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Global climate change and regional sustainable development: the case of Mackenzie Basin in Canada

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Cohen et al. [16] suggest that in order to explore ways to bring climate change (CC) and sustainable development (SD) research together, it is necessary to develop more heuristic tools that can involve resource users and other stakeholders. In this respect, this paper focuses on methodological development in research to study climate change impacts and regional sustainable development (RSD). It starts with an introduction of an integrated land assessment framework (ILAF) which is part of the integrated phase of the Mackenzie Basin Impact Study (MBIS) in Canada. The paper then provides some articulation on how the integrated approach was applied in the Mackenzie Basin to show implications of climate change for RSD.

Keywords: integrated assessment, climate change, regional sustainability

1. Introduction

Among the pressing global environmental issues is global climate change, particularly its implications for ecosystems, food production and sustainable economic development (Article 2 of the UN Framework Convention on Climate Change). There is an increasing concern about the effects of climate change arising from human activity on sustainable regional development [33]. The risk of global warming is so high that it could affect our planet's life-support system. Economies directly dependent on natural resource sectors could be very sensitive to climate change. The land base and water resources have to provide a number of economic sectors and communities in different jurisdictions with a range of different and often conflicting functions to meet their demands. While the demands for resources increase as populations and economies grow, the availability and the inherent functions of natural resources are being reduced by climate change, land conversion, water pollution, and environmental degradation.

The objective of this study is to test a methodology we call the Integrated Land Assessment Framework (ILAF). It is designed to identify implications of climate change for regional sustainable development (RSD). To obtain a scientific understanding of the interactions between RSD and climate, integrated analytical methods are needed to provide holistic analysis of climate change and response policy. The analytical framework presented here has been developed as part of the Mackenzie Basin Impact Study (MBIS), which described potential impacts of climate change scenarios in Northwest Canada [13–15]. This framework attempts to integrate major physical, biological, and socio-economic components of the region and identify the regional economic–environmental impacts of climate change. Moreover, alternative response options can be evaluated against multiple sustainability goals/indicators, and linkages established between impact assessment and decision making, and between climate change and RSD.

Understanding the relationship between climate change impacts and RSD is a prerequisite for better decision making. Smit and Smithers [40] suggested that once an understanding of climate related threats to RSD is established, consideration of adaptation options can then follow. Adaptation options can be based on demonstrated strategies from the past or on identified opportunities relative to sensitive areas. Any adaptation strategy should then be evaluated according to the goals/indicators of RSD, such as economic viability, environmental maintenance, and social acceptability [41].

2. Climate and regional sustainable development

Although the concept of sustainable development lacks a uniform definition, a general consensus holds that sustainability, in principle, represents a long-term goal in planning or development which incorporates a holistic view of social, economic and ecosystem values explicitly [5,33,39,42]. The desire for sustainability in regional planning and development reflects an increasing public concern over whether the existing resource base can provide goods and services to support a full range of human and ecological values, equitably, and in perpetuity [31,35,45].

The concept of sustainable development is unlikely to have a universally accepted general definition. It may not be desirable or appropriate to use only one specific defin-

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ition as human perspectives and values are quite different among cultures, sectors, and interest groups. Lack of a universally accepted definition, however, should not be used as a reason to stop working towards a more sustainable future, and/or attempting to ensure RSD within the challenge of climate change. In this paper, RSD is broadly defined as the long-term use of regional resources which is economically viable, socially desirable, and environmentally non-degrading.

In the Mackenzie Basin, the ecological and economic damage associated with climate change may be quite significant. Even with a rich and diversified natural resource base, dramatic changes in temperature, precipitation, and climate patterns may increase the pressure on the limited land base. It has become a major concern internationally that global warming may cause a series of economic, environmental, and social problems [28–30]. These problems are examples of some of the main reasons for uncertainty concerning the sustainability of various regions to support their future societal needs. Reports from the Intergovernmental Panel on Climate Change (IPCC) have shown, however, that major research gaps exist which inhibit a satisfactory resolution of many potential problems related to climate change and RSD.

Whilst the concept of sustainable development has been discussed world-wide, it seems to have made little progress towards linking climate change impact assessment and regional sustainability evaluation. Cohen et al. [16] indicate that while very little attention has been paid by climate change research to sustainable development, the sustainable development research community has not specifically studied the impacts of climate change on societal sustainability. Successful implementation of the concept of sustainable development will require new approaches built upon a foundation of better research into the links between climate change and sustainable development. One challenging issue in evaluating regional sustainability under climate change conditions is to design the effective options or policies that can reduce potential damages or take advantage of opportunities associated with global warming. This will be facilitated by integrated assessment and policy evaluation.

3. An integrated approach for the study of climate change and regional sustainability

The IPCC Technical Guidelines [10] suggests that integrated assessment (IA) methods are desirable to obtain a scientific understanding of the interactions between sustainable development and climate change. It is obvious that integrated impact assessment will never be achieved based on partial analyses of the total system. Integrated study requires a multidisciplinary and holistic approach to deal with the interrelations among the economic, ecological, and social systems. Many commonly used approaches and methods, based on selected segments of the earth system, need to be incorporated into an integrated framework.

Since the Mackenzie Basin is essentially a natural resource based economy and a number of resource sectors could be vulnerable to climate change, understanding the impacts of climate change on the resource use system is crucial to sustainable development of the region. Examples include:

(a) changing opportunities for agriculture and forestry, and how these might affect aboriginal communities;

(b) changing ecosystems, and how they might affect wildlife co-management and aboriginal land claims agreements;

(c) the increased risk of erosion from permafrost thaw, and its implications for transportation, mining, buildings and other engineered structures; and

(d) potential changes in hydrology and water demands, and their implications for interjurisdictional water management.

The IA phase of the MBIS included the ILAF among several integration exercises [15,26]. The overall philosophy of this IA approach was to involve many stakeholders, and to consider multiple sustainability goals/indicators that are often in conflict. The complex nature of RSD and climate change requires integrated and comprehensive assessment systems to identify a range of climate change impacts and various conflicts associated with alternative sustainability indicators/goals, and to decide which response options are more desirable against these indicators/goals [53].

Ideally, a regional IA method would: (a) involve multiple stakeholders, (b) be systematic and holistic, (c) account for multiple objectives and sectors, (d) be able to easily identify trade-offs, and (e) be able to link climate change and RSD. The ILAF was an attempt to achieve a systems analysis approach assisted by the analytic hierarchy process (AHP) and goal programming (GP). The study focused on the identification and specification of regional sustainability goals/indicators and their relationship with climate change impacts. The approach attempted to identify how the potential climate change impacts may affect regional sustainability.

4. The general research approach

Figure 1 represents a research scheme of the ILAF approach which consists of the following main components:

Definition of problems (box 1).
In conducting climate change impact assessment and RSD evaluation study, two essential questions need to be addressed: (1) What are the impacts of climate change scenarios on various sustainability goals/indicators of a region, a nation, or the globe? (2) What are the effects of various response options available to reduce the adverse consequences of climate change and to improve sustainability? Finding answers to the two questions

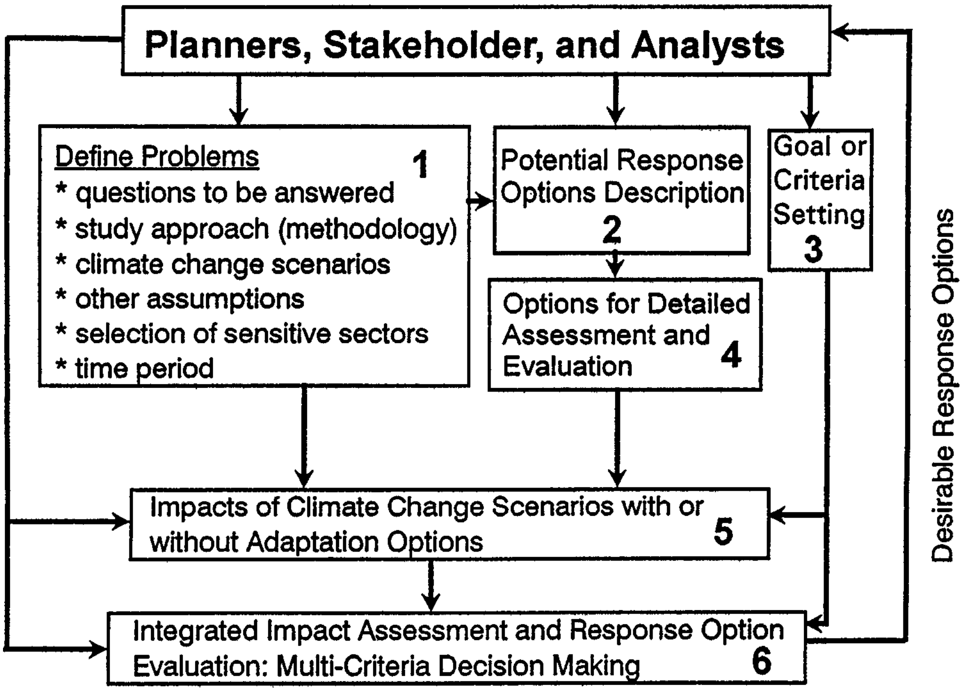

Figure 1. The scheme of the integrated land assessment framework (ILAF).

can be approached in different ways by applying various methods.

Climate change scenarios are specified in this research component to examine their economic-environmental impacts. General circulation models' (GCMs) outputs and historical information can be used to design scenarios representing different climate change conditions. Other methods can also be used to set future population increase and economic growth scenarios. The purpose of scenario setting is to establish a common set of assumptions and conditions to be used by all of the study participants when they conduct climate change impact assessments. Economic and resource sectors sensitive to climate change in the region should be included for impact assessments. The IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptation [10] indicates that the selection of a time horizon for study is influenced by the goals of the assessment. All future assumptions should be consistent with the selected time period under consideration.

Description of potential response options (box 2).

A set of possible adaptation options or policies to deal with negative consequences of climate change and thus to ensure RSD can be identified for evaluation. An inventory of potential response options categorized by types can be developed. The options inventory may include descriptions of the options and other relevant information.

Setting of sustainability goals/indicators (box 3).

The research procedure follows with an identification of goals/indicators of regional sustainability. In this study, goals and/or indicators are evaluation criteria or standards by which the effects of climate change or/and the efficiency of alternative adaptation options can be measured. Generally, goals are reflections of the preferences and desires of decision-makers and indicate some specific target levels to be achieved through resource development. Thus, efforts to measure regional sustainability under climate change conditions must first confront the problem of identifying and specifying sustainability goals/indicators. The analytic hierarchy process (AHP), a multi-criteria decision making (MCDM) technique, is employed in the ILAF to identify the priorities of sustainability goals/indicators and their priorities. The MCDM can provide means by which alternative goals can be compared and evaluated in an orderly and systematic manner.

Initial screening of options (box 4).

Numerous potential response options are available to alleviate negative consequences associated with climate change, and to safeguard regional sustainability. An inventory of potential options is initially identified in step 2. These options can then be grouped into different categories to facilitate policy evaluation. An initial screening process can be conducted to reduce the number of options for further detailed evaluation to improve effectiveness. A practical method can be used to arrive at a collective group recommendation on the selection of response options for further multi-criteria evaluation.

Climate change impact assessment (box 5).

Various simulation or statistical models can be employed by sectoral impact analyses to study the first and higher order impacts of climate change scenarios. A major part of impact assessment is to determine whether alternative response options or policies can lead to a reduction in damages or taking advantage of opportunities associated with climate change scenarios. Thus, the impact assessment should be conducted with different climate change scenarios coupled with or without certain adaptation options. To identify the regional environmental and socio-economic impacts of climate change, several practical methods should be used in combination such as climate change scenario setting, methods for identifying impacts of climate change on yields of crops, forests, wildlife, water resources, and other aspects of the region.

Integrated impact assessment and regional sustainability evaluation (box 6).

An integrated analytical system is developed for climate change impact assessment and regional sustainability evaluation. The integrated system is the core of the ILAF. The system can be used to relate impact information to regional sustainability requiring subjective judgment and interpretation, and thus to identify effective and desirable options among alternatives. In the ILAF study, alternative scenarios were evaluated by relating their various impacts to a number of relevant sustainability goals/indicators. These goals are presented in detail later and they are used as standards by which the significance of various impacts and the strengths and weaknesses of the alternative options or policies can be evaluated. The system uses advanced analytical techniques that will be discussed in the case study.

5. Applying the ILAF approach in the Mackenzie Basin

The preceding section has portrayed the conceptual framework of ILAF. The best way to evaluate its capability in integrated climate change assessment is to apply the method in a real world case. The ILAF was applied to the Mackenzie Basin for illustration purposes. However, it should be noted that in the case study presented below, not all the components of ILAF are covered in detail. Rather, the focus is on the two main concerns of the paper: the sustainability indicators/goals identification and the integrated climate change impact assessment.

The following sections present the importance of indicator/goal setting in regional sustainability research and the approach to identify RSD indicators/goals. Then, an analytical system assisted by goal programming (GP) is introduced to illustrate how sustainability indicators/goals can be represented in the analytical system to link climate impact assessment and regional sustainability evaluation. While the ILAF is a tool that can be used with others to help identify the climate change impacts and to reveal possible response options, the policy evaluation is presented in a highly general way. More detailed consideration of such options should be part of a broad discourse with stakeholders over the longer term.

5.1. The study area

The ILAF has been applied to the Mackenzie River Basin in Canada. The Basin is located in the Northwest part of Canada and is the largest river basin in the country. The Basin includes parts of three provinces (Alberta, British Columbia and Saskatchewan) and two territories (Northwest Territories and Yukon). Figure 2 is a map of the Basin. The Basin provides a large amount of rich agricultural land, plentiful water resources, and extensive navigation routes. It also offers diverse recreational opportunities and contains important ecological systems. While the Basin has fostered the development of many service and single industry towns, energy and forest industries, hydropower plants, a large number of native communities, and government agencies, potential climate change may impose considerable economic, social, and environmental impacts.

To reflect the interregional and spatial considerations in the assessment, the Mackenzie Basin is partitioned into sets of sub-regions (figure 2). These correspond to administrative zones of the Mackenzie Basin (as in [26]), and represent different ecological, social, and economic characteristics. Sub-regions 1, 3, 6, 8–11, 14, 15, 19, and 21 are included in the integrated analysis. The study time horizon was 50 years, which was decided by the MBIS Working Committee [11].

5.2. Assumptions and scenario conditions

One of the distinctive features of climate change impact assessment is the emphasis placed on the design of meaningful scenarios representing different future conditions. Assessing the implications of different response options, policies, or climate change for achieving RSD is as much an art as it is a science. This situation exists because of uncertainties over future conditions such as the magnitude of warming, the timing of climate change, the impacts of climate change, and other factors such as future societal demand associated with population growth and income increase, economic development, and institutional and technological changes. In response to these uncertainties, scenarios can be created to represent alternative future conditions. In the MBIS study, three types of scenarios were specified: climate change, future socio-economic conditions, and response options.

In developing scenarios, the MBIS identified a set of baseline assumptions and conditions. Thus, climate change scenario specification for this study represents the possible future climate conditions under various assumptions. Data sets of baseline climate, three GCMs scenarios, and one composite scenario for the Mackenzie Basin have been developed. To establish the baseline climate, archived climate data (1951–1980) at Atmospheric Environment Service (AES) were used. Other MBIS participants in conducting their individual impact assessments [12,13] applied these same assumptions and scenarios. Readers who are interested in more detailed information on data sets of base-

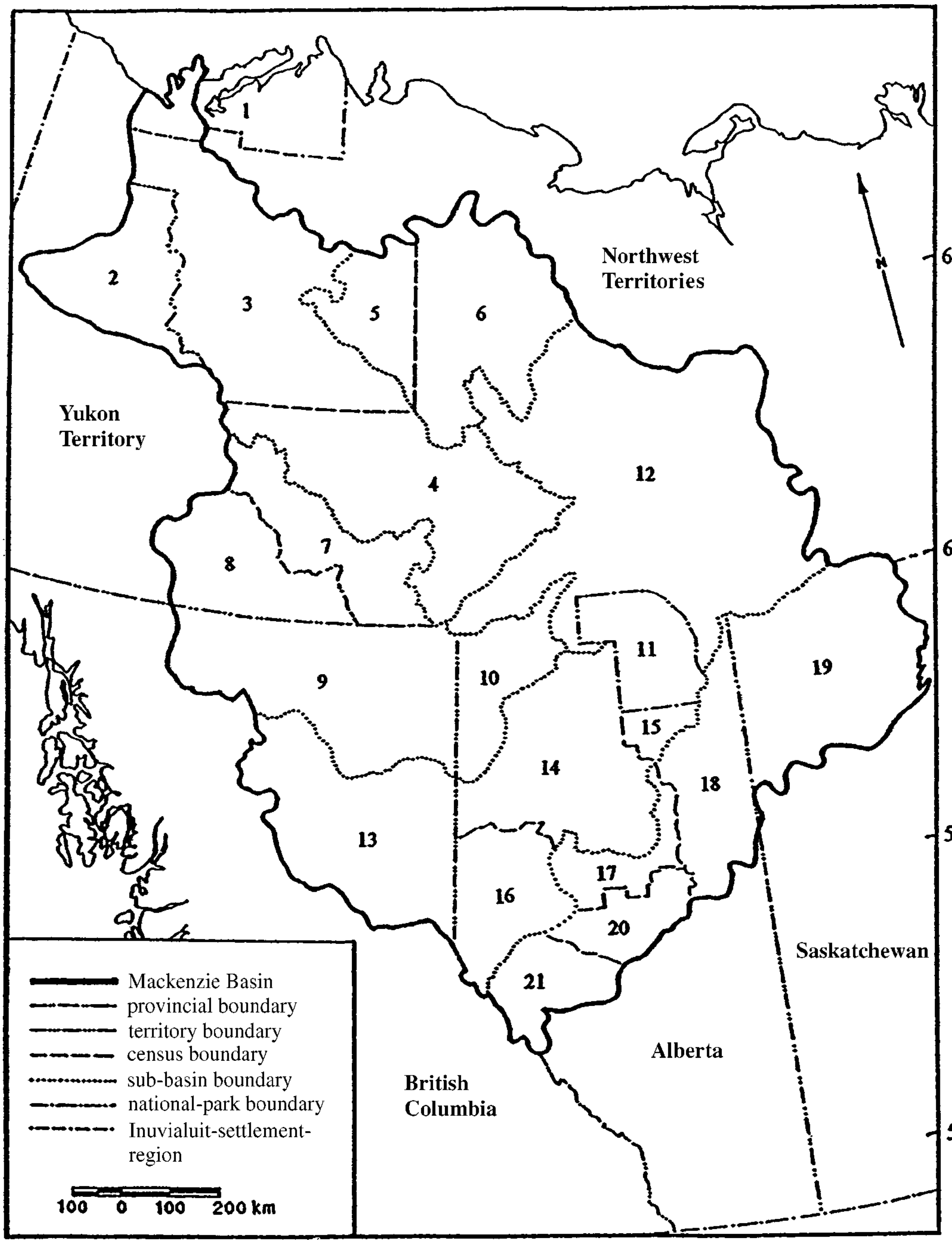

Figure 2. Distribution of the study sub-basins and sub-areas.

line conditions, future climate scenarios, and other socio-economic factors for the study can refer to the MBIS First Interim Report and other publication [11,50].

5.3. Design of indicators/goals to measure regional sustainability

To link climate change impact assessment and sustainability evaluation, regional sustainable development goals and indicators must be set and performance of policies must be measured in a manner that integrates social, environmental, and economic parameters that may be influenced by climate. Generally, goals/indicators are reflections of the preferences and desires of decision makers and indicate some specific target levels to be achieved through development options or policies. In a regional climate change study, goals/indicators act as decision criteria or standards by which the impacts of climate change and the efficiency of alternative response options to deal with climate change can be measured. Thus, efforts to identify climate change impacts and to measure regional sustainability must first confront the problem of setting and specifying sustainability goals and indicators.

Maclaren [32] suggests six general frameworks that can be adopted for developing sustainability indicators. The first one is a domain-based framework that groups indicators into three main dimensions of sustainability (economic, environmental, and social). The three-dimensional nature of sustainability and the need to make trade-offs (e.g., between economic growth and environmental quality) require maintaining these three components in a dynamic balance. In this respect, sustainability indicators should include economic, social, and environmental information in an integrated manner. Results of the performance measurements can reveal conditions and trends that help improve regional development. One example of such a framework was devised by the Scientific Committee on Protection of the Environment (SCOPE) [43].

The second framework is a goal-oriented indicator system. In a study for sustainable agriculture in Australia and New Zealand, four goals were identified, which reflect the major concerns of the two countries on agricultural development. These concerns represent their national objectives of economic viability, maintenance of the resource base, and minimizing the impacts of agriculture on natural ecosystems. Each goal is composed of a number of attributes or indicators which are measurable by using existing sources of information in most cases [20].

Other types of indicator frameworks are based on sector, issue, cause-effect, and combinations of these. Indicators can be developed for each sector or community to measure the condition and trends in each critical sector. Maclaren [32] describes these indicator frameworks in some detail. No single indicator would be sufficient enough to determine sustainability or non-sustainability of a region or a system. A set of goals and/or indicators is required in sustainability evaluation. Notwithstanding the risks in using aggregated indicators, there are also risks in using too many indicators. A large number of indicators may lead decision-makers only to select those that support their particular purpose. It may also cause confusion in making trade-offs among indicators.

The term “indicator” is not a new concept. Indicators have been used to measure performances of regional development policies or plans, to identify growth trends, to monitor the social and economic conditions of regions or nations, to inform the general public, to define planning goals or objectives, to guide strategic development options, and to compare different regions. For example, the GDP, housing price, unemployment rate, DOW stock index, are used commonly to measure social or economic performance of a society or economy. While these indicators still strongly influence decision making by government, policy makers, and the general public, they have shortcomings when used for measuring sustainable development. Recently, research has been initiated in developing indicators of societal sustainability. For example, the World Resources Institute (WRI) developed a systematic approach which uses environmental indicators to measure and report on environmental policy performance in the context of sustainable development [21].

Indicators may be conflicting in that the achievement of one precludes the achievement of another. Possible trade-offs between indicators therefore need to be identified. Very often the trade-off relations are non-linear, creating situations of dramatic changes in the attainment of certain indicator levels once a threshold has been surpassed. Other indicators, however, are complementary. That is, by increasing the attainment of one indictor target it is possible to increase the attainment of other indicators. It has been suggested, for example, that development and environment are complementary up to some level of resource use. Indicators are also considered compatible when the attainment of one does not sacrifice the attainment of others.

Measurability of indicators is crucial in determining the appropriateness for assessing sustainability. This will facilitate planners and analysts to understand how the indicator levels are derived, either qualitatively or quantitatively, and to decide how such information can be applied in the evaluation and decision-making process. Given uncertainties in environmental and social conditions, qualitative data from rapid appraisals, informal surveys, and opinion polls are also important.

5.4. Selection of regional sustainability goals/indicators for the Mackenzie River Basin

There are a number of stakeholders in the Mackenzie River Basin who have different values or preferences in dealing with climate change and regional development. To select regional sustainability goals or indicators, the first major source of information used for the study area was government reports, documents, and other published materials on resource issues [1–4,7,8, 18,38]. In order to improve the reliability of the information on goals derived from the literature review, an integration workshop with senior decision-makers in the Basin was held to discuss major policy issues related to climate change [11]. At the workshop, senior decision-makers worked with the stakeholders and researchers from different disciplines in an interactive way. Through building co-operation and cohesiveness among representatives of stakeholders, major policy concerns and their priorities with respect to climate change and sustainable regional development were clarified and refined.

Based on these key policy concerns, four goals were specified for this study including economic growth, resource sustainability, environmental quality, and social stability. The four goals were further divided into ten indicators to measure regional sustainability under climate change scenarios. They are listed in table 1.

It is obvious that economic growth is one of the most important goals for measuring development performance. Most development plans attempt to maximize net monetary and social benefits. Improvements in economic efficiency occur in principle as long as gainers can compensate losers. For this to take place, total benefits must exceed total costs.

Table 1
Regional sustainability indicators used in ILAF application.

Goals	Indicator
Economic growth	economic return, energy development, transportation
Sustainable resource use	sustainable resource production, water balance, and forest cover enhancement
Environmental quality	wildlife habitat protection, soil erosion control, greenhouse gas (GHG) emission reduction
Social stability	community stability

Assuming that proper accounting is taken of all resource impacts, measures of improvements in economic return are an important element in ensuring that society in reaping the benefits from its resource use.

There has been a concern about Canada's agricultural and forest production, particularly in the study region [1,2,7,8]. The sustainable resource production indicator may be defined as the ability of a resource base to maintain in perpetuity a given flow of goods and services at an acceptable cost. Sustainable resource production can also be considered as a security indicator to achieve higher levels of self-sufficiency and adequate food supply and/or it may be considered as an intergenerational equity indicator to safeguard the resource base for present and future generations.

Many of the agricultural and economic developments may occur in productive forest lands and wetlands, and areas which are perceived to be of natural, historical, scenic, or scientific importance. Rural areas contain most of the green space, beautiful landscapes, and all of the natural parks, wildlife habitats, and other open and less congested space [34]. How to slow down the conversion of woodland and wetland to urban and industrial uses is critical for regional sustainability. The indicators of woodland and wetland protection and conservation reflect the region's main concern on the issue of woodland and wetland conversion to other land uses.

It is now generally realized that environmental concerns should be incorporated in resource use decision making in an effort to achieve sustainable development [45]. There are a large number of parameters that can be used as indicators of environmental quality. For example, environmental concern may mean protecting natural resources, or it may mean minimizing the concentration of atmospheric carbon dioxide at a global scale [27–29,47]. In this study, the environmental concern is reflected in the indicators of soil erosion control, wildlife habitat protection, and greenhouse gas (GHG) emission reduction.

There is an increasing concern about the implications of climate change for interjurisdictional water management [19]. Global warming may change average and extreme high and low river flow, and sediment load in the water body. Changing water quantity and quality induced by climate warming may increase interjurisdictional conflicts in water management in the basin. Dealing with potential water use conflicts with changing climate is therefore considered as an important indicator.

Since many native communities are located in the basin, the potential implications of a warmer climate for their traditional lifestyles are another major concern in the region. Thus, sustainability of native lifestyles under climate change is specified as a goal in this study.

Climate warming in the basin would lead to a series of changes to the physical and biological environment. These, in turn, could affect the economic viability of energy development activities by altering the factors determining production and transportation costs. As a major energy supply region in Canada, increasing energy production is one objective of regional development planning for the Mackenzie Basin. Changes in permafrost, snow cover and ice conditions associated with climate warming in the north could affect the design, operation, and maintenance of winter roads, pipelines, and shipping facilities in the region. Although reduction of greenhouse gas emissions is a recognized global strategy for responding to climate change, assessing the implications of this strategy on regional development were beyond the scope of this study [13,14]. In the absence of alternative global economic scenarios that could be quantitatively linked with regional economic development, it was assumed that regional fossil fuel development would continue to be pursued. Future studies should incorporate alternative global scenarios into climate change assessments.

5.5. Goals/indicators priority setting

One of the most important aspects of evaluating regional sustainability is to identify conflicts among various goals/indicators, which represent different preferences and aspirations of several stakeholders. Given the fact that not all the goals can be achieved simultaneously, a choice must be made to place different priorities for different goals in a multi-criteria decision making (MCDM) process. Much of the effort in MCDM has been devoted to constructing the preference relations between goals. Since goal/indicator priority identification is a difficult and complex process, an MCDM technique, the analytic hierarchy process (AHP) developed by Saaty [37], was used to assist goal setting in this study. AHP provided a means by which alternative goals identified were compared and evaluated in an orderly manner.

Yin and Cohen [49] presented a systematic approach, assisted by AHP, to identify and specify regional sustainability goals/indicators relating to climate change. Results of the AHP application illustrate the regional rank ordering of sustainable development goals. The responses to a list of interviews are indicative of the diverse range of values associated with the real and perceived benefits to be derived from the land resource base. In the AHP results, a stakeholder's preferences of goals/indicators are expressed by goal ranking orders or the relative importance of goals on an ordinal scale. That is, goals are ranked as "most important" or first priority, "next most important" or second priority, and so on. Thus, the results of priority ranking represent stakeholders' preferences for a set of goals. Due to large amount of uncertainty involved, considerable variation on goal ranking was experienced in the study.

Five stakeholder groups were identified: agriculture, native people, environmental groups, industrial and energy sector, and government. Table 2 lists the goal priority rankings for the five stakeholders. Not surprisingly, the agricultural sector is more concerned with sustainable crop production and economic return than with regional forest cover. Energy industries place their priorities on economic return and energy development. The aggregated goal preferences' general patterns were used to assign priority ordering for the region. The aggregation was done by using survey results to calculate numbers of the responses to each rank for all ten goals. Numbers of responses corresponding to each goal in table 3 were derived from the calculation. For each goal, the rank corresponding to the highest number of responses was considered as the overall priority of the goal for the Basin. Table 3 shows the overall goal priority ranking for the Basin. For more detailed explanation of the process related to goal setting, please refer to Yin and Cohen [49].

The results on goal priority rankings were incorporated in the ILAF model to examine the regional impacts of climate change on sustainability. In particular, the objective function of the GP model was set with the regional goal priority ranking. Figure 1 shows the link between goals/indicators and the impact assessment component. The model was run repeatedly with different priority rankings. This will be discussed further in the following sections.

5.6. Climate change impacts

Data required for the integrated impact assessment come from several sources: existing data derived from previous studies on land resource analysis and management, government documents, consultant reports, and scientific literature. Analyses of the social, economic, and environmental impacts of alternative climate change scenarios for different economic sectors were undertaken by a number of individual research projects of the MBIS study [13]. For example, Huang [25], and Hartley and Marshall [23] provided data for the forest sector. Stumpage rates and annual allowable cut (AAC) data were derived from Rothman and Herbert [36]. Crop yields data were derived from studies

Table 2
Goal priority rates of the five stakeholder groups.[a]

Survey respondent ID	Goal rating										
	Clusters of five groups	Sustainable G1	Economic G2	Habitat G3	Erosion G4	GHGs G5	Water G6	Energy G7	Community G8	Forest G9	Transport G10
1	4	0.05	0.23	0.18	0.14	0.06	0.08	0.07	0.08	0.07	0.04
2	1	0.25	0.03	0.04	0.04	0.07	0.19	0.08	0.08	0.18	0.05
3	5	0.08	0.05	0.17	0.15	0.09	0.1	0.07	0.1	0.09	0.09
4	1	0.23	0.03	0.15	0.15	0.04	0.08	0.05	0.08	0.13	0.05
5	2	0.06	0.18	0.07	0.07	0.03	0.07	0.18	0.1	0.07	0.15
6	5	0.07	0.03	0.07	0.09	0.13	0.07	0.16	0.24	0.07	0.07
7	2	0.09	0.25	0.08	0.07	0.03	0.05	0.15	0.1	0.02	0.16
8	3	0.04	0.03	0.13	0.14	0.19	0.13	0.02	0.11	0.11	0.09
9	5	0.07	0.02	0.22	0.14	0.06	0.11	0.03	0.1	0.19	0.06
10	1	0.09	0.03	0.11	0.28	0.03	0.12	0.04	0.07	0.21	0.04
11	5	0.14	0.06	0.1	0.1	0.09	0.08	0.16	0.12	0.06	0.09
12	3	0.15	0.11	0.06	0.1	0.2	0.08	0.04	0.15	0.06	0.06
13	4	0.17	0.23	0.04	0.16	0.06	0.1	0.07	0.02	0.06	0.1
14	5	0.09	0.04	0.24	0.14	0.02	0.12	0.06	0.12	0.1	0.06
15	3	0.06	0.04	0.21	0.15	0.15	0.12	0.03	0.06	0.13	0.05
16	3	0.13	0.03	0.05	0.1	0.29	0.1	0.03	0.14	0.1	0.02
17	3	0.05	0.02	0.28	0.13	0.13	0.11	0.04	0.1	0.1	0.03
18	5	0.12	0.03	0.13	0.13	0.08	0.06	0.12	0.11	0.11	0.11
19	2	0.02	0.16	0.1	0.1	0.06	0.11	0.04	0.13	0.14	0.15
20	4	0.2	0.14	0.06	0.09	0.14	0.11	0.09	0.07	0.02	0.09
21	3	0.08	0.06	0.11	0.13	0.12	0.19	0.05	0.07	0.15	0.05
22	1	0.18	0.04	0.18	0.13	0.06	0.13	0.03	0.09	0.14	0.02
23	1	0.14	0.1	0.05	0.2	0.02	0.2	0.04	0.11	0.08	0.04
24	4	0.09	0.07	0.09	0.11	0.11	0.11	0.05	0.18	0.13	0.06
25	3	0.04	0.02	0.24	0.12	0.03	0.1	0.1	0.16	0.05	0.15

[a] G1, G2, …, G10: Goal 1, Goal 2, …, Goal 10 (please see table 1 for goal explanation). Clusters of five groups: 1 = environment, 2 = industry, 3 = native, 4 = agriculture, and 5 = transport.

Table 3
Number of times each goal achieves a given ranking from survey responses.[a]

Rank	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
1	4	5	8	3	3	2	2	2	0	0
2	5	1	2	6	3	1	2	3	5	3
3	1	1	1	6	2	8	1	6	5	2
4	1	1	4	7	3	7	2	8	6	3
5	8	1	3	0	3	5	4	3	3	4
6	3	4	5	1	4	1	4	1	3	5
7	2	6	2	2	2	0	5	1	2	5
8	0	4	0	0	4	1	4	1	0	2
9	1	2	0	0	1	0	1	0	0	1
10	0	0	0	0	0	0	0	0	1	0
Basin ranking	5	7	1	4	6	3	7	4	4	6

[a] G1, G2, …, G10: Goal 1, Goal 2,…, Goal 10 (please see table 1 for goal explanation). Sources: see [49].

conducted by Brklacich et al. [9] and Yin and Pierce [48]. Soil loss coefficients or soil loss rates by water erosion for each crop in each land unit were not available from existing sources and therefore were calculated by using the Universal Soil Loss Equation (USLE) [46]. This computation was based on a report completed by Van Vliet [44], which provided the values of key factors of the USLE. Soil erosion rates for cropland, pasture, woodland, and summer fallow for each sub-region were calculated.

It is obvious that the sources of data for the integrated impact study are diverse and extensive. Such data sources are often limited for integrated impact assessment by inconsistencies in scale and coverage and definition. The data inconsistencies pose problems of comparability. For example, the spatial scale used by Huang and others [26] was sub-basin, while the forest impact study by Hartley and Marshall [23] adopted a much finer scale. Consistent and comparable data sets would improve the reliability of the integrated impact study.

Yin et al. [50] presented an integrated database for the integrated impact study. Data required for coefficients of various activities include prices of products, costs of production, average yields, areas of different types of land, soil erosion rates and wetland values. The data collected also have spatial and temporal dimensions. The model variables and parameters differ among sub-regions, and vary between the present and the future (changed climate condition). Thus, the database consists of information for each sub-region under both current and future conditions (tables 4–8).

The information collected was sorted into sub-regions and land use activities. Economic activities considered for each sensitive sector are consistent with those selected for sectoral analyses. These activities are represented in the model by decision variables. The model is flexible enough to incorporate other variables for assessment. With limited data provided by MBIS individual projects, three sectors were selected in the GP model: agriculture, forestry, and wetland. Land use activities considered for the agricultural sector include wheat, barley, oats, canola, hay, and summerfallow. These crops and forage might be grown only in certain sub-regions based on climate conditions. The activities in the forest sector include timber productions of spruce, lodgepole pine, and deciduous trees. Wetland habitat value was based solely on waterfowl numbers.

5.7. Integrated assessment through goal programming (GP)

It is obvious that decision-makers have difficulty in relating to RSD upon findings based on a range of impact results from many individual studies. How to determine climate change scenarios that most affect regional sustainability is still unclear. In this respect, a GP model was applied here to identify possible impacts of climate change scenarios on RSD. The GP model is able to incorporate sustainability goals/indicators and climate change impacts data to examine the implications of climate change scenarios for regional sustainability. A brief introduction of the GP model is presented below to show how sustainability goals/indicators and climate change impacts can be represented in the model to study the implications of climate change for regional sustainability.

5.7.1. The basic structure of the GP model

As indicated above, the integrated assessment needs to link multi-criteria (sustainability indicators) with a range of economic, social, and environmental impacts of climate change scenarios upon several sectors. The GP model provides a means for integrating climate change impact assessments conducted by different individual sectoral studies mentioned previously. For the integrated model, linkages between climate change impact assessment and regional sustainability need to be incorporated in the structure of the model by a clear articulation and reconciliation of objective functions and decision variables. The basic structure of the GP model adopted in the ILAF includes goals and constraints. The specific equations of the model are grouped into the following types: resource and other restrictions, supply–demand balances, goal constraints, and the objective function. A simple formulation of the goal

Table 4
Coefficients for representative activities in sub-regions of the Mackenzie Basin (current condition).[a]

	Sub-region coefficient										
	1	3	4	8	9	10	13	14	16	20	21
Wheat yield coeff. (t/ha/yr)	0	0	2.3	0	2.3	2.8	3.3	3.2	2.8	3.1	2.8
Barley yield coeff. (t/ha/yr)	0	0	2.1	0	2.5	2.5	3.6	3.1	4.8	3.2	3.1
Oats yield coeff. (t/ha/yr)	0	0	2.3	0	2.35	2.54	3.86	3.15	3.85	3.65	3.25
Hay yield coeff. (t/ha/yr)	0	0	3.8	0	3.36	3.8	3.8	4.47	5.38	5.38	3.8
Canola yield coeff. (t/ha/yr)	0	0	0	0	0	0.74	0.91	0.89	1.11	0.89	0.89
Spruce yield coeff. (m^3/ha/yr)	1.43	1.31	1.65	1.43	1.98	1.98	2.052	2.03	2.2	1.9	2.5
Lodgepole pine (m^3/ha/yr)	1.26	1.11	1.53	1.26	1.83	1.98	1.95	1.95	2.17	1.8	2.4
Deciduous tree (m^3/ha/yr)	0.86	0.72	1.19	0.86	1.51	1.5	1.68	1.5	1.5	1.55	1.4
Wetland habitat coeff. (bird/yr)	0.545	1.41	5.62	0.242	0.485	1.5	1.25	0.922	0.914	2.21	0.91

[a] Sources: see [1–4,7,18,22,25,38].

Table 5
Net annual economic return coefficients (current condition).[a]

	Sub-region coefficient										
	1	3	4	8	9	10	13	14	16	20	21
Wheat production ($/ha)	0	0	40.1	0	82.35	102.2	127	107	132	112	107
Barley production ($/ha)	0	0	22.96	0	20.13	29.83	40.5	39.83	40.2	39.85	32.85
Barley on converted land ($/ha)	0	0	12.29	0	12.96	14.5	23.9	24.55	26.35	24.55	21.25
Oats production ($/ha)	0	0	27.1	0	28.13	29.83	40.5	34.5	40.2	38	35
Hay production ($/ha)	0	0	44.8	0	42.4	44.8	44.8	48.3	52.1	52.1	44.8
Hay on forest converted ($/ha)	0	0	29.3	0	26.55	29.27	29.27	34.2	38.05	38.05	29.27
Hay on wetland converted ($/ha)	0	0	30.6	0	27.78	30.62	30.62	35.3	39.39	39.39	30.62
Canola production ($/ha)	0	0	0	0	0	73.46	180	137.7	232.97	137.7	137.7
Spruce timber production ($/ha)	54.57	50	63	54.6	75.56	75.56	78.23	77.46	83.95	72.5	95.4
Lodgepole-pine timber ($/ha)	21.53	18.97	26.1	21.5	31.27	33.84	33.33	33.33	37.09	30.76	41
Deciduous timber ($/ha)	4.5	3.75	6.2	4.48	7.87	7.82	8.75	7.82	7.82	8.08	7.29

[a] Sources: see [6,17,25,36].

Table 6
Soil erosion rate coefficients (t/ha/yr) (for both scenarios).[a]

	Sub-region coefficient										
	1	3	4	8	9	10	13	14	16	20	21
Wheat	0	0	10.9	0	6.6	15.4	15.4	11.7	5.8	14.1	11.7
Barley	0	0	10.9	0	6.6	15.4	15.4	11.7	5.8	14.1	11.7
Oats	0	0	10.9	0	6.6	15.4	15.4	11.7	5.8	14.1	11.7
Hay	0	0	1.8	0	1.1	2.6	2.6	2	1	2.4	2.4
Canola	0	0	0	0	0	15.4	15.4	11.7	5.8	14.1	14.1
Summer fallow	0	0	22	0	22	38.9	51.37	38.9	51.3	46.9	46.9
Spruce	0.7	0.7	0.8	0.7	0.3	0.5	0.6	0.3	1.49	1.2	1.49
Lodgepole-pine	0.7	0.7	0.8	0.7	0.3	0.5	0.6	0.3	1.49	1.2	1.49
Deciduous	0.7	0.7	0.8	0.7	0.3	0.5	0.6	0.3	1.49	1.2	1.49

[a] Sources: see [2,25,44].

programming model designed for this study is expressed as follows:

$$\text{Min.}Z = \left[g_1(d^-, d^+,), g_2(d^-, d^+,), \ldots, g_n(d^-, d^+)\right] \quad (1)$$

subject to

$$\sum_p x_{pj} + \sum_i x_{ij}^{\otimes} - \sum_i x_{ji}^{\otimes} \leqslant A_j, \quad (2)$$

$$\sum_p \sum_j (R_{pj} x_{pj}) + \sum_p \sum_i \sum_j \left(R_{pij}^{\otimes} x_{pij}^{\otimes}\right) + d_r^- - d_r^+ = b_r, \quad (3)$$

$$\sum_p \sum_j \left[Y_{pj}\left(x_{pj} + \sum_i x_{pij}^{\otimes}\right)\right] + d_y^- - d_y^+ = b_y, \quad (4)$$

$$\sum_p \sum_j \left[E_{pj}\left(x_{pj} + \sum_i x_{pij}^{\otimes}\right)\right] + d_e^- - d_e^+ = b_e, \quad (5)$$

$$\sum_t \sum_j \left(x_{tj} + \sum_i x_{tij}^{\otimes}\right) + d_f^- - d_f^+ = b_f, \quad t\forall j, \quad (6)$$

$$\sum_c \sum_j (V_{cj} x_{cj}) + d_v^- - d_v^+ = b_v, \quad (7)$$

$$x, x^{\otimes}, d^-, d^+ \geqslant 0, \quad (8)$$

Table 7
Coefficients for representative activities in sub-regions of the Mackenzie Basin (GISS scenario).[a]

	Sub-region coefficient										
	1	3	4	8	9	10	13	14	16	20	21
Wheat yield coeff. (t/ha/yr)	0	0	1.75	0	1.75	2.13	2.51	2.44	2.13	2.36	2.13
Barley yield coeff. (t/ha/yr)	0	0	1.72	0	2.05	2.05	2.95	2.54	3.93	2.62	2.54
Oats yield coeff. (t/ha/yr)	0	0	1.88	0	1.92	2.08	3.16	2.58	3.15	2.99	2.66
Hay yield coeff. (t/ha/yr)	0	0	3.8	0	3.36	3.8	3.8	4.47	5.38	5.38	3.8
Canola yield coeff. (t/ha/yr)	0	0	0.42	0	0.42	0.74	0.89	0.91	1.11	0.77	0.74
Spruce yield coeff. (m^3/ha/yr)	0.715	0.655	0.825	0.715	0.99	0.99	1.03	1.02	1.1	0.95	1.25
Lodgepole pine (m^3/ha/yr)	1.26	1.11	1.53	1.26	1.83	1.98	1.95	1.95	2.17	1.8	2.4
Deciduous tree (m^3/ha/yr)	1.55	1.3	2.14	1.55	2.72	2.7	3.02	2.7	2.7	2.79	2.52
Wetland habitat coeff. (bird/yr)	0.545	1.41	5.62	0.242	0.485	1.5	1.25	0.922	0.914	2.21	0.91

[a] Sources: see [9,23,25].

Table 8
Net annual economic return coefficients (GISS scenario).[a]

	Sub-region coefficient										
	1	3	4	8	9	10	13	14	16	20	21
Wheat production ($/ha)	0	0	30.51	0	62.66	77.75	96.6	81.59	100.41	85.26	81.4
Barley production ($/ha)	0	0	18.81	0	16.51	24.46	33.19	32.63	32.91	32.63	26.92
Barley on converted land ($/ha)	0	0	12.29	0	12.96	14.5	23.9	24.55	26.35	24.55	21.25
Oats production ($/ha)	0	0	22.15	0	22.98	24.43	33.16	28.26	32.89	31.13	28.65
Hay production ($/ha)	0	0	44.8	0	42.4	44.8	44.8	48.3	52.1	52.1	44.8
Hay on forest converted ($/ha)	0	0	29.3	0	26.55	29.27	29.27	34.2	38.05	38.05	29.27
Hay on wetland converted ($/ha)	0	0	30.6	0	27.78	30.62	30.62	35.3	39.39	39.39	30.62
Canola production ($/ha)	0	0	29.25	0	29.25	73.46	176.04	140.79	232.97	119.13	114.49
Spruce timber production ($/ha)	54.57	50	63	54.6	75.56	75.56	78.23	77.46	83.95	72.5	95.4
Lodgepole-pine timber ($/ha)	21.53	18.97	26.1	21.5	31.27	33.84	33.33	33.33	37.09	30.76	41
Deciduous timber ($/ha)	4.5	3.75	6.2	4.48	7.87	7.82	8.75	7.82	7.82	8.08	7.29

[a] Sources: see [25,36].

where Z is the objective function or achievement function of the integrated model, which is to minimize the non-attainment of defined target levels of goals/indicators; $g_k(d^-, d^+)$ is a linear function of the deviation variables at priority level $k = 1, 2, \ldots, n$; x is area of land use; x_{pj} is the area of land use p in sector j; $x^{\otimes}$ is land conversion variable; $x^{\otimes}_{ij}$ and $x^{\otimes}_{ji}$ are two decision variables representing respectively land areas converted from sector i to j, and land areas converted from sector j to sector i; $x^{\otimes}_{pij}$ is area of land use p on converted land (from sector i) in sector j; A_j is resource availability for sector j; R_{pj} is net return for land use p in sector j; $R^{\otimes}_{pij}$ is net return from converted land (from other sectors i) for land use p in sector j; Y_{pj} is yield of land use p in sector j; E_{pj} is soil erosion rate of land use p in sector j; x_{tj} is tree species t in sector j; $x^{\otimes}_{tij}$ is land converted from sector i to j for tree (t) planting; x_{cj} is the area of wetland class c in sector j; V_{cj} is the habitat value for waterfowl capability class c in sector j; b_r, b_y, b_e, b_f, and b_v are the right-hand-side vector representing the target values for goals r, y, e, f, and v (resource production, economic return, soil erosion, forest, and waterfowl habitat) respectively; d^+ and d^- are the over-achievement and under-achievement vectors of goal target levels, respectively.

The objective function or achievement function of the GP model is the minimization of non-attainment of defined target levels of sustainability goals/indicators. The purpose of the model solution is thus to achieve as close a match to the target levels of indicators as possible given certain conditions. In the case study, ten regional sustainability indicators identified previously were represented in the objective function and goal constraints of the model. Results of the AHP application presented in table 3 were used as inputs to represent the priority ranks of the objective function. For each goal/indicator, the score corresponding to it was assigned as the priority rank of the objective function. For example, since the habitat protection goal was ranked as priority one, this goal was thus satisfied first in the model solving process. In solving the integrated model, higher priority goals are satisfied first, then the lower priorities are considered.

Existing data from previous studies were used to derive the target levels of goals/indicators. Government documents, consultant reports, and scientific literature provided extensive data on target levels as well as other required information [2,6–8,17,26,36]. Field trips and interviews were conducted to collect additional information on goal targets values not available from the above sources. For example, information for the wetland sector was mainly collected through interviews with regional habitat biologists and experts from Ducks Unlimited [22]. Target levels for different goals are listed in table 9. Please notice that target levels

Table 9
Results of the MBIS/ILAF model runs under current and GISS scenarios (000′).[a]

	Wheat (t/yr)	Barley (t/yr)	Oats (t/yr)	Hay (t/yr)	Canola (t/yr)	Spruce (m^3/yr)	Pine (m^3/yr)	Deciduous (m^3/yr)	Net return ($/yr)	Soil erosion (t/yr)	Habitat value (bird/yr)
Basic scenario											
Goal target	432	767	231	1517	350	1198	409	952	102015	43511	6663
Deviation	0	0	0	0	0	0	0	0	0	0	0
GISS scenario											
Goal target	648	1151	347	2276	525	1115	429	808	153022	43511	6663
Deviation	0	0	0	0	0	−154	0	0	0	10715	0

[a] Please refer to section 5.7.1 for explanation.

for the basic scenario (current condition) are different from those for the climate change scenario reflecting changes of social and economic conditions in the future. For instance, Rothman and Herbert [36] indicate in their forest impact study that the annual allowable cut (AAC) will be changed under climate change scenarios. This information is used to derive the timber production target levels for the GISS scenario in the integrated assessment.

Two technical items were created to achieve the integration. First, inter-sectoral relationships are established by development of an integrated model structure. Second, the creation of land conversion variables, co-ordinating constraints, and joint goal constraints in the integrated model makes the integration of the three resource sectors possible. The integrated model represents the combined land use systems of agricultural, forestry, and wetland sectors in a region. The structure of the integrated model reflects interactions among resource sectors. The flow of land resources from one sector to another is an important feature of the integrated model, which provides a linkage among resource sectors. Shifting land use from one sector to another is also an important consequence of climate change.

Joint land constraints (equation (2)) which take account of land conversion from one sector to another are created in the integrated model to co-ordinate various resource sectors. These inequalities (equation (2)) represent the fact that land resources used for various purposes in each sector are limited. The total land used by different resource sectors cannot exceed existing lands plus lands converted from other sectors and minus lands converted to other sectors.

To reflect resource flow between sectors (i.e., land use change) in the study region, conversion variables, $x_{ij}^{\otimes}$ and $x_{ji}^{\otimes}$ are created and incorporated in the integrated model for each land sector j. The conversion variables represent respectively land areas converted from other sectors i to sector j, and from j to other sector i annually.

The primary purpose of the application of the GP model in this study is for integrated impact assessment and scenario analysis. More specifically, the model is used to identify the implications of various climate change scenarios, which are specified to represent different climate change conditions and/or response options, for regional sustainability. In this connection, the parameters of the GP model are thus modified to reflect conditions under certain scenarios. The model solving procedure of the scenario analysis is similar to sensitivity analysis. It is an iterative process and the results of alternative runs can be compared with a base scenario condition.

Alternative climate change scenarios are specified to explore the possible implications of climate change for regional sustainability. These forces may significantly affect the quality/quantity of resources available for crop and forest production. Such changes are accommodated by altering the yield coefficients of the model from current yields, called the base scenario, to adjusted yields which reflect conditions following climate change. By proceeding in this manner through a series of scenarios, it is possible to evaluate whether the changes that may occur are in keeping with the stated regional sustainability goals or indicators. Sometimes it is preferable to make only one change at a time, and then obtain a solution before making further changes. This permits identification of the impacts of each individual climate change scenario. Commonly, several changes (climate and other socio-economic changes) are needed to reflect new scenario conditions. Comparisons of the results with baseline conditions will show whether levels of goal achievement improve, decline, or vary significantly with climate change scenario. These results provide information on the implications of CC for RSD – whether CC will damage or enhance RSD.

5.7.2. Climate change impacts on regional sustainability

As explained above, the GP model was applied to indicate the impacts of climate change scenarios on the attainment of regional sustainability goals/indicators. That is, to what extent do climate change scenarios threaten the achievement of regional sustainability goals/indicators? In addition, the ILAF approach can be used to evaluate alternative adaptation policies in order to reduce negative climate change impacts and to improve the achievement levels of sustainability goals/indicators.

Given the fact that the ILAF was part of the integrated phase of MBIS, the GP analysis relied on data provided by other MBIS individual projects. As a result, the integrated assessment is limited in some aspects. The number of goals actually included in the prototype assessment is reduced (see table 9). Considering that impact data for some sectoral studies were available only for one of the climate change scenarios, “GISS” (the Goddard Institute for Space Studies transient GCM output), the GP model was run under only current and GISS scenarios. For instance, the impact of climate change on forest sector was based on the GISS transient GCM scenario. The Mackenzie Basin Forest Productivity (MBFP) model was run with current and GISS transient GCM scenarios [23]. As a result, in the integrated assessment, the first scenario is the base scenario for comparison, which represents the current condition. The baseline scenario was derived from weather observation data from 1951 to 1980 [11]. Scenario 2 reflects the conditions under the GISS transient GCM results.

5.8. Results and discussion

Comparison of the results of the two separate runs of the model can reveal the implications of climate change scenarios for achieving regional sustainability goals/indicators. The results of the two runs are presented in table 9. In the Mackenzie Basin, the short and cool frost-free periods under current climate condition impose considerable constraints on agricultural development. It is estimated that global warming might ease the thermal constraints on crop growing. Extension of the frost-free period also implies an increase in effective growing days. Brklacich et al. [9] indicate that, while a warmer climate may increase the total area suitable for agricultural production in the Basin, less favourable moisture conditions under climate change scenarios will reduce crop yields in the region. Comparing with the agricultural impact results, the forest impact assessment conducted by Hartley and Marshall [23] shows a different impact pattern. Whereas potential yield increase for deciduous trees is expected under a warmer climate, spruce will suffer a loss in the region. These results are shown in tables 4 and 7. The impact results provided by the sectoral studies suggest that the Basin may experience a wide range of both potential risks and opportunities under climate change scenarios. It is obvious that information on how these potential costs and benefits will affect regional sustainability is desirable for improving decision making in the region.

Referring to the results in table 9, no significant changes are identified under scenario 2 in goal achievements for net economic return and grain production compared with results for the base case (scenario 1). However, it is estimated that climate change (GISS scenario) will result in a moderate reduction in the attainment of spruce timber production goal, and a significant increase in soil erosion in the Basin. This is due to the fact that declining crop and forest yields associated with climate change reduce the capacity of the region to achieve its timber production target and forces more land for grain production. Since more land will be suitable for crop production under a warmer climate in the region, the crop production goal can still be achieved. This is consistent with the finding of another MBIS integrated analysis presented in Huang et al. [26]. Brklacich et al. [9] indicated that expanded irrigation services would increase yields/hectare, but that was not included in this model since water resource use scenarios were not constructed. This would be a useful exercise to pursue as a follow-up to this study.

A significant increase in land area devoted to crop production will raise soil erosion rates dramatically in the Basin. It might also affect wildlife habitat. Wildlife habitat protection is essential to ensure native community sustainability. The habitat protection goal in the model reflects this concern. The results of the assessment indicate that potential climate change may not significantly affect the habitat value goal. However, this result should be interpreted with caution since the model only takes account of waterfowl numbers. Incorporating other wildlife habitats in the model, including caribou, fur-bearers and fish, will provide better information for measuring native community sustainability.

5.9. Response policy analysis

The GP model could also be used for policy analysis to estimate the likely consequence of a potential response policy on regional sustainability goal achievement. This type of information provides a basis for planners or decision-makers to determine the adequacy and effectiveness of the policy before it is implemented. In policy analysis, a potential response option can be specified as a policy scenario. The policy scenario can then be represented in the model by adjusting parameters or structure of the model. The aim of the response policy is to reduce negative impacts or to take advantage of potential benefit of possible climate change scenarios, and thus to improve regional sustainability.

One essential step in scenario evaluation is the identification of possible response options to deal with climate change impacts. Since the options possess different characteristics, implementing them would have various impacts on different locations and on different goal achievements. Each option may cause both positive and negative impacts. For example, a new irrigation system may reduce negative impacts on crop yield, but may also create negative impacts on the water balance goal.

According to the Tinbergen principle, in order to achieve a desirable outcome, it is necessary to design as many options or policies as there are objectives [24]. In an analogous manner, the number of scenarios required in impact studies will be directly related to the issues or policies requiring investigation. Thus the number of response option scenarios required for study depends on how many adaptation/limitation alternatives or options need to be investigated.

The procedure of the policy analysis is to translate response policy scenarios into specific analytical questions that can be addressed by the model. Response policies will influence resource production, resource availability and suitability for each sector, demands for resource products, greenhouse gas emission and soil erosion rates, and other factors relating to regional sustainability. In the analytical process, different policy scenarios are represented in the structure of the GP model by modifying parameters in the coefficient matrix, the right-hand-side (RHS) vector, and the objective function.

In the ILAF policy evaluation, alternative policies can be evaluated by relating their various effects to a number of relevant goals/indicators. In order to assess the effectiveness of different adaptation policies in achieving regional sustainability, a base scenario reflecting "business as usual" conditions of the region is usually created for comparison. Alternative scenarios can then be created to reflect conditions coupled with a specific adaptation option to deal with climate change impacts. A comparison of the results between the policy scenario and the baseline scenario would show the different goal achievements under the two scenarios. If the goal achievements are improved significantly under the policy scenario, then this policy is assumed to be effective. The model would be run iteratively with a list of alternative policy scenarios. By proceeding in this manner through a series of scenarios, it is possible to evaluate whether the policies are in keeping with the stated goals or indicators, and the desirable policy options can be identified. Thus the most effective or desirable policies or adaptation options can be identified to ensure regional sustainability under climate change conditions. At this stage, however, no real run of the model for policy scenario has been conducted yet.

6. Conclusion

The preceding discussion has illustrated an integrated climate change impact assessment approach that can be employed to link climate change assessment and sustainable policy evaluation. The approach presented here provides an introduction to the integrated research framework that incorporates geographical information system (GIS), the analytic hierarchy process (AHP), simulation modelling, goal programming (GP), and other technologies in examining the implications of climate change for regional sustainable development. More detailed discussion on major techniques employed to form the integrated approach can be found in other articles [49–52].

In summary, the chief contribution of this paper is not so much to provide information or solutions for improving regional sustainability under climate change conditions. Rather, it is to provide procedures for integrating regional sustainability goals/indicators within a range of resource sectors, in order to systematically investigate the impacts of possible climate change on regional sustainability. In this sense the model developed is for heuristic purposes. The integrated land assessment framework (ILAF) model possesses some characteristics of a learning tool and a means of communication. As such, the results presented in the case study should not be viewed as a final analysis of the issues in relation to climate change and regional sustainable development.

Although an extensive endeavour has been made in model development, there are limitations in the integrated assessment system and thus there is room for improvement. For example, it is obvious that the reliability or usefulness of the model depends on the accuracy of the parameters and equations. Model testing and validation is critical to provide potential users with confidence in model results. In this study, many efforts have been made in the model construction and application phases to detect possible errors and unreliable aspects in the model. The MBIS case study provided a good opportunity for testing the ILAF system. However, the case study has not tested the model systematically and comprehensively with respect to model sensitivity. In order to realize the potential of the ILAF system as a means to provide meaningful and reliable guidelines for land policy making considering climate change, the model must be further tested. In this respect, much work in modelling improvement has been carried out in a follow-up research project in the Yangtze Delta region of China [52].

Certain aspects of the land use system have not been addressed explicitly in the integrated land assessment system such as recreation, fisheries, defence, and various wildlife activities. Adjustments to the integrated assessment system could be undertaken by adding livestock activity to the agricultural sector, and adding more wildlife habitats, recreation, and range use to the forestry and wetland sectors, as well as fishery and defence sectors in the models. At this point, data for these land use activities are either not available or insufficient for analysis. The present structure of the assessment system consists of only land resource constraints. Labour, capital, and technology constraints are not considered in the assessment. Thus, it is assumed that labour and capital are not scarce resources in the study region. The incorporation of labour and capital resource constraints in the models would be helpful in studying land use problems from a different perspective.

Owing to the complex nature of climate change and regional sustainability, the data required for the integrated assessment is extensive. Although certain data are available and relatively accurate, others are less so. The data availability for the case study was characterized by a lack of consistency among various individual sectoral impact projects for different resource sectors [15]. Improved and more complete data sets would improve the integrated assessment. For example, this study only considered the GISS transient scenario. If impacts of other climate change scenarios become available in the future, the model can be run with additional results to provide further information. Also, land use shifts under a climate change scenario was not studied by MBIS individual projects, so this type of climate change impact was not included in the integrated assessment, though Huang et al. [26] do provide an indication of land use shifts that may occur. Yin [51] illustrates a systematic approach to take land use shifting under climate change into consideration in the ILAF framework.

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