Association for Information Systems
AIS Electronic Library (AISeL)

PACIS 2018 Proceedings | Pacific Asia Conference on Information Systems (PACIS)

6-26-2018

Information Systems to Manage Local Climate Change Effects: A Unified Framework

Carlos A. Manzano
Universidad de Chile, Carlos.A.Manzano@outlook.com

Arkalgud Ramaprasad
University of Illinois at Chicago, prasad@uic.edu

Thant Syn
Texas A&M International University, thant3303@gmail.com

Information Systems to Manage Local Climate Change Effects: A Unified Framework

Completed Research Paper

Carlos A. Manzano
Universidad de Chile
Santiago, Chile
Carlos.A.Manzano@outlook.com

Arkalgud Ramaprasad
University of Illinois at Chicago
Chicago, Illinois, USA
prasad@uic.edu

Thant Syn
Texas A&M International University
Laredo, Texas, USA
thant.syn@tamiu.edu

Abstract

In many localities, local climate change effects are disasters-in-the-making or -in-waiting. They must therefore be managed coherently and consistently to assure the resilience of the local population and its communities. They are of deep concern at the local, state, federal, and international levels of government. Information systems play a critical role in managing local climate change effects. We draw upon many simple and selective frameworks in the literature, some explicitly articulated, and others implicitly incorporated, to present a unified framework for information systems to manage local climate change effects. The framework is both systemic in its coverage and systematic in its development. Its outlook is symmetrically neutral with respect to local climate change effects, recognizing that the change could be both beneficial and harmful to the local community. It is presented using structured natural English and can be easily understood, interpreted, and applied by the researchers, policy makers, and practitioners.

Keywords: Local climate change, framework, management, ontology, information system

Introduction

The concept of climate change refers to statistically significant variations in the average state of climate or its variability, observed over decades or longer, produced either by natural or anthropogenic actions (VijayaVenkataRaman et al. 2012). Despite some debate on the sources of these variations (Barnett et al. 1996), there is consensus that they can be attributed to human activities, and that global emissions of greenhouse gases such as carbon dioxide, methane, and nitrous oxide are the main contributors (Crowley 2000; IPCC 2014; Jones and Mann 2004; Mann et al. 1998). Changes of climate extremes are expected at a global scale during this century, and include the increase in heat wave episodes over land surfaces, heavy precipitation events and their global distribution, and changes in migration patterns and seasonal activities in some terrestrial, freshwater, and marine species (IPCC 2014; Midgley et al. 2002; Planton et al. 2008; Waluda et al. 2014). Alternatively, there are other expected changes that do not show a clear global trend. These include regional changes in drought duration and wind patterns that can affect local precipitation events (Planton et al. 2008). There is high confidence that these changes will influence local communities, assets, economies, and ecosystems, by increasing the risks related to heat stress, storms, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea level rise, and storm surges (IPCC 2014; VijayaVenkataRaman et al. 2012). The lack of essential infrastructure, services, or emergency response capabilities could further amplify local risks. This emerges a challenge for policy makers, considering that risks are already unevenly distributed, and are generally greater for disadvantaged people and developing countries.

Today, climate change effects are of deep concern to researchers, policy makers, politicians, and the population. It is the object of research, policy, and action at the global, hemispherical, national, and local levels. The antecedents and consequences of climate change effects at the different levels are interrelated but the issues and the method of addressing the issues at each level are different. According to the Intergovernmental Panel for Climate Change (IPCC), national governments play a key role in the adaptation, planning, and implementation of strategies to fight climate change effects through coordinated actions and providing frameworks and support (IPCC 2014). Therefore, we focus on local climate change effects (LCE) at the level of a city, state, province, or region within a country. These local units may be defined administratively, geographically, or a combination of the two. They are also characterized by the commonality of the issues they must address and the internal communication, coordination, and control necessary to address them.

LCE have progressively become relevant in the last decades and are an emerging subject of research, policy, and practice. On the one hand, new data, information, and knowledge about LCE are being generated through research and applied to the formulation of policies and to practice. For example, several efforts have recently focused on the effects of precipitation patterns over local hydrological systems, which can affect the quality and quantity of water resources (Tong and Chen 2002), local land use (Lin et al. 2012), hydropower generation (Hamududu and Killingtveit 2012), local health systems (Van Minh et al. 2014), and agriculture (Nguyen et al. 2013). On the other hand, more data, information, and knowledge need to be generated and applied to assure that research, policy, and practice are grounded in the locality and based on evidence from the locality. They must systematically and systemically draw upon understanding the similarities and differences between localities in different parts of the globe, to adapt and transfer the learning from the global to the local and vice versa. It has been shown that predictions related to climate change at the local level are more relevant and have less associated uncertainties than predictions at a global scale (Hawkins and Sutton 2009). Additionally, adaptation and mitigation strategies at a local (national) level are more effective when they reflect local visions and approaches to sustainable development in accordance with local circumstances and priorities (IPCC 2014). Such is the case of coastal multi-hazard assessment and management research, which are based on a common methodology designed for local, regional, and national hazard screening (Jayasinghe et al. 2015; Rosendahl Appelquist and Balstrøm 2014; Rosendahl Appelquist and Balstrøm 2015). However, in other cases (for example, when assessing biological impacts) the global pattern of change is far more important that any individual localized study (Parmesan and Yohe 2003).

In many localities LCE is a disaster-in-the-making or -in-waiting, and must therefore be managed coherently and consistently to assure the resilience of the local population and its communities. Although limiting LCE would require substantial and sustained reductions in greenhouse gas emissions, a timely adaptation and an adequate local risk assessment can help reducing their impact. Many of those most vulnerable to climate change have contributed, and contribute, little to the emissions of greenhouse gases. Therefore, effective decision-making to limit LCE and the consequent development of mitigation and response strategies need to rely on local evaluation of expected risks and potential benefits considering ethical dimensions, equity, value judgments, economic assessments, and diverse perceptions of risks and their uncertainties (IPCC 2014). Delaying the development and implementation of mitigation and response strategies will shift the burden from the present to the future generations, and is already eroding the basis for sustainable development. Although many adaptation and mitigation strategies are potentially helpful to address LCE, no single option is sufficient by itself. Their effective implementation depends on cooperation at all scales, and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives (IPCC 2014).

Traditionally, climate change research was based on a sequential process focused on a time-consuming step-by-step generation and delivery of information between separated scientific disciplines. The paradigm has changed in the last decade, favoring a more coordinated and simultaneous process based on local climate observations to evaluate local adaptation needs and strategies (Moss et al. 2010). In this context, we present a unified framework for information systems (IS) to manage LCE (ISMLCE). We emphasize the indefinite article ‘a’ instead of the definite article ‘the’ in characterizing the framework. In doing so, we recognize the possibility of other equally plausible frameworks developed from other perspectives. It draws upon many simple and selective frameworks in the literature, some explicitly articulated and others implicitly incorporated. The unified framework is both systemic in its coverage and systematic in its development. Its outlook is symmetrically neutral with respect to LCE, recognizing that the change could be both beneficial and harmful to the local community. It is presented using structured natural English and can be easily understood, interpreted, and applied by the researchers, policy makers, and practitioners. In the following we describe the framework, discuss its application, and conclude with a roadmap for future research on the topic.

Unified Framework

ISMLCE is a complex domain. The challenge in deploying IS to manage LCE is to construct a framework which is a logical, parsimonious, and a complete description of ISMLCE. It must be logical in the deconstruction of the domain, and parsimonious yet complete in the representation of the domain. It must be a closed description of ISMLCE in its entirety yet adaptable to evolution of the domain. We represent the combinatorial complexity of ISMLCE using an ontology.

Information Systems						**Manage**				**Local Climate Change**	
Structure		**Function**		**Semiotics**		**Stakeholders**		**Resilience**			
Infrastructure	**[to]**	Acquire	**[+]**	Data	**[by/for]**	Agencies	**[for local]**	Resistance	**[to/of/from]**	Storms	**[effects]**
Organization		Measure		Information		International		Response		Flooding	
System		Other		Knowledge		Federal		Recovery		Pollution	
Policy		Store				State		Restoration		Heat/Cold	
Procedure		Retrieve				Local		Renascence		Infection	
		Process				Researchers				Sea Level	
		Compare				Meteorologists					
		Evaluate				Climatologists					
		Other				Env. Scientists					
		Distribute				Users					
						Citizens					
						Emergency Personnel					
						Health Personnel					
						Media					

Illustrative Components [5 x 8 x 3 x 11 x 5 x 7 = 46,200]

- Infrastructure to acquire (measure) data by agencies (international) for local resistance to agriculture effects.
  Example : Hardware, software, networks, peopleware to collect current data from farmers.
- Procedure to distribute knowledge by users (media) for local renascence from land use effects.
  Example : Procedures to distribute research findings about reversing adverse land use effects.
- System to retrieve information by researchers (climatologists) for local response to human health effects.
  Example : Curated archival system of historical human health information about a local community.

Figure 1: Unified Framework of IS to Manage LCE

The ontology represents our conceptualization of the ISMLCE domain (Gruber 2008). It is an “explicit specification of [our] conceptualization,” (Gruber 1995, p. 908) and can be used to systematize the description of the complexity of ISMLCE domain knowledge (Cimino 2006). The ontology organizes the terminologies and taxonomies of the ISMLCE domain. “Our acceptance of [the] ontology is… similar in principle to our acceptance of a scientific theory, say a system of physics; we adopt, at least insofar as we are reasonable, the simplest conceptual scheme into which the disordered fragments of raw experience can be fitted and arranged.” (Quine 1961, p. 16) It is a domain ontology that “helps identify the semantic categories that are involved in understanding discourse in that domain.” (Chandrasekaran et al. 1999, p.23) Ontologies are used in computer science, medicine, and philosophy. Our ontology of ISMLCE—unified framework—is less formal than computer scientists’, more parsimonious than medical terminologists’, and more pragmatic than philosophers’. It is designed to be actionable and practical and not abstract and meta-physical. Its granularity matches that of the discourse in research, policy, and practice and facilitates the mapping and translation of the domain-text to the framework and the framework to the domain-text. It is also adaptable. In the concluding section of the paper we will discuss how the framework can be scaled and zoomed (in and out) to adapt to changing requirements.

The framework is shown in Figure 1. Three illustrative components derived from the framework are shown below it with an example of each. The elements of the framework are defined in the glossary in Appendix A. In the following subsections, we describe the construction of the unified framework and argue about its validity. In the next section, we will articulate the application of the framework.

Construction of the Framework

The domain of interest is ISMLCE. It is a composite of three subdomains—local climate change effects (LCE), their management (M), and the information system (IS) required to manage them—each with a considerable corpus of research and practice anchored in very different academic disciplines. Thus:

ISMLCE = Local Climate Change Effects (LCE) + Management (M) + Information System (IS)

The understanding of LCE cuts across the physical, natural, biological, and social sciences, and the latter two (M and IS) are an amalgamation of social and computer sciences. The present concern is the concatenation of the three domains for harnessing the capability of IS to manage LCE. The unified framework provides an interdisciplinary perspective to address the problem of LCE.

LCE can affect a locality's Agriculture (Howden et al. 2007), Coast (if there is one) (McGranahan et al. 2007), Ecology (Parmesan 2006), Hydrology (Huntington 2006), Human Health (Noyes et al. 2009), Land Use (Foley et al. 2005), and Meteorology (Dawson et al. 2009). (Note: Elements of the framework referred in the text are capitalized and in normal case otherwise) These are the seven broad categories of effects mentioned in the literature. These effects can be independent and interactive. Thus, the effects on Land Use, Agriculture and Human Health may be independent of each other; or, changes in Land Use may have an important effect on Agriculture and food production, which may also affect Human Health through malnutrition and other mechanisms such as air quality reduction, floods, and the spread of infectious diseases (Foley et al. 2005; Patz et al. 2004). Research has identified four main categories of adaptation options: technological developments, government initiatives, farm practices, and farm financial management (Smit and Skinner 2002). Such findings also signify the importance of both IS and M in understanding LCE. The seven categories are presented in alphabetical order. Their relative importance may vary by locality. They can be reordered by priority in a locality. Thus:

Local Climate Change Effects (LCE) ⊂ (Agriculture, Coast, Ecology, Hydrology, Human Health, Land Use, Meteorology)

The core concern regarding LCE is the continuity and viability of the community affected—the resilience of the community. Further, in addition to the citizens of the community, there is likely to be several other stakeholders in the resilience of the community (Bulkeley 2010; Grimm et al. 2008). Thus, in managing the effects of LCE the Stakeholders seek to make the local community Resilient to the effects of the climate change. Thus:

Management (M) = Stakeholders + Resilience

The Stakeholders in managing the effects of LCE can be broadly classified as Agencies, Researchers, and Users. The Agencies may include International, Federal, State, and Local government agencies. The Researchers may include Meteorologists, Climatologists, and Environmental Scientists. And the Users (of the information system) may include Citizens, Emergency Personnel, Health Personnel, and the Media. This taxonomy of stakeholders may be modified to fit individual localities. Thus:

Stakeholders ⊂ (Agencies, Researchers, Users)

Agencies ⊂ (International, Federal, State, Local)

Researchers ⊂ (Meteorologists, Climatologists, Environmental Scientists)

Users ⊂ (Citizens, Emergency Personnel, Healthy Personnel, Media)

Urban planners for example have increasingly focused on LCE (Heinrichs et al. 2013). "The task of adapting cities to the impacts of climate change is of great importance—urban areas are hotspots of high risk given their concentrations of population and infrastructure; their key roles for larger economic, political and social processes; and their inherent instabilities and vulnerabilities." (Birkmann et al. 2010, p. 185) Urban emission and air quality (Alonso et al. 2010; Slovic et al. 2016) are two major concerns for local as well as national governments around the world.

A five-step process defines Resilience starting with Resistance, followed by Response, Recovery, Restoration, and last Renascence. This definition of resilience is a synthesis of the engineering, biological sciences, and social sciences definitions. At the core of the definitions in the three disciplines is the continuity of the resilient entity despite discontinuous changes in its environment—like the LCE. At first, the entity is likely to resist the change, then respond to it if the change persists, recover from any damage that may have been caused by the change, restore itself in the changed environment, and then rejuvenate itself in the new environment. The five steps are generally sequential although some steps may be skipped or not completed in specific instances. For example, Restoration and Renascence are often deemphasized or overlooked in resilience. The steps can be independent and interactive. The Climate Effect and the Resilience to it will be distributed geographically (spatially) and temporally. Different parts of a locality may be simultaneously in different stages of Resilience. Different steps may interact through feedback and feedforward mechanisms between the different parts of the locality. Thus:

Resilience ⊂ (Resistance, Response, Recovery, Restoration, Renascence)

The Information System for managing the effects of climate change can be defined by its Structure, Function, and Semiotics—a commonly used deconstruction. Thus:

Information System = Structure + Function + Semiotics

There are many ways of defining the Structure of an information system. The traditional taxonomy is: hardware, software, networks, people, policies, and procedures (Rainer and Cegielski 2012). We have modified the taxonomy in the context of ISMLCE. The emergence of technologies like cloud computing and IoT (internet of things) have blurred the lines between hardware, software, and networks. Hence, they have been combined and subsumed under Infrastructure. There is also likely to be multiple IS competing and collaborating with each other to manage the LCE; thus, the two categories of Organization of the systems, and the Systems themselves. The last two elements are the Policies and Procedures, within and between Organizations and Systems. Thus:

Structure ⊂ (Infrastructure, Organization, System, Policy, Procedure)

The traditional Functions of an information system are to Acquire, Store, Retrieve, Process, and Distribute (Rainer and Cegielski 2012). Usually these functions are sequential and iterative. In the context of LCE, Measurement is an important aspect of Acquisition and hence has been included as a subcategory. Other types of Acquisition may include observation, reporting, prediction etc. Similarly, Comparison and Evaluation are two key aspects of Processing, particularly in the context of LCE in which time trend and uncertainties are a key aspect of the ongoing research (Hawkins and Sutton 2009). Hence, they have been included as subcategories. Thus:

Function ⊂ (Acquire, Store, Retrieve, Process, Distribute)

Acquire ⊂ (Measure, Other)

Process ⊂ (Compare, Evaluate, Other)

Semiotics is the repetitive cycle of generation and application of knowledge. The taxonomy of the Semiotics dimension is commonly used (Ramaprasad and Rai 1996). They correspond roughly to morphologics (data), syntactics (information), semantics and pragmatics (knowledge) (Ramaprasad and Rai 1996). Sometimes Wisdom is included as a fourth element of the taxonomy. It is still an ephemeral construct and hence not included in the present taxonomy. They are generally sequential and iterative. Data is translated into Information and Knowledge in the generation phase, and from Knowledge to Data in the application phase.

Semiotics ⊂ (Data, Information, Knowledge)

The dimensions of the framework are arranged left to right with adjacent words/connectors such that the concatenation of an element from each dimension with adjacent words/connectors creates a natural English sentence illustrating a potential component of ISMLCE. The components and fragments (incomplete components) define the domain.

At the most detailed level, the framework encapsulates 46,200 (5 x 8 x 3 x 11 x 5 x 7) potential components of ISMLCE. It encapsulates the ‘big picture’ of the domain and helps visualize the combinatorial complexity of ISMLCE. Three illustrative components and examples are listed in Figure 1 which are discussed below. In the following, we discuss the validity of the framework and its application for a systematic review of the literature in the domain. We conclude with a roadmap for future research.

Validity of the Framework

The validity of the framework in Figure 1 will determine how well it captures and represents ISMLCE. The common methods of ontology development—the framework is an ontology—focus on induced ontologies at a finer level of detail, greater formalism, and machine readability, but not on deduced ontologies at a higher-level of abstraction such as ours. Past studies have identified methods for validating ontologies (Burton-Jones et al. 2005; Evermann and Fang 2010; Staab et al. 2004). These methods however are mostly suitable for formal ontologies that represent concepts using the triples of subject, predicate, and object to facilitate machine-learning. Our ontology on the other hand aims to facilitate human understanding of ISMLCE. Each component of the domain is represented by a sextuple in natural English based on the six dimensions.

We construct the framework by deconstructing major dimensions of ISMLCE; each dimension represents a corresponding taxonomy that incorporates the terminology of the domain. We draw upon the traditional constructs of validity commonly used in social sciences (Brennan et al. 2011; Horn and Lee 1989) to justify the face, content, semantic, and systemic validity of the framework of ISMLCE.

The framework is a complete and closed description of the construct of ISMLCE. It is logically derived as described earlier. Each dimension is logically complete. It is a novel reorganization and representation of traditional bodies of knowledge from multiple disciplines such as information systems, environmental sciences, and social sciences. It derives part of its validity from that of the knowledge in these underlying disciplines.

It comprehensively describes ISMLCE using structured natural English understandable to novices and experts alike. It deconstructs the combinatorial complexity of the construct and presents it visually as an easily readable, parsimonious text-table (Tufte 1990). The framework encapsulates all 46,200 possible components of the phenomenon in a human-readable form on a single sheet of paper. Thus, its face validity is high.

Each logical component derived from the ontology is semantically meaningful as illustrated above; thus, its semantic validity is high. It is easy to ascertain whether a component is instantiated or not. Obversely, it is also easy to ascertain the component that matches an instantiation. We simply need to identify the ontology elements present in a policy, research, or practice, and vice-versa.

Its dimensions are based on the common bodies of knowledge from underlying disciplines. The taxonomies include the basic categories of knowledge from these disciplines. For example, the Structure, Function, and Semiotics of information systems are well-known and well-defined in the IS field. Hence, the content validity of the dimensions, the taxonomies, and the large number of consequent components is high.

Further, the framework encapsulates all possible components of ISMLCE, however many there are. We can describe any policy, research, or practice in ISMLCE using the framework. It has high systemic validity.

Discussion

The proposed framework is a lens to study the anatomy of ISMLCE. The complexity of local and urban systems, in relation to LCE, has been intensively described (Grimm et al. 2008). For a complex domain like this, there may be other lenses to study the same and each can be encapsulated by a different framework. Each will provide a different perspective of ISMLCE. We will discuss the present one in detail.

We have discussed the individual dimensions (columns) and elements of the framework while describing the construction of the ontology. Multiple elements of a dimension may coexist independently but may also interact with each other. Thus, many stakeholders, resilience stages, and climate effects may coexist and interact with each other. Knowing the independent and interacting elements is critical to understanding ISMLCE. The framework can help systematically study and manage the elements' independence and interactions. In the following we discuss how the ontology can be used to systematically study the interaction of: (a) elements within a dimension, (b) elements across two dimensions, and (c) elements across multiple dimensions, to understand the anatomy of ISMLCE at different levels of granularity and complexity.

Combinations Within a Dimension

All possible first-order interactions among the elements of a dimension can be mapped into a table of the dimension with itself. Such a mapping can reveal strong interactions (both constructive and obstructive), weak ones, absent ones, and unexpected ones among the elements. It can also highlight the direction of the interaction—one-way (*a* to *b* OR *b* to *a*), and two-way (*a* to *b* AND *b* to *a*). In the following, we will discuss some possible insights from such a mapping of each dimension.

Local Climate Change Effects (LCE)

Many elements of LCE are likely to interact with each other strongly. For example, Meteorology is likely to affect Agriculture, which in turn is likely to affect Land Use, and subsequently Human Health (Foley et al. 2005; Patz et al. 2004). Another example is the interaction between Hydrology and Land Use. Some of these interactions are well known are but many are unknown and may have to be discovered. Lin et al. (2012) and Tong and Chen (2002) for instance have established the relationships between Land Use and hydrological processes of urbanized watershed, and surface water quality, respectively. These interactions are also likely to be distributed spatially over the locality and temporally over a long period. Moreover, the interactions may create feedback and feedforward loops which may amplify or attenuate the effects. The policies and practices of the locality must address these complex dynamics (Bolay and Kern 2011; Kern and Alber 2008). A table of interactions among the LCE elements will help parse the effects. An objective of ISMLCE would be to sense the individual effects and the interactions so that the locality can resile appropriately.

Resilience

The resilience steps are sequential. The effects of actions in the early steps will likely be carried forward to the subsequent steps. The domino effect may be functional or dysfunctional for the locality. Among the dysfunctional actions and effects, those that are reversible will be far less costly than those that are irreversible. Ideally, the ISMLCE should help feedforward data, information, and knowledge to the subsequent steps; and feedback the same to the prior steps. For example, given that local vulnerabilities to LCE are particularly acute in the Southern Hemisphere (where LCE may also exacerbate problems related to poverty and equity) (Bulkeley 2010), such a system will facilitate learning by the affected locality and to transfer the learning to other localities facing similar local climate change effects. It will thus help prevent irreversible actions and their effects.

Stakeholders

The stakeholders act independently and interactively. Their interaction may be collaborative and competitive. Local Climate governance is a complex process driven by the combination of scenarios that require a reconfiguration of political authority across multiple levels, and between public and private sectors, including citizens (Bulkeley 2010). An interaction matrix of the stakeholders will help map the dynamics which can affect the resilience to LCE. A frequent source of conflict among stakeholders is the differences in their data, information, and knowledge about the problem, and their confidence in the processes employed. Additionally, there is often disagreement on what constitutes an 'important' factor to consider, particularly those related to LCE that are currently 'weak' but are likely to persist and increase (Parmesan and Yohe 2003). An ISMLCE can partially help reconcile the differences by developing a common repository on a universally accessible platform. Such a platform can make visible and public the similarities and differences between the stakeholders' perspectives, even if it does on reconcile the differences.

Semiotics

Data, Information, and Knowledge are bi-directionally sequential. From Data to Knowledge during generation, and in the opposite direction during application. Management of LCE will require repeated cycles of generation and application of knowledge. Errors in data can lead to errors in knowledge and subsequently errors in actions resulting from the application of that knowledge. The errors may be perpetuated and amplified in subsequent cycles unless they are identified and attenuated. By the same token, valid data can lead to valid knowledge and appropriate action. These too may be perpetuated and amplified in subsequent cycles unless they are overlooked and attenuated. A challenge in the design of ISMLCE is to attenuate the dysfunctional cycles and amplify the functional ones.

Functions

The Function elements are strictly sequential—Storage follows Acquisition, Retrieval follows Storage, and so on. Consequently, the impact of ISMLCE choices will be propagated from Acquisition to Distribution. For example, inclusion of data on people's health in the specification of the system can help acquire data about it and process the same. On the other hand, ignoring people's health data will result in the inability to obtain information about and knowledge of variations in health due to LCE. There is also likely propagation effect from higher-level elements to lower ones and a barrier to propagation from lower-level elements to higher ones—the limitations of Infrastructure and Systems foster non-inclusive Services and Processes while preventing Policies and People to influence Infrastructure and Systems.

Structure

The Structure elements are generally hierarchical. Architecture defines the Infrastructure, Infrastructure defines the Systems, and so on. As such the lower-level elements are likely to inherit their properties from the higher ones. Although possible, it is less likely that the properties of the lower elements will be propagated to the higher ones. Thus, elements of ISMLCE which is part of the Architecture will likely permeate the Policies, Processes, and People. However, elements of ISMLCE inserted at the lower levels in Policies, Processes, and People are less likely to be propagated into the Architecture and Infrastructure; in fact, such propagation is likely to be resisted.

Combination between Dimensions

In addition to interactions among the elements of a dimension, all possible first-order interactions among the elements of a pair of dimensions can be mapped into a table. Such a mapping can reveal strong interactions (both constructive and obstructive), weak ones, absent ones, and unexpected ones between the elements of the two dimensions. It can also reveal the direction of the interaction—one-way (*a* to *b* OR *b* to *a*), and two-way (*a* to *b* AND *b* to *a*). With the six dimensions of the framework there are fifteen possible pairs. In the examples in the previous section we have some possible interactions between many of the dimensions. Here we will summarize the fifteen possible pairs and the potential insights from them.

1. Resilience x Climate Effect: Mechanisms of resilience with respect to each type of climate effect.
2. Stakeholders x Climate Effect: Roles of stakeholders in each type of climate effect.
3. Semiotics x Climate Effect: Role of data, information, knowledge about each type of climate effect.
4. Function x Climate Effect: Role of functions with respect to each type of climate effect.
5. Structure x Climate Effect: Role of structure elements with respect to each type of climate effect.
6. Stakeholders x Resilience: Role of stakeholders in each phase of resilience.

7. Semiotics x Resilience: Role of data, information, knowledge in each phase of resilience.
8. Function x Resilience: Role of functions in in each phase of resilience.
9. Structure x Resilience: Role of structure elements in each phase of resilience.
10. Semiotics x Stakeholders: Semiotics needs of and support for stakeholders.
11. Function x Stakeholders: Function needs of and support for stakeholders.
12. Structure x Stakeholders: Structure needs for and support of stakeholders.
13. Function x Semiotics: Functional needs of semiotics.
14. Structure x Semiotics: Structural needs of semiotics.
15. Structure x Function: The alignment of structure and function.

Some of these interactions have already been studied. Some examples include: the active participation of stakeholders from all levels of society in transforming Mexico City into a sustainable city [Stakeholder x Resilience] (Madero and Morris 2016); the use of satellite imagery to detect wetland changes in Shanghai, China [Function x Climate Effect] (Tian et al. 2015); and the assessment of the use and reliability of disaster databases in climate change [Structure x Climate Effect] (Huggel et al. 2015).

Components of Information Systems to Manage Local Climate Change Effects

The framework in Figure 1 encapsulates 46,200 components and numerous fragments that represent the domain of ISMLCE. However, it would be laborious and voluminous to enumerate all components and fragments. The ontology provides a convenient and concise ‘big picture’ of the domain in a limited space. It helps visualize the combinatorial complexity of the domain and see beyond the minutiae.

A component of ISMLCE may be instantiated in many ways. Consider the first illustrative component in Figure 1: *Infrastructure to acquire (measure) data by agencies (international) for local resistance to agriculture effects.* This would include the infrastructure to collect data about how the local farmers are countering the adverse agricultural effects of diminished precipitation due to local climate change. An example of such an infrastructure is computer hardware, software, networks, and peopleware to collect current data from farmers. The data may be collected manually by local social workers or researchers talking to the farmers, electronically by having the farmers send messages to a central system, or indirectly by observing the farmers’ actions.

Consider the second illustrative component in Figure 1: *Procedure to distribute knowledge by users (media) for local renascence from land use effects.* This would include procedures to distribute knowledge through the media about rejuvenating the use of land for agricultural or other purposes. The raw knowledge may be distributed to the media for propagation by a method the media choose. Alternately, educational programs based on the knowledge and broadcast through the media.

Last, consider the third illustrative component in Figure 1: *System to retrieve information by researchers (climatologists) for local response to human health effects.* This could be thought of as a research information management system. It could simply be (a) a system to provide access to global databases on the topic; (b) be a customized local database on the topic; or (c) a combination of the two.

Thus, overall, some components may be instantiated frequently, some infrequently, and some not at all. The frequently instantiated components will constitute the dominant themes, the infrequently instantiated ones the less-dominant themes, and the un-instantiated one the non-dominant themes or potential gaps in ISMLCE. The frequency of instantiation of a component may not necessarily indicate its importance, centrality, criticality, or other priority. A dominant theme may simply be a product of convenience or a ‘herd effect’; a less-dominant theme may be a product of inexperience or oversight; and a gap may in fact have been overlooked or infeasible. Understanding the antecedents and consequences of the differences in emphasis is necessary to develop a roadmap for future research, policy, and practice.

Application of the Framework

The initiatives of local governments regarding LCE have been described to be focused mainly on renewable energy target settings and energy efficiency (Bulkeley 2010), where the environmental wing of local authorities is isolated from other areas of policy making, such as human health and air quality (Kern and Alber 2008). To complement these efforts, the framework presented in this paper can be used to assess the information system requirements to manage LCE in a locality, and plan for the development of appropriate systems. The objective of the assessment would be to map the state-of-the-practice and -of-the-need of the locality onto the framework. The assessment could proceed sequentially and iteratively as follows.

1. *Assessment of the critical LCE*: The taxonomy of LCE in the framework provides a starting point. A major challenge would be to differentiate the LCE from natural climate variation effects. The signals of LCE are likely to be weak and delayed, often discovered only in hindsight. Ideally, anecdotal data and personal local knowledge must be validated against objective data and scientific knowledge to reduce the errors of over-identification (normal variations as LCE) and under-identification (LCE as normal variations) (Aswani et al. 2015; Hoy et al. 2014; Morzillo et al. 2015). The minimization of these errors will be dependent on the stakeholders' effective use of IS.
2. *Assessment of the LCE resilience stages*: If a LCE is predicted or identified early, it would be logical to start with resistance (e.g. prevention) and follow through with the subsequent steps. Delayed recognition of the LCE would require accelerating or skipping some of the steps. Moreover, multiple LCE may require response at different stages of resilience to be coordinated. The stakeholders will ultimately make the choice using IS.
3. *Assessment of the critical stakeholders in LCE*: The framework identifies the types of stakeholders likely to manage LCE. Identifying the specific stakeholders in a LCE to elicit their participation will be critical to managing the LCE. Managing LCE is likely to be a combination of scientific, economic, managerial, and political process (Kern and Alber 2008). It would be important to include those with a direct stake in it and exclude those that do not—however, the politics of the process may make such rational inclusion and exclusion difficult.
4. *Assessment of the semiotics of the information systems*: Evidence-based management of LCE will require a clear assessment of the state of data, information, and knowledge about the LCE. It is necessary to assess what is known, unknown, can be known, and cannot be known. Evidence about what is unknown but can be known must be generated provided sufficient resources are available. The evidence must be available to and used by the stakeholders. This will enable the stakeholders to use their best judgment in the absence of evidence.
5. *Assessment of the functions of the information systems*: The generation and application using semiotics will depend on the ability to perform the functions effectively and efficiently. The overall performance of the functions will be determined by the weakest link in their sequence. The assessment may also vary by effects. For example, the functions may be effective for managing coastal effects but may be inadequate to manage human health effects. Moreover, the functions are likely to be performed by multiple systems which are neither integrated not interoperable. There is likely to be significant barriers to the integration of the functions across the systems, and significant facilitators too. These barriers and facilitators must be identified during the assessment.
6. *Assessment of the structure of the information systems*: Mapping the structure of the systems is likely to be a challenge. There may be many information systems, some documented and many undocumented, some formal and many informal, which can play a role in managing LCE. A census of the systems together with a description of their organization, policies, and processes would be a good starting point to determine the strengths and weaknesses of the systems and hence the overall infrastructure.

Conclusion

The proposed framework fills an important gap in the literature on ISMLCE. It defines the domain of ISMLCE systematically, systemically, and symmetrically (by being effect-neutral and hence including both positive and negative effects of local climate change). All researchers, policy makers, and practitioners may not universally agree with the framework even though a systematic attempt has been made to include all the key elements from the extant literature. The disagreements can be accommodated by extending the taxonomies by including overlooked elements, reducing them by eliminating redundant elements, coarsening them by combining elements, and refining them by dividing the elements. For example, another LCE such as on Aquatic Animal Health may be included in the future, or Mitigation and Adaptation processes may be included as a subdivision of Resistance and Resilience, where Renascence and Restoration may also be combined.

The scope of the framework can be broadened by adding absent dimensions and narrowed by deleting present dimensions. For example, a Temporal dimension may be added with three elements—Short, Medium, and Long term as a second-level dimension of Management. Inclusion of this dimension will compel consideration of the Resilience phases in each of the time horizons by the stakeholders, rather than in the aggregate. It would also require information system support with finer granularity, lead times, and response time. On the other hand, the Semiotics dimension may be eliminated if Data, Information, and Knowledge for ISMLCE are aggregated and labeled Information. These properties of scalability (extensibility, reducibility), and zoomability (up and down) make the unified framework versatile to study the domain.

The framework of ISMLCE presented in this paper makes visible the combinatorial complexity of an important and timely topic in information systems. The ontology is logically constructed but grounded in the theories prevalent in the domain and relevant disciplines. The dimensions are logically specified and not empirically generated. They are deduced from the definition of the domain. Thus, it helps us address the problem of ISMLCE in its entirety rather than fragmentarily. A common tendency in research into a complex domain is to highlight the complexity of the whole domain and then to address selected parts of the domain, hoping that somehow the parts will fit together and enlighten the whole problem. Unfortunately, very often, even after an extensive body of research is accumulated the problem is not illuminated in its entirety. The proposed framework and the mapping of the literature will help obviate the problem.

The framework is a lens to study ISMLCE. There may be other lenses to study the same. Each can be described by an ontology. Each ontology is logically constructed but grounded in theory and practice of the domain. The logical construction of our ontology minimizes the errors of omission and commission. For example, inclusion of the Stakeholder dimension compels the researchers to explicitly consider different stakeholders. Without consideration for the Stakeholder dimension (error of omission), researchers will be unlikely to advance the field of ISMLCE. By the same token in may specify LCE (error of commission) like local Coast effects not relevant to a community.

Last, the framework is a multi-disciplinary lens. The Structure, Function, and Semiotics dimensions are drawn from the information systems and knowledge management literature; the Stakeholders and Resilience are from the disaster management literature; and the Local Climate Change Effects is from the climate change literature. The framework compels the user to analyze the issues surrounding ISMLCE and synthesize solutions by drawing upon these disciplines. One may construct other frameworks/lenses and study the subject from a different perspective.

The framework of ISMLCE can advance the state-of-the-research in the domain. It can be used to systematically identify the ‘bright’, ‘light’, and ‘blind/blank’ spots in the research on the topic, particularly when a gap between rhetoric and reality of urban responses to LCE has been consistently pointed out by researchers (Bulkeley 2010). The state-of-the-research can be analyzed by mapping the corpus of research onto the framework. The mapping can be done by identifying categories within each dimension articles in the corpus fit into. An article may be mapped to one or more categories in one or more dimensions, or none. Such mapping will highlight the bright, light, and blind/blank spots in ISMLCE research. The map will help researchers visualize the landscape of the ISMLCE enabling them to set appropriate research direction. Similarly, the state-of-the-practice can be analyzed by mapping current practices onto the framework. The resultant mapping will identify the focus of and gaps the inclusive practices. The comparison of the ontological maps of research and practice will bring to fore the alignment between the two states, or lack thereof. The gaps between the two states should inform researchers, practitioners, and policy makers alike the need for action to advance research and policy.

In other words, the maps can be used as a roadmap for ISMLCE research and practice. It can illuminate the 'big picture' of the domain.

The landscape of a domain can change over time with emerging climate changes. The ontology-based roadmap can be amended to reflect the changing landscape. New categories and dimensions can be added, obsolete ones discarded, and existing ones modified. Changes can also be introduced by the shifting focus in the domain. The finer levels of dimensions and elements can be added to the ontology to reflect the greater focus on certain dimensions or categories. On the other hand, sub-categories and -dimensions can be collapsed to echo their diminishing importance in the domain. The shifting focus and direction of research and development can be monitored by analyzing the snapshots of the ontological maps over time. The ontology can help visualize the past and present of the domain, and envisage its future.

References

Alonso, M.F., Longo, K.M., Freitas, S.R., Mello da Fonseca, R., Marécal, V., Pirre, M., and Klenner, L.G. 2010. "An Urban Emissions Inventory for South America and Its Application in Numerical Modeling of Atmospheric Chemical Composition at Local and Regional Scales," *Atmospheric Environment* (44:39), pp. 5072-5083.

Aswani, S., Vaccaro, I., Abernethy, K., Albert, S., and de Pablo, J.F.L. 2015. "Can Perceptions of Environmental and Climate Change in Island Communities Assist in Adaptation Planning Locally?," *Environmental Management* (56:6), pp. 1487-1501.

Barnett, T.P., Santer, B.D., Jones, P.D., Bradley, R.S., and Briffa, K.R. 1996. "Estimates of Low Frequency Natural Variability in near-Surface Air Temperature," *Holocene* (6:3), pp. 255-263.

Birkmann, J., Garschagen, M., Kraas, F., and Quang, N. 2010. "Adaptive Urban Governance: New Challenges for the Second Generation of Urban Adaptation Strategies to Climate Change," *Sustainability Science* (5:2), pp. 185-206.

Bolay, J.-C., and Kern, A. 2011. "Technology and Cities: What Type of Development Is Appropriate for Cities of the South?," *Journal of Urban Technology* (18:3), pp. 25-43.

Brennan, L., Voros, J., and Brady, E. 2011. "Paradigms at Play and Implications for Validity in Social Marketing Research," *Journal of Social Marketing* (1:2), pp. 100-119.

Bulkeley, H. 2010. "Cities and the Governing of Climate Change," *Annual Review of Environment and Resources, Vol 35* (35), pp. 229-253.

Burton-Jones, A., Storey, V.C., Sugumaran, V., and Ahluwalia, P. 2005. "A Semiotic Metrics Suite for Assessing the Quality of Ontologies," *Data and Knowledge Engineering* (55:1), pp. 84-102.

Chandrasekaran, B., Josephson, J.R., and Benjamins, V.R. 1999. "What Are Ontologies, and Why Do We Need Them?," *IEEE Intelligent Systems* (14:1), pp. 20-26.

Cimino, J.J. 2006. "In Defense of the Desiderata," *Journal of Biomedical Informatics* (39:3), pp. 299-306.

Crowley, T.J. 2000. "Causes of Climate Change over the Past 1000 Years," *Science* (289:5477), pp. 270-277.

Dawson, J.P., Racherla, P.N., Lynn, B.H., Adams, P.J., and Pandis, S.N. 2009. "Impacts of Climate Change on Regional and Urban Air Quality in the Eastern United States: Role of Meteorology," *Journal of Geophysical Research-Atmospheres* (114), p. 11.

Evermann, J., and Fang, J. 2010. "Evaluating Ontologies: Towards a Cognitive Measure of Quality," *Information Systems* (35:4), pp. 391-403.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., and Snyder, P.K. 2005. "Global Consequences of Land Use," *Science* (309:5734), pp. 570-574.

Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X., and Briggs, J.M. 2008. "Global Change and the Ecology of Cities," *Science* (319:5864), pp. 756-760.

Gruber, T.R. 1995. "Toward Principles for the Design of Ontologies Used for Knowledge Sharing," *International Journal Human-Computer Studies* (43:5-6), November 1995, pp. 907-928.

Gruber, T.R. 2008. "Ontology," in *Encyclopedia of Database Systems,* L. Liu and M.T. Özsu (eds.). New York: Springer-Verlag.

Hamududu, B., and Killingtveit, A. 2012. "Assessing Climate Change Impacts on Global Hydropower," *Energies* (5:2), pp. 305-322.

Hawkins, E., and Sutton, R. 2009. "The Potential to Narrow Uncertainty in Regional Climate Predictions," *Bulletin of the American Meteorological Society* (90:8), pp. 1095-+.

Heinrichs, D., Krellenberg, K., and Fragkias, M. 2013. "Urban Responses to Climate Change: Theories and Governance Practice in Cities of the Global South," *International Journal of Urban and Regional Research* (37:6), pp. 1865-1878.

Horn, B.R., and Lee, I.-H. 1989. "Toward Integrated Interdisciplinary Information and Communication Sciences: A General Systems Perspective," in *Proceedings of the 22nd Hawaii International Conference on System Sciences (Hicss 1989)*. Kailua-Kona, Hawaii, USA: IEEE, pp. 244-255.

Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M., and Meinke, H. 2007. "Adapting Agriculture to Climate Change," *Proceedings of the National Academy of Sciences of the United States of America* (104:50), Dec, pp. 19691-19696.

Hoy, D., Roth, A., Lepers, C., Durham, J., Bell, J., Durand, A., Lal, P.N., and Souares, Y. 2014. "Adapting to the Health Impacts of Climate Change in a Sustainable Manner," *Globalization and Health* (10:1).

Huggel, C., Raissig, A., Rohrer, M., Romero, G., Diaz, A., and Salzmann, N. 2015. "How Useful and Reliable Are Disaster Databases in the Context of Climate and Global Change? A Comparative Case Study Analysis in Peru," *Natural Hazards and Earth System Sciences* (15:3), pp. 475-485.

Huntington, T.G. 2006. "Evidence for Intensification of the Global Water Cycle: Review and Synthesis," *Journal of Hydrology* (319:1-4), Mar, pp. 83-95.

IPCC. 2014. "Climate Change 2014: Synthesis Report," Geneva, Switzerland, p. 151 pp.

Jayasinghe, P., Bandara, N., Jayasinghe, A.B., Chemin, Y., and Mahanama, P.K.S. 2015. "Assess the Level of Vulnerability to Climate Induced Disasters in Sri Lankan Coastal Areas: An Application of Open Source Geographic Information System," *International Journal of Geoinformatics* (11:3), pp. 53-58.

Jones, P.D., and Mann, M.E. 2004. "Climate over Past Millennia," *Reviews of Geophysics* (42:2), May, p. 42.

Kern, K., and Alber, G. 2008. "Governing Climate Change in Cities: Modes of Urban Climate Governance in Multi-Level Systems," in *Competitive Cities and Climate Change*. Paris: OECD, pp. 171-196.

Lin, Y.P., Hong, N.M., Chiang, L.C., Liu, Y.L., and Chu, H.J. 2012. "Adaptation of Land-Use Demands to the Impact of Climate Change on the Hydrological Processes of an Urbanized Watershed," *International Journal of Environmental Research and Public Health* (9:11), pp. 4083-4102.

Madero, V., and Morris, N. 2016. "Public Participation Mechanisms and Sustainable Policy-Making: A Case Study Analysis of Mexico City's Plan Verde," *Journal of Environmental Planning and Management* (59:10), pp. 1728-1750.

Mann, M.E., Bradley, R.S., and Hughes, M.K. 1998. "Global-Scale Temperature Patterns and Climate Forcing over the Past Six Centuries," *Nature* (392:6678), pp. 779-787.

McGranahan, G., Balk, D., and Anderson, B. 2007. "The Rising Tide: Assessing the Risks of Climate Change and Human Settlements in Low Elevation Coastal Zones," *Environment and Urbanization* (19:1), Apr, pp. 17-37.

Midgley, G.F., Hannah, L., Millar, D., Rutherford, M.C., and Powrie, L.W. 2002. "Assessing the Vulnerability of Species Richness to Anthropogenic Climate Change in a Biodiversity Hotspot," *Global Ecology and Biogeography* (11:6), pp. 445-451.

Morzillo, A.T., Colocousis, C.R., Munroe, D.K., Bell, K.P., Martinuzzi, S., Van Berkel, D.B., Lechowicz, M.J., Rayfield, B., and McGill, B. 2015. ""Communities in the Middle": Interactions between Drivers of Change and Place-Based Characteristics in Rural Forest-Based Communities," *Journal of Rural Studies* (42), pp. 79-90.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., and Wilbanks, T.J. 2010. "The Next Generation of Scenarios for Climate Change Research and Assessment," *Nature* (463:7282), pp. 747-756.

Nguyen, Q., Hoang, M.H., Oborn, I., and van Noordwijk, M. 2013. "Multipurpose Agroforestry as a Climate Change Resiliency Option for Farmers: An Example of Local Adaptation in Vietnam," *Climatic Change* (117:1-2), Mar, pp. 241-257.

Noyes, P.D., McElwee, M.K., Miller, H.D., Clark, B.W., Van Tiem, L.A., Walcott, K.C., Erwin, K.N., and Levin, E.D. 2009. "The Toxicology of Climate Change: Environmental Contaminants in a Warming World," *Environment International* (35:6), pp. 971-986.

Parmesan, C. 2006. "Ecological and Evolutionary Responses to Recent Climate Change," *Annual Review of Ecology Evolution and Systematics* (37), pp. 637-669.

Parmesan, C., and Yohe, G. 2003. "A Globally Coherent Fingerprint of Climate Change Impacts across Natural Systems," *Nature* (421:6918), Jan, pp. 37-42.

Patz, J.A., Daszak, P., Tabor, G.M., Aguirre, A.A., Pearl, M., Epstein, J., Wolfe, N.D., Kilpatrick, A.M., Foufopoulos, J., Molyneux, D., Bradley, D.J., Working, M.o.t., and Group on Land Use Change and Disease Emergence. 2004. "Unhealthy Landscapes: Policy Recommendations on Land Use Change and Infectious Disease Emergence," *Environmental Health Perspectives* (112:10), Jul, pp. 1092-1098.

Planton, S., Deque, M., Chauvin, F., and Terray, L. 2008. "Expected Impacts of Climate Change on Extreme Climate Events," *Comptes Rendus Geoscience* (340:9-10), Sep-Oct, pp. 564-574.

Quine, W.V.O. 1961. *From a Logical Point of View*, (Second, revised ed.). Boston, MA, USA: Harvard University Press.

Rainer, R.K., and Cegielski, C.G. 2012. *Introduction to Information Systems: Supporting and Transforming Business*, (4th ed.). Hoboken, NJ: Wiley.

Ramaprasad, A., and Rai, A. 1996. "Envisioning Management of Information," *Omega-International Journal of Management Science* (24:2), pp. 179-193.

Rosendahl Appelquist, L., and Balstrøm, T. 2014. "Application of the Coastal Hazard Wheel Methodology for Coastal Multi-Hazard Assessment and Management in the State of Djibouti," *Climate Risk Management* (3), pp. 79-95.

Rosendahl Appelquist, L., and Balstrøm, T. 2015. "Application of a New Methodology for Coastal Multi-Hazard-Assessment & Management on the State of Karnataka, India," *Journal of Environmental Management* (152), pp. 1-10.

Slovic, A.D., de Oliveira, M.A., Biehl, J., and Ribeiro, H. 2016. "How Can Urban Policies Improve Air Quality and Help Mitigate Global Climate Change: A Systematic Mapping Review," *Journal of Urban Health* (93:1), pp. 73-95.

Smit, B., and Skinner, M.W. 2002. "Adaptation Options in Agriculture to Climate Change: A Typology," *Mitigation and Adaptation Strategies for Global Change* (7:1), pp. 85-114.

Staab, S., Gómez-Pérez, A., Daelemans, W., Reinberger, M.-L., and Noy, N.F. 2004. "Why Evaluate Ontology Technologies? Because It Works!," *IEEE Intelligent Systems* (19:4), 2004, pp. 74-81.

Tian, B., Zhou, Y.X., Thom, R.M., Diefenderfer, H.L., and Yuan, Q. 2015. "Detecting Wetland Changes in Shanghai, China Using Formosat and Landsat Tm Imagery," *Journal of Hydrology* (529), Oct, pp. 1-10.

Tong, S.T.Y., and Chen, W.L. 2002. "Modeling the Relationship between Land Use and Surface Water Quality," *Journal of Environmental Management* (66:4), Dec, pp. 377-393.

Tufte, E.R. 1990. *Envisioining Information*. Cheshire, CT: Graphics Press.

Van Minh, H., Anh, T.T., Rocklöv, J., Giang, K.B., Trang, L.Q., Sahlen, K.G., Nilsson, M., and Weinehall, L. 2014. "Primary Healthcare System Capacities for Responding to Storm and Flood-Related Health Problems: A Case Study from a Rural District in Central Vietnam," *Global Health Action* (7:1).

VijayaVenkataRaman, S., Iniyan, S., and Goic, R. 2012. "A Review of Climate Change, Mitigation and Adaptation," *Renewable & Sustainable Energy Reviews* (16:1), Jan, pp. 878-897.

Waluda, C.M., Dunn, M.J., Curtis, M.L., and Fretwell, P.T. 2014. "Assessing Penguin Colony Size and Distribution Using Digital Mapping and Satellite Remote Sensing," *Polar Biology* (37:12), pp. 1849-1855.