter et al., 2003, Metzger et al., 2006 and Acosta et al., 2013) particularly those of Greiving et al. (2011; see Discussion).

Figure 4b shows coping capacity as it is mapped for the CLIMSAVE socio-economic scenarios. The method maps a significant variety of spatial patterns that reflect the storylines of the scenarios. For example, in the "We are the world" scenario (WRW) successful innovation and steady economic growth lead to a scenario in which effective governments change the focus from GDP to welfare leading to a redistribution of wealth, less inequality and more global cooperation. This was interpreted by the stakeholders as a slow reduction in financial capital, and an increase in human, social and manufactured capitals. The overall impact on coping capacity is seen as a steady improvement in coping capacity through the 2020s where the southern and eastern European countries rise to the level of the northern countries at baseline, and the northern countries improve to a time in the 2050s where coping capacity is "high" or better across Europe. Conversely, the "Icarus" scenario, where short-term policy planning and a stagnating economy lead to the disintegration of social fabric and a shortage of goods and services is reflected by an initial increase in financial capital and a moderate loss of social capital followed by high losses of human capital and moderate losses of financial and manufactured capitals in the 2050s. The coping capacity maps reflect these changes well by showing an initial improvement in coping capacity in many places resulting from the short-term policies. However by the 2050s, there has been a significant downturn and coping capacity in Europe has worsened to the position that the majority of countries are considerably less able to cope with climate change than they were at baseline. The other two scenarios also reflect expectations, the dystopian society of "Should I stay or should I go"' (SoG) shows a continual decline in coping capacity, and the world of "Riders on the storm" shows significant improvements following a slow start (for more detail on the scenarios see Kok et al. 2013).

3.3. Vulnerability

Vulnerability maps can be created for each of the ecosystem service indicators and each of the combined climate and socio-economic scenarios for the two time slices (e.g. Figure 5). The vulnerability maps are a powerful tool, spatially representing the combined influence of both the modelled level of impact and the ability of society to cope, both of which are independently influenced by both the climate projection and the socio-economic scenario. The vulnerability maps can be produced before or after adaptation within the IAP. The results shown here are without adaptation. Figure 5 illustrates a worked example for the two "positive" scenarios "WRW" and "Riders" in the 2020s and 2050s time slices.



(c)	WRW		Icarus		SoG		Riders	
	2020s	2050s	2020s	2050s	2020s	2050s	2020s	2050s
Human	M+	H+	0	H-	0	M-	M+	H+
Social	H+	M+	M-	0	M-	M+	M+	M+
Financial	M-	M-	M+	M-	M-	M-	M-	M+
Manufactured	M+	M+	0	M-	M-	M-	M-	M+

Figure 4: Estimating coping capacity: (a) coping capacity map for baseline; (b) coping capacity maps for the four CLIMSAVE socio-economic scenarios in the 2020s and 2050s; and (c) the changes in capital stocks driving the changes as estimated by stakeholders at the socio-economic scenario workshops. "H" = high and "M" = moderate "+" = positive and "-" = negative.

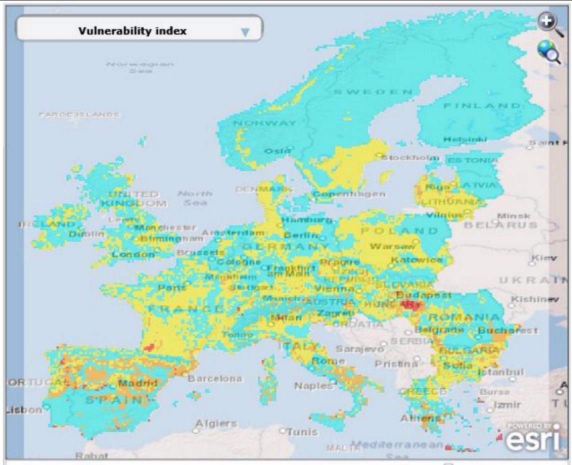
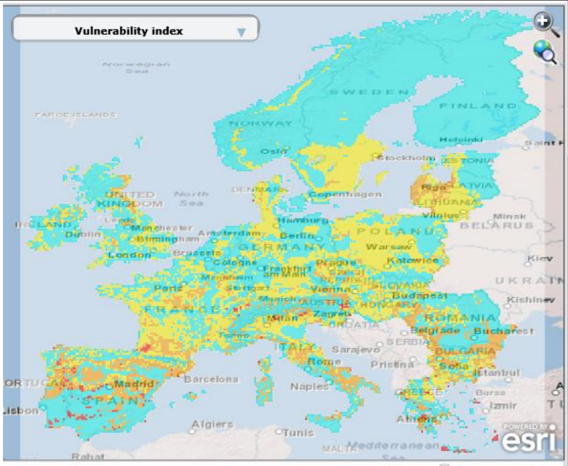
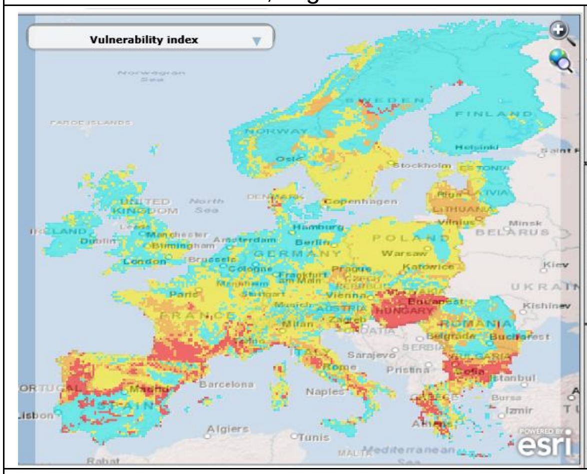
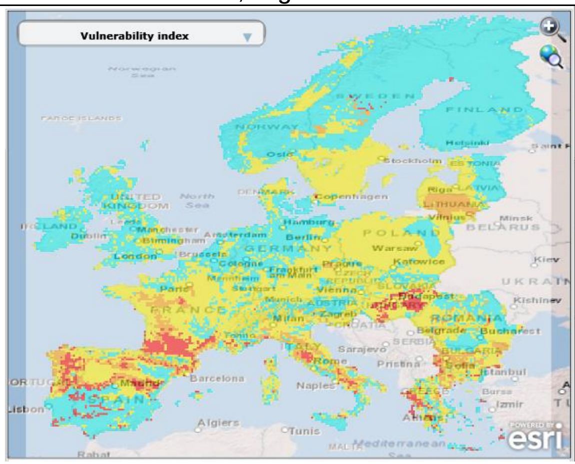
(a) Biodiversity Vulnerability, 2020s	
WRW, 2020s MPEH5, High Emissions	Riders, 2020s MPEH5, High Emissions
	
Vulnerable People: 34,141,000 (7%)	Vulnerable People: 66,207,000 (13%)
Vulnerable Area: 358,039 km^2 (8%)	Vulnerable Area: 615,294 km^2 (13%)
(b) Biodiversity Vulnerability, 2050s	
WRW, 2050s MPEH5, High Emissions	Riders, 2050s MPEH5, High Emissions
	
Vulnerable People: 88,754,000 (18%)	Vulnerable People: 50,173,000 (10%)
Vulnerable Area: 951,652 km^2 (20%)	Vulnerable Area: 557,183 km^2 (12%)
Not vulnerable, negligible Impact	Vulnerable, not coping
Not vulnerable, coping	Vulnerable, impossible to cope

Figure 5: Worked example illustrating the vulnerability maps with respect to the biodiversity sector for selected climate and socio-economic scenarios in the 2020s and 2050s.

The storyline for WRW is one of steady growth, with improvements in government effectiveness, a declining focus on financial capital and global efforts to focus on sustainable development. Conversely, the storyline for "Riders" is one where Europe is on its own in the global market, it has invested heavily in green technology, but there is no buyer to sell it to, and as such there is a strong economic recession. In terms of capitals, both socio-economic scenarios reflect a positive move forward in terms of social and human capital and a decrease in financial capital. The "togetherness" of the "WRW" scenario is reflected as a larger boost to social capital than that in "Riders". The economic downturn of the "Riders" scenario is reflected as a decrease in financial and manufactured capitals leading to "WRW" having greater levels of coping capacity than "Riders" across Europe in the 2020s (Figure 5a).

In the worked example, the combination of the "not vulnerable, coping" (yellow) and the "vulnerable, not coping" (orange) areas highlight where there is a significant residual impact that could be coped with given sufficient capital. The spatial pattern of this combined area is very similar in both socio-economic scenarios in the 2020s. However, the proportion that is vulnerable due to its inability to cope (orange and red combined) changes notably between the socio-economic scenarios with areas of the UK, France, Italy, Lithuania and Bulgaria being more able to cope with the impacts on biodiversity in the "WRW" than in the "Riders" scenario. This is reflected in the summary figures for the 2020s: 358,039 km^2 is mapped as vulnerable in "WRW", whereas 615,294 km^2 is vulnerable in "Riders".

In the 2050s, the "Riders" storyline indicates that the initial investments in green technology have paid off, protecting Europe from some of the worst impacts of climate change, positioning it as a leader in green technology markets and improving its position in the world economy; this is reflected in a significant improvement in all capitals and thus, coping capacity. "WRW", conversely, is a storyline of steady increase, but a move away from market economies, this is reflected by similar increases in human, social and manufactured capitals, but a decrease in financial capital, and as a result a slightly lower coping capacity than "Riders" in the UK, Austria and northern parts of Spain, Portugal and Italy (Figure 5b).

In the worked example, both the influence of the increasing climatic pressures and the influence of the changes in coping capacity are identifiable. A comparison of the 2020s and 2050s maps for both socio-economic scenarios reveals a reduction in the "Not vulnerable, negligible impact" class and a greater proportion of both maps in the "Vulnerable, impossible to cope" class. Both these factors indicate that socio-climatic pressures have increased the significant residual impact with respect to biodiversity for Europe. In some areas, such as southern France the increase in significant residual impact is reflected by an increase in vulnerability in both scenarios. However, the increase in coping capacity in "Riders" means that some of the areas, such as Norway, the UK and Spain which were vulnerable under "Riders" in the 2020s are no longer vulnerable in the 2050s. Furthermore, areas of Hungary, Romania and Greece in the 2050s are more vulnerable in the "WRW" scenario than they are in "Riders". This is reflected by the vulnerable area in "WRW" increasing from 358,039 km^2 (2020s) to 951,652 km^2 (2050s), whereas the vulnerable area in "Riders" decreases from 615,294 km^2 (2020s) to 557,183 km^2 (2050s). The ability to explore vulnerability spatially in this way, and to unpick the different roles played by different socio-economic scenarios and climate projections across multiple time periods is one of the great advantages of the CLIMSAVE approach.

3.4. Sectoral vulnerability

Figures 6 and 7 present, respectively, for 40 combined climate and socio-economic scenarios: (a) the number of vulnerable people; and (b) the vulnerable area with respect to six sectoral impacts (represented as ecosystem service indicators). The relative levels of vulnerability reproduced are in line with expectations based on the socio-economic scenarios and the climate projections. In general terms, the more dystopian scenarios (SoG/Icarus) show greater vulnerability in terms of both the number of vulnerable people and the area vulnerable than the more utopian scenarios (WRW and Riders) for the majority of sectors. Similarly in most cases, the more moderate climate scenarios (B1 emissions, low climate sensitivity) generally have lower vulnerability than their extreme counterparts (A1 emissions, high climate sensitivity). In terms of the socio-economic scenarios, these general trends reflect the lower significant residual impacts in the scenarios where innovation is successful, and higher coping capacities where higher capital stocks are available in the utopian scenarios. In a climatic context, vulnerability tends to be higher in high emissions scenarios as these scenarios tend to experience the greatest climatic changes, which puts greater stress on the ecosystem services. However, in addition to these general trends, Figure 7 shows that the indices show a more nuanced impression reflecting the exact combination of climate model, level of climate sensitivity, socio-economic scenario and sector.

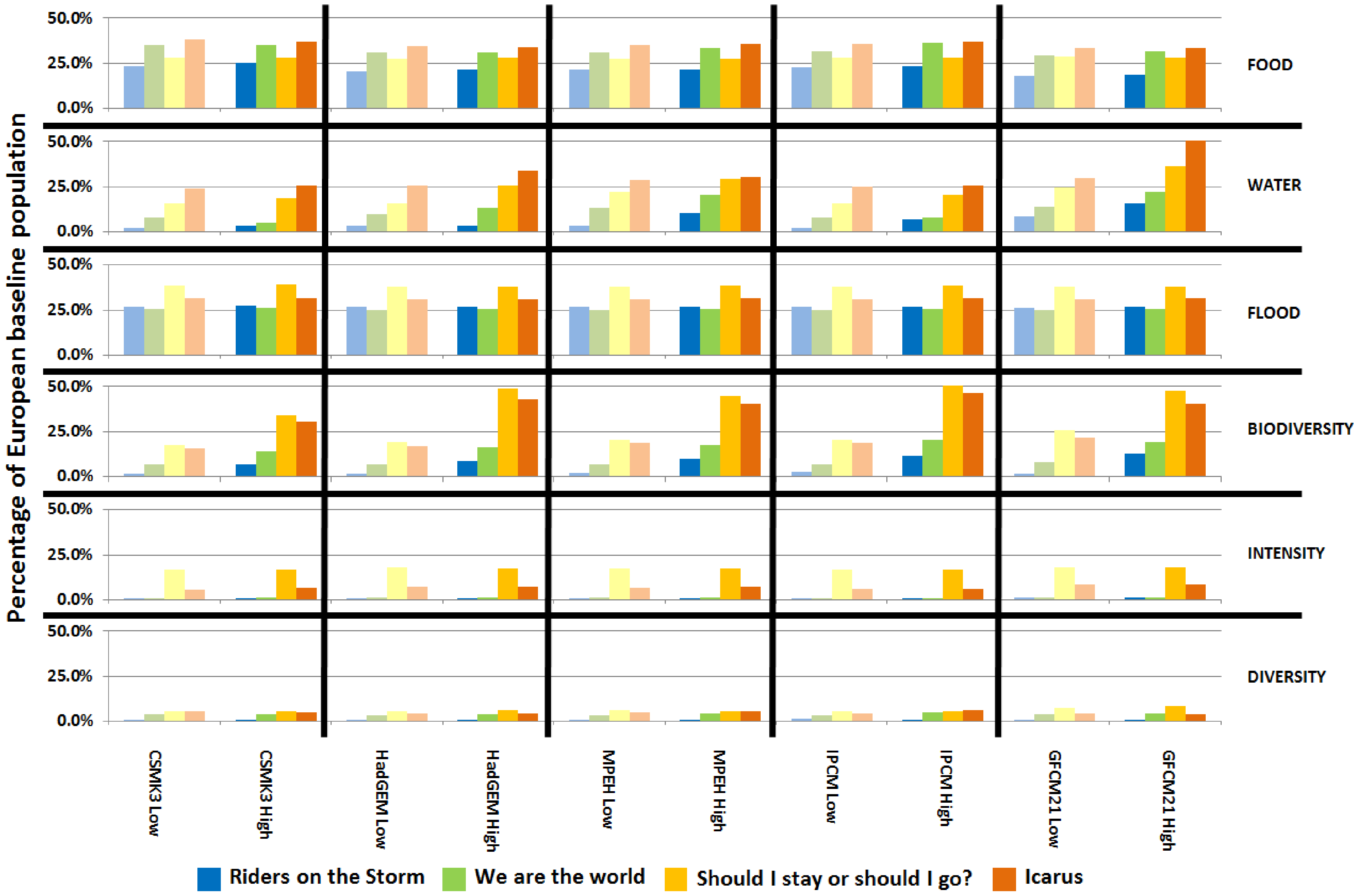


Figure 6: Percentage of the European population vulnerable, relative to baseline, for the six ecosystem service indices by socio-economic and climate scenario.

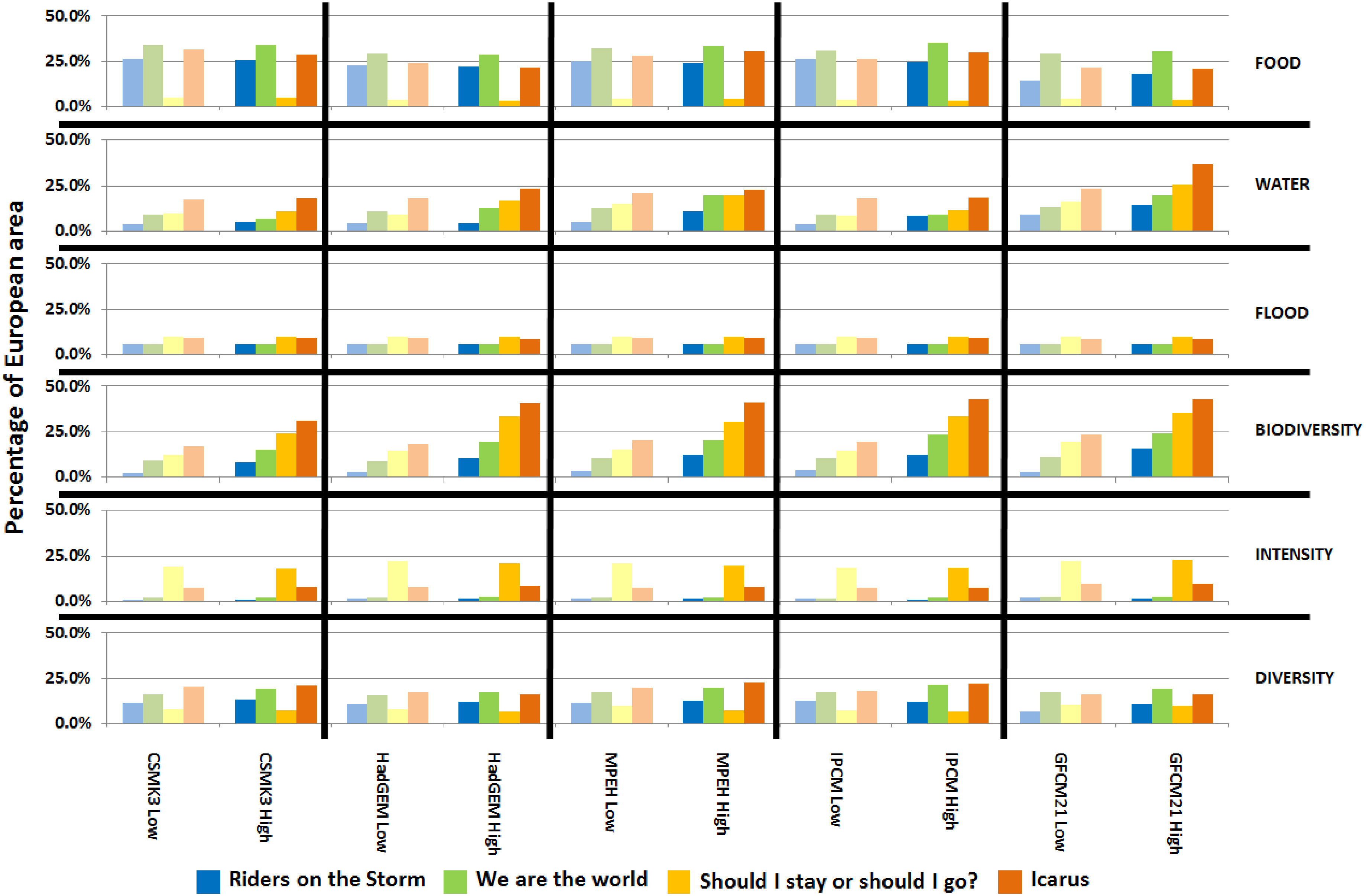


Figure 7: Percentage of European area vulnerable for the six ecosystem service indices by socio-economic and climate scenario.

3.4.1 *Food provision*

The Food Provision Index is a grid cell-level index of self-sufficiency in terms of food provision. It does not take either existing food stores within these regions, or imports from external areas into consideration. Therefore scenarios with widespread agricultural production will be seen as less vulnerable in terms of food provision than those scenarios where food provision is concentrated into particular regions. It should be noted that, as a result, heavily urbanised and afforested grid cells are considered more vulnerable, due to the fact that these areas are by their nature lacking food production ability. As an index of vulnerability in terms of the food provisioning ecosystem service (and not food availability) this is reasonable as, in terms of coping in a scenario where food is sparse, urban areas will always be dependent on food producing areas.

In the majority of climate scenarios, the WRW scenario has the greatest vulnerable area (VA), followed by Icarus and Riders, with the majority of climate scenarios showing a VA_{FOOD} between 20 and 35%. SoG has considerably smaller VA_{FOOD} (<5%). This is due to the fact that, in contrast to the utopian scenarios, agricultural yields are low, GDP and irrigation efficiency have decreased, and the population has shown no change in dietary patterns away from space-intensive meat production. In comparison with the dystopian Icarus scenario, which shares many of these problems, the SoG population is growing fast (+23%), rather than declining (-9%). The combination of all these issues leads to a situation where things are going so badly in SoG that food provision is the primary focus and food is produced wherever it is possible. In comparison to WRW, where Norway and a belt from southern France across the Alps to Hungary is projected to produce little to no food, in SoG there are very few grid cells that do not produce food. The ordering of the scenarios in terms of vulnerable population (VP) is different: VP_{FOOD} in SoG is of the same order of magnitude to that of Icarus and WRW (between 27 and 38%) and it is Riders that has notably lower VP_{FOOD} (< 25%). This difference between VP and VA in SoG with respect to the socio-economic scenarios reflects the fact that, although food is being grown wherever possible, urban areas, which do not grow food, remain vulnerable. Furthermore, with an increasing population in SoG these urban areas become even more dependent on those areas that supply food: and more vulnerable in terms of food provision.

In terms of climate, there is relatively little difference between the scenarios in terms of overall vulnerability, CSMK3 and MPEH5 show relatively greater vulnerability and HadGEM and GFCM21 show relatively less, but in general the patterns are similar across climate scenarios, and there is little difference between the high and low emissions scenarios. Much like the socio-economic scenarios the differences identified are driven by the extra stress put on the system by the climate: where there is greater stress, such as in the hotter, drier GFCM21 scenario the vulnerability to food provision is projected to be less because food is being grown wherever possible, at the expense of other land uses. A comparison of Riders' food provision vulnerability in GFCM21 and the milder CSMK3 scenario shows that the increased stress on the system leads to food being produced higher into the Alps and in areas of Sweden, France, Austria, Hungary, Estonia, Latvia and Lithuania that are not needed for cultivation under the CSMK3 scenario.

3.4.2 Water exploitation

The Water Exploitation Index (WEI) takes into consideration both the availability of water and its utilisation for human consumption, agriculture and industry. The index works at the level of a river basin and allocates the same level of vulnerability to all grid cells within each river basin.

In general, the WEI shows increasing vulnerability through the socio-economic scenarios in the order Riders < WRW < SoG < Icarus both in terms of VA and VP. Furthermore, low emissions climate scenarios show less vulnerability than their high emissions counterparts. There are differences between climate models with those which are generally milder and wetter (e.g. CSMK3) showing considerably less vulnerability than those which are hotter and drier (e.g. GFCM21). Furthermore, in some scenarios, such as MPEH and IPCM the difference between socio-economic scenarios is much less notable, than in others (such as GFCM21). This is illustrated in Figure 8a. Both the WRW and SoG scenarios have approximately 900,000 km^2 vulnerable area when combined with the MPEH model. However, despite the similarity in overall area, the spatial patterns are different. In WRW there is no vulnerability in the UK, Belgium or the Netherlands, whereas these areas show some vulnerability in SoG. These differences are most likely driven by the higher coping capacity in WRW. On the other hand, there is vulnerability in Greece and the southern coast of France that is present in WRW, but not in SoG. Such differences exist despite WRW's higher coping capacity in these areas and instead reflect changes from the increased GDP in the WRW scenario. In WRW GDP has increased by 94% whilst it has decreased by 36% in the SoG scenario. This leads to an increase in vulnerability that is particularly notable in areas with a low GDP at baseline as, in the water model, increasing GDP increases water use to reflect changing lifestyles and the use of more water intensive appliances. Another factor that explains areas where WRW has greater vulnerability than SoG is the fact that SoG's reduced water efficiency leads to irrigation becoming less profitable. This, in turn, leaves more water available for other purposes: it means that in some areas SoG may have more water available for exploitation than WRW as in WRW the water is being used to irrigate fields.

Figure 8b shows a different situation where the vulnerability in the WRW scenario is considerably lower than that of SoG. Under the hotter, drier GFCM21climate model the level of vulnerability increases in both scenarios, with more areas classified as "vulnerable, impossible to cope". However, in the WRW scenario, only a very small additional area is vulnerable in comparison with the area vulnerable using the MPEH climate model, and an area of central Spain is less vulnerable using GFCM21 than using MPEH5. Conversely, in the SoG scenario there is considerably greater area vulnerable using the GFCM21 scenario than with MPEH5. Furthermore, using the GFCM21 climate scenario rather than showing similar levels of vulnerability with different spatial patterns, there is considerably greater area vulnerable in SoG than in the WRW scenario. Areas of Spain, Corsica, the UK, Belgium and the Netherlands are vulnerable in SoG but are "not vulnerable, coping" in WRW.

3.4.3 Biodiversity

The Biodiversity Index identifies, for a mixed group of 11 representative species, where habitat and climate suitability have changed from baseline; it is a grid-cell based index. The biodiversity index follows a consistent trend across the socio-economic scenarios. $VA_{BIODIVERSITY}$ increases in the order Riders < WRW < Icarus < SoG: a pattern that reflects the decreasing amounts of coping capacity across these scenarios. In terms of $VP_{BIODIVERSITY}$, the same pattern is clear for the two utopian scenarios, however, the dystopian scenarios show Icarus to have greater $VP_{BIODIVERSITY}$ than SoG due to SoG's higher population. In terms of the climate scenarios, the Biodiversity Index is shown to be one of the most climatically sensitive: low emissions scenarios show considerably less VP and VA than their high emissions counterparts, irrespective of socio-economic scenario. The CSMK3 high emissions scenario is shown to be about a third less vulnerable than the high emissions scenarios of the other models (Riders CSMK3 high $VA_{BIODIVERSITY}$ = 8%; the mean of the equivalent variable from the other scenarios is 12.5%). This is most likely because this scenario is the least extreme and the most like current conditions. As such it had fewer negative implications on species.

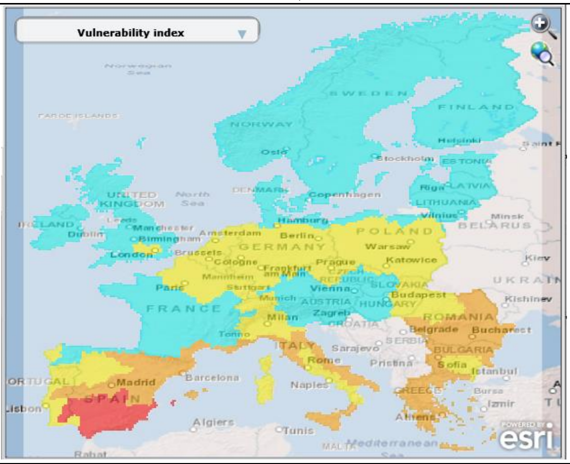
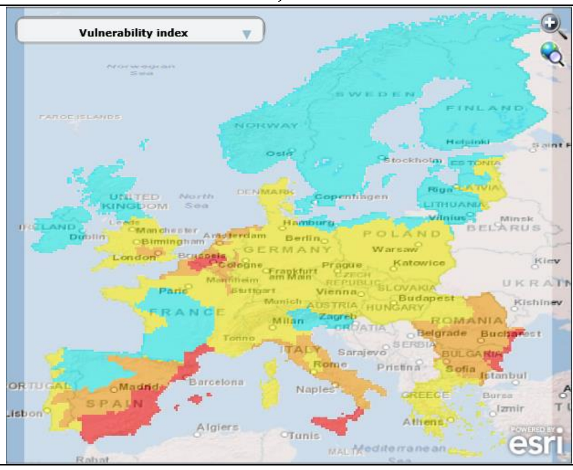
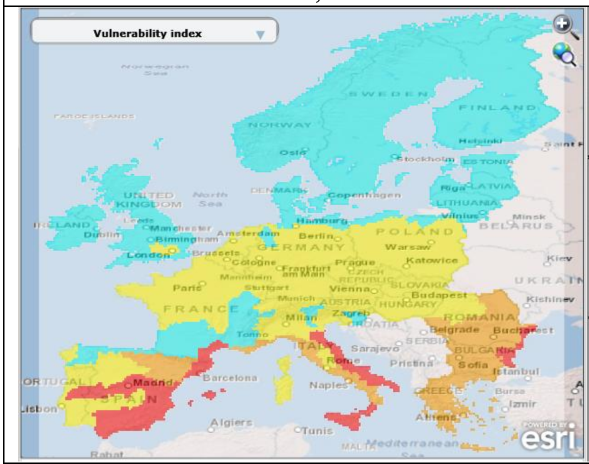
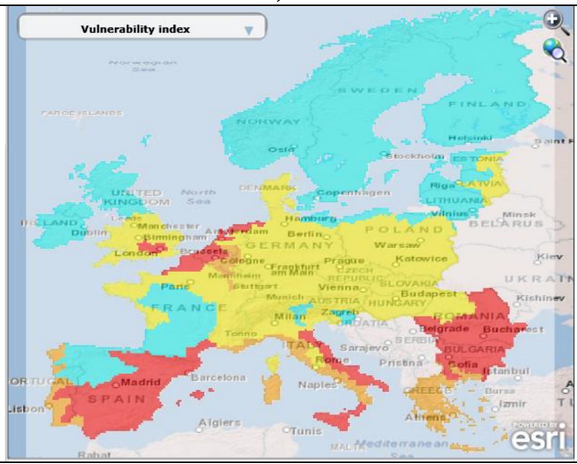
<table>
<tr><td colspan="2">(a) Water Exploitation Vulnerability: MPEH5, High Emissions</td></tr>
<tr><td>WRW, 2050s</td><td>SoG, 2050s</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Vulnerable People: 101,268,000 (20%)</td><td>Vulnerable People: 146,726,000 (29%)</td></tr>
<tr><td>Vulnerable Area: 911,081 km^2 (20%)</td><td>Vulnerable Area: 928,670 km^2 (20%)</td></tr>
<tr><td colspan="2">(b) Water Exploitation Vulnerability: GFCM21, High Emissions</td></tr>
<tr><td>WRW, 2050s</td><td>SoG, 2050s</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Vulnerable People: 111,209,000 (22%)</td><td>Vulnerable People: 181,456,000 (36%)</td></tr>
<tr><td>Vulnerable Area: 920,816 km^2 (20%)</td><td>Vulnerable Area: 1,180,404 km^2 (25%)</td></tr>
<tr><td>Not vulnerable, negligible Impact</td><td>Vulnerable, not coping</td></tr>
<tr><td>Not vulnerable, coping</td><td>Vulnerable, impossible to cope</td></tr>
</table>

Figure 8: Water exploitation vulnerability maps showing the influence of selected climate and socio-economic scenarios on vulnerability for the 2050s.

3.4.4 Flooding

The Flood Index is based on the number of people impacted by a 1 in 100 year flood event. The index considers both fluvial and coastal flooding and is calculated for every grid cell. In all scenarios VA_{FLOOD} increases in the order WRW < Riders < Icarus < SoG and VP_{FLOOD} follows the order Riders < WRW < Icarus < SoG.

Although climatic changes do influence the levels of vulnerability, the differences across climate models are very small (range of both VA and VP_{FLOOD} is < 0.5%). This insensitivity to climate is primarily due to the fact that sea-level rise, the primary driver of coastal flooding, does not change significantly between the climate scenarios (from 0.12 in B1 Low to 0.3 in A1 High). Fluvial flooding increases in the wetter climate scenarios. However, the vulnerability index counts the number of cells affected. The lack of sensitivity to climate suggests that, unlike the water and biodiversity indices where there are significant shifts in spatial pattern, there are very few cells which change class between scenarios as a result of fluvial flooding. This could be explained by the effect of topography, i.e. the flood prone zones, which do not change between the scenarios. Instead, differences between the socio-economic scenarios are shown to be considerably more noticeable reflecting lower coping capacity in the more dystopian scenarios. The key variables driving the differences are the change in population, which drives the differences in VP_{FLOOD} within the utopian/dystopian scenario pairs and coping capacity which drives the differences between these two sets of scenarios.

3.4.5 Intensity

The Intensity Index represents changes in the intensity with which the landscape is used between baseline and the scenario. In terms of ecosystem services, cultural and aesthetic services such as recreation and natural beauty are expected to be better correlated with less intensive landscapes – hence, vulnerability in terms of these services increases with the intensity index. The index is based on the relative proportions of five land use classes output from the IAP. These are, in order of increasing intensity: abandoned land, forestry, extensive agriculture, intensive agriculture and urban. As such, areas which change from forestry to extensive agriculture are seen as increasing in intensity, and those seen to be changing from forestry to intensive agriculture are expected to experience even greater increases in intensity.

In terms of VP and VA, the order of the socio-economic scenarios, are similar: the dystopian scenarios have the greatest vulnerability, with SoG having the most ($VA_{INTENSITY} \approx 20\%$) followed by Icarus ($VA_{INTENSITY} \approx 8\%$). Neither of the utopian scenarios show significant vulnerability ($VA_{INTENSITY} < 3\%$). In SoG the high vulnerability results to a large extent from the focus on food provision identified above. As all available areas are converted to agriculture, at the expense of less intensive land uses, the majority of Europe is shown as increasing in intensity, and only those areas with little agricultural development (i.e. eastern Sweden) or higher coping capacity (France) are not vulnerable. In Icarus, despite similarly low coping capacity, fewer areas are vulnerable as agricultural intensification is lower due to the lower population. In the utopian scenarios (WRW and Riders) there is both a lower need for extreme agricultural intensification and greater coping capacity, which significantly reduces vulnerability.

There seems to be very little difference between the climate scenarios in terms of intensity, although GFCM21 is relatively more vulnerable and CSMK3 and IPCM4 are relatively less so. This suggests that socio-economic changes are projected to have a greater influence on land-use in terms of intensity than climate. This is supported by Rounsevell et al. (2006) who concluded that land-use change was relatively more sensitive to socio-economic change than climate change.

3.4.6 Diversity

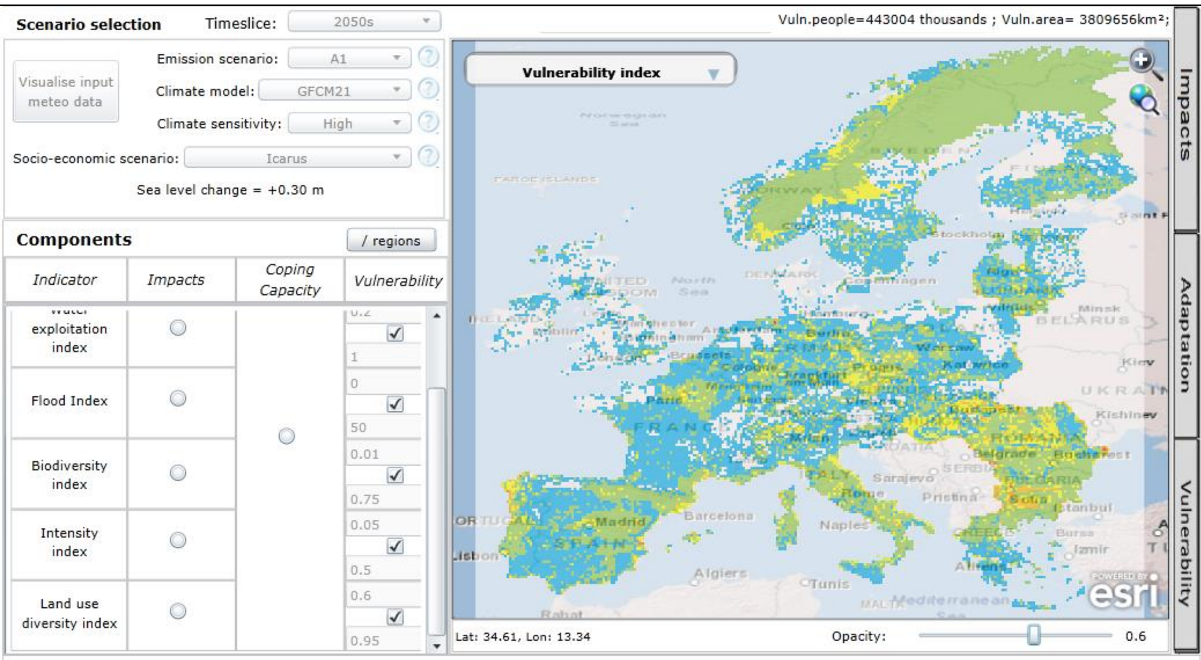
The Diversity Index is calculated by applying the Shannon diversity index at the grid cell level to six landscape components (arable, intensive agriculture, extensive agriculture, forest, abandoned land and urban). The index is highest where there is an equal mix of all six proportions, and lowest where there is only a single land use type present – irrespective of which land use that is. In an ecosystem services context the diversity index is seen as representing the multi-functionality of the environment, areas with high diversity are seen as being less vulnerable as their inhabitants have access to a greater range of ecosystems, and therefore a greater range of ecosystem services. It can also reflect the role of land use diversity in supporting the cultural service of landscape aesthetics.

The order of the socio-economic scenarios in terms of $VA_{DIVERSITY}$ is similar to that of VA_{FOOD}. SoG shows the least vulnerability followed by Riders, WRW and Icarus. This suggests that the widespread increase in agriculture seen in SoG contributes to greater landscape diversity at a European scale. Again, similar to the patterns seen for $VP_{FOOD,}$ vulnerability in terms of population for SoG is greater than in terms of area. In fact, SoG $VP_{DIVERSITY}$ is often greater than in all the other socio-economic scenarios for a given climate. Again this reflects the areas where vulnerability is identified; in urban areas where agricultural land has not increased, the population is high. In the SoG scenario, population is increasing rapidly leading to increased vulnerability relative to the other scenarios. Whilst the Diversity Index is closely linked to the food indicator for the standard settings of the socio-economic scenarios, an analysis of uncertainty associated with the parameter values for the amount of set-aside, agricultural yields and dietary preferences shows that the index is considerably more sensitive to these values than the food indicator. This is because these variables shift the distribution of land uses between classes within the food-providing land uses (i.e. between arable and the different grassland types) and between food-producing and abandoned land. As such the index has the potential to pick up very different stories to those shown by the Intensity and the Food Provision indices. The climatic sensitivity of the Diversity Index is also similar to the Food Index, being highest in the least severe climates (where food provision is less impeded, and expansion to marginal areas is less necessitated) and lowest in the more extreme climates, such as GFCM21.

3.5. Multi-sectoral aggregate vulnerability

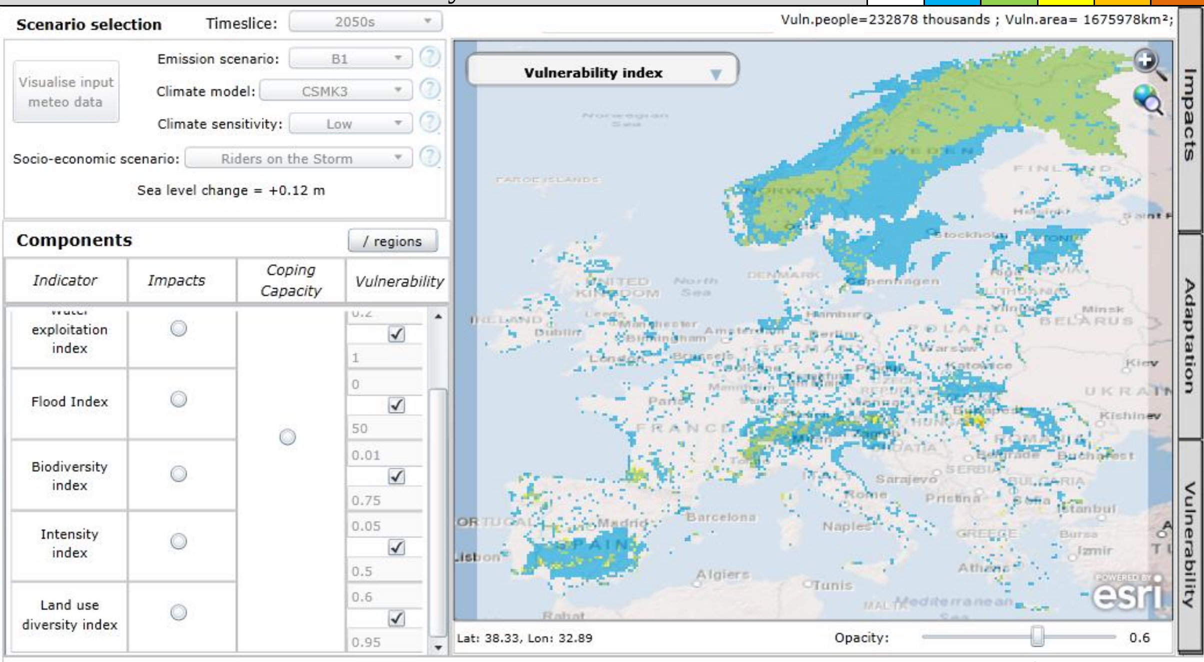
The sectoral vulnerability maps can be aggregated to highlight multi-sectoral hotspots. Aggregate vulnerability maps are shown in Figure 9 for two different combinations of climate and socio-economic scenarios which produce low and high vulnerability outcomes. In the low vulnerability case (CSMK3, low emissions, WRW, 2050s) there are a few key areas of vulnerability linked mostly to single indicators – for example, southern Spain (water exploitation) and Estonia (food) along with some coastal areas, particularly in northeast Italy (flood). There are very few areas highlighted as hotspots for multiple indicators, the most notable being Scandinavia and the Alps (food and diversity) and pockets of France, Austria and Hungary (food, biodiversity and diversity). This is reflected by the low proportion of Europe vulnerable to at least one indicator both in terms of people (46%) and area (36%).

In the high vulnerability case (GFCM21, high emissions, Icarus, 2050s) the proportion of Europe vulnerable is considerably greater with 81% of the area and 88% of the baseline population (443,004,000 people) vulnerable in at least one sector. Furthermore, significant areas of Scandinavia, France, Spain, Italy, Lithuania, Romania, Bulgaria and Greece are vulnerable to more than one indicator. The types of vulnerability differ with geographical area: in Scandinavia, the vulnerability is due to food and diversity, whilst in southern and eastern Europe, and the areas around Prague and Paris, the vulnerability is from biodiversity and water exploitation. Some areas are vulnerable to three indicators mostly along the coast where they are vulnerable to floods, but also in areas of Germany, the Czech Republic and Romania where the vulnerability to intensity is identified.



GFCM21, high emissions, Icarus: 443,004,000 people; 3,809,656 km^2

Colour varies by number of sectors vulnerable:	0	1	2	3	4	5	6



CSMK3, low emissions, WRW: 232,878,000 people; 1,675,978 km^2

Figure 9: Illustration of European multi-sector aggregate vulnerability in the 2050s.

4. Discussion

4.1. Comparison with previous studies – coping capacity vs. adaptive capacity

The CLIMSAVE methodology enables maps of vulnerability to be generated that take into consideration climate and socio-economic scenarios, adaptation and coping capacity. Indicator-based approaches similar to this have been used previously to create maps of adaptive capacity (e.g. Acosta et al. 2013). However, the focus here on coping capacity is novel. Coping capacity draws on indicators of four types of available capital that can be used to deal with an emerging crisis. Adaptive capacity takes a much longer-term view and associated indicator-based approaches focus on entirely different aspects: (i) the awareness of the population; (ii) the ability of that population to respond; and (iii) the level of action (Schröter et al. 2004; Metzger et al. 2006; Grieving et al. 2011; Acosta et al. 2013).

Table 2 highlights the similarities and differences between the two approaches in terms of the indicators used. There is some overlap: education, income inequality, income and transport are common to the two approaches. However, even for some of these overlaps the reason for their selection is very different. For example, in the adaptive capacity methodologies, education-based indicators such as commitment, computer skills and literacy are used as indicators of knowledge and awareness – higher values indicate populations that are more likely to know that climate change is a risk and take action. In the coping capacity approach, tertiary education is seen as a resource, more educated populations are more likely to be better skilled and able to apply those skills to cope with an impact. The differences are not just conceptual either: the coping capacity approach does not include top-down indicators such as “R&D expenditure”, “capacity to undertake research”, “GDP per capita” or “government effectiveness” or “democracy”. Instead the coping capacity indicators focus very much on the bottom-up, household level, for example, “help when threatened” and “household savings”. Similarly, they also include a focus on the health of the population which is not something considered in the adaptive capacity methodologies.

With these similarities and differences in mind, it is useful to compare the two methodologies to determine the extent to which coping and adaptive capacities follow the same spatial patterns (see Appendix F). The maps produced using the CLIMSAVE methodology compare at a general level with the maps from other studies (Schröter et al. 2004; Grieving et al. 2011; Acosta et al. 2013) in that Portugal, Spain, southern Italy and Greece are often areas identified as having the least capacity to either adapt or cope and central European and Nordic countries as having comparatively high adaptive/coping capacities. There are some key differences particularly with respect to Scandinavia, the United Kingdom and northern Italy. With the CLIMSAVE methodology, Scandinavian countries and the UK are shown to have coping capacity similar to countries in central Europe in most scenarios and time slices. Norway, in particular, is shown to have a large ability to cope, driven by high levels of human, social and financial capital, especially by significant levels of household savings. Conversely, both southern and northern Italy have lower coping capacities more in line with southern Europe.

A final difference between the methods is that in Schroter et al. (2004) and Acosta et al. (2013) the measures of adaptive capacity are driven by prescribed relationships identified between the trends in indicator variables, population and GDP. As such, the future projections are driven by changes in population and GDP according to the SRES scenarios and both are projected to grow. The resulting scenarios show very little decrease in adaptive capacity, whilst down-turns are possible (and are identified in France by Schroter et al. (2004) for 2050; Appendix F), the predominant trend is for a steady increase in adaptive capacity. The CLIMSAVE maps show considerably more variety in terms of trend and direction reflecting the greater variety of the CLIMSAVE stakeholder-derived socio-economic futures.

Table 2: Differences between the CLIMSAVE approach and that of Acosta/Metzger (A) and Grieving (G).

CLIMSAVE Capital	CLIMSAVE Variable	Approach	Project variable	Project Typology	Class
Human (Health)	Life expectancy	**CLIMSAVE ONLY**			Awareness
Human (Education)	Tertiary education (captures similar aspects)	G	Educational commitment	Knowledge and awareness	
		G	Computer skills		
		A	Literacy rate		
		A	Enrolment ratio		
Social (Engagement/ Preparedness)	**Not included in CLIMSAVE**	G	Attitudes towards climate change		
Social (Social equality)		A	Female activity rate	Equity	
Social (Economic equality)	Income inequality	A	Income inequality		
Social (Community networks/ Trust)	Help when threatened (CLIMSAVE only)	**CLIMSAVE ONLY**			
Social (Engagement/ Preparedness)	**Not included in CLIMSAVE**	G	National Adaptation Strategies (NAS)	Institutions	Action
Social (Government)	**Not included in CLIMSAVE**	G	Democracy	Institutions	
		G	Government effectiveness	Institutions	
Social (Vulnerability) or Financial (National)	**Not included in CLIMSAVE**	A/G	Dependency ratio	Flexibility (A) Economic resources (E)	
Social (Vulnerability) or Financial (National)	**Not included in CLIMSAVE**	G	Unemployment	Economic resources	
Financial (Household)	Household income	G	Income per capita	Economic resources	
Financial (National)	Correlates highly with household income	A	GDP per capita	Flexibility	
		A	Budget surplus	Economic power	
		A	World trade share	Economic power	
Financial (Household, reserves)	Household savings	**CLIMSAVE ONLY**			
Manufactured (Research/innovation)	**Not included in CLIMSAVE**	A	R&D expenditure	Technology	Ability
		G	Capacity to undertake research		
		G	Resources for technology		
		A/G	Number of patents		
Manufactured (Transport infrastructure)	Roads, rail and inland waterways	G	Road network density	Infrastructure	
Manufactured (Other infrastructure)	**Not included in CLIMSAVE**	A	Number of doctors		
		G	Hospital beds		
		G	Sustainable water infrastructure		
Manufactured (Assets)	Produced capital	**CLIMSAVE ONLY**			

4.2. Vulnerability

Vulnerability is defined in CLIMSAVE as the situation that occurs when the level of significant residual impact is greater than an area's ability to cope. However, the way that this is interpreted will vary with the sector. Coping with clear threats to well-being, such as lack of food or water, or flooding, is easy to conceptualise: areas that cannot cope are likely to experience real physical impacts on human health. People may die. Vulnerability to a loss of biodiversity, or to an intensifying landscape or one with a lack of diversity, is harder to conceptualise, but the impacts on human well-being may be no less significant due to impacts on mental and spiritual well-being and associated knock-on impacts on physical health. Even in the more clear-cut examples the impacts vary greatly; quite different impacts would result from realised flood vulnerability than food provision vulnerability – with different decisions needing to be made. The expert-based thresholding approach taken goes some way to standardising the amount of vulnerability, but the type of coping that would be needed will be different in each case. It is for this reason that the CLIMSAVE IAP is stressed as an exploratory tool providing the user with the ability to produce vulnerability maps for discussion in the context of the multiple scenarios and sectors to begin to unpick the factors that drive vulnerability in different contexts.

The vulnerability maps produced by the CLIMSAVE project serve their purpose as illustrative representations of the potential levels of vulnerability in the stakeholder-generated socio-economic scenarios combined with a range of climate scenarios. The aggregate vulnerability maps reproduce expectations with human well-being considered to be most at risk from water stress and biodiversity loss in southern Europe, and most at risk due to lack of food provision self-sufficiency and lack of land use diversity in northern Europe.

4.3. Methodological approach

The indicator-based methodology presented here is repeatable and, given the complexity of the concepts involved, comparatively simple. It allows abstract concepts such as the four capitals and coping capacity to be included in quantitative analyses. Furthermore, it directly integrates the views from stakeholder discussions in a way that allows complex stories of changing levels of both capital and coping capacity to be spatially depicted and used in the same system as the quantitative analysis.

With only two indicators being used for each capital the method is necessarily strongly influenced by the indicators chosen. It may be that additional indicators could help catch additional aspects of each of the capitals to reduce the influence of individual variables. However, more is not always better, and the concepts being represented are relatively abstract and intended for exploratory analysis rather than definitive explanation. Furthermore, where identified and explored, additional indicator variables correlated strongly with the selected variables. Whilst their inclusion may have diluted the influence of extremes in particular variables, the two-indicator approach maintains the simplicity whilst reproducing patterns that match expectation.

The capitals are combined equally to create coping capacity, but in practice it is likely that impacts in different sectors may require different types of capital to be able to cope. Changing this was considered when developing the methodology, but it is conceptually difficult to justify any weighting scheme and determine the levels of capital, particularly human and social, that are required to address a particular sectoral impact. It is possible that a capitals-based analysis of past disaster responses may help to quantify this. However, the decision of which weighting to give which capital will always involve some subjectivity and it is likely that allowing the IAP user more flexibility to create their own coping capacity in an interactive manner may be a better solution.

Further development of the IAP could allow a user this greater flexibility in the construction of the capitals, coping capacity and vulnerability itself by providing the user with control over the variables included, the standardisations applied, the thresholds used to determine vulnerability and the form of the relationship between coping capacity and vulnerability. The IAP could also be further developed to create a fully dynamic rather than time-step based system. This would be quite a significant computational task, and would probably need to be performed outside of the web-based version, but the outputs could be made available in an IAP-style system to enable users to explore the path dependency and spatial evolution of vulnerability hotspots.

5. Conclusions

The CLIMSAVE approach to vulnerability assessment allows a multi-sectoral analysis of vulnerability to be carried out. This analysis is based on integrating impacts from a broad range of climate and socio-economic scenarios with maps of coping capacity derived from the different participatory socio-economic scenarios. The process is replicable and transferable, and allows the concepts of the capitals approach, coping capacity, and stakeholder-derived scenarios to all be included in a quantitative system.

The methodology reproduces the expected patterns of coping capacity well for the socio-economic scenarios. It allows comparative levels of vulnerability to be explored across socio-economic and climate scenarios, across individual sectors and multiple sectors combined. As such, it provides a valuable methodology for decision-makers and other stakeholders to inform their understandings of potential future impacts of climate change and the related vulnerability.

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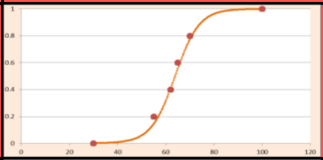
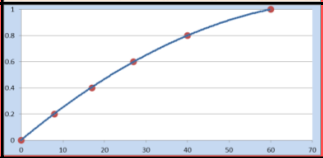
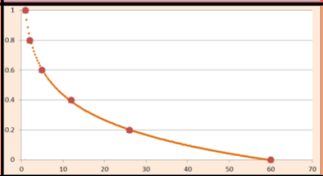
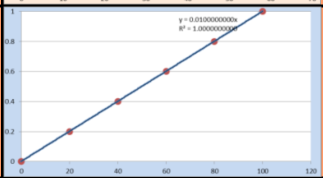
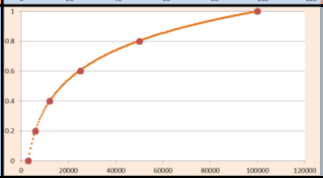
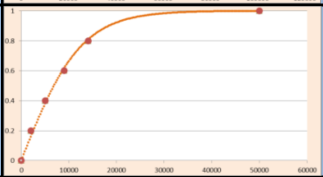
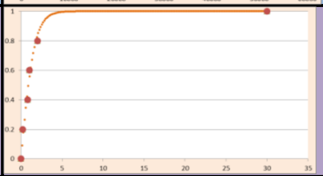
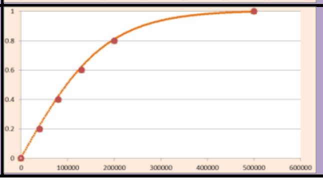
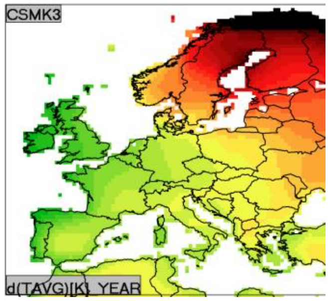
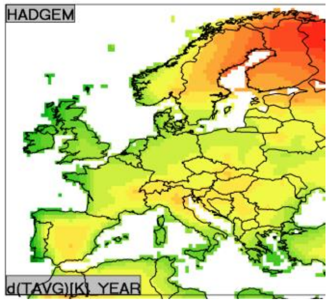
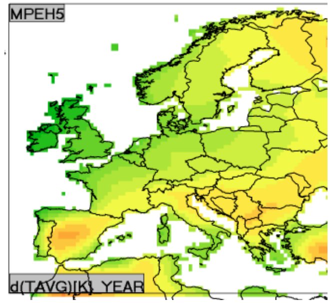
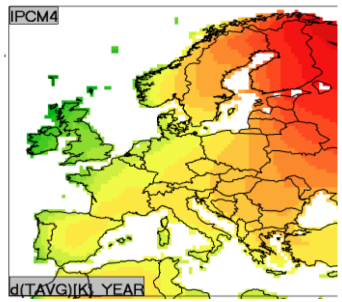
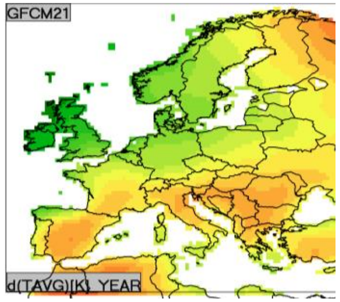
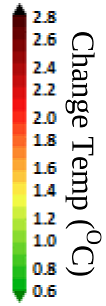
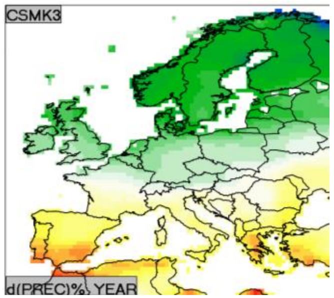
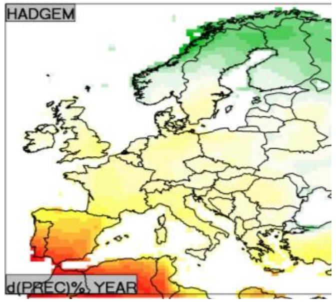
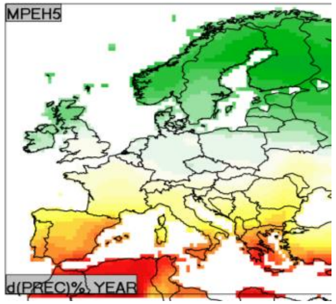
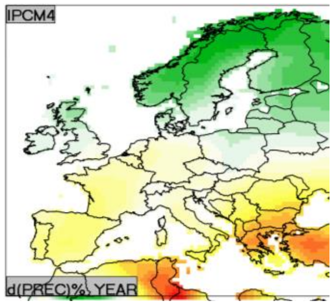
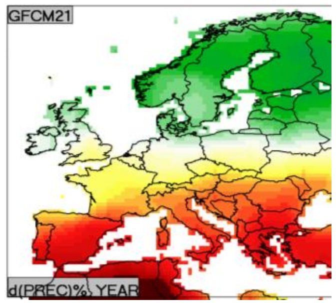
Appendix A: Correlation analysis for the indicator variables considered for inclusion.

	Life Expectancy	**Tertiary Education**	Longterm Unemployment	HRST (HR in Sci-Tech)	**Income Inequality**	**Help when threatened**	At-risk-of-poverty	Corruption Perception	Trust	Volunteering	**Household Income**	Financial Assets (raw)	Household saving rate	Net household savings rate	Financial Assets (% of GDP)	Net Foreign Assets	Net National Assets	GDP	**Transport (Density)**	**Transport (Area)**	**Transport (Pop)**	**Produced Capital**
Tertiary Education	0.26																					
Longterm Unemployment	-0.32	-0.51																				
HRST (HR in Sci-Tech)	0.41	**0.89**	-0.55																			
Income Inequality	-0.41	0.00	0.10	-0.31																		
Help when threatened	0.30	0.53	-0.39	**0.71**	-0.36																	
At-risk-of-poverty	-0.34	-0.06	0.13	-0.41	**0.91**	-0.50																
Corruption Perception	**0.60**	**0.67**	-0.57	**0.82**	-0.43	**0.66**	-0.48															
Trust	0.46	0.53	-0.53	**0.66**	-0.37	**0.62**	-0.43	**0.82**														
Volunteering	**0.61**	0.55	-0.45	**0.79**	**-0.61**	**0.73**	**-0.64**	**0.85**	**0.71**													
Household Income	**0.91**	0.31	-0.24	0.47	-0.30	0.35	-0.30	**0.61**	0.41	**0.66**												
Financial Assets (raw)	**0.74**	0.47	-0.48	**0.62**	-0.33	0.55	-0.41	**0.76**	**0.67**	**0.69**	**0.76**											
Household saving rate	**0.73**	-0.05	0.16	0.14	-0.49	0.14	-0.35	0.31	0.11	0.38	**0.66**	0.31										
Net household savings rate	0.09	0.25	-0.41	0.50	-0.38	0.51	-0.38	0.56	0.53	0.56	0.10	0.29	0.26									
Financial Assets (% of GDP)	**0.68**	0.28	-0.34	0.38	-0.21	0.31	-0.24	0.57	0.48	0.42	**0.68**	**0.90**	0.34	0.11								
Net Foreign Assets	0.12	0.25	-0.18	0.35	-0.19	0.24	-0.13	0.27	0.02	0.33	0.01	0.25	0.29	0.52	0.21							
Net National Assets	**0.80**	**0.63**	-0.52	**0.76**	-0.39	**0.60**	-0.38	**0.83**	**0.68**	**0.83**	**0.88**	**0.92**	0.51	0.31	**0.77**	0.44						
GDP	**0.66**	0.44	-0.38	**0.61**	-0.37	0.43	-0.36	**0.66**	0.43	**0.71**	**0.91**	**0.88**	**0.60**	0.28	**0.71**	**0.76**	**0.88**					
Transport (Density)	0.13	0.26	-0.05	0.26	-0.09	0.25	-0.14	0.28	0.18	0.23	0.16	0.04	0.09	0.25	-0.05	-0.11	0.14	-0.03				
Transport (Area)	0.11	-0.14	-0.04	-0.04	-0.27	-0.02	-0.23	0.10	0.01	0.16	0.15	0.38	0.06	0.36	0.36	0.12	-0.01	0.01	-0.13			
Transport (Pop)	-0.44	0.33	-0.17	0.31	0.01	0.06	-0.08	0.05	0.03	0.06	-0.33	-0.32	-0.41	0.22	-0.37	-0.03	-0.17	-0.26	0.30	0.10		
Produced Capital	**0.74**	0.55	-0.47	**0.70**	-0.39	0.50	-0.38	**0.75**	0.57	**0.77**	**0.88**	**0.88**	**0.60**	0.28	**0.72**	**0.61**	**0.95**	**0.96**	0.00	-0.03	-0.20	
Construction	0.40	-0.04	-0.08	0.12	-0.30	0.18	-0.33	0.14	0.10	0.20	0.37	**0.62**	0.28	-0.03	**0.75**	0.16	0.30	0.33	-0.32	0.53	-0.35	0.32

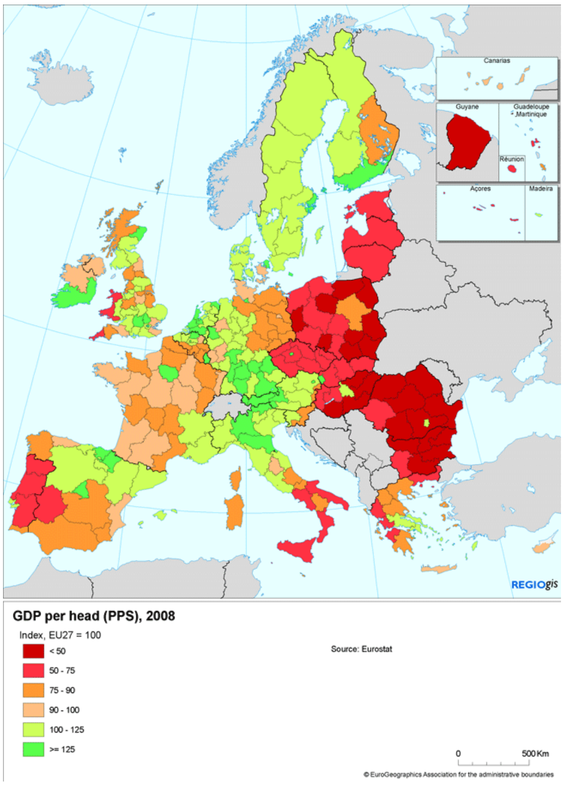
Appendix B: Standardising capital indicators: average European national statistics determining thresholds. Scale: N = NUTS. Capital: H = Human; S = Social; F= Financial; M = Manufactured.

Scale	Capital	Variable name	Form	Graph	EU current max	EU current min	2020s Europe: Min Max	2050s Europe: Min Max
N2	H	Life Expectancy	Logistic		72.08 (Lithuania @N0/2) 83.6 (Switzerland @N2)	31.88 (Swaziland) 89.73 (Monaco)	**60** **90**	**30** **100**
N2	H	Tertiary Education	Squared		13.8 (Malta/ Romania) 53.1 (Finland @N2)	2 (Sub-Saharan Africa) 42 (Canada)	**10** **55**	**0** **60**
N0	S	Income Inequality	Log		3.4 (Slovenia/ Hungary) 7.3 (Lithuania)	3.4 (Japan) 57.6 (Sierra Leone)	**2** **10**	**1** **60**
N0	S	Help When Threatened	Linear		15% Hungary 70% (Netherlands/ Sweden)		**10** **75**	**0** **90%**
N2	F	Household Income	Log		3623.8 (Bulgaria @N2) 26324.9 (UK @N2)		**€5000** **€80000**	**€3000** **€100000**
N0	F	Net household savings rate	Logistic		-2600 (Greece) 9500 (Norway)		**€-5000** **€25000**	**€-5000** **€40000**
N2	M	Transport	Logistic		4.063 (Belgium @N2) 0.019 (Greece @N2)	Mali (0.029) Monaco (25.5)	**0.01** **15**	**0.01** **30**
NO	M	Produced Capital	Logistic		6975 (Albania) 213425 (Luxembourg)	166 (Burundi) 213425 (Luxembourg)	**5040** **350000**	**0** **500000**

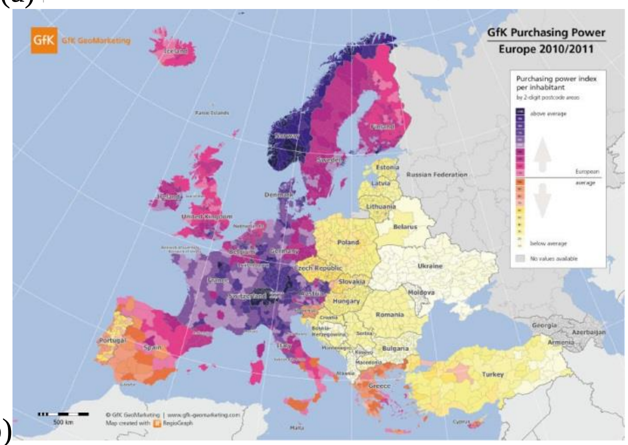
Appendix C: Spatial patterns of annual temperature and precipitation changes for the GCMs used within the CLIMSAVE IAP.

	CSMK3	HADGEM	MPEH5	IPCM4	GFCM21	
Temperature						
Precipitation						

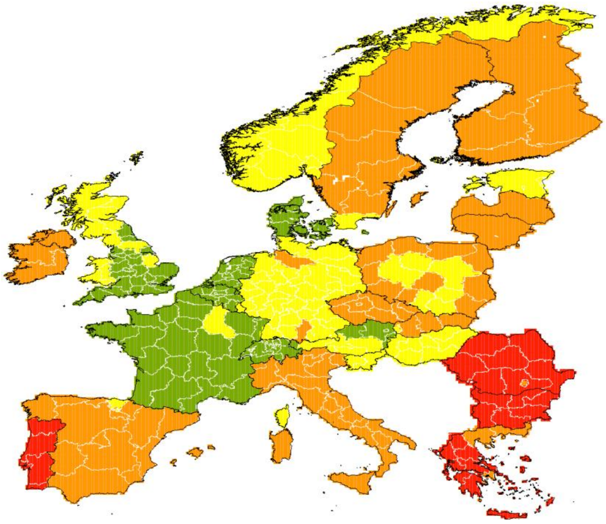
Appendix D: Comparing financial capital with other data: (a) GDP per capita from Eurostat, (b) GfK purchasing power and (c) CLIMSAVE estimated financial capital.



(a)

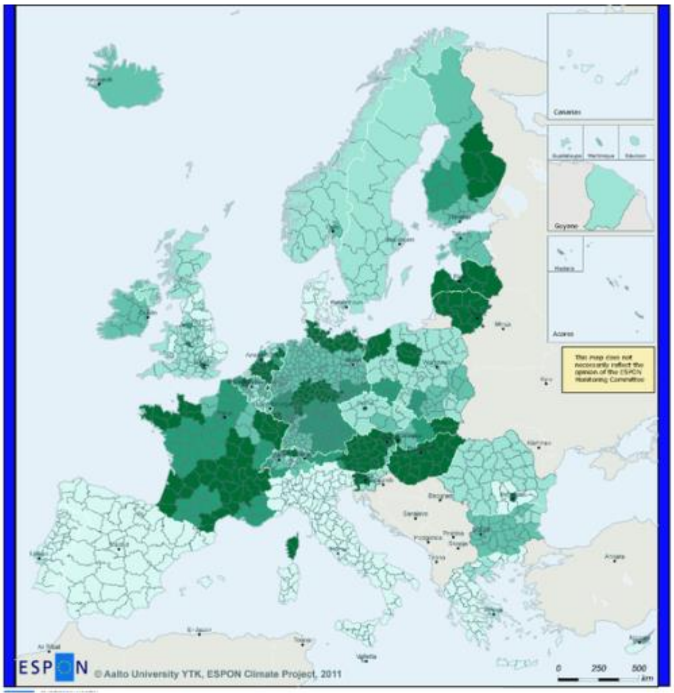


(b)

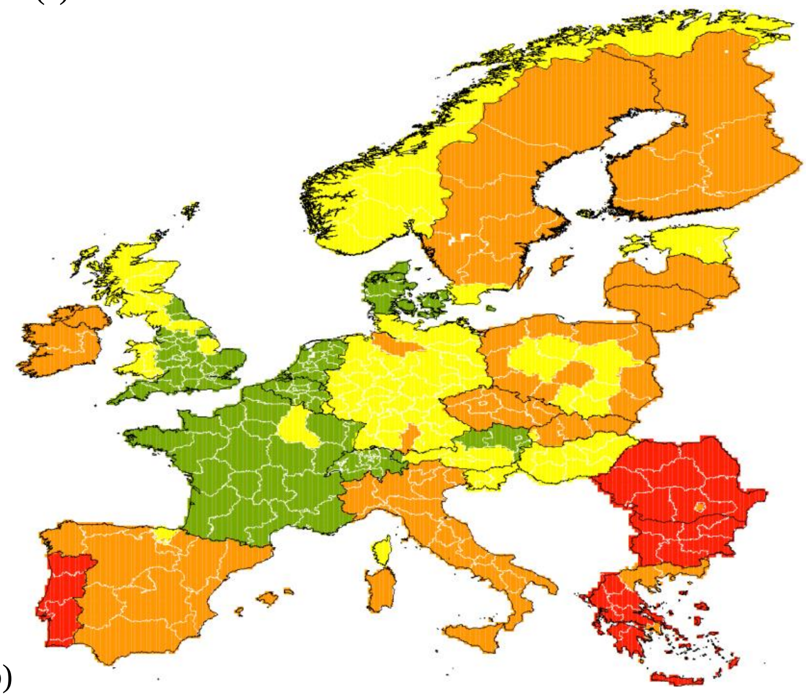


(c)

Appendix E: Comparing manufactured capital with other studies: (a) adaptive capacity from infrastructure (Grieving et al. (2011) and (b) CLIMSAVE estimated manufactured capital.



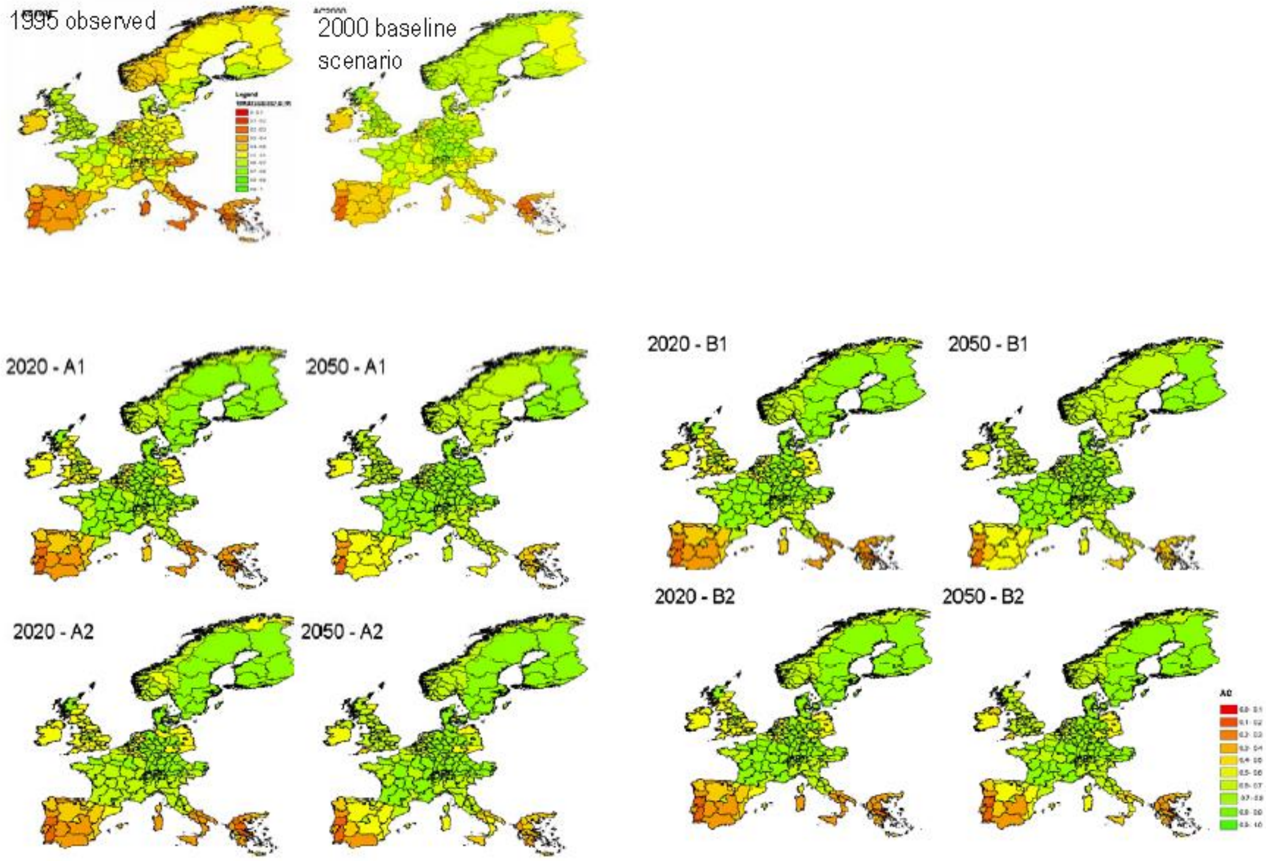
(a)



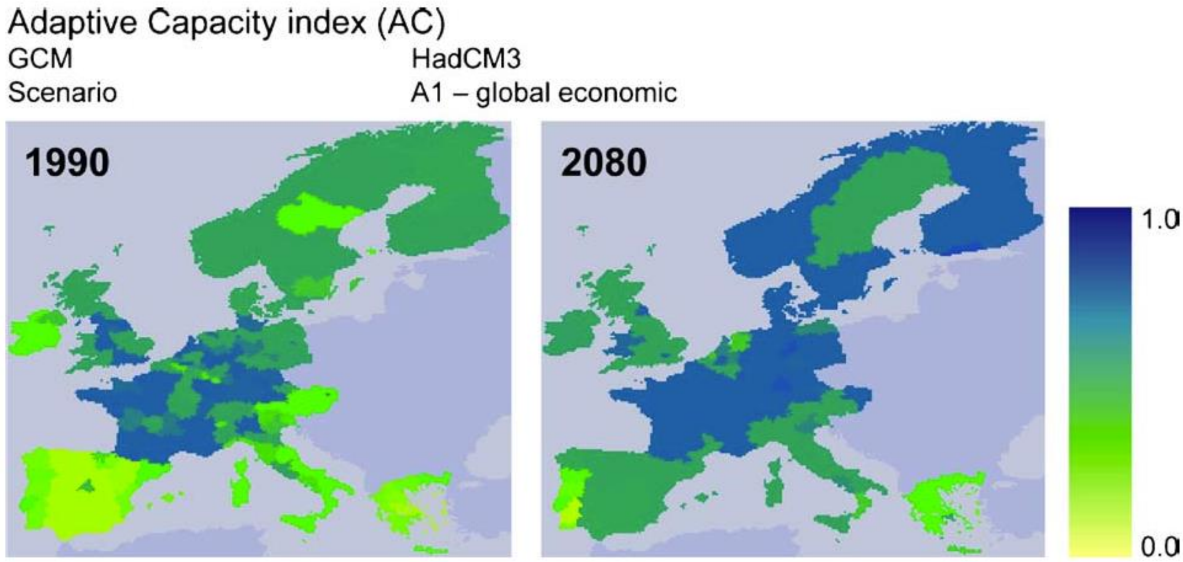
(b)

Appendix F: Comparing adaptive capacity maps with other studies: (a) Schroter et al (2004) for baseline and IPCC scenarios of the 2020s and 2050s; (b) Metzger et al. (2004) for baseline and the 2080s; (c) Grieving et al. (2011) for the baseline; and (d) the CLIMSAVE coping capacity map.

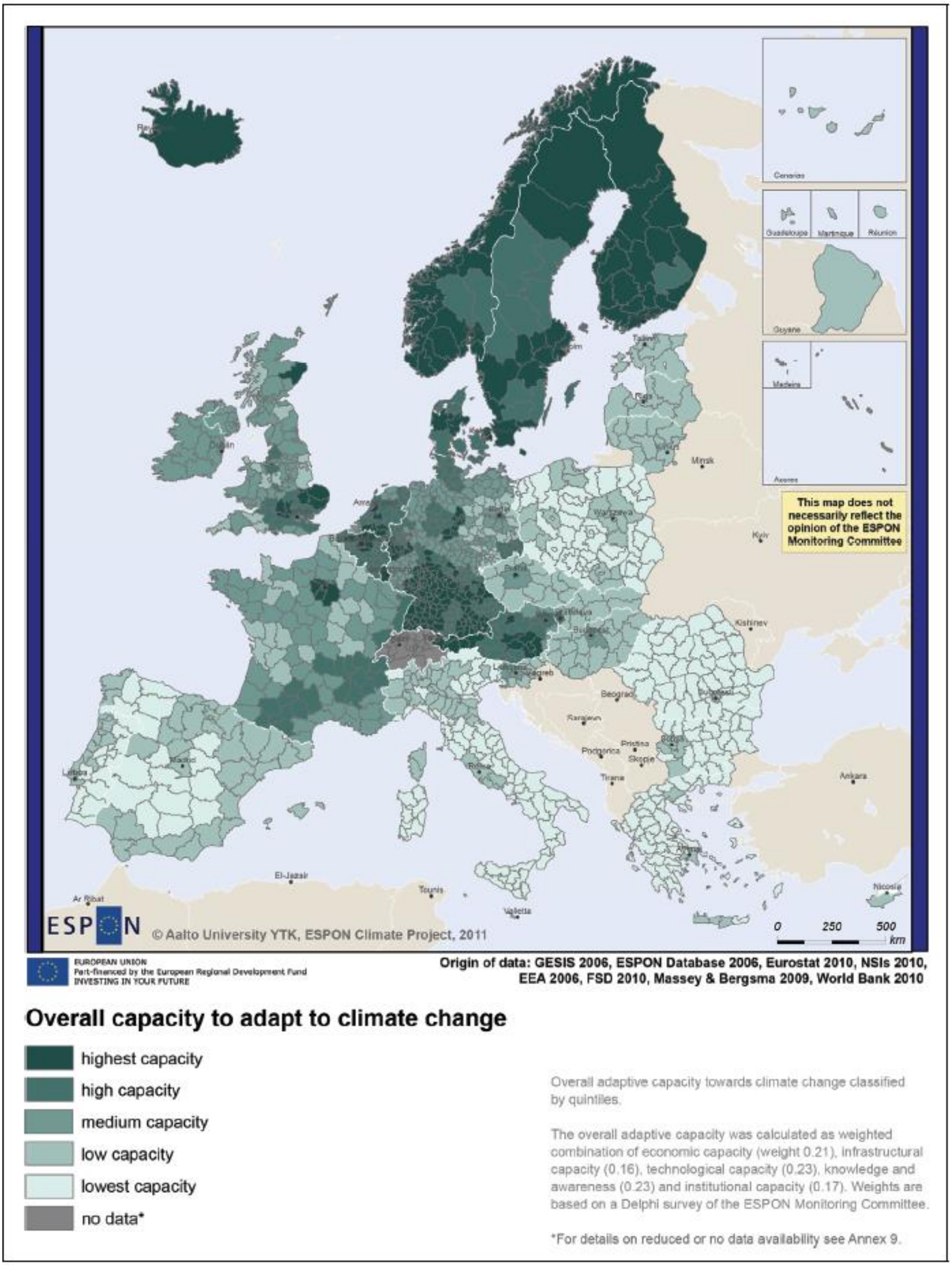
(a) Schroter et al. (2004)



(b) Metzger et al. (2004)



(c) Grieving et al (2011)



(d) Coping capacity for baseline using the CLIMSAVE method.