



Climate change, vulnerability, and risk linkages

Climate change

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Abstract

Purpose – This research aims to develop a model that may be used to determine the effective adaptive measures to implement in a system affected by climate change.

Design/methodology/approach – The three primary dimensions of the model were individually investigated and then the linkages among them were developed. Specifically, the nature of climate change was examined and the issues emerging from the changes were analyzed. Next, an intensive study of system vulnerabilities was conducted, and the third factor in the model, risk, is then explored. Afterwards, the conceptual framework, which is the foundation of the climate change vulnerability risk model, was devised and the model created.

Findings – The model is a three-dimensional matrix with the nature of climate change, vulnerabilities, and risks as its chief dimensions. It identifies the four natures of climate change, namely: variability, intensity, frequency, and quantity and the vulnerability types to be socio-economic, biophysical, technological, and institutional. Meanwhile, risks are classified as income, biodiversity, health, mortality, and infrastructure risks.

Research limitations/implications – The research is the first phase of a three-stage study on the linkages among climate change, vulnerability, and risks. It is the development stage of the framework that exemplifies the interrelationships among these variables and is the basis of the statistical and econometric analyses in the later stages.

Originality/value – The climate change vulnerability risk model was developed to act as an analytical guide in understanding the effects of climate change to systems. The model may be used to determine the effective adaptive measures to apply in the system, through a comparative analysis of the variables in the matrix.

Keywords Global warming, Risk analysis

Paper type Research paper

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1. Introduction

Trepidation over the state of the environment has been intensifying in recent decades. The number and force of natural catastrophes since the start of the new millennium alone leave marks in history. These events are pieces of evidence of the world's changing climate.

In 2001, the country of Kazakhstan in Central Asia experienced its coldest winter in 40 years, with temperatures dropping as low as -47°C in its northeast territory, accompanied by severe snowstorms. During the same period, the Russian region of Siberia recorded a -57°C temperature (*BBC News Online*, 2001). In 2005, the USA experienced its worst hurricane season, with 26 storms, surpassing the record of 21 set in 1933. About 13 of the storms were hurricanes, one more than the previous record in 1969, with seven of them considered to be major ones (CNN.com, 2005). These included the Category 5 hurricanes Katrina and Wilma which hit New Orleans and Florida, respectively, and had wind speeds reaching more than 155 mph. In a country where a normal hurricane season produces an average of ten named storms, six hurricanes, and two major hurricanes, the numbers and intensities of the 2005 season were unexpected. Meanwhile, in August 2006, typhoon



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Saomai, the most powerful storm to hit China in five decades, traveled with winds of up to 135 mph (*The Manila Times Online*, 2006).

Australia first thought that the 2002 drought has been the worst in its history. However, the arid condition persisted in many parts of the continent, and in 2006, drought was declared the worst in 1,000 years (*ABC News Online*, 2006). The same year across the globe, reports claimed that East Africa experienced its toughest drought in 20 years, with temperatures soaring above 100 degrees Fahrenheit. (*ABC News Online*, 2006, 20 April). This continent has been hit by extreme conditions; after the severe dry season, the torrential rains in 2007 brought the worst flood in the region in 50 years. (*International Herald Tribune Online*, 2007). In another part of the world, the August 2007 flood in South Asia marked what the “United Nations says is the worst flooding in living memory” (CNN.com, 2007). The fierce monsoon rains have submerged areas in India, Pakistan, Bangladesh, and Nepal.

In July 2007, Europe encountered weather extremes where England experienced its worst flooding in 60 years, while the south and east of the continent suffered from heat wave. The year’s summer experience surpassed the 2003 heat wave; it recorded maximum temperatures of 35-40°C in most of the southern and central countries like 38.1°C in the UK, 40°C in France, 41.5°C in Switzerland (with June as the hottest month ever recorded in 250 years of archives), and with temperatures exceeding the average by +5.4°C in Geneva (United Nations Environment Programme, 2004). Authorities in Greece described its 2007 condition as the country’s “longest heat wave in over 100 years”. Bulgaria registered temperatures as high as 45°C (104 Fahrenheit), the country’s hottest since records started 120 years ago. Meanwhile, Italy encountered series of forest and bush fires during the period and reports of fire incidents were “twice the daily average for the season.” Moreover, 11 cities – including Rome, Venice, Naples, and Palermo – were on “high alert” for heat-related health problems amid temperatures exceeding 40°C (104 Fahrenheit; *Terra Daily Online*, 2007).

In a country like the Philippines where typhoons are a normal occurrence, the 2006 season was an unforgettable one. Typhoon Milenyo (international name: Xangsane), which hit in September, reached an average wind speeds of 185 km per hour and resulted to massive flooding and landslides in the provinces of Eastern Samar, Albay, Camarines Sur, Ormoc City, Sorsogon, and Catanduanes and infrastructure destruction in the capital, Metro Manila. Milenyo affected at least 43,061 families and heavily disrupted the communications systems and the electricity grid in the country. Two months later, the Philippines experienced the super typhoon “Dorian” with 265 km per hour winds and created a 466 mm of rainfall, the highest in 40 years. Reports posted more than 1,000 deaths and destruction of more than 100,000 homes (Inquirer.net, 2006; International Federation of Red Cross and Red Crescent Societies, 2006; USA Today.com, 2006). Three years later, in 26 September 2009, the Philippines again experienced a devastating calamity through the tropical typhoon Ondoy (international name: Ketsana). It caused the worst flooding in the country in more than 42 years. Ondoy submerged parts of the country’s capital with a month’s worth of rain that only fell within six hours – approximately 13.4 inches of rain – close to the 15.4 inch average rainfall during the month of September (*Times News Network*, 2009). The estimated cost of the flooding was PhP23 billion (Baunto and Arquiza, 2009) and has placed the nation’s capital and two dozens more provinces into a state of calamity.

These are only some of the recent events pertaining to climate change; however, the phenomenon has already been observed and debated over for a number of years. Thorough studies and analyses have been made on this concern, and “today, it is widely agreed by the scientific community that climate change is already a reality” (The World Bank, 2003). Evidence of global warming and climate change are hard to ignore. Efforts to address, and adapt to, the changing environment have been and still are being undertaken by the international organizations, national governments, academic institutions, and by the research and scientific communities. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established to assess the scientific, technical, and socio-economic evidence relevant to understanding the issue. The first assessment report generated by the IPCC, in August 1990, presented one of the early scientific confirmations of climate change. It further provided the foundation for negotiations on an international response to the problem. Meanwhile, the United Nations Framework Convention on Climate Change, established in the 1992 UN Conference on Environment and Development held in Rio de Janeiro, embodied the international community’s collective response to climate change (Department for International Development, 2004).

Climate change issue is not only a global concern but also a temporal one. Indications of climate variations have been observed in the past and are experienced at present; still, studies further suggest that oscillation will continue in the future. In the September 2007 issue of *Time* magazine, the article “Global warning” stated:

US Government scientists announced that the Arctic ice cap is melting even more rapidly than they had feared; by 2050, 40% of the ice cover in the Arctic Ocean could be gone, a loss that wasn’t supposed to happen for 100 years [...] The 2008 Old Farmer’s Almanac predicts that the coming year will be the warmest in a century (Time.com, 2007).

The examples provided above, in no doubt, have significant effects on the lives of people. Lecocq and Shalizi (2007) summarized the causal chain linking economic behavior today to economic consequences tomorrow via climate change as: economic activities → emissions → concentrations → climate change → impacts on (ultimate damages to) physical and ecological systems and finally → impacts on (ultimate damages to) economies. Meanwhile, Richards (2003) classified in his research the impacts of climate change as direct, i.e. loss of life, livelihoods, assets, infrastructure, etc. from climatic extreme events, and indirect, pertaining to its effect on economic growth. It is foreseen that the continuing climate variation would alter the sectoral origins of growth, and with this, the ability of the poor to engage in the non-farm sector. Furthermore, it will increase inequality and, therefore, would reduce the poverty elasticity of growth.

The IPCC (2001a) Third Assessment Report presented possible consequences from extreme climatic events such as the higher maximum and increasing minimum temperatures, more intense precipitation events, and intensified droughts and floods associated with El Niño events, among others. Temperature variations are expected to increase the incidence of death and serious illness in older age groups and the urban poor; raise the heat stress in livestock and wildlife; create a shift in tourist destinations; worsen the risk of damage to a number of crops; and increase the electric cooling demand and reduce the energy supply reliability. On the other hand, the more intense precipitation events would likely increase flood, landslide, avalanche, and mudslide incidences and damages; aggravate soil erosion condition; and raise the pressure on government and private flood insurance systems and disaster relief. Finally, the intensified droughts and floods are predicted to lessen the agricultural and rangeland

productivity in drought and flood-prone regions and decrease the hydropower potential in drought-prone regions.

Basically, climate change influences all the aspects of human existence – from the phenomenon's direct harm on human life, i.e. deaths and destruction of properties due to extreme conditions and natural disasters, to its effect on man's physical environment, to its indirect influence on the national and global social, economic, and even political structures. From the examples provided earlier, climate variation affects all nations, may they be developed or developing countries; even if they are rich in natural resources or surrounded by deserts; or whether they are located in the north or the south. It does not matter where you are in the world, you will feel the changes. But, the underlying question is who will be most affected of all? Who is the most vulnerable?

Vulnerability is interpreted in various ways, in different fields of studies. When applied to the concept of climate change, no single definition exists; descriptions of vulnerability to climate change depend on diverse interpretations of researchers and experts. Thus, there is neither an accurate nor erroneous use of vulnerability. The significance of the principle lies on the objectives of the study.

This paper is the first phase of a three-stage study on the linkages among climate change, vulnerability, and risks. It aims to develop an analytical framework that exemplifies the interrelationships among these variables; a model that will be the basis of the statistical and econometric analyses in the later stages. The model will primarily work on the premise that nature of climate change affects the vulnerabilities of systems and in turn these vulnerabilities create different types of risks. It intend to identify which type of climate change a system is more at risk to and hence will help analyze the appropriate measures to diminish that risk. By understanding these linkages, systems will be able to adapt to the changes that take place and minimize the costs incurred, may they be social, economic, or whatever form.

In the development of the model, the paper is structured to individually investigate the three primary dimensions and build the linkages among them. Hence, the nature of climate change is examined and the issues emerging from the changes analyzed. This is followed by an intensive study of system vulnerabilities which includes the different perceptions of the concept as well as the various indicators formulated to represent and quantify them. The third factor in the model, risk, is then explored. Afterwards, the conceptual framework, which is the foundation of the model, is devised and the climate change vulnerability risk model is presented.

2. Climate change: a reality

Weather, in simple definition, is the state of the atmosphere in a given time and place, with respect to variables such as temperature, moisture, wind velocity, humidity (rainfall), cloudiness, etc. Even with the unchanging climate conditions, weather changes quickly from day to day, from year to year, in any area. It is inconsistent, thus, has limited predictability. Climate, on the other hand, is the long-term average of the weather condition, over a specific period and area. Climate differs from place to place, depending on the following factors: latitude, distance to the sea, vegetation, presence or absence of mountains, or other geographical features. Climate is also a function of time – it changes from season to season, year to year, decade to decade, or on much longer time scales.

Meanwhile, the “statistically significant variations of the mean state of climate or its variability, typically persisting for decades or longer, are referred to as climate change.”

One of the most obvious manifestations of climate change is the increased surface temperatures[1]. Studies show that the rate and duration of warming observed during the twentieth century are exceptional in the past thousand years. There have been detected rise in maximum temperatures and numbers of hot days, while the heat index has been observed to increase over all continents during the second half of the twentieth century. According to the latest IPCC Climate Change Report, Fourth Assessment (2007), “11 of the last 12 years (1995-2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850).”

Region-wise, records post that Africa is warmer today than it was 100 years ago. Similarly, most of Europe has experienced increases in surface air temperature during the period, to an average of 0.8°C in annual temperature. This warming has been largest over northwestern Russia and the Iberian Peninsula and stronger in winter than in summer (IPCC, 2001a). Consistent with the global warming trend, the Asia/Pacific region also experienced temperature rise in the twentieth century. Specifically, Southeast China warmed by 1-2°C, the Tibetan Plateau by 0.16-0.32°C (per decade), Vietnam by 0.32°C (over the past three decades), and Sri Lanka and tropical India by 0.30°C and 0.68°C, respectively, while coastal Pakistan warmed by 0.6-1.0°C. Collectively, Central Asia warmed by approximately 0.1-0.2°C per decade, suggesting warming of 1-2°C over the past 100 years (Preston *et al.*, 2006). Meanwhile, Australia and New Zealand's mean temperatures have risen by 0.05-0.1°C per decade over the past century, with a corresponding climb in the frequency of very warm days and fall in the incidence of frosts and very cold days (IPCC, 2001a).

Accompanying the temperature change is the variability in precipitation. Highly dependent on temperature, precipitation is the general term for rainfall, snowfall, and other forms of frozen or liquid water falling from clouds. Observations showed that changes are occurring in its amount, frequency, intensity, and type. These aspects of precipitation normally show great natural unpredictability, but analyses confirm that the El Niño-Southern Oscillation[2] (ENSO) and changes in atmospheric circulation patterns such as the North Atlantic Oscillation[3] (NOA) have significant influence in the occurrence of recent noticeable changes. From 1900 to 2005, there have been long-term trends in the amount of precipitation in some areas. It has been considerably wetter in eastern North and South America, northern Europe, and northern and central Asia, in contrast to the drier conditions in the Sahel, southern Africa, the Mediterranean, southern Europe, and southern Asia. Furthermore, more precipitation now falls in the form of rain rather than snow in northern regions. There has also been extensive rise in heavy precipitation events, even in places where total amounts have decreased. These changes are linked with increased water vapor in the atmosphere arising from the warming of the world's oceans, especially at lower latitudes (IPCC, 2007a).

There is a contrast in the annual precipitation trends between northern Europe (wetting) and southern Europe (drying). In the twentieth century, precipitation over northern Europe has increased by 10-40 percent, while some parts of southern Europe have dried by as much as 20 percent. This fall relates to a decline in the number of days with precipitation over the Spanish southern coast, by 50 percent, and the Pyrenees region, by 30 percent, in the period of 1964-1993. In Italy, total precipitation has decreased by about 5 percent in the north and by about 15 percent in the south (IPCC, 2001a). In Asia, rainfall trends have been difficult to interpret as some areas experienced decreases while others, the reverse. Specifically, there has been a decline in

the annual average rainfall in the coastal margins and arid plains of Pakistan, the east coast of India, Indonesia, and Thailand, while an increase in western and southeast coastal China, Bangladesh, the Philippines, and the Korean Peninsula is observed (Preston *et al.*, 2006).

Precipitation in the Latin American region is highly influenced by the extremes of the ENSO. In Mexico and parts of the Caribbean, the ENSO signal corresponds to more winter precipitation and less summer precipitation. And like in most parts of the globe, the ENSO events in Columbia are associated with reductions in precipitation; conversely, La Niña[4] is associated with heavier precipitation and floods. Likewise, short rainy seasons have been recorded in the northern Amazonia and northeast Brazil. Precipitation irregularities are also commonly observed over the eastern part of the Andes, Ecuador, and northern Peru during the warm episodes. The same ENSO influence is assumed over the variations in the precipitation in some parts of Australia and New Zealand, though the strength of the relationship between Australian climate and ENSO has been observed to vary over the past century (IPCC, 2001a).

With the rise in temperature and anomalies in precipitation, it is believed that there has been significant variation in the tropical storm and hurricane frequency and intensity, and the ENSO is considered to greatly affect the location and activity of tropical storms around the world. Estimates of the potential destructiveness of hurricanes exhibit a considerable rising pattern since the mid-1970s, with a trend suggesting an increase in storm duration and intensity. Analysis shows that the activity is strongly correlated with tropical sea surface temperature. Moreover, there has been a great escalation in the incidence and proportion of strong hurricanes globally since 1970; specifically, the number of category 4 and 5 hurricanes rose by about 75 percent. The largest increases were experienced in the North Pacific, and Indian and Southwest Pacific Oceans (IPCC, 2007a).

3. Vulnerability and climate change

3.1 Vulnerability and its components

One of the chief concerns commonly associated with climate change is vulnerability. Vulnerability has a complex relationship with this occurring climate variability, such that it encompasses an extensive range of areas and involves a number of factors. To have a better grasp at the concept, this section will first investigate the different definitions that identify vulnerability and later on examine the issues surrounding it.

The etymology of vulnerability can be traced back to the Latin words *vulnus*, meaning “a wound”, *vulnerare*, “to wound”, and *vulner-*, *vulnus* which mean “wound” The late Latin term, *vulnerabilis*, referred to a wounded soldier, i.e. already injured and vulnerable to death. The Merriam-Webster dictionary defines vulnerability as “capable of being physically or emotionally wounded”. From these roots, all core vulnerability concepts convey the same thought, involving ideas of wound, injury, and harm, though worded differently and expounded to include other factors. These descriptions generally involve a “stimulus” which creates the harm to a “system” which receives it. The vulnerability concept gained grounds in research circles analyzing risks and hazards, climate impacts, and resilience (Turner *et al.*, 2001, as cited in Maxim and Spangenberg, 2003). It has been extensively applied in the physical and social sciences’ studies dealing with hazards, climate change, health, epidemiology, crime, military planning, ecology, and engineering (Ford, 2002). Hence, the definition of vulnerability became diverse,

and in some cases the ideas incompatible, depending on the significance and use of the term by different research communities from which it originated.

Most researchers believe that there is “no single ‘correct’ or ‘best’ conceptualization of vulnerability”, though many definitions of the basic concept exist (Fussel, 2005; Maxim and Spangenberg, 2003). Frameworks have been built around it, creating different relationships between and among numerous factors. The main contention among these descriptions stems from the varying elements that compose and are included in the study of vulnerability. For instance, social scientists view vulnerability to involve socio-economic factors that influence people’s ability to cope with environmental hazards. In this context, vulnerability is a “state of the system before the hazard acts” or is the “starting point” of analysis. This notion places a stress on the components of the social system that turn an external stimulus into a disaster. Meanwhile, climate scientists generally regard vulnerability in terms of the probability of occurrence and impacts of the hazard. Thus, the concept is considered as the “likelihood and outcome of the hazard” or the “end point” for analysis. This approach is based on the traditional risk analysis that emphasizes on the probability and size of the damage. It places an importance on the bio-geo-science factors that determine the hazard challenging the system, the frequency of its occurrence, and the natural factors influencing its effects (Maxim and Spangenberg, 2003; O’Brien *et al.*, 2004).

These two concepts are summarized into the types of vulnerability namely, the social (socio-economic) and the biophysical. Cutter (1996, as cited in Cocklin, 1998) defined social vulnerability as the “social and institutional capacities that determined both susceptibility to, and the ability to cope with, hazards and environmental change.” On the other hand, biophysical vulnerability refers to the “potential for loss from natural hazards, environmental variability, and change” (Cocklin, 1998). There are some researchers who treat the natural and socio-economic factors as interrelated concepts wherein one determines the other, i.e. natural vulnerability as one of the determinants of socio-economic vulnerability (Klein and Nicholls, 1999, as cited by Fussel, 2005) or social vulnerability as one of the determinants of biophysical vulnerability (Brooks, 2003). Conversely, Cutter (1996) considers the biophysical and the social dimension of vulnerability as independent from one another (as cited by Fussel, 2005).

Clearly, there are variations on how vulnerability is conceptualized; these create the inconsistencies on each of the vulnerability factor’s significance. Recognizing the divergence in vulnerability concepts, Fussel (2005) analyzed the cause of the discrepancies. By combining the different aspects of the conceptual structures, he was able to develop a new approach in viewing vulnerability. Fussel identified four fundamental dimensions of a vulnerable assessment, namely:

- (1) the system (or region and/or population group and/or sector of concern);
- (2) the hazards (or threats or stressors) considered;
- (3) the valued attribute (or variables of concern of the vulnerable system that are threatened by its exposure to the hazard); and
- (4) a temporal reference (or the time period of concern).

Thus, he proposed the description of a vulnerable situation to be the “vulnerability of a system’s valued attribute(s) to a hazard (in temporal reference)”. Further examination of the matter led him to conclude that the terminologies become incompatible due to the

“failure to distinguish between two largely independent dimensions of vulnerability (or risk) factors, scale and disciplinary domain”.

Fussel’s investigation determined the various factors surrounding the concept of vulnerability. According to him, some researchers have distinguished two facets of vulnerability, which are the external and internal sides. Others, as discussed earlier, identified vulnerability to be biophysical (or natural) and social (or socio-economic). In Fussel’s model, the internal and external elements enter in the scale dimension. On the other hand, the disciplinary domain includes the socio-economic and biophysical components. In this context, internal vulnerability factors pertain to characteristics of the vulnerable system or community itself, including those features that can be controlled by the considered community, i.e. land use within their jurisdiction, while all other vulnerability factors are denoted as external. Socio-economic vulnerability factors, meanwhile, are those associated to the following: economic resources, the distribution of power, social institutions, cultural practices, and other characteristics of social groups usually examined by the social sciences and the humanities. Biophysical vulnerability factors, in contrast, are those related to system properties investigated by the physical sciences. Sometimes, these two factors overlap.

Basically, Fussel’s analysis of the assorted conceptual frameworks identified six dimensions of vulnerability which need to be carefully considered in generating vulnerability assessments. These dimensions are:

- (1) temporal reference (current vs future vs long term);
- (2) scale (internal vs external vs cross-scale – combinations of internal and external);
- (3) disciplinary domain (socio-economic vs biophysical vs integrated – combinations of socio-economic and biophysical);
- (4) vulnerable system;
- (5) valued attribute; and
- (6) hazards.

3.2 Vulnerability to climate change

Vulnerability has also been defined as the “measure of the degree to which a system maybe harmed in response to a stimulus”. Treating climate change as the stimulus to the probable damage to a system determines vulnerability as the risk to exposure. With this, vulnerability is highly dependent on the nature of this stimulus, in terms of magnitude, frequency, spatial distribution, duration, and its implications for exposure. Researches are primarily concerned with the changing nature of this stimulus and the impacts of these changes in the biophysical systems (Ford, 2002).

This kind of vulnerability description is similar to that of the IPCC’s (2001a), wherein the nature of climate change and the system exposure play significant roles – “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”. This definition expands vulnerability’s linkages as it introduces concepts of sensitivity and adaptive capacity, in addition to exposure. The IPCC considers sensitivity as the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. These stimuli cover all the elements of climate change, including the mean climate characteristics, climate variability, and the frequency and magnitude of extremes. The effect may be direct – a change in crop yield in response to a change in the mean, range,

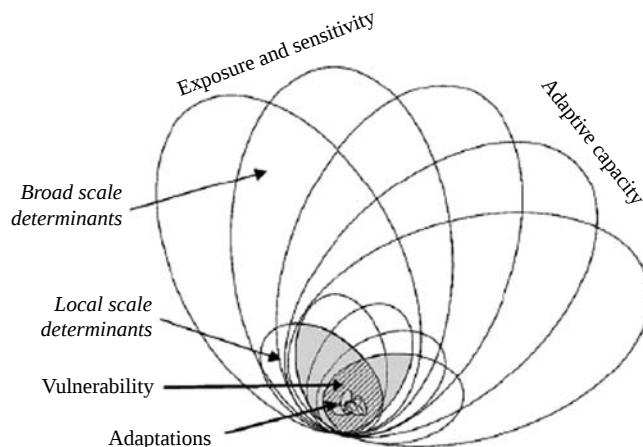
or variability of temperature – or indirect – damages caused by an increase in the frequency of coastal flooding due to sea-level rise. According to Smit and Wandel (2006), exposure and sensitivity are “almost inseparable properties of a system (or community) and are dependent on the interaction between the characteristics of the system and on the attributes of the climate stimulus.”

Adaptive capacity, meanwhile, is the ability of a system to adjust to climate change in order to take advantage of opportunities or to cope with the consequences brought about by the change (IPCC, 2001a). Adaptive capacity is also synonymous to a number of concepts such as adaptability, coping ability, management capacity, stability, robustness, flexibility, and resilience. The forces that influence the ability of the system to adapt are the drivers or determinants of adaptive capacity (Smit and Wandel, 2006).

A simple description of vulnerability involves two players, the – “stimulus” and the “system”; however, the exposure, sensitivity, and adaptive capacity concerns intensify the depth of vulnerability to include multiple aspects of the system and the nature of the stimuli.

Figure 1 shows the basic vulnerability relationships as developed by Smit and Wandel (2006). The larger sets of the Venn diagram signify the broader stresses and forces that determine exposure and sensitivity and also shape the adaptive capacity at the local or community level (denoted by the smaller embedded sets). The interaction of environmental and social forces determines exposures and sensitivities, while the different social, cultural, political, and economic forces form the system’s adaptive capacity. The overlap among these factors acknowledges that the processes driving exposure, sensitivity, and adaptive capacity are frequently related and interdependent. The finer scale interaction of these elements represents local vulnerability, and adaptations are particular expressions of the inherent adaptive capacity. In this context, a system (e.g. a community) that is more exposed and sensitive to a climate stimulus, condition, or hazard will be more vulnerable, *ceteris paribus*; and a system that has more adaptive capacity will tend to be less vulnerable, *ceteris paribus*.

The forces that influence the ability of the system to adapt are the drivers or determinants of adaptive capacity. These fundamentals are considered to be non-static,



Source: Smit and Wandell (2006)

Figure 1.
Vulnerability components
and their relationships

consequently, result to a significant characteristic of adaptive capacity – being dynamic. Adaptive capacity of a system is not fixed; it changes from area to area, among social groups and individuals, and over time.

The economic conditions of countries or groups are considered one of the determinants of their adaptive capacities, whether they are in the forms of economic assets, capital resources, financial means, wealth, or poverty, creating the notion that rich countries are better equipped to endure the costs of climate change impacts and risks than poor nations. It is also acknowledged that poverty is directly related to vulnerability, though the two should not be considered synonymous. Poverty, in this sense, is considered “a rough indicator of the ability to cope” (Dow, 1992, as cited in IPCC, 2001a). Several studies have confirmed this relationship between poverty and vulnerability, one of which is the research of Deschingkar (1998, as cited in IPCC, 2001a). According to his paper, the situation in which pastoralist communities in India are “locked into” a vulnerable situation is partly due to their lack of financial power enabling them to diversify and engage in other sources of income. This finding coincides with that of Kelly and Adger’s (1999) wherein “poor regions tend to have less diverse and more restricted entitlements and a lack of empowerment to adapt”. Furthermore, other studies provided pieces of evidence that prove that poorer nations and disadvantaged groups within nations are especially vulnerable to disasters and hazards (IPCC, 2001a).

The availability (and lack) of technology and infrastructures is also a significant factor of a system’s adaptive capacity. These two components measure the limitation of the system and, therefore, can either hinder or abet one’s capabilities to implement adaptation options. A number of the adaptive strategies developed to manage climate change generally include technological components such as the existence of warning systems, protective structures, crop breeding and irrigation, settlement and relocation or redesign, and flood control measures. Moreover, vital to strengthening the adaptive capacity is the openness of the system to the development and utilization of new technologies for sustainable extraction, use, and development of natural resources (Goklany, 1995, as cited in IPCC, 2001a). In the same way, infrastructure facilities influence one’s adaptive capacity as they determine the access of the system to resources.

Information has always been a vital component in developing strategies. In the climate change scenario, better knowledge on weather hazards and the nature of changes enables a system to study, analyze, plan, and implement adaptation measures. Systems are able to better strategize, thus improving their adaptive capacities. Similarly, communities or nations with well-developed social institutions are considered to have a greater adaptive capacity, than those with less effective institutional arrangements. Institutions are defined as public system of rules that specify certain forms of action permissible, others as forbidden, and provide for certain penalties and defenses when violations occur (Runge, 1984). Under well-organized institutions and institutional arrangements, systems are able to adjust and quickly adapt to the changes that may occur. Studies by Kelly and Adger (1999) in Vietnam, Huq *et al.* (1999), and Baethgen (1997) in Latin America illustrated how the institutional constraints, weaknesses, and deficiencies affected the vulnerabilities of the said areas (as cited in IPCC, 2001a).

Thornton *et al.* (2006) summarized the determinants of adaptive capacity to be:

- economic resources;
- technology;

- information and skills;
- infrastructure;
- institutions; and
- equity.

Greater economic resources improve the adaptive capacities of systems while the lack of them limits the adaptation alternatives. Similarly, the technological deficiency restricts the range of adaptation options; thus, the technologically challenged regions are less likely to incorporate technological adaptations. This notion is congruent to the availability of information the level of skilled personnel and the development of infrastructures in a system. Meanwhile, advanced or well-established social institutions and the equitable distribution of resources enhance the adaptive capacity and one's potential to mitigate climate-related risks.

3.3 Vulnerability indicators

All the factors discussed in this section can be generally categorized into three classifications, the social (socio-economic), biophysical, and technological (Chambers, 1989 and Bohle *et al.*, 1994, as cited in Thornton *et al.*, 2006). And as shown in Figure 1, the forces affecting adaptive capacity are related and interdependent to the determinants of exposure and sensitivity. Thus, vulnerability can also be grouped into the same three categories.

Among the vulnerability classifications, social vulnerability is the aspect investigated by most authors, and there is a general agreement among literatures regarding the perception on this type of vulnerability. Social vulnerability is typically illustrated by the characteristics inherent to the system; it is the vulnerability which exists within, before it encounters a hazard event.

Social vulnerability influences how a unit will respond to the changing exposures and affects the degree by which the system will be affected by the said exposure (Ford, 2002). Philip and Rayhan (2004) identified the following factors to be causes for a high vulnerability: rapid population growth, poverty and hunger, poor health, low levels of education, gender inequality, fragile and hazardous location, and lack of access to resources and services, including knowledge and technological means, and disintegration of social patterns. Others, like Dao and Peduzzi (2003) and Brooks *et al.* (2005), view the economic, health and nutrition, education, governance, agriculture, demographic, sanitation, political, and development indicators to compose social vulnerability. And due to the significance of this type of vulnerability, indices to measure it and quantify the sensitivity of a system have been developed to aid in estimating the present and future climate change impacts. Authors like Vincent (2004) and Leichenko *et al.* (2004) were among those who created social vulnerability indices for these purposes, along with organizations like The Energy Resource Institute (TERI). Comparison of the different components used in estimating the various vulnerability index versions showed one common key factor – the people. That is, social vulnerability signifies the characteristic of the system as influenced by the actions of the people, as they function within the system. Some indicators characterize the:

- people's sources of income;
- economic well-being;
- poverty status;

- demographic properties;
- health and educational status;
- state of governance; and
- institutional conditions (Table I).

On the other hand, biophysical vulnerability is generally associated with the end-point approach of vulnerability analysis. In studies that provide comparisons of climate change costs and greenhouse gas mitigation, the emphasis lies on biophysical vulnerability “whereby the most vulnerable are considered to be those living in the most precarious physical environments or in environments that will undergo the most dramatic physical changes” (O’Brien *et al.*, 2004). Thus, this type of vulnerability involves the physical sciences, in terms of examining the natural characteristics of areas by which the hazards may affect. Meanwhile, Cutter *et al.* (2000) consider biophysical vulnerability in the geographic context. In this sense, the “geographic filter includes the site and situation of the place and its proximity to the hazard sources and events”. Hence, in their study, biophysical vulnerability was measured by the event frequency and the delineation of the hazard zones. The paper of Leichenko *et al.* (2004) illustrates the composition of biophysical vulnerability through the index they have constructed. The biophysical vulnerability index has two dimensions namely, the soil quality and the ground water scarcity indexes. Soil quality encompasses depth or soil cover and soil degradation severity, while ground water scarcity deals with the replenishable groundwater available for future use.

Biophysical vulnerability, according to Brooks (2003), focuses more on the impacts of extreme events and is usually regarded in terms of the amount of harm experienced by a system as a consequence of an encounter with a hazard. According to him, this type of vulnerability is a function of four factors, namely, the nature of the physical hazard, the frequency of occurrence of the hazard, the extent of human exposure to the hazard, and the system’s sensitivity to the impacts of the hazard. Jones and Boer (2003, as cited in Brooks, 2003), similarly, defined biophysical vulnerability in terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard. This approach is basically associated with the traditional risk analysis whose primary concern is the probability and the size of the damage. In this case, bio-geo-science factors matter and that the vulnerability of systems or people to natural hazards is dependent on their locations (where they reside) and the resources they have to cope with. In general, biophysical vulnerability is a function of sensitivity and exposure, and “depending on the time scale related to an observed impact and its severity, a system can be called biophysically vulnerable or not” (Maxim and Spangenberg, 2003).

In the broad sense, technological vulnerability refers to the probability that a technological system may fail due to external forces. A technological system is considered resilient against a specific threat if it is able to maintain its purposes when exposed to the threat (Martin, 1996). Technological vulnerability has not been traditionally related to climate change. Early studies generally focused on the biophysical and social types of vulnerability, leaving the technological abilities of a system outside the analysis. This type of vulnerability, however, gains its significance through the concept of adaptive capacity. Hence, the availability (and lack) of technology and infrastructures are vital factors to be considered in climate change investigations. They gauge the limitations of the system, affecting its ability to execute adaptation options. Some of the indicators used

Author	Indicators	Description
Vincent (2004) ^a	Economic well-being sub-index: standard of living/poverty and percent change in urban population; demographic structure: dependency ratio and proportion of working population with HIV/AIDS; Institutional stability and strength of public infrastructure: health expenditure, number of telephones, corruption; global interconnectivity: trade balance; natural resource dependence: rural population	Index has been generated weighted average of five composite sub-indices: economic well-being and stability, demographic structure, institutional stability and strength of public infrastructure, global interconnectivity and dependence on natural resources
TERI ^a	Agricultural dependency index: percent of district workers employed in agriculture; landless index: percent of landless laborers in agricultural workforce; education index: adult literacy rate (greater than seven years); female disadvantage index: "Missing girls", i.e. < 48.5 percent girls in 0-6 population; female literacy and child survival index: female literacy rate	Composite index formulated that represents the following dimensions: agricultural dependency, vulnerability of the agricultural workforce, human capital, female disadvantage and female literacy and child survival chances
Dao and Peduzzi (2003)	Economic: gross domestic product per inhabitant at purchasing power parity, human poverty index, total dept service (percent of the exports of goods and services), inflation, food prices (annual percent), unemployment, total (percent of total labor force); type of economical activities: percentage of arable land, percentage of urban population, percentage of agriculture's dependency for GDP, percentage of labor force in agricultural sector; demography: population growth, urban growth, population density, Age dependency ratio; health and sanitation: average calorie supply per capita, percentage of people with access to adequate sanitation, percentage of people with access to safe water (total, urban, rural), number of physicians (per 1,000 inh.), number of hospital beds, life expectancy at birth for both sexes, under five-year old mortality rate; politic: transparency's CPI (index of corruption); education: illiteracy rate, school enrolment, secondary (percent gross), labor force with primary, secondary or tertiary education; development: human development index	Parameters that reflect the socio-economic vulnerability

(continued)

Table I.
Social vulnerability
components

Table I.

Author	Indicators	Description
Brooks <i>et al.</i> (2004)	Economy: GDP per capita (US\$ PPP), GINI coefficient, debt repayments (percent GNI, averaged over decadal periods), GNI (total, PPP); health and nutrition: health expenditure per capita (US\$ PPP), public health expenditure (percent of GDP), disability adjusted life expectancy, life expectancy at birth, maternal mortality per 100,000, AIDS/HIV infection (percent of adults), calorie intake per capita, food production index, food price index; education: expenditure as percent of GNP, education expenditure as percent of government expenditure, literacy rate (percent of population over 15), literacy rate (percent of 15-24-year olds), literacy ratio (female to male); governance: internal refugees (1,000s) scale by population, control of corruption, government effectiveness, political stability, regulatory quality, rule of law, voice and accountability, civil liberties, political rights; agriculture: agricultural employees (percent of total population), rural population (percent of total), agricultural employees (percent of male population), agricultural employees (percent of female population), agricultural production index	Indicators representing the economy, health and nutrition, education, governance and agriculture

Note: ^aEstimated a social vulnerability index

to determine technological vulnerability involve the existence (and absence) of warning systems, protective structures, crop breeding and irrigation, settlement and relocation or redesign, and flood control measures.

Leichenko *et al.* (2004) presented a concrete example of how this type of vulnerability can be measured. The technological vulnerability index they created was computed by utilizing indicators that measure the area's technological capacity or access to technology helps in examining the overall vulnerability of districts in India. To illustrate, the irrigation rate, as quantified by the net irrigated area as percentage of sown area, determines the farmer's vulnerability to low and erratic rainfall since water scarcity is the chief productivity constraint for Indian agriculture. On the other hand, it is believed that districts with better infrastructures have a greater capacity to adapt to climate change, thus the measurement of the infrastructure development index.

3.4 Institutional vulnerability

One element that gained significance from the climate change phenomenon is coined as institutional vulnerability. North (1993) defined institutions as:

[...] the humanly devised constraints that structure human interaction. They are made up of formal constraints (rules, laws, constitutions), informal constraints (norms of behavior, conventions, and self-imposed codes of conduct), and their enforcement characteristics.

Institutions are also defined as public system of rules that specify certain forms of action permissible, others as forbidden, and provide for certain penalties and defenses when violations occur (Runge, 1984). They are set of working rules that are used to determine who is eligible to make decisions in some arena, what actions are allowed or constrained, what aggregation rules will be used, what procedures must be followed, what information must or must not be provided, and what payoffs will be assigned to individuals dependent on their actions (Ostrom, 1990). Institutions are deemed powerful instruments in molding individual into collective actions. They transform belief structures into societal and economic structures, both the formal rules and the informal norms of behavior. As North (1993) stated:

[...] The relationship between mental models and institutions is an intimate one. Mental models are the internal representations that individual cognitive systems create to interpret the environment; institutions are the external (to the mind) mechanisms individuals create to structure and order the environment.

As mentioned earlier, institutions are composed of formal and informal constraints. The former is defined to be the rules that people devise intentionally, while the latter are the norms, conventions, and code of ethics that societies automatically evolve over time. They are seen as a result of complex process of evolution, and not of any purposive action (North, 1990, as cited in Hasan, 2000). In the realm of climate change, these rules can be viewed as arrangements rather than constraints. The coordinating function of institutions is heightened through the arrangements that build the expectations of people from others. "Institutions reduce uncertainty of people by defining and stabilizing their expectations". Uncertainty, on the other hand:

[...] comes from incomplete information about the behavior of other individuals in the process of human interaction. Even if complete information was available, individuals have limited mental capacity to process, organize, and utilize information-bounded rationality. This bounded rationality, combined with uncertainty in deciphering the environment, implies

the need to develop the regularized pattern of human interactions called institutions” (Runge, 1984, and North, 1990, as cited in Hasan, 2000).

Thus, institutions deal with individuals, communities, organizations, and society in general, and to a great extent, the government that primarily provides the formal arrangements.

Institutions and institutional analysis have been proven to be significant in the context of climate change. In a study conducted by Agrawal *et al.* (2008), local institutions were determined to be crucial in molding adaptive capacities of systems. They are the essential links that connects households to local resources and collective action; determine flows of external support to different social groups; and relate local populations to national interventions. Local institutions, in this case, are defined to be the civic (rural producer organizations, cooperatives, savings and loan groups, etc), public (local government, local agencies like extension services, and other arms of higher levels of government operating and local levels), and private (non-governmental organizations, charities, private businesses that provide insurance and loans) formal and informal institutions. They characterize the impacts of climate hazards to the livelihoods of people through their functions in disseminating and gathering information, mobilizing and allocating resources, developing skills and building capacities, providing leadership, and networking with other decision makers and institutions. One interesting discovery of this study is the significance of informal institutions in developing the system’s adaptive capacity. By reviewing 118 cases of adaptation in 46 countries, Agrawal *et al.* showed that most of the local civil society institutions involved in climate change adaptation are the informal ones, especially those associated to labor sharing, indigenous information exchanges, savings societies, commons institutions, and indigenous knowledge institutions around migration and storage. Moreover, the study also classified local adaptation responses to climate variability into the following categories:

- mobility that the movements of various types of adaptation in response to risks and scarcities;
- storage of past surpluses against future livelihood failures;
- diversification in relation to on and off employment opportunities, productive and non-productive assets, and consumption strategies;
- communal pooling that refers to adaptation responses involving joint ownership and sharing of wealth, labor, or income across households, or mobilization of resources held collectively during times of scarcity; and
- market exchange which is perceived to be the most versatile mechanism for adaptation and requires well-developed markets, exchange instruments, and widespread access.

Basically, adaptation to climate change rests on the arrangements that determine the collective action of individuals in the systems. These institutional arrangements shape the system’s adaptive capacity and consequently determine its vulnerability. This strengthens the concept shown in Figure 2[5] and reinforces the significance of institutions to vulnerability, hence the institutional vulnerability.

In the climate change framework, institutional vulnerability consists of knowledge development with regard to the phenomenon. This involves the questions on whether societies are aware of the changing climate and to what degree. It also deals with the

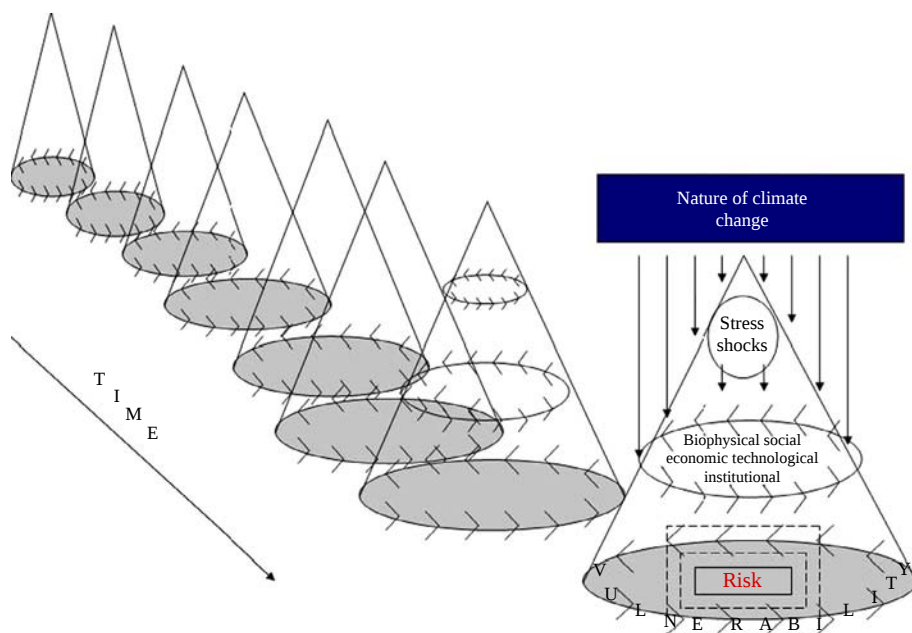


Figure 2.
Climate change
framework

organized programs of societies and governments to address the issue, and the practices and policies established to adapt. According to Haanpää and Peltonen (2007), the:

[...] institutional aspect of vulnerability can be defined as the awareness on the effects of climate change, long term institutional preparedness and possibilities for adaptation, in terms of spatial planning practices, co-operation and dissemination structures.

Unlike the study of Agrawal *et al.* (2008) which concentrated on local institutions, Haanpää and Peltonen performed a macro-level analysis of institutions. And though the two studies approached the analysis of institutions in different angles, they both agree on the strong relationship between institutions and adaptive capacity. In fact, Haanpää and Peltonen further associated institutional vulnerability to the five aspects of adaptive capacity, namely the capacities to:

- (1) formulate policies, legislations, strategies, and programmes;
- (2) implement policies, legislations, strategies, and programmes;
- (3) engage and build consensus among stakeholders;
- (4) mobilize information and knowledge; and
- (5) monitor, evaluate, and learn[6].

Using these aspects as criteria, they analyzed the institutional vulnerabilities of eight countries in the Baltic Sea Region on three levels – systematic, organizational, and individual.

The types of analyses applied in the two researches insinuate that the study of institutional vulnerability is a complex endeavor and that examination of individual components of this type of vulnerability is not sufficient to arrive at a

definitive conclusion. The various factors that compose institutional vulnerability must be juxtaposed, combined, and investigated on different angles to determine the overall situation of a system. Moreover, the level of analysis should also be clear. The institutional vulnerability in the local or micro-environment is not reflective of the type or the existing vulnerability in the macro-level.

Comparatively speaking, among all the types of vulnerabilities, social, economic, biophysical, and technological, institutional vulnerability is the only type which did not stem out from the inherent characteristic of the system, but one which emerged due to the existence of climate change. Institutional vulnerability is measured through the systems' ability to cope and adapt to the climate variability and will be evaluated in the systems' response to it. In this sense, it can be viewed as an internalized externality, a product of the external climate change variable which became an internal process due to the need of systems to adapt.

4. Risk and climate change

4.1 Vulnerability and risk

Risk is generally defined in relation to a hazard and is described to be probabilistic in nature. Specifically, it is either:

- the probability of occurrence of a hazard that acts to trigger a disaster or series of events with an undesirable outcome; or
- the probability of a disaster or outcome, combining the probability of the hazard event with a consideration of the likely consequences of the hazard (Brooks, 2003; Brooks *et al.*, 2005; Sarewitz *et al.*, 2003).

In some of the definitions presented in Table II, the vulnerability-risk relationship is explicit. Adger *et al.* (2004) pointed out that:

[...] where vulnerability is included in the definition of risk, it is viewed as distinct from hazard: it is, therefore, social vulnerability that is being referred to. Risk defined as a function of hazard and social vulnerability is compatible with risk defined as probability $\times$ consequence, and also with risk defined in terms of outcome. The probability of an outcome will depend on the probability of occurrence of a hazard and on the social vulnerability of the exposed system, which will determine the consequence of the hazard.

Thus, the presence of risk is dependent on the existing vulnerability.

This relationship is also apparent in quantitative presentation of risk, as given by the equations of Dao and Peduzzi (2003) wherein risk is a function of hazard occurrence probability, element at risk (population), and vulnerability:

$$0 \text{ (hazard)} \times \text{population} \times \text{vulnerability} = 0 \text{ (Risk)} \quad (1.1)$$

Risk is a product of all the three factors; thus, if there is no hazard or externality introduced in the system, then risk is non-existent. Similarly, the risk is also zero if the area exposed to the hazard is unpopulated (population = 0) or if the population is not vulnerable (vulnerability = 0):

$$R = H * \text{Pop} * \text{Vul} \quad (1.2)$$

where:

Author	Definition
Adams (1995) ^a	"A compound measure combining the probability and magnitude of an adverse affect"
Asian Development Bank (2005)	The combination of a hazardous event occurring and the impact or consequence of that event
Crichton (1999) ^a	"Risk is the probability of a loss and depends on three elements, hazard, vulnerability and exposure"
Dao and Peduzzi (2003)	Potential losses (casualties) resulting from expected future hazard
IPCC (2007b)	Probability × consequence
Sarewitz <i>et al.</i> (2003)	Integrates both the characteristics of the system and the chance of the occurrence of an event that, jointly, result in losses
Smith (1996) ^a	Probability × loss (probability of a specific hazard occurrence) Hazard = potential threat
Stenchion (1997) ^a	"Risk might be defined simply as the probability of occurrence of an undesired event [but might] be better described as the probability of a hazard contributing to a potential disaster [...] importantly, it involves consideration of vulnerability to the hazard"
UNDHA (1992) ^a	"Expected losses (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the product of hazard and vulnerability"
UNDRO (1979) ^b	Risk results from three components: hazard occurrence probability, defined as the probability of occurrence of a specified natural hazard at a specified severity level in a specified future time period, elements at risk, an inventory of those people or artifacts which are exposed to the hazard and vulnerability, the degree of loss to each element should a hazard of a given severity occur

Note: ^aRisk definitions cited by Brooks (2003, Table 1) and Adger *et al.* (2004, Table 3, p. 32)

Source: ^bAs cited in Dao and Peduzzi (2003)

Table II.
Risk definitions

- R risk, i.e. the expected human impacts (number of killed people).
- H hazard, which depends on the frequency and strength of a given hazard.
- Pop population living in a given exposed area.
- Vul is the vulnerability and depends on socio-politico-economical context of this population.

Equation (1.2) was further expounded to include the physical exposure component defined to be the combination of both the frequency and the population exposed to a given magnitude of a selected type of hazard. The $H*Pop$ component of Equation (1.2) was substituted by physical exposure, resulting to:

$$R = PhExp * Vul \quad (2)$$

where:

- PhExp physical exposure, i.e. the frequency and severity multiplied by exposed population.

This direct link between vulnerability and risk implies that a decrease in the level of vulnerability will decrease the risk confronted by the system, and vice versa, holding

all other factors constant. Moreover, a system is not at risk to any kind of externality if its vulnerability is zero, regardless of the behavior of the other risk components. Similarly, Sarewitz *et al.* (2003) stated that the vulnerability-risk relationship is not commutative: “reduced vulnerability always means reduced outcome risk[7], but reducing the outcome risk does not always reduce vulnerability”. They believe that in addressing the prospect of disasters, policy discussions must not only focus on strategies of risk assessment but on vulnerability management as well. Kaspersen *et al.* (2001) agree with this notion and stated that it is essential to assess vulnerability as an integral part of the causal chain of risk and to appreciate that altering vulnerability is one effective risk-management strategy (as cited in Adger *et al.*, 2004).

4.2 Climate change risks and impacts

Studies have been conducted to determine the kind of risks and impacts associated with climate change. These risks adversely affect people, directly or indirectly. The changes in the intensity and frequency of rainfall and temperature and the occurrence of extreme weather events could trigger potentially dramatic increases in chronic poverty, hunger, disease, mortality, displacement, and violent conflict in many developing countries (Heltberg *et al.*, 2008). Moreover, climate variability and change pose risks to ecosystems, social and cultural systems, and economic systems (Scheraga and Grambsch, 1998). It is perceived that these risks can only be mitigated by adaptation measures. In fact, others say that the only certain way of reducing risk is through a combination of adaptation and mitigation strategies, the purpose of the latter being to reduce hazards (Brooks, 2003).

Scheraga and Grambsch (1998) view that for adaptive responses to be effective, important issues must be considered; they presented nine principles for designing adaptation policies. Two of these principles – the effects of climate change vary: by region and across demographic groups – illustrate the specificity feature of adaptive measures. One measure perceived applicable to a system should not be assumed appropriate in another. Consequently, the risks to climate change may also vary from one system to another. Adger *et al.* (2004) discussed this by distinguishing between the generic and the specific adaptive capacities. Adaptation process is determined, to a large extent, by the nature of the hazard to which a system or population must adapt to. However, it also depends on the inherent characteristics of the system as there are certain factors that make it particularly vulnerable to specific types of hazard. Similarly, other factors may determine a system to have a high capacity to adapt to some hazards, but not to others. Since vulnerability determines risk, therefore, depending on its characteristics, systems may be at risk to specific hazards, but may be unaffected by others. Emphasis on the “risk of occurrence of any particular hazard or extreme event” is what Sarewitz *et al.* (2003) defined as an “event risk.”

Still depending on the system’s characteristics, some of its components may be at risk and some may not. Therefore, systems face different risks; health concerns may be a priority in a highly populated area and this may be compounded by occurrence of deaths. On the other hand, economic risks may be encountered by an agricultural community, while ecological risks are the main concern of a system with rich biodiversity. These types of risk were identified by Sarewitz *et al.* (2003) to be the “outcome risk” or the risk of a particular outcome. Outcome risk “integrates both the characteristics of a system and the chance of the occurrence of an event that jointly results in losses.” It can be observed

that while the event risk is associated with the occurrence of climate change, outcome risk is related to the impacts of such occurrence.

The potential effects of climate change may be on human, animal, or plant lives. It affects societies, ecosystems, and biodiversity. Meanwhile, the variability in weather can also result to deaths and thus the mortality impact of the externality. Resources or the natural environment are also at risk; climate change affects the land, water, forest, and many other components that constitute the livelihood of rural populations in developing countries (Adger *et al.*, 2004). These impacts trickle down to the industries dependent on these resources such as agriculture, fishery, forestry, and tourism, among others, hence the economic risks faced by systems. Furthermore, these effects may transcend to problems in water and food security and the displacement of people and settlement.

Impacts of climate change also include the demographic aspect of systems such as the size of their populations and their age categories; health issues emerge based on these characteristics. Aside from natural resources and people, buildings and infrastructures also feel the impacts of climate change. As the “climate change, risk and vulnerability” report of the Australian Greenhouse Office (2005)[8] pointed out:

[...] impact on settlements and infrastructure could be severe, especially if acute weather events like cyclones move into areas where infrastructure is not designed to cope with them. Prolonged instances of heat, wind and rainfall, and increased variations in these phenomena, can also lead to accelerated structural fatigue and greater demands on construction and drainage needs.

There are varying methods by which the effects of climate change have been analyzed by researchers. Scheraga and Grambsch (1998) identified the potential impacts of climate change to be:

- health impacts – weather-related mortality, infectious diseases, and air-quality-respiratory illnesses;
- agriculture impacts – crop yields and irrigation demands;
- forest impacts – change in forest composition and shift geographic range of forests;
- water resource impacts – changes in water supply and water quality, increased competition on water;
- impacts on coastal areas – erosion of beaches, inundation of coastal areas, costs to defend coastal communities; and
- species and natural areas – shift in ecological zones and loss of habitat species.

Meanwhile, Nagy *et al.* (2006) classified the effects of climate change into three – income effects, human development effects, and environmental effects – in their study of the potential impacts of climate change in Latin America and the Caribbean. They infer that agriculture will be the most affected income sector by the temperature and rainfall variability, followed by energy through the supply of hydropower and the increase in demand for electricity. Infrastructures, on the other hand, will be affected by extreme wind, rainfall, and runoffs in coastal zones. The losses in income will eventually affect the countries’ gross domestic product (GDP). Human development effects, on the other hand, was built on the expectation that climate change will aggravate the vulnerability of people and will pose new threats on the availability of fresh water supplies and

efficiency of local sewerage systems, food security, and on the distribution and seasonal transmission of vector-borne infectious diseases. Finally, environmental effects are related to the impacts of runoff, wildfires, biome change, reduction of tropical forests, and the loss of biodiversity.

The potential effects of climate change have also been analyzed by categorizing systems as natural and human systems. The first generally deals with biodiversity, ecosystems, rainforests, marine life, and coral reefs, among others. Conversely, human system analysis treats the natural environment as the primary income source, hence the focus on economic industries (Australian Greenhouse Office, 2005). Preston *et al.* (2006) examined the climate change impacts by identifying five core sectors: coastal communities, ecosystems and biodiversity, infectious disease and heat-related mortality, water resources, agriculture and commercial forestry, and regional economies.

5. Conceptual framework

The framework, shown in Figure 2, operates in the premise that all systems are dynamic; change is the only constant element.

One of the key factors in this framework is not the phenomenon of climate change itself, but that of its nature, namely, the frequency, intensity, quantity, and variability, among others. Each one or combinations of these factors are externalities that affect the different aspects of systems, may they be economic, social, biophysical, or technological. They create stress and shocks, whose effects are highly dependent on the extent of the system's vulnerabilities.

Vulnerability is inherent to each system; with the various aspects of the system, it is inevitable that one may be vulnerable to something. And since systems are dynamic, in which new factors are introduced such as new technologies or new institutional arrangements, or taken out like obsolete techniques or practices, new relationships and associations arise. And again, the cycle continues, as new vulnerabilities are formed.

Each system is unique in a sense that one cannot generalize how climate change would affect it. Increased temperatures would have different effect on tropical areas compared to those in the arctic primarily due to their biophysical characteristics. Still, depending on the availability, or lack of, technology to adapt, a society may be more affected by the changing temperatures than another even though they may be located in the same hemisphere. Moreover, a more populated community may be considered to be adversely distressed than one with less. Thus, a system may be vulnerable to temperature change while another is not, or both may be vulnerable but with different intensities. The same concepts may be applied to the other nature of climate change such as in the quantity, frequency, or duration of precipitation. Consequently, a system may be vulnerable to:

- only one;
- a combination; or
- all climate change occurrences, depending on its characteristics.

Inter-system analysis, on the other hand, may result to system A to be vulnerable compared to system B in terms of climate change nature 1, but not vulnerable with regard to climate change nature 2, and vice versa. Thus, overall vulnerability, compared to another, involves a combination of the individual vulnerabilities of the system, within itself, to each nature of climate change.

To illustrate, an uninhabited island in the Pacific may have an intensified biophysical vulnerability to the increasing sea level, as it may be submerged underwater over time, than an island country like the Philippines. However, with the existence of coastal communities creating the other types of vulnerabilities, the Philippines may still emerge to be more vulnerable to the rising sea level even though the uninhabited island may be wiped out of the map in the future.

In the concept of climate change, vulnerabilities define or characterize a system. They mold the system's ability to absorb, withstand, or basically react to the shocks and stress introduced. Vulnerabilities are dynamic and change based on the elements existing in the system, thus their depiction in the framework as forces moving in a circular continuous flow. As mentioned earlier, the impacts of climate change depend on the system's vulnerabilities. This is so because they determine the magnitude of the risk faced as externalities enter the system. Vulnerabilities, therefore, link the nature of climate change to the risks created and ultimately define the impacts to the system.

Risk to climate change encompasses a wide range of possibilities. There are multiple factors of the system which may be affected, and some, if not all, are associated with each other one way or another. For example, risk on income may be through the direct effect of climate change on the sources of income, like agriculture or fisheries, wherein production will be affected. This may be further sub-categorized by resource type such as agriculture, fishery, and forestry risks. On the other hand, it may be indirect such as the effect on the energy sector in which series of events must take place before the impact on income is felt. The economic effect of climate change can also transcend to social effects through poverty; if the income sources of people are disturbed, naturally, this will have consequences on their socio-economic statuses. What is significant for an organized analysis of risk is to identify the primary risk in the chain of risk associations. If one is not careful, there could be a possible cyclical analysis of risks since the risks are linked to each other.

Recall that the framework was introduced with an emphasis on dynamism and change. This is so because the concept of climate change is temporal; time is a significant factor in all the entities involved – the nature of climate change and the characteristics and vulnerabilities of systems. The types of climate-related events in the past are different compared to those occurring today, in terms of frequencies, intensities, etc. and they may also vary in the future. This is why the analysis centers on the nature of changes in climate; it is for the framework to take into account the factor of time. In the same manner, vulnerabilities are also dynamic; based on the adaptive capacities of systems, the types and intensities of the system's vulnerabilities may vary through time. More importantly, a system may become immune to one kind of vulnerability and still, in some cases, may be able to develop new ones. One example of the latter case is when the uninhabited island becomes populated, form societies, and therefore develop social, economic, technological, and institutional vulnerabilities. With this framework, adaptation must address vulnerabilities of systems and not the risks, because vulnerabilities determine the risks and consequently the impacts of climate change.

6. Results and discussion

The model developed relies on the relationships among climate change, vulnerability, and risks. It primarily works on the premise that the nature of climate change affects the vulnerabilities of systems, and in turn, these vulnerabilities create different types of risks. It focuses not on the climate change phenomenon itself but on the nature of the change.

The model identifies four nature of climate change namely: variability, intensity, frequency, and quantity. Variability is the nature that deals with the rate of change in climate and incorporates concept of time. It covers all types of weather or climate changes but focuses on the time periods of the occurrences. Variability is manifested in the:

- rate of increase in temperature;
- the speed in the decrease (or increase) is sea levels; and
- the annual differences in precipitation – rainfall, snowfall, etc.

Intensity, on the other hand, defines the power or strength of climate-related occurrences like typhoons, cyclones, snowstorms, droughts, and heat waves, while frequency is related to the number of such occurrences. Quantity is the nature that characterizes amount, the excess or lack of, such as the volume of rainfall.

Vulnerabilities of systems are dependent on the characteristics of their elements. The most identifiable of these are the economic, social, technological, and biophysical. Economic and social vulnerabilities are closely related, hence are combined in this model to form socio-economic vulnerabilities. The central factors in this type of vulnerability are people and resources and some of the indicators which characterize it are:

- income sources;
- economic well-being;
- poverty status;
- demographic characteristics; and
- health and educational statuses.

Biophysical vulnerability, on the other hand, involves the physical sciences in terms of examining the natural characteristics of areas which the hazards may affect. It is dependent on the physical features such as location, soil quality, vegetation, etc. as well as the system's geographical features like the site and situation of the place and its proximity to the hazard sources and events. Meanwhile, technological vulnerability is derived from the existence or absence of technologies and infrastructures that gauge the limitations of the system, affecting its ability to execute adaptation options. It involves the probability that a technological system may fail due to external forces. Some of the indicators used to determine technological vulnerability involve the existence (and absence) of warning systems, protective structures, crop breeding and irrigation, settlement and relocation or redesign, and flood control measures. Another significant vulnerability type is institutional vulnerability which consists of knowledge development with regard to the phenomenon. It also involves the organized programs of societies and governments to address the issue and the practices and policies established to adapt. Institutional vulnerability is the only type which did not stem out from the inherent characteristic of the system, but one which emerged due to the existence of climate change. In this sense, it can be viewed as an internalized externality, a product of the external climate change variable which became an internal process due to the need of systems to adapt.

Risk to climate change encompasses a wide range of possibilities. In this model, risks are categorized as: income, biodiversity, health, mortality, and infrastructure. Income risk incorporates the economic effect of climate change that can also transcend to social effects through poverty. As mentioned earlier, if the income sources of people are

disturbed, this will have consequences on their socio-economic statuses. Impacts on natural resources are also associated with ecosystems, plant and animal life, and the survival of species, hence the biodiversity risk of climate change. Risks on human welfare involve health risk as a consequence of hazardous environment, water supply and food shortage, and extreme temperature conditions. Mortality risk, on the other hand, may be interpreted as an extreme outcome from the health risk, or may be regarded as a direct impact from increased levels of rainfall (resulting to landslides and floods), intense heat waves, and increased temperatures that cause forest fires. Finally, infrastructure risk deals with the effect on constructions like buildings, bridges, dwellings, roads, power plants, water reservoirs, and other man-made structures vital to the existence of societies and economies.

The model links nature of climate change to the risks by identifying and describing how each nature influences the vulnerabilities of systems and afterwards determining and describing the resulting risks due to the existing vulnerabilities. It is presented in matrix form shown in Figure 3 – a three-dimensional model that presents the nature of climate change's association with the system's vulnerabilities and then the extension of the linkages through the relationship between vulnerabilities and risks.

The elements in the lower case letters describe the different climate-related occurrences, categorized by nature that would affect a specific type of vulnerability. They identify which factor or characteristic of the system would be vulnerable and to which nature. Meanwhile, the elements represented by the upper case letters are the

Variability	a	e	i	m
Intensity	b	f	j	n
Frequency	c	g	k	o
Quantity	d	h	l	p
	Socio-economic	Biophysical	Techno-logical	Institutional
Income risk	A	F	K	P
Bio-diversity risk	B	G	L	O
Health risk	C	H	M	R
Mortality risk	D	I	N	S
Infra-structure risk	E	J	O	T

Figure 3.
Climate change
vulnerability risk model

risks resulting to the vulnerabilities created or aggravated by the elements in the other dimension. The model concentrates in analyzing the relationships between and among the three variables – nature of climate change, vulnerabilities, and risks. The model assumes that relationships are present, in some degree, in all kinds of systems.

Any combination of the identified nature of climate change may influence the vulnerabilities of the system, and therefore, by transitivity, also affect the risks encountered by the system. If the system is not vulnerable in any way, then there would be no risk to, and impact from, climate change. In that same train of thought, if all the vulnerabilities are affected, the risks and impacts of the externality to the system will exist but their scale will depend on the degree of the vulnerability. It is possible that one nature may affect all vulnerabilities, or all natures will influence only one kind of vulnerability. Similarly, this pattern may exist between vulnerabilities and risks. What the matrix offer is an analysis of the different combinations of the variables, may they be an intra or inter dimensional examination. The matrix can also be transformed into a cube and is presented in Figure 4.

Figure 4 shows the possible relationships among the three variables – the front (and back), being the nature of climate change, the left (and right) side, the vulnerabilities, and the top (and bottom) the risks. A micro-analysis is denoted by the smaller cube wherein the possible relationships are:

- A1;
- $A1 \times A2$;
- $A2 \times A3$;
- $A1 \times A2 \times A3$; and
- $A1 \times A2$; if $A2 = 0$, then $A3 = 0$.

With the same climate change nature A1 and the same vulnerability A2, but a different risk type B3, the relationships maybe:

- A1;
- $A1 \times A2$;
- $A2 \times B3$;

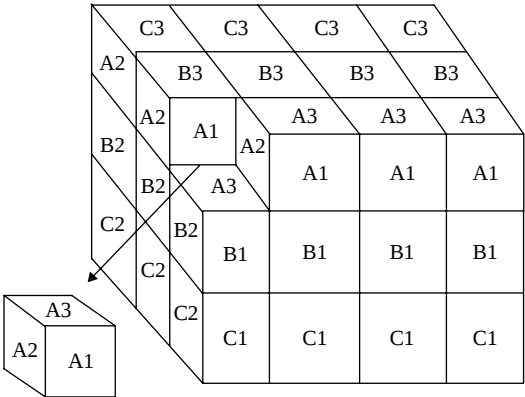


Figure 4.
Relationships in the
climate change
vulnerability risk model

- $A1 \times A2 \times B3$; and
- $A1 \times A2$; if $A2 = 0$, then $B3 = 0$.

7. Summary and conclusions

In an attempt to understand the adaptation practices and methods needed to implement in systems, the linkages between and among climate change, vulnerabilities, and risks were explored. The research identifies vulnerability to be the vital link between climate change and risks. In the concept of climate change, vulnerabilities define or characterize a system. They mold the system's ability to absorb, withstand, or react to the shocks and stress introduced by this externality. Moreover, vulnerabilities are deemed dynamic and change based on the elements existing in the system. Given these characteristics, this research established vulnerability to be the key that determines the impacts of climate change.

The climate change vulnerability risk model was developed to act as an analytical guide for understanding the effects of climate change to systems. It is a framework that will help determine how systems need to react to minimize the casualties and costs brought by the phenomenon. The model is a three-dimensional matrix with the nature of climate change, vulnerabilities, and risks as its chief dimensions. It identifies four nature of climate change, namely: variability, intensity, frequency, and quantity and the vulnerability types to be socio-economic, biophysical, technological, and institutional. Meanwhile, risks are classified as income, biodiversity, health, mortality, and infrastructure risks. The model links nature of climate change to the risks by identifying and describing how the nature influences the vulnerabilities of systems and afterwards determining the resulting risks due to the existing vulnerabilities. With this, the model may be used to determine the effective adaptive measures to implement in the system through a comparative analysis of the variables in the matrix.

The model is also designed to be dynamic and analysis may be adjusted based on the changes in any of its dimensions. The model works under the premise that climate change is a temporal issue; time is a significant factor in all the factors involved. Owing to the nature of climate change, the types of climate-related occurrences in the past are different compared to those occurring today, and they may still vary in the future. In the same manner, vulnerabilities are also dynamic; through the adaptive measures implemented, system's vulnerabilities may vary. A system may become immune to a previous vulnerability, thus may not be at risk to a type of climate change. And still in some cases, it may develop new vulnerabilities to a new kind of externality. An urban city may no longer be vulnerable to rains and floods though better drainage system, but may become vulnerable to intensified winds of typhoons never experienced before, affecting the infrastructure risk. Furthermore, due to population growth, impacts of increase in temperatures may become more hazardous today than in the past because of an increase in socio-economic vulnerability. Hence, in this line of reasoning, adaptive measures must address vulnerabilities of systems and not the risk encountered, because vulnerabilities determine the risk to systems. This substantiates the linking function of vulnerability.

This paper is the first phase of a three-stage study on the linkages among climate change, vulnerability, and risks; it is the development stage of the framework that exemplifies the interrelationships among these variables. The second phase of the research will focus on the application of the model as a tool for the quantitative analysis

of the effects of climate change. This stage will involve formulation and computation of significant indicators and indices identified in the model. The third stage, on the other hand, involves the application of the indices developed (in the second phase) in an econometric analysis and the presentation of case studies. While this is the initial part of the research, it is deemed the most significant since the model developed is the foundation of the series.

Notes

1. The average of near surface air temperature over land and sea surface temperature.
2. El Niño, in its original sense, is a warm water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. This oceanic event is associated with a fluctuation of the intertropical surface pressure pattern and circulation in the Indian and Pacific Oceans, called the Southern Oscillation. This coupled atmosphere-ocean phenomenon is collectively known as ENSO. During an El Niño event, the prevailing trade winds weaken and the equatorial countercurrent strengthens, causing warm surface waters in the Indonesian area to flow eastward to overlies the cold waters of the Peru current. This event has great impact on the wind, sea surface temperature, and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world. The opposite of an El Niño event is called La Niña (IPCC, 2001b).
3. The NOA consists of opposing variations of barometric pressure near Iceland and near the Azores. It is the dominant mode of winter climate variability in the North Atlantic region ranging from central North America to Europe (IPCC, 2001b).
4. La Niña is the opposite of El Niño.
5. Factors affecting vulnerability to climate change.
6. For more information, see Haanpää and Peltonen (2007, p. 11).
7. Sarewitz *et al.* (2003) defined “outcome risk” to be the risk of a particular outcome, as against “event risk” which is the risk of occurrence of any particular hazard or extreme event.
8. Report to the Australian Greenhouse Office, Department of the Environment and Heritage by the Allen Consulting Group.

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