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From Indicators to Action: Evaluating the Usefulness of Indicators to Move from Regional Climate Change Assessment to Local Adaptation Implementation

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FROM INDICATORS TO ACTION: EVALUATING THE USEFULNESS OF INDICATORS TO MOVE FROM REGIONAL CLIMATE CHANGE ASSESSMENT TO LOCAL ADAPTATION IMPLEMENTATION

A Thesis Presented

by

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ABSTRACT

FROM INDICATORS TO ACTION: EVALUATING THE USEFULNESS OF INDICATORS TO MOVE FROM REGIONAL CLIMATE CHANGE ASSESSMENT TO LOCAL ADAPTATION IMPLEMENTATION

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As the effects of climate change become increasingly damaging and costly, a public and political consensus is building for planning that will protect private property and public infrastructure. Climate-related planning has primarily focused on mitigation, assessing vulnerability, and building adaptive capacity. Adaptation has not gained substantial ground in the area of implementation. The uncertainty associated with climate change projection and variability has emerged as a dominant barrier to adaptation. However, as knowledge accrues, the global and national science communities have been developing more detailed, fine-scale climate projections. Regional climate assessments are available for the sub-national climate regions in the U.S., and have been created based on the measurement of many components of climate, often referred to as indicators. This thesis evaluates the use of those and other indicators as adaptation decision support tools. Findings suggest that indicators can be effectively integrated into a step-wise, risk-based adaptation planning process to overcome barriers to adaptation, many of which contain concern over climate change uncertainty at their core. The combination of

climate science data and information about the local experience of climate change are found to be key to the effective use of indicators in adaptation, as is the direct integration of indicators into the policy-making process. Ideally, these indicators can be used to inform trigger points for phases in a flexible adaptation approach, but more work is needed to develop methods for managing the risks and costs associated with adaptation.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION

1.1 Climate Change as a Planning Issue

As the effects of climate change become increasingly damaging and costly, a public and political consensus is building for planning and policies to protect private property and public infrastructure. There is much to be said for planning ahead for climate adaptation: "Ex-ante planning and infrastructure design to account for expected climatic and natural disaster occurrences can increase resilience, as can retrofitting existing infrastructure to increase its capacity to withstand such events," (Prasad, 2008, p. 34).

Societal efforts to cope with climate change typically fit within the concepts of mitigation or adaptation, as they are defined within the climate change context. Mitigation refers to the effort to curtail climate change by reducing the greenhouse gas emissions or increasing carbon dioxide sinks (IPCC, 2007). Climate change adaptation is understood as the process of adjusting to the current climate or the anticipated changes in climate to support the continued wellbeing of the adapting party (IPCC, 2012).

Mitigation has thus far had a stronger foothold in scientific focus and policy development than has adaptation. Füssel (2007a) explains that the dominance of mitigation over adaptation in the realms of science and policy are due to issues of scope, the distribution of responsibility, and measurement. In terms of scope, there is little likelihood that all natural systems being affected by climate change will be able to adapt, but would have their harm mitigated by the global reduction of greenhouse gas emissions. When identifying the distribution of the burden of climate-related actions, it is easy to arrive at the solution that those contributing substantial amounts of emissions are the ones with the power to stop or cut down. The distribution of adaptation responsibilities is more complicated, in part because the human populations that will be impacted most severely by climate change are those who have contributed very little to the atmospheric carbon concentration and who have the least resources with which to adapt. When it comes to certainty and measurement, greenhouse gas emissions are a quantifiable indicator of the level of anthropogenic contributions to climate change, and therefore the comparative success of mitigation over time. Introducing quantifiability to adaptation is much more challenging. Adaptation decision-making and its success after implementation are dependent on accurate projections of a naturally uncertain system, and little progress has been made in the methods of measuring the efficacy of adaptation strategies. Adaptation, in its current state, simply does not have the quantifiability and ubiquity of impact to make it as approachable as mitigation as a target for policy-makers.

Mitigation of global emissions must happen soon and affect change quickly. Atmospheric stabilization models suggest that even a sudden drastic reduction in emissions would take decades to effectively reduce atmospheric CO_2 concentration to an accepted target, and even longer to manifest climatic impacts. Furthermore, the rate of increase in emissions and the peak concentration that is reached – whether temporary or static – may trigger "tipping points" in ecological functioning, causing rapid environmental changes at a rate unfixed to the rate of emissions increase. These tipping points would pose challenges even more difficult to overcome than climate forcing by global emissions, and our society may not have the capability to do so. While mitigation proceeds, adaptation must be part of the societal response to climate change in order to enable communities to endure and thrive through the intermediate and enduring changes in climate (Vaughan, Lenton, and Shepherd, 2009; Füssel, 2007a).

Many planners and leaders at the municipal and regional levels have been working on climate adaptation for years. The results have included the development of reports and plans that assess climate-related impacts – most often extreme weather events – and offer recommendations for measures to adapt to the most likely impacts. However, adaptation has not gained substantial ground in the area of implementation, such as the actual expenditures and retrofitting of facilities in the U.S. (Smit and Wandel, 2006).

Common barriers to adaptation fit within general themes of leadership, resources, communication, and values. These barriers may be situated within various scales of spatial organization and within any step of the adaptation planning process. Communities are identifying the ways that climate change could threaten them and beginning planning processes to find appropriate adaptation measures, but the process frequently seems to stall at this stage. Barriers in the themes cited above appear to be hindering progress toward choosing adaptation strategies and implementing them. Research on barriers finds that a lack of certainty about climate projections is one of the most prominent inhibitors to adaptation planning (Moser and Ekstrom, 2010; Hamin, 2012). In the face of myriad complicated climate projections, planners find it difficult to choose one to plan around for fear of choosing wrong or seeing the projection change after adaptation actions have been undertaken (Hamin et al., 2012). However, as knowledge accrues, the global and national science communities have been developing more detailed, fine-scale climate projections. Regional climate assessments are available for the entire United States, which have been created based on the measurement of many components of climate, often referred to as indicators. The composite of this measured data is a snapshot of the current state of the climate system, and tracking measurements of the system over time can imply a pattern of change. This information can be used to inform adaptation decision-making, an invaluable tool for overcoming the barriers to adaptation planning, including the perceived uncertainty surrounding the projection of climate change, political obstacles and lack of state or federal mandates (US Global Change Research Program, 2012).

1.2 Purpose of Study

The transition from assessment to implementation is a key issue in the progress of climate change adaptation at all scales. This thesis will explore the potential benefits of the strategic selection and use of indicators by municipalities and to advance their adaptation goals and objectives. The primary hypothesis is that the use of indicators can bridge the gap between intention and implementation by acting as a decision support mechanism, helping planners overcome the uncertainty inherent in climate change projection. Regional climate assessments are highly important to climate-related planning; linking localized climate measurements that align with the indicators used to create the region's climate assessment will make climate projections more actionable.

Indicators are measurable, recordable characteristics that contribute to the understanding of a complex system by clarifying the changes within its parts (Janetos et al, 2012). The European Environment Agency defines an indicator as "a measure, generally quantitative, that can be used to illustrate and communicate complex phenomena simply, including trends and progress over time" (2005, p. 7). Climate change indicators can offer answers to questions about how the climate is projected to change and what impacts those changes will cause, as well as societal questions about preparation, adaptation, and vulnerability within communities (Janetos et al., 2012). By evaluating the methods for the use of indicators, planners and others involved in local and regional adaptation may be better prepared to take action once comprehensive indicators are established. In addition, connecting indicators to the adaptation decision-making process can help create opportunities for community involvement and cultivation of the political support necessary to advance needed adaptation implementation measures (Hamin, Abunassr, & Brabec, 2012). This thesis seeks to understand and evaluate whether the linking of indicators to the decision-making process may be one of the most effective tools in the municipal climate change adaptation toolbox.

1.3 Goals, Research Questions, and Objectives

1.3.1 Goals

The goal of this thesis is to contribute to the academic and professional understanding of how indicators can provide links between regional climate assessments and municipal adaptation planning, and how these linkages can overcome barriers to adaptation. It is the author's hope that the examination of this issue from a vantage point between the regional and municipal scales will advance the applicability of the indicator frameworks and enable more communities to implement adaptation planning.

1.3.2 Research Question

Research question: How can indicators facilitate the connection between regional climate assessments and municipal climate change adaptation planning?

1.3.3 Objectives

Objective 1: To improve understanding of how climate change indicators are and can be better used in planning practice.

Methods:

- Literature search on general usage of indicators in planning to look for characteristics of effective indicators. Literature search will use Web of Science database, using topics such as climate change, adaptation, indicators, and will focus on sources that have been cited 50 or more times.

Objective 2: To identify common barriers to adaptation implementation at the municipal scale.

Methods:

- Analysis of qualitative data collected in coastal Massachusetts adaptation planning pilot study (Hamin, 2012).

Objective 3: To develop a decision-making strategy supported by indicators selected on the basis of scalability, potential for municipal relevance, and the capacity for overcoming barriers to adaptation.

Methods:

- Literature search on existing and developing indicators.
- Construction of a integrative matrix using information gained from literature search and research on barriers to adaptation.

1.4 Scope

1.4.1 Limitations

- The National Climate Assessment indicator framework is not yet fully developed, therefore this research will include as much information on their work as is available, but the final product from NCA (due to be launched as a pilot program is 2014, and a full program in 2015) may differ from the currently available information.
- The usage of climate change indicators in planning is relatively new, so examples available for comparison are sparse.

- Climate change is a dynamic process, in both nature and in the advancement of the science that studies it. New developments in climate science may occur that would lead to future adoption of indicators that are more accurate or applicable than those included herein, though the theory covered by this study would still apply.

1.4.2 Delimitations

- This study will not argue the science of climate change, nor will it argue the effect of anthropogenic carbon emissions on the climate. The dominant scientific data in the field, such as the findings mentioned in this study, are accurate according to the vast majority of climate scientists and practitioners.
- This study will not seek to groundtruth the individual indicators in each framework studied. Though the findings may suggest that some indicators are more applicable than others, this study should not be considered a comprehensive review of all climate change indicators.
- This study will not recommend specific climate change adaptation strategies. Adaptation actions are differentially appropriate for different communities or regions, and so the findings of this research should be viewed as a guide to finding the right strategies, not as a prescription that all communities should take the specific actions mentioned here.
- Planning is implemented differently across regional, state, and international borders. This thesis was developed within the context of planning in the Commonwealth of Massachusetts, mostly done by municipalities rather than

counties or regions. Regional planning agencies in Massachusetts are advisory, with the exception of the Cape Cod Commission which holds some regulatory power. However, the findings of this research are applicable in other locales because of similarities in the barriers to climate change adaptation and the strength of local planning in various types of regulatory frameworks.

1.4.3 Definitions

Adaptation: "Adaptation is defined as the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC, 2012).

Anticipatory adaptation – "Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation" (IPCC, 2007).

Autonomous adaptation – "Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation" (IPCC, 2007).

Planned adaptation – "Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state" (IPCC, 2007).

Adaptive capacity: "The potential or capability of a system to adapt to (to alter to better suit) climatic stimuli" (Smit et al., 2000, p. 238).

Backcasting: "A method in which the future desired conditions are envisioned and steps are then defined to attain those conditions, rather than taking steps that are merely a continuation of present methods extrapolated into the future" (Holmberg and Robert, 2000, p. 294).

Barrier: "Any obstacle to reaching a goal, adaptation or mitigation potential that can be overcome or attenuated by a policy, programme, or measure" (IPCC, 2007).

Decision support: "An activity that provides data, tools, and other types of information products that make scientific information more accessible to decision makers" (NRC, 2009, p. 34).

Indicators: "Indicators are usually thought of as measurements or calculations that represent important features of the status, trend, or performance of a system of interest" (Janetos et al., 2012, p. 4).

Mitigation: "An anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks" (IPCC, 2007).

Regional: This thesis uses "regional" to refer to sub-national U.S. climate regions as designated in National Climate Assessment reports. This differs from the spatial jurisdiction of "regional planning agencies", which operate on a sub-state scale. Mentions of "regional" areas outside of the U.S., as in reference to European Environment Agency indicators, refer to multi-national regions that spatially compare to U.S. states or regions.

Resilience: "The capacity of a system to absorb disturbance and reorganize so as to retain essentially the same function, structure, and feedbacks - to have the same identity" (Walker and Salt, 2012, p3).

Tipping points: "Points where the magnitude of change due to climate change or sea level rise is such that the current strategy will no longer be able to meet the objectives" (Kwadijk et al., 2010).

Trigger points: Conditions that signal the appropriate moment in a phased or flexible adaptation process for "movement to the next stage of [the] adaptation plan" (Hamin, Abunassr, & Brabec, 2012, p. 15). *Related terms: triggering conditions, triggering mechanisms, triggering indicators, triggers.*

Vulnerability: "Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC, 2007).

1.4.4 Acronyms

EEA: European Environment Agency

EPA: Environmental Protection Agency

IPCC: Intergovernmental Panel on Climate Change

NCA: National Climate Assessment

NCADAC: National Climate Assessment and Development Advisory Committee

NCDC: National Climatic Data Center

NOAA: National Oceanic and Atmospheric Administration

NPCC: New York City Panel on Climate Change

NRC: National Research Council

RCP: Representative Concentration Pathway

USGCRP: United States Global Change Research Program

USGS: United States Geological Survey

CHAPTER 2

LITERATURE REVIEW

2.1 Climate Projection

2.1.1 Overview of Climate Change Observations and Forecasts

Climate change is understood as a “statistically significant variation in the mean state of the climate or its mean variability, persisting for an extended period” (IPCC, 2001, p. 711). This is the definition used by the Intergovernmental Panel on Climate Change (IPCC), the leading body in climate change research. The world has already seen changes to the climate: the ten warmest years on record have occurred since 1998, and the 20 warmest years on record have occurred since 1981 (Cole and McCarthy, 2011). The IPCC estimates with over 90% probability that the 1950-2000 time period was the warmest 50-year period in the last 500 years in the Northern Hemisphere, and with over 66% probability that it was the warmest 50-year period in the last 1,300 years at least (IPCC, 2007). The sea level measured around the globe rose by approximately 17 centimeters (6.7 inches) in the 20^{th} century; the rate of change measured from 1990-2000 was nearly double the rate of sea level rise for the rest of the century (Church, 2006). It is likely that heat waves, the global area affected by draught, and heavy precipitation events have all increased, though these changes are experienced differentially according to location.

Climate hazards, including extreme temperature, gradual shift in average temperature, precipitation events, droughts, and storm surge, range from likely to virtually certain to increase in frequency and intensity this century (Alley and

Arblaster, 2007). The presence of carbon dioxide in the atmosphere is inextricably linked with climate because of its heat trapping properties. The warmer the air and oceans get, the warmer they will continue to get due to the self-propagating carbon cycle, which is also susceptible to other contributions of carbon into the atmosphere (Friedlingstein et al., 2006), such as anthropogenic emissions. The rise in atmospheric carbon dioxide concentration triggers a great number of additional changes in climate with noticeable variability and a range of extremes (McCarthy, 2001), which is one reason "climate change" has emerged over "global warming" as the dominant term for this global environmental shift. Also important to the conversation of climate change semantics is the fact that humans do not experience this environmental shift through the singular dimension of temperature rise (Conway, 2008). Most of these triggered changes are catalyzed by the intermediary rise in temperature from heat trapping, though carbon dioxide does directly influence some processes including ocean acidification (NCADAC, 2013). The perceived simplification of this dynamic process to a singular dimension because of the name "global warming" has traditionally made it very difficult to spread understanding and support for mitigation and adaptation outside the climate science field, so research into the multitude of observed and anticipated changes has been essential to the progress of climate change as a discernable process.

When developing climate projections, climatologists usually consider likely future trends in global emissions, then apply the expected emissions levels to the extant knowledge on atmospheric CO_2 concentration's impact on climate. In order to build reference points for those likely future trends in global emissions, climatologists have published multiple iterations of scenarios based on growth characteristics as new information surfaces. The latest incarnation of climate scenarios, Representative Concentration Pathways (RCPs), also take a range of possible mitigation actions into account; the 2014 IPCC Fifth Assessment Report (AR5) will use analysis based on these RCPs.

Since climatologists' emissions scenarios were first used in an official capacity in the 1990 IPCC First Assessment Report and continually updated based on increasingly sophisticated scientific data, it is now possible to compare actual emissions with the projections that were made in the past. This comparison can be seen in Figure 1, where a broad array of emissions scenarios developed since 1990 are pictured along with measured annual CO_2 emissions worldwide. While there are many greenhouse gases that contribute to overall emissions measurements, CO_2 is the primary anthropogenic greenhouse gas and is therefore often looked to as a representative indicator for overall emissions. It is plain to see that CO_2 is being emitted at the high end of levels projected in the pictured scenarios. Observed emissions – represented by the dotted black line – are currently following the scenario that allows for the largest increase in emissions out of the newly developed RCPs. The red line running parallel to the measured emissions in Figure 1 is the projection for RCP8.5, which estimates that CO_2 emissions will rise to approximately 1,370 parts per million (ppm) by 2100. It is expected that by 2100, this level of CO_2 in the atmosphere would cause a mean annual global temperature increase of 4.2-5°C (Peters et al., 2013). If emissions continue to follow the RCP8.5 pattern, the annual global temperature could rise by approximately 8°C by the year 2300

(Meinshausen et al., 2011). Temperature rise of this magnitude would cause dramatic changes to the global ecosystem and would have a devastating impact on communities (see Appendix B, tables B-1, B-2, and B-3 for descriptions of emissions scenarios as SRES storylines and RCPs).

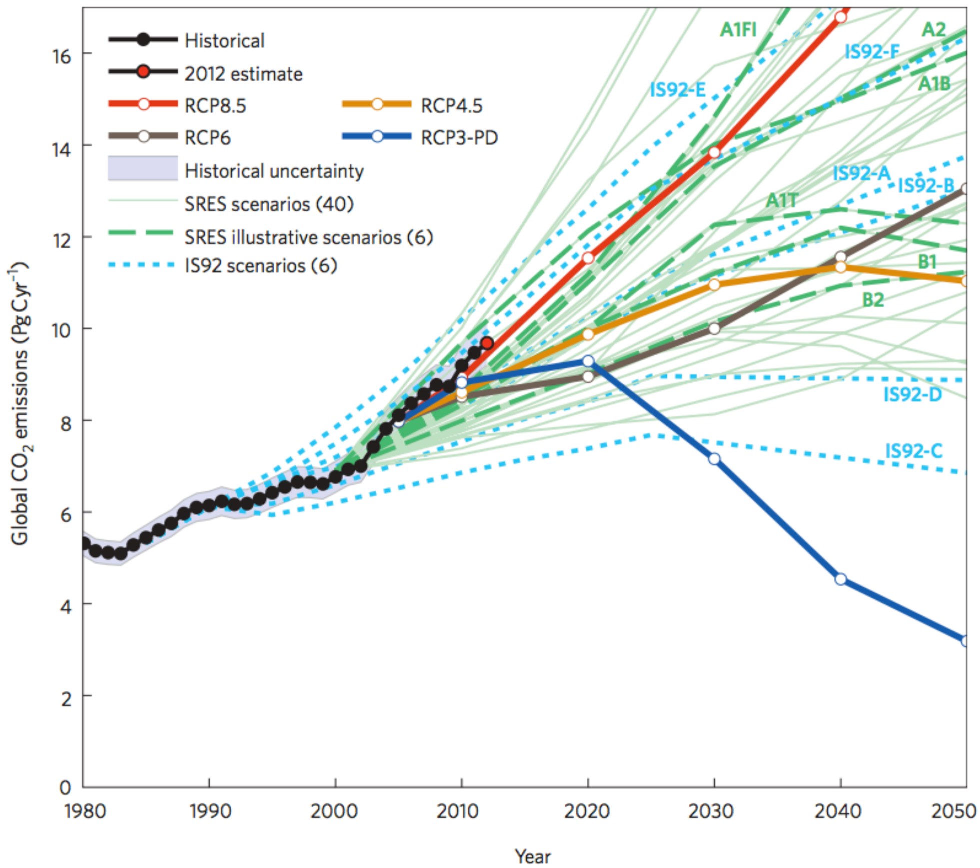

Figure 1: Estimated CO2 emissions since 1980, comparing scenarios developed by climatologists with historically observed data (Peters et al., 2013).

Of course, the path of global emissions is not predetermined, nor is unchangeable. With swift mitigative action, industrialized countries could change the course of climate change by the end of the century. The international climate policy community would like to limit global warming to 2°C, but the pledges expressed to the UNFCCC in 2010 by nations participating in the 2009 Copenhagen Accord would not be enough to meet the 2° goal (Rogelj et al., 2010). Schaeffer et al. (2012) states that if all pledges from the Copenhagen Accord are met, 3°C of warming above pre-industrial temperatures can be expected. Referring to Figure 2, which shows the emissions and warming characteristics of all four RCPs through 2300, 3°C of warming above pre-industrial temperatures by 2100 aligns with the RCP6 scenario (Rogelj et al., 2012). For the reference pathway with no Copenhagen Accord pledges, 3.5°C of warming by 2100 is expected, which lies between RCP6 and RCP8.5 (Schaeffer et al., 2012).

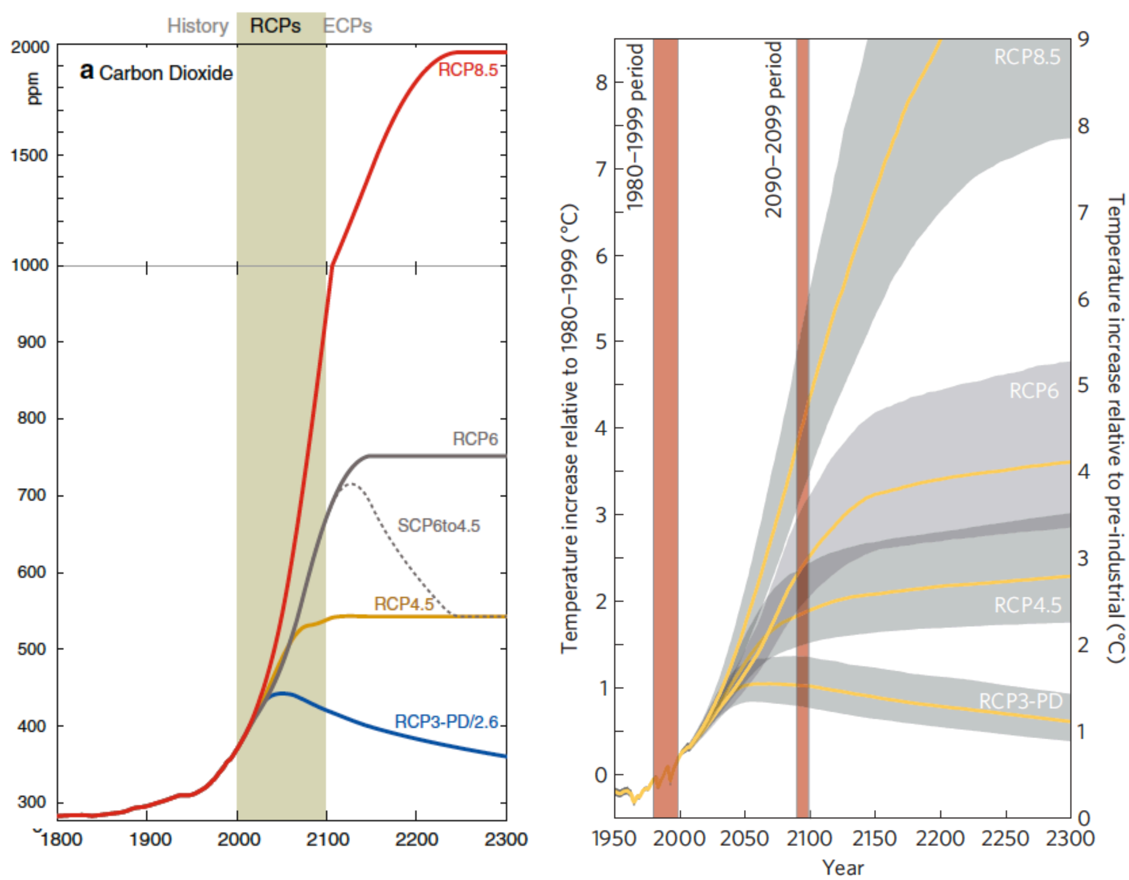

Figure 2: Emission (2a) and temperature (2b) projections through 2300 based on RCPs (2a Meinshausen et al., 2011; 2b Rogelj et al., 2012).

With this information in mind about likely possibilities for global temperature rise, it is important to next evaluate the spectrum of impacts that are being experienced, and what can be expected in the future. Globally, temperature and sea level will continue to rise. In order to delve into more specific climate changes, one must narrow the geographical focus because of natural differences in climate between locations. Nationally, the annual average temperature has risen by approximately 0.83°C since 1895 with the vast majority of warming occurring since 1980; sea level has been rising as in the rest of the world; the frost-free season, which corresponds with the growing season, is growing in length everywhere in the US; annual average precipitation has been increasing since about 1900 and heavy downpour events have been increasing since the mid-1900s; ice volume has been declining; hurricanes have been increasing in intensity and winter storms have been increasing slightly in frequency – both types may be increasing in both frequency and intensity; and extreme drought and heat waves have been increasing (NCADAC, 2013). Many of these indications of climate change are insufficiently described by these national-level reports. The NCA goes on to further narrow the geographic scope of their observations and projections for this reason.

Some of the key regionally-focused climate observations are explained here. Very heavy precipitation has been increasing much more dramatically in the East than it has in the West (for example, the Northeast has experienced 74% increase in the amount of precipitation falling during the heaviest 1% of precipitation events since 1958, compared with 7% in the Northwest) (NCADAC, 2013). Sea level rise varies dramatically across the US, with large increases occurring since 1960 in some locations on the Gulf Coast and the Mid-Atlantic, and some Pacific Northwest areas experiencing cumulative decreases (EPA, 2013). The frost-free season has increased in the Southwest over four times as much as it has in the Southeast (21 days annually versus 5 days) since the average measurement from 1901-1960. While annual average precipitation has been increasing nationally, the distribution of change is such that the Midwest, southern Great Plains, and Northeast experiencing the biggest increases and some areas in the Southeast, Southwest, and the Rockies are experiencing decreases, and these trends are expected to become more extreme, especially in winter. Heat waves are becoming more frequent, especially in western regions, exacerbated by summer droughts which are also increasing. Heat waves are projected to become more intense throughout the nation, droughts will become more dramatic in the Southwest especially, and flooding has been and will continue to increase in magnitude in the Midwest and Northeast. North Atlantic hurricanes are becoming stronger and it is projected that strong hurricanes (Category 4 and 5) will increase in frequency by the end of the century while weaker hurricanes (Tropical Storms and Category 1, 2, and 3) will become less frequent; the increase in strong hurricanes is expected to outweigh the decrease in weaker hurricanes in terms of frequency. Winter storms have become slightly more frequent and strong, and other, less understood storm characteristics are being studied intensively (NCADAC, 2013). The recent NCA draft includes the following table to further highlight observed climate changes by region:

Table 1: Regional observations of climate change (NCADAC, 2013).

Northeast	Heat waves, coastal flooding due to sea level rise and storm surge, and river flooding due to more extreme precipitation events are affecting communities in the region.
Southeast	Decreased water availability, exacerbated by population growth and land-use change, is causing increased competition for water; risks associated with extreme events like hurricanes are increasing.
Midwest	Longer growing seasons and rising carbon dioxide levels are increasing yields of some crops, although these benefits have already been offset in some instances by occurrence of extreme events such as heat waves, droughts, and floods.
Great Plains	Rising temperatures are leading to increased demand for water and energy and impacts on agricultural practices.
Southwest	Drought and increased warming have fostered wildfires and increased competition for scarce water resources for people and ecosystems.
Northwest	Changes in the timing of streamflow related to earlier snowmelt have already been observed and are reducing the supply of water in summer, causing far-reaching ecological and socioeconomic consequences.
Alaska	Summer sea ice is receding rapidly, glaciers are shrinking, and permafrost is thawing, causing damage to infrastructure and major changes to ecosystems; impacts to Alaska native communities are increasing.
Hawaii	Increasingly constrained freshwater supplied, coupled with increased temperatures, are stressing both people and ecosystems, and decreasing food and water security.
Coasts	Coastal lifelines, such as water supply infrastructure and evacuation routes, are increasingly vulnerable to higher sea levels and storm surges, inland flooding, and other climate-related changes.
Oceans	The oceans are currently absorbing about a quarter of human-caused carbon dioxide emissions to the atmosphere and over 90% of the heat associated with global warming, leading to ocean acidification and the alteration of marine ecosystems.

If sea level rise accelerates at the rate that was measured from 1990 to 2000 continues, global sea level rise of 28-34 cm (11-13.4 inches) will be observed by 2100 (Church, 2006). All projections based on emissions scenarios foretell a much steeper increase in the rate of sea level rise. The range of most projections for sea level rise by the end of the century is one to four feet over the baseline, putting as many as 5 million Americans' homes at risk at high tide (NCADAC, 2013), without taking into account storm surge, the exacerbation of storm surge by sea level rise, nor the full impact of potential glacial and sea ice melting. In Figure 3 one can see that, using the reference scenario (CPH reference), 102 cm (3.3 feet) of sea level rise can be expected by 2100 if no international pledges are made toward mitigation. The Copenhagen Accord pledges (CPH policy) would reduce global sea level rise to 96 cm (3.1 feet). To put these projections in perspective, in a hypothetical scenario in which all global emissions are reduced to zero by 2016 (Zero 2016 in Figure 3), sea level rise would increase to 59 cm (1.9 feet) by 2100 and 131 cm (4.3 feet) by 2300. If emissions follow the RCP4.5 scenario – which they're currently exceeding – the projections call for a 355 cm (11.6 feet) rise in sea level by 2300 (Schaeffer et al., 2012).

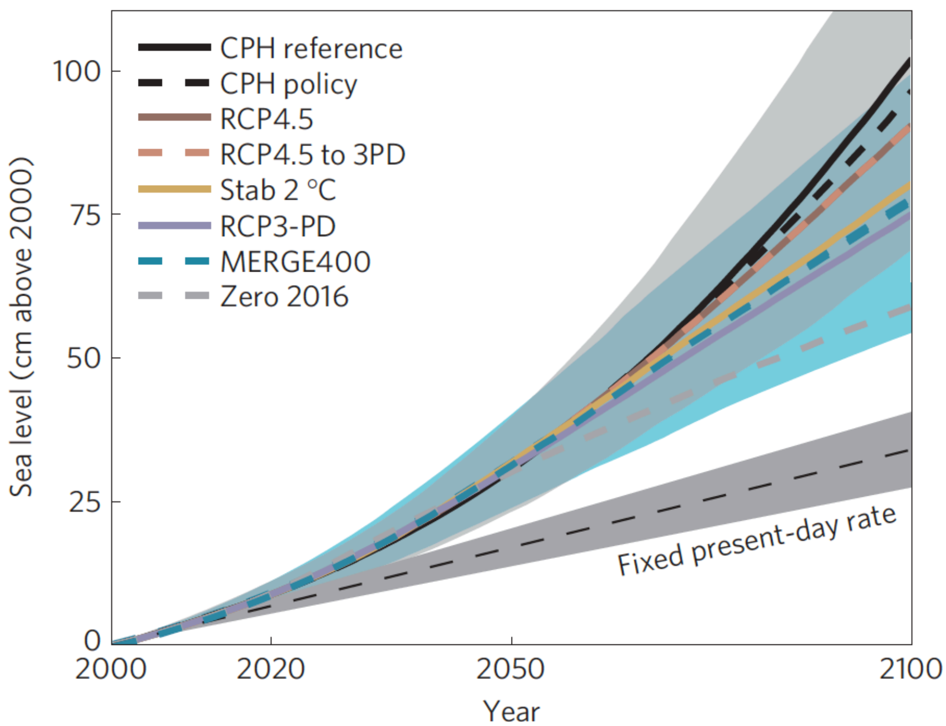

Figure 3: Sea level rise above 2000 levels for a variety of emissions scenarios (Schaeffer et al., 2012).

Secondary impacts of climate change are less understood but just as important as the climate changes themselves. The EEA presents Figure 4 as a depiction of examples of secondary climate impacts. All impacts through at least the center of the figure can be expected with the current trajectory of emissions, including possible mitigation actions as outlined by Schaeffer et al. (2012) (see Appendix B, Figure B-1 for secondary climate impacts shown with emissions scenarios).

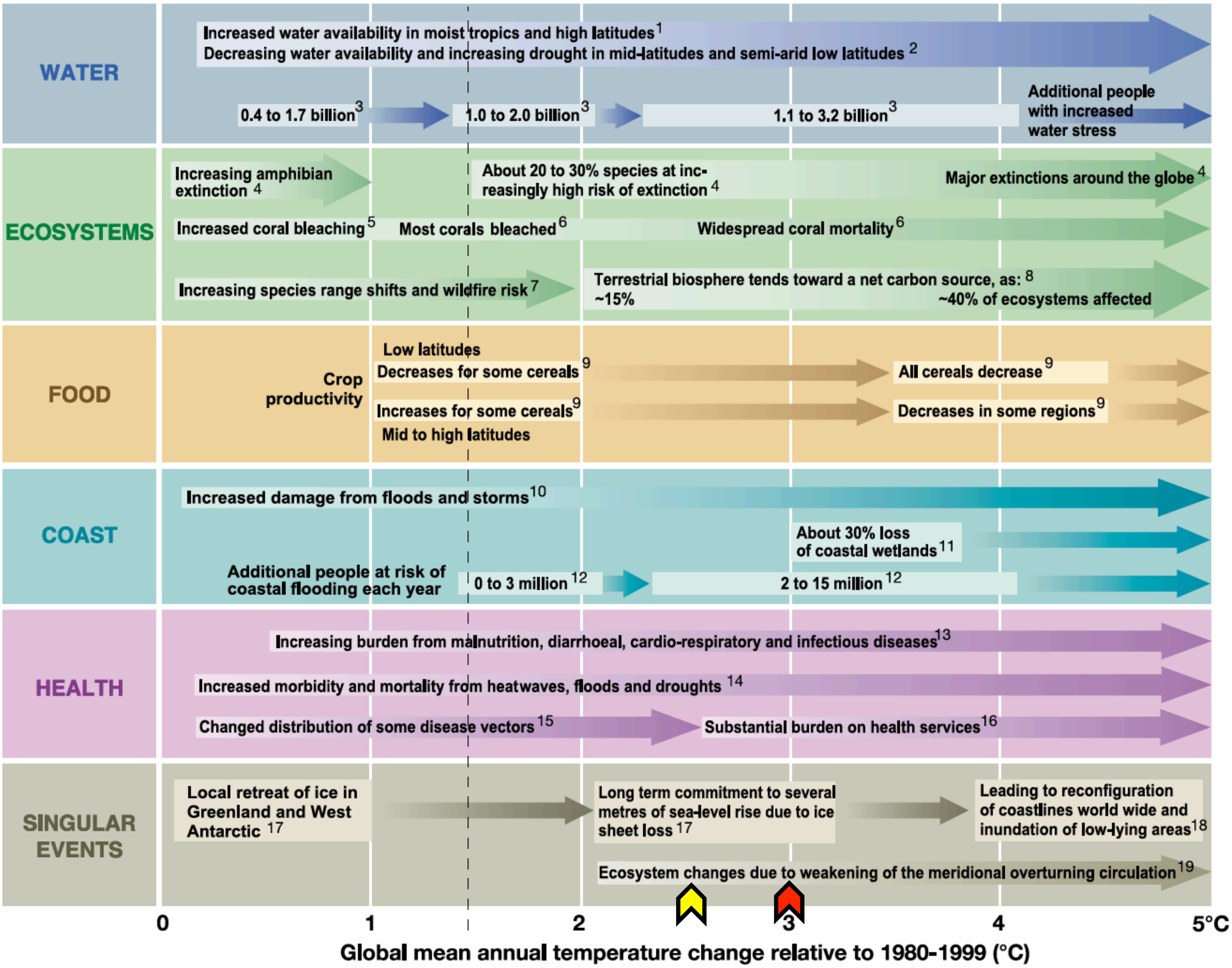

Figure 4: Examples of global secondary impacts from a scale of global average surface temperature increase by 2100. As the source states, "boxes indicate the range of temperature levels to which the impact relates. Arrows indicate increasing impacts with increased warming (...) The black dashed line indicates the EU objective of 2°C maximum temperature increase above pre-industrial (or 1.5°C above 1990 levels)." Yellow and black arrow added by author to indicate likely temperature rise if Copenhagen Accord pledges are met, per Schaeffer et al. (2012). Red and black arrow represents the reference pathway without pledges. (EEA, 2008, referencing IPCC, 2007 WGII).

2.1.2 Progress in Climate Projection

Climate projection is accomplished through the analysis of climate observations and the extrapolation of those conditions based on the likely pathways of their driving forces. The development of climate projection practices has been an area of rigorous global research that has moved the field of study from inception to improved applicability over the course of several decades. Since the late 1980s, there has been a concerted effort by the international policy community to address climate science and its impacts. Scientists had been studying atmospheric gases and their relationship to climate since the 1800s, but it was not until 1988 that the World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC). The IPCC is open to all member governments of the UN and encompasses the work volunteered by thousands of scientists from all over the world with the goal of furthering understanding of climate change and its impacts through comprehensive review of the most recent climate knowledge base. The IPCC releases reports approximately every six years, with the fifth assessment report (AR5) set to be finalized in 2014. These reports are "policy-relevant, and yet policy-neutral, never policy-prescriptive" (IPCC, 2013).

In the United States, the Global Change Research Act was passed in 1990 which requires federal science agencies to collaborate on a National Climate Assessment (NCA) report every four years. The agencies that form this collaboration make up the U.S. Global Change Research Program (USGCRP) and the federal committee charged with guiding the report process is the National Climate

Assessment and Development Advisory Committee (NCADAC). Since the first NCA, released in 2000, the process has included regionally based projections as well as sector-oriented impacts, both of which help policy-makers understand the ways in which their communities are vulnerable.

Since climate change is a global, complex system, it is best understood by examining its parts to make up the larger image of its conditions. These parts whose evaluation contribute to the big picture are known as indicators. The monitoring of climate indicators has allowed the international climate science community to move from its broad initial understanding of the system, to finer-tuned spatial and temporal specificity that makes the data actionable for decision-makers (Janetos et al., 2012).

2.2 Climate Change Indicator Frameworks

Indicators can be described as "statistical evaluative rubrics that reflect the status of a more complex system" (Hamin, Abunassr, & Brabec, 2012, p. 15-16). They are the measured items that, when composited, produce a progress report, of sorts. For example, one might track measurements of rainfall and heat waves over time to develop an understanding of how the climate is changing. A common framework for indicators is the Pressure-State-Response model (closely related to the Driving Force-State-Response framework used by the UN Commission on Sustainable Development, and the Driving Force-Pressure-State-Impact-Response model that has been used by the EEA) (Singh et al., 2012). This model, shown in Figure 5, provides a way of analyzing the relationships between human activities, the physical environment, and the societal responses to both. This framework is most frequently used in the context of sustainability (United Nations, 2007), though the model offers an excellent example of an internationally used indicator framework in general. The set of indicators used within this framework was pruned from 134 in 1996 to a final set in 2001 of 58, spanning 38 sub-themes within 15 main themes, the end result being a manageable suite of indicators deemed useful and appropriate through a multi-national, multi-year testing process (see Appendix B, Table B-4 for final UN CSD indicators) (United Nations, 2007).

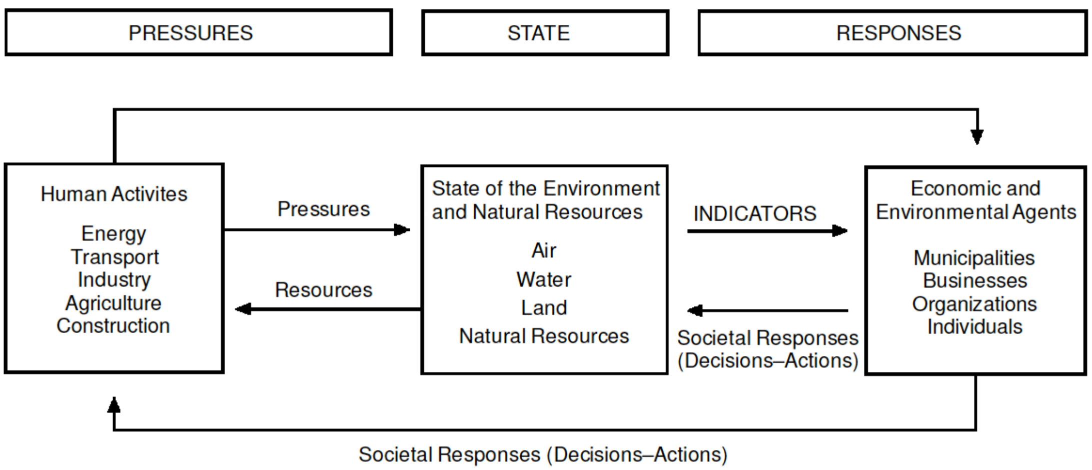

Figure 5: Pressure-State-Response model for indicators, which links human activities to the state of the environment and to society's responses to both. Guy and Kibert (1998) altered the original OECD version of this model by entering "Indicators" between State and Responses where it had previously said "Information". This change helps viewers understand the role of indicators to the framework.

Several institutions have developed frameworks of indicators designed to be used to develop a comprehensive portrayal of the complex system they represent. Within the U.S. Global Change Research Program (USGCRP), the National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA) use physical indicators such as atmospheric conditions and weather. The U.S.

Geographical Survey (USGS), the Heinz Center, and the National Report on Sustainable Forests measure ecological reactions to the climate as indicators of climate change. The National Environmental Public Health Tracing Network (EPHT) uses human health effects from environmental exposure as climate change indicators (Janetos et al., 2012). These are several examples of the sources of indicators the USGCRP uses to develop its National Climate Assessment, which fit within the categorical framework shown in Figure 6:

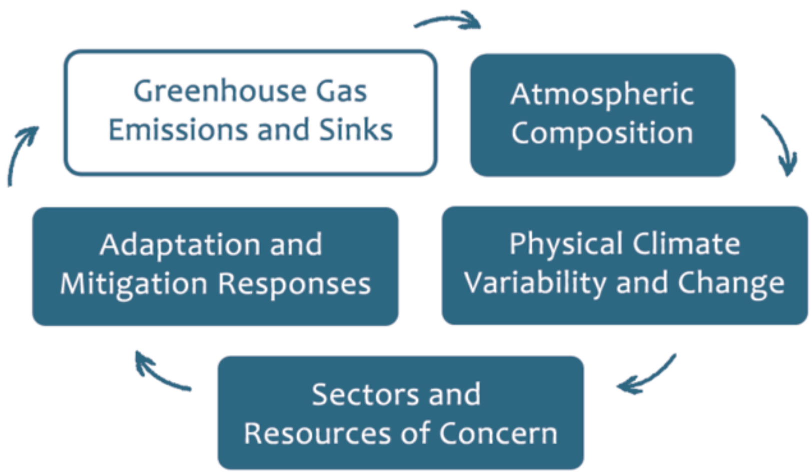

Figure 6: The National Climate Assessment Indicator System's categories, which function in a cyclical framework (USGCRP, 2012).

The categories within this model make it clear that the physical signs of climate change are only a part of the monitoring that is needed. It includes the measurement of impacts on society and its resources, as well as the monitoring of implemented adaptive and mitigative actions themselves. The cyclical form acknowledges the role of emissions and the potential for affecting climate change impacts through adaptation and mitigation. The take-away message from this model is the importance of monitoring a breadth of indicators related to climate change, its causes, and its impacts.

The European Environment Agency (EEA) released the report *Impacts of Europe's changing climate* in 2004 in which it identified 37 indicators as a core set, then released updates that included expansions of the Agency's indicator-based assessment in 2008 and 2012 as well as a green economy focus to the 2012 report; between core and peripheral indicators, the EEA now maintains 242 indicators in its suite (European Environment Agency, 2013). The EEA uses physical, ecological, human health, and economic indicators, and classifies its indicators by typology (descriptive, performance, eco-efficiency, policy effectiveness, or total) and by relationship (driving forces, pressures, state of the environment, impacts from environmental change, or societal response) (European Environment Agency, 2012).

2.2.1 Sustained Assessment

The EEA's indicator data are available to the public online and have been since 2001; they are updated as data becomes available and public users can view the measurements graphically as well as support the figures with background information about each indicator (European Environment Agency, 2005). The addition of new indicators and data on existing indicators can occur at any time. The indicator reporting process is continual, not perennially updated in distinct reports, though reports are released periodically to provide a comprehensive overview of the data.

The USGCRP will begin following a similar sustained assessment practice in order to support decision-making across spatial scales by offering its indicators as tools and templates that individual communities, counties, states, or regions can use to inform planning processes (USGCRP, 2012). The new suite of indicators may be similar to the continually updated EEA framework, though the extent and focus of the new NCA indicator suite remains to be seen; a pilot program is scheduled to be launched in 2014 for external review, and the final program is expected to be released for public use in 2015 (USGCRP, 2013). The strength of the forthcoming USGCRP system is that it is being developed following goals that explicitly emphasize the importance of applicability for decision-makers (Janetos et al., 2012). Between data offered publicly by the NCA and local knowledge and conditions, this data gathering framework with cyclical themes can help decision-makers organize the information they need to weigh priorities and create context-appropriate policies. Further information about the use of indicators in planning is presented in the Results chapter of this thesis.

2.3 Current Approach to Climate-Related Planning: Mitigation

Many nations, regions, cities and towns have adopted plans that address climate change, but the focus is usually on mitigation (Preston et al., 2011; Füssel, 2007a). Mitigation is vital, and must be given high priority with very near-term goals. Global actions taken this decade to reduce emissions will have significant impacts on the progress of climate change. The concept is simple: the sooner worldwide emissions peak and begin decreasing, the less the climate will change as a result of human actions (IPCC, 2007), but that simplicity obscures the daunting power structure it is necessary to navigate to accomplish broad-scale mitigative regulations.

The UN Framework Convention on Climate Change developed the Kyoto Protocol in 1997, establishing the standard practice of setting a goal to reduce the emissions of a participating country (or regional economic integration organization) by a percentage by a target year. The overall intended goal of the Kyoto Protocol at the time of its adoption was to reduce greenhouse gas emissions to 5.2% below 1990 levels, the U.S. portion of which would have been a 7% reduction by 2012. However, the U.S. did not ratify the treaty that would have enacted mitigative goals.

In the absence of a strong national effort to reduce emissions in the U.S., states and regions have adopted their own plans that establish goals of emissions reductions: for example, Massachusetts passed Senate Bill 2540 in 2008, which requires the state to reduce emissions by 25% from 1990 levels by 2020 and by 80% by 2050; the Regional Greenhouse Gas Initiative, made up of Connecticut, Delaware, Massachusetts, Maryland, Maine, New Hampshire, New Jersey, New York, Rhode Island, and Vermont, established a cap-and-trade program that seeks to reduce the region's emissions by 10% from 1990 levels by 2018; in 2009, New York's Executive Order 24 set the goal of reducing the state's emissions by 80% from 1990 levels by 2050. In addition, many states have developed climate change action plans; the most recent information from the EPA lists 32 states that have completed plans that include goals and strategies for reducing greenhouse gas emissions, some including additional strategies for improving energy efficiency ("State Climate Change", 2013).

On the sub-state scale, there are many examples of mitigation plans completed by counties, cities, and towns that set goals and plans for reducing emissions and highlight the additional societal benefits of doing so. This level of governance is uniquely positioned to make strides in the mitigation arena because of the local control over infrastructure. There is a wealth of technical and financial assistance available from federal agencies, such as the EPA and the Department of Energy, and state governments to help communities enact mitigative policies. These organizations, and the sub-national government participants themselves, are essential for the sharing of information and power that is necessary for many small actors to affect change on a global system. Environmental regulation is usually established at the national level and influenced on the local scale by federal and state offices, but climate change-related law has been developing in a unique fashion. Global climate change mitigation requires dramatic emissions reductions and/or carbon capture by every capable nation in the world, but in the U.S. it is an issue that has been taken up by sub-national governments without federal guidance (Engel, 2006). It may be true that state and local governments stand more to gain, politically, from pursuing climate change mitigation, and that the governments that choose to do so may set and meet more aggressive targets than if the effort was guided by the federal government, but it will take a great many state and local mitigative actions to reduce atmospheric greenhouse gases to the point deemed necessary by the climate science community. Regardless of the success of mitigation in the near future, adaptation actions are needed to make communities resilient to the climate stressors that continue to arise.

2.4 Climate Change Adaptation

2.4.1 What is Adaptation?

Adaptation is "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC, 2012). It is essentially the practice of manifesting adaptive capacity to reduce vulnerability and improve community resilience to changes in the environment and the weather variability that are being exacerbated by climate change (Smit and Wandel, 2006). The impacts of climate change are manifesting worldwide in varying ways with pervasive societal consequences, and the rate of change causing these impacts is expected to increase.

Figure 7 answers the question, "What is adaptation?" with three more questions: "Adaptation to what?", "Who or what adapts?", and "How does adaptation occur?" Non-climatic forces influence the system, and outside of the central model of adaptation lies the process of evaluation. Answering each of these three questions leads to a comprehensive understanding of adaptation. The question, "Adaptation to what?" may be answered a broad or narrow selection of climate hazards or stressors, selected as relevant from global, national, or regional climate projections. "Who or what adapts?" addresses the system in which adaptation occurs, which can vary by spatial scale ranging from an individual or a household to a nation or multinational group. The answer may also be a distinct sector within a society, such as transportation or public health, or could even range temporally by pertaining to a system with fast-acting responses, or to one with a long-term adaptation approach. "How does adaptation occur?" may be answered in a number of ways, since adaptation may be organized by various typologies (Smit et al., 2000); the process begins with evaluations of expected climate changes and their impacts on a community.

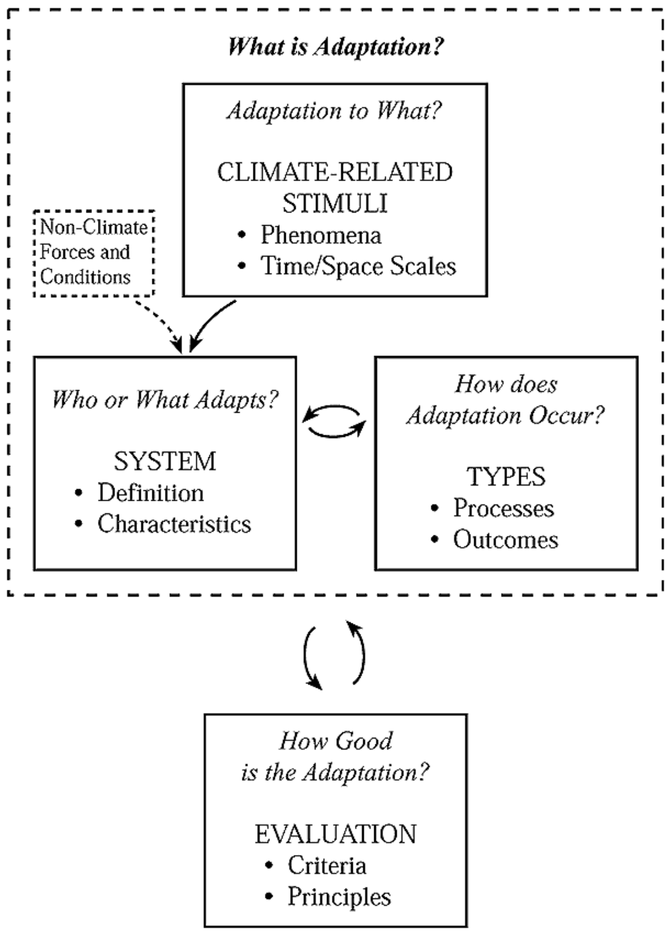

Figure 7: Anatomy of adaptation to climate change and variability (Smit et al., 2000, p. 230).

2.4.2 Adaptation Planning

Adaptation planning is not unlike other planning processes. The steps include identifying a planning issue, developing understanding of the issue, defining objectives, outlining strategies for accomplishing objectives, implementing strategies, and monitoring implemented strategies. Figure 8 portrays these elements in a cyclical, iterative model using terminology specific to a climate change adaptation planning process.

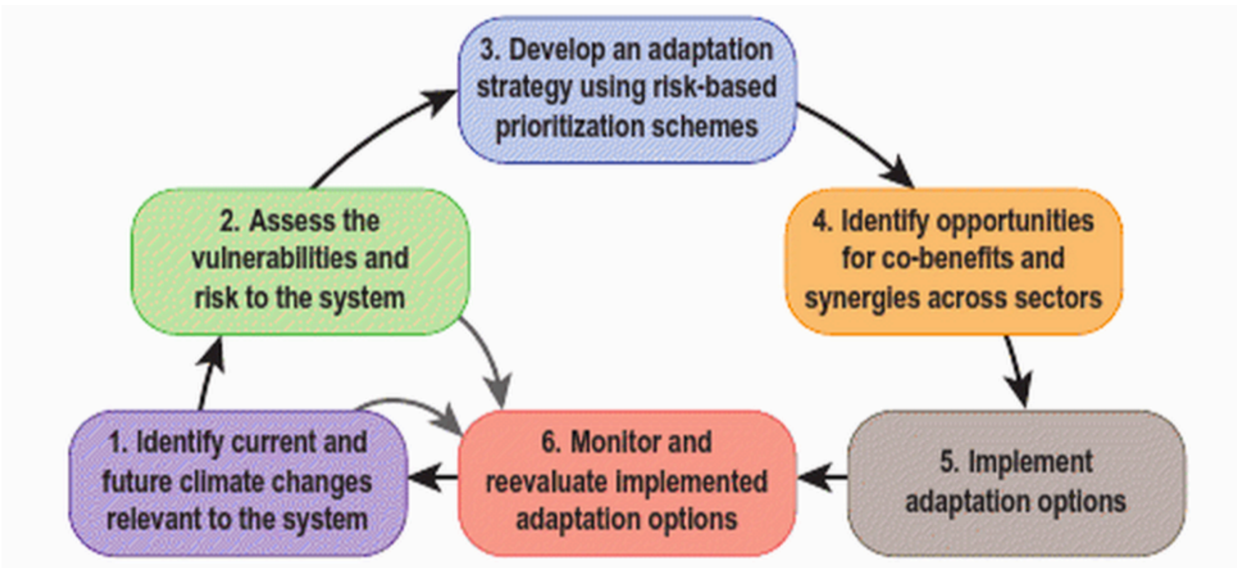

Figure 8: Development of an adaptation plan (NRC & America's Climate Choices, 2010).

Step 1 in Figure 8 is the point at which a climate projection should be selected to use as the reference for future conditions, which can be supported by the local use of indicators. Step 2 is when a vulnerability assessment can be completed, using the current and future climate conditions from step 1 as the element the system is exposed to. The NRC cites the uncertainty of future climate change as a main reason step 6, monitoring and reevaluating adaptation options, is necessary. The specific approaches to adaptation that make up the remaining steps in the model are described in the following section (NRC & America's Climate Choices, 2010).

2.4.2.1 Adaptation Typologies

Adaptation planning can be accomplished through a variety of methods, which can be distinguished by timing of response, spatial scale, function, form, level of intent, degree of integration, degree of ambition, or approach to planning.

2.4.2.1.1 Timing

In terms of timing of response, adaptation may be anticipatory, reactive, or concurrent, relating to a distinct climate stressor. As an example of anticipatory adaptation, policies may be implemented to begin planned retreat amidst coastline development in advance of projected sea level rise; in reactive adaptation, farmers across an agricultural region may change the crops they plant as the viability of their former crops shift; or in concurrent adaptation, cooling centers may be opened in a community during a heat wave. Reactive adaptation is currently more common than anticipatory, though there is great interest in expanding anticipatory planned adaptation in all sectors (Preston, 2011). Timing is also a distinguishing factor when considering adaptation plans with short-term versus long-term scopes of action, or short- or long-term implementation plans.

2.4.2.1.2 Level of Intent

When evaluating adaptation from the approach of level of intent, some practices may be passive and some may be deliberate. Passive, or autonomous, adaptation usually occurs in ecology, as in the migration of a fish species in response to a change in water temperature, whereas deliberate, or planned, adaptation encompasses most human actions related to climate change.

2.4.2.1.3 Form and Function

In regards to form, adaptation practices may be categorized as being technological, behavioral, economic, infrastructural, or educational, or could be divided by what societal sector they treat, such as water resources or tourism (Smit et al., 2000; IPCC, 2007). Adaptation practices may also be organized by their function. Along the coast, a common functional approach to adaptation is retreat, accommodate, or protect. The practice of retreating involves relocating development or restricting further development from coastal floodplains to more inland locations. Accommodating actions include elevating buildings, modifying drainage systems, and other actions that allow coastal structures to stay in place, but with alterations to make them safer and less likely to incur damages as sea level and storm surge threaten them. Protecting within this three-pronged approach is the act of leaving coastal structures as they are and instead administering adaptive treatment to the shoreline itself, often through armoring (Bijlsma et al., 1996). Another function-oriented adaptation approach is “no-regrets” planning, in which implemented actions lead to community benefits regardless of how climate change unfolds; the community would experience positive changes whether or not the climate change projection that called for the plan turns out to be accurate. This technique is particularly useful when planning in the face of substantial uncertainty of a certain climate-related outcome, or when planning professionals are having trouble gaining consensus among stakeholders over how climate projection should be integrated into planning (Heltberg, Siegel, & Jorgenson, 2009). The no-regrets approach allows communities to increase their resilience to climate without requiring planners to host a debate over the validity of climate change every time a proposed action relates to adaptation (Hamin, Abunassr, & Brabec, 2012). Spatially, plans may focus on localized issues, or may address widespread needs for adaptation (Smit et al., 2000).

2.4.2.1.4 Degree of Integration

Degree of integration is emerging as an approach to describing adaptation practices, organizing them by how they fit into the municipal planning process (Hamin, Abunassr, & Brabec, 2012; Smit and Wandel, 2006). An adaptation plan may be developed in a stand-alone process; this practice is common in the development of climate action plans, and adaptation is receiving more treatment along these lines as time goes on. The strength of this type of planning is that it draws attention to the matter at hand and often calls for broad participation, which generates support for subsequently proposed policies that fall in line with the plan. Unfortunately, there is often disagreement over what climate projection to use for plan guidance, and there are still many additional barriers that challenge planning specifically for climate change adaptation, leading some researchers to believe that stand-alone climate adaptation planning is unlikely to lead to successful action (Smit and Wandel, 2006). An alternative approach is “mainstreaming”, which involves integrating climate projection and adaptive community needs directly into the standard planning process. The mainstreaming approach is receiving increased attention in recent planning efforts (Ayers and Forsyth, 2009; Füssel, 2007a; Asian Development Bank, 2005). Mainstreaming may not increase the public discussion of climate change adaptation to the degree that stand-alone adaptation planning would, but it could speed up the implementation of individual policies. Though policies would not be packaged in a comprehensive manner with overall adaptation objectives in sight, it is more likely that some mainstreamed policies may be passed in communities where it would be difficult to garner support for a larger adaptation planning processes (Smit and Wandel, 2006; Hamin, Abunassr, & Brabec, 2012). There is an additional classification in this approach which can be referred to as "stealth". This practice is closely related to no-regrets planning, in that it involves highlighting climate-unrelated co-benefits as the main benefits of a policy, regardless of the adaptive capacity-building potential of the policy (Hamin, Abunassr, & Brabec, 2012). Communities may engage in stealth adaptation unintentionally, since many planning strategies implemented to advance healthy communities or sustainability goals also promote adaptation. For example, a community may implement a street tree planting plan with the intention of promoting walking by improving the aesthetics of sidewalks, but such a plan would simultaneously reduce heat island effect, improve air quality, and increase stormwater absorption, all climate change adaptation goals. Stealth planning may also be done purposefully, as was the case in one Massachusetts community where wetlands bylaws were altered to increase accessibility and viewsheds to waterfronts, but the planner was also aware of the adaptive potential of the plan – the reduction of flood damage risk (Hamin, 2012).

2.4.2.1.5 Degree of Ambition

Incremental and transformative adaptation policies are distinguishable by their degree of ambition. Incrementalism is a technique that has been practiced in various planning sub-fields and in policy-development for decades. It is the act of developing change through a series of small steps toward specific goals, as opposed to transformative planning which seeks to make significant change through faster, more robust actions. Incrementalism is sometimes likened to mainstreaming, while transformative planning would be akin to a stand-alone adaptation plan (Hamin, Abunassr, & Brabec, 2012).

2.4.2.1.6 Planning Approach

An important planning method that is gaining attention as a strategy for adaptation planning is phased implementation. Phased implementation does not fit neatly into one of the above approaches because it is not time-based, but rather involves linking actions to tipping points; in climate change planning, those tipping points would be signaled by indicators measuring the climate system. It is also difficult to categorize because it utilizes multiple approaches in itself. The process begins with setting a significant, comprehensive end goal, establishing specific objectives, and planning a series of incremental steps to reach those goals and objectives. Necessary to the phased adaptation process is continual monitoring of the climate indicators that inform the implementation timing of phased steps.

Figure 9 is a generic model of how phased implementation can work for climate change adaptation, using temperature rise as the indicator against which the phasing is set, though it points out that additional monitoring indicators will likely set the triggering conditions. Annual average temperature is less likely to be an indicator that will inspire change in a community than one that describes a local climate-related experience, such as flood events or days per year with heat index over 90°F.

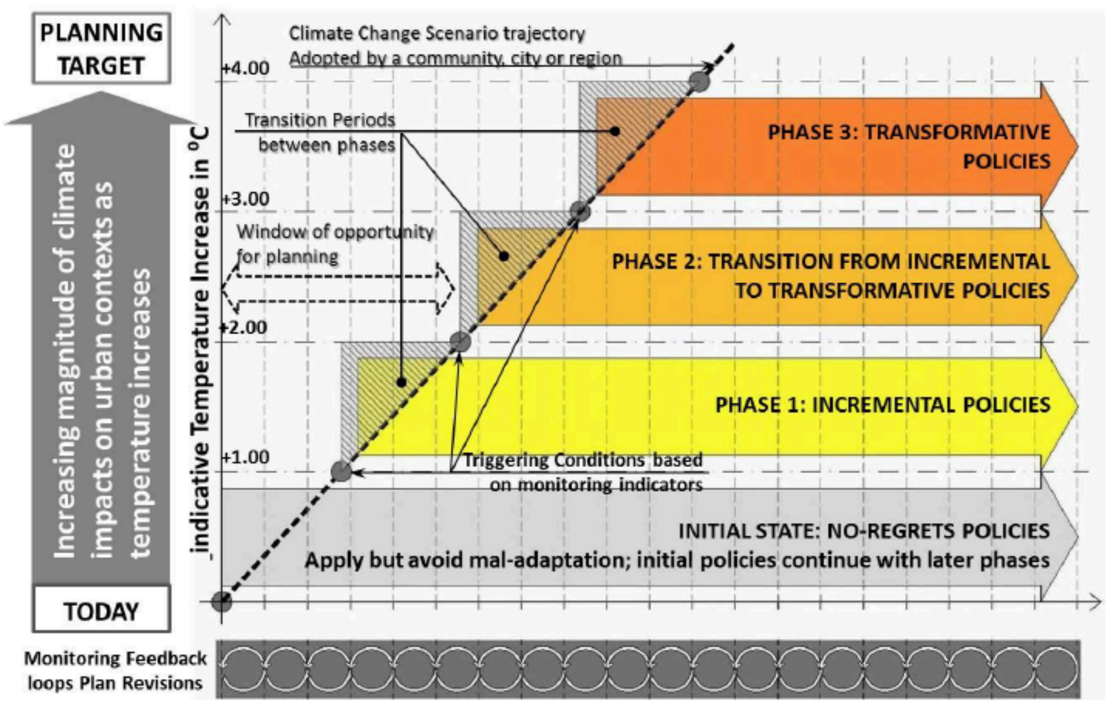

Figure 9: Model of phased implementation based on temperature rise from climate change (Hamin, Abunassr, & Brabec, 2012).

The model includes common phasing of no-regrets, incremental, and transformative adaptation policies; the ordering of these approaches is based on risk and cost. As climate change impacts become more dramatic, more ambitious and costly adaptation strategies are called for.

In Figure 10, researchers apply a phased implementation model to part of Copenhagen's Climate Adaptation Plan which addresses current and future flooding. Flooding from precipitation and sea level are of significant concern in the low-lying waterfront city of Copenhagen, and so the triggering indicators selected for the model are modeled flood area in a 100-year rainfall event, and sea level rise measured nationally (Hamin, Abunassr, & Brabec, 2012).

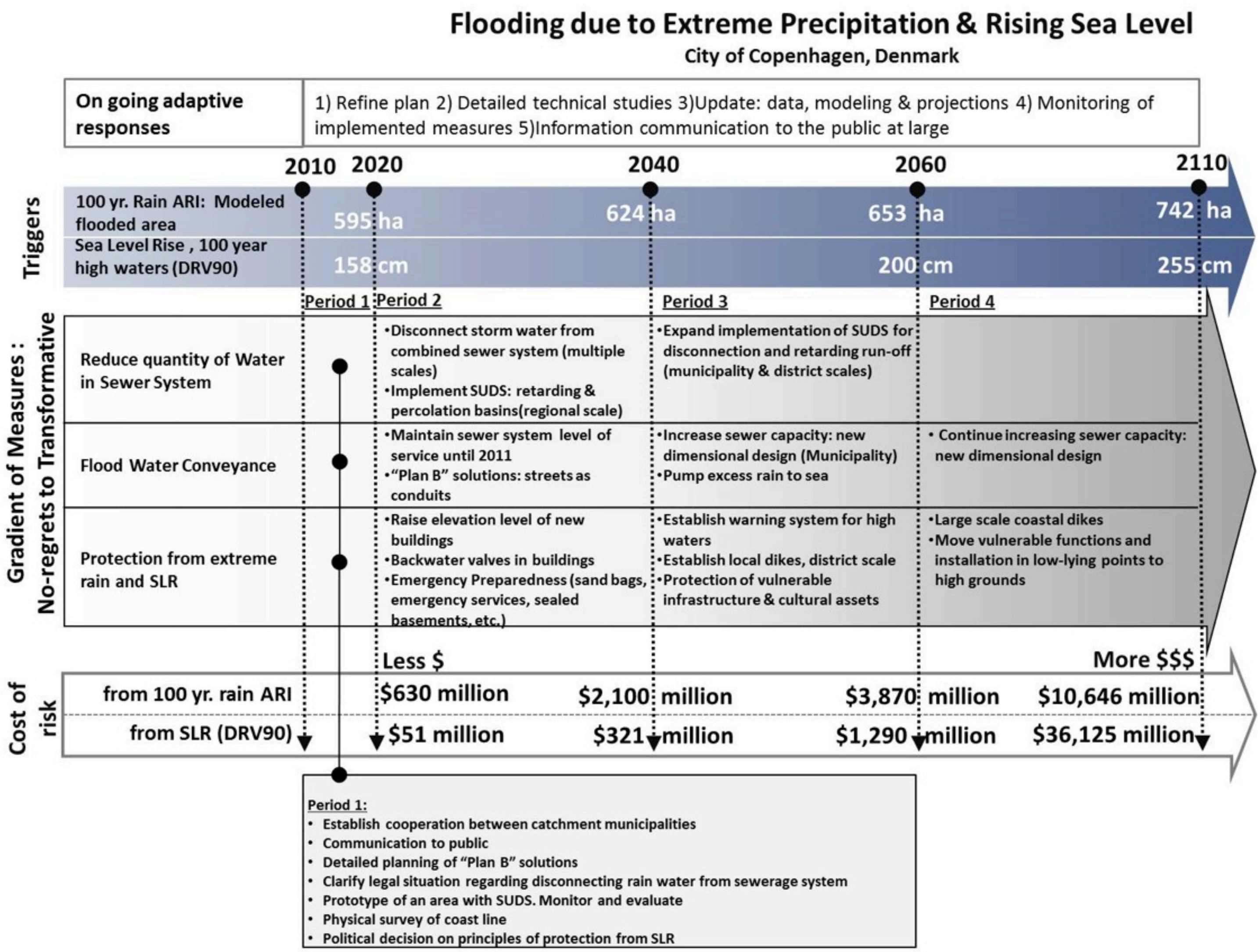

Figure 10: Phased implementation model applied to Copenhagen Climate Adaptation Plan, addressing the impact of flooding due to extreme precipitation and sea level rise (Hamin, Abunassr, & Brabec, 2012).

The New York City Panel on Climate Change (NPCC) has proposed a strategy for flexible adaptation pathways, which are defined as, "a sequence of adaptation strategies policy makers, stakeholders, and experts develop and implement that evolve as our knowledge of climate change progresses" (Yohe and Leichenko, 2010, p. 30). Figure 11 provides a conceptual depiction of flexible adaptation and mitigation pathways:

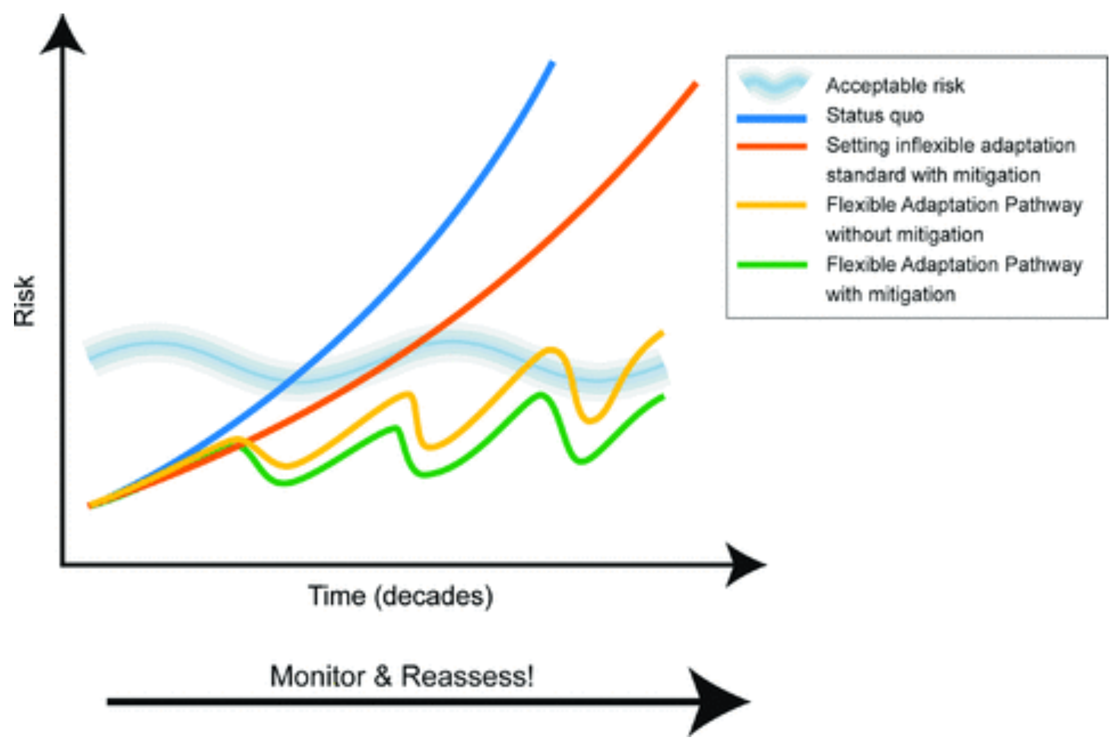

Figure 11: Conceptual model of flexible adaptation and mitigation pathways (Yohe and Leichenko, 2010, adapted from City of London, "The Thames Estuary 2100 Plan," April 2009).

The argument for flexible adaptation, which encompasses phased implementation, is based on the uncertainty that decision-makers must take into account when planning for climate change (Yohe and Leichenko, 2010). If one assumes a hypothetical situation in which some degree of mitigation and adaptation are underway, one is left to compare the red and green lines in Figure 11. The risk associated with an inflexible adaptation plan (red line) rises with time because of the growing possibility that the conditions upon which the plan is based no longer apply. The peaks and valleys of risk with a flexible adaptation planning process (green line) are due to periodic adjustments informed by updated climate or vulnerability data.

Figure 12 shows an actual flexible adaptation strategy being used to deal with potential coastal storm flooding exacerbated by sea level rise. Since average storm surge and the height of the Thames Barrier are known, and sea level rise that would exacerbate storm surge has been projected to the end of the century, the London Environment Agency was able to calculate what protective measures would be required for a range of water level rise.

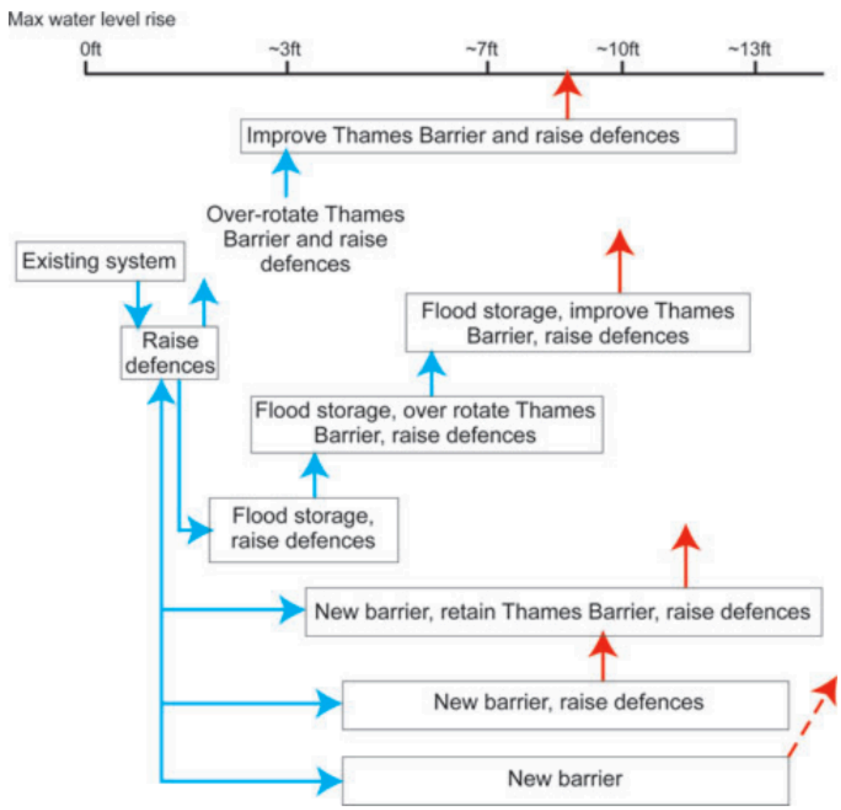

Figure 12: Phased implementation adaptation strategy using water level rise as the trigger (Yohe and Leichenko, 2010, adapted from City of London, "The Thames Estuary 2100 Plan," April 2009).

The analysis required to expand this practice to adaptation strategies for different types of climate impacts is more difficult; sea level rise – which directly impacts potential height of storm surge – rises somewhat steadily, and its direct impacts are limited to shorelines and riverbanks. Most other climate impacts are subject to far more variability, which makes phasing adaptation measures more challenging.

The NPCC has embraced the phasing model used by the City of London as an example, and is integrating thresholds into its indicator monitoring for decision support in adaptation planning. A footnote to the indicators proposed for usage by the NPCC in Table B-5 in Appendix B points out which indicators have preset thresholds, though it is stated that they "require further processing to customize" (Jacob et al., 2010, p. 130). The NPCC acknowledges the use of trigger points as key to the movement through a flexible adaptation pathway, but has not yet published information on how they will define those trigger points. The NPCC 2010 Report calls for "an appropriate body" to establish the thresholds for the indicators it will use (Jacob et al., 2010, p. 139). The Panel wants to expand the usage of flexible adaptation pathways and it recognizes that more analysis, combined with stakeholder engagement, is necessary to define triggering mechanisms:

> Statistical measures of confidence need to be calculated for the given indicators, and criteria can be defined to flag "thresholds" or "trigger points." These criteria, which vary by indicator, need to be decided through a documented consensus process involving both scientists and stakeholders. (Jacob et al., 2010, p. 132)

Such consensus-building comes about through the engagement of scientists and stakeholders in the adaptation planning process itself; when utilizing a phased or flexible adaptation process, backcasting is an important step that integrates community members' visioning with expert knowledge, including climate scenarios in the case of adaptation planning (Wheeler, 2008).

Backcasting is a useful planning approach that is necessary to phased implementation and flexible adaptation; it is defined as "a method in which the future desired conditions are envisioned and steps are then defined to attain those conditions, rather than taking steps that are merely a continuation of present methods extrapolated into the future" (Holmberg and Robert, 2000, p. 294). The act of planners and community members looking forward, envisioning an ideal future state, and planning the intermediary time to achieve that state is how phased implementation works, with climate change projections acting as an input of conditions for the future. Dreborg (1996) explains that the characteristics of complexity, a long time horizon, and the presence of dominant trends are some that make a planning issue favorable for the use of backcasting. Climate change adaptation fits Dreborg's list of characteristics well, and so it is natural that backcasting and phased implementation would emerge as suitable planning methods.

2.4.2 Progress in Adaptation Planning

Adaptation is starting to become a stronger focus for regional and municipal planning, but there is usually a tentativeness to the approach. Planning is being initiated, but adaptation actions are slow to be implemented (NCADAC, 2013). In an analysis of 57 adaptation plans from Australia, the United Kingdom, and the United States, ranging in scope from municipal to national, researchers studied the types of strategies they included within a functional typology. Figure 13 shows the dominance of assessment and the establishment of support, characterized here as "Building Adaptive Capacity," and weaker representation of strategies that call for specific actions, identified here as "Delivering Adaptation Actions" (Preston et al., 2010).

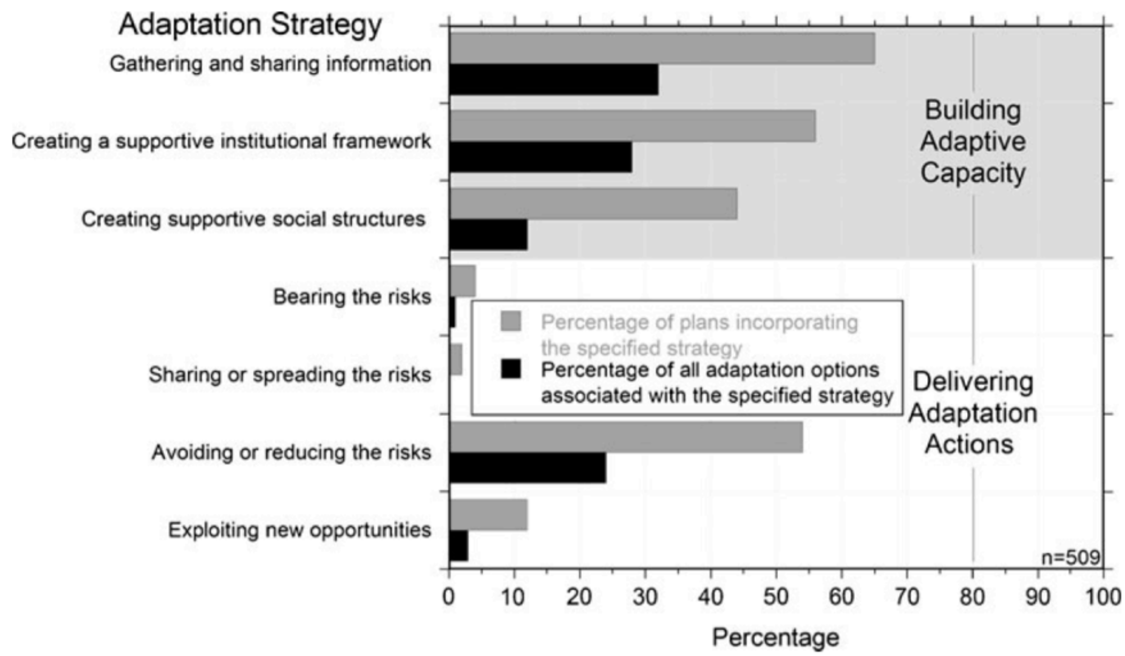

Figure 13: Results of analysis of adaptation strategies in adaptation plans surveyed by Preston et al. (2010, p. 425).

The strategies that were characterized as "Delivering Adaptation Actions," particularly those aimed at "avoiding or reducing the risks," were often measures already being undertaken for other reasons, such as heat wave warning systems or increasing water supply capacity. These no-regrets actions are important, and as Hamin, Abunassr, and Brabec pointed out (2012), they are a common first step in the larger adaptation planning framework. However, in the phased implementation framework the no-regrets actions were modeled to be followed by incremental and then transformational adaptation actions as laid out by a back-casted planning process with an end goal in sight. If adaptation plans are used solely as opportunities to lobby for existing planning goals meant to solve anticipated short-term problems without a demonstrated commitment to a larger adaptation process, it will be difficult to secure capital and political will to accomplish adaptation actions to improve the resilience of long-surviving architecture (Preston et al., 2010).

The disconnect between the spatial scales of traditional climate scenarios and the governance levels at which adaptation planning occurs (Dessai, Lu, & Risbey, 2005) has hindered action-oriented adaptation. This gap has proven to be an opportunity for progress, and the resulting development of publicly available, regionally-relevant climate projections will be an important step toward adaptation implementation. The vaguely adaptive and no-regrets strategies reported to be dominant by Preston et al. (2010) reveal the reality of a warning from Dessai, Lu, and Risbey (2005), that a lack of locally useful climate scenarios could leave adaptation planning to be derived from past climate observations, leading to the passage of policies that will prove to be inadequate under future climate conditions.

2.6 Local Adaptation Planning

2.6.1 Barriers and Strengths

The lack of federal and state mandates that would provide local governments with technical and political support in advancing climate change adaptation has led to a build-up of pressure on local actors to take the matter into their own hands. However, local governments are faced with a slew of barriers to adaptation, a local study of which will be explored in this thesis. A general consensus has emerged from research on local adaptation planning and its barriers that more support is needed from higher levels of government in order to develop technical capability and political impetus (Hamin, 2012; Heltberg, Siegel, & Jorgensen, 2009; Baker et al., 2012). As it stands, there appears to be a high level of awareness of climate issues in local governance, but implementation of true adaptive action is rare (Smit and Wandel, 2006; Preston, Westaway, & Yuen, 2011; IPCC, 2007). Local actors are currently overlooked in the process of disseminating funding for adaptation, a surprising pattern considering the vast degree to which local organizations and governance would need to be involved in implementation (Heltberg, Siegel, & Jorgensen, 2009).

Despite slow uptake, local governance remains the most fitting spatial scale to target climate change planning actions (Hamin, 2011; Measham et al., 2011). Climate stressors affect communities through physical, place-based issues, and so adaptation measures can be implemented most effectively and most quickly if done successfully in direct response to observed or anticipated climate impacts (Heltberg, Siegel, & Jorgensen, 2009). The success of this planning depends on an evidence-based, consensus-building process involving participation with stake-holders.

2.6.2 Participatory Adaptation Planning

Community participation in any planning process improves the long-term viability of a plan, since the participatory gathering of perspectives means that more groups within the community will have their interests represented. When planning around uncertainty, as is the nature of climate change-related planning, participation is very important for building support for the plan, and for improving the plan itself by providing broad understanding of local challenges (Measham et al., 2011; Baker et al., 2012). Participatory community and vulnerability assessments have been used in many social sciences fields and policy-related practices, including climate change adaptation (Smit and Wandel, 2006), and this precedence lends itself well to the next step of participatory planning for adaptation with vulnerability in mind.

The National Research Council called for a risk-based adaptation planning model, and for local governments to address adaptation "in consultation with the broad range of stakeholders in their communities" (NRC & America's Climate Choices, 2010). Moser and Ekstrom (2011) took cues from the NRC in their San Luis Obispo and Fresno case studies, which sought to model an adaptation process in two California communities who were not actively planning for adaptation by providing downscaled climate projections and social vulnerability assessments for use in a public participation process. One additional aspect seems to have been key: though outside agencies were active in this process, they had the explicit goal of establishing local leaders as central hosts of the public workshops, which positively impacted the local ownership of the issue of local adaptation planning. This study may be seen as a step toward participatory adaptation planning, particularly as a positive example for the U.S., where this type of planning for climate adaptation is lagging behind other developed and developing nations (Moser & Ekstrom, 2011). However, the San Luis Obispo and Fresno examples do not model the full range of ways community engagement can be useful to the process of adaptation.

The California case studies acted as a conversation starter for communities who needed tools and encouragement to jumpstart inactive adaptation planning; different models may be used to involve the community earlier in the process, such as in Ebi and Semenza's (2008) model shown in Figure 14. Community outreach is the first step to this process, and is used to gather information about public concerns and needs before moving on to a situation analysis.

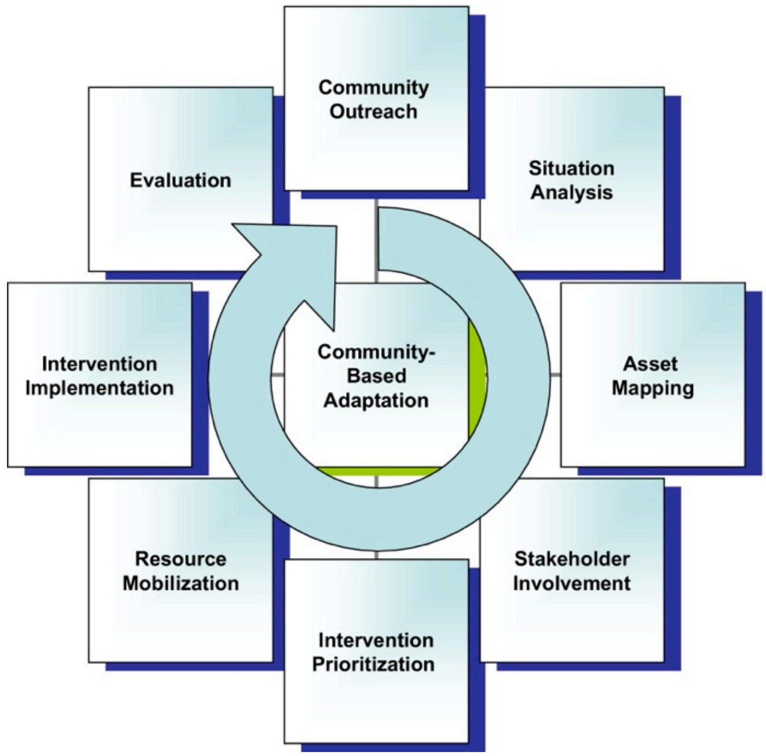

Figure 14: Community-based adaptation model developed within the context of adapting to health risks of climate change (Ebi & Semenza, 2008).

In writing about this model, Ebi and Semenza repeatedly bring up social capital, making it clear that the development of social capital is not a byproduct of the planning process, but is a central goal. This social capital is key to the success of the eventual implementation of the plan. The researchers include a further step of community involvement at the stage of implementation, where many plans consider implementation to be the policy-passing action of the government. They cite an example in Portland, OR, where a nonprofit organization began a community-based project to reduce urban heat island effect, and did so through repeated and extensive community engagement. The public was involved in planning, and also in the implementation of ideas generated by the planning process, such as the installation of green roofs, trellises for hanging gardens, and other greening projects. Aside from the successful implementation of cooling measures, the project also had a statistically significant positive impact on mental health, sense of community, and the expansion of social interactions and social capital (Ebi & Semenza, 2008). Including local knowledge in the selection of climate change indicators and involving the public in post-planning indicator monitoring can have the same positive effect on community ownership of the adaptation planning process.

Research has mounted supporting the involvement of the public in the assessment of vulnerability and the development of adaptation plans. Public participation has been said to be "a crucial element of successful adaptation planning" (Baker et al., 2012, p. 135) because it improves the quality of the plans and increases the likelihood of their implementation. Robust participatory planning for adaptation is known as "community-based adaptation"; it integrates scientific information gathered by experts outside the community with the local experience of climate change, as well as local knowledge of past strategies that can inform decision-making on the best options for adaptation strategies (Measham et al., 2011; Reid et al., 2009). As Lim et al. (2004) puts it, "The principal resource for responding to climate change impacts is people themselves, and their knowledge and expertise" (p. 51). It is the community members who will be witness to and have the greatest stake in the success or failure of adaptation strategies. Moreover, as Ebi and

Semenza (2008) discuss in relation to their Portland, OR example, the very process of public participation in vulnerability assessment and adaptation empowers the community. The consensus-building on defining the planning issue to be addressed and the resulting improvement in understanding of that issue contribute to the building of adaptive capacity, thus reducing vulnerability to climate change (Lim et al., 2004).

2.7 Summary

The measurement of climate change and planning for projected climate conditions have evolved over the course of decades; recent developments in these areas are making it easier to bring data and planning together for improved adaptation. Organizations responsible for climate monitoring are downscaling their projections to the regional level and increasing accessibility to their data. The collection and publication of that data are moving toward continually releasing climate monitoring data, measured by indicators, as the climate science moves too quickly for periodic reports to keep up. In terms of how communities deal with that information, adaptation lags behind mitigation in climate-related planning, but is seeing a boost in municipalities from the lack of national and state mandates, and the need in many places to manage extreme weather events. When adaptation is addressed, vulnerability and adaptive capacity assessments dominate plans over real adaptive action. The barriers that arise in adaptation planning processes are being researched to help communities deal with them and implement adaptation strategies. There are many ways to approach adaptation in planning; one approach that holds significant potential is flexible or phased adaptation, which can use continuously monitored indicators of climate change and its impacts as triggers for strategies. The local level is the most useful scale for adaptation planning, and public participation strengthens those plans and their chances of success. The research methodology outlined in Chapter 3 explains how this thesis will explore the use of indicators as decision-support tools to overcome barriers to adaptation at the local level.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Selecting Methods

Based on an initial literature review and the goals and objectives set at the beginning of the research design process, the research methods were selected with the intention to integrate the findings in the form of a matrix, the development of which is described in Section 3.4. Since this thesis focuses on integrating existing planning techniques and evaluating the state of the art approach to climate change planning, many sections in this thesis are informed by thorough literature searches. A review of a primary research project on the barriers to adaptation planning was also included in order to build a comprehensive matrix. The matrix is developed as a decision support tool, and is used to organize information about climate impacts, adaptation strategies, barriers to adaptation, and selection of indicators.

3.2 Literature Search on Use of Indicators in Planning

Some sources had been obtained for prior research by the author, and others were found through reading relevant literature and seeking their references. When new searches were needed, the following protocol was followed. The research database Web of Science served as the primary search platform.

3.2.1 Defining Research Topics

Four foci were used as primary topics of interest: climate impacts, adaptation strategies, barriers to adaptation, and indicators and their role in planning.

Literature searches were conducted to find relevant sources within each focus, and those that provided linkages between the foci. Table 2 shows the search keywords used for this research methodology organized by focus.

Table 2: Search keywords organized by focus.

Climate Impacts	Adaptation Strategies	Barriers to Adaptation	Indicators
climate change	climate AND adaptation	barriers AND adaptation	indicators AND planning
climate AND impacts	adaptive measures	challenges AND adaptation	indicators AND climate
environmental change	adaptive capacity		indicators AND sustainability
			climate AND vulnerability
			climate AND resilience
			climate AND assessment
			community indicators

3.2.2 Inclusion/Exclusion criteria

Web of Science categories were refined to include only the following: urban studies, planning development, social sciences interdisciplinary, public administration, sociology, anthropology, and environmental studies. When researching climate science, some categories were added such as environmental sciences, geography physical, multidisciplinary sciences, and water resources. Search results were sorted by the number of times the source was cited in other literature, and in most cases, sources cited fewer than 50 times were excluded. Exceptions were permitted if the source was very recent or highly relevant to the specific topic of this thesis. The time scale was 2000-present, with exceptions for older articles permitted if they were highly relevant to the research topic.

3.3 Identifying the Barriers to Climate Change Adaptation

Barriers to adaptation were identified primarily through pilot research being done by Dr. Elisabeth Hamin at the University of Massachusetts, Amherst as part of an ongoing study sponsored by the Massachusetts Chapter of the American Planning Association. The research was presented at the Chameleon Research Workshop on "Barriers to Adaptation to Climate Change" in Berlin in September, 2012 under the title *By Stealth or by Spotlight: Matching Barriers to Adaptation Approaches*. This thesis's author acted as a research assistant on the project; through assisting Dr. Hamin with research on the barriers to climate change adaptation in Massachusetts, the author gained insight to the barriers that exist in 15 Massachusetts coastal communities.

Hamin and assistants collected informed consent forms from participants, then conducted interviews with municipal planners from each community. Interviews were 30-60 minutes long and questions addressed anticipated climate change impacts, the status of any municipal adaptation planning, and the barriers to adaptation progress. Interviews were conversational; interviewees were told that the interviewers were interested in what municipalities were doing about climate change, and if the conversation did not move naturally to the barriers to adaptation planning, the level of public discussion on climate change in the communities, and preferred sources for training and information materials, interviewers used questions to guide the discussion to those topics.

Interviews were recorded and transcribed, then uploaded to the web-based qualitative research program Dedoose. In Dedoose, interviews were coded to quantify the appearance of statements that fit categories based on prior literature, and more categories were added as needed (Hamin, 2012). Town-wide demographic data including population, household income, home value, educational attainment, racial diversity, population density, and 2008 presidential election voting characteristics, were also uploaded to Dedoose for the purpose of analyzing barriers data against town characteristics.

As Hamin points out, two ways to analyze the most dominant barriers to adaptation are to compare each community's most challenging barrier as identified by the interviewees, and to perform a frequency analysis of coded responses about barriers across interviews. A frequency chart of all barrier mentions by topic was made, as was a frequency chart of the percentage of towns concerned with each barrier topic. Excerpts were then gathered from each interview that addressed the questions of what stands in the way of adaptation and what is needed to move forward; each town's excerpt selections were summarized with 1-2 sentences to tease out the most emergent themes. Towns were sorted to bring together interviews with similarly emergent themes. Similarities between the most closely aligned emergent themes provided the categories for the most pressing barriers, as described in Sections 4.1.2.1-6. A representative excerpt from each town is provided in the results section, divided by the emergent themes of barriers, for the purpose of illustrating planners' perspectives for the reader.

3.4 Organizational Matrix for Multi-Dimensional Qualitative Data

3.4.1 Purpose

The matrix format for organizing information is used in this thesis as a research method for evaluating the relationships between the dimensions represented in its columns, and ultimately for presenting those relationships to the reader. The organization of the matrix functions as a set of research questions and responses (Miles and Huberman, 1984; Given, 2008). The matrix format used in this thesis most closely resembles a conceptually clustered matrix, which connects information to form coherent concepts. This organization of data "assists the researcher in seeing possible connections among the concepts under investigation" (Given, 2008, p. 100). Elements of the case dynamics matrix model shine through as well, being that the research questions in this thesis require the evaluation of a consequential process. A conceptual model for the process is portrayed in Figure 15.

Literature has demonstrated the links between the dimensions of the matrix, such as the relationships between climate change impacts, the adaptation strategies that can manage them, and the barriers to adaptation in general with some mention of specific adaptation strategies. Some literature has discussed the relationships between indicators and adaptation strategies (e.g. Hamin, Abunassr, & Brabec, 2012), but indicators have not yet been explored to their full capacity in the planning field. There has not yet been a prominent study that integrates the relationships between impacts and adaptation strategies, adaptation and its barriers, and barriers and the indicators that could empower communities to circumvent them. Figure 15 shows this inter-dimensional relationship as it is intended to be viewed within the context of the matrix.

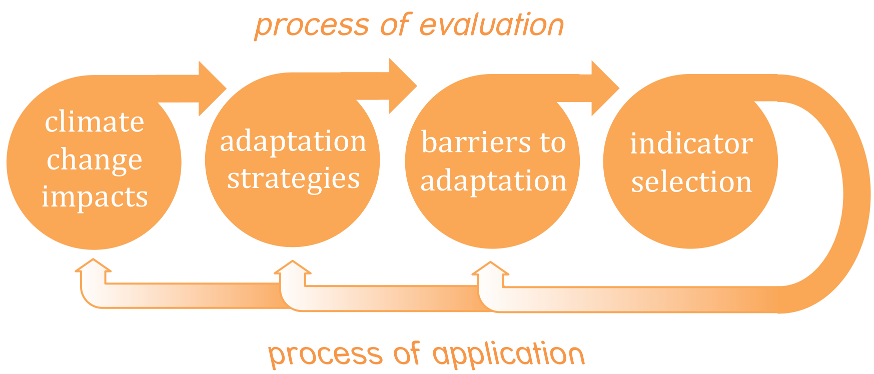

Figure 15: Conceptual diagram of the relationships between the dimensions within the organizational matrix. Process of evaluation leads to the selection of best-fitting indicators; process of application leads from indicator monitoring to successful adaptation to climate change impacts.

Within the process of evaluation, indicated in Figure 15 by right arrows, evaluating the information within each dimension leads to the development of the next. The knowledge gained from the process of evaluation may then be applied in a reverse step-wise manner, as indicated by the left arrows. The process of application is thus: once all dimensions are developed, the indicators selected as most fitting during the process of evaluation may be used to overcome the barriers to adaptation. This application will allow adaptation strategies to be implemented, which will help the community adapt to climate change impacts.

This format seeks furthermore to bring together different indicator frameworks including those that focus on measuring climate science, and others that measure vulnerability and resilience. These frameworks are usually used at broad scales to inform national or international programming, but indicator-based climate projections are becoming more available to the public in the hopes that communities will be able to use indicators for their own planning (Janetos et al., 2012). By integrating the types of indicators used to assess the facets of climate change, this matrix could help communities organize assessment strategies in a comprehensive manner that would not rely on science or vulnerability alone.

The development of this matrix is also intended to highlight opportunities for overcoming barriers to adaptation, taking cues from the intentions of Moser and Ekstrom's (2010) matrix usage in diagnosing barriers, and from Smith's (1996) recommended usage of decision matrices for selecting adaptation actions. The result is a matrix that displays linear relationships as well as treatment options.

3.4.2 Development

Data from the variety of methods in this chapter were compiled with the intention to build a matrix comprised of anticipated climate change impacts, the adaptation strategies that would improve community resilience to those impacts, barriers to the implementation of those strategies, and the indicators or measurement tools that would help communities reach consensus to overcome those barriers. Anticipated climate change impacts, the indicators used to measure them were gathered from national and global sources through a literature review; adaptation strategies were also researched through a literature review, though the sources were more locally and regionally based because of their nature as planning tools; adaptation barriers were gleaned from the research described in the previous section and supplemented with literature; some additional indicators, mostly those relating to vulnerability, adaptive capacity, and resilience were gleaned from international sources that address these elements at a community level.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Literature Search on Use of Indicators in Planning

4.1.1 Results

In the planning field, indicators are developed and used for the purpose of linking data to policy decisions. This practice has been used in a number of planning assessment efforts, such as community indicator projects, sustainability, and vulnerability assessment; climate change adaptation is emerging as the next sub-field to join this list. Referring to empirical data provides a boost of substantiation when developing plans relating to topics rife with uncertainty, such as climate change. An indicator index containing many in-use climate indicators from U.S. and European frameworks can be found in Appendix A, and will be used to support the development of the decision-making matrix in Section 4.1.3. Supporting policy decisions with such data makes those decisions more palatable for those involved in the political side of policy acceptance. Indicators can also be used to monitor the success of a policy after it has been implemented (Segone et al., 2009). In order to expand understanding of how indicators are used in planning, Sections 4.1.1.1-4 explore how they are used in a selection of planning sub-fields.

4.1.1.1 Community Indicators

Community indicators measure the economic, social, and environmental factors that make up the overall success of a community, or the quality of life of its residents. The concept of assessing social conditions based on more specific proxies was developed by the Russell Sage Foundation in 1910 and was first administered to evaluate the city of Pittsburgh. The social unrest of the 1960s led to an uptick in community indicators' popularity and, in the 1970s, local and state governments began using them to seek understanding of the causes of social problems. Their use waned for a time but surged again in the last 1980s and 1990s, sometimes being used as general community indicators and sometimes splintering into more specified foci (Philips, 2003).

The general community indicator process most frequently covers the topics of quality of life, sustainability, performance evaluation, and healthy communities (listed in order of frequency according to a review of over 200 community indicators projects in The Community Indicators Handbook published in 1997 by Redefining Progress) (Philips, 2003). The Boston Indicators Project is an excellent local example of a community indicators process managed by a non-profit organization but with ties to its regional planning agency, the Metropolitan Area Planning Council, and the City of Boston. It is not clear exactly how and to what extent the data is used by local governments, but great effort is made to involve stakeholders including citizens and policy-makers through collaboration on Civic Agenda goals, data gathering, and consensus-building on what constitutes success or growth in each of the project's ten indicator sectors. The ten central sectors of indicators are Civic Vitality, Cultural Life & The Arts, Economy, Education, Environment & Energy, Health, Housing, Public Safety, Technology, and Transportation. Data can also be evaluated through the crosscutting topics of Boston

Neighborhoods, Children & Youth, Competitive Edge, Fiscal Health, Race/Ethnicity, and Sustainable Development. The Civic Agenda goals defined through a ten year collaborative process are 21st Century Infrastructure, Open, Dynamic & Inclusive Civic Culture, 21st Century Jobs & Economic Strategies, and World Class Human Capital. The Civic Agenda goals are established with 2030 as their horizon, and are measured by the indicators that fit into the ten sectors (The Boston Foundation, 2013). The strength of the Boston Indicators Project is the democratization of data, which is one of the project's key principles and which means that its data is publicly available for use by any organization, citizen, or government agency.

4.1.1.2 Sustainability Indicators

Indicators have also gained a foothold in the assessment of sustainability, a central piece in many community indicator projects and a common standalone indicator process. Sets of indicators are used in sustainability planning to measure how well a community is supporting its population, and how successfully it will continue to do so. Sustainability indicators can measure the current conditions of a place but can also look forward, using mathematical projections to evaluate future capacity and needs (Maclaren, 1996). When Agenda 21 called for the development of sustainability indicators, it was for the purpose of building a platform upon which decisions would be made (Hinkel, 2011). This concept is in keeping with the use of indicators as a tool for implementation, not just for assessment without action (Roseland, 1998). However, the focus of sustainability indicator projects tends to be the evaluation of success of existing sustainability measures, and questions have been raised over whether or this process can promote change without being tied to a more formal planning process (Brugmann, 1997).

Sustainable Seattle was one of the first projects to develop sustainability indicators, which it did to inform citizens about the progress of sustainability in their community, with hopes that understanding would encourage further progress. The project convened in 1990 and published its first report in 1993, providing public information about their process and findings that prompted many other communities to follow their model (Sustainable Seattle, n.d.). They adjusted and added to their indicators through multiple iterations over the following decade and a half, but in the 2000s the project experienced a decline in interest and a period of self-evaluation because the system of reporting on the indicators did not seem to be substantially impacting the decision-making process in Seattle (Guy and Kibert, 1998). This may be connected to the project being geared primarily toward an audience of citizens and media (Maclaren, 1996) with the main goals of visioning, public participation in community development, and public awareness whereas other indicator-based projects have seen longer-term success. The City of Santa Monica's Office of Sustainability and the Environment, for example, geared its indicators directly toward local government goals for the purpose of informing the decision-making process (Guy and Kibert, 1998), and it is still informing policy today. The process in Santa Monica involves setting a goal, then using indicators to measure the progress toward that goal, not unlike backcasting.

4.1.1.3 Vulnerability Indicators

Indicators are also commonly used in assessing vulnerability or resilience to natural hazards, a practice that is increasingly popular in the planning field. In order to support adaptation policy development, there is a need for both physical climate projection and for an assessment of vulnerability of the societal systems that function within that climate (Eriksen and Kelly, 2007). Vulnerability is a nonspecific term, but in current planning it is frequently used in relation to hazards or climate change; it may be defined through the characteristics of a place, a societal or infrastructural sector, or a section of the population. It is a topic about which much has been written in an attempt to sort out the vagueness of its meaning, which can be a source of discord when collaborators in academia or planning practice disagree over how the issue should be defined and assessed. Füssel (2007b) is an excellent source for readers interested in the variety in potential scope of the term; for the purposes of this thesis, vulnerability means "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC, 2007).

Vulnerability can be assessed from the perspective of exposure and sensitivity to physical hazards, and of the social characteristics that contribute to a community's ability to withstand or recover from such hazards. Examples of biophysical vulnerability indicators could be characteristics of place such as elevation above sea level, or hazard indicators such as draught days per year; social vulnerability indicators may be poverty, education level, and race (Cutter, Boruff, & Shirley, 2003). Vulnerability assessment may also address a single type of hazard (such as river flooding), or be used to study potential impacts of multiple hazards (Kappes, Papathoma-Köhle, & Keiler, 2012).

In an interesting Indian agricultural example, a study effectively operationalized the IPCC's definition of vulnerability by measuring and mapping adaptive capacity and climate sensitivity under exposure to climate change, then combined these indices to form a mapped, indicator-based climate change vulnerability index (O'Brien et al., 2004). The study was completed at the district level, so that all of India's 466 districts are represented according to 1991 geography and characteristics. The biophysical, socioeconomic, and technological indicators used to measure adaptive capacity addressed soil conditions, groundwater availability, adult literacy rates, social equity, alternative economic activities, irrigation rates, and quality of infrastructure. Agricultural climate sensitivity under exposure to climate change was indicated by dryness and monsoon dependence. Figure 16 is the resulting map showing the composite of adaptive capacity and climate sensitivity at the district level, which "represents *current* vulnerability to *future* climate change" (O'Brien et al., 2004, p. 307, italic emphasis in the original). This methodology could serve as a model for sub-national vulnerability indicator usage elsewhere.

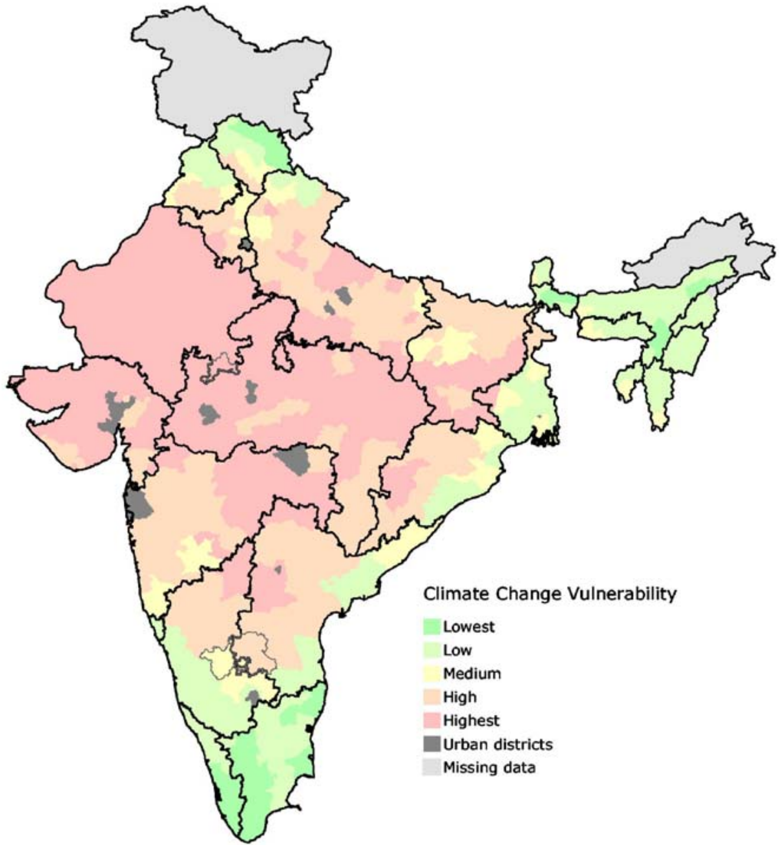

Figure 16: Climate change vulnerability in India's districts mapped by quintiles as a function of adaptive capacity and climate sensitivity under exposure to climate change (O'Brien et al., 2004).

4.1.1.4 Emerging Usage of Climate Change Indicators in Planning

While the analysis of vulnerability through indicators is essential for understanding where adaptation planning should be targeted, indicators are also useful for understanding how adaptation should proceed. The New York City Panel on Climate Change (NPCC) (Jacob et al., 2010) plans to use indicators to alert stakeholders of the most up-to-date climate change and risk information, to signal thresholds in the climate system that could change the risk profile, to act as "decision triggers" (p. 129) in an adaptation process, and to prompt alterations to policies or the timing of policy implementation. The Panel chooses indicators carefully, a process it bases on the Pressure-State-Response method shown in Figure 5, with its criteria that emphasizes policy relevance, analytical soundness, and measurability. The inclusion of policy relevance as the first of three criteria for indicator selection is an important strength to this approach. Another strength is the acknowledgement that if they were to be highly useful for New York City policy-making, indicators must reflect regionally specific conditions. The physical climate change indicators proposed in Table B-5 in Appendix B are all climate indicators measured at stations in or near New York City, with the exception of the greenhouse gas index which is measured globally. The NPCC's inclusion of climate impact indicators (shown in Table B-6), nearly all already measured by New York City agencies, makes the approach all the more impactful. As the Panel points out, "Combining the physical climate data with the impact data is necessary to fully understand and successfully monitor changing climate risk exposures" (Jacob et al., 2010, p. 134).

These indicators are not actionable on their own. As evidenced by the NPCC policy relevance criterion, the monitoring of the indicators must be integrated into a policy-making process in order to be effective. Part of the NPCC's intention is to enable decision-makers to mainstream climate change information into day-to-day decisions, but the overall goal is to build a flexible adaptation process informed by trigger points in indicator measurement (Jacob et al., 2010). As the New York City adaptation process progresses, other communities will be able to look to the flexible adaptation model in practice for guidance.

4.1.2 Discussion

4.1.2.1 Issues with Indicators in Planning

Some research on indicators has focused on the issues inhibiting their successful use as decision-making tools. Data from indicators, particularly vulnerability analyses, is sometimes aggregated to a national level for purposes of comparison with other nations; the resulting data is useful for international aid organizations or intergovernmental agencies, but does little good at the national or sub-national levels, where decisions are made and where such analysis would be very helpful in the policy-development process. It is at the local and regional levels that the factors determining vulnerability and best options for adaptation strategies intersect. Therefore, measuring community characteristics contributing to physical and societal vulnerability to climate change for the purpose of supporting municipal planning should be done at the local and regional levels to provide the clearest data (Moss et al, 2001; Eriksen and Kelly, 2007).

As indicators are used to aggregate more and more data, it becomes less and less clear how their findings should affect decision-making, or even which decisions to apply them to. Indicators by nature reduce a complex system to simplified terms, but not necessarily to its origins or contributing factors (Eriksen and Kelly, 2007). It is helpful to think of indicators as the symptoms by which an ailment might be diagnosed, but not the infections or injuries that led to the ailment. This fact can sometimes hinder the usefulness of indicators, if there is not a clear plan for how they will be used to inform the planning process. As the example of the Sustainable Seattle indicator project revealed, indicators designed without paying heed to a planning process that can use them effectively can lead to the process stalling in evaluation, without progress in the form of action (Guy and Kibert, 1998). The same was found to be true at the national level when sustainability indicators were being tested in their beta form. Some testing nations who implemented indicators without integrating them into an overall sustainable development policy experienced difficulty tying indicators to their decision-making (United Nations, 2007).

4.1.2.2 Implications for Adaptation Planning

The characteristics that contribute to the range of success of previous indicator usage in various planning sub-fields are telling about the potential for indicators in climate change adaptation. Taking a lesson from Santa Monica's sustainability indicators project, it is clear that indicators do the most good when they are integrated into a planning process; this means indicators should be selected that lend themselves well to decision support, as is also recommended by the NPCC policy relevance indicator selection criterion. An example using this criterion would be, if climate indicators were selected for assessment purposes alone, one might opt to use annual average temperature as a signal for the progress of temperature rise over time. But if the community in question is struggling with public health issues as a result of heat waves, a more helpful indicator would be the number of days per year with a heat index over 90°F.

Indicators can also be used in a more traditional sense to measure the effectiveness of an implemented adaptation strategy, similar to how sustainability indicators measure the success of sustainability programs. In keeping with the heat wave example, the average number of visitors to cooling centers per day (centers that open only when the heat index is above a certain threshold) would be an apt community-based indicator to measure the continued need for those centers. Indicator selection may also depend on the dominant barrier to adaptation in the system. A community may choose to take action based on physical indicators such as inches of rainfall or extreme heat days if their most pressing barrier is skepticism of climate science or the long-term time frame of anticipated changes; global average surface temperature may be an appropriate indicator in a large area where the main barrier is the variation in the types of climate change impacts that are experienced across the region; if political will is the dominant barrier, social indicators such as public support for adaptation as measured by a community survey may be the best option.

The climate is a complex, dynamic system and there exists a substantial amount of skepticism around the validity and causes of its changes. Adaptation is often costly, and policy-makers must feel that the case for climate change adaptation is strong in order to push for their communities to spend capital on adaptive strategies. It is not uncommon for local planners to have a general understanding of the global climate issues, but lack a solid grasp of the community-specific impacts and vulnerabilities (Baker et al., 2012). Indicators offer to planners an opportunity to improve understanding of climate change for themselves, their elected officials, and their communities. Planning while taking into consideration the uncertainty of the future of climate change is a prominent discussion in the planning field. By making the connection between indicators of the physical climate system and community vulnerability, and the adaptation planning process, uncertainty can be managed. Indicators can be used in planning for climate change by signaling when a system is approaching a tipping point. When a system threatens to surpass the capacity of its current management strategy, it has reached its tipping point and requires a new adaptive strategy (Kwadijk et al., 2010). Though work remains to be done to better understand how trigger points can be defined in terms of indicators, the characteristics of climate change as a planning issue support the use of climate change indicators as triggers for phased or flexible adaptation.

Climate change indicators are commonly used to measure the progress of change in the physical environment on a global or national scale for the purpose of recording and reporting. Once the data are made public, governing bodies may use them to inform regulatory decisions, but there is not currently a prescriptive framework to reference on how to do so. Figure 17 depicts the potential role of science in a nonspecific decision-making process. It makes a very fitting argument for how planners could conceptualize the use of indicators in their approach to adaptation, in the absence of policy mandates or instructions on using climate data from higher levels of government or regional planning agencies.

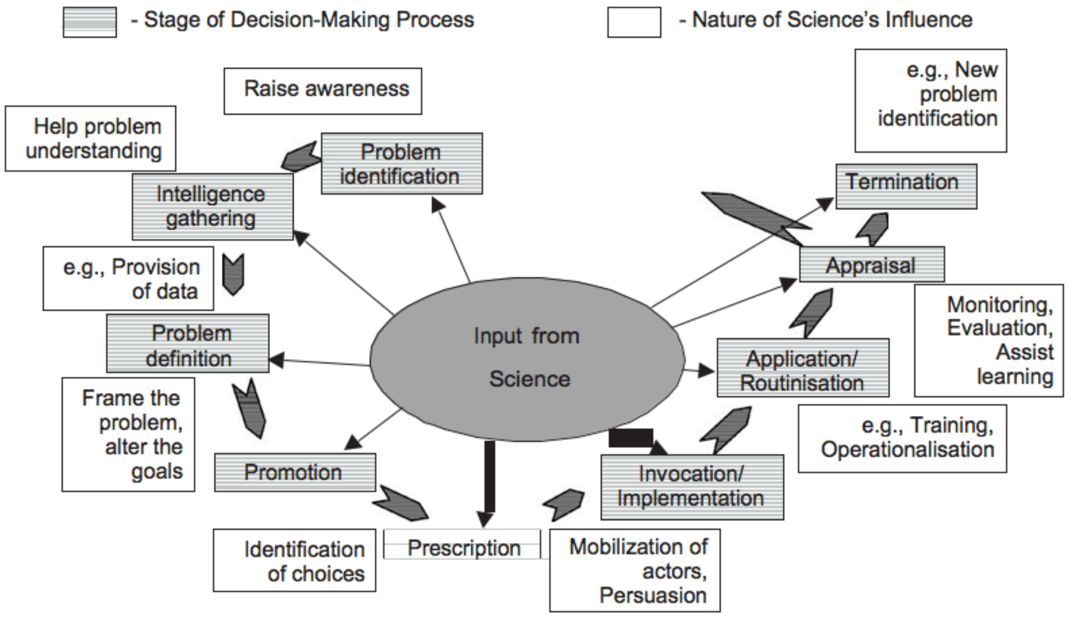

Figure 17: The role of the input from science and the nature of its influence on the decision-making process (Vogel et al., 2007).

Measuring climate change has become more rigorous, as is the case with the renewed focus on the development and use of indicator sets by national government agencies. The development of the NCA sustained assessment program will allow policy-makers to access vital information in a more useful way than via traditional periodically updated climate assessment reports. As the NCADAC states, "Sustained interactions among scientists and stakeholders have consistently been shown to improve the utility and effectiveness of assessment processes and outcomes (…) and to facilitate the development of decision support tools" (2013, p. 1049). By referring to a continually updated, publicly available climate indicator system, and by measuring the progress of climate change locally, planners can monitor the system for which they are planning while keeping their climate sources consistent. As climate science sources become more fixed and reliable, planners will be able to use them more easily as decision-making support.

4.2 Barriers to Adaptation

4.2.1 Results

In the 15 interviews with municipal planners from Massachusetts, the most frequently mentioned barriers were politics, staff and money, and uncertainty of science or projections. Figure 18 shows the frequency breakdown of all barrier topics mentioned.

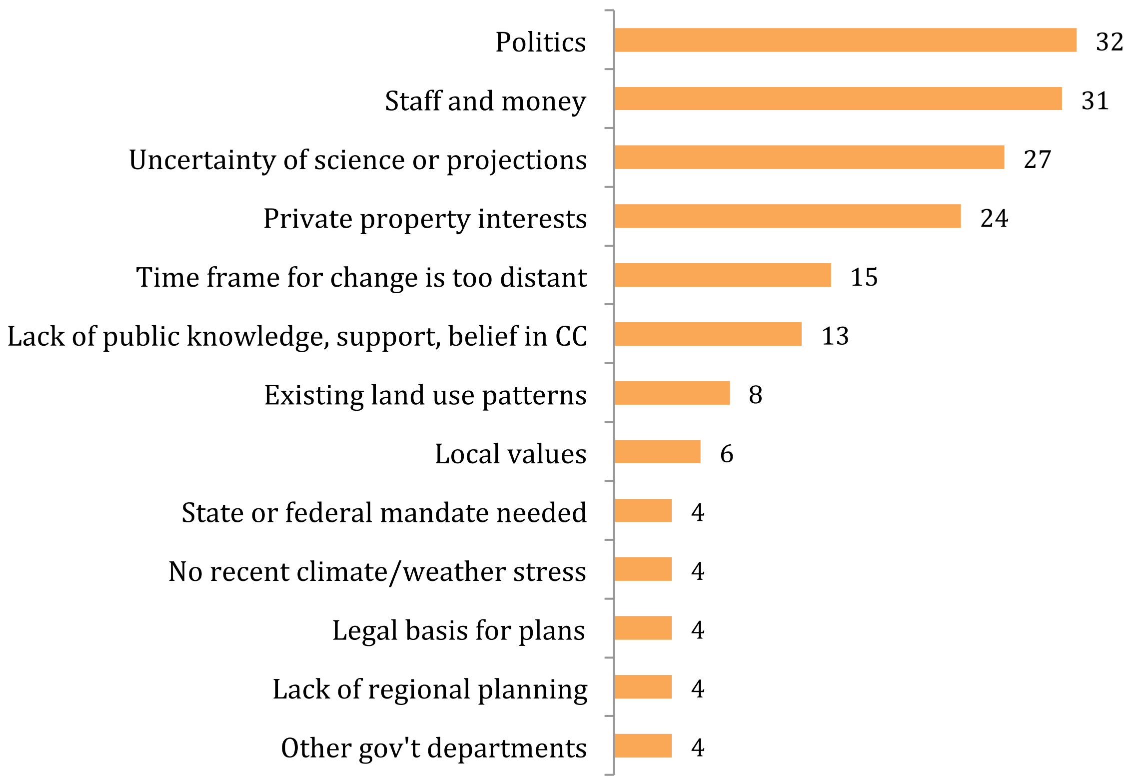

Figure 18: Frequency chart of all barriers mentioned, sorted by topic (n=176) (data source: Hamin, 2012).

By also looking at the percentage of towns that mentioned each barrier topic, one can discern differences between the number of times a barrier topic is mentioned (Figure 18), and the percentage of participants concerned about each barrier, as seen in Figure 19. Not much changes in this shift of perspective, but it is worth noting that politics is no longer the top barrier; uncertainty of science or projections and staff and money emerge as the barrier topics about which the most towns are concerned.

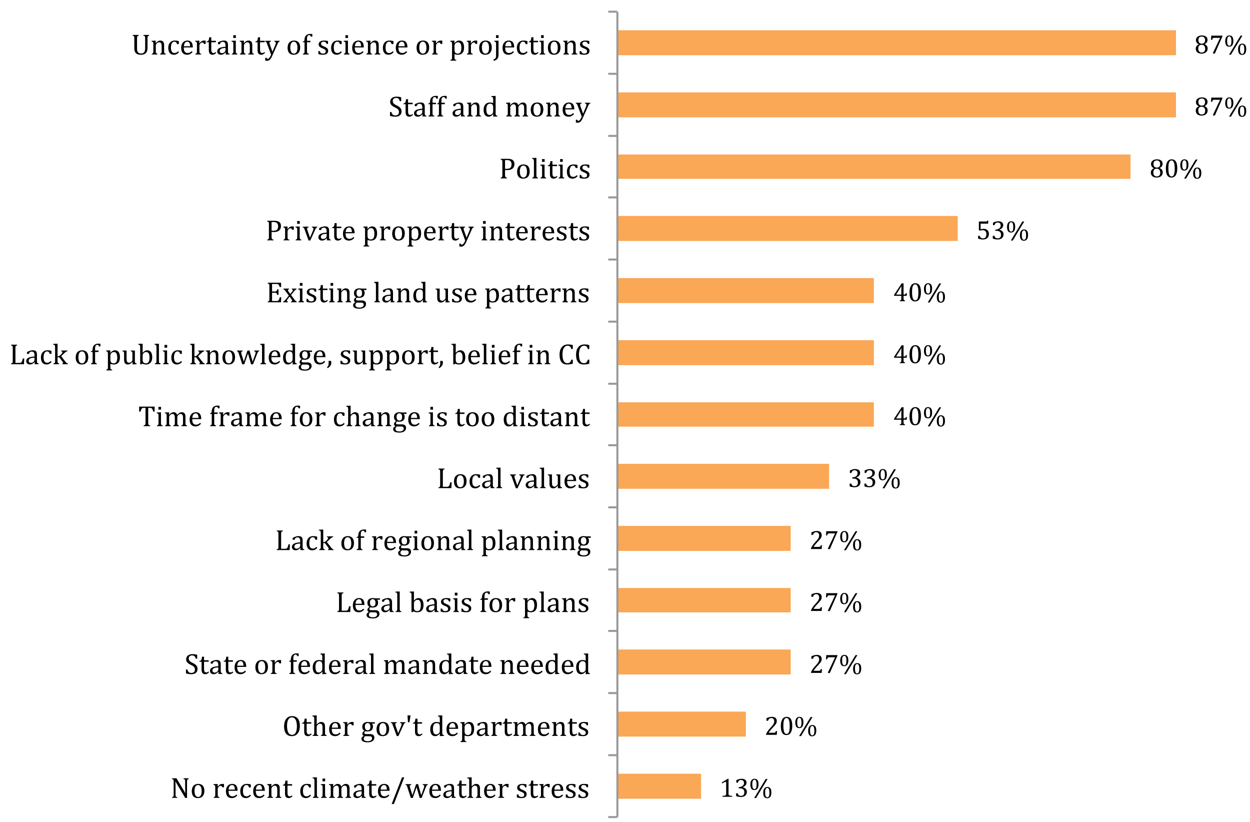

Figure 19: Percentage of interviews mentioning barriers, sorted by topic (data source: Hamin, 2012).

When conceptually evaluating the main reasons planners believe adaptation is hindered, several themes emerge. The 15 interviews revealed that in order to move forward with adaptation planning, the following are needed: scientific tools to support decision-making (13%, n=2), a short-term framework for climate impacts (20%, n=3), planner training (20%, n=3), development of political will (13%, n=2), policy guidance from higher levels of government (20%, n=3), and reallocation of planners' time (13%, n=2).

4.2.1.1 Need for Scientific Tools

Of particular interest to this thesis are instances in which uncertainty of science or projections was mentioned as a barrier (includes 87% of towns, n=13), or when climate data in general was mentioned. The role of climate data was a widely discussed topic, with 73% (n=11) of interviewees bringing up the subject, mostly expressing a need for clear, specific scientific data that could be used to support decision-making. Statements such as these depict the impact of uncertainty of the decision-making process:

> "It's just harder to initiate any action if you don't have specific estimates. Specific estimates, and specific impacts, you know? A huge range is good (…) to talk about, but to actually get some actions, get something happening, you really need something more specific." *(Town 1)*
>
> "[We] need a scientific study that we can put out to the public and say, 'Here, it's not just logical, we don't just think that these are the problem spots, we know these are the problem spots." *(Town 2)*

None of the planners interviewed stated that they had access to climate data that was scaled for their purposes, and that they were using them effectively. 33% (n=5) of interviewees indicated that they had access to climate data or impact maps that could be useful to them, but that they weren't being used in planning currently. 47% (n=7) expressed interest in having localized climate data and maps prepared for their planning purposes.

4.2.1.2 Need for Short-term Framework

The timing of climate change impacts is often discussed with a very far-term scope, and several interviewees indicated that this was the most significant impediment to adaptation. As a stand-alone barrier topic, 40% (n=6) of interviews mentioned the distance of the climate change impact timeline as a barrier. The following excerpts are succinct representation of this perspective:

> "I think they've framed it in too far a distant episode for people to be really concerned with, because they are only concerned with their health and up to the year 80, maybe." *(Town 3)*
>
> "I think that people just not understanding the issue- it seems kind of nebulous. It seems like, 'Oh yeah, but that's not going to happen for another hundred thousand years'. (…) people need to have better sense of what the timing is" *(Town 4)*
>
> "I find in my experience that unless people perceive some sort of crisis or unless they perceive some issue, it's hard to get them to react" *(Town 5)*

Two of the towns whose emergent barrier theme was the need for a short-term framework for climate information made direct connections between this and other issues:

> "…without any kind of mandate from state or (…) the federal government to adopt regulations to put those things in local plans, I think it's unlikely. That it will be one of the last things that communities are looking at because they have much more urgent concerns." *(Town 4)*
>
> "…it's having the tools to tell the story. I think if we can tell the story of what we think is going to happen. I think I still see a broader picture of trying to bring the greater community of the United States together to actually acknowledge this. (…) I think the first thing needs to be national awareness and so you get to the local level where people start to feel there's something valid here." *(Town 5)*

These excerpts made it clear that some municipal planners are looking to broader scales of government and public discussion to encourage communities to take adaptive action.

4.2.1.3 Need for Policy Guidance

Climate change is a system rife with uncertainty, and planners need decision-making support of some kind, whether in the form of information to help with education for the public and elected officials, or policy guidance from state or federal government such as incentives or mandates.

“So FEMA always gives you incentive, it’s an incentive-based approach to doing coastal regulations and coastal mitigation. That only goes so far. But they’re not willing to take on and say “no”. And the state follows and, “no,” so they leave it to the local jurisdiction to fight that battle in the political trenches, and I don’t see it happening here. Not in my lifetime, not in my career time.” *(Town 6)*

“I always thought the key to that would be a funding source from the state because we have a very fragmented government, we have a lot of different elected boards, and the planning board has talked about doing a master plan but there is water and sewer commissions that are down there forty years and, ‘Why is the planning board telling us what to do, why are they asking?’ So if there was some requirement like- state funding that would assist with it and then some requirement that in order to get state funds, (…) you need to do this kind of thing.” *(Town 7)*

“I think the greatest difficulty is, you're probably - you know, a state initiative is probably where things would likely have to go. I think you're going to have a tough time having 351 communities kind of take this on individually. I think one of the pieces that's probably the most difficult to nail down, and I was in a group that was talking about, you know, the coastal zone and potential impacts - there was a separate group that was talking about habitat, there was another group that was talking about the actual kind of measures of things -

and I think we probably had about 8 sessions and they were completely dominated by trying to pick the number of what we should plan to. And I think that that's probably one of the biggest impediments right now. There's a lot of information about, a lot of data collected, a lot of projection, of where things may go but that range is pretty broad, you know anywhere from a foot to 2 meters (...) So I think that's probably where things get really problematic, of how you're going to convince one community that this is the right target to use when there's a lot of disagreement on what it might be." *(Town 8)*

Municipal planners will sympathize with the statement from Town 7; the individual boards and committees each have their own priorities and the issue of climate change is so complex that there is no simple way of dealing with it. While state and federal governments are fragmented as well, they have more resources and political power than municipal planners, so some planners have expressed the desire for them to provide tools or strategies. One planner summed up this need for guidance with a question: "And so, that's the fundamental question, it's not that we don't want to do something; how do you engage in the political process to get something effective done?" *(Town 6)*

4.2.1.4 Need for Political Will

The barrier of politics is a difficult one for planners to overcome, because it is a dominant, powerful one, and because planners lack control over it. 80% (n=12) of interviewees cited it as a barrier that applied to their community, and some explained it like this:

> "It is not on the political radar screen. It's probably [on] political radar at the national levels, bigger cities and towns perhaps, to some extent, but we are more worried about the ten weekends of the year to survive down here. (…) It's #32 on a locality's list of things to do sometimes. It is not our priority." *(Town 9)*

> "Our biggest issue here though is, we've submitted material out of this department to the other pieces of the government, whether it's DPW, ***'s office, executive branch, and it just disappears. So you know, it's difficult for a planning department to influence other city functions on the importance of this stuff. (…) I think government as an institution just doesn't like change. (…) And that stems from- people are elected into office. It's very difficult for us to get a mayor to go along with a new initiative especially if it's beyond an election cycle. And I think one of the inherent issues with climate change planning is, we're talking about something 20-30-40-50 years down the road." *(Town 10)*

This issue of the allocation of political will based on what can yield results during an election cycle is a very challenging one in a climate change-related planning process. Since climate change is a politicized topic, towns that have struggled with political will may want to emphasize co-benefits. It is sometimes the case that planners themselves are unaware of the adaptive benefits of otherwise helpful planning; such is the case in Town 9, where the planner states that there is a lack of political will and that local efforts are focused on tourism and economic development, yet the town had, in the past, purchased frequently flooded properties to limit redevelopment, and are engaged in a pre-disaster planning process.

4.2.1.5 Need for Planner Training

Some planners were open in explaining that they simply did not know how to go about an adaptation planning process; others seem to have been so put off by the political discord over climate change that they are wary to bring it up in a planning capacity. Some interviewees anticipated questions from the public about why adaptation planning should be a priority, and they did not seem to know how to respond. Others, as in the case of Town 9, were seemingly unaware of the connections between adaptation and planning issues their communities were already addressing. Examples of interviews that featured the need for training can be seen here:

> "…it's not a part of the traditional land-use planning, which is what we as planners are more used to doing. (…) I think that a lot of planners are looking at energy management, as it ties in with sustainability, which is of course a new buzzword for planning these days. But I think it's outside our knowledge base, so I don't really know what we-what should we be doing?" *(Town 11)*

> "…in truth I confess I haven't tried it yet. It is really difficult to get people to raise their hand at town meetings for something that really

> directly impacts their property in a way they might not be all that happy about." *(Town 12)*
>
> "…we've got to convince the Town Manager that it's a good idea, he's got to convince the Board of Selectmen that it's worthwhile having his staff spending time doing this. Then once we have sort of centered on the essence, it's a good use of the planners' time and all the other department heads to move in this direction, then we need to take that message out to the public and then we have to say, 'And this is why.' You know, I mean, I can't imagine that any of them have any idea what adaptation planning is, or they're probably still struggling to [??] pre-disaster mitigation and that has been something that has been talked about at plan board meetings and zone board meetings and zone board meeting and Board of Selectmen meeting and we still have people saying, 'Well why are we doing it?' so I think that PR part of it is something that is holding us back." *(Town 13)*

All of the difficulties described by interviewees from Towns 12 and 13 are true: it is difficult to pass regulations that affect private property through town meeting, and also to get climate change adaptation through the proper chain of command. However, what emerge as dominant barriers from these interviews are not simply what the planners believe the barriers to be – what emerges is the planners' lack of confidence or knowledge in the reasons for and methods of planning for climate change.

4.2.1.6 Allocation of Planners' Time

Staff and money were often cited as barriers by 87% (n=13) of interviewees, with 31 mentions in total. There are studies on the financial benefits to early adaptation (e.g. Stern, 2007) and there are some funding opportunities from state and federal governments to support adaptation; with that in mind, and since the issue of time emerged as a more important issue via interviews, the focus of this section will be staff time instead of money. Many interviews made it clear that municipal planners did not have the time to do large scale, long-term planning aside from the required master plan because of their daily obligations.

> "And they haven't updated their plan, a year out of date for a hazard mitigation plan. (…) So right now we are out of date and I don't know who's going to do it because there's no staff that's going to do it. It goes back to the first issue of inadequate staff on a small town level. (…) I know the data is out there. I know the sources. I haven't got the time to research them all or do anything with them so between those two, it's a political problem that there is no support from the staff to do it." *(Town 14)*

> "Our planning department is me and a full time secretary and she is off today, and if the phone rings, no one will answer it. And under state law, when someone brings in a subdivision plan, submits it here for the planning board to review and approve, there are mandatory, statutory deadlines, and if the planning board doesn't act [on] that

within 145 days, it gets approved by default and so, I have little control in managing my time." *(Town 15)*

It appears that climate change adaptation brings up a conflict with the way municipal planners have traditionally spent their time. It is an issue well suited for planners to take on, and is unlikely to be addressed by any other member of town government, but the traditional layout of a planner's day is based on development as the biggest element of change in a community. It may be time to reevaluate how municipal planners' efforts are allocated.

4.2.2 Discussion

Researchers who actively work in barriers to adaptation distinguish barriers from limits, the former being those obstacles that can be overcome by "concerted effort, creative management, change of thinking, prioritization, and related shifts in resources, land uses, institutions, etc" (Moser and Ekstrom, 2010, p. 22027), whereas limits are absolute obstacles that cannot be overcome. Since barriers are resolvable, it is logical to frame them by the functional needs they create. This practical reframing highlights opportunities for creative problem-solving.

It is clear that there is substantial overlap between barriers, and that towns struggling with adaptation experience a much more complex set of obstacles than barriers presented as a list. For instance, while Town 8 was categorized as one whose most pressing barrier is the need for policy guidance, the excerpt in that section also touched on the need for clear and specific scientific projections, and for ways to generate consensus on problem definition. The need for more robust problem definition is seen by researchers as a substantial barrier to environmental planning (Measham et al., 2011). It is expected that advances in climate projection and the communication of those projections with the public through locally relevant impacts will help in this regard.

There is a thematic storyline of uncertainty running through many of the barrier topics that, from the planning perspective, is at once a significant challenge and an opportunity. Compared with the vast range of topics planners work in, climate change is unusually murky (Measham et al., 2011). The confluence of an uncertain system, a rapidly advancing threat to many sectors, and large price tags on both adaptation and failing to adapt, make planning for climate change different from planning for other issues. The barriers experienced by planners heavily emphasize the need for outside help. Planners need a model to follow to help them assess physical and social vulnerability to locally specific climate impacts, and the training to help them use that information effectively. When asked about what would be helpful to advance adaptation planning, interviewees frequently expressed the need for better information from outside sources, whether it was for supporting planning decisions, educating the public, or training the planners themselves. The following excerpt from Town 9 provides insight into the power of information from reputable sources:

> "I always tell those folks and the academic community don't worry about the front line stuff we'll take care of the front line stuff, help us with some ideas, thinking and journals. (…) There's some external validity, I might say something here like, 'We got this from Tufts

> University.' They would read from a journal like Harvard or Tufts or UMass more readily than they would, say '*** said at a town meeting that *** Shores is going to be gone.'" *(Town 9)*

It is important to note that this study is not an analysis of adaptation planning processes with objective explanations for their barriers; it is a study of the barriers as they are perceived by planners. Many of the planners had not yet begun an adaptation planning process, so their answers stem from their subjective opinions of a hypothetical event. That said, their perspectives are invaluable because of their understanding of how planning can be accomplished in their communities, and since the interviewees themselves are a significant part of that process.

Though barriers may manifest as a variety of topics, analyzing them through an operational lens by considering what communities need to overcome them reveals a current of uncertainty running beneath many of those barrier topics. That uncertainty must be addressed in order for adaptation planning to move forward at the municipal level. Planners need education and training so they may understand locally relevant climate projections and the effects of projected climate changes on their communities, and they need materials to help them disseminate that information to other government departments and to the public. To move beyond education to action, planners and their communities need decision support tools to help them organize and understand that information.

4.3 Organizational Matrix for Decision Support

4.3.1 Results

The conceptual model in Figure 14 calls for a linear process of moving from the assessment of climate change impacts, to identifying adaptation strategies, to identifying adaptation barriers, to selecting appropriate indicators for integrating clear and specific data as a way to effectively make climate-related decisions and overcome barriers. The model provides a step-wise framework for the data found in the indicators literature search and the primary research on barriers.

Table 3: Step-wise decision support matrix example using climate change impacts from NCA regional assessment for the Northeast. Orange columns correspond to model in Figure 15 (continued onto next page).

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Identify climate change impacts	**Assess physical vulnerability**	**Assess social vulnerability**	**Look for physical & social vulnerability overlap**	**Identify potential adaptation strategies**	***Community Engagement***
Temperature rise, extreme heat days and heat waves	Places with sparse tree cover; places with large amount of paved surfaces	Age (elderly & children); public health issues (asthma, respiratory illness)	Use census data to identify census tracts with higher elderly and young populations, and with higher rates of asthma	Set up cooling centers; plant shade trees; establish summer activities open to public in cooled central location; plant green roofs to absorb solar heat	Public workshop to: A) Provide data and visualization tools to advance stakeholder understanding of locally specific climate change impacts. B) Establish adaptation priorities. C) Gather stakeholder feedback on potential adaptation strategies, including new ideas. D) Identify no-regrets adaptation strategies.
Flooding from sea level rise and storm surge	Low-lying areas, especially with dense development; buildings currently outside NFIP flood zones that will be inundated as sea level rises; vulnerable public infrastructure; evacuation routes or emergency vehicle routes that may be inundated; drinking water wells	Access to vehicle for evacuation; age (especially elderly who may not be able to evacuate without help)	Use census data to identify census tracts with low access to vehicles, higher elderly population	Building elevation in flood areas; planned retreat from flood areas (e.g. purchase or transfer of development rights); living shoreline to soften storm surge impact and mitigate beach erosion; coastal armament and hard infrastructure; abandonment of vulnerable wells; groundwater desalination	
Extreme precipitation events	Low-lying areas, places with poor drainage, places with combined sewer overflow	Location of social services	Map low-lying areas and impervious surfaces, and identify social services offered in any vulnerable locations	Separate sewer and stormwater management; resurface poor drainage locations with pervious surface; green roofs to absorb precipitation	

Step 7	Step 8	Step 9	Step 10	Step 11
Identify barriers to adaptation	**Identify what scientific info would help overcome planning barriers**	**Select indicators that provide that information**	***Community Engagement***	**Develop implementation plan**
Low public awareness of unscheduled services; building owner reluctance to pay for green roofs	Numbers of extreme heat days and events; number of people using cooling centers	Annual average highs and lows, by weather station (NOAA Climate Data Online); # days/year with max. temp. over x° by county (CDC); # days/year with heat index over x° by county (CDC); Heat stress (NOAA-NCDC); U.S. Annual Heat Wave Index (EPA); annual user count at community cooling centers	Public workshop to: A) Develop understanding of indicators and how they will be used. C) Present options for data management system, asking for volunteers who may want to get involved. E) Hold breakout sessions for stake-holders to work on developing climate indicator triggers for phased adaptation.	A) Set no-regrets adaptation strategies in motion. B) Meanwhile, establish data management roles (who is responsible for reporting each indicator, who is the central data manager). Involve community member whenever possible. C) Establish a data reporting system and decide how data will be managed technologically (e.g. Excel spreadsheet), and how it will be communicated to the public. D) Conduct cost-benefit analysis on adaptation strategies vs. risk without adaptation.
High cost of adaptation strategies; long timeframe of adaptation strategy completion; lack of political will because long timeframe of adaptation outlasts election cycles; public support difficult to generate for strategies that are perceived to only help coastal residents	Sea level rise measurement; number of times per year water reaches a predetermined level	NOAA Sea Level Trends by nearest station; number of times per year building owner reports water reaching their building; number of times per year a pre-assigned community member reports seawall being topped		
High cost of adaptation strategies	Rainfall; extreme rainfall events	NOAA annual statewide departure from average precipitation; EPA extreme one day precipitation by percent of land area in contiguous US (currently no state or regional indicator)		

4.3.2 Discussion

4.3.2.1 Organization of Matrix

The goal of this matrix is to contribute to the understanding of the relationships between the dimensions within it, represented by columns. The step-wise nature of the matrix is helpful because of the need for planner preparation to manage uncertainty. Steps 1-5 can be seen as preparation for the first phase of community engagement, in which planners thoroughly establish the basis for the planning process, as well as a preliminary menu of options for the public discussion of adaptation strategies. This menu of adaptation strategies can be a collection of strategies that have been used or proposed in other communities, in order to support the discussion for the first community engagement workshop (Step 6) with as many options as possible. Step 6 is an opportunity to establish understanding of the climate scenario the community will plan for, and publicly disseminate locally specific climate impact information. At this step, planners and stake-holders can establish adaptation priorities through backcasting, identify no-regrets strategies that will begin the adaptation process and meet other community needs, and engage in a discussion about the menu of adaptation strategies, including new ideas that may have been overlooked by the planner.

Steps 7-9 focus on how adaptation can be accomplished, starting with the identification of barriers. Barriers exist at every step of adaptation planning, but as this thesis focuses on overcoming the pervasive barrier of uncertainty which acts as a root for other barriers, it is the author's hope that the preparatory steps leading up to the first community engagement opportunity will provide the scientific basis for the further steps of the process. Since information and training are prominent needs that emerged from research on the barriers to adaptation, it is likely that addressing these needs through the preparatory Steps 1-5 will change the barrier profile in ways that can be discerned during and after the first community engagement workshop. This is why identifying barriers (Step 7) is placed after the information gathering and analysis steps and Step 6.

Once the connection between locally-relevant scientific data and the planning process is established, next steps include identifying what scientific or observational data would be helpful as sustained information inputs to support the iterative adaptation decision-making process (Step 8). A list of indicators can then be identified that will combine physical climate change data with impact data that reflects the local experience of climate change (Step 9). Table 4 contains a selection of locally-relevant indicators with data available to the public; these indicators will be helpful to communities who intend to use scientific data in an adaptation process:

Table 4: Climate change indicators recommended for communities engaging in an indicator-based adaptation process. These indicators are monitored by national agencies but are measured at locally-relevant scales (continued onto next page).

Useful Climate Change Indicators Using Outside Data				
Climate stressor	**Indicator**	**Source**	**Scale**	**Link**
Extreme heat	Number days per year with maximum temperature greater than or equal 90°F, compared to long-term mean at nearby weather station	NCDC CDO*	weather station	https://www.ncdc.noaa.gov/cdo-web/search
	Number of heat stress emergency department visits	CDC National Environmental Public Health Tracking Network	state	http://ephtracking.cdc.gov/showIndicatorPages.action

Temperature	Seasonal mean temperature anomaly from base period means using 4-month means (Dec-Mar, Mar-Jun, Jun-Sep, Sep-Dec); can also use monthly or annual means if better suited for community needs	NCDC Climate at a glance	U.S. climate divisions†	http://www.ncdc.noaa.gov/cag/
Precipitation	Seasonal mean precipitation anomaly from base period means using 4-month means (Dec-Mar, Mar-Jun, Jun-Sep, Sep-Dec); can also use monthly or annual means if better suited for community needs	NCDC Climate at a glance	U.S. climate divisions†	http://www.ncdc.noaa.gov/cag/
	Monthly or annual total precipitation	NOWData‡	sub-state divisions or individual weather stations	http://www.nrcc.cornell.edu/page_nowdata.html in Northeast
Sea level rise	Relative sea level rise at nearby monitoring station	NOAA	varies by distribution of monitoring stations - usually more than one per state	http://tidesandcurrents.noaa.gov/sltrends/
Snow	Monthly or annual total snowfall; monthly total or annual average snow depth	NOWData‡	sub-state divisions or individual weather stations	http://www.nrcc.cornell.edu/page_nowdata.html in Northeast
West Nile	Number of cases and dates of diagnosis	USGS	county	http://diseasemaps.usgs.gov/wnv_ma_human.html
Drought	Palmer Drought Severity Index annual anomaly from base period	NCDC Climate at a glance	U.S. climate divisions†	http://www.ncdc.noaa.gov/cag/
Growing conditions	Monthly and annual growing degree days	NOWData‡	sub-state divisions or individual weather stations	http://www.nrcc.cornell.edu/page_nowdata.html in Northeast

**CDO: NCDC Climate Data Online*
†U.S. Climate Divisions reference map: http://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php
‡NOWData: NOAA Online Weather Data

As was discussed in Section 2.6.2, the integration of scientific climate data with information about the local experience of climate change makes an adaptation process more likely to succeed. The participation of community members in assessment and decision-making also empowers participants, which contributes to the reduction of vulnerability. Table 5 provides a variety of examples of indicators that are measured within the community and are fine-scaled, which makes them particularly policy-relevant.

Table 5: Examples of indicators informed by local knowledge and measured within the community.

Example Local Knowledge Indicators			
Climate stressor	**Indicator**	**Source**	**Scale**
Frost season	Dates of first frost and last thaw	Community member or governmental office	municipality
Combined Sewer Overflow	CSO discharge to waterways	Governmental office	municipality (or scale of stormwater management system)
Flooding	Number of times floodwaters reach pre-determined point monthly, seasonally, or annually	Community member	location-specific
Flood and storm damage	Estimates of municipal building damage from flooding	Public Works department	municipality
	Annual sum of damages in flood insurance claims, or number of claims annually	Conservation Commission (or corresponding department)	municipality
Beach erosion	Monthly measurements at multiple locations of distance between fixed features and high water mark	Community member	location-specific
Wetland migration	Monthly measurements at multiple locations of distance between fixed features and wetland boundary	Community member	location-specific
Cooling center usage	Number of visitors to public cooling centers per extreme heat day	Cooling center volunteer	municipality

The next opportunity for community engagement, Step 10, is to focus on how climate change and impact data should be used to meet the continued reference needs of the community to support adaptation decision-making. The planner can present the physical climate change indicators whose data comes from outside the community, and can engage the public in the development of appropriate local knowledge indicators. At this point community members may volunteer to participate in local knowledge indicator measurement, and roles can be distributed within the government for remaining indicator monitoring. Alternately, an adaptation committee can be established, which would be responsible for monitoring indicators. An implementation plan must next be developed (Step 11), ideally using a flexible adaptation approach with phases triggered by indicators.

4.3.2.1.1 Limitations of the Organizational Matrix

There is no one-size-fits-all adaptation planning progress. The process presented in the organizational matrix is meant to operate as a template for planners to use when beginning an adaptation planning process, and it is expected that each community would need to tailor the process to fit their needs. One possible change could be that a community may want to hold more public workshops in order to build consensus; reducing the number of community engagement events is not recommended. Naturally, each community's barrier profile will be different, and those barriers determine which parts of the planning process will require more attention than others. This particular approach to adaptation planning is designed for managing uncertainty, and if a community is dealing with barriers that are not related to uncertainty, the approach will be less successful.

It is important to note that this linear process encompasses the steps of the adaptation planning process, ending with the development of the implementation plan. Specific approaches for implementation are not prescribed due to the fact that a flexible or phased adaptation process is recommended, but methods for phasing based on indicator trigger points are, at present, unripe for specific recommendations. The development of an implementation plan is likely to include further community engagement steps, and may include meetings with town boards and the public to obtain approval.

4.3.2.2 Contribution of Research to Existing Knowledge

While organizing data in the matrix, it became clear that including intermediary steps would be helpful in illustrating the relationships between the originally conceived dimensions (shown in orange). Since a prominent result of the barriers research was the need for detailed information, providing as much information about a potentially useful decision-making process was an opportunity to contribute to the existing knowledge base. The result is a model for a data-informed, risk-based adaptation planning process that takes into account common barriers to adaptation as part of the process, and includes an opportunity for science to inform the decision-making process in a transparent, community-engaged manner.

4.3.2.3 Impact on Community Decision-Making

Table 3 provides an example using locally relevant climate impacts rather than generic concepts in the hopes that it will be more accessible for planners who may connect some of the sample data to experiences in their own communities. However, the step of identifying climate change impacts, in practice, requires a far more detailed look into the regional climate projection. Planners should have and be able to communicate a solid understanding of their region's specific projected climate change impacts. With advances in climate projections in terms of their specificity, regional downscaling, and their accessibility to the public, it is likely that this task will only become easier for planners. There is a difference, however, between improving awareness of locally relevant climate data and knowing how to use it. This is where the decision support matrix in Table 3 is useful.

For climate change-related planning, decision support "involves organized efforts to produce, disseminate, and encourage the use of information that can improve climate-related decisions" (NRC, 2009, p. 36). The purpose of decision support tools is not to push the decision-maker to a certain conclusion, but to provide the information and promote the understanding that the decision-maker will need to find the right solution for the situation at hand. In the case of adaptation, having tools that connect decisions to climate science will be very helpful in the development of strategies for risk reduction (NCADAC, 2013). Indicators will be highly useful for municipal planners as a form of decision support, and in the generation of public and governmental understanding and support for the adaptation process. Since uncertainty is a pervasive theme to many barriers, this integrated use of scientific data in a community-engaged planning process will help move adaptation forward.

CHAPTER 5

RECOMMENDATIONS

5.1 Recommendations for Municipal Planners

5.1.1 Step-Wise, Risk-Based Planning

It is recommended that planners prepare a step-wise, risk-based adaptation planning process using a regional climate projection, such as NCA regional climate assessments, to define the conditions upon which to plan. Planners should engage the community in a backcasting step early in the process; it is important to backcast with a vision in mind for the community's future rather than "muddling through" (Baker et al., 2012, p. 135) without consideration of a comprehensive, goal-based process that takes stock of the connections between impacts and vulnerabilities.

5.1.2 Flexible Adaptation

Planners are advised to integrate flexibility into adaptation whenever possible. The term "flexible adaptation" is used here to encompass planning that allows for updating an adaptation plan as relevant climate data is updated. This includes phased implementation as it was described in Section 2.4.2.1.6. In that section, the generic phased implementation model shown in Figure 9 calls for a progression through no-regrets, incremental, transitional, and transformative strategies. Communities planning a long-term step-wise adaptation process may choose to stray from this ordering of actions, particularly if an expensive, transformative change will be necessary in the future that inherently include a delay between policy passage and completion, such as infrastructural projects. These big-ticket adaptation measures – separating stormwater from sewers, for example – require early planning to allot funding, and do not lend themselves well to incremental adaptation, nor should planning for them be left until when they are needed. Indicators can be used to plan in advance of this need, and would help a community overcome wariness of climate change uncertainty. The delay between the beginning of planning for a large, expensive adaptation measure and its completion means the community must trust the regional climate assessment enough to support that measure before the anticipated actions requiring it are observed.

Planners, community members, and additional municipal government members can develop adaptation strategies, seek their approval by necessary methods, and include them in capital planning before climate stressors measured by indicators reach a critical point. This creates a pathway for implementation that offers a smooth transition through adaptive steps. Since climate change does not obey municipal boundaries, this thesis recommends that indicators are measured on a regional level; however, due to the lack of regional governance in some areas, including Massachusetts (with the exception of Cape Cod), this thesis recommends that adaptation strategies are tailored for municipal implementation.

5.1.3 Indicator Use

A key element to both phased implementation and Flexible Adaptation Pathways is the measurement of climate change progress using indicators.

Indicators selected for use by the NPCC can be seen in the Appendix B (Tables B-5 and B-6). There is great potential in the linking of indicators to adaptation strategies. This linkage can be prescriptive, developed hypothetically before the tipping point is signaled by the indicator so that when the tipping point is reached, the planning body will have an established set of actions to take.

Establishing in advance the indicator measurements that will trigger a new phase of the plan is a major challenge in using flexible adaptation. The starting point should be the adoption of a climate projection that is as locally-focused as possible, such as the National Climate Assessment regional projections. From there, indicators must be chosen that balance scientific climate data and the local experience of climate change. Using locally measured indicators to track the progress of the climate changes described in the climate projection connects community members and policy-makers to the adaptation planning process. Moving averages should be used with locally measured indicators to avoid erratic triggers from climate variability. Using moving averages in locally measured indicators means that there will be a delay between the beginning of the measurement process and the opportunity to use them for planning. That early lapse can be used to implement no-regrets strategies, and planning can be based on national databases that measure climate change impacts at the regional level. Planners interested in this approach will find useful the indicators in Table 4.

5.1.4 Cost and Risk Analyses

It will be very difficult for planners to identify trigger points within indicators that signal when a new phase of implementation should begin, under current barrier conditions. The low priority of climate change in many communities, the lack of time planners have for tackling new substantial planning projects, and the scarcity of comprehensive training for planners on this issue make it unlikely that they will be able to tackle this time-intensive process without help. A partnership between the municipal planner and the finance controller would be helpful in developing a cost inventory for adaptation strategies, once they have been selected through the participatory decision-making process. Planners must also consider funding sources in their prioritization of strategies. The distribution of costs and benefits is often disproportionate (Rose et al., 2009), so in a planning process, questions may arise over differential vulnerability and who is responsible for improving resilience.

Researchers have also raised questions over whether all benefits and costs can be monetized (Yohe and Leichenko, 2010), and thus have departed from the traditional cost-benefit analysis in favor of the broader risk management approach. The conceptual basis for the risk management approach is taking into account the probability of an event, and multiplying it the power of its impact. The NPCC points out the difficulty of this process in their planning documents, and warns that, "While a risk-based approach can certainly be applied to many types of adaptation decisions, the requisite data may not always exist" (Yohe and Leichenko, 2010, p. 32). Considering the challenge this poses for a large planning department that employs climate change experts as in the case of New York City, municipal planners with small planning departments will likely need to seek help from outside the community to establish an understanding of risk both with and without adaptation.

It is this author's opinion that a cost inventory – perhaps loosely titled a cost-benefit analysis – is a necessary piece within a larger risk-based planning approach, particularly for municipal planners. Planners must be able to justify adaptation strategies within the context of the municipal budget. A cost analysis comparing the costs of inventoried adaptation strategies to the costs of projected damages without adaptation, supported by local knowledge of possible funding sources, is vital to creating a fact-based platform for a context-appropriate phased implementation strategy.

5.1.5 Outside Opportunities

Planners should look for technical assistance from their regional planning agencies, state and federal governments, NGOs, and universities to have climate science or risk assessment studies done. Alternatively, there may be funding opportunities, especially from state and federal governments, that would support hiring consultants from the private sector. Many planners interviewed in the research on adaptation barriers expressed a desire for detailed mapping of projected future flooding; technical assistance from outside the community is likely to be the best way to accomplish this.

5.1.6 Robust Public and Government Education Campaign

Planners should seek to have detailed local climate projections and their impacts on the community developed into clear, informative data visualization tools. These tools will support a robust education campaign for the community members and for government officials, which will improve the local knowledge base and support adaptation decision-making. In order to administer this education campaign, planners must be well-versed and confident enough about climate data to answer questions about anticipated climate change, possible impacts on the community, and why adaptation planning should be a priority.

5.2 Recommendations for Regional Planning Agencies

It is recommended that regional planning agencies evaluate regional climate projections and make policy-relevant reports of expected climate change impacts in detail to municipal planners. As stated earlier, climate change does not respect municipal boundaries. Impacts are likely to be experienced on the geographic scale of watersheds or weather regions, by common factors such as coastlines or degree of urbanization, and by economic base characteristics such as tourism or agriculture. Regional planning agencies have the opportunity to advance adaptation on a regional scale by channeling and interpreting regional climate data, and using it to inform detailed policy recommendations.

The Pioneer Valley Planning Commission has done this effectively in its updated Climate Action and Energy Plan, funded by the U.S. HUD Sustainable Communities Initiative Regional Planning Grant Program; the plan does not fall victim to the common climate action plan trait of addressing mitigation alone. Locally specific climate change impacts are explained clearly and visual presentation of data is clear. Adaptation is explained in terms of vulnerability and resilience, recommended adaptation actions are organized by topics. Communities who are aware of their most prominent vulnerabilities can easily navigate to strategies that will help them improve their climate resilience. Furthermore, adaptation strategies recommended in the document are state-of-the-art, with tie-ins to the region's new Green Infrastructure Plan (PVPC, 2013).

Regional planning agencies are advised to develop similarly comprehensive climate-related plans that address regional adaptation through municipally-scaled policy recommendations. Next steps include technical assistance in building climate data visualization tools to help communities in their adaptation planning processes, and advisory support on developing risk-based adaptation informed by indicators.

5.3 Recommendations for Future Research

Communities attempting to implement a flexible adaptation process are inhibited by limited technical capacity in the development of triggering mechanisms based on risk assessment. Planning researchers' position between science and practice is ideal for improving the knowledge base on the "outcomes of the risk management approach and the potential of enhancement of existing design standards and policies" (Yohe and Leichenko, 2010, p. 37) for integration into adaptation planning practice.

There is some focus on operationalization of climate data and risk in current planning research and practice (e.g. Hamin, Abunassr, & Brabec, 2012; Yohe and Leichenko, 2010; Kwadijk, et al., 2010). Using indicators to connect climate science to adaptation strategies is likely to be the next step in breaking through the political stalemate regarding climate change. There is a growing need for studies that will explore the most effective methods of assessing the risk of climate exposure. Specifically, research that contributes to the development of a framework for analyzing costs of adaptation strategies compared to the advancing costs of climate-related damage without adaptation will be key in the advancement of flexible adaptation practices, as will research that elucidates the details of how the implementation of those adaptation strategies can be best timed along the timeline of climate change impacts.

APPENDIX A

INDICATOR INDEX

Appendix A: Index of indicators from various national and international climate indicator frameworks (NOAA-NCDC; EPA 2012; Global Climate Observing System (GCOS); CDC; EEA; Brooks et al., 2012). In US-based indicators, regional refers to sub-national regions such as the climate regions defined the NCADAC. In European indicators, regional means multinational regions, and sub-national indicators are referred to as divisional. Biogeographical regions refer to natural systems that may or may not cross European national borders. These word choices are meant to maintain spatial regularity between international indicator scales (continued onto next pages).

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
Indicator set: NOAA-NCDC					
Societal	Crop Moisture Stress Index (CMSI)	Drought index (Palmer Z); annual average crop productivity per U.S. climate division			national
	Residential Energy Demand Temperature Index (REDTI)	Population weighted heating and cooling degree days		Diaz and Quayle, 1980	national
	Air stagnation index	Gridded mean sea level pressure; 500mb wind components; surface and 850mb temperature data	NCEP/NCAR reanalysis/CDAS system	Kalnay et al., 1996; Wang and Angell, 1999	national
	Convective Sigmets (CSIG)	Frequency of CSIGs per month	NOAA's Aviation Weather Center	Slemmer and Silberberg, 2004	national
	U.S. wind climatology	Temporally and spatially continuous wind dataset per month	NCEP reanalysis wind data	Kalnay et al., 1996	national
	Apparent temperature	Apparent temperature (AT) outdoors in shade, exposed to wind	NCDC's Integrated Surface Data	Steadman, 1971, 1979, 1984	national
	Northeast index to potential ozone exposure	Annual exceedance-days (ozone concentration over 80 ppbv 8-hour mean) regressed against summer mean temperature	NERCC		regional

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	West Nile Virus mosquito crossover dates	Climate models that predict what day each year the northern house mosquito becomes the dominant species over the white-spotted mosquito	Experimental data for Champaign-Urbana, Illinois	Kunkel et al., 2006	regional & national
Extremes	North American Climate Extremes Monitoring (NACEM)	Analysis of daily maximum temperatures and daily minimum temperatures	Global Historical Climatology Network-Daily (GHCN-D)		multinational
	U.S. Records	Daily maximum and minimum temperatures; precipitation; snow	NOAA-NCDC		national
	U.S. Climate Extremes Index (CEI)	Monthly maximum and minimum temperature; daily precipitation; monthly Palmer Drought Severity Index (PDSI); landfalling tropical storm and hurricane wind velocity	GHCN-D; NCDC; National Hurricane Center's North Atlantic Hurricane Database (HURDAT)		national
	National Climate Extremes Committee (NCEC)	Daily maximum and minimum temperatures; snowfall; rain (and lack of rain); wind gust; hail; air pressure	National Weather Service; NCDC		national
	State Climate Extremes Committee (SCEC)	Daily maximum and minimum temperatures; 24-hour precipitation; snow depth; monthly snowfall; additional elements tracked by individual states as needed	NCDC		state
	Extreme climates in the U.S.	Hottest, coldest, driest, wettest, windiest, snowiest, sunniest, cloudiest, most humid, least humid, most frequent rain and snow, and least frequent rain and snow climates in continuous 48 states by 30-year averages (last updated 2008)	NCDC		regional & national

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	Mapped global temperature and precipitation means and anomalies, spring and winter	Land-only mean temp anomalies, land & ocean temperature anomalies; land & ocean temperature percentiles, land & ocean temperature Z-score, land-only precipitation percentiles, land-only precipitation anomalies, land-only precipitation percent of normal	GHCN-M; MLOST		regional & global
	Daily temperature	Temperature departure and degree day maps	U.S. ASOS Network		regional
	Weekly mean temperature data	Temperatures measured and averaged, per division	NOAA's Climate Prediction Center		regional
	Month-to-date temperature anomaly	Temperature anomalies measured and averaged, per division	NOAA's Climate Prediction Center		regional
	National, Regional, Statewide, and Divisional Temperature Ranks	Temperature measurements as departure from normal, ranked against 119 year history	NOAA's Climate Prediction Center		national - divisional
	Heat stress	Temperatures exceeding 85th percentile thresholds, humidity derived from sea level pressure	TD3280 dataset	Steadman, 1984; Gaffen and Ross, 1998, 1999	regional
	Percentage area of contiguous US with top and bottom 10% of historical temperature and precipitation	Percentage areas (Very warm/cold, very wet/dry)	NCDC		
	Total weekly precipitation	Precipitation measured, per division	NOAA's Climate Prediction Center		regional
	Weekly precipitation anomaly	Precipitation anomalies measured and totaled, per division	NOAA's Climate Prediction Center		regional
	National, Regional, Statewide, and Divisional Precipitation Ranks	Precipitation measurements as departure from normal, ranked against 119 year history	NOAA's Climate Prediction Center		national - divisional
	Various drought products using same data	Palmer Drought Severity Index (PDSI); primary precipitation and hydrological data	http://www.ncdc.noaa.gov/temp-and-precip/drought/drought-tools.php		regional & state

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
Snow and ice	Snowfall; snow depth	U.S. daily snowfall and snow depth data	NWS		national
Teleconnections	Arctic Oscillation (AO)	Projection of AO loading pattern to daily anomaly 1000 millibar height field over 20°N-90°N latitude	NWS Climate Prediction Center		global
	El Niño/Southern Oscillation (ENSO)	Zonal winds; sea level anomalies; sea surface temperatures; outgoing longwave radiation; Southern Oscillation Index	NWS Climate Prediction Center		global
	North Atlantic Oscillation (NAO)	Projection of NAO loading pattern to daily anomaly 500 millibar height field over 0-90°N latitude	NWS Climate Prediction Center		global
	Pacific Decadal Oscillation (PDO)	Regression of Extended Reconstructed Sea Surface Temperature (ERSST) anomalies against Mantua PDO index for overlap period	NOAA		global
	Pacific-North America Index (PNA)	Projection of PNA loading pattern to daily anomaly 500 millibar height field over 0-90°N latitude	NWS Climate Prediction Center		global
Indicator Set: EPA 2012 (More indicators can be found at http://www.epa.gov/roe/) (Source: EPA 2012)					
Greenhouse gases	U.S. greenhouse gas emissions	Emissions of carbon dioxide, methane, nitrous oxide, and several fluorinated gases; emissions and sinks by economic sector; emissions per capita and per dollar of GDP	EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010*		national
	Global greenhouse gas emissions	Global emissions of carbon dioxide, methane, nitrous oxide, and several fluorinated gases; emissions by sector; global carbon dioxide emissions by region	World Resources Institute's CAIT database		global

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	Atmospheric concentrations of greenhouse gases	Global atmospheric concentrations of carbon dioxide, methane, nitrous oxide, over approximately 700,000 years; global atmospheric concentrations of selected halogenated gases, 1978-2011	Carbon dioxide, methane, and nitrous oxide concentrations from various sources and peer-reviewed literature; selected halogenated gases concentrations from NOAA's AGAGE 2011, Arnold et al. 2012, Weiss et al. 2008		global
	Climate forcing	Radioactive forcing caused by greenhouse gases	NOAA		global
Weather and climate	U.S. and global temperature	Temperature measured by weather stations and satellite in contiguous 48 states and worldwide, 1901-2011	NOAA's NCDC		national & global
	High and low temperatures	U.S. Heat Wave Index annual values, 1895-2011; area of contiguous U.S. with usually hot summer temperatures (unusually defined by long-term average per location), 1910-2012; area of contiguous U.S. with usually cold winter temperatures (unusually defined by long-term average per location), 1911-2012; record high and low temperatures in contiguous U.S. by decade	NOAA; NWS Cooperative Observer Network; U.S. Climate Extremes Index		national
	US and global precipitation	Precipitation anomalies over and under baseline average in contiguous U.S. and worldwide, 1901-2011; rate of precipitation change in U.S., 1901-2011	NOAA's NCDC		national & global

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	Heavy precipitation	Land area of contiguous U.S. with extreme one-day precipitation events, 1910-2011; land area of contiguous U.S. with unusually high annual precipitation per Standardized Precipitation Index, 1895-2011	NOAA's NCDC; U.S. Climate Extremes Index		national
	Drought	Annual Palmer Drought Severity Index values averaged over contiguous 48 states, 1895-2011; percent U.S. land area classified under drought conditions by severity categories, 2000-2011.	NOAA's NCDC; National Drought Mitigation Center		national
	Tropical cyclone activity	Annual count of hurricanes that formed in North Atlantic Ocean and that reached U.S., 1878-2011; Accumulated Cyclone Energy Index values, 1950-2011; annual values of Power Dissipation Index, 1949-2011	NOAA; NOAA's Climate Prediction Center		national
Oceans	Ocean heat	Ocean heat content, 1955-2011	NOAA and international organizations		global
	Sea surface temperature	Annual average of worldwide ocean surface temperature, 1880-2011	NOAA's NCDC		global
	Sea level	Global average absolute sea level change, 1880-2011; relative sea level change along U.S. coasts, 1960-2011	Australia's Commonwealth Scientific and Industrial Research Organization; NOAA		regional, national, global

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	Ocean acidity	Ocean carbon dioxide levels and pH; changes of aragonite saturation in ocean surface waters, 1880-2012	Bermuda Atantic Time-Series Study; European Station for Time-Series in the Ocean; Hawaii Ocean Time-Series; NOAA; Woods Hole Oceanographic Institution; Community Earth System Model data		global
Snow and ice	Arctic sea ice	Arctic sea ice extent measured by September monthly average, 1979-2012; distribution of Arctic sea ice extent by age of ice, 1983-2012	National Snow and Ice Data Center		global
	Glaciers	Average cumulative change in mass balance of "reference" glaciers, 1945-2010; cumulative mass balance of three U.S. "benchmark" glaciers, 1958-2010	World Glacier Monitoring Service; U.S. Geological Survey Benchmark Glacier Program		global
	Lake ice	Duration of ice cover, date of first freeze, and date of ice thaw for eight U.S. lakes, 1850-2010	Global Lake and River Ice Phenology Database maintained by National Snow and Ice Data Center		national
	Snowfall	Change in total snowfall in contiguous 48 states, 1930-2007; change in winter snow-to-precipitation ratio, 1949-2011	NOAA; U.S. Historical Climatology Network	Kunkel et al., 2009	national

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	Snow cover	Annual average area covered by snow in North America, 1972-2011; snow-covered area in North America by season, 1972-2011	Rutgers University Global Snow Lab from NOAA National Environmental Satellite, Data and Information Service measurements		national
	Snowpack	Trends in April snowpack in Western U.S. and southwest Canada by snow water equivalent	U.S. Department of Agriculture's Natural Resources Conservation Service Water and Climate Center	Mote et al., 2005	regional & national
Society and ecosystems	Streamflow	Volume of seven-day low and three-day high streamflows in U.S., 1940-2009; timing of water-spring runoff in U.S., 1940-2009	USGS		national
	Ragweed pollen season	Change in length of ragweed pollen season at 10 locations in central U.S. and Canada	National Allergy Bureau		regional & national
	Length of growing season	Annual deviation from long-term averaged growing season in contiguous U.S. and comparison of western and eastern U.S., 1895-2011; timing of last spring frost and first fall frost in contiguous U.S., 2895-2011	NOAA's NCDC	Kunkel, 2012	national
	Leaf and bloom dates	Lilac and honeysuckle first leaf dates and first bloom dates in contiguous U.S., 1900-2010	USA National Phenology Network; U.S. Historical Climatology Network	McCabe et al., 2011	national
	Bird wintering ranges	Change in latitude of bird center of abundance, 1966-2005; change in bird center of abundance's distance from coast, 1966-2005	National Audobon Society; Bird Studies Canada		national

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	Heat-related deaths	Deaths classified as "heat-related" in U.S.; 1979-2009	CDC		national
Indicator set: Essential Climate Variables (ESVs) by Global Climate Observing System (GCOS) (Source: All data from Global Observing Systems Information Center: http://gosic.org/ios/MATRICES/ECV/ECV-matrix.htm)					
Atmospheric surface	Air temperature				global
	Wind speed and direction				global
	Water vapor				global
	Air pressure		GCOS Surface Network		global
	Precipitation				global
	Surface radiation budget				global
Atmospheric composition	Carbon dioxide				global
	Methane and other long-lived greenhouse gases (nitrous oxide, chlorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons, sulphur hexafluorides, perfluorocarbons)				global
	Precursors (supporting the Aerosols and Ozone ECVs)				global
	Ozone				global
	Aerosols properties	AERONET data (NASA)	Global Climate Observing System (GCOS		global
		Aerosol products			global
Ocean subsurface	Temperature				global
	Salinity				global
	Current				global
	Nutrients				global
	Carbon				global
	Ocean acidity				global
	Oxygen				global
	Tracers				global
[illegible]	Temperature				global

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	Wind speed and direction				global
	Water vapor				global
	Cloud properties				global
	Earth radiation budget				global
Ocean surface	Sea-surface temperature				global
	Sea-surface salinity				global
	Sea level				global
	Sea state				global
	Sea ice				global
	Surface current				global
	Ocean color				global
	Carbon dioxide partial pressure				global
	Ocean acidity				global
	Phytoplankton				global
Terrestrial	River discharge				global
	Water use				global
	Land cover				global
	Snow cover				global
	Ground water				global
	Glaciers and ice caps				global
	Lakes				global
	Ice sheets				global
	Permafrost				global
	Albedo				global
	Leaf area index				global
	Above-ground biomass		FAO's Forest Resource assessment Project (FRA); FLUXNET		global
	Fraction of absorbed photosynthetically active radiation				global
	Soil carbon				global
	Fire disturbance				global
	Soil moisture				global

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
CDC National Environmental Public Health Tracking Climate Change Indicators					
Health	Extreme heat days and events	Counts and dates of extreme heat days and events, 2000-present	NASA; North American Land Data Assimilation System	Burrows, 1990; NYCDOHMH, 2006; Anderson and Bell, 2011	regional & national
	Heat vulnerability	Percentage of adults with diagnosed diabetes, 2008; heart disease hospitalization rates among Medicare beneficiaries, 2000-2006; percent of population below poverty line; percent population non-white; percent population aged 65+ living alone; percent population aged 5+ with disability; population density; percent forest canopy; percent developed land use; percent cultivated crop land use	U.S. Census Bureau, 2000; CDC; National Diabetes Surveillance System; USGS	Luber and McGeehin, 2008; CDC, 2006; Reid et al., 2009; Dolney and Sheridan, 2006; Mastrangelo et al., 2007; Diez Roux, 2004; Martinez et al, 1989; Smoyer, 1998; Khosla and Guntapalli, 1999; Klinenberg, 2002	regional
	Heat-related mortality	Number of heat-related deaths, 2000-present	CDC	Chestnut et al., 1998; Curriero et al., 2002; Medina-Ramón et al., 2006; Semenza et al., 1996; Mastrangelo et al., 2007; CSTE, 2009	state & national
	Temperature distribution	Daily estimates of maximum temperature and heat index for summer months, 2000-present	NASA; North American Land Data Assimilation System		
EEA Core Set of Indicators (integrated information from 2004-2013)					
Air pollution and ozone depletion	Emissions of acidifying substances	National emission ceilings inventory (from 2005)	Environment DG		national & regional
		Trends in emissions of acidifying pollutants (CLRTAP/EMEP)	Convention on Long-range Transboundary Air Pollution (CLRTAP/EMEP)		national & regional

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	Emissions of ozone precursors	Trends in emissions of ozone precursors (CLRTAP/EMEP)	Convention on Long-range Transboundary Air Pollution (CLRTAP/EMEP)		national & regional
		Trends in emissions of acidifying pollutants (CLRTAP/EMEP)	Convention on Long-range Transboundary Air Pollution (CLRTAP/EMEP)		national & regional
		Trends in emissions of greenhouse gases (EEA sector classification and IPCC sector classification)	United Nations Framework Convention on Climate Change (UNFCC); Environment DG		national & regional
		National emission ceilings inventory (from 2005)	Environment DG		national & regional
	Emissions of primary particulates and secondary particulate precursors	Trends in emissions of acidifying pollutants (CLRTAP/EMEP)	Convention on Long-range Transboundary Air Pollution (CLRTAP/EMEP)		national & regional
		Trends in emissions of particulates	Convention on Long-range Transboundary Air Pollution (CLRTAP/EMEP)		national & regional
		RAINS Model CAFÉ baseline PM_{10} emissions estimates	IIASA		national & regional
		National emission ceilings inventory (from 2005)	Environment DG		national & regional
	Exceedance of air quality limit values in urban areas	Settlements pan-Europe (STEU)	Eurostat		regional
		Airbase	Environment DG		national & regional
		Questionnaire for annual reporting on ambient air quality assessment	Environment DG		national & regional

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	Exposure of ecosystems to acidification, eutrophication and ozone	Airbase ozone measurements EMEP Chemical Coordinating Centre (CCC) ozone measurements EMEP Coordination Centre for Effects (CCE) critical thresholds and their exceedances European land use database (to be replaced from 2004 by Corine Land Cover)	EMEP Chemical Coordinating Centre (CCC)		national & regional
	Production and consumption of ozone depleting substances (2004 title: Consumption of ozone-depleting substances)	Production of ozone depleting substances	UNEP (United Nations Environment Programme) Ozone Secretariat		national & regional
		Ozone-depleting substances - statistical fact sheet	Environment DG		national & regional
Biodiversity	Species of European interest (2004 title: Threatened and protected species)	IUCN Red List of Threatened Species	IUCN - World Conservation Union		national & biogeographical region
		Annexes of the EC 79/709 and 92/43 Directives	Environment DG		national & biogeographical region
		Annexes of Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention, 1979)	Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention)		national & biogeographical region
	Designated areas	Nationally designated areas (CDDA)	EEA		national & biogeographical region
		Common database on designated areas (CDDA International)	UNEP/WCMC (World Conservation Monitoring Centre)		national & biogeographical region
		Conclusions of the Natura 2000 bio-geographic seminars	Environment DG		national & biogeographical region

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
		Natura 2000 database	Environment DG		national & biogeographical region
	Species diversity	Trends of bears	Large Carnivore Initiative Council of Europe/WWF		national & biogeographical region
		Trends of wolves	Large Carnivore Initiative Council of Europe/WWF		national & biogeographical region
		Trends of farmland birds	European Bird Census Council, BirdLife International; Royal Society for the Protection of Birds		national & biogeographical region
		Trends of woodland, park and garden birds	European Bird Census Council, BirdLife International; Royal Society for the Protection of Birds		national & biogeographical region
		Trends of butterflies	The Dutch Butterfly Conservation		national & biogeographical region
Climate change	Greenhouse gas emission trends (2004 title: Greenhouse gas emissions and removals)	Trends in emissions of greenhouse gases (EEA sector classification and IPCC sector classification)	United Nations Framework Convention on Climate Change (UNFCC); Environment DG		national & regional
	Progress to greenhouse gas emission targets (2004 title: Projections of greenhouse gas emissions and removals and policies and measures)	National communications	UNFCC		national
		National projections, policies and measures	Environment DG		national
	Global and European temperature	Global average monthly and annual temperature	Climatic Research Unit (CRU) University of East Anglia, UK		regional

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
		European average annual and monthly temperature, Based on CruTempV2 (CRU, KNMI)	KNMI (Netherlands Meteorological Institute)		regional
		Trends in annual, summer and winter temperature station data in Europe	KNMI (Netherlands Meteorological Institute)		divisional
		Trends in the frequency of summer days (>25°C) and cold, and heat wave occurrence, based on station data in Europe	KNMI (Netherlands Meteorological Institute)		divisional
	Atmospheric greenhouse gas concentrations	CO_2 concentrations	SIO (Scripps Institution of Oceanography)		national & regional
		CH_4 and N_20 concentrations	Atmospheric lifetime experiment (ALE), the global atmospheric gases experiment (GAGE), and the present advanced GAGE (AGAGE)		national & regional
		HFC-134a and SF6 concentrations	NOAA/CMDL/HATS (National Oceanic and Atmospheric Administration/ Climate Monitoring and Diagnostics Laboratory)		national & regional
Terrestrial	Land take	Land use by main category	Eurostat		divisional & national
		CLC2000, CLC change database	EEA		divisional & national
	Progress in management of contaminated sites	Soil contamination	EEA		divisional & national
Waste	Municipal waste generation	Population: total, urban and rural	World Bank		divisional & national
		Wastebase - Municipal waste	Eurostat; OECD		divisional & national
	Generation and recycling of packaging	Packaging waste generation and treatment in EU	Environment DG		divisional & national

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	waste	Gross domestic product at market prices (Eurostat)	Eurostat		divisional & national
		Population: total, urban and rural	World Bank		divisional & national
Water	Use of freshwater resources	Annual water abstraction by source and by sector	Eurostat		divisional & national
		Irrigated area	Food and Agriculture Organisation (FAO)		divisional & national
		Population: total, urban and rural	World Bank		divisional & national
	Oxygen-consuming substances in rivers	Waterbase - Rivers	EEA		divisional & national
	Nutrients in freshwater	Waterbase - Groundwater	EEA		divisional & national
		Waterbase - Lakes	EEA		divisional & national
		Waterbase - Rivers	EEA		divisional & national
	Nutrients in transitional, coastal and marine waters	Waterbase - Transitional, coastal and marine waters	EEA; ICES (International Council for the Exploration of the Seas); Black Sea Environmental Programme (OceanBase Version 2.02 TU-BS)		divisional & national
		Euromaps in CD-ROM. Digital Map Data, Version 1.0	Bartholomew Digital Data. Harper Collins Publishers, London, UK		divisional & national
	Bathing water quality	Compliance to the bathing water quality directive 76/160/EEC: coastal and fresh water zones	Environment DG		divisional & national
	Chlorophyll in transitional, coastal and marine waters	Waterbase - Transitional, coastal and marine waters	EEA; ICES (International Council for the Exploration of the Seas); Black Sea Environmental Programme (OceanBase Version 2.02		divisional & national

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
			TU-BS)		
		Euromaps in CD-ROM. Digital Map Data, Version 1.0	Bartholomew Digital Data. Harper Collins Publishers, London, UK		divisional & national
	Urban wastewater treatment	National population connected to wastewater treatment plants	Eurostat		divisional & national
		National programmes for urban wastewater treatment	Environment DG		divisional & national
Agriculture	Gross nutrient balance	Nitrogen balances	Eurostat		divisional & national
	Area under organic farming	Certified and policy-supported organic and in-conversion and area	Organic Centre Wales		divisional & national
		Land use, utilised agricultural area (UAA)	Eurostat		divisional & national
Energy	Final energy consumption by sector (2004 title: Final energy consumption)	Supply, transformation, consumption - all products - annual data	Eurostat; International Energy Agency (IEA)		divisional & national
	Total primary energy intensity (2004 title: Total energy intensity)	Energy intensity of the economy	Eurostat		divisional & national
		Gross inland consumption of energy (Supply, transformation, consumption - all products - annual data)	Eurostat		divisional & national
		Gross domestic product at (1995) market prices	Eurostat		divisional & national
	Primary energy consumption by fuel (2004 title: Total energy consumption)	Supply, transformation, consumption - all products - annual data	Eurostat; International Energy Agency (IEA)		divisional & national
		Supply, transformation, consumption - solid fuels - annual data	Eurostat; International Energy Agency (IEA)		divisional & national

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
		Supply, transformation, consumption - oil - annual data	Eurostat; International Energy Agency (IEA)		divisional & national
		Supply, transformation, consumption - gas - annual data	Eurostat; International Energy Agency (IEA)		divisional & national
		Supply, transformation - nuclear energy - annual data	Eurostat; International Energy Agency (IEA)		divisional & national
		Supply, transformation, consumption - renewables and wastes (total, solar heat, biomass, geothermal, wastes) - annual data	Eurostat; International Energy Agency (IEA)		divisional & national
	Renewable primary energy consumption (2004 title: Renewable energy consumption)	Supply, transformation, consumption - all products - annual data	Eurostat; International Energy Agency (IEA)		divisional & national
		Supply, transformation, consumption - renewables and wastes (total, solar heat, biomass, geothermal, wastes) - annual data	Eurostat; International Energy Agency (IEA)		divisional & national
		Supply, transformation, consumption - renewables (hydro, wind, photovoltaic) - annual data	Eurostat; International Energy Agency (IEA)		divisional & national
		Supply, transformation, consumption - renewables (biofuels) - annual data	Eurostat; International Energy Agency (IEA)		divisional & national
	Renewable electricity consumption (2004 title: Renewable electricity)	Share of renewable energy (including indicative targets)	EnvironmentDG; Eurostat; International Energy Agency (IEA)		divisional & national
		Primary production of hydro power (Supply, transformation, consumption - renewables (hydro, wind, voltaic) - annual data)	Eurostat; International Energy Agency (IEA)		divisional & national
		Primary production of wind energy (Supply, transformation, consumption - renewables (hydro, wind, voltaic) - annual data)	Eurostat; International Energy Agency (IEA)		divisional & national

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
		Primary production of photovoltaic power (Supply, transformation, consumption - renewables (hydro, wind, voltaic) - annual data)	Eurostat; International Energy Agency (IEA)		divisional & national
		Gross electricity generation - Geothermal power plants (Supply, transformation, consumption - electricity - annual data)	Eurostat; International Energy Agency (IEA)		divisional & national
		Gross electricity generation - Biomass-fired power stations (Supply, transformation, consumption - electricity - annual data)	Eurostat; International Energy Agency (IEA)		divisional & national
		Total gross electricity generation (Supply, transformation, consumption - electricity - annual data)	Eurostat; International Energy Agency (IEA)		divisional & national
		Gross inland consumption of electricity (Supply, transformation, consumption - all products - annual data)	Eurostat; International Energy Agency (IEA)		divisional & national
Fisheries	Status of marine fish stocks	ICES Advisory Committee on Fishery Management (ACFM) Reports	ICES (International Council for the Exploration of the Seas)		national & biogeographical region
		General Fisheries Commission for the Mediterranean (GFCM) Sub-Committee on Stock Assessment (SCSA) reports	Food and Agriculture Organisation (FAO)		national & biogeographical region
		International Commission for the Conservation of Atlantic Tuna (ICCAT) Standing Committee on Research and Statistics (SRCS) reports	International Commission for the Conservation of Atlantic Tuna (ICCAT)		national & biogeographical region
		ICES Fishing areas	ICES		national & biogeographical region
		GFCM management units	Food and Agriculture Organisation (FAO)		national & biogeographical region

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	Aquaculture production	Aquaculture production: quantities 1950-	Food and Agriculture Organisation (FAO)		national & biogeographical region
		Aquaculture production - Quantities (tonnes live weight)	Eurostat		national & biogeographical region
		Gross aquaculture production	OSPAR		national & biogeographical region
		Total nutrient loads	Helcom		national & biogeographical region
		Fishing areas			national & biogeographical region
		Length of coastline			national & biogeographical region
	Fishing fleet capacity	Fishing fleet	Eurostat		national & biogeographical region
		FAO Bulletin of Fishery Statistics	Food and Agriculture Organisation (FAO)		national & biogeographical region
		Fishing fleet (no formal title)	Fisheries DG		national & biogeographical region
Transport	Passenger transport demand	Volume of passenger transport relative to GDP	Eurostat		national
		Modal split of passenger transport	Eurostat		national
		Passenger-kilometre	International Civil Aviation Organisation (ICAO)		national
		Final energy consumption of the air transport sector	Eurostat		national
	Freight transport demand	Volume of freight transport relative to GDP	Eurostat		national
		Modal split of freight transport	Eurostat		national
	Use of cleaner and alternative fuels	Supply, transformation, consumption - gas - annual data	Eurostat		national
		Supply, transformation, consumption - oil - annual data	Eurostat		national

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
		Supply, transformation, consumption - renewables (biofuels) - annual data	Eurostat		national
		EU fuels sales by fuel type	Environment DG		national
Brooks et al., 2005: Potential proxies for national-level vulnerability to climate change					
Economy	National wealth	GDP per capita; GNI	World Bank (WB)	See Brooks et al., 2005 for methodology (http://climateknowledge.org/figures/Rood_Climate_Change_AOSS480_Documents/Brooks_Vulnerability_Adaptation_GlobEnvirChange_2005.pdf)	national
	Inequality	GINI coefficient	World Income Inequality Database (WIID)		national
	Economic Autonomy	Debt repayments (% GNI, averaged over decadal periods)	WB		national
Health and nutrition	State support for health	Health expenditure per capita; public health expenditure	Human Development Index (HDI)		national
	Burden of ill health	Disability adjusted life expectancy	World Health Organization (WHO)		national
	General health	Life expectancy at birth	HDI		national
	Healthcare availability	Maternal mortality per 100,000	HDI		national
	Removal of economically active population	AIDS/HIV infection (% of adults)	HDI		national
	Nutritional status	Calorie intake per capita	UNEP/GRID-Geneva (GRID)		national
	General food availability	Food production index (annual change averaged over 1981-90 and 1991-99)	WB		national
	Access to nutrition	Food price index (annual change averaged over 1981-90 and 1991-99)	WB		national
Education	Educational commitment	Educational expenditure as % of GNP and government expenditure	HDI		national
	Entitlement to information	Literacy rates and gender-based literacy ratio	HDI		national
Infrastructure	Isolation of rural communities	Roads (km, scaled by land area with 99% of population)	WB; Center for International Earth Sciences Information Network (CIESIN)		national

Category	Indicator	Proxy	Data Source	Method Justification (if provided in source material)	Scale
	Commitment to rural communities	Rural population without access to safe water (%)	HDI		national
	Quality of basic infrastructure	Population with access to sanitation (%)	HDI		national
Governance	Conflict	Internal refugees (1000s) scale by proportion	WB		national
	Effectiveness of policies	Control of corruption	Kaufmann, Kray and Zoido-Lobaton governance data set (KKZ)		national
	Ability to deliver services	Government effectiveness	KKZ		national
	Willingness to invest in adaptation	Political stability; rule of law	KKZ		national
	Barriers to adaptation	Regulatory quality	KKZ		national
	Participatory decision making	Voice and accountability	KKZ		national
	Influence on political process	Civil liberties; political rights	FH		national
Geography	Coastal risk	km of coastline (scale by land area); population within 100km of coastline (%)	GRID		national
	Resource pressure	Population density	CIESIN		national
Agriculture	Dependence on agriculture	Agricultural employees (% of total, male, female populations); rural population (% of total)	WB		national
	Agricultural self-sufficiency	Agricultural production index (1985,1995)	WB		national
Ecology	Environmental stress	Protected land area (%); forest change rate (% per year); % forest cover; unpopulated land area	GRID; CIESIN		national
	Sustainability of water resources	Groundwater recharge per capita; water resources per capita	GRID		national
Technology	Commitment to and resources for research	R&D investment (% GNP)	WB		national
	Capacity to undertake research and understand issues	Scientists and engineers in R&D per million population	WB		national

APPENDIX B

ADDITIONAL FIGURES AND TABLES

Table B-1: Descriptions of SRES scenarios storylines (IPCC, 2000, Special Report on Emissions Scenarios, Box TS-1).

SRES Storyline	Description
A1	The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).
A2	The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.
B1	The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.
B2	The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Table B-2: Main characteristics of RCPs (Van Vuuren et al., 2011).

Scenario Component	RCP2.6	RCP4.5	RCP6	RCP8.5
Greenhouse gas emissions	Very low	Medium-low mitigation Very low baseline	Medium baseline; high mitigation	High baseline
Agricultural area	Medium for cropland and pasture	Very low for both cropland and pasture	Medium for cropland but very low for pasture (total low)	Medium for both cropland and pasture
Air pollution	Medium-Low	Medium	Medium	Medium-high

Table B-3: Comparing RCPs with SRES scenarios (Rogelj et al., 2012).

Table 3 | Main similarities and differences between temperature projections for SRES scenarios and RCPs.

RCP	SRES scenario with similar median temperature increase by 2100	Particular differences
RCP3-PD	None	The ratio between temperature increase and net radiative forcing in 2100 is 0.88 °C $(W\ m^{-2})^{-1}$ for RCP3-PD, whereas all other scenarios show a ratio of about 0.62 °C $(W\ m^{-2})^{-1}$; that is, RCP3-PD is closer to equilibrium in 2100 than the other scenarios.
RCP4.5	SRES B1	Median temperatures in RCP4.5 rise faster than in SRES B1 until mid-century, and slower afterwards.
RCP6	SRES B2	Median temperatures in RCP6 rise faster than in SRES B2 during the three decades between 2060 and 2090, and slower during other periods of the twenty-first century.
RCP8.5	SRES A1FI	Median temperatures in RCP8.5 rise slower than in SRES A1FI during the period between 2035 and 2080, and faster during other periods of the twenty-first century.

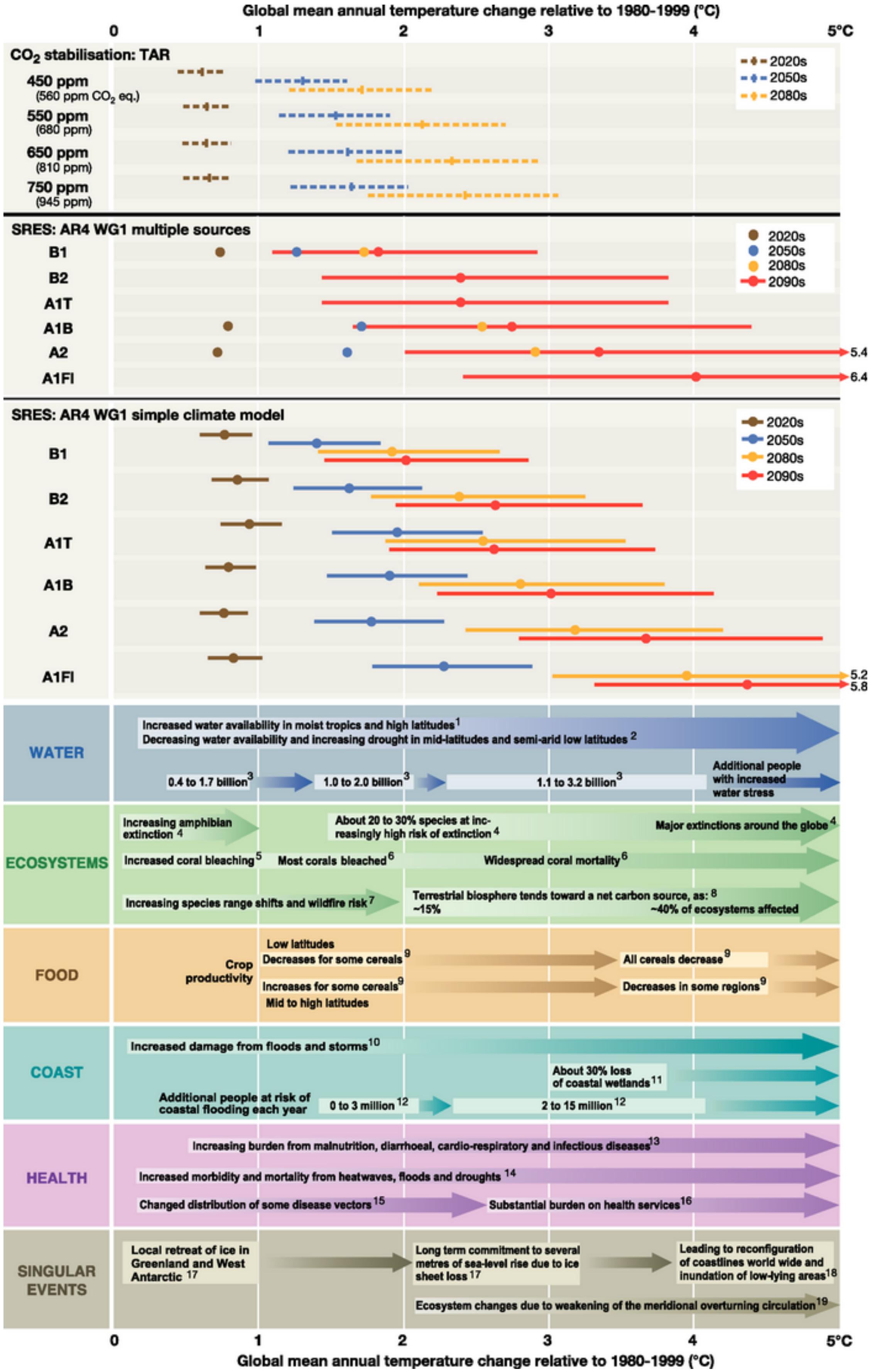

Figure B-1: Magnitudes of impact from varying amounts of climate change, with examples of global impacts (IPCC 2007, WGII, TS.4.3)

Table B-4: UN Commission on Sustainable Development indicators (United Nations, 2007). Numbers in parentheses relate to relevant chapters in Agenda 21 (continued onto next page).

SOCIAL		
Theme	**Sub-theme**	**Indicator**
Equity	Poverty (3)	Percent of Population Living below Poverty Line
		Gini Index of Income Inequality
		Unemployment Rate
	Gender Equality (24)	Ratio of Average Female Wage to Male Wage
Health (6)	Nutritional Status	Nutritional Status of Children
	Mortality	Mortality Rate Under 5 Years Old
		Life Expectancy at Birth
	Sanitation	Percent of Population with Adequate Sewage Disposal Facilities
	Drinking Water	Population with Access to Safe Drinking Water
	Healthcare Delivery	Percent of Population with Access to Primary Health Care Facilities
		Immunization Against Infectious Childhood Diseases
		Contraceptive Prevalence Rate
Education (36)	Education Level	Children Reaching Grade 5 of Primary Education
		Adult Secondary Education Achievement Level
	Literacy	Adult Literacy Rate
Housing (7)	Living Conditions	Floor Area per Person
Security	Crime (36, 24)	Number of Recorded Crimes per 100,000 Population
Population (5)	Population Change	Population Growth Rate
		Population of Urban Formal and Informal Settlements

ENVIRONMENTAL		
Theme	**Sub-theme**	**Indicator**
Atmosphere (9)	Climate Change	Emissions of Greenhouse Gases
	Ozone Layer Depletion	Consumption of Ozone Depleting Substances
	Air Quality	Ambient Concentration of Air Pollutants in Urban Areas
Land (10)	Agriculture (14)	Arable and Permanent Crop Land Area
		Use of Fertilizers
		Use of Agricultural Pesticides
	Forests (11)	Forest Area as a Percent of Land Area
		Wood Harvesting Intensity
	Desertification (12)	Land Affected by Desertification
	Urbanization (7)	Area of Urban Formal and Informal Settlements
Oceans, Seas and Coasts (17)	Coastal Zone	Algae Concentration in Coastal Waters
		Percent of Total Population Living in Coastal Areas
	Fisheries	Annual Catch by Major Species
Fresh Water (18)	Water Quantity	Annual Withdrawal of Ground and Surface Water as a Percent of Total Available Water
	Water Quality	BOD in Water Bodies
		Concentration of Faecal Coliform in Freshwater
Biodiversity (15)	Ecosystem	Area of Selected Key Ecosystems
		Protected Area as a % of Total Area
	Species	Abundance of Selected Key Species

ECONOMIC		
Theme	**Sub-theme**	**Indicator**
Economic Structure (2)	Economic Performance	GDP per Capita
		Investment Share in GDP
	Trade	Balance of Trade in Goods and Services
	Financial Status (33)	Debt to GNP Ratio
		Total ODA Given or Received as a Percent of GNP
Consumption and Production Patterns (4)	Material Consumption	Intensity of Material Use
	Energy Use	Annual Energy Consumption per Capita
		Share of Consumption of Renewable Energy Resources
		Intensity of Energy Use
	Waste Generation and Management (19-22)	Generation of Industrial and Municipal Solid Waste
		Generation of Hazardous Waste
		Generation of Radioactive Waste
		Waste Recycling and Reuse
	Transportation	Distance Traveled per Capita by Mode of Transport
INSTITUTIONAL		
Theme	**Sub-theme**	**Indicator**
Institutional Framework (38, 39)	Strategic Implementation of SD (8)	National Sustainable Development Strategy
	International Cooperation	Implementation of Ratified Global Agreements
Institutional Capacity (37)	Information Access (40)	Number of Internet Subscribers per 1000 Inhabitants
	Communication Infrastructure (40)	Main Telephone Lines per 1000 Inhabitants
	Science and Technology (35)	Expenditure on Research and Development as a Percent of GDP
	Disaster Preparedness and Response	Economic and Human Loss Due to Natural Disasters

Table B-5: Physical climate change indicators selected for use in Flexible Adaptation Pathway by NPCC (Jacob et al., 2010).

	Climate hazard	Location	Time series	Timescale	Source[a]
Temperature	Mean temperature	Central Park	1876–present	Daily, monthly	NCDC
		Kennedy Airport	1948–present	Daily, monthly	NCDC
		LaGuardia Airport	1947–present	Daily, monthly	NCDC
	Days with temp > X°F	Central Park	1944–present	Monthly	NCDC
	Days with temp < X°F	La Guardia Airport	1948–present	Monthly	NCDC
	Number of consecutive days[b]	Central Park	1876–2001	Monthly, annual	NCDC
		Kennedy Airport	1949–present	Monthly	NCDC
		LaGuardia Airport	1949–2001	Monthly, annual	NCDC
			1948–2001	Monthly, annual	NCDC
	Global surface temperatures	Global value	1880–present	Annual	NCDC
	U.S. heat stress index	New York City	1948–present	Annual	NCDC
Precipitation	Total precipitation	Central Park	1876–present	Daily, monthly	NCDC
		Kennedy Airport	1949–present	Daily, monthly	NCDC
		LaGuardia Airport	1947–present	Daily, monthly	NCDC
	Drought	New York City region	1900–present	Monthly	NCDC
	Thunderstorms/lightning	New York County	1950–present	Daily	NCDC
	Snow	Central Park	1876–present	Daily, monthly	NCDC
		Kennedy Airport	1948–present	Daily, monthly	NCDC
		LaGuardia Airport	1947–present	Daily, monthly	NCDC
	Downpours (precipitation rate/ hour)	Kennedy Airport	1949–present	Hourly	NCDC
		La Guardia Airport	1948–present	Hourly	NCDC
	Days with rainfall > X in	Central Park	1944–present	Monthly	NCDC
	Number of consecutive days[b]	Central Park	1876–2001	Monthly, annual	NCDC
		Kennedy Airport	1949–present	Monthly	NCDC
			1949–2001	Monthly, annual	NCDC
		LaGuardia Airport	1948–present	Monthly	NCDC
			1948–2001	Monthly, annual	NCDC
Sea level rise and coastal storms	Sea level rise: mean water level	The Battery	1856–present	Monthly	NOS
		Sandy Hook, New Jersey	1932–present	Monthly	NOS
	Hourly height water level	The Battery	1958–present	Hourly	NOS
	Extreme winds	Sandy Hook, New Jersey	1910–present	Hourly	NOS
	Tropical cyclones	Central Park	1900–present	Daily	NCDC
		New York	1851–present	Annual	NCDC
Other	Greenhouse gas index	Global values	1979–present	Annual	ESRL

[a]Sources of data are the National Climatic Data Center (NCDC), National Ocean Service (NOS), and Earth System Research Laboratory (ESRL), all part of the National Oceanic and Atmospheric Administration (NOAA).
[b]Thresholds preset, requires further processing to customize.

Table B-6: Climate change impact indicators selected for use in Flexible Adaptation Pathway by NPCC (Jacob et al., 2010).

	Climate-related impact	Is it currently tracked?	By which agency?	How long is the series?
Temperature	Electrical outages (frequency/extent)	Yes	EDC	2000–present
	Emergency service calls (fire and ambulance)	Yes	FDNY	1998–present
	Transit service interruptions (electrical outage/rail buckling)	Yes	MTA	2004–present
	Cooling equipment purchases	Yes	IBO	NA
	Extreme heat- or cold-related illness/death	Yes	DOHMH	1999–present
	Unhealthy air quality days	Yes	DOHMH	1995–present
	Roadway pavement condition	Yes	DOT	2003–2007
	Swimming pool usage	Yes	DPR	2003–present
Precipitation	Reservoir capacity	Yes	DEP	2003–present
	Roadway traffic/accidents	Yes	DOT	1987–2007
	Combined sewer overflows	Yes	DEP	2004–present
	Water quality	Yes	DEP	1997–present
	Winter road maintenance	Yes	DSNY	1999–present
	Pumping equipment purchases	Yes	IBO	NA
	Parking suspensions	No		
	Sewer backup complaints	Yes	DEP	2004–present
	Transit service interruptions (flooding)	Yes	MTA	2004–present
Sea level rise and coastal storms	Brownfield cleanup acreage	Yes	MOER	No data
	Flight delays	Yes	PANYNJ	1996–present
	Beach erosion	No		
	Ferry service interruptions	Yes	DOT	2005–present
	Salt water intrusion	Yes	USGS	1988–present
	Water treatment plant operations	Yes	DEP	2006–present
	Emergency services preparedness	Yes	OEM	2004–present

[a]Sources include documents released by New York City, such as the Mayor's Management Report (MMR), City-wide Agency Performance Reports (CPRs), and PlaNYC/sustainability reports. Much of the raw data found in these reports is available online in a statistical database NYCStat, managed by the Mayor's Office of Operations. http://www.nyc.gov/html/ops/nycstat/html/home/home.shtml.

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