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Ecology and economy in the Arctic

Uncertainty, knowledge and precaution

Abstract:
Climate change impacts in the Arctic require that complex relationships between the economy, the environment, and the living conditions of indigenous and local people be taken into account. While traditional approaches to economic valuation may not be sufficient to capture these relationships, the research area of ecological economics suggests broader approaches to environmental uncertainties, taking into account ethical values and conflicts of interest. Increased activity in petroleum exploration, manufacturing, transportation, tourism and other services have the potential to alter the Arctic environment and societies considerably. Application of the precautionary principle is suggested as a way to manage situations with large degrees of environmental uncertainty and potentially irreversible consequences. Precautionary approaches require the development of processes for acknowledgement of uncertainties, facilitation of stakeholder participation, recognition of ethical values, and taking into account the traditional ecological knowledge of indigenous people of the Arctic. Combining traditional and scientific knowledge about nature is an important part of understanding the resilience capacity of ecological and social systems, and of enhancing the potential for sustainable development.

Keywords: Arctic, Environmental uncertainty, Ecological Economics, Precaution

JEL classification: Q54,Q57

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1. Introduction

The Arctic is in the midst of rapid and unpredictable change, with respect to climate, economy and social organization. Climate change impacts manifest themselves more rapidly there than in other regions. The vulnerable Arctic environment represents an important example of the need for new approaches to environmental uncertainty, since the complex relationships between the economy, the environment and cultural values are very strong and well documented; see ACIA (2005), AHDR (2004) and AMAP (2002). International and national policies in the Arctic region focus strongly on climate change, its detrimental impacts, and potential beneficial impacts on accessibility and extraction of natural resources.

Given the substantial environmental uncertainty, the irreplaceability of the Arctic landscapes, and the complex ethical issues involved, we argue that economic valuation should be supplemented with other methods, such as focus on the processes for assessing uncertainty, through interdisciplinary approaches like ecological economics, with explicit incorporation of stakeholders' values, interests and knowledge. The Arctic environmental problems are a strong reminder of the importance of approaching valuation of nature in terms of sustainability, resilience and environmental responsibility.

In particular, valuation of nature needs to be addressed in terms of multiple uses of the Arctic landscapes of frozen sea, glaciers, tundra, grasslands, and forests. The valuation should reflect the different options for subsistence production, biodiversity protection and ecosystem services. The Arctic Human Development Report AHDR (2004) emphasizes that the Arctic is the homeland of diverse groups of indigenous people. The ecological values of the Arctic are compounded by their culture, and indigenous and local knowledge is crucial for establishing the information basis for sustainable development.

The Arctic natural environment provides subsistence livelihoods for indigenous and local people, and resources for the market economy. The intertwined nature of the subsistence and market economies gives Arctic societies their dual characteristics (Glomsrød and Aslaksen (eds) 2006). Climate change impacts and other environmental problems can dramatically affect the conditions for subsistence activities and the well-being of the indigenous and local people. Knowledge about these changes is crucial for identifying conditions and policy measures to ensure economic, environmental and cultural sustainability in the Arctic, within the framework of the global economy.

Climatic and other environmental impacts have already dramatically altered the living conditions of indigenous peoples, and ongoing economic and social impacts may substantially affect their opportunities (Ford et al. 2006). The most recent IPCC (2007) report included the following statement.

'In the Polar Regions, the main projected biophysical effects are reductions in thickness and extent of glaciers and ice sheets, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals and higher predators. In the Arctic, additional impacts include reductions in the extent of sea ice and permafrost, increased coastal erosion, and an increase in the depth of permafrost thawing. For Arctic human communities, impacts, particularly resulting from changing snow and ice conditions, are projected to be mixed. Detrimental impacts would include those on infrastructure and traditional indigenous ways of life. Beneficial impacts would include reduced heating costs and more navigable northern sea routes. In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climate barriers to species' invasions are lowered. Arctic human communities are already adapting to climate change, but both external and internal stressors challenge their adaptive capacities. Despite the resilience shown historically by Arctic indigenous communities, some traditional ways of life are being threatened and substantial investments are needed to adapt or relocate physical structures and communities' (IPCC 2007).

Precautionary perspectives are required to balance the economic, environmental and ethical values of the economic activities in the Arctic, to integrate divergent interests and to protect biological and cultural diversity. A key concept in precautionary strategies is resilience, understood as the capacity to recover after disturbance, absorb stress, internalize it and transcend it (Berkes, Colding and Folke 2000; Holling 1973; Holling et al. 1995; Gunderson 2000). Resilience refers to both ecological and cultural resilience of individuals, of ecosystems and of local communities. An important precondition for resilience is involvement of local and traditional knowledge and practice.

Climate change is already having a strong impact on nature and livelihoods in the Arctic. Although a comprehensive precautionary perspective would have necessarily addressed values and policies in the past, the ongoing climate change process demands a continuous effort to learn from the 'late lessons' that may be drawn from earlier experience, and to develop 'early warnings' of future impacts. We suggest that environmental uncertainty in the Arctic is addressed in terms of the framework in the European Environment Agency report 'Late lessons from early warnings: The precautionary principle 1896–2000' (EEA 2001). The report describes environmental and health costs of not responding to credible scientific 'early warnings', summarizes some 'late lessons' that may be drawn from these

experiences, and suggests important elements in precautionary approaches (see also Aslaksen, Natvig and Nordal 2006). A comprehensive empirical application of the framework suggested by the 'Late lessons from early warnings' is beyond the scope of this paper, however we outline some points for future empirical application.

The main focus of this paper is to address the environmental uncertainty in the Arctic in terms of 'strong uncertainty', with 'ignorance' about the future outcomes (Funtowicz and Ravetz 1991, 1994). Strong uncertainty challenges cost-benefit analysis and calls for precautionary approaches. We consider stakeholder involvement to be crucial for improving the knowledge basis, in identifying 'early warnings', as well as in elaborating strategies to mitigate and adapt to environmental and social consequences of climate change impacts.

2. Uncertainty, valuation and precaution

The Arctic ecosystems and social systems are unique, and represent a valuable part of the world's common ecological and cultural heritage. The dual characteristics of the Arctic economies, with strong and complex relationships and barriers between subsistence activities and markets, represent considerable challenges for evaluating the conditions for sustainability and developing precautionary strategies for environmental uncertainty. The economic, social and cultural well-being of indigenous people living in remote areas is shaped under conditions that deviate from standard assumptions in economic theory and models for well-developed markets that do not take into account the barriers and transaction costs associated with their traditional basis for living.

To examine this complexity, we apply the distinction between 'practical' and 'technical' problems as outlined by Ravetz (1971) and applied to environmental uncertainty by Cañellas-Bolta, Strand and Killie (2005). 'Practical' problems are defined as problems for which the solution consists of the achievement of a human purpose, such as welfare, health, or the natural environment remaining in a good state. In the context of the Arctic economy, the practical problem may refer to the challenge of achieving balance between economic profitability and sustainable development. 'Technical' problems are defined in terms of functions to be performed, and their solutions consist of finding a technical specification that performs the function. In the context of the Arctic economy, the technical problem may refer to the policy means to ensure sustainability. Despite their intertwined nature, the market economy and subsistence economy represent different spheres with different approaches to values. The challenge is to integrate the two approaches, to ensure that the practical problems are explicitly addressed, and to discuss how sustainable development in the Arctic can be achieved, while

recognizing that the technical problems and the instrumental approaches specific to each discipline do not necessarily capture the whole picture. Even problems that are considered technical have practical aspects, in that their solution requires an explicit analysis of the human purpose that should be achieved (Ravetz 1971, p. 319).

Political approaches to environmental risk and quality, in particular at local and regional levels, almost exclusively focus on technical solutions, neglecting the questions related to the practical targets: What type of nature conservation do we want? What is the authentic quality of this particular type of environment? Which results of development in nature should be preserved? Which glaciers, boreal forests and fishing communities? What would the loss of these places mean to humanity (Latour 2004)? Who are the stakeholders representing the sea ice and the polar bear? Raising these questions has implications for employment of economic valuation and risk governance, represents a different dimension to optimism or pessimism, and is different from being 'for or against' a particular economic or technological development, by demanding perspectives on needs and goals at a more conceptual level.

Considering potential harm to a wide range of stakeholders implies a larger context than a cost–benefit analysis allows. The environmental uncertainties in the Arctic involve 'ignorance' about future outcomes, representing 'strong uncertainty' (Funtowicz and Ravetz 1991, 1994). 'Post-normal science' focuses on uncertainties in valuation and complexities in ethics from a new perspective: When science is no longer imagined as delivering 'truth' irrespective of context, science should follow a new organizing principle; that of quality (Funtowicz and Ravetz 1991, 1994). A central concept in this approach is procedural rationality (Simon 1976), a scientific principle with a stronger focus on the process of knowledge generation and the implicit values involved. Such procedural rationality could imply an extension of the peer-review community to people from other disciplines, and to people affected by the particular environmental issue. It involves recognition of the importance of context, and the possibility of more egalitarian access to knowledge and to knowledge-generating processes. This may be facilitated by extending the peer community for the accumulation of knowledge, encompassing the perspectives of multiple stakeholders (Kinzig and Starrett et al. 2003). Examples include the processes involved in the work of IPCC, and also the Arctic Council, where cooperation between indigenous people across the Arctic is building an institutional framework for multiple voices. New institutions for participatory processes are needed to strengthen dialogue between stakeholders and secure the role of less powerful stakeholders.

The challenge of finding practical applications of the precautionary principle needs to be addressed specifically in each situation (case-by-case evaluation). Generally, the presence of ignorance and strong uncertainty calls for precautionary approaches and development of 'early warnings'. Ignorance can no longer be ignored. Perrings (2003) discusses climate change and precautionary response.

Uncertainty about the value of the natural environment can be understood not only as a lack of scientific knowledge, but also as a lack of coherence between competing scientific disciplines, each with its own tradition, approaches, and models (Sarewitz 2004). The values and normative assumptions held in different scientific disciplines can represent contrasting scientific views of nature, human nature, the relation between nature and humanity, and the extent of the ethical responsibility of the individual, the scientist and the politician. What Sarewitz (2004) denotes as an 'excess of objectivity' refers to the observation that available scientific knowledge can be interpreted in different ways to yield competing views of the 'practical' and 'technical' problems, and how society responds. From this perspective, demand for 'more research' is not sufficient to reduce scientific uncertainty and infer the value of nature and the conditions for sustainability. In fact, the incapacity of science to provide a unified picture of the natural environment contributes to the lack of coherence about its valuation. What is needed is an explicit discussion of the plural values and scientific approaches involved in a particular environmental controversy, thereby making a distinction between the practical and technical problems involved, and management of the uncertainties that are characteristic of each field so that information of the highest possible quality can be obtained (Funtowicz and Ravetz 1990, 1994). Central to uncertainty management and environmental valuation is the recognition that the scientific, economic and social contexts are intertwined (Myhr 2002). The challenge is to enhance communication between the various perspectives and implicit values in science. Only by acknowledging the importance of environmental responsibility can a comprehensive perspective on the relationship between environmental uncertainty and sustainability be developed (O'Neill 1993, 1996, Vatn 2005). Considering environmental responsibility for future generations, Jonas (1984) suggests that responsibility is a more basic ethical principle than reciprocity, since there is no reciprocity between future generations and us. With respect to responsibility, the distinction between 'is' and 'ought' is no longer relevant. Environmental responsibility relates to human existence in the future, and suggests that the Earth should not be left in a worse state than when the present generations received it.

Economic valuation methods that rely only on quantitative valuations, without considering particular environmental qualities and uncertainties, can appear blind to natural and cultural values that are

difficult to measure. This apparent blindness may be subject to criticism from other disciplines, questioning the relevance of economic trade-offs for valuation of environmental qualities (Aslaksen and Myhr 2007).

Figure 1. Valuation and evaluation in social context

Economic valuation	and	Evaluation in ecological and social context
Valuation without context		Neglecting economic trade-off

Valuation without context refers to the practice of considering the value of nature as being similar to the value of other goods, without taking into account the ecological processes and cultural context embodied in the natural environment. As suggested in Figure 1, the bridge across this duality is to emphasize that multidimensional evaluation, not only one-dimensional monetary valuation, of environmental qualities, uncertainties, and impacts should take place in processes that recognize the ecological and social context of economic evaluation. More comprehensive and contextual evaluation methods could include multicriteria analysis and participatory methods such as stakeholder participation and deliberative processes for assessing uncertainty, for accommodation of scientific disagreements, and for integration of stakeholder interests and perspectives (Vatn 2005; Martinez-Alier, Munda and O'Neill 1998).

3. Traditional ecological knowledge

To provide a better perspective on the appropriate context for economic valuation of environmental uncertainty, traditional ecological knowledge may be crucial, as for instance in the process of identifying the impact of climate change in the Arctic. Traditional ecological knowledge is defined as knowledge, practices and beliefs about the dynamic relationships of living beings and the environment, knowledge that has evolved by adaptive processes and been handed down from generation to generation (Berkes 1999, Ingold 2000, AHDR 2004). For example, traditional ecological knowledge of animal migrations, ice patterns, vegetation and weather is important in order to supplement and enrich scientific data on climate change impacts. These impacts on the texture of snow and ice are important determinants of the access of reindeer to food (Tyler et al. 2007). This makes local inhabitants unique observers of how changing winter weather patterns are altering the grazing possibilities for reindeer. In reindeer herding, 'reading' nature is the process of observing and evaluating grazing pastures and weather conditions, the texture of snow and ice, wind directions and

the sequence of changes in nature, which determine access to nature and the behaviour of the reindeer (Heikkilä 2006).

Combining traditional and scientific knowledge about ecology is considered an important part of understanding the resilience capacity of ecological and social systems and identifying factors that can enhance it (Berkes 1999, Berkes et al. 2000, Berkes et al. 2003, Gadgil et al. 1993, 2003). Although the informal character of traditional ecological knowledge makes it difficult to record in scientific formats, many scientists contribute to integrating traditional ecological knowledge and western scientific knowledge (ACIA 2005). Traditional ecological knowledge is often embodied in practices and stories (narratives) that provide a systematic outline of the information relevant to particular habitats, ecosystems and landscapes (Helander and Mustonen 2004). Stories about the land and their detailed and systematic descriptions of changes in the environment can be valuable input in the process of analysing scenarios of climate change impacts. To ensure sustainable resource management, it is crucial to integrate scientific knowledge with indigenous and local knowledge of weather patterns, seasonal changes, migration of animals, growth of plants, traditional uses of land and natural resources.

Traditional ecological knowledge reminds us that there are multiple ways of knowing about the world, and that effective resource management requires an understanding of this diversity. Awareness of traditional ecological knowledge also encourages participatory, community-based resource management systems that allow diverse approaches to knowledge, practices and beliefs to become visible. This also makes the 'blind spot' of implicit normative assumptions in scientific approaches visible. Traditional ecological knowledge emphasizes the importance of the relationship between human beings and nature, a viewpoint that is also recognized in ecological economics.

Figure 2. Relation between human beings and nature

Human needs	and	Relation between human beings and nature
Anthropocentric		Disregards human needs

As suggested in Figure 2, the bridge between the human-oriented perspective of mainstream economics and a more human and nature-oriented perspective of ecological economics necessitates that a narrow anthropocentric view is avoided, and likewise that disregard of human material needs is avoided. The relation between human beings and nature needs to be recognized on many levels, in our own perception of our humanity, and in the different scientific approaches, leading to interdisciplinary

perspectives on environmental responsibility and the value of nature. Use of traditional ecological knowledge can contribute to strengthening the information base about the complex relationships between the economic, environmental and social conditions in the Arctic.

4. Precautionary perspectives: 'Late lessons from early warnings'

The large degree of uncertainty about climate change impacts in the Arctic requires precautionary approaches to economic and political decision making, in particular consideration of resilience capacity, and recognition of traditional ecological knowledge. Improved dialogue between stakeholders can provide a better understanding of the social and scientific contexts where data are created, and hence contribute to improving the empirical basis for policy advice on how to deal with environmental risk and protect environmental qualities. Precautionary perspectives should be developed within a specific context and evaluated case by case (UNESCO 2005).

Box 1. "Late lessons from early warnings"

1. Acknowledge and respond to ignorance, as well as uncertainty and risk, in technology appraisal and public policy-making
2. Provide adequate long-term environmental and health monitoring and research into early warnings
3. Identify and work to reduce "blind spots" and gaps in scientific knowledge
4. Identify and reduce interdisciplinary obstacles to learning
5. Ensure that real world conditions are adequately accounted for in regulatory appraisal
6. Systematically scrutinize the claimed justifications and benefits alongside the potential risks
7. Evaluate a range of alternative options for meeting needs alongside the option under appraisal, and promote more robust, diverse and adaptable technologies so as to minimize the costs of surprises and maximize the benefits of innovation
8. Ensure use of "lay" and local knowledge as well as relevant specialist expertise in the appraisal
9. Take full account of the assumptions and values of different social groups
10. Maintain the regulatory independence of interested parties while retaining an inclusive approach to information and opinion gathering
11. Identify and reduce institutional obstacles to learning and action
12. Avoid "paralysis by analysis" by acting to reduce potential harm when there are reasonable grounds for concern

Source: EEA (2001).

In particular, we suggest that climate change impacts and other environmental uncertainties in the Arctic are addressed in terms of the framework of the European Environment Agency (EEA 2001) report 'Late lessons from early warnings'. The climate change process in the Arctic demands a continued effort to learn from the 'late lessons' that may be drawn from earlier experiences and to develop 'early warnings' of future impacts. The EEA report suggests 12 precautionary strategies to address environmental uncertainty; see Box 1.

It should be emphasized that the purpose of discussing Arctic environmental problems in terms of this framework is to provide more focus on the processes of knowledge generation. The framework of 'Late lessons from early warnings' is a reminder, for policy makers as well as the scientific community, of the "blind spots", gaps in knowledge and conflicting interests that may not be sufficiently taken into account in research-based knowledge and political decision making.

Providing cases and examples to illustrate the 12 late lessons is the topic of our ongoing research, and a comprehensive discussion and analysis is beyond the scope of the present paper. Here, we only outline some examples for future empirical application.

A key element in precautionary approaches is the recognition that not all future outcomes are well defined at the time of risk assessment. What is referred to as uncertainty can hide the distinction between uncertainty, risk and ignorance, where the concept of ignorance refers to situations where the definition of a complete set of outcomes is problematic; see Funtowicz and Ravetz (1990), Wynne (1992) and Stirling (1999). The usefulness of the concept of ignorance lies in its reminder that unexpected events are easily overlooked in risk assessment. Hazards not yet identified will not be analysed, unless the risk assessment explicitly searches for 'early warnings' of unexpected events. In the Arctic, ignorance about outcomes is particularly important to consider when outcomes are irreversible, such as climate change impacts and loss of ecosystem resilience. Systematically looking for 'early warnings' may be facilitated by investigation of resilience capacity in Arctic ecosystems and livelihoods, with recognition of the traditional ecological knowledge of indigenous and local people.

Changes in ecosystems need to be monitored over time in order to establish indicators for 'early warnings'. Traditional ecological knowledge is crucial for obtaining information on how climate and ecosystems develop over time. Environmental and health parameters that need to be monitored include climate change impacts, for example thawing permafrost, with detrimental effects on forests, roads, other transportation infrastructure and buildings (Ford *et al.* 2006). Moreover, there is need for

monitoring long-range transported pollution of environmental toxins, harming life and subsistence living in the Arctic (WWF 2006). Information about the disproportionately high accumulation of persistent organic pollutants (POPs) in the Arctic and their impact on human health played a role in the successful effort to negotiate the 2001 Stockholm Convention to curb the production, uncontrolled use and release of POPs (Downie and Fenge 2003). Large-scale resource extraction has a considerable impact on the natural environment and human health. Examples are toxic discharges from gold and nickel mining, causing problems that have yet to be solved (AHDR 2004). Effects on the natural environment, human health and social conditions are manifold, and often poorly documented (AMAP 2002). Deposition of mercury in the Arctic is influenced by the scale of coal use and energy technology in other regions of the world, and thus influenced by climate policies and costs of cleaner coal technologies.

Based on IPCC (2007) information, scenarios for how climate change impacts will influence the Arctic economy and subsistence livelihoods should be developed; for example, on the effects of snow and ice conditions for reindeer grazing on the Sámi population, of reductions in sea ice and poorer conditions for hunting on the Greenland population, and of thawing permafrost on dwellings and transportation in affected regions. To develop precautionary strategies for sustainable development in the Arctic, interdisciplinary approaches are needed, involving natural sciences, philosophy of science, anthropology and economics, including approaches based on ecological economics (Norgaard 1994, Vatn 2005).

A precautionary approach may provide a rationale to restrain certain industries and enhance others. Tourism in the Arctic is an important example of an economic activity with a strong potential to flourish based on the natural and cultural qualities of the Arctic. The option value of preserving nature for tourism is high, but sustainable tourism may conflict with other commercial interests, like resource extraction. The conflict of interest between traditional and modern lifestyles is exemplified by a case from Finnmark in Northern Norway. In the 1980s, when a road project to a remote village was considered, one of the elders remarked: ‘We have all that we need—and more than we need. But if the road is built, we will be invaded by people who never get enough’ (Nergård 2006, p. 109). This illustrates that the limits for sustainable use of nature, as embedded in the nature-related cultural and spiritual values of Sámi nature management, were not only based on knowledge of harvesting, but on insight into the forces that pull human beings away from traditions based on long-term perspectives. Indigenous Arctic worldviews are characterized by their holistic nature, which means that they are not easily compartmentalized into spiritual, cultural, economic, social, or other components.

The complex environmental problems of the Arctic require stakeholder participation. For example, fisheries represent an area of conflicting interests between small-scale coastal fisheries and large-scale industrial fisheries. Mineral extraction leads to conflicting interests between indigenous people and other Arctic residents (Duhaime, Rasmussen and Comtois 1998). More systematic knowledge of the relationships and barriers between the subsistence and market economies will contribute to a better understanding of the resource basis of the indigenous and local communities, their production technology, and their values and preferences. Considering living conditions along these dimensions reveals a more complex picture than the usual perception of economic inequality, as people in the Arctic have unequal access to the different bases of their livelihood. Rights to land and to natural resources have been and remain the essential challenge in Arctic governance systems. A major trend in both international and national law is the enhanced recognition and protection of the rights of indigenous people of the Arctic within international human rights, the United Nations Declaration on the Rights of Indigenous People, and ILO convention 169 on indigenous and tribal people.

Examples of new approaches to stakeholder involvement are methods like multicriteria evaluation that can be used to map and investigate social choices and perspectives (Munda 2004). Multicriteria methods can be used to supply a framework for policy analysis in a very effective way, since they can accomplish the goals of being interdisciplinary (with respect to a research team), participatory (with respect to stakeholders) and transparent (with respect to presentation of criteria). To achieve this goal, it is crucial to develop a stakeholder approach: identify stakeholder groups, and identify areas for stakeholder processes. For example, as part of strategies for corporate social responsibility for resource extraction, it is necessary to develop dialogue between stakeholders such as companies, authorities and local communities.

5. Precautionary responses to climate change: Mitigation and adaptation strategies

Designing mitigation and adaptation strategies with explicit focus on stakeholder involvement is important for improving the knowledge base for environmental and social change, and for understanding the diverging interests in the face of climate change impacts. While the Arctic is experiencing large effects of climate change that are occurring more rapidly than expected, feasible options to mitigate climate change through reduced greenhouse gas emissions are crucially dependent on actions undertaken by people living at more southern latitudes. The ACIA (2005) report has its main emphasis on adaptation strategies. However, as pointed out by IPCC (2007), there is a need to consider both mitigation and adaptation in the Arctic regions, given the trends in resource extraction

and modernization taking place in these regions. The Arctic is also a powerful source of global warming. The Arctic regions are rich in fossil energy. Currently, they supply about 10 and 25 per cent, respectively, of the global oil and gas production (Lindholt 2006). Any measures of climate change mitigation will be strongly felt in the petroleum-producing Arctic regions. Decisions on the scale of petroleum production and exploration and emissions of CO2 are beyond the influence of the indigenous people in the Arctic, yet they are recipients of the full impact of climate change impacts on the environment and communities.

An important task for future assessments of impacts and strategies for mitigation and adaptation is to conduct vulnerability studies of Arctic communities, evaluating both environmental and social change. In order to obtain adaptive strategies, the perspectives, knowledge and concern of indigenous people and other local Arctic residents will be essential (ACIA 2005, p. 1020). Studies of climate change impacts need to be conducted within the framework of stakeholder involvement, with dialogue between local residents, industry and government. As some will gain and some will lose from climate change impacts and changing economic opportunities, stakeholder involvement is necessary to represent the diverging interests. Changes in public policy for Arctic regions, new strategies in resource management, extended petroleum exploration, industrial development, growth in tourism and new forms of transportation illustrate the need for stakeholder participation in order to evaluate how development processes contribute to adaptation to climate change impacts. For example, increased ship traffic in the Northwest Passage will increase the risk of potential damage from oil and other chemical spills and change the social and economic conditions of the region (ACIA 2005, p. 1013).

The ACIA (2005) report presents examples of studies of adaptation to climate change impacts from Sachs Harbour, Canada, and Greenland, pointing out that increased participation in the market economy and industries such as tourism raise new questions about sustainability and vulnerability of the socio-ecological system (ACIA 2005, p. 963). The involvement of indigenous people as key stakeholders is a crucial part of improving this framework for assessment of vulnerability, sustainability and adaptation strategies. The ACIA (2005) report also presents an in-depth study of adaptation to climate change of Sámi reindeer herding in Finnmark, Norway. The report indicates that reindeer herding is not only affected by climate change, but by the political and socio-economic environment in which it exists (ACIA 2007, p. 971; Reinert 2006; Tyler *et al.* 2007). The flexibility to move reindeer herds between summer and winter pastures represents an important part of the traditional adaptive strategy, which may be challenged by climate change and difficult ice and snow conditions (ACIA 2007, p. 981). To enhance the adaptive capacity of reindeer herding, as well as of

traditional hunting, fishing and herding activities in other Arctic regions, stakeholder participation of indigenous people is crucial because of their reliance on the changing environment, and because their adaptive capacity has sustained their livelihood in the Arctic environment. For example, indigenous people observe weather patterns and animal movements and contribute to the understanding of climate change (ACIA 2005, p. 992). Involvement of indigenous and other local people will contribute to an adaptive and precautionary perspective by expressing qualities, values and uncertainties that are easily overlooked in risk assessments, hence helping to obtain a more complete understanding of the interrelations between livelihood, climate change, economic development and public policy.

6. Concluding remarks

The large degree of uncertainty about environmental impacts in the Arctic requires precautionary approaches to economic and political decision making under uncertainty. In particular, environmental responsibility, multiple value concepts and resilience capacity must be taken into account, and traditional knowledge must be recognized. Improved dialogue between stakeholders can provide a better understanding of the conflicting interests, the values at stake, and the social and scientific contexts in which environmental knowledge is created and hence, contribute to improving the empirical basis for precautionary strategies that deal with environmental risk and protection of environmental quality. The conceptual and empirical challenges for developing precautionary approaches involve processes of stakeholder participation, multicriteria approaches to valuation of nature, and integrated knowledge bases for evaluating the sustainability of the unique value of the Arctic environment.

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