A Collaborative Potential Assessment of Project Atmospheric Brown Clouds

by

Amy McNally

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Collaboration between scientists and decision makers is a critical element in mobilizing science into action. Likewise, the United Nations defines collaboration between scientists and policymakers as a requisite component in the process of sustainable development. Despite the UN sustainability movement beginning in 1983, scientists may still be frustrated by their findings being misinterpreted or manipulated by policymakers while policy scholars contend that scientific policy designs may not adequately address social concerns. Studies indicate that shared understandings, achieved through dialogue, perceived interdependence and collaborative processes can

address the concerns of both science and policy communities and make progress toward the goals of sustainability.

This case study assessed the collaborative potential of Project Atmospheric Brown Clouds (ABC), an institution that aims to advance sustainable development through climate and pollution observations, impact assessments and the promotion of awareness and mitigation measures. Collaborative potential is defined as the ability for parties to work together toward a common goal. In this case scientists and policymakers are working toward the common goal of managing transboundary air pollution and its associated impacts on human and climate systems.

To explore Project ABC's approach to integrating science and policy, I conducted a content analysis of ABC documents and created composite conceptual maps of ABC programs. I then compared these models, or concept maps, to an ideal, collaborative model of program management to assess ABC's collaborative potential. I find that ABC effectively engages in dialogue and perceives interdependence while managing programs that conduct basic research and impact assessments. However, the Impact Assessment and Awareness and Mitigation programs have low collaborative potential with social interest groups and policymakers because ABC does not perceive interdependence or engage in dialogue with these parties. The implications are that ABC is not effectively communicating information to non-scientists, thereby impeding the promotion of sustainable development policy.

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APPROVED:

Major Professor, representing Water Resources Policy and Management

Director of the Water Resources Graduate Program

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of the Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Amy McNally, Author

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Introduction

Background

In 1983 the United Nations (UN) General Assembly established the World Commission on the Environment and Development to address the relationships between poverty, international inequality and environmental degradation. Four years later the Brundtland Commission issued a report entitled "Our Common Future" that evolved into the UN Program on Sustainable Development and called for "Development that meets the needs of the present generations without compromising the ability of future generations to meet their own needs." Since these beginnings and emerging concerns over human induced climate change, there have been a number of multinational initiatives including the 1988 establishment of the Intergovernmental Panel on Climate Change (IPCC), 1992 Rio Principles and the 1997 Kyoto Protocol. In each of these efforts, the United Nations identify collaboration with the scientific community as one of the critical components needed to achieve the goals of sustainable development.

Atmospheric and pollution scientists who study climate change have emerged as a group of experts who are concerned that global and regional climate changes may hamper development efforts in various sectors. Moreover, present development choices will influence the capacity to mitigate and adapt to future climate change (UN 2007). To incorporate science into the sustainable development process, researchers studying the impacts of haze over the Indian Ocean and the United Nations Environmental Program (UNEP) teamed up in 2001 to design Project Atmospheric Brown Clouds (ABC).

Researchers studying the effects of air pollution over the Indian Ocean found that the persistence of aerosols and their resulting haze reduce seasonal average solar radiation (energy from sunlight) by as much as 10%. While air pollution is known to cause respiratory illness (Ramanathan 2006) and acid rain (Likens, Driscoll et al. 1996; Ramanathan 2006), more recent simulations suggest that aerosol-induced perturbation to the radiative energy budget impacts monsoon rainfall distributions and therefore has implications for regional and global water budgets, agriculture and public health (Ramanathan 2006). To investigate these complex relationships, Project ABC established a unique framework for integrating research on air pollution, climate change and related impacts (Ramanathan and Crutzen 2001). The results, plus strategies for mitigating the production of aerosols, are used by the ABC Awareness and Mitigation (AM) program that aims to provide information to policymakers and promote sustainable development policies.

<u>Research Problem and Significance</u>

Understanding the role of science and concerned scientists in policy making is helpful in the context of sustainable development. Science plays an important role in environmental policy, ecosystem based management and sustainable development

(UN 1993; Daniels and Walker 2001:208; Lemos and Morehouse 2005; UNEP 2007). Subsequently, the United Nations has mandated that, in conjunction with improving public participation and coordinating protection of the environment with social and economic development, collaboration with the scientific community is essential to achieve the goals of sustainable development (UN 1993). While the *integration* of science and technology is often at the forefront of strategies promoting sustainable development, *collaboration* between scientists and decision makers is under emphasized (Jasanoff 1987; Cash and Moser 2000; Cash, Clark et al. 2003).

Scientific research and impact assessments can contribute to sustainability initiatives, however these efforts are more likely to be effective when collaboration is used to manage interactions between scientific knowledge, political expertise and decision making (Agrawala, Broad et al. 2001; Miller 2001; Cash, Clark et al. 2003; Clark 2007). Through collaboration the substance of scientific research becomes more salient, in turn improving learning[1] and strengthening the relationship between scientists and decision makers (Cash and Moser 2000; Daniels and Walker 2001:83; Cash, Clark et al. 2003; Lemos and Morehouse 2005).

[1] Adult learning theory state that needs assessments ensure that information is relevant thereby improving an adult's ability to learn new information.

Given that the United Nation's definition of sustainable development and the ideal model for mobilizing science into action both require collaboration between scientists and policymakers, one may expect to find evidence of collaboration in the framing of issues and dissemination of scientific information by Project ABC's Impact Assessment and Awareness and Mitigation programs.

This study will assess the collaborative potential of these programs through an analysis of ABC documents. Documents provide a written interpretation of the project's relationships between scientists and policymakers and the procedures that are used to promote sustainable development policy. I then interpret the data from documents by creating concept maps to visualize patterns of interdependence and communication. Finally, I compare these maps to an ideal model of collaborative management to assess the potential for scientists and policymakers to work together toward the goals of sustainable development.

Thesis Organization

First, this thesis provides a selective literature review on collaboration between scientists and decision makers and organizational theories that provide insight into how organizations manage the boundary between science and policy. Second, I state my objectives to explore the Project ABC case study and assess the collaborative potential between project scientists and policymakers. Third, I explain my approaches to research that use conceptual models to assess the collaborative potential between scientists and policymakers. Fourth, I explain methods I used to collect and analyze data from Project ABC documents. I then describe and discuss the results from the ABC Impact Assessment and Awareness and Mitigation programs and assess the collaborative potential. Finally, I conclude with a discussion on how findings from the ABC case study can be generalized to the role of collaboration between scientists and decision makers in sustainable development.

Literature Review

Dialogue and Interdependence

Collaboration is a process in which interdependent parties work together to affect the future of an issue of a shared interest (Gray 1989; Daniels and Walker 2001). In the context of sustainable development, interdependence is implicit in the UN definition that states scientists, decision makers and the public need to collaborate with one another to coordinate environmental protection with social and economic development to address the uncertainties, challenges and conflicts that are a part of 'meeting today's needs without compromising the needs of future generations' (Brundtland 1987). Similarly, interdependence is a key component of programs that aims to mobilize *science* into *action,* i.e. scientists are necessary to conduct research and decision makers are necessary for policy action. Moreover, without perceived interdependence there is little need or opportunity for collaboration (Daniels and Walker 2001).

A simple definition of interdependence is "we sink or swim together" (Walker 1996). It follows then that interdependence can be a source of both cooperation and conflict. According to conflict theorists, interdependence is likely to be a source of conflict when efforts of one party impede the efforts another (Daniels and Walker 2001) or when boundaries between interdependent parties are crossed too freely (e.g. politicalization of science, inequities that result from rational policymaking (Stone 2001)). At the same time, interdependence can promote the cooperation that is necessary to tackle complex environmental policy issues like climate change and sustainable development (Lemos and Morehouse 2005).

It is helpful for interdependent parties to understand that sustainable development and collaboration are evolutionary processes that improve the management of systems through shared understandings (Cary 1998:12; Kates, Clark et al. 2001; Clark 2007). To reach these shared understandings and implicit in the definition of collaboration stakeholders need to engage in dialogue, defined as open, inclusive and iterative communication that holds learning and shared understanding as a primary goal (Yankelovich 1999; Daniels and Walker 2001:132; Lemos and Morehouse 2005).

Adult learning experts find that dialogue narrows the teacher-student gap, creating an environment that is comfortable and secure for the learner while allowing teachers to assess the needs of students. By assessing the needs of knowledge users, targeted, relevant information can be provided. This is especially important for adults to be able to quickly assimilate new technical, or complex information (Daniels and Walker 2001).

Often, scientific, technical information is conveyed through capacity building tools that provide training, education and resources to both scientists and non-scientists (Schneider and Ingram 1990). Capacity building tools tend to lack the opportunity for dialogue, and if used exclusively experts may incorrectly assume that they know what questions are salient to decision makers, or decision makers may incorrectly assume that their questions can be credibly answered by experts (Cash, Clark et al. 2003). In contrast, collaborative processes allow experts to learn what information stakeholders need and adjust research directions accordingly (Cash, Clark et al. 2003).

In conclusion, environmental policy issues are difficult to tackle because their solution depends on a commitment to dialogue and the abilities for involved parties to recognize interdependence (Lemos and Morehouse 2005). Despite the benefits of developing high quality information, innovative ideas, building relationships and the cascade of changes in attitudes that result from learning, collaborative processes are time consuming and may be deemed failures by traditional evaluation standards (Connick and Innes 2001). Taking collaboration between scientists and policymakers seriously is central if science and policy communities wish to succeed in addressing complex public policy decisions and linking knowledge to action (Daniels and Walker 2001; Cash, Clark et al. 2003; Kurtz and Snowden 2003; Senge 2005:161).

Cynefin Framework

According to Kurtz and Snowden (2003), boundaries are abstractions that help us make sense of a situation. Boundaries can be distinguished by knowledge domains, actors' world views and the strategic actions that actors perceive as best suited for the situation. Knowledge domains, for example, differ between scientists and policymakers. Here, "knowable" knowledge (e.g. systems thinking, reductionist approach) is the purview of scientific research while "complex" knowledge characterizes the domain of environmental policy making (e.g. pattern management, plurality of world views) (Figure 1). Because of these differences, there is a boundary between science and policy making communities.

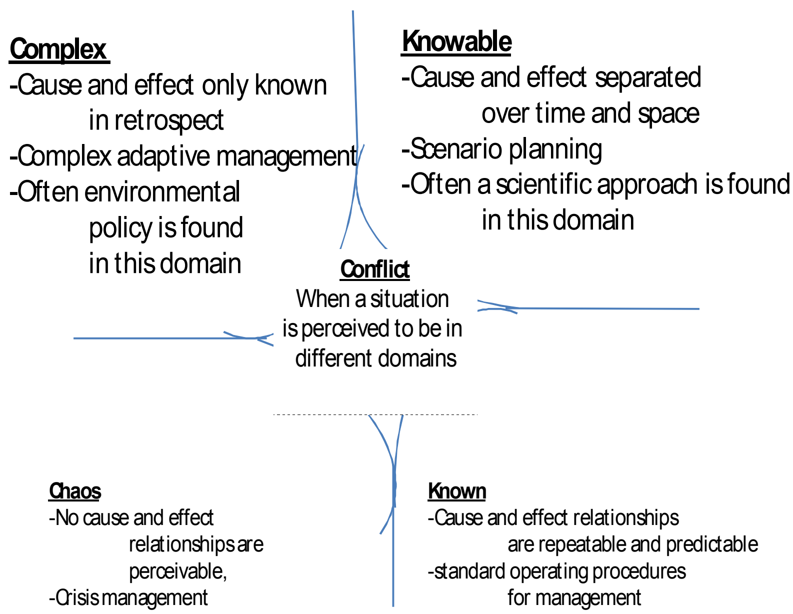

Figure 1.Cynefin Framework.
This framework shows that boundaries exist between types and perceptions of knowledge (Kurtz and Snowden 2003). Boundaries are dynamic and there is no axis.

When there is an issue is of interest to parties on opposing sides of a boundary, the issue may be pulled into the center domain of "conflict". Furthermore, conflict is augmented when parties from different domains have different ideas about what constitutes a persuasive argument (Cash, Clark et al. 2003) and what actions are best suited to address the issue. At the same time, collaboratively managing an issue that spans a boundary can be a source of new ideas and innovation, especially for science (Kurtz and Snowden 2003).

As defined earlier, collaborative management requires dialogue and interdependence. While dialogue may be easy to initiate, perceived interdependence requires a internalized, cognitive shift on behalf of scientists and policymakers (Daniels and Walker 2001). Literature from business and organizational scholars explores how shifting perceptions of interdependence can help organizations, specifically corporations, develop strategies, exchange knowledge and make decisions (Daniels and Walker 2001; Kurtz and Snowden 2003; Senge 2005). The literature on the way that corporations profit from boundary spanning interactions may provide useful insight for organizations wishing to effectively mobilize science into action.

Kurtz and Snowden (2003) suggest a number of ways that an organization can capitalize on differences that define boundaries. First, engaging in a collaborative process, that actively relaxes assumption of roles, can improve the development of shared understandings. For example, some science and policy literature implies that scientists are knowledge producers and decision makers are knowledge users (Lemos and Morehouse 2005). By relaxing preconceived notions of which party is the knowledge user and which is the knowledge producer parties can create shared understandings of both the technical and social aspects of the science-policy system

(Miller 2001). This idea resolves the contradiction in the Cash and Clark (2003) observation that organizations who successfully mobilize science into action, *learn* from *knowledge users* and adjust research accordingly.

Complementing the idea of relaxing preconceived notions of party roles, Kurtz and Snowden (2003) suggest relaxing central control of organizational processes and relationships to allow new patterns and leadership to emerge. In the context of business management, corporations will explore various relationships and send resources to those that show progress, rather than investing in a single strategy. In some cases, where experts tend to be conservative with respect to procedures and relationships, entrainment breaking or a brief movement of the system into the chaos domain (Figure 1) is recommended. This idea may be especially useful for sustainability actions at the global scale that have been relying on well established, bureaucratic development agencies.

As concerned scientists become more active in efforts to mobilize science into action and as collaboration between scientists and sustainable development policymakers becomes increasingly important, it is useful to draw on expertise from the field of science-policy interactions and the field of strategic organizational management. Literature from these fields gives insight into the importance of managing boundaries and suggests techniques that can be used to capitalize on differences between actors who will more and more frequently be called upon to collaborate in tackling the complexities of sustainable development.

Research Question and Objectives

As effective communication of scientific information to policymakers depends, in part, on scientists' and policymakers' ability to collaborate, this case study answers the question: What is the collaborative potential of ABC's Impact Assessment and Awareness and Mitigation programs? Here, collaborative potential is defined as the opportunity[2] for parties to work together assertively in order to make progress toward the goals sustainability (Daniels and Walker 2001:63). The objectives of this assessment are as follows:

1. Explore ABC's patterns of communication and interdependence through concept mapping.

2. Describe the collaborative potential of Project ABC and its participants and recommend how improvements can be made.

3. Discuss how Project ABC provides insight into collaboration between scientists and policymakers in the process of sustainable development.

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2 For this research, opportunities for collaboration include open communication, dialogue and interdependence between the procedural, substantive and relationship dimensions of a boundary.

Approaches to Research

Introduction

After receiving a National Science Foundation (NSF) East Asia research grant in April 2007, I began working with members of the Project Atmospheric Brown Clouds science community in Washington D.C, Oregon, California and Korea. I conducted empirical research that investigated the difference between observed precipitation patterns in rice producing and aerosol-impacted regions of India and Korea. While conducting background research I learned that feedbacks between global change, aerosols, clouds and the hydrologic cycle are not accurately known and produce key differences in models that project climate change (Oki and Kanae 2006; NOAA 2008). Despite scientific uncertainty, Project ABC aims to promote sustainable development by providing policy makers with "firm information based on sound science" (UNEP 2007). The juxtaposition between firm information and uncertainty, in conjunction with their purpose to promote sustainable development policies, makes Project ABC a useful case study to explore and describe collaborative interactions between scientists and policymakers.

After reflecting on my research fellowship, I identified methods and approaches that would allow me use my experience with the ABC science team as leverage for an appropriate analysis of data. I adapted the Daniel and Walker (2001) Collaborative Learning Approach to conduct a case study. In doing so, I created concept maps to conceptually model the ABC system from the data collected in a content analysis of ABC documents. In using these methods I assumed that the documents from a variety of sources, targeted at a variety of audiences, would provide comprehensive insight into the structure and function of Project ABC and the perspectives held by Project ABC managers. Next, I assessed collaborative potential using the Progress Triangle by comparing my models of Project ABC to an ideal model of an organization that is designed for collaborative management. Here the ideal model assumes that all organizations have interrelated procedural, substantive and relationship dimensions that are mutually reinforcing when managed successfully. Finally, using these comparisons, I recommended ways the collaborative potential of ABC scientists and policymakers can be improved.

This section is intended to describe the qualitative research approaches and methods that I used to systematically and unobtrusively collect, model and analyze data.

Case Study

According to Yin (2003) a case study is an inquiry that investigates a contemporary phenomenon within its real-life context, specifically when boundaries between the phenomenon and context are not clearly evident. In this study collaboration (interdependence and dialogue) was the phenomenon of interest, while the context was a unique, integrated science-policy project design that consists of a global research team, regional impact assessments and policymakers in multiple countries. This single case study was not intended to prove or disprove a project design that aims to mobilize science into action, however, according to Yin (2003) analytic generalizations can be made by exploring the theory of why collaboration is a key component in 'harnessing science for sustainability'(Cash, Clark et al. 2003).

For this case study I used an exploratory research design to explain how and why ABC managers made a set of decisions and examine project assumptions. This approach allowed me to carefully evaluate the ABC processes and relationships that communicate science to policymakers and influence collaboration. Moreover, from exploratory research one can potentially draw inferences that can turn into hypotheses worthy of future investigation. Additionally, to characterize how much collaborative potential was evident, I used a descriptive research design that compared data from documents to an ideal management model.

Collaborative Learning Approach

It is acceptable to use a variety of methods for data collection and analysis within a case study (Yin 2003), thus I was able to incorporate techniques used by the Daniels and Walker Collaborative Learning Approach (2001). This approach was developed for parties who wish to collaboratively manage environmental conflict situations and is based on theories of conflict management, adult learning and systems thinking. As noted by the authors, a failure to have sufficient training before embarking on a collaborative project raises the risks of negatively impacting real people, places, relationships and the acceptance of collaborative approaches in general (Daniels and Walker 2001). With this in mind, I adapted the guidelines for conducting a collaborative potential assessment.

The first step in using the Collaborative Learning Approach was to understand and describe the system of interest (Daniels and Walker 2001). I used a content analysis, described in detail in the methods section, to gather data from a range of ABC documents. The Collaborative Learning Approach also suggests concept mapping to think about the given situation from a systems perspective. Here I created maps to examine, classify, and amalgamate the data from the content analysis into a single representation (Daniels and Walker 2001:115). The concept maps were then analyzed to under the assumption that:

1. Documents comprehensively represent the views, values and opinions of the ABC participants
2. All concepts and linkages in the maps are explicitly stated in the documents
3. All interactions between people and procedures for communication are explicitly stated in the documents.

While the ABC system is based on a scientific observation program, I chose to focus on the science-policy relationships and processes in the Impact Assessment and Awareness and Mitigation programs.

Concept Maps

Concept maps, also known as situation maps or mind maps, are graphical tools for organizing and representing knowledge (Wilson and Morren 1990; Daniels and Walker 2001; Novak and Cañas 2008). The use of concept maps is rooted in systems thinking, an approach that focuses on interrelationships and processes (Daniels and Walker 2001). To create the maps, concepts, generally nouns, are placed in boxes to represent the elements of the system and linking words, or phrases are used to label lines between boxes to convey the relationships between the elements. Figure 2 shows two examples of maps, without linking words. The technique I used to create maps for this research is described in detail in the methods section.

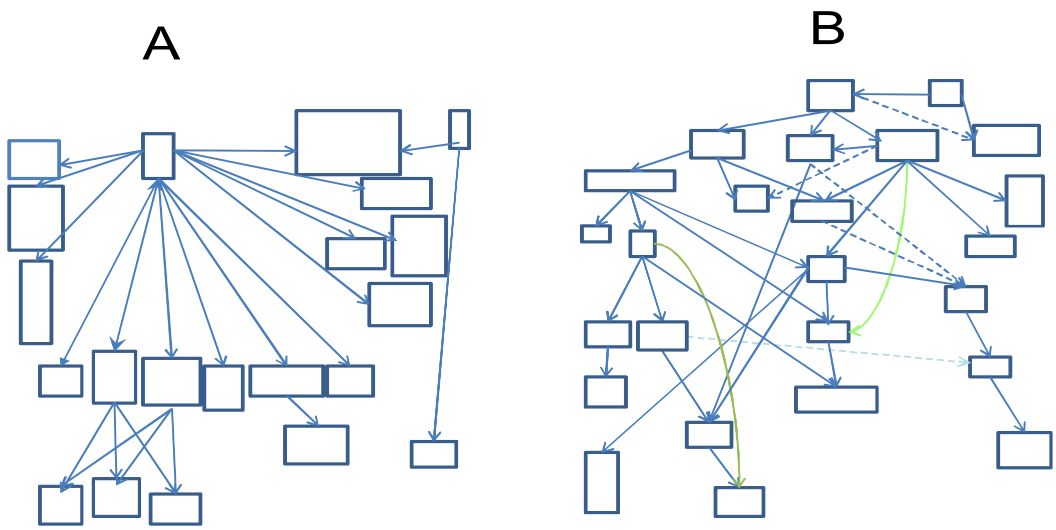

Figure 2. The structure of different concept maps.

As a tool, mapping provided information that allowed recognition and assessment of unexpected patterns that would not be captured by more constrained methodologies and allowed me to treat evidence fairly (Novak and Cañas 2008). It is assumed that, for example, the general shape or structure of a map can provide information about perceived interdependence and types of communication. In Figure 2, the multiple, cross cutting links shown in map B may indicate a greater extent of perceived interdependence than found in the hierarchical structure of map A. The concept maps allowed me to easily identify the relationships and procedures that were described in the documents to assess collaborative potential, using the Progress Triangle model.

Progress Triangle

The Progress Triangle (Figure 3) is a model that is based on the assumption that improvements in management can be made on any one of the three fundamental dimensions of a project or situation: substantive, procedural and relationship (Daniels and Walker 2001:156). As a technique in the Collaborative Learning Approach, the Progress Triangle model is used to examine tradeoffs that are associated with different strategies so that one could potentially improve the situation. It is referred to as Progress Triangle because management is an incremental process of making changes that can be characterized by three dimensions and these changes or improvements can be thought of as progress.

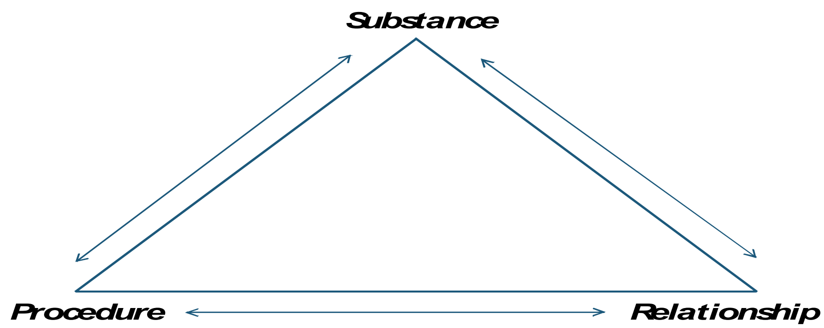

Figure 3. The Progress Triangle from Daniels and Walker (2001)

The mutually re-enforcing dimensions of a triangle (Figure 3) represent the idea that changes or progress made in one dimension will have impacts to the other dimensions. Therefore, the double headed arrows between the vertices show that parties in the relationship dimension must engage in a process to create and support the substance of a given project.

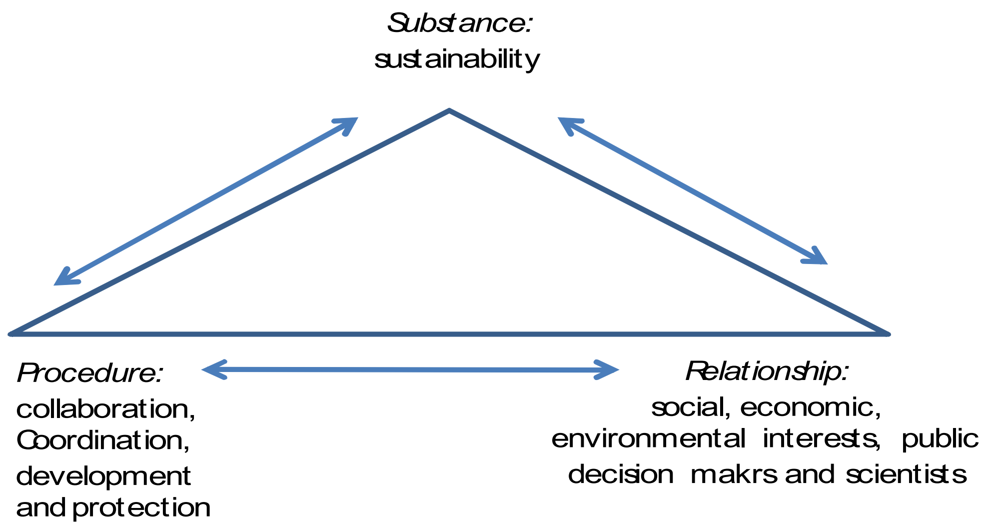

Figure 4. Three dimensions of the United Nations' concept of sustainability.

To illustrate the model, the Progress Triangle (Figure 4) shows UN defined sustainable development as an approach to management where decision makers, the public and scientists representing social, economic and environmental interests must be present. These parties form the relationship dimension of the triangle (Figure 4). As defined by the UN, these parties interact through processes of coordination and collaboration. These elements, characterized in the procedural and relationship dimensions are necessary to support the goal of sustainable development or the substance of any sustainable development initiative.

Research Methods

Content Analysis

To gather data on the concepts and relationships ABC perceives as meaningful to the functioning of their program, I undertook a content analysis of ABC documents. Content analysis served as an unobtrusive research technique used for making replicable and valid inferences from data to their context (Robson 2002:272). Using an unobtrusive method minimized the danger that the act of measuring was a force of change to confound the data that I collected[3] (Weber 1990:10). I analyzed a range of documents from 2001 to present, including concept papers, impact assessments, news reports and peer reviewed journal articles (Table 1). The initial list of documents was (and can be) found on the principle investigator, Dr. Vedraheme Ramanathan's homepage at Scripps Institute for Oceanography (http://ramanathan.ucsd.edu/). I also conducted web searches to find other documents relating to the project that were not listed on the website or found in bibliographies.

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3 The decision to use existing documents was somewhat limiting in that I was subjected to the author's need to cater to a particular audience or write in a specific format (e.g. peer reviewed journal articles vs. newsletter content). Because my attempts to contact key informants were unsuccessful I was willing to accept the limitations of my methods.

Table 1. Summary of documents

Types of Documents	Number analyzed
Concept Papers	3
Annual Reports/ House committee report	4
Peer reviewed journal articles	12
Impact Assessments	1
New reports	7
Brochures, advertisements	3
Reviews	5
Total	34

A purposive sample of the population of journal article and news reports was selected to improve the efficiency of data analysis. Journal articles were included in the research project when their content included human impacts of aerosols on water resources, agriculture and public health. This stipulation allowed me to focus on and code documents of interest to my study and exclude ABC documents that solely describe physical processes (e.g. chemical transport of aerosols, aerosols-cloud physics). Ten peer reviewed articles out of 12 contained some information on policy framing and were coded.

I selected, when possible, to code news articles from mass media outlets with a general audience in effort to gain a different perspective from that of the scientific journal articles. News reports were sampled to avoid coding replicate stories that were printed on the same day and pertaining to the same topic. The following table summarizes the news reports used.

Table 2. Summary of new articles used for the document analysis

Date	Topic	#Related articles	Source used
August 2007	Brown Clouds, Solar heating and Atmospheric Warming Trends	12	BBC News
April 2007	Trans-Pacific flight to track Asian dust	7	Scientific American
March 2007	Black Carbon and Climate	4	San Diego Union Tribune
February 2007	Scientists Predict Droughts, Rise in Temperatures, Sea Levels in Global Warming Report		University of California San Diego campus news
December 2006	ABCs and Rice Production	4	Science News
May 2006	Pollution, Greenhouse Gases and Climate Clash in South Asia		National Science Foundation Press Release
May 2004	Globe Grows Darker as Sunshine Diminishes 10% to 37%	2	New York Times

The documents that were coded were first divided into thematic recording units defined by any unit of text (phrases, sentences or paragraphs) that showed a relationship between two concepts. For example *aerosols change rainfall* was a recording unit because aerosols and rainfall are concepts, and their relationship was *change*.

Thematic units preserved important information related to context, such as word order (Weber 1990:23). For example, thematic units distinguish the phrases *aerosols change rainfall* from *rainfall changes aerosols*. This form of identifying recording units was labor intensive but led to more detailed and sophisticated comparisons (Weber 1990:22). To record thematic units, the author, year and unit were complied in an excel spreadsheet shown Table 3.

Table 3. Example of thematic units recoded in excel spreadsheet.

Year	Author	Thematic unit
2001	Ramanthan, V	warming increases precipitation at high latitudes
2001	Ramanathan, V	warming decreases precipitation in the subtropics
2001	Ramanathan, V	greenhouse gasses change climate
2003	Ramanathan	There is an urgent need for long term measurements of aerosols and their sources
2005	Ramanathan	fossil fuel combustion is a source of black carbon
2006	UNEP	The Awareness and Mitigation program presents information from the impact assessments at bilateral discussions
2005	Auffhammer et al	Agro-economic models model rice yields

After identifying the recording units I developed a coding scheme that reflected components of collaboration defined by the literature and specific topics that I foresaw exploring in the discussion (e.g. climate change) (Yin 2003:109).

First, a priori codes were assigned to indicate which of the three ABC programs the recording unit pertained to: Observation Program, Impact Assessment, Awareness and Mitigation program or Project wide. For example, '*ABC information was presented at the air quality management initiative'* was coded as *Awareness and Mitigation* because the unit referred to providing information to non-scientists. Example units that were coded as Impact Assessment (IA), Observation (OP) and Project wide (ABC) are in Table 4.

Next, an a priori code of transition or transformation was assigned to indicate if the recording unit identified how the system works (transformation) or goals, future plans and values (transition). For example, '*solar radiation impacts agriculture'* (Ramanathan 2006) explains how the system works and was coded as 'transformation' and '*Project ABC is moving towards a policy dialogue in 2008'* (UNEP 2007) was coded as transition because it indicates future directions of the Project and implies that dialogue is a value that will be operationalized in the future. Examples of codes that were assigned to each of the recoding units are shown in Table 4.

Table 4: recording units coded for transitional and transformative statements

Year	Author	Program	Transition/ Transformation	Thematic unit
2001	Ramanthan	OP	transform	warming increases precipitation at high latitudes
2005	Ramanathan	ABC	trans	availability of freshwater is a major concern for the future
2001	Ramanathan	ABC	transform	greenhouse gasses change climate
2003	Ramanathan	OP	trans	There is an urgent need for long term measurements of aerosols and their sources
2005	Ramanathan	OP	transform	fossil fuel combustion is a source of black carbon
2006	UNEP	AM	transform	The Awareness and Mitigation program presents information from the impact assessments at bilateral discussions
2005	Auffhammer	IA	transform	Agro-economic models model rice yields

Caption: OP= observation program, IA= impact assessment, ABC = Project Wide, transform = transformation, trans= transition

I operationalized concept from the literature using a priori codes for categorizing thematic units. These codes were not necessarily used in my analysis but were a starting point when I began the data collection processes. Examples are as follows and more examples are shown in Table 5.

1. Interdisciplinary work: the project is considering connections between social, economic, environmental, political considerations for sustainable development (e.g.

‘*anthropogenic activities such as biomass burning lead to … layers of haze’* (UNEP 2007).)

2. Useable knowledge: information that has been repackaged or translated to improve communication and learning for actors outside of the scientific community (e.g. ‘*quantification of pollutant damages’* (UNEP 2007).)

3. Boundary work: initiatives that facilitate communication and learning between science and policy communities, (e.g.’ *data will be used to produce policy options’* (Ramanathan and Crutzen 2003).)

4. Stakeholder and or Public Participation: a tenet of Sustainable development (e.g.’ presentations to members of civil society’ (UNEP 2007).)

5. Climate change: a cross cutting issue that leverages interdisciplinary, work (e.g. ‘*brown clouds change climate’* (Ramanathan 2007).)

Table 5: Thematic units coded with a priori codes from literature

Year	Author	Program	Trans/ Transform	code1	code2	Thematic unit
2001	Ramanthan	OP	transform	CC		warming increases precipitation at high latitudes
2005	Ramanathan	ABC	trans			availability of freshwater is a major concern for the future
2001	Ramanathan	ABC	transform	CC		greenhouse gasses change climate
2003	Ramanathan	OP	trans			There is an urgent need for long term measurements of aerosols and their sources
2005	Ramanathan	OP	transform	interd		fossil fuel combustion is a source of black carbon
2006	UNEP	AM	transform	bound	know	The AM program presents information from the IA at bilateral discussions
2005	Auffhamer	IA	transform	interd		Agro-economic models model rice yields

Caption: OP= observation program, IA= impact assessment, ABC = Project Wide, AM= Awareness and Mitigation, CC= climate change, Interd = interdisciplinary, Bound = boundary spanning, Know = useable knowledge, Trans = transition, Transform = transformation

Once all of the documents were divided into thematic units and the units were coded, I grouped thematic units using different combinations of codes. In preparation for the construction of concept maps I separated the “transitional” and “transformational” codes. As described in Table 5, transformational statements that explain how the systems work, could later be used to define relationships between concepts. In contrast, transitional statements (Table 6) were more abstract or in the future tense and therefore were not useful for mapping but provided insight into the case.

Table 6: The grouping of transitional statements.

Year	Author	Prog ram	Trans/ Transform	code1	Thematic unit
2001	Ramanthan	OP	transition		perturbation in aerosols is an environmental concern
2005	Ramanathan	ABC	transition		availability of freshwater is a major concern for the future
2001	Ramanathan	ABC	transition	CC	Indirect effects of agriculture and water can be discussed in future reports on health.
2003	Ramanathan	OP	transition		There is an urgent need for long term measurements of aerosols and their sources
2005	Ramanathan	IA	transition	interd	The impact of the ABC on monsoon rainfall, in conjunction with the health impacts of air pollution, provides a strong rationale for reducing air pollution

2006	UNEP	AM	transition		ABC assumes knowledge concerning mitigation measures will be effectively communicated to decision makers

Caption: OP= observation program, IA= impact assessment, ABC = Project Wide, AM= Awareness and Mitigation, CC= climate change, Interd = interdisciplinary, Bound = boundary spanning, Know = useable knowledge, Trans = transition, Transform = transformation

To describe values and goals that the project participants have for the system I grouped the transitional statements based on theme (Table 7). These transitional statements were useful in understanding how the ABC steering committee's world view influenced decision making (Daniels and Walker 2001). Characterizing goals and values gave insight into potential trajectories for the system that may be a source of conflict or collaboration in the future. Additionally, by augmenting concept maps with transitional statements I ensured that the case retained nuance and was comprehensively analyzed.

Table 7. Coded transitional statements and their themes.

Transitional Statement Recording Units	Themes
-perturbation in aerosol loading is environmental concern -basic scientific questions have to be addressed for further progress -Urgent need for longer term measurements of aerosols and their sources	Choices/Concerns of ABC scientists
-Indirect effects of agriculture and water can be discussed in future reports on health. -Study should focus on selected regions.	Choices/ actions in the Impact Assessment Program

-The regions should cover both irrigated as well as rain fed crops	
-The impact of the ABC … provides a strong rationale for reducing air pollution - The policies should include mitigation of aerosols	Awareness and Mitigation program values

Concept Mapping

After grouping the transitional statements, I grouped recording units that were coded as transformational statements. From these, I developed composite models to explain how the ABC system works. The concepts within the thematic unit, shown as text underlined in Table 8, were enclosed in boxes, using Microsoft Power Point. Then, concept boxes were linked together using arrows that indicated which concept is acting and which concept is being changed (Figure 5)

Table 8. Characterization of the concepts for maps in a recording unit.

Year	Author	Program		Recording Unit
2005	Auffhammer	IA	transform	The IA program assess impacts on health
2006	UNEP	IA	transform	Health assessments focus on rural areas
2006	Ramanathan	IA	transform	aerosols impact human health
2005	Auffhammer	IA	transform	climate change has potential impacts health
2006	UNEP	IA	transform	The IA program conducts health assessments

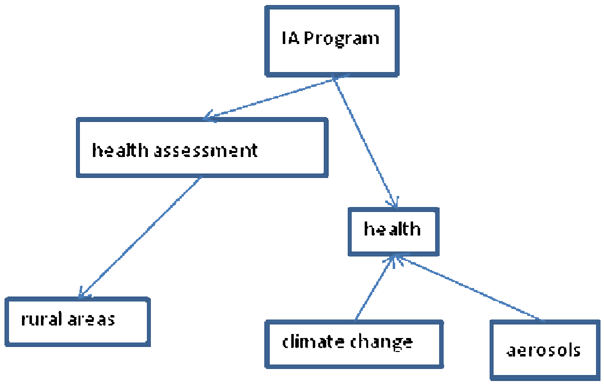

Figure 5. Linking concepts to construct maps.

The transformation or relationship, underlined in Table 9 describes how the linkages were labeled to explicate the relationship between concepts (Figure 6).

Table 9. The linking words that are used to define the relationships

Year	Author	Program	Code	Recording Unit
2005	Auffhammer	IA	transform	The IA team assess impacts on health
2006	UNEP	IA	transform	Health assessments focus on rural areas
2006	Ramanathan	IA	transform	aerosols impact human health
2005	Auffhammer	IA	transform	climate change has potential impacts health
2006	UNEP	IA	transform	The IA program conducts health assessments

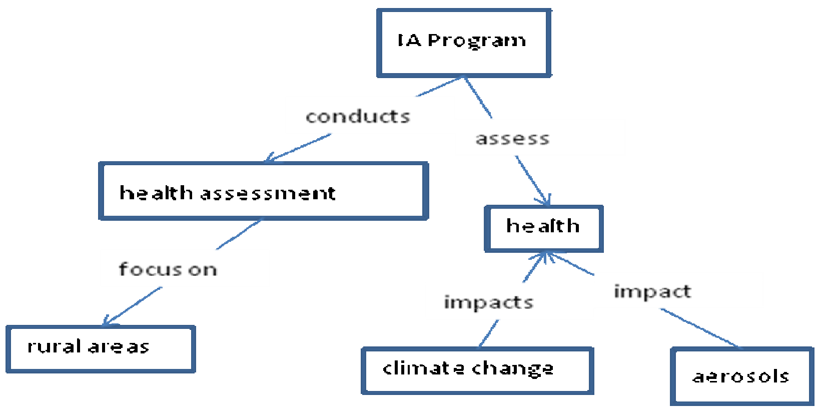

Figure 6. Labeled linkages between concepts

These steps were repeated by combining the recording units that were coded as impact assessment (IA) and Awareness and Mitigation (AM), AM and boundary, Project wide (ABC) and Climate Change (CC) and CC and IA (Table 10) to create composite concept maps:

Table 10. Combinations of codes that were mapped together.

	IA	AM	ABC	CC	transform	boundary
IA	-	X			X	
AM		-			X	X
ABC			-	X	X	
CC	X			-	X	

After constructing the maps using the steps previously mentioned, I decided that the Impact Assessment, Climate Change, Awareness and Mitigation + boundary codes created the most comprehensive maps.

To simplify the maps I arranged them in hierarchical structures, as suggested by Novack (2008). This involved changing some of the relationship labels and merging some closely related concepts[4]. An example is shown in Figure 7, where the concept of health and health assessment were merged and arranged from Figure 6, in a hierarchical manner so that the Health Assessment is the broadest concept and the concepts of rural communities, aerosols and climate change are components of the Health Assessment. Here the arrow direction indicates sub-divisions from broader concept to more specific concepts.

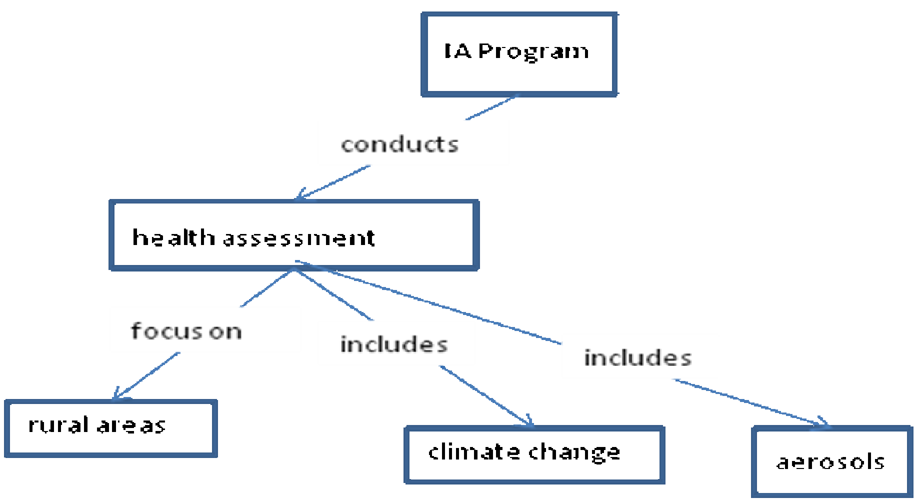

Figure 7. Re-organization of the concept maps as recommended by Novack (2008)

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[4] In the future I would distinguish between labels and connections that were explicitly stated in the data and those that I had changed. Unfortunately, these changes were not well recorded, thereby compromising the validity of my data.

The example in Figure 8 shows how the maps are displayed in the results section.

Interpreting the maps and transformations with the Progress Triangle

As previously mentioned, concept maps can be useful in showing interdependence in a system as indicated by the general structure where cross cutting links may indicate a greater extent of perceived interdependence and communication. In addition to the visual cues, having a single representation of the concepts found in a range of documents allowed me to identify the procedural, relationship and substantive dimensions needed to use the Progress Triangle models.

Daniels and Walker (2001) outline specific questions that can be asked to define the substantive, procedural and relationship dimension. This information was gleaned from concept maps (Figure 8 and Figure 9) and transitional statements. In contrast, the final category of question "Connections" (Table 11) is a subjective assessment of the interdependence between dimensions of management.

Table 11. Characterizing dimensions of the Progress Triangle

Relationship dimension 1. Who were the primary parties involved? 2. Is there evidence that suggests these parties are willing to collaborate? 3. Who are the decision makers? 4. Do parties have the resources to work	Concept Maps

collaboratively?	Transitional Statements
Procedural dimension 1. What methods are the parties using to reach their goals? 2. Are the parties contributing to the decision making process? 3. Is the process accessible and inclusive of the parties in the systems? 4. Who is facilitating this process?	Concept Maps
Substantive dimension 1. What are the issues in the situation? 2. Is there a difference in how parties prioritize issues? 3. Does key information need to be addressed as part of the process?	Transitional Statements
Connections 1. What are the connections between these dimensions? 2. How can these connections be improved?	Subjective Analysis

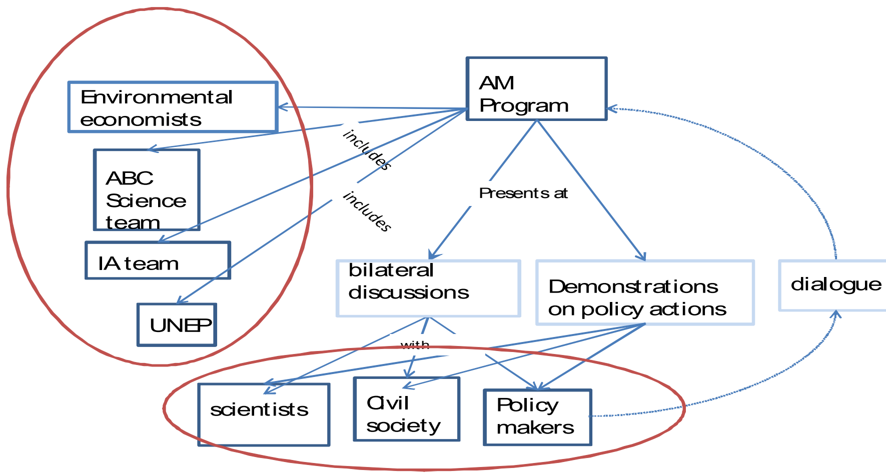


Figure 8. Example of concepts that would be in the relationship dimension of the Progress Triangle.

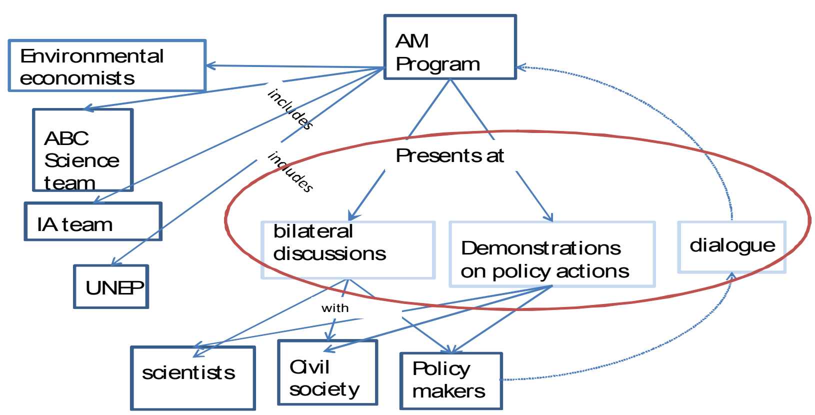


Figure 9. Example of concepts that would be in the procedural dimension of the Progress Triangle.

Relationships (Figure 8), procedures (Figure 9) and transitional statements were then used to populate the Progress Triangle. To illustrate how 'connections' (Table 12) are made, there is no arrow between procedural and relationship dimensions (Figure 10) because scientists are presenting information (no evidence of feedback from other parties). A weak arrow is shown between the procedure and substance dimensions because, according to the literature, without evidence of collaborative procedures the AM team is not necessarily effectively communicating information to policymakers.

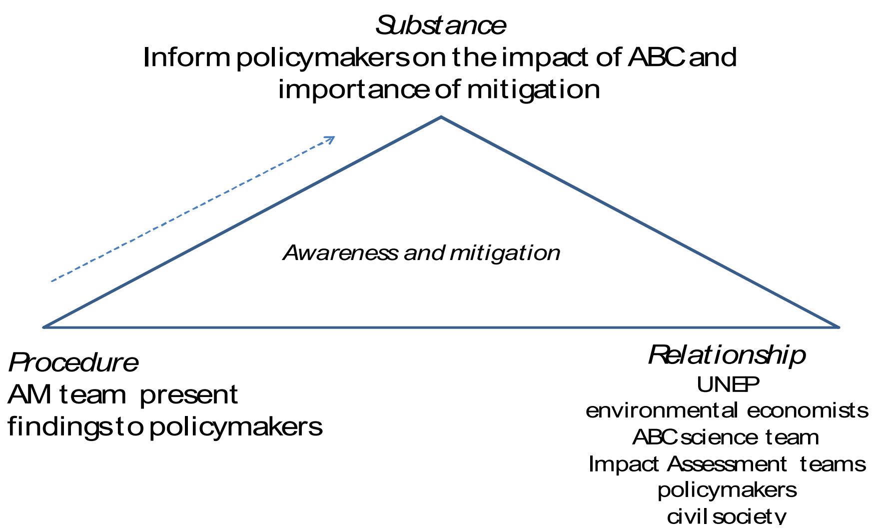


Figure 10. How the Progress Triangle is constructed from information on the concept maps.

After a Triangle was constructed from the ABC data, it was possible to make statements about the differences between the ideal Triangle (Figure 11) and the ABC

Progress Triangle created from the concept maps and transitional statements. In this step, the task of modeling is to examine tradeoffs that are associated with different strategies so that one could potentially improve the situation (Daniels and Walker 2001).

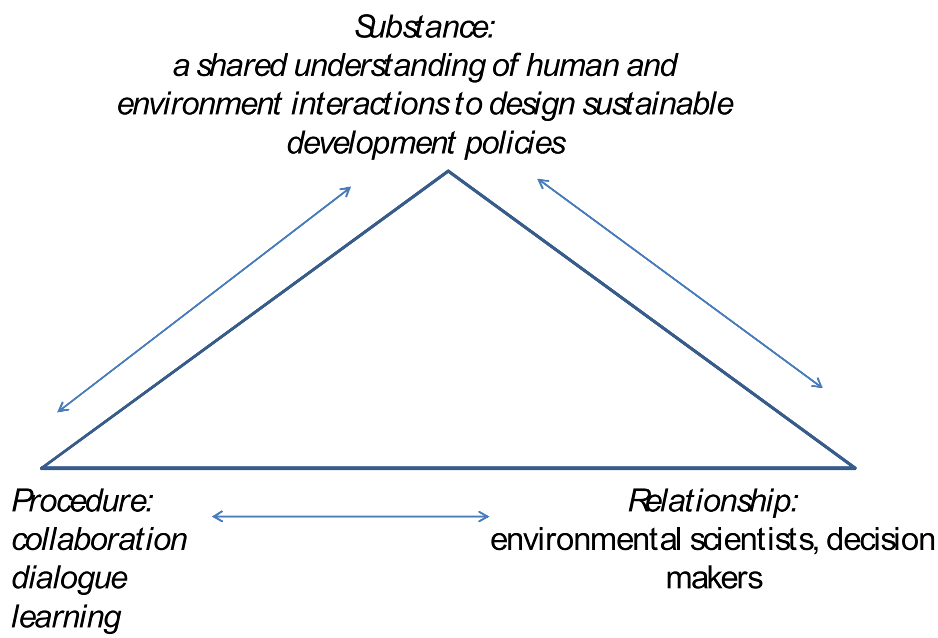


Figure 11. Progress Triangle for communicating information between scientists and decision makers.

The Progress Triangle (Figure 11) represents the ideal model of collaborative science and policy interactions to promote sustainability. In the relationship dimension, scientists and decision makers use dialogue to collaborate (procedural dimension) and achieve their substantive goals. In comparing the Triangle developed from ABC data and the ideal, I assessed the collaborative potential of the ABC system. Collaborative potential is high when the three elements are interdependent and mutually re-enforcing. Conversely, if elements of the triangle were not mutually reinforcing it is possible to identify weaknesses in or between dimensions and draw recommendations from the literature to improve collaborative potential.

Results

Collaboration between ABC's three programs

In 2002, the United Nations Environmental Program (UNEP) established Project Atmospheric Brown Clouds (ABC), an institution that integrates a climate and pollution observation program with impact assessments. According to the project framework, findings from these programs are provided to policymakers by an Awareness and Mitigation (AM) team. The AM program is the official organization that works with policymakers, while the research on aerosols, water, agriculture and health from the Impact Assessment (IA) team frames the issues in a way that may secure aerosols a place on policy agendas.

The chair of the ABC Observation program and the UNEP oversee the three teams and conduct annual meetings to ensure that there is dialogue and coordination between ABC researchers who collect, analyze and apply data to impact assessments and those who disseminate the information to an audience of policymakers and civil society (Concept Maps in Appendix 1 and 2). To illustrate ABC's framework, future plans for the Observation Program include new high altitude observatories in the Himalayas and a partnership with the Nepalese government. In parallel, the IA team proposes to explore the role of aerosols in glacier retreat. The potential implications for glacially fed rivers and their associated communities in India and Asia are issues that can be capitalized upon by the AM team to capture the attention of a broad audience.

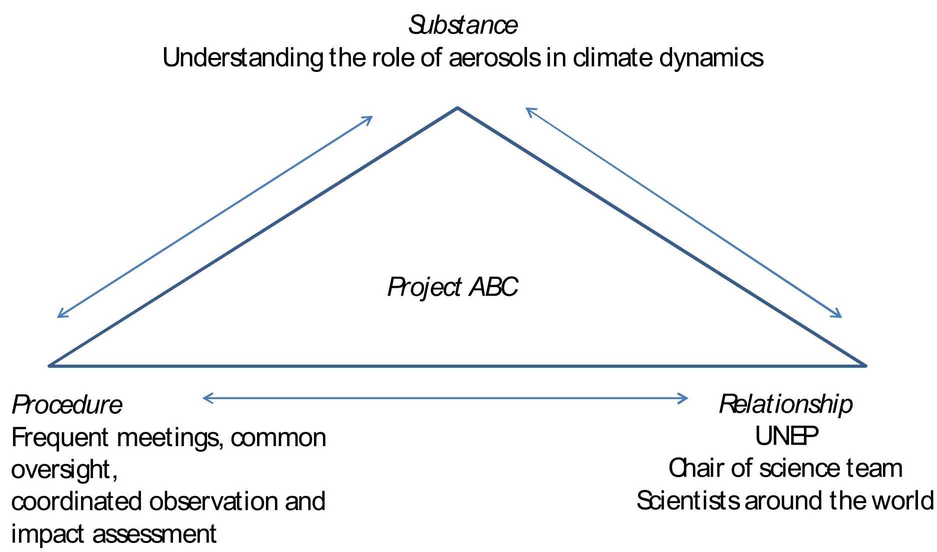


Figure 12. The three interdependent dimensions of the ABC programs.

Under the assumption that the documents offer a comprehensive description of the participating actors and their interactions, the Progress Triangle (Figure 12) shows how the global network of scientists (relationship dimension). These parties communicate through frequent meetings and joint oversight (procedural dimension) allowing researchers to work toward the shared mission of understanding aerosols (substantive dimension).

Discussion of Project ABC models

With this design, Project ABC has cultivated interdependence between the three programs that and made the boundaries between data, application and action easier to cross. Because these programs are integrated, team members share an understanding of issues, there is communication between programs and a narrow gap between knowledge users (IA and AM team members) and producers (Observation and IA team members) .

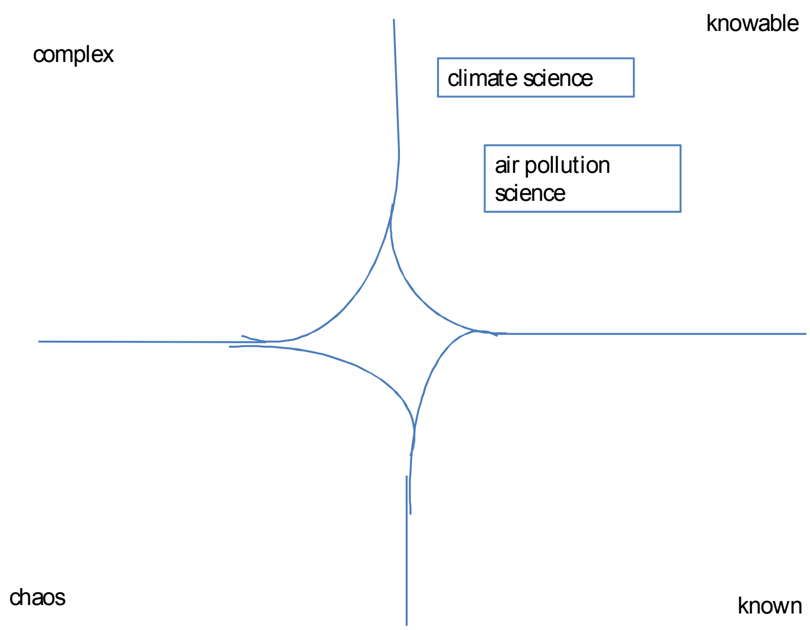


Figure 13. Knowledge domains of ABC Impact Assessment and Observation programs.

According to Kurtz and Snowden (2003) the work of the observation program and impact assessment could be categorized in the “knowable” knowledge domain of the Cynefin framework. That is, there are cause and effect relationships between aerosols, radiation and agriculture that may not be fully known or are only known to a limited group of people. In the “knowable” domain, trust between the knowledge user and producer is important due to the specialized content of knowledge. In the context of Project ABC, an expert who studies the impacts of aerosols on respiratory health must trust results from a scientist researching the chemical transport if they wish to apply this information to their research. The common mission and shared oversight that characterizes the relationships of Project ABC solidifies trust between observation and impact assessments researchers.

Collaboration between ABC and greater systems

Organizational theorists and systems thinkers find that there are strategic benefits to conceptualizing the boundaries of a system beyond an individual institution (Daniels and Walker 2001:94). In this case, Project ABC’s framework has been successful by creating an institutional boundary that encompasses three programs. However, to know if ABC is meeting its goals of assessing the impacts of aerosols on society and providing information to policymakers, this research broadened the scope to include society and policymakers.

Impact Assessment and Climate Science

The Observation and IA teams aim to validate connections between humans, aerosols, climate change and the environment to provide rationale for sustainable development policy actions. The concept map in Figure 14 is a conceptual model of the elements and relationships related to climate change that were recorded from ABC documents.

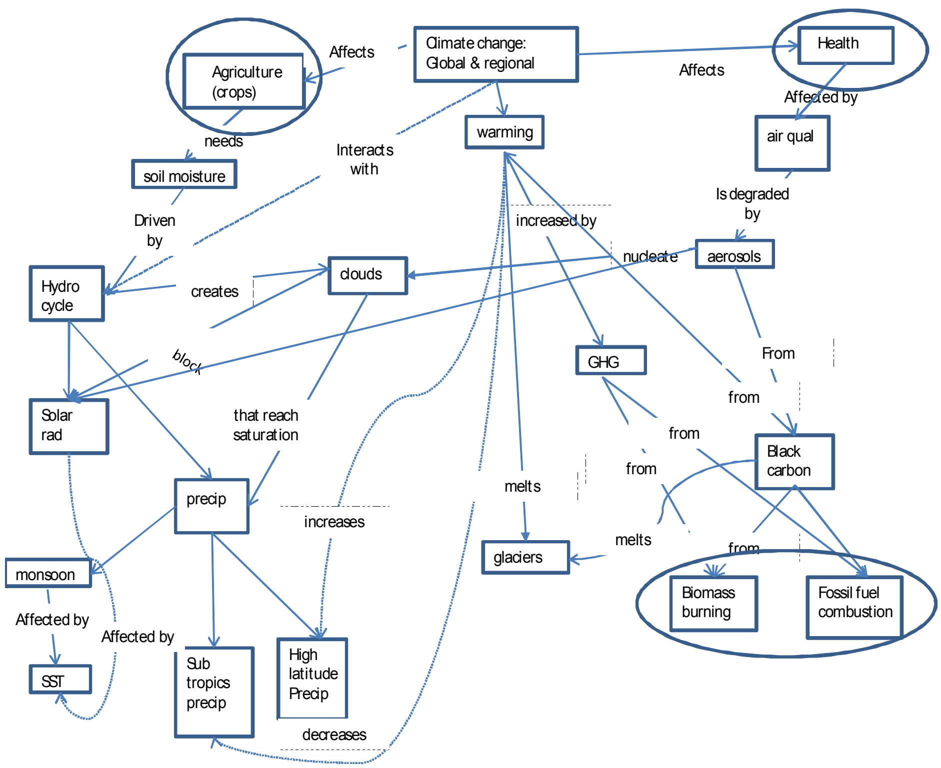


Figure 14. Climate change concept map.

Human activities are both at the root of aerosols–climate interactions and impacted by aerosol-climate interactions.

As shown in Figure 14, human activities that involve fossil fuel combustion and biomass burning are constituents of black carbon, the major source of anthropogenic of aerosols. The environmental impacts of aerosols include direct changes in air quality and indirect changes to monsoon and hydrologic cycles. By following a series of concepts on the map (via air quality and the hydrologic cycle) aerosols have implications for human health and agriculture. The structure and concepts in both Figures 14 and 15 suggest that there are interdependent relationships between aerosols, environment and society's natural resources.

The members of the IA team produce three impact assessment reports and have developed a climate-agro-economic model that simulates interactions between aerosols, greenhouse gases and rice harvests (Figure 15, circled). Other IA models simulate the interactions between black carbon and glaciers that feed downstream communities on the Ganges and Yangtze Rivers.

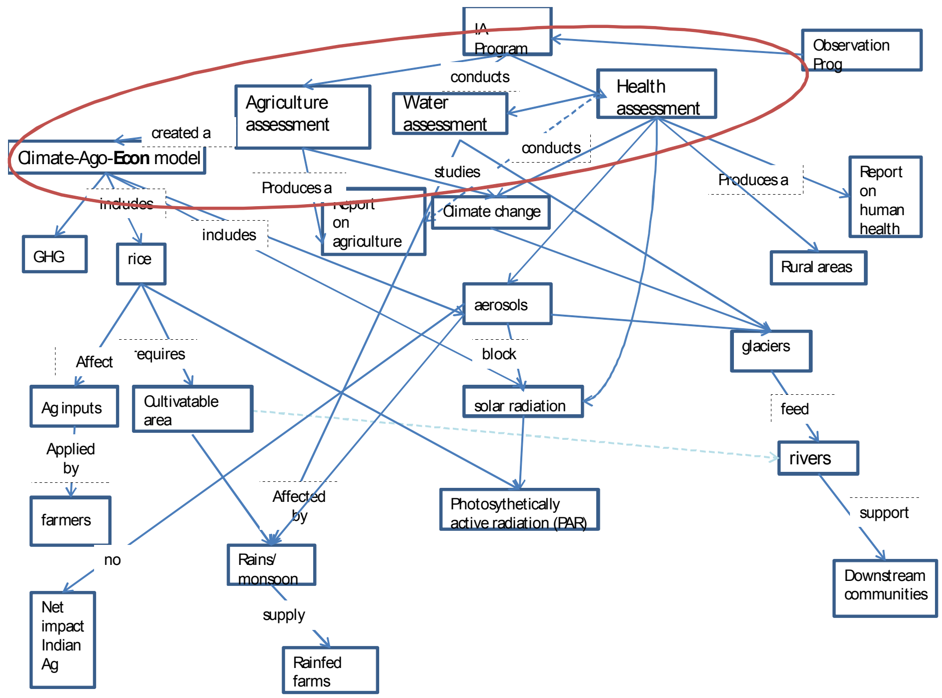


Figure 15. Impact Assessment concept map.

Circles indicate the procedures ABC uses to integrate science and policy.

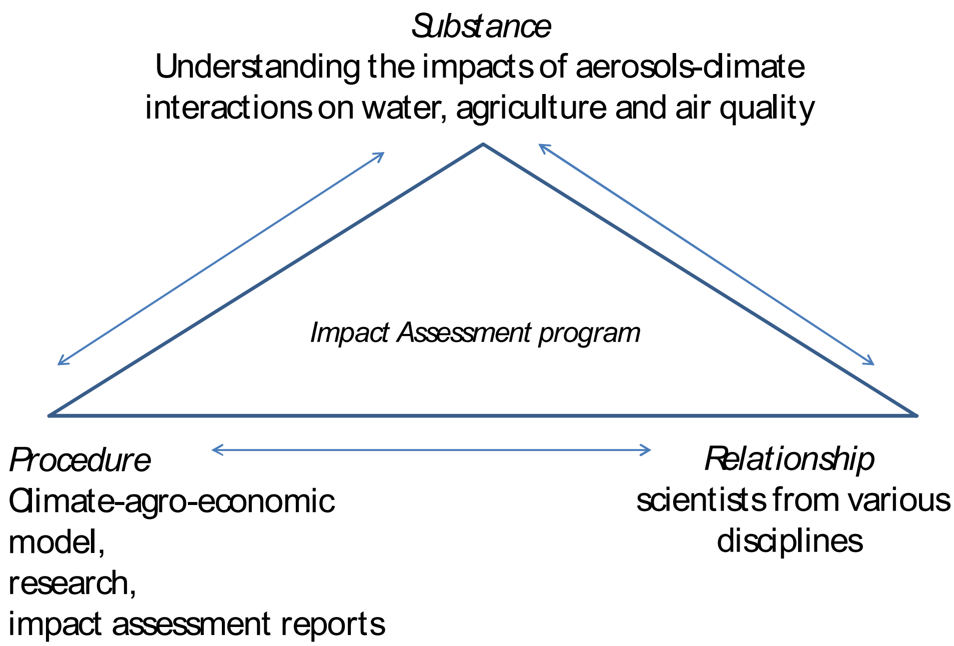


Figure 16. Progress Triangle of Impact Assessment team and climate science.

Assuming that the documents comprehensively represent the interactions among ABC participants, the Progress Triangle (Figure 16) is comprised of researchers from different disciplines working together using procedures popular with the scientific community (models and assessment reports). The findings generated from these procedures further scientific understanding of aerosol interactions with water, air quality and agriculture (substantive dimension). Assuming that collaborative potential is indicated by the degree to which the three dimensions are mutually reinforcing, the IA program has high collaborative potential between researchers interested in climate science and researchers that study society's natural resources.

Building on success thus far, transitional statements indicate that Project ABC is "focusing on impact assessments with high priority" (United Nations Environmental Program 2007) with plans to assess the indirect impacts of aerosol-water budget interactions on public health, land-use change and crop yields. These assessments will further develop the linkages between humans and aerosol impacts to "provide strong rationale for policy action" (UNEP 2007).

Discussion of Impact Assessment and Climate Change models

Within the scientific community, ABC impact assessments are lauded for making great strides in showing that humans are indeed changing the environment thus, building an argument for the mitigation of aerosols. According to Cash and Clark (2003) this success can be attributed to the idea that scientists have a common idea about what constitutes a persuasive argument. In this case scientific models and observations are used to produce impact assessments findings, for scientists, provide strong rationale for policy action.

Similar to the interactions described within Project ABC, an application of the Cynefin framework suggests that the greater scientific community resides in the 'knowable' knowledge domain. Both climate science and IA teams perceive that through research and experimentation the complex relationships between climate and pollution are knowable; as are the relationships between the monsoon cycle, solar radiation, rice production and so on. Here the Cynefin framework explains that the scientific method promotes transfer of knowledge from the “knowable” to the “known” domain. In this case, ABC continues to develop linkage between humans and the environment findings will become less frequently disputed. For purposes of innovation, Kurtz and Snowden recommend that this boundary be linked occasionally with movement into a different domain of knowledge.

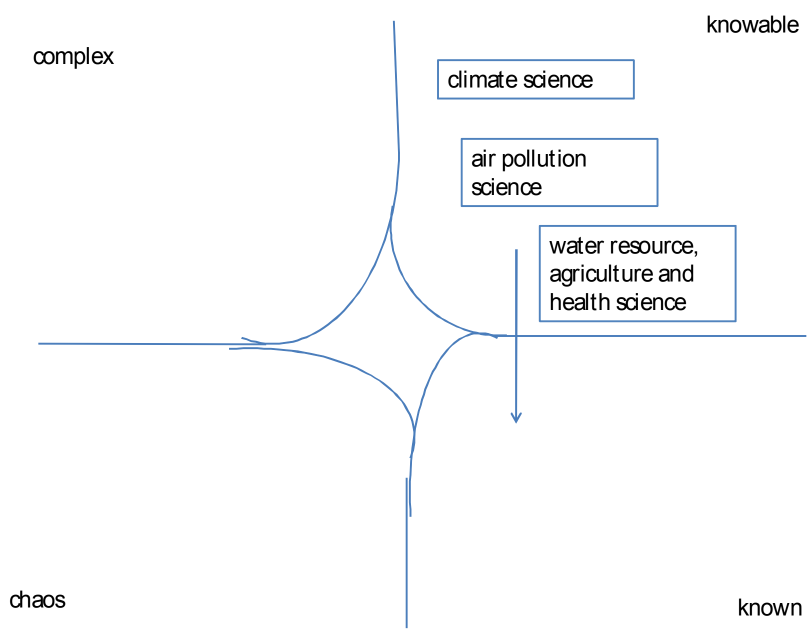


Figure 17. Cynefin framework for knowledge and boundary management. The scientific method aims to move concepts from knowable to known.

Harkening back to the work of Cash and Clark (2003), scientists and policymakers have different ideas about what constitutes a convincing argument. By extension, if policy policymakers do not find increasing scientific consensus (movement from ‘knowable’ to ‘known’) to be a convincing argument for policy action there may be diminishing returns observed in Project ABC’s current and proposed impact assessments to promote sustainable development policy.

Impact Assessment and Society

ABC’s Impact Assessment network is comprised of experts from a variety of disciplines that comprehensively assess the impacts of aerosols on water, agriculture and public health. The IA program is directed by the Chulabhorn Health Research Institute, Thailand, Indian Agriculture Research Institute, Nangyang Technological University, Singapore, the chair of the science team and UNEP. Secondary parties that steer the project include development agencies such as the World Health Organization (WHO) and Food and Agriculture Organization (FAO), atmospheric scientists, researchers and environmental economists from Europe, Asia, and the United States. In the future, transitional statements indicate that more environmental economists will be included into the IA network to quantify the damages related to aerosols.

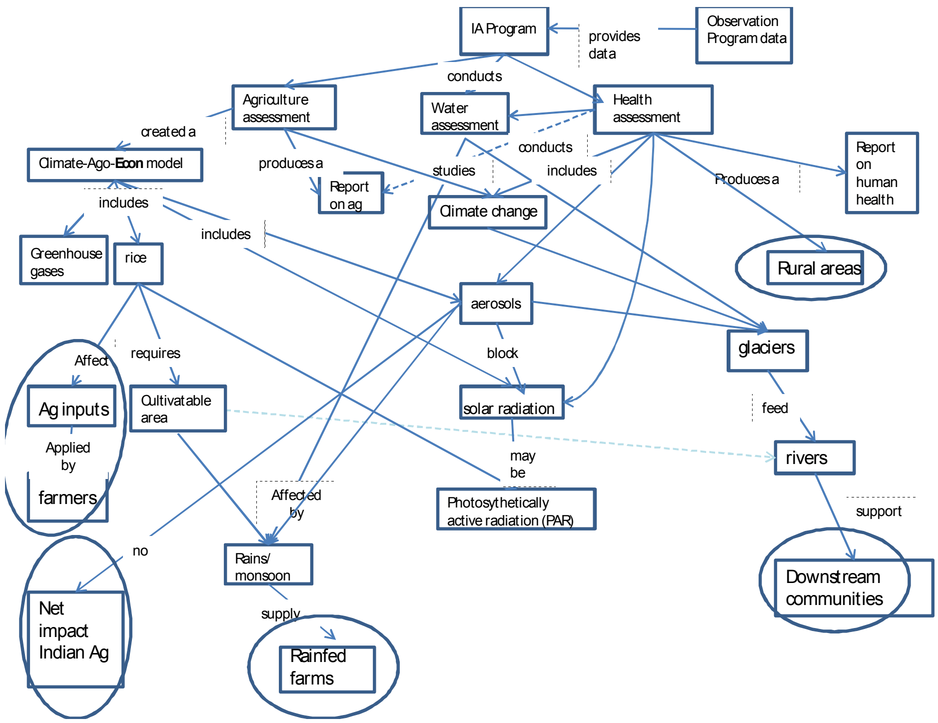


Figure 18. Impact Assessment map with circles indicating social elements that are described in ABC documents.

This network assesses the impacts of aerosols on water budgets, agricultural production and human health, and reports on threats to food security from reduced harvests and implications downstream communities impacted by changing temporal distribution of flows from glacially fed rivers (Perkins 2006; UNEP 2007). While useful for framing policy, the concept map in Figure 18 suggests that the downstream and farm communities that bare burdens of aerosols impacts (concepts circled), are not providing feedbacks to other concepts on the map. The map also indicates that, from

ABC models, aerosols have no net impact on Indian agriculture (Figure 18, circled) (Auffhammer, Ramanathan et al. 2006).

Assuming that the documents comprehensively and explicitly represent the procedures, parties and goals of Project ABC, it is unclear how the rural communities that are categorized in the relationship dimension are linked to procedures (Figure 19). It is possible that there is social research conducted through development agencies however the documents do not show explicit or implicit evidence of this (through relational linkages). Therefore, without research or other feedbacks it is not clear the procedures that are being used to accurately describe the impact of aerosols on rural communities.

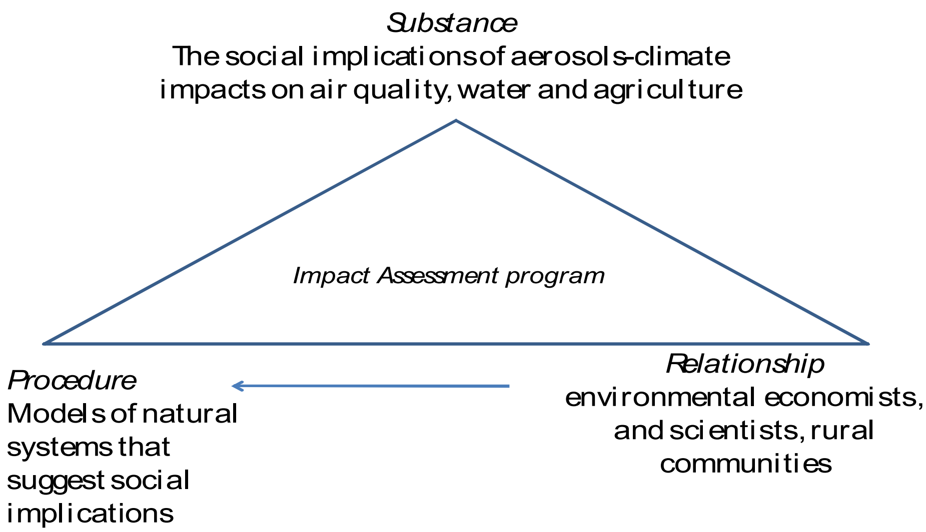


Figure 19. Progress Triangle for Impact Assessment team and social interest groups.

In comparing Figure 19 to an ideal model of mobilizing science into policy, the relationships and procedures used by ABC's impact assessment program do not support the goal of assessing the impact of aerosols on human communities, indicating low collaborative potential (assuming that collaborative potential is indicated by the degree to which the three dimensions of the Progress Triangle are mutually reinforcing). Documents do support a disconnect between research and reporting in selected reviews of ABC science that voice concerns that UNEP and Project ABC are misusing science for political purposes (Srinivasan and Gadgil 2002a; Srinivasan and Gadgil 2002b; Pielke 2004; Raghavan 2004; D'Monte 2007).

In order to match an ideal model that has mutually reinforcing dimensions and improve collaborative potential, the procedures that scientists are using to assess the impacts on rural communities would need to be clarified. Alternatively, adding parties to the relationship dimension who conduct research on social impacts of climate change would bolster both the relationship and procedural dimensions, in turn supporting the goal of assessing social impacts of aerosols.

Discussion of IA and Society models

In addition to the concerns that UNEP and ABC are misusing science for political purposes there is a contingent of social scholars who doubt the effectiveness of a scientific approach to adequately address issues related to climate and pollution (Schneider 1997; De Mello Lemos 2003; Pandey 2004; Lemos and Dilling 2007). One explanation for these concerns, and mentioned in earlier discussion, is that the task of communication and translation can be hindered by experiences and presumptions about what constitutes a persuasive argument (Cash, Clark et al. 2003). These voices of skepticism on the social side of climate research indicate that groups do not necessarily hold shared understandings of the relationships between aerosols and society. In general, environmental interest groups agree that perturbation in aerosol loading is an environmental concern; however the means to address these issues vary depending on one’s perspective. ABC scientists perceive there is an urgent need to *reduce* uncertainty through long term measurements and basic scientific research to make progress. In contrast, environmental policymakers look for ways to *manage* uncertainty and complexity (Schneider and Ingram 1997; Shackley, Young et al. 1998; Daniels and Walker 2001; Kates, Clark et al. 2001; Lemos and Morehouse 2005).

The differences in perception of an issue are closely tied to the preference for action (Kurtz and Snowden 2003). The authors of the paper concerning the impacts of aerosols on rice harvest (Auffhammer, Ramanathan et al. 2006) acknowledge that agronomic inputs, the forces of supply and demand and aerosols impact the production of rice in India. The authors then suggest that the direct and indirect impacts of aerosols and rice are correlated, such that a reduction in aerosols would improve rice harvests. As illustrated in Figure 19, ABC researchers perceived rice production to be 'knowable' in that models that project futures change can be perfected to recommend policy actions.

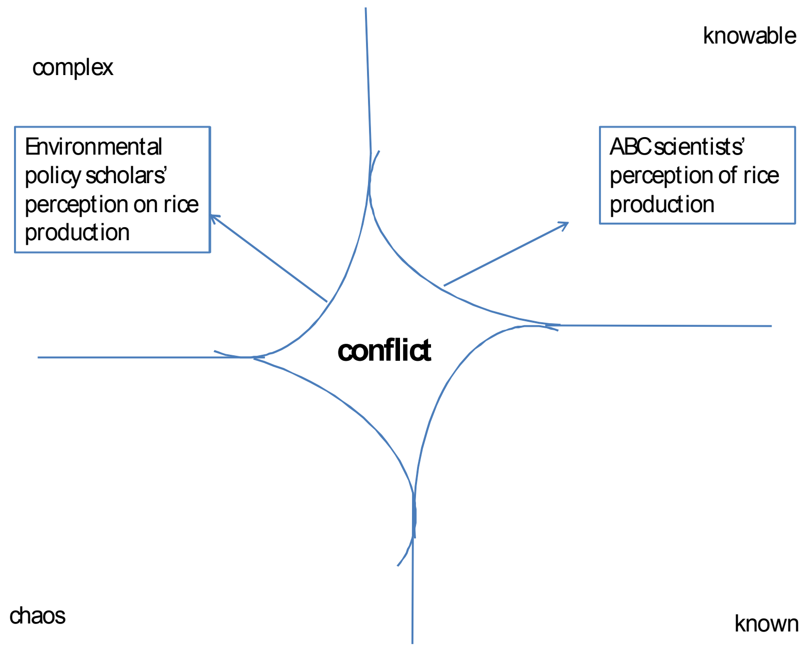
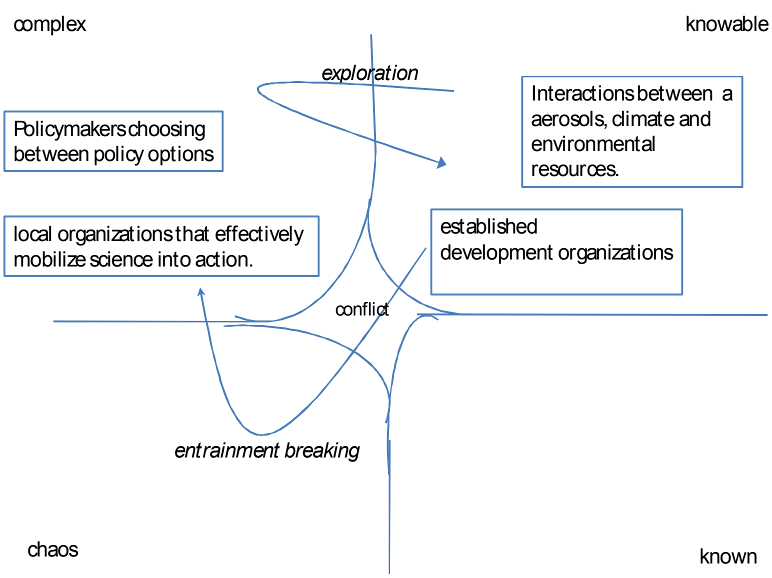


Figure 20. Diagram showing conflictive perceptions of a concept (adapted from Kurtz and Snowden 2003).

In contrast, policymakers that perceive economic, political, social and cultural forces play a role in rice production may give climate variables less weight and argue that it is characteristic for complex patterns, which ABC scientists are observing, can only emerge through retrospective investigation. These patterns may indeed be evident but because the underlying sources are not open to inspection we will be insufficiently prepared to project and act on unexpected patterns in the future (Schneider 1997; Kurtz and Snowden 2003; Davies and Simonovic 2007). It follows then, that policymakers may feel that the issue of rice production is more appropriately classified as 'complex'. The pull between 'knowable' and 'complex' moves the concept of 'rice production' into the conflict domain[5], a place where the opposing perceptions of social and environmental scientists do not share a common understanding. These different perspectives highlight the need for careful management of interactions between scientists and policymakers that, despite common interests in sustainability, have different ways of understandings issues and taking action.



[5] An alternative way of viewing the figure is that the pull between knowable and complex domains expands the conflict arena.

Figure 21. Exploratory movement across Cynefin framework boundaries.

Another potential application of the Cynefin framework can be illustrated with ABC's relationships with development agencies, such as the FAO, WHO, UNEP and the Asian Institute of Technology. These agencies support basic and applied research, use expert knowledge to collect, analyze and disseminate data and work closely with the scientific community to frame policy (UNEP 2007; FAO 2008; WHO 2008). If these organizations are not effectively addressing concerns of society, Kurtz and Snowden's framework puts forth that by relaxing central control of procedures and relationships with known institutions, the various IA teams can collaborate with other experts (perhaps in the social sciences). By relaxing central control new patterns and new leadership may emerge that address weaknesses in management. The Cynfin framework refers to this as entrainment breaking, where the chaos dimension may be briefly visited as the system moves to the complex domain. The complex domain is the realm of adaptive management, a process of iterative decision making in the face of uncertainty (Lemos, Boyd et al. 2007). Documents indicate that members of the IA team are expected to form their own networks of advisors, thus there may be high potential for entrainment breaking to occur (Figure 21).

<u>Awareness and Mitigation Program and the Environmental Policy systems</u>

In contrast to the Impact Assessment (IA) program that focuses on producing new scientific knowledge, the Awareness and Mitigation (AM) Program is designed to translate and disseminate information to policy makers and civil society. The AM program is lead by the Asian Institute of Technology, UNEP Regional Resource Center for Asia and the Pacific, the ABC Chair and Vice-Chair and is associated with policymakers, heads of governments, development agencies, the media and civil society.

The UNEP provides a link between the AM Program and governments that help fund Project ABC and or have signed on to the Malè declaration, an agreement that aims to manage transboundary air pollution. The UNEP is mandated by the United Nations to coordinate the development of environmental policy consensus by keeping the global environment under review and bringing emerging issues to the attention of governments and the international community for action (UNEP 2007).

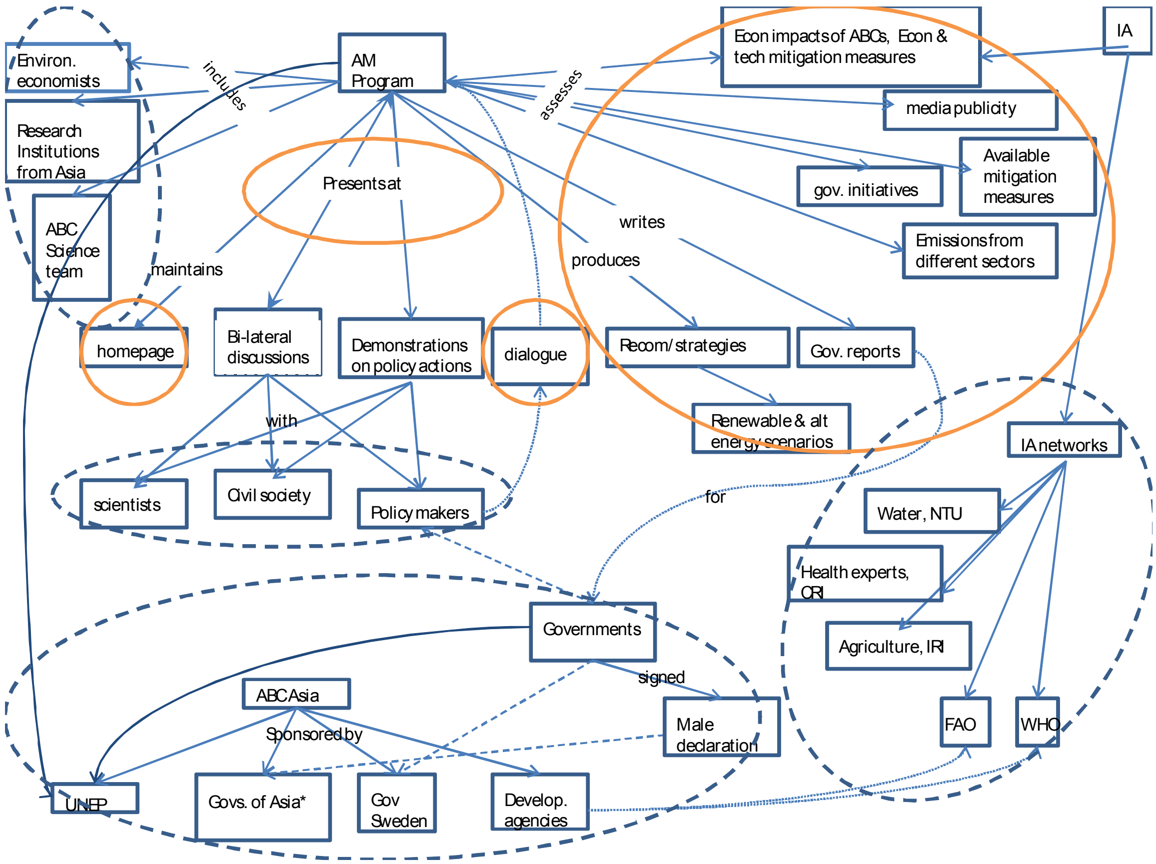


Figure 22. Concept map of ABC's AM program and science-policy boundary work. Blue circles indicate concepts in the relationship dimension and orange circles indicate concepts in the procedural dimension

The concept map of ABC's interactions with non-scientists (Figure 20) shows the procedures (orange, solid line circles) and relationships (blue, dashed line circles) related to policy that are perceived as relevant to the AM Program. The AM program's diverse set of actors appears as a well organized hierarchical structure with few links that are indicative of interdependence and feedbacks, or dialogue, throughout the system.

Transitional statements captured ABC's implicit and explicit assumptions about the relationships between science and policy. In the context of the Malé Declaration the UNEP states that "experience shows that most effective way of tackling air pollution issues is through international cooperation and in this, accurate scientific data are fundamental" (RRC.AP 2003). In parallel, the ABC framework emphasizes the role of scientific data and impacts assessments to provoke attention from policymakers and assumes: (a) that the outcome of the project fits the requirements for emission reduction and sustainable development (b) there is close collaboration from all the participating parties and (c) that governments will incorporate their recommendations into sustainable development strategies (UNEP 2007). From the map and transitional statements ABC's model of the policy making process can be summarized as follows: when policy makers are aware of an issue deemed important (a presentation), policy action (mitigation measures) will be taken.

As represented by the structure of the map lacking cross links, ABC's assumptions leave the key mechanisms for operationalizing collaboration and sustainable development largely undefined. Moreover, documents do not indicate that there are mechanisms for the audience to provide feedback after receiving information from the AM program. This type of communication is characteristic of capacity building tools such as government reports, presentations, websites and books (Figure

20, orange circle). Beyond these capacity building tools, there is a planned policy dialogue, providing a link back to the AM program.

Assuming that the documents comprehensively represent the interplay between ABC researchers and policymakers, evidence of dialogue is lacking. Moreover, ABC's assumptions that collaboration will happen without explicit mechanisms renders ambiguous dimensions and relationships in the Progress Triangle (Figure 21). As mentioned earlier, in an ideal model of the interactions between scientists and decision makers, interdependence and collaborative processes support the mission (substantive dimension) to inform policymakers on an issue, in this case the importance of mitigating aerosols.

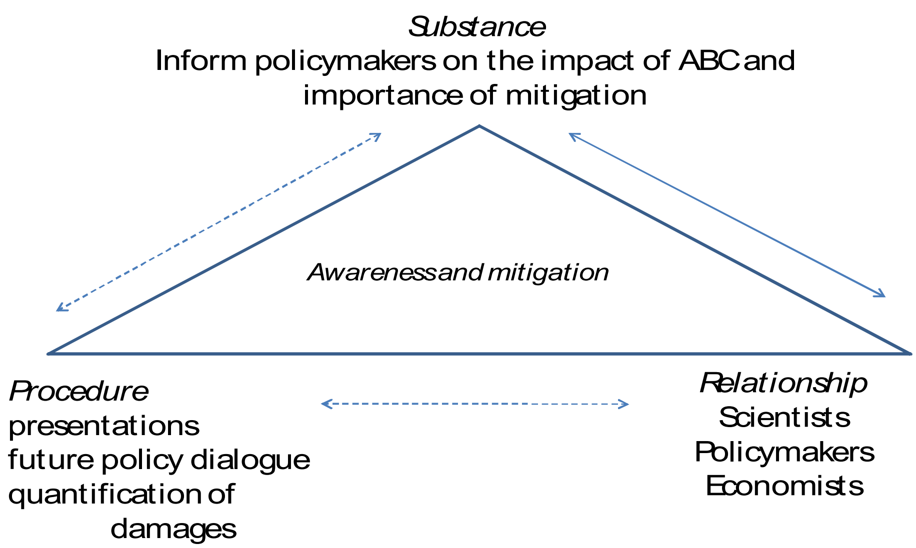


Figure 23. Progress Triangle showing interdependencies in AM program

To match the ideal model of mobilizing science into action, concept maps would need to show evidence of collaborative procedures used by scientists and policymakers. Without this evidence from ABC documents, relationship and procedure dimensions of the AM program do not support the goal of informing policymakers on ABC's aerosol mitigation recommendations. These procedural weaknesses in Project ABC hinder the program's ability to capitalize on ABC's connections to policymakers (relationships) and research that addresses major implications of climate change (substance). Assuming that the presences of mutually reinforcing dimensions of the Progress Triangle indicate collaborative potential, Figure 23 suggests that collaborative potential between scientists and policymakers is low.

Discussion of Awareness and Mitigation Program models

The boundary between science and policy is not easily permeated because different perspectives and information require translation and possibly mediation to reach shared understandings (Cash, Clark et al. 2003). The directors of ABC make efforts to translate and frame the findings of scientific research in a way that is meaningful to decision makers. For example, transitional statements indicate that environmental economists that will quantify societal impacts and damages incurred by aerosols. Nevertheless, without mechanisms for dialogue the AM program risks providing irrelevant information to stakeholders and may lead policymakers, the media and civil society to overestimate the power or misinterpret of scientific results (Cash, Clark et al. 2003).

Communication with non-science actors through presentations, government and media assessments may be characterized as dialogue if ABC uses mechanisms for feedback and evaluation that are then used to cater information to the audience. This approach effectively supplies decision makers with information and cultivates a demand for that information. This type of dialogue, i.e. exploratory movements across the science-policy divide, allows for careful control of the boundary to monitor for concerns of politicization of science and allows scientists to learn more about the deliberative political process. The stated focus on the IA program, in conjunction with the established practice at the UNEP and other development organizations, suggests that exploring complexity and relaxation of central control would need to be actively facilitated to allow new leadership and directions to emerge, to transform the new and current relationships from coordinated to collaborative.

Perhaps a more fundamental issue suggested by the structure of the map, is that Project ABC's conceptualization of the policy system is missing components of the most rudimentary cyclical policy models. For example, ABC's recommended mitigation strategies are premature from a political perspective because they lack input from a variety of interests and alternative policies (e.g. adaptation) have not been explored. In other words, ABC's recommendations for mitigation preclude the implicit deliberative processes that are involved in policy formation. This is a concrete instance where, as stated by scholars who work with boundaries, rules and norms that guide science do not apply to policymaking and vice versa (Cash, Clark et al. 2003; Kurtz and Snowden 2003).

Ultimately, incentive to engage in collaboration hinges on interdependence: until ABC perceives that the policy community is an integral part of mobilizing science into action it will be difficult to reach their goals of informing policymakers to promote sustainable development. Moreover, if ABC wishes to move beyond assessments into action, attention will need to be given to the processes promote shared understandings and learning. However, ABC's undeveloped understanding of the policy process and assumption that collaboration will spontaneously occur may suggest that they are not taking boundary work seriously; a paramount barrier to 'harnessing science for sustainability'(Cash, Clark et al. 2003).

Conclusion

The global network of scientists and partnership with UNEP puts Project ABC in a unique position to promote sustainable development by providing information to policymakers on a global scale. The organizational design of Project ABC has made the boundaries between scientific observation and impact assessment easy to cross by bringing these tasks under a common framework to facilitate dialogue, shared understandings, interdependence and hence, collaboration between programs. The high collaborative potential between ABC programs may offer insight into the success that the project has had in advancing understanding the role of aerosols in climate change.

However, as Project ABC's interactions move away from the scientific community toward social applications and implications, the IA and AM programs exhibit low collaborative potential. The program procedures promote communication with policymakers through issue framing and translation of scientific findings into economic terms; still, project documents suggest that ABC team members do not engage in dialogue with policymakers. This suggests that ABC will have difficulties meeting its goals because collaboration has been identified as a key component in sustainable development and the most effective way to mobilize science into action.

One way for policymakers and scientists to perceive interdependence would be to conceptualize the Awareness and Mitigation Program as the intersection of Observations, Impact Assessment and Policy Making, rather than the terminus of information produced by Project ABC.

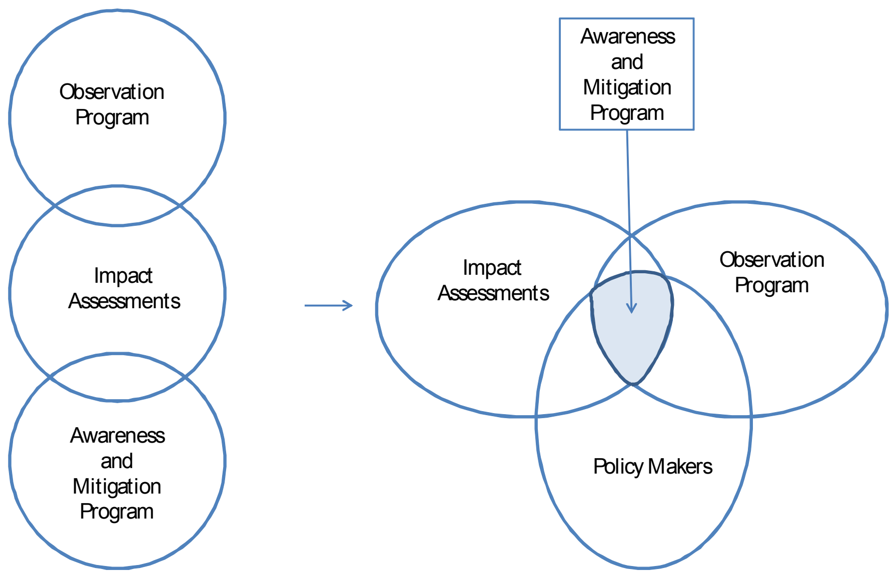


Figure 24. Conceptualizing the Collaboration between ABC and Policymakers

This conceptualization of the AM Program creates an arena for dialogue and collaboration between scientists and policymakers. And, more importantly, Figure 24 shows that policymakers are an integral part of the AM Program, thus fostering interdependence. The evolutionary nature of this shift may allow the UNEP and

Project ABC to remain at the forefront of innovative strategies for sustainability science. Or more simply, Figure 24 may be a model that more explicitly illustrates that policymaker's needs are being assessed and that ABC scientists are gaining insight into the public policy process from environmental policy experts.

Based on the Collaborative Learning Approach, this study used Project ABC as a case to explore how systems thinking, conflict management and learning theories can be useful perspectives where the environmental, social and economic interactions of sustainable development are complex and often conflictive. Moreover, by conceptualizing sustainable development and collaboration as tools for management it was possible to examine how relationship and procedures influence a program's ability to achieve their substantive goals. The collaborative potential assessment combined with a case studies approach provided an interesting opportunity for academic research while describing how collaboration can develop strategic and innovative relationships that effectively provide information to policymakers.

Furthermore, in the interest of mobilizing science into action, collaborative relationships that hold shared understandings and learning as primary goal can address the issue that while scientific information provides a persuasive argument for member of the scientific community, social, political and economic interests may be less easily convinced by these arguments. Here interdependence plays a critical role, in that without decision makers being persuaded science cannot be put into action.

Despite the centrality of perceived interdependence perceptions are very difficult to change and, as often noted by opponents and proponents of collaborative processes, building bridges across the chasm between science and policy is a time and energy intensive process. Here the Cynefin framework, developed by business management scholars, offer useful insight into how organizations can reap benefits, promote innovation and develop strategies by changing perceptions, exploring, managing and respecting boundaries.

Boundaries need to be respected to maintain integrity and control of an organization for strategic and competitive reasons. The same can be said in the context of sustainable development where managing science and policy interactions through collaboration can address the concerns of misusing science for political purposes and the inadequacy of scientific knowledge to address social issues related to climate change and pollution. In ABC's enthusiasm to lower the boundaries between observation, impact assessment and policymaking this case study offers some examples of the boundary between science and policy being haphazardly crossed.

In summary, perhaps the most important characteristic of an effective institution, that aims to mobilize science into action, is that boundaries between science and policy need to be taken seriously (Cash, Clark et al. 2003). Even with the premier scientists from around the world teamed with the UNEP and a specialized program that aims to provide information to policymakers, the ABC case study shows that without carefully designed collaborative procedures and perceived interdependence, the goal of promoting sustainable development will be difficult to achieve.

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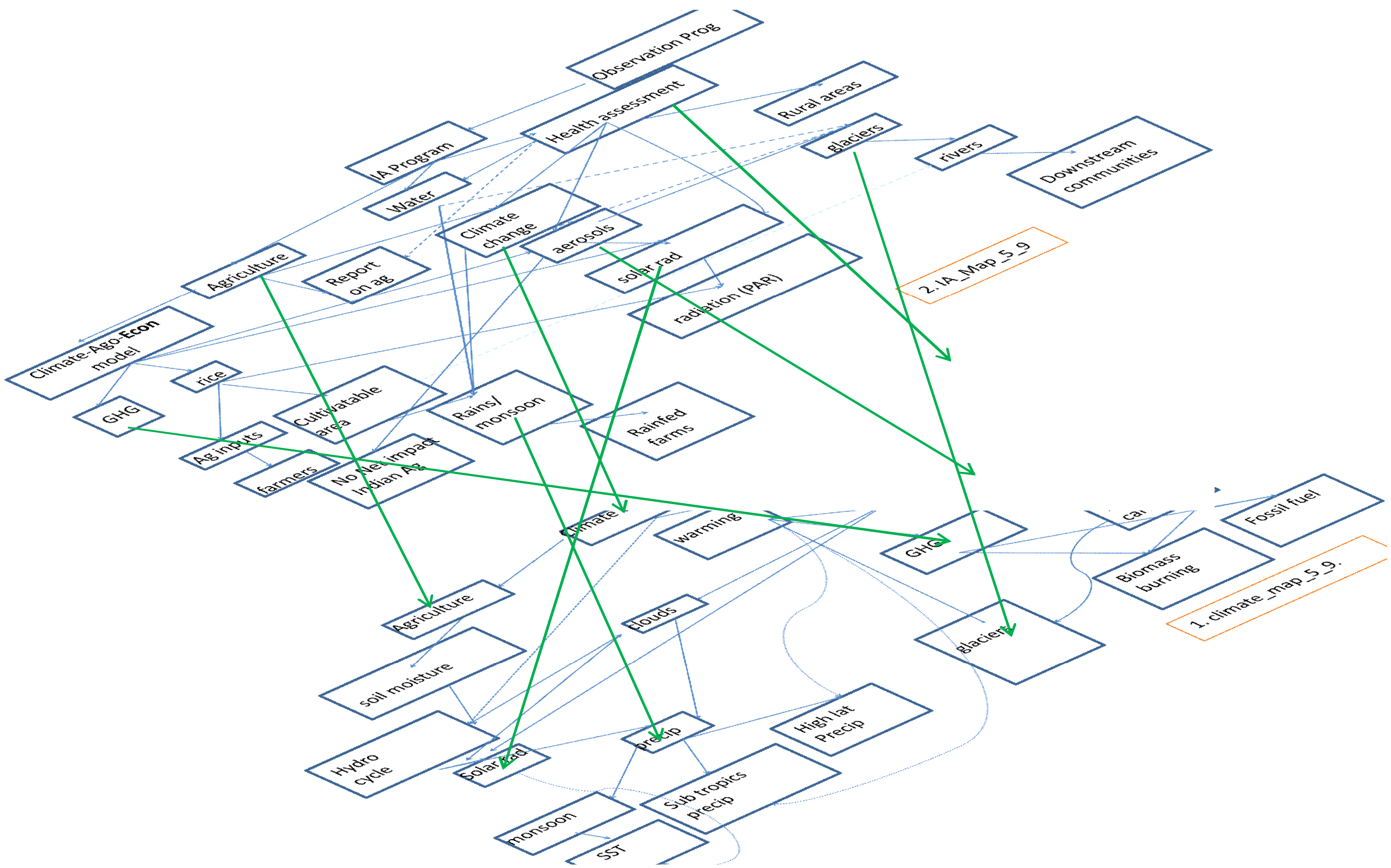
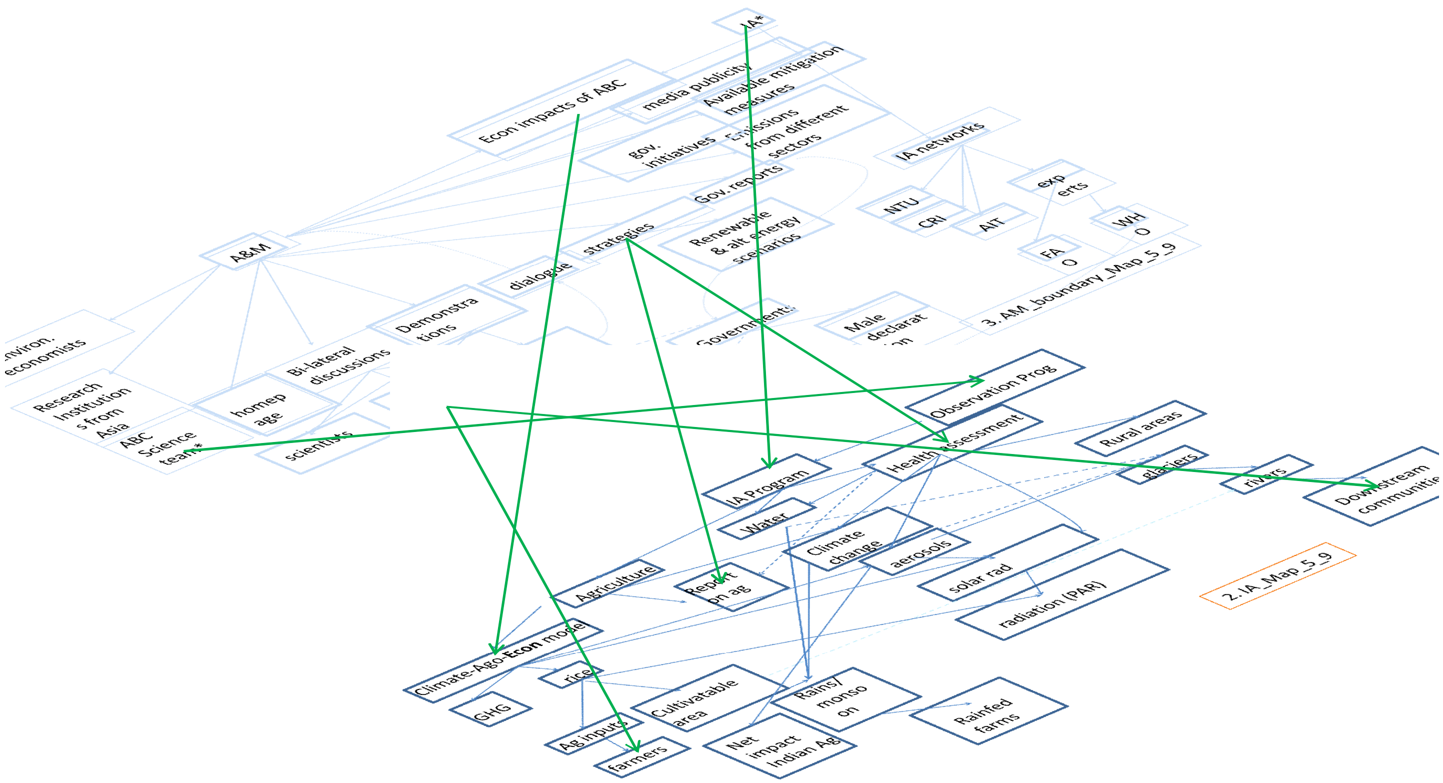
APPENDIX

Appendix 1.Connections between Impact Assessment map and Climate Change map showing relationships between Project ABC programs.



Appendix 2. Connections between Awareness and Mitigation map and Impact Assessment map showing relationships between Project ABC programs.



Appendix 3. Documents in content analysis

(Ramanathan and Crutzen 2001; Ramanathan, Crutzen et al. 2001; ABC 2002; Ramanathan, Crutzen et al. 2002; Srinivasan and Gadgil 2002; Srinivasan and Gadgil 2002; Crutzen, Ramanathan et al. 2003; Ramanathan 2003; Ramanathan and Crutzen 2003; Ramanathan and Ramana 2003; RRC.AP 2003; UNEP, ABC et al. 2003; Chang 2004; Pandey 2004; Ramana, Ramanathan et al. 2004; ABC 2005; Chung, Ramanathan et al. 2005; Ramanathan, Chung et al. 2005; Auffhammer, Ramanathan et al. 2006; Chung and Ramanathan 2006; Cramer 2006; NSF 2006; BBC 2007a; D'Monte 2007; Haag 2007; Hadley, Ramanathan et al. 2007; Lee 2007; Ramanathan 2007; Ramanathan, Ramana et al. 2007; UNEP 2007; UnionTribune 2007; United Nations Environmental Program 2007)