The Future of Canada's Ski and Mountain Destinations in an Era of Climate Change

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

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Chapter 2: Knowles, N.L.B., Scott. D., Steiger, R. (submitted – March 24, 2023). Climate Change and the Future of the Ski Industry in Canada's Western Mountains. Journal of Sport and Tourism.

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I hereby declare that I am the lead author for all three manuscripts, and I served as principal investigator for all three studies that pertain to this dissertation. I conceptualized the research, collected, and analyzed research data, drafted, and submitted the manuscripts to reputable journals and addressed the comments and feedback from peer-reviewers. My supervisor (Dr. Daniel Scott) offered intellectual insight, feedback, suggestions, and editorial changes to all three chapters. In Chapter 2 and 3 my collaborator and committee member (Dr. Robert Steiger) provided mentorship on SkiSim2.0 climate modelling, as well as insight, feedback, suggestions, and editorial changes to these manuscripts.

Abstract

Climate change represents a grand challenge for society and the far-reaching risks for the global tourism sector is no exception. As one of the largest sectors globally, tourism is not only highly affected by the biophysical impacts of climate change but is also a major source of greenhouse gas emissions contributing to anthropogenic climate change. Tourism's entrenchment in global socio-ecological systems mean that how tourism identifies and responds to climate change risks will have extensive implications for sport, recreation, livelihoods, culture, real estate, infrastructure, and community resilience in tourism destinations worldwide. While the international tourism sector has highlighted climate change as the primary threat to tourism sustainability, lack of viable climate change adaptation and mitigation strategies raise fundamental questions about the place of tourism in a warmer and decarbonized future. Considering the urgency and salience of these questions for winter tourism specifically, research on highly climate sensitive ski tourism provides important learnings and potential leadership for other tourism sectors that will inevitably face transformative risks as climate change accelerates.

This dissertation therefore investigates the complex physical climate and carbon risks within the Canadian ski and mountain tourism system to explore potential pathways towards sustainability and climate resiliency. Canada's diverse ski tourism industry provides an exemplary case study to identify the range of climate and carbon risks, investigate climate adaptations, and understand other socio-ecological factors contributing to or hindering climate impacts, responsiveness, and resilience. Through three interrelated studies, this dissertation combines qualitative and quantitative methodologies using a tourism geography lens to; (1) apply industry-specific climate risk modeling, (2) conduct empirical analysis on the sustainability of snowmaking as a climate adaptation, and (3) understand diverse and inter-connected stakeholder climate risk and response perspectives. Through this process, the research aims to understand the "wicked" challenge of climate change in complex tourism systems, provide information needed for relevant and dynamic climate response planning, decision-making and action, and enable discussions on sustainability transformations and climate resilient futures for diverse mountain tourism destinations.

Findings suggest climate risk and resilience is relative across temporal and spatial scales, with potential cross-regional implications for competitiveness and demand patterns. Empirical assessments of snowmaking as a climate adaptation further demonstrate that the national scale is too coarse to evaluate (mal)adaptation or sustainability, instead showing how regional and destination-scale differences in climate impacts, tourism markets, ecosystems (e.g., water availability), and energy sources result in differing assessments of adaptation sustainability. Multi-stakeholder narratives situate modelled and observed climate and carbon risks within complex socioeconomic systems and identify diverse actors, structures, and perspectives influencing destination-scale climate (in)action and potential levers to affect more transformative change towards climate resilient futures.

More broadly, this dissertation broaches important sustainable tourism and climate change theories, concepts and paradoxes including: temporal and spatial scale, relative climate risk (impacts and adaptive capacity); private-public sector relations and responsibility; (mal)adaptation; scope 3 emissions and current-future tourism mobility; tourism growth and decarbonization; pluralistic value(s) of tourism and sustainability; top-down vs bottom up decision-making; and climate justice, with the aim of extending the important conversation on [sustainable] tourism's place in a decarbonized economy and warmer world. In investigating the intersection of these research questions, this dissertation presents novel conceptual frameworks, empirical analysis, and participatory methods which could be replicated in other tourism contexts and applied to support ski tourism operators and local mountain communities responding to climate change.

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Dedication

Dedicated to the smartest person I know, Mary (Granny, Honey) Knowles.

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List of Abbreviations and Acronyms

BBC	British Broadcasting Corporation
CBC	Canadian Broadcasting Corporation
CER	Canada Energy Regulator
COVID	Coronavirus disease 2019 (COVID-19)
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CMIP	Coupled Model Inter-comparison Project (Phase 5 & Phase 6)
CSC	Canadian Ski Council
ECCC	Environment and Climate Change Canada
EPA	Environmental Protection Agency (United States)
GDP	Gross domestic produce
GHG	Greenhouse gas
IPBES	Intergovernmental Science-Policy Platform on Biodiversity & Ecosystem Service
IPCC	The UN Intergovernmental Panel on Climate Change
IPCC ARI-VI	Intergovernmental Panel on Climate Change Assessment Reports 1 to 6
kWh	Kilowatt hour
LARS	Long Ashton Research Station
NBC	National Broadcasting Company (United States)
NIMBY	“Not in my backyard”
NOAA	National Oceanic and Atmospheric Administration (United States)
NRCan	Natural Resources Canada
NSAA	National Ski Areas Association (United States)
RCP	Representative concentration pathways
SDG	Sustainable Development Goals
SkiSim2.0	Ski season simulation model (V1 [Scott et al. 2003, 2007], V2 [Steiger 2010])
SSP	Shared socioeconomic pathways
UN	United Nations
UNEP	United Nations Environmental Programme

UNFCCC	United Nations Framework Convention on Climate Change
WASP	World Adaptation Science Program
WEF	World Economic Forum
WTTC	World Travel and Tourism Council

Chapter 1

Introduction to Dissertation

1.1 Research Context

In the 50 years since the first UN environment conference, held in Stockholm in 1972, climate change has become the most pressing issue facing global society (UNFCCC 2021). The IPCC special report on Global Warming of 1.5ºC (2018) highlights the catastrophic consequences of allowing human induced carbon emissions to heat global average temperatures above the 1.5ºC target set out in the Paris Agreement. Anthropogenic emissions are estimated to have already caused over 1.1ºC of warming above pre-industrial (1850-1900) levels (IPCC 2023). At the current rate of emissions, the international community will use the carbon budget compatible with a 1.5ºC future in the next 11 years (Friedlingstein et al. 2022) and will likely reach 1.5°C before 2030 (IPCC 2018, 2023; Jones 2023). Limiting total anthropogenic warming to less than 2°C with a probability of greater than 66% would require cumulative emissions from all anthropogenic sources since 1870 to remain below a finite planetary carbon budget of 2900GtCO_2 (Rockstrom et al. 2017). The Glasgow Climate Pact makes clear that 2ºC would have grave consequences on communities and the natural world (UNFCCC 2021), yet most analyses conclude the world is unlikely to achieve the Paris Climate Agreement's highly ambitious emission reduction targets (as low as 5% change – Lui & Raftery 2021). Despite strengthening emission reduction ambitions, with more than 150 countries pledging to achieve net-zero emissions by 2050 (UNFCCC 2021), if all current emission reduction pledges are achieved, research suggests over 3ºC average global temperature rise by the end of the century (UNEP 2022) with other models suggesting additional warming (Brown & Caldeira 2017).

In alignment with the UN Intergovernmental Panel on Climate Change's (IPCC 2018) conclusions that human-induced global warming is unequivocal, unprecedented, already having wide-spread impact on human and natural systems and will require drastic emission reductions to avoid dangerous levels of future climate change, the UN World Tourism Organization (2008:38), as early as 2008, identified climate change as, "...the greatest challenge to the sustainability of tourism." Tourism is one of the largest (10.2% of global GDP and 9.6% total employment, WTTC 2017) international industries and is deeply entrenched and reliant on global human and natural systems (Bellato et al. 2022; Bosak 2016; Hall 2011; Hussain 2021; Jakulin 2016; Klein 2017; Klein & Juhola 2014; McCool 2015; Steiger et al. 2022), thus is an industry most likely to be impacted by climate change (IPCC 2014; Mora et al. 2018). Despite international tourism organizations acknowledgement of climate impacts and risks, and the UNWTO's Glasgow declaration to "halve emissions over the next decade and reach net-zero emissions as soon as possible before 2050" (One Planet Sustainable Tourism Programme 2021), tourism still accounts for approximately 8% of global emissions with no credible plan by which tourism emissions could be reduced sufficiently to achieve net-zero commitments by mid-century (Scott & Gössling 2022). The absence of viable climate change response strategies, both adaptation and mitigation, raise fundamental questions on the future role of tourism in a decarbonized and warmer world (Gössling & Scott 2018; Scott et al. 2016).

The highly climate sensitive mountain tourism sector, with skiing as a primary market segment, (Steiger et al. 2022) provides an exemplary case study to investigate complex climate and carbon risks within tourism systems and potential transformative pathways towards sustainable tourism. Considered the tourism sector "canary in the coal-mine" by many (Bicknell & McManus 2006; Knowles 2019; Knowles & Scott 2020; Sauri & Llurdes 2020; Scott et al.

2021), significant evidence demonstrates the international ski industry is facing a climate-induced transition yet remains ill-prepared to respond and adapt to changing climates and carbon emission reduction responsibilities (Knowles & Scott 2020; Scott & Steiger 2020; Steiger et al. 2019). Research shows limited industry or destination climate change awareness, concern and responsiveness, driven or justified by a perceived lack of relevant climate information in key geographic locations; dynamic stakeholder relations and responses to climate and carbon risks; a disconnect between science, industry, and policy; and difficulties with decision-making amidst complex systems and high uncertainty (Bicknell & McManus, 2006; Gössling & Scott 2018; Knowles, 2019; Knowles & Scott 2020; Scott et al. 2019, 2016; Steiger et al., 2019; Trawöger, 2014; Weaver 2011). How ski and mountain tourism understand and respond to the climate crisis is not only critical to its own future viability and that of its destination communities, but will provide important learnings and potential leadership for other tourism markets and destinations that will inevitably face similar risks as climate change accelerates, as the international community strengthens decarbonization targets, and as public concern for environmental and social responsibility grows (Knowles 2019; Scott 2011, 2021; Scott & Gössling 2022).

As Canada's average temperatures increases at double the global rate (ECCC 2023), the Commissioner of the Environment and Sustainable Development (2017) emphasized that Canada is not prepared to adapt to climate change, emphasizing the imperative for new knowledge to prepare for the risks and opportunities of accelerating changing climate. The tourism sector, and other service sectors, were specifically identified as a priority knowledge gaps by Canada's Pan-Canadian Framework on Climate Change and Clean Growth (2016). Winter mountain destinations, including 237 ski areas operating across the country, employing over 35,000 people, and generating economic impact estimated at over $4 billion CAD, are a key part of

Canada's tourism sector (CSC 2019). Ski visits across Canada have declined from 18.6 million (2009-2014 annual average) to 18.4 million (2015-2019) with declining visitation in Quebec and static visitation across Alberta and Ontario (CSC 2019, 2018, Knowles 2019). The four largest regional markets in Quebec (QC), Ontario (ON), Alberta (AB), and British Columbia (BC), which make up over 96% of Canada's skier visits and skiable terrain (CSC 2019), offer a diverse skiing experience and operate within very different socio-ecological systems, resulting in both varied climate impacts and relevant climate adaptations, as well as operational emission intensities. Considering the salience of climate change for the ski industry, and it's complex and far-reaching implications for alpine ecosystems, winter sport, recreation, employment, culture, real estate, and local economies in Canada's tourism-dependent mountain communities, applicable multi-disciplinary research is needed to prepare the ski tourism industry and its destinations (Scott et al. 2017; Scott & Steiger 2020).

As such, investigations into climate change and ski tourism need to fill key regional gaps in Western Canada to allow for a complete picture of relative climate risks at the national scale, examine the limits and sustainability of key adaptation strategies, produce decision-relevant climate information that is industry and destination specific, situate climate risk within the complex socio-economic system, and give agency to diverse decision-makers (Gössling & Scott 2018; Knowles & Scott 2020; Steiger et al. 2022). This dissertation meets these research needs, filling empirical climate impact and adaptation sustainability analysis gaps, exploring new quantitative and qualitative methodologies, and presenting novel conceptual frameworks to support ski tourism operators and local mountain communities as they respond to climate change. The dissertation contributes important theoretical and applied research, including insights on scale and relative climate risk; private-public sector relations and responsibility;

(mal)adaptation; scope 3 emissions and tourism mobility; growth and decarbonization; pluralistic value(s) of tourism and sustainability; top-down vs bottom up decision-making; climate justice, among others with the aim of extending the important conversation on [sustainable] tourism's place in a decarbonized economy and warmer world, all of which could be replicated in other international contexts.

1.2 Theoretical Frameworks

This dissertation takes its core theoretical frame from the broad and interdisciplinary department within which it lies: Geography. As early as 1887, geography was defined as the bridge between the natural and social sciences (Castree et al. 2009; Mackinder 1887). While a century and a half of scholarly specialization has led to the segmentation of physical and human geographies (Holt-Jensen 1999), many geographers remain at the human-environment intersection (Turner 2002) as this dissertation does. Physical geography's focus on understanding the biophysical components of climate change, and social behaviour and stakeholder perspectives that are prominent in human geography, both provide valuable and interacting quantitative and qualitative insights that are essential to understanding the human-environment nexus (Philip 1998; Holt-Jensen 1999; Castree et al. 2009). As climate change and tourism both incorporate a complex landscape of stakeholders, politics, and environments, this dissertation takes a multiple methods approach, applying geography's natural and social science lenses, relational concepts of scale, and socio-ecological system-based thinking (Bjurstrom & Polk 2011; Gregory et al. 2009).

By viewing climate change and tourism across scales and as constructions of interconnected socio-ecological systems, geography opens new arenas to investigate the mechanisms driving global climate change and local manifestations, as well as identifying and mobilizing responses for the tourism system (Bjurstrom & Polk 2011; Haarstad 2014; NRC

1997). The study of climate change in isolation from other environmental and social factors creates an incomplete picture and potentially misleading conclusions (Blokland 2019; Burnham et al. 2018; Gillard et al. 2016; IPCC 2014; Klein 2017; Klein & Juhola 2014; Williams & van t' Hof 2016), thus this research uses a systems lens, situating climate change risk and response within tourism's broader socioeconomic context (Bellato et al. 2022; Jakulin 2016). This lens brings forth subjective concepts of boundaries, scale, relationality, risk, value, all of which vary over space and time and influence the drivers, perceptions, and responses to climate change. Furthermore, the recent Covid-19 pandemic, revisions to international trade agreements, social justice movements, and political instability demonstrate the interconnectedness of our social-political-economic-ecological systems within which tourism exists (Gossling et al. 2021; Scott 2021). A systems framework therefore embraces climate change as a 'wicked problem' (Blokland 2019; Jakulin 2016) and grounds this research in the dynamic, complex, situated, and uncertain realities of the world wherein tourism must prepare not only for environmental change, but significant political, economic, and social shifts (WEF 2022).

Understanding that tourism's response to climate and carbon-induced risk is entrenched in local to global socio-ecological systems means applied climate change research and practice may be better placed within wider sustainability transformations (Gillard 2016; Higgins-Desboilles 2018; IPCC 2014; Werner et al. 2021; Westley et al. 2011; 2013). Pursuing an integrated sustainable tourism strategy, rather than a narrow focus on climate change, has the potential to yield benefits for both climate adaptation and mitigation in most cases (Burch 2019; Dale et al. 2019; O'Neill et al. 2014). Many of the direct and indirect climate change impacts, such as droughts, famines, heatwaves, floods, biodiversity loss, invasive species, wildfires and more, coincide with and exacerbate underlying socio-ecological system vulnerability (Klein, 2011).

Conversely without addressing climate change, environmental, economic, and social sustainability (including concepts like sustainable tourism) may not be sustainable or attainable in the long-term and therefore heighten future climate risk (Carney 2015; Crishna et al. 2019; Nerini et al. 2019). Despite being a dominant paradigm in tourism research, policy, and development (Ruhanen et al., 2015), sustainable tourism has been critiqued as a “policy failure” (Hall, 2011), a “threat” (McKercher, 1993), and ultimately failing to achieve its namesake objective (Becken & Schellhorn, 2007; Espiner et al. 2017; Gill, 2000; Higgins-Desboilles, 2018; McCool & Moisey, 2001; Pigram, 1990). More recently, some researchers have pointed out that sustainable tourism cannot be achieved without solving climate change and tourism (Becken 2019; Sharpley 2020 Scott 2021; Scott & Gossling 2022)

As sustainable tourism is increasingly put in the spotlight (Fodness, 2017; Ruhanen et al., 2015) and evidence grows on the transformative impact accelerating climate change will have on mountain and ski tourism worldwide (Steiger et al. 2019, 2022) there is urgent need for researchers, tourism managers and destination communities alike to understand pathways to achieving climate resilient, just, and sustainable futures. As leisure scholar Henderson (2013: 68) stated, "some people believe sustainability means to maintain the status quo, when, in fact, the status quo is not currently sustainable". As such, this analysis does not assume current tourism system structure or functioning to necessarily be satisfactory nor aim to sustain the status quo. Instead, the entwined ecological, social, and economic tensions provide an opportunity to re-envision the mountain tourism system through sustainability transformations. Transformations, like adaptations, are not innately positive or negative and can be anticipatory or reactive, autonomous, or planned and range in scale, but require a systemic shift in institutional underpinnings of society including deeply held values, logics and beliefs, multi-level governance and management structures, and patterns of behaviour (Westley et al. 2011, 2013; Wise et al. 2014). To navigate shifts and direct large-scale transformations towards climate compatible futures, this research seeks to understand the underlying values and perceptions of what tourism's role is in society and identify opportunities to reimagine tourism and redefine its success to align with ecological sustainability, ethical principles, and climate resiliency.

1.3 Methodological Approaches

Climate responsiveness and system-wide sustainability transformations in mountain tourism require restructuring and reprioritizing research in a way that ensures information produced is relevant and reduces barriers of communication between disciplines, sectors, and stakeholders (Knowles & Scott 2023). This includes industry relevant and destination specific climate risk assessments that are comparable across space and time (Scott et al. 2019b), research both *on* and *for* climate adaptation to understand potential maladaptation including evaluations of snowmaking as a key industry climate response (Scott et al. 2022b), and an increase in participatory research and science communication (Steiger et al. 2022). As such, this program of research begins by applying SkiSim2.0 climate modelling in Western Canada to complete Canada's nation-wide ski tourism climate risk analysis. In doing so, this not only provides empirical evidence on Alberta and British Columbia ski tourism's current and future climate change impacts, but also allows for understanding of relative risks across Canada's national ski tourism market, including discussions on potential cascading and compounding risks across various timeframes and geographies.

Considering the urgency and complexity of the climate challenge, mountain tourism destinations need to move beyond assessing the impacts to what Klein (2017) calls research *on* adaptation (Scott & Becken 2010; Scott & Gossling 2022). Research *on* adaptation seeks to understand how responses perform in future climate change and societal scenarios, including sustainability, equity, and testing the limits of effectiveness (Dilling et al. 2015; IPCC 2014). The IPCC states that '[T]he adaptation literature is replete with advice to avoid maladaptation, but it is less clear precisely what is included as "maladaptation"' (Noble et al. 2014:28). In the tourism sector, Scott and Gössling (2022:8) emphasize that, "there remains highly inadequate research on the limits to adaptation (physical, economic, social) under future climate scenarios, the scalability of adaptations, associated co-benefits, maladaptation, and adaptive capacity (including enablers and constraints)." For ski tourism, snowmaking remains an integral industry specific climate adaptation with ski tourism operators and executives across a range of ski tourism markets investing in expanded snowmaking capacity in response to future climate change (Abegg et al., 2017; Hopkins, 2014; Knowles, 2019; Scott et al. 2022b; Trawöger, 2014). Some media and scholars consider all snowmaking to be unsustainable or maladaptive, yet there lacks empirical evidence on snowmaking's water use, energy consumption, and carbon emissions (Knowles & Scott 2021; Scott et al. 2022b). This dissertation provides new methodological approaches to quantify snowmaking water use, energy consumption and related emissions both currently and under a range of future climate impacted scenarios and energy system decarbonization policies. This new empirical evidence is analyzed using a geography lens, systems-thinking, and concepts of scale to inform discussions on under which circumstances snowmaking may be considered [mal]adaptive for Canadian mountain tourism.

Throughout broader climate policy discourse, technological innovation such as snowmaking, is consistently prioritized over social change, despite well-established understanding that barriers to reducing reliance on fossil fuels and adapting to change are often social and institutional (Cinner et al. 2018; Klein 2017; Stephens & Markusson 2018; Wise et al., 2012; Werner et al. 2021). This technology-focused and science-based climate risk and response discourse often aims to define, synthesize, simplify, and reduce complexity (Krauss 2020), yet climate actions are rarely taken in response to climate change alone and a clearly identifiable and rational decision-maker with the mandate to make decisions rarely exists (Smit & Wandel 2006; Wise et al. 2014). Instead, decisions are made and implemented at multiple scales, by multiple actors with varying climate change knowledge and risk perceptions, and influenced by various interacting stressors (Burnham et al. 2018). Climate response outcomes are subjective to stakeholder perspectives, temporally ambiguous, and intrinsically linked to dynamic cultural, political, economic, and environmental contexts (Wise et al. 2012). Recognizing mountain tourism climate change risk and responsiveness plays out in multi-stakeholder settings as part of a larger socioeconomic system (Bellato et al. 2022; Hussain 2021; IPCC 2014; Klein & Juhola 2014; Steiger et al. 2022), this dissertation contributes to fourth generation climate adaptation research (Klein 2017) by engaging diverse stakeholders to investigate social, institutional, and systemic barriers and pathways to effective climate action. Using a system framework to embrace the 'wicked problem' of climate change (e.g., Blokland 2019; Gillard et al. 2016; Williams & van t' Hof 2016) and complex nature of tourism (e.g., Bellato et al. 2022; Jakulin 2016), this research uses the dynamic, interconnected, situated and uncertain attributes to discuss deep-rooted socio-economic drivers and identify potentially unexpected levers for change (Goodman 2002; Hassmiller & Kuhl 2020; Hovmand 2014; IPCC 2014; Jakulin 2016; Stave 2010; Wyborn et al. 2020). Furthermore, navigating and directing large-scale transformations requires widespread support and broad input, mobilizing collective action (Westley et al. 2011). Therefore, participatory research which incorporates diverse decision-makers' perspectives can enhance communication and collaboration amongst stakeholders, including researchers (Krauss

2020; Knowles & Scott 2020; Steiger et al. 2022), encourage action by integrating and applying stakeholders' own language, concerns, ideas, and connections into solutions, particularly the private sector (Bisaro & Hinkel, 2018; Buchner et al. 2014; Crick et al. 2017, IPCC 2014; Krauss 2020), identify aspirational visions for the future (Hussain 2021) and ultimately encourage decision-makers to see social and ecological tension as opportunities for thinking and acting differently (Gillard et al. 2016).

1.4 Research Objectives

The overarching goal of this research is to advance climate risk responsiveness in Canadian ski tourism destination socio-economic systems by leveraging industry specific climate modelling, research *on* and *for* climate adaptation, complex socioeconomic systems, and stakeholder engagement. More specifically this dissertation combines qualitative and quantitative methods to evaluate the current state of climate and carbon risk, climate change adaptation and mitigation strategies, and identify transformative pathways that enable intersectoral collaboration for increasing resilience to climate change in alignment with broader sustainability goals. To this end, the three studies that comprise this dissertation address the broad research objective of projecting and preparing Canadian ski and mountain destinations for a warmer and decarbonized future. Each study also stands alone with specific research questions and objectives which are described below.

1. **Climate Change Impact Modelling (Chapter 2)**

   Research Questions: (RQ1) What are the current and future climate change impacts for British Columbia and Alberta ski areas? (RQ2) How do these physical climate risks in Western Canada compare to other regions across national and international scales?

Objective 1: Use historical daily weather data (NOAA 2018) identified as representative of each of Canada's western ski areas, common ensemble climate scenarios (CMIP-5 and CMIP-6 [IPCC2022a]), and SkiSim2.0 (Scott et al. 2003; Steiger 2010) to model current baseline ski conditions and projected impacts of climate change on key industry-specific indicators (including season length, seasonality, snowmaking requirements) across a range of potential future climates (based on diverse emission scenarios RCP4.5, RCP8.5, SSP245, SSP370, SSP858) and timelines (2050s, 2080s).

Objective 2: Assess implications for future ski area operability at the regional market-scale including market capacity (indicators include terrain-days, lift capacity, skier intensity) and economic viability (indicators include climate impact on key season segments, and probability of meeting industry-set operating thresholds) using physical climate projections (*Objective 1)* and destination-regional tourism market metrics (e.g., skier-days, terrain)

Objective 3: Discuss Western Canada's intra-regional patterns of climate risk (*Objective 1* and *2)* and compare relative inter-regional climate risks across Canada and other continental and international markets.

2. **Snowmaking Sustainability: 'for' Adaptation (Chapter 3)**

Research Questions: (RQ1) How much water-use, energy consumption and carbon emissions stem from Canada's snowmaking production at the tourist, destination, region, and national scale? (RQ2) How could accelerating climate change and Canada's decarbonization targets impact future snowmaking water-use, energy consumption, and carbon emissions?

(RQ3) At what scales (geographically, temporally, spatially) can snowmaking in Canada be considered a climate (mal)adaptation?

Objective 1: Develop snowmaking sustainability assessment tool based on establishing ratios of water-use (m^3), energy consumption (kWh) and related carbon emissions (based on provincial electricity grid carbon intensity [gCO_2e/kWh]) per snow produced (m^3) adjusting for low, central, and high efficiency snowmaking systems.

Objective 2: Using the tool (*Objective 1)* and assuming central efficiency snowmaking infrastructure, conduct the first national assessment of Canada's snowmaking to identify total water-use, energy consumption and related carbon emissions currently and by mid-century across a range of climate (RCP4.5 & RCP8.5) and carbon (Canada Energy Regulator's policy targets for net-zero by 2050) futures.

Objective 3: Discuss the role of snowmaking as a climate (mal)adaptation in the Canadian ski tourism context including the dynamic nature of adaptation, the adaptation-mitigation nexus, tourism system boundaries, and the scale(s) at which environmental sustainability can/should be assessed.

3. **Mountain Tourism System Transformation (Chapter 4)**

Research Questions: (RQ1) What do diverse ski tourism stakeholders perceive as current and future climate and carbon risks for mountain tourism destinations? (RQ2) What other socioeconomic determinants are contributing to the current state of climate preparedness in ski tourism destinations across Canada? (RQ3) Which stakeholder perspectives enhance versus inhibit destination climate resilience and sustainability, and how can these narratives be used as levers to accelerate climate responsiveness?

Objective 1: Engage diverse stakeholders from Canada's ski tourism system (including tourism industry experts, municipality staff members, and community leaders) in participatory research methods (including interviews, workshops, and focus groups) to collect qualitative narratives on climate change risk, response, and resilience in mountain tourism systems.

Objective 2: Situate climate and carbon risks and responses within the mountain tourism socioeconomic system including linking qualitative stakeholder risk perceptions, relationships, and decision-making influences (Objective 1), with quantitative climate risk and responses (Chapter 2 & 3 results), and the broader literature (including academic, industry reports, municipal policy documents).

Objective 3: Conceptualize gaps between climate risks and existing responses. And potential levers for transformative change in research, theory, policy, and action that could enable pathways towards climate resilient futures in Canadian mountain tourism destinations.

1.5 Outline of Dissertation

This dissertation is written in a manuscript-style format composed of five chapters. This introduction (**Chapter 1)** provides an overview of climate change and tourism nexus, outlines the problem context of climate change and ski tourism specifically, and describes how this dissertation addresses geographical, methodological, and theoretical gaps identified by international scholars throughout the literature. The body of this dissertation is divided into three chapters (Chapters 2, 3 and 4). Each of these chapters presents its own set of research questions, literature review, methodology and results, but they are conceptually aligned and build upon one another.

Chapter 2, entitled "Climate Change and the Future of the Ski Industry in Canada's Western Mountains" is under review in the *Journal of Sport and Tourism.* Using SkiSim2.0 to analyze climate risk for Western Canada ski areas across a range of climate futures, this study provides an empirical contribution to the climate change risk and ski tourism literature by filling a key geographical gap. Using comparable methods allows for a national scale climate risk analysis, while results highlight the comparative resilience of Western Canada relative to other continental markets as well as intra-regional variance in climate impacts. These empirical results form the basis for discussions on climate change implications within and across Canada's ski tourism destination socio-economic systems including geographically and temporally shifting supply and demand, the adaptation-mitigation nexus and bespoke climate resilient sustainability transformations, which are expanded upon through *Chapter 3, 4* and *5.*

Chapter 3 entitled " Sustainability of Snowmaking as Climate Change (mal)Adaptation: An Assessment of Water, Energy and Emissions in Canada's Ski Industry" is published in the journal *Current Issues in Tourism.* This study uses baseline and projected snowmaking production in Eastern (Scott et al. 2019) and Western Canada (Chapter 2 - Knowles et al. 2023a) to quantify water, energy, and emissions from snowmaking at the individual tourist, destination, provincial and national scales. This study advances methodological approaches as the first snowmaking sustainability assessment tool and provides empirical findings on snowmaking sustainability. Application of these results range from addressing assumption-fueled debate amongst scholars, media, and industry members to providing practical data and conceptual insights to inform ski tourism climate adaptation-mitigation planning and snowmaking investment on multiple scales.

Chapter 4 entitled "Canadian Ski Tourism Transformations Amidst Accelerating Climate Change; A Participatory Systems Mapping Approach" is under submission to the journal *Annals of Tourism Research Empirical Insights*. This chapter situates the quantitative findings of Chapter 2 and 3 within qualitative stakeholder narratives to map the complex, cascading and compounding drivers of climate and carbon risks within Canadian mountain tourism's local to global socio-economic systems. Results demonstrate climate and carbon risks extend within and beyond destination boundaries, across sectors, and have implications for other social, ecological, and economic sustainability objectives. Furthermore, narrative analysis demonstrates how tourism's deep entrenchment in its socio-economic system provides both barriers to internal transformation as well as opportunities for tourism to be a catalyst for wider transformative change by incorporating pluralistic values and re-envisioning the role of tourism in society. This study fosters engagement of and collaboration amongst diverse stakeholders, embraces complexity as an agent for creative solutions and presents new conceptual pathways to approach climate adaptation, mitigation, resilience, and sustainability transformations.

Chapter 5 draws conclusions from the manuscripts' integrated findings, including novel empirical, methodological, and theoretical contributions to the climate change and tourism literature more broadly, implications for applied climate action within tourism systems. This chapter is also informed and supported by a larger body of studies, exploring inter-related questions on overlapping topics of tourism, sport, outdoor recreation, climate change, ecological conservation, and sustainable development, conducted concurrently to the dissertation (see Figure I-1). Chapter 5 then presents an agenda for future research and practice.

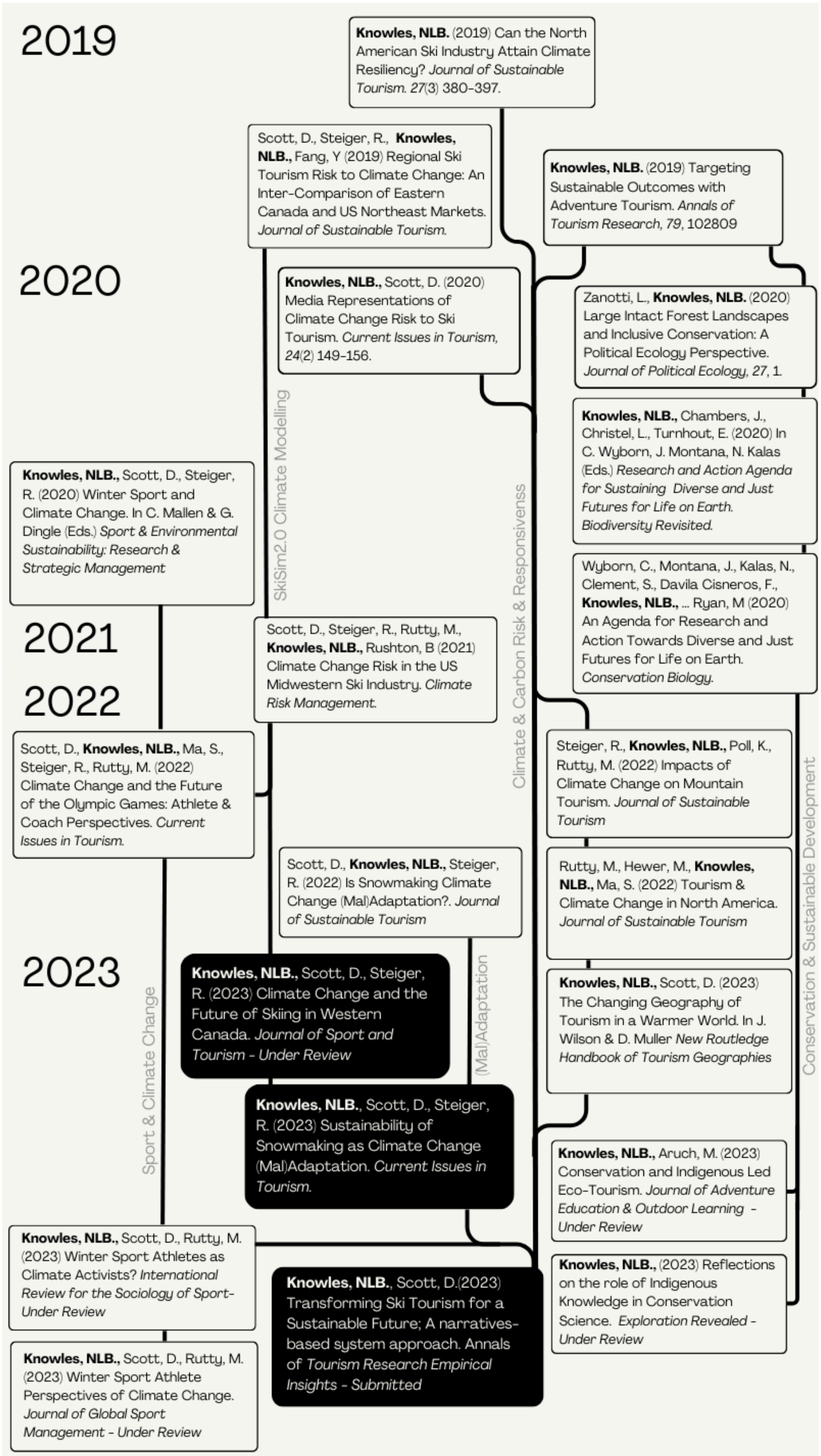

Figure I-1. Timeline of body of interdisciplinary research supporting and informing dissertation program of study.

Chapter 2

Climate Change and the Future of the Ski Industry in Canada's Western Mountains

Knowles, N.L.B., Scott. D., Steiger, R. (submitted March 24, 2023). Climate Change and the Future of the Ski Industry in Canada's Western Mountains. Journal of Sport and Tourism.

This manuscript has been modified for use in this dissertation.

Winter, snow, and mountains, epitomized by the world-renowned Rocky Mountain range, are an integral part of Canada's sport-culture identity and international tourism attraction, yet the climate change risk posed to this important ski tourism region remains uncertain. This study uses the ski operations model SkiSim 2.0 to analyze the climate risk for the region's ski industry (26 ski areas in the province of Alberta and 40 in British Columbia), including changes in key performance metrics of ski season-length, snowmaking requirements, holiday operations, and lift and terrain capacity. If Paris Agreement targets are met, average seasons across all ski areas decline by 14-19% while required snowmaking production is projected to increase 126-196%. More pronounced impacts are projected under longer-term, high-emission scenarios, and in low latitudes and coastal British Columbia regions. When compared with continental and international markets, Western Canada has relatively lower climate change impacts, leading to discussions on the implications of climate change on local tourism socio-economic systems. Results from this study can inform further research on demand-side climate risks and winter sport-tourism industry and destination scale climate change adaptation and mitigation strategies.

2.1 Introduction

Mountain regions across the world are experiencing rapid climate change with average temperature increases outpacing the global mean by an estimated 25 to 50 percent since around 1950 (Pepin et al. 2022). Snow-cover, glaciers, and permafrost decline has begun, and continued warming will accelerate exposure to related climate induced natural hazards, as well as impact the aesthetic, spiritual and cultural values associated with mountains (Hock et al. 2019; IPCC 2022b). Many mountain regions are "near the hard limits of their natural adaptation capacity" (IPCC 2022a, p28), emphasizing mountain communities' high vulnerability to climate change and the imperative to increase resiliency. Dependence on climate-sensitive livelihoods, including tourism development expansion and shifting population demographics - both amenity migration increases and urbanization decreases (Hock et al. 2019; IPCC 2022b), mean mountain communities dependent on winter sport tourism are increasingly negatively affected by climate change (IPCC 2022a; Steiger et al. 2019, 2022) and remain a priority knowledge gap (IPCC 2022b; Hock et al. 2019). Ski tourism is a complex and interrelated socio-ecological system in mountain regions that influences fragile alpine habitats and endemic and endangered biodiversity; sport, recreation, and culture; livelihoods and community well-being; through to accessible housing and local water and energy security. A review of climate change and the global ski tourism industry concludes the multi-billion-dollar international ski industry is in the early stages of a climate-induced transition (Steiger et al. 2019). In Canada, understanding of physical climate risk on the ski industry is limited to eastern ski markets in Ontario and Québec (Scott et al. 2019). Although research on climate change risks to the ski industry in Eastern Canada has continued for twenty years (Scott et al. 2003, 2007b, 2019b) the larger Western Canadian market is a priority gap which this research addresses.

Using the ski operations model SkiSim 2.0, this study analyzes the physical climate impacts in Western Canada, including changes in key performance metrics of natural snowpack, ski season-length and reliability, snowmaking requirements, and holiday operations across a range of low to high-emission climate futures. These climate performance impacts are assessed for 40 ski areas in British Columbia (BC) and 26 ski areas in Alberta and compared alongside destination, provincial and regional scale capacity to discuss comparative impacts and ability to meet current and future ski tourist demand. This research not only provides the first climate change and ski tourism operation analysis in the region, but the common climate forecast modelling also allows for discussions on national, continental, and international scale trends. Within Western Canada, this research sets the foundation for discussions and future research on effective climate strategies for local winter sport industries and ski tourism destination communities including adaptation planning and feasibility of proposed ski resort developments. More broadly this research, can be used alongside current and future research to take a tourism-systems approach to better understand the adaptation-mitigation nexus, and assist the winter-sport tourism industry in transforming to fit the warmer winters and decarbonized economy of the future.

2.1.1 Study Area: Skiing in Canada's Western Mountains

Winter, snow, and mountains, epitomized by the world-renowned Rocky Mountain range and over 74 ski areas (32 in Alberta and 42 in BC) (CSC 2019), are an integral part of Canada's national sport culture identity and international tourism brand. Western Canadian markets represent an average of 48% of Canada's annual skier days (2.3 million in Alberta, 5.9 million in BC) and over 1 million regional residents consider themselves active skiers (537,802 British Columbians, 473,649 Albertans) (CSC 2018, 2019). Western Canada is also a global ski tourism destination. Several resorts like Whistler, Lake Louise, Kicking Horse, and Revelstoke are listed in the top destinations world-wide by tourism industry media such as Snow Magazine, World Atlas, and Oyster attracting on average over 2 million international skier days from the US, UK, Australia, New Zealand, Germany, and Mexico (CSC 2019). Transitioning from natural resource extraction-based industries, rural and remote mountain communities in Alberta and BC have focused on outdoor sport recreation, amenity migration and sport tourism, with expansion of ski tourism a central pillar (BC 2012). In British Columbia, ski areas stimulate $1.4 billion in incremental visitor spending and create over 18,800 full time equivalent jobs in the province (BC 2015). This represents a significant portion of BC's provincial tourism markets (9% of total tourism revenues and 13% of tourism's GDP contribution [BC 2015]). While ski tourism demand has remained steady, revenues and profitability have declined since the early 1990s (Williams & Fidgeon 2000; CSC 2019). Despite plateaued demand and diminishing profits, the Canadian ski tourism industry is predicting new skier markets will lead to regional market growth of 13.3% by 2030 (CSC 2019). While indicative of the economic, geographic, and cultural significance to Western Canada, these ski industry metrics and projected growth do not include any legacy of recent COVID-19 pandemic disruptions or future climate change impacts.

Understanding the range of potential climatic futures, and the related risks to ski tourism operations is essential to climate adaptation and tourism planning across Canada's Western ski industry from individual ski area management to mountain community development strategies to regional water and energy policy. For example, while there is significant debate on the (mal)adaptation of snowmaking (Aall et al. 2016; de Jong 2015; Dunstan 2016; Hopkins 2014). Scott et al. (2022b) find that the effectiveness and sustainability is highly context specific. Energy and water sources and costs, existing infrastructure, local microclimates, global emission futures, and even participant perceptions play a role in if snowmaking is viable or desirable now or in the future. Snowmaking has been an integral climate adaptation across the global industry since the 1950s (Scott et al. 2003) with many regions highly reliant on machine-made snow for over 20 years. Western Canada has relatively limited snowmaking infrastructure capacity on ski terrain. Of the ski resorts that reported, on average 25% of terrain is covered by snowmaking, with individual resorts ranging from no coverage to 100% (Onthesnow, 2022). Unlike Eastern Canadian markets which are already highly dependent on snowmaking, and visitors expect groomed snow and icy conditions, Western Canada is known for being the "powder highway" may not meet demand expectations on snow quality. How snowmaking may perform as an adaptation in the west requires insight into its ability to meet the physical changes of various future climate scenarios.

As Canada's mountainous regions continue to experience warming and the resulting loss of snow and ice cover (ECCC 2022) there are far-reaching consequences for tourism, sport, recreation, livelihoods, culture, real estate, and community resilience in Canada's winter-sport tourism-dependent mountain communities (Knowles 2019). Ski areas in Western Canada lean heavily on four-season activity diversification (mountain biking, hiking, and events such as weddings or concerts), increasing summer activities to reduce the economic risks of adverse weather and snow conditions during winter (Knowles 2019). The importance of summer-sport tourism will only increase under climate change. Whistler Resort Municipality now reports peak visitation in the summer rather than winter, and Jones and Scott (2006) projecting climate-induced visitation increases throughout the national parks in BC and Alberta (an average of 5-15% under low emissions, 15-50% under high emissions). These climate influences in shifting seasonality of ski and mountain tourism patterns and resulting socio-ecological impacts in fragile alpine ecosystems and small isolated communities have not yet been studied in Canadian contexts. Understanding how winter seasons will be affected by future climate scenarios is essential for both industry and community stakeholders to inform investment and development, especially as ski industry stakeholders are increasingly required to disclose information about climate impacts, risks, and sustainability responses. Having accurate information regarding the projected localized climate change impacts would allow ski areas to reduce operational maladaptation and risks of perceived greenwashing by improving the transparency and legitimacy of climate risk and response actions and communications.

2.2 Methodology

The SkiSim ski operations model analyzes climate risks for 66 of the 74 operating ski resorts in the Canadian provinces of British Columbia (40 of 42 are included in this study) and Alberta (26 of 32), including projected changes in key operational metrics of ski season-length, natural snowfall, snowmaking requirements, and key holiday operations. To enable cross-regional comparisons, a priority identified by Steiger et al. (2019), this analysis used the SkiSim2.0 model and a common set of ensemble climate scenarios from Coupled Model Inter-comparison Project (CMIP) Phase 5, which has been used extensively in studies in Canada and the US (e.g., Scott et al. 2019b, Scott et al. 2021), diverse international markets (e.g., Abegg et al. 2015, Fang et al. 2019; Rice et al. 2021; Steiger & Abegg 2018; Steiger & Stotter 2013) as well as applied to all Winter Olympic Games locations (Scott et al. 2022a). Detailed methodology on climate data, climate change scenarios, and SkiSim2.0 model parameterizations used for this study are outlined below.

2.2.1 Baseline Climate Data and Climate Change Scenarios

Daily weather data including temperature (maximum, minimum and mean), precipitation (rain and snowfall), and snow depth (where available) was obtained from the Meteorological Service of Canada (2017) and the National Oceanic and Atmospheric Administration (NOAA) (2018) for the 30-year (1981–2010) baseline period from 53 unique climate stations. Climate stations were chosen to represent each ski area based on (1) proximity (latitude and longitude, elevation) and (2) data availability for the variables and baseline period. Rural and mountain regions globally face challenges with a low density of climate stations, some areas in this study had limited climate stations available, particularly at elevations of ski operations (i.e., not the valley floor). Therefore, the closest (average distance between ski area and climate station was 11 km, and maximum distance 31.4 km) or most applicable (based on elevation, aspect, and localized knowledge of microclimate where possible) station(s) were chosen. Where a suitable representative climate station was unavailable, the ski area was not included in the study. The proximity of the 43 selected climate stations allowed the representation of 57 ski areas (with differential adjustments for elevation, as outlined below). For the remaining 9 ski areas, an additional 10 climate stations were combined, wherein a primary climate station was filled through interpolated data from a nearby secondary climate station, to fill minor data gaps (missing weeks or months). In all cases gaps of less than 5% of daily observations were filled. Where available, daily snow depth data was also obtained to train and refine the natural snow and snowmaking modules in the SkiSim model.

This study used an ensemble of 16 CMIP-5 and 17 CMIP-6 global climate models developed by the World Climate Research Programme for the IPCC Fifth and Sixth Assessment Report (IPCC 2022a) to five GHG emissions scenarios: RCP4.5 and RCP8.5 [from CMIP5], SSP245, SSP370, and SSP585 [from CMIP6]. These five climate change scenarios were selected to represent a range of possible emission futures with RCP 4.5 and SSP245 representing low emission scenarios consistent with the full achievement of current emission reduction pledges to the Paris Climate Agreement, leading to 2.7^{o}C global average temperatures increase by 2100 (IPCC 2021). RCP 8.5 and SSP585 represent a high-emissions trajectory where countries fail to achieve current emission reduction pledges to the Paris Climate Agreement, leading to an estimated 4.4^{o}C increase by 2100 (IPCC 2021). SSP370 represents a moderate emission scenario, resulting in 3.6^{o}C by the end of the century (IPCC 2021). While the rapid and deep emission reduction pathways of RCP 2.6, SSP119 and SSP126 are the only pathways that result in limiting warming to below 2^{o}C as suggested by the IPCC, the literature increasingly considers these scenarios unlikely (Raftery et al. 2020; UNEP 2022) thus were not included. The Long Ashton Research Station (LARS) stochastic weather generator (Semenov & Stratonovitch, 2010) then downscaled the monthly temperature and precipitation ensemble scenarios from CMIP-5 and -6 for mid- (2040–2069) and late-century (2070–2099) to daily resolution at the 53 climate station locations. LARS was selected because it has been identified as the best performing weather generator to simulate North America precipitation statistics (Mehan et al. 2017; Qian et al., 2004). These synthetic weather time series were used for all time periods (baseline and future periods). While tourism or business planning do not generally consider end of century time horizons, this study included late-century scenarios to explore the long-range future of winter sports (Scott et al. 2007b) and facilitate community discussions on implications for regional cultural identity and rural/small town economies that characterize the study area.

2.2.2 Ski Season Simulation Model

This study uses the SkiSim2.0 model (Steiger 2010), based off the original SkiSim 1.0 model (Scott et al. 2003), which includes (1) a physical snow model of the natural snowpack (2) a snowmaking production module producing outputs across the entire ski area elevation range (in 100m intervals), and (3) refined industry-based ski operations decision rules. Each of these model components are outlined below.

The SkiSim2.0 models the natural snowpack using two parameters: (a) snowfall temperature (or precipitation typing) and (b) degree-day factors (snow-water equivalent melt), calibrated from the observed daily snow depth data over a 30-year observation period (1981-2010 baseline) from the closest climate station to the ski area. Snowfall temperature calibrations define a lower value that represents the temperature threshold for 100% snow and an upper value for the 100% rain threshold and linearly interpolates the snow-rain ratio between these two values. Snowfall measurements are then used for model calibration to compare observed versus modelled cumulative snowfall per season. Degree-day factor calibration is evaluated with a multi-year analysis of days with snow cover (snow depth threshold of 1cm or more) per season to define the amount of snow water equivalent that is melted per 1^{o}C using mean daily temperature that increases sinusoidally between December 21st and June 21st.

Following the snow model calibration, SkiSim simulates the natural snow-based ski season from the climate station's daily precipitation and temperature data and calculates additional snowmaking requirements to achieve 30cm snow depth for ski operations (Scott et al. 2003). The model assumes ski groomers prepare the snow surface, which results in snowpack density of 400kg/m^3 (Fauve et al. 2002) and undertakes analysis at the critical elevation of each individual ski area. The critical threshold is the highest elevation where the ski lift system accesses skiable terrain which allows skiing even when conditions at lowest elevations are not suitable. 50 ski areas in this study, use the base elevation as critical elevation while 16 ski areas have a substantial vertical wherein mid- or upper mountain lift elevation is considered the critical elevation. Climate station data was adjusted to this critical altitude based on a generalized lapse rate (temperature at 0.65/100m) and (precipitation at 3%/100m) to represent the altitudinal difference between the station and the altitude of its corresponding ski area.

The snowmaking production module represents operational capacity and industry defined decision-making which includes avoiding snow production when it is warmer than the -5ºC model threshold, as efficiency declines rapidly, and costs increase substantially. Because the Christmas-New Year holiday (defined as December 15 to January 5) represents an economically important period, if needed the model activates an 'emergency snowmaking' decision rule (with snowmaking up to -2ºC) to support sufficient snow base for operations. SkiSim2.0 snowmaking module therefore produces a) an early season dense base layer (40cm) to provide a durable foundation for ski operations, b) improvement snowmaking to respond to mid-season melts and repair high traffic areas to enable continuous ski operations until the planned season end (usually in late-March to early April in the study area), and c) emergency snowmaking during warm temperatures (-2ºC or warmer) in the two weeks preceding the economically important Christmas-New Year holiday period. SkiSim2.0 records snowmaking production whenever combined natural and machine-made snow depth is insufficient to guarantee safe ski operations (minimum 30cm) throughout the industry defined snow-making period (between 1 November and 1 April in the study area). Potential snowmaking hours per day are calculated by linearly interpolating minimum and maximum temperature to simulate the daily variation of temperature, and both daily and seasonal snowmaking requirements are recorded.

Data on the differing snowmaking capacity across all 66 Western Canada ski areas is not available; therefore, this analysis assumes advanced snowmaking production rate of approximately 10cm/day, which represents the current capacity of many ski areas, and the potential capacity other ski areas could reach with additional investment into snowmaking system upgrades. Like other regional analyses, this snowmaking capacity is assumed across all skiable terrain and therefore represents a more climatically adapted operational state than currently exists in some ski areas. Because of the very long ski seasons in some parts of the study area, the potential season opening and closing dates were extended to allow SkiSim to model such extended seasons that are not typical in Eastern Canada. For this study, ski areas are considered operational if snow depth (natural or combined with machine-made snow) exceeds 30 cm threshold during the defined potential operating season (1 October to 31 May). These two model parameterizations have important implications for model performance versus the range of season lengths reported by individual ski areas, which are examined in the discussion section.

Additional ski operations indicators including ‘terrain-days’ and 'skier intensity' developed by Scott et al. (2019b; 2021) to represent estimated changes in ski operations capacity across an entire market region were also included in this study. These indicators recognize that disruption in ski operations at some high-capacity ski areas may have cascading implications to the future of ski tourism in a region and assess cumulative change in operational ski terrain and lift capacity at the regional market scale, as well as the resulting implications for skier density/crowding (number of skiers per acre). Additional methodological details on the physical snow model and other components of the SkiSim model can be found in Scott et al. (2003) and Steiger (2010).

2.3 Results

Results project decreases in average ski season-length and increases in snowmaking requirements across the Western Canadian ski market with more pronounced changes under high-emissions scenarios (RCP8.5, SSP585) and longer timelines (2080s). The following analyzes projected impacts under the range of climate futures for key ski industry indicators including: (1) ski area operational impacts – changes in viable ski days and snowmaking needed to support ski operations; (2) regional market capacity – changes in total available skiable terrain and lift capacity; and (3) economic viability – changes in likelihood of meeting economic indicators in the literature (including 100-day rule and key holiday operations). Study area projections are then compared with national, North American, and international ski markets in the discussion.

2.3.1 Ski Area Operational Impacts

Season-length (with advanced snowmaking capacity): The average baseline season-length (1980-2010) with advanced snowmaking across ski areas in the study area was 155 days, with ski areas in British Columbia slightly higher at 156 days and Alberta averaging 153. Within Western Canada there are substantial differences in modelled baseline season-length as some coastal resorts like Grouse Mountain have average season-lengths under 100 days and others such as Whistler over 200 days.

As climate change accelerates throughout the 21st century, ski areas across Canada's western mountains are projected to experience shorter average season-lengths across all scenarios (see Table II-1), with more pronounced season-length reductions in longer-term, high-emission scenarios. While resorts in BC have longer average baseline seasons than Alberta, they are projected to see greater changes because of the proximity to marine climate influences. If high-emission trajectories continue (RCP8.5 and SSP585) even by mid-century (2050s) BC ski areas are projected to experience an average 21% season-length reduction, with lesser 14-16% average losses in Alberta. By 2080s, season-length losses under high-emission scenarios are projected to nearly double, reaching 36-39% in BC and 26-30% in Alberta. Very different outcomes are projected under low-emission futures. If current emission reductions pledged under the Paris Climate Agreement are achieved (RCP4.5 and SSP245) Alberta may on average maintain as much as 90% of current ski seasons in the 2050s (average of 139 days) and 87% in the 2080s (average of 133 days). Season-length reductions are more pronounced in BC, maintaining 83% of baseline season-length in the 2050s and 78% in the 2080s (average of 131 and 121 days respectively).

Subregional season-length impacts are diverse and consistent with the literature, influenced by latitude, elevation, and maritime climate. The five ski areas facing the greatest season-length losses are all located in BC, south of the 50th parallel, have base elevations below 1000m, and 4 of the 5 are in coastal regions. Inland ski areas including central BC and Alberta, as well as those in more northern latitudes and at higher elevations are generally more resilient to climate change.

Table II-1. Ski season-length with snowmaking (days and percentage reduction compared to baseline)

Region		*2050s*					*2080s*				
	Baseline (Days)	*RCP 4.5 (%Δ)*	*SSP 245 (%Δ)*	*SSP 370 (%Δ)*	*RCP 8.5 (%Δ)*	*SSP 585 (%Δ)*	*RCP 4.5 (%Δ)*	*SSP 245 (%Δ)*	*SSP 370 (%Δ)*	*RCP 8.5 (%Δ)*	*SSP 585 (%Δ)*
Alberta (26 ski areas)	153	138 (-10)	140 (-8)	134 (-13)	132 (-14)	128 (-16)	133 (-13)	132 (-14)	118 (-23)	114 (-26)	107 (-30)
British Columbia	156	130	131	131	123	122	123	119	108	98	94

(40 ski areas)		(-17)	(-16)	(-16)	(-21)	(-21)	(-21)	(-23)	(-30)	(-36)	(-39)
Western Canada Average	155	134 (-14)	135 (-13)	133 (-14)	127 (-18)	126 (-18)	126 (-18)	125 (-19)	115 (-26)	105 (-32)	103 (-33)

Snowmaking: Western Canada ski resorts currently require 64cm of snowmaking annually on average (Table II-2). Similar to season-length, results demonstrate that BC currently has a lower reliance on snowmaking (baseline of 55cm) than Alberta (baseline of 76cm) but will see greater increases in snowmaking needs under future climate change (upwards of a 400% increase over baseline by late century under high-emission scenarios). Alberta is projected to require, a relatively lessor yet still substantial, two-fold increase in the same high-emission scenarios. By mid-century Western Canada ski areas will require a 108-161% increase in snowmaking (based on low-high emissions scenarios) to limit losses in season-length to those presented in Table II-1. BC will require a greater increase in snowmaking (138-198%) than Alberta (75-121%) during this time and will surpass Alberta's annual average snowmaking needs under the 2050s high-emission scenarios.

Table II-2. Snowmaking production increase (relative to baseline) under future climate scenarios

Region		*2050s*					*2080s*				
	Baseline (cm)	*RCP 4.5 %Δ*	*RCP 8.5 %Δ*	*SSP 245 %Δ*	*SSP 370 %Δ*	*SSP 585 %Δ*	*RCP 4.5 %Δ*	*RCP 8.5 %Δ*	*SSP 245 %Δ*	*SSP 370 %Δ*	*SSP 585 %Δ*
Alberta (26 ski areas)	76	+96%	+121%	+75%	+79%	+102%	+127%	+234%	+111%	+150%	+218%
British Columbia (40 ski areas)	55	+154%	+199%	+138%	+146%	+193%	+208%	+401%	+214%	+287%	+401%
Western Canada Average	64	+126%	+161%	+108%	+114%	+149%	+169%	+321%	+164%	+221%	+313%

2.3.2 Regional Market Capacity

Ski areas vary considerable in size (acres of skiable terrain) and lift capacity, thus the climate impacts at each ski area represents a variable portion of the region's ski market. Small and often community-run ski areas, are more likely to have less advanced snowmaking capacity and financial capacity to invest in large capital projects or withstand consecutive poor revenue season, are more vulnerable to the operational impacts of climate change. While small ski areas are often essential for local community outdoor recreation and tourism, losses of these smaller ski areas will have less of an impact on overall regional ski market capacity, relative to the potential loss of one of the 13 large resorts which would reduce system capacity and have negative implications for skier experiences including increasing lift wait times and crowding. To understand Western Canada's capacity to meet ski tourist demand (current and planned growth - CSC 2019, BC 2012) and potential impacts on ski tourist experiences under climate change, this analysis examined potential changes in market-level terrain-days, lift capacity and skier intensity. Collectively, skier intensity, lift capacity, and terrain days provide insight into the total number of skiers the region could serve over a season under the range of future climates, with implications for destination market share and marketplace-scale capacity management (Scott et al. 2021).

Overall, the 66 ski areas included in this study represent 88% (approximately 79,000 acres) of Canada's total skiable terrain (estimated at 90,000) and 39% (approximately 378,000 lift rides per hour) of Canada's total lift capacity (estimated at 960,000) (calculated based on data reported by ski areas at SkiResort 2022). BC represents a much larger area of skiable terrain (over 59,900 acres) and lift capacity (over 256,500 lift rides per hour) with 10 major ski resorts each with over 2000 acres and 10,000 lift capacity per hour. Alberta has over 19,200 acres of skiable terrain and a 121,600 skier per hour lift capacity, but only large 3 resorts with over 2000 skiable acres and 10,000 lift capacity and many smaller community ski areas of only a few acres.

Terrain-Days: represents the daily skiable area in operation for each individual ski area, aggregated to the regional market scale to provide a metric of system capacity (i.e., the cumulative acres of skiable terrain operational at all ski areas over an entire season). Western Canada has a baseline average of over 121.9 million acre-days and can expect 4% losses in acre-days by the 2050s under low-emissions, increasing to 9% loss by the 2080s (see Table II-3). Under high-emissions futures, the region is projected to experience 9% to 26% reductions in mid- and late-century. While Alberta was more resilient to climate change in terms of operational impacts, this sub-region is projected to experience higher losses in skiable terrain (-31%) than BC (-24%) under high-emission scenarios. This is primarily the result of substantial impacts to one of their four major ski resorts, but conversely may highlight market opportunities or pressure for nearby ski areas in both Alberta and BC with relatively limited climate impacts.

Table II-3. Projected changes in average skiable terrain and lift capacity

Region		*2050s*					*2080s*				
	Baseline AC=acres-days L=seasonal lift capacity	*RCP 4.5 (%Δ)*	*RCP 8.5 (%Δ)*	*SSP 245 (%Δ)*	*SSP 370 (%Δ)*	*SSP 585 (%Δ)*	*RCP 4.5 (%Δ)*	*RCP 8.5 (%Δ)*	*SSP 245 (%Δ)*	*SSP 370 (%Δ)*	*SSP 585 (%Δ)*
Alberta (26 ski areas)	AC=2,947,653 L=121,948,271	-6% -3%	-12% -7%	-4% -1%	-6% -3%	-11% -6%	-11% -7%	-31% -22%	-12% -7%	-19% -13%	-30% -21%
British Columbia (40 ski areas)	AC=8,425,237 L=262,941,173	-3% -1%	-7% -5%	-3% -1%	-4% -2%	-8% -6%	-7% -5%	-23% -20%	-9% -7%	-16% -14%	-25% -22%
Western Canada Average	AC=11,394,386 L=385,621,227	-4% -2%	-9% -6%	-4% -2%	-5% -2%	-9% -6%	-8% -6%	-25% -21%	-10% -7%	-17% -14%	-26% -22%

Lift Capacity: indicates the potential seasonal lift capacity for each ski area based on stated lift capacity per hour (based on data report to OntheSnow, 2022) assuming all lifts are operating from 9am to 4pm during the entire season-length (modelled operational days). The lift capacity of individual ski areas is then aggregated to estimate the total capacity for the Western Canada ski market. The region has a baseline seasonal average lift capacity of approximately 385.6 million rides across the 66 ski areas. Assuming each of the 8.2 million reported average annual skier visits (CSC 2019) takes 10 lift rides per day, current skier visits use approximate 20% of Western Canada's total lift capacity. By mid-century, as season-lengths shorten, market wide seasonal lift capacity are projected to decrease only slightly (2%) in both low- and medium-emission scenarios. While regional season-length losses are projected at 14% in low-emissions short term futures, losses in skiable terrain days and lift capacity losses are only 2% which demonstrate the proportional impact based on ski area size and capacity. The more limited impacts on larger resorts demonstrate the importance of a regional market perspective. Under longer timeframes and high-emission scenarios, Western Canada average lift capacity, terrain days and season-length losses are closer, 22%, 26% and 33% respectively suggesting some of the larger resorts experiencing climate impacts which have greater implications to the overall regional market. In the 2080s, lift capacity is reduced less than 15% in low- and medium-emission scenarios but up to 22% in high-emission scenarios, resulting in only 380 million lift rides across the entire region (down from 407 million currently). If skier visits remain consistent, demand will be using 26% of supply capacity (up from only 20% in the baseline).

Skier Intensity: is calculated based on the annual average number of skiers per acre-day (i.e., operational terrain) at the regional ski market scale, and provides insight into potential crowding. Baseline utilization intensity is estimated at 0.7 skiers per acre-day of operational terrain (see Table II-4). This calculation is based on a pre-covid decade average in regional skier visits (8.2

million [CSC 2019]) and assumes an even distribution of skiers across all available terrain and operating days. While an even spatial and temporal distribution is not the observed pattern, assuming demand and distribution patterns remain largely unchanged, this metric demonstrates potential trends in crowding as supply side changes in capacity occur. Skier utilization intensity is anticipated to increase to between 4% and 10% skiers per acre-day under low- and high-emissions scenarios respectively by mid-century. By late century, crowding could intensify up to 35% under high-emission scenarios. Alberta will experience greater crowding, up to 42%, versus only 33% in BC.

It is notable that if future skier visits approximated industry estimated regional market growth of 13.3% by 2030 (reaching 9.3 million skier visits annually on average), skier intensity would be over 1 skier per acre-day (a 30% increase) and reach 30% of the region's lift capacity (up from 20% currently). Any new supply added by the opening of new ski areas would reduce terrain and lift capacity utilization rates but would require several large new resorts to substantially reduce region-wide utilization rates.

Table II-4. Changes in skier intensity (skiers per terrain acre) under future climate scenarios.

Region		*2050s*					*2080s*				
Western Canada Skier Intensity Average	Baseline skier intensity (skiers/acre-day)	*RCP 4.5*	*RCP 8.5*	*SSP 245*	*SSP 370*	*SSP 585*	*RCP 4.5*	*RCP 8.5*	*SSP 245*	*SSP 370*	*SSP 585*
Current Skier Visits (8.2 million)	0.67	0.7	0.74	0.7	0.71	0.74	0.73	0.9	0.75	0.81	0.9
Projected Skier Visit (9.3 million)	0.76	0.8	0.84	0.79	0.8	0.84	0.83	1	0.85	0.92	1

2.3.3 Economic Viability

Season Segments: Within a ski season the New Years holiday (Dec 20-Jan 4) and March school break holiday (March 1-20) are noted by (Scott et al. 2019b, 2021) as key operational periods in North America markets because they represent high skier visitation season segments. A key finding is that ski areas in Western Canada remain reliably operational in these essential seasonal segments across all climate scenarios. Early season (Nov 1-Dec 19) and late-season (March 21-April 30) segments, while currently reliable in Western Canada, are projected to experience substantial losses (up to 52% and 28% respectively), with potentially greater losses in BC (up to 58% of early season and 36% of late season ski day losses). While some ski areas in this region may open in the pre-season (before Nov 1) and post-season (May and beyond) when anomalous snow conditions allow (e.g., Nakiska's earliest opening on Oct 26, 2019, for a "preview weekend" following an early cold period [Floyd 2022]), these season segments are not usually reliable in terms of natural snowpack or the conditions to produce enough snow for operating.

Economic Viability: To further assess the economic viability of each ski area within the Western Canada ski market under future climate scenarios, two key indicators that have been used in the literature are evaluated: (1) a 100-day or more season-length (Abegg & Frosch 1994; Elsasser & Bürki 2002; Scott et al. 2007b), and (2) operational conditions during New Year season segment. (Scott et al. 2007b, 2019ab, 2021; Steiger & Mayer, 2008). Consistent with the aforementioned literature a threshold of achieving both metrics in 70% of all seasons was considered indicative of climate resilience and continued economic viability. Importantly, the study area remains highly resilient to climate change on both metrics, with all but one ski area currently meeting both criteria and the regional average falling to between 83-86% in the 2050s and as low as 71% under high emissions in the 2080s. Further research on the relationship of season-length, operating costs, demand and revenue, and adaptation investments is needed in this region to improve insight into the economic prospects of the ski industry in Western Canada under climate change. Ultimately, only the companies or communities that operate ski areas can accurately assess the financial viability of the ski area as climate change impacts operating costs, demand, and visitor dynamics.

Table II-5. Percentage of ski areas meeting both indicators of economic viability (100+ day season-length and operational during the New Year Holiday segment) with a probability of >70% under current and future climate scenarios.

Region	*Baseline (Meeting criteria/total)*	*2050s*					*2080s*				
		RCP 4.5 (%)	*SSP 245 (%)*	*SSP 370 (%)*	*RCP 8.5 (%)*	*SSP 585 (%)*	*RCP 4.5 (%)*	*SSP 245 (%)*	*SSP 370 (%)*	*RCP 8.5 (%)*	*SSP 585 (%)*
Alberta	26/26	88	88	88	88	85	88	85	85	85	81
British Columbia	39/40	85	85	83	83	83	83	83	75	70	65
Western Canada	65/66	86	86	85	83	83	85	83	79	76	71

2.4 Discussion

This study expands the geographic scope of climate change and ski tourism research in North America, finding that broad climate change patterns of season-length contraction, increased snowmaking needs, and reduced available terrain and lift capacity seen globally (Steiger et al. 2019) are also prevalent across Western Canada. Understanding and comparing the nuance of the projections within intra-regional markets can inform individual ski area management strategies to community and provincial climate action and sport and tourism planning, while inter-regional climate risks relative to the impacts across other continental and international markets are essential for dynamic planning for national tourism marketing and development policy. Multi-scalar implications of the results of this study are therefore examined below.

2.4.1 Intra-regional Model Performance and Differential Climate Risk

Intra-regional results show BC as currently having a longer baseline season-length, yet throughout all future scenarios Alberta becomes more climate resilient and maintains a 100-day average season across all scenarios. In their review of the ski industry and climate change literature, Steiger et al. (2019) noted the discrepancy between observed and modelled ski seasons in some studies and emphasized the importance of assessing model performance against metrics of ski operations. A comprehensive dataset on historical ski industry performance was not available for Western Canada. To examine SkiSim model performance in the study area, multiple data sources of ski industry performance over the last decade were combined. Self-reported ski season-length for the five-year period of 2015/16 to 2020/21 (not including 2019/2020 due to COVID disruptions) was available for 37 ski areas in the study area (obtained from Snowpak 2022, Onthesnow 2022). For these ski areas average seasons begin on November 26 and lasts until April 14 (139-day season). The average reported season was longer at the 12 ski areas in Alberta (155 days) than for the 25 BC ski areas (131 days). When comparing the SkiSim baseline average season (1981 to 2010) for the same 37 ski areas with reported average season data available, SkiSim was found to overestimate season-length in both Alberta (160 day simulated vs 155 days reported) and more so in BC (163 day simulated vs 131 days reported). Regional or provincial averages mask the wide range in average season-length, which for this period ranged from 112 to 202 days in Alberta and 105 to 188 days in BC.

This intra-provincial range is consistent with previous applications of SkiSim in other regional markets, and the overestimation in BC is influenced by two model parameterizations: snowmaking infrastructure and business models. The assumption of 100% snowmaking terrain coverage is much higher than the reported coverage at the 25 BC ski areas (14%) yet was made to enable comparisons with Alberta (with a reported average of approximately 70% terrain coverage) and other regions of Canada and the US where coverage exceeds 90%. For ski areas with ample natural snow that do not need the assumed extra snowmaking capacity, SkiSim2.0 will not activate snowmaking, while ski areas with limited snow resources assumed extra snowmaking capacity is utilized, and modelled ski seasons can be substantially longer. For example, at Sunshine (AB) which has only 1% snowmaking terrain coverage, the reported and modelled season-lengths were within 3 days versus Big White (BC) with no snowmaking capacity, the modelled season is 28 days longer than the reported average season. Differing business models also influence operational approach to season opening and closing. Ski areas with average reported seasons approaching or exceeding 200 days (e.g., Lake Louise, Marmot Basin, Norquay, Sunshine, Whistler) do not end their season at a fixed date, but rather cease operations based on available snow conditions. In contrast, several ski areas in the study area will begin or cease operations at a specified date regardless of snow conditions (e.g., ski areas in National Parks close related to wildlife regulations). To model these long seasons, an unconstrained end of season date was used in this study which overestimated season-length at several BC ski areas by three to four weeks. Unfortunately, comprehensive data on these key operational capacities and heuristics that would inform multiple model parameterizations to reflect specific current and advanced adaptation simulations are not available for ski areas in the study area. Where such information on snowmaking capacity and management approaches is available, the SkiSim model can be parameterized to represent individual ski area operations and site-specific performance metrics, which are best to inform local climate risk assessment and adaptation planning.

Recent record warm winters provide analogies for future climate change impacted ski seasons demonstrating additional insights into the intra-regional model results and impacts on tourist demand. Consistent with SkiSim projected futures, Alberta ski areas demonstrate more climate resilience because of their colder temperatures and greater snowmaking capacity. Environment Canada data indicates that in Alberta, 2011/2012 and 2015/2016 are the second and third warmest winters on record with 6.1ºC and 5.5ºC above 1971-2000 normals respectively (ECCC 2020). In BC's Pacific Coast and South Mountains, the 2014/2015 season was the warmest and second warmest winter since records began in 1948, with regional average temperatures 2.9ºC and 3.4ºC above 1971-2000 normals respectively (ECCC 2020). While the temperature departures are larger in Alberta, the observed season-length from 2015/2016 and skier visits from both seasons demonstrate that losses are not as significant as in BC. With average daytime high winter temperatures in southern Alberta in the -5ºC to -15ºC range, even these near record warmer temperatures provide temperatures required for efficient snowmaking and natural snowfall. Compared to the five-year average season-length, Alberta's anomalously warm season was six days longer. Conversely average ski season-length reported by the aforementioned 25 BC ski areas during this region's anomalously warm season was 13 days or 10% shorter than the available five-year average for the province.

The implications of warmer weather on economic viability similarly demonstrates greater resilience in Alberta. Alberta remained constant across the 2008-2018 decade despite the 2011/12 and 2015/16 record warm winters, while operating ski areas in the province remained constant or grew following these years. BC's record warm winter contributed to substantial declines in ski areas and skier visits. Province wide, the Canadian Ski Council (2019) reports that skier visits to BC's 46 ski resorts declined by 1.43 million or -24% versus the previous three-year average and only 39 ski areas operating the following winter, 7 less than before the record warm winter. It is uncertain to what extent the record warm winter contributed to this loss of operating ski areas, but considering this analogy represents less than SkiSim's RCP4.5 2050 scenario in terms of season-length losses, further research on the implications of climate change on economic viability and demand-side shifts would be valuable. Future research to investigate the characteristics of the ski areas lost after the record warm winter in BC and determine regional, elevational, size, corporate structural and other factors that may have led to their closure would be useful to inform destination communities and enable them to adapt proactively considering future changes projected. While the impact of record warm winters in BC was much greater, there remains uncertainty across Western Canada as to the implications of multiple consecutive shortened seasons.

2.4.2 Inter-regional Comparisons

Because Western Canada is a national and international ski destination, it is important to compare the projected impacts of climate change in this regional market with others across North America and internationally. Table II-6 provides a comparison of the projected impacts of common (RCP 4.5 & 8.5) climate change scenarios on multiple North American regional ski markets assessed with the SkiSim model. Other studies that use different methodologies and have been found to not model observed seasons as accurately as SkiSim (see comparisons in Scott et al. 2019b and 2021) are not included in this comparison. Western Canada's 155-day current average season-length is 14%, 34%, 29% and 37% longer respectively than Quebec, Ontario, the United States northeast and mid-west regional baseline season (Table II-6). Across Canada, baseline snowmaking requirements are the lowest in Quebec (31cm), followed by BC (55cm) and Ontario (63cm) and Alberta with the largest current average use of snowmaking

(76cm) (Table II-7). The United States regions have greater baseline snowmaking requirements than Canada, with the Northeast requiring an average of 81cm and the Midwest requiring 107cm.

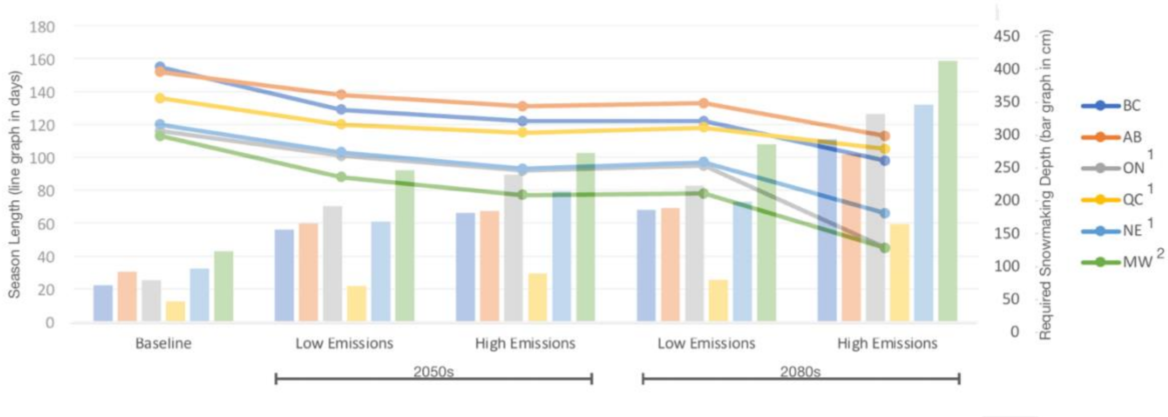

Figure II-1. Continental Comparison of Projected Ski Season Losses and Snowmaking Requirements in Regional Markets. [1]*Scott et al. 2019b*, [2]*Scott et al. 2022*

As climate change accelerates particularly under high-emission and end-of-century horizons, inter-regional disparities become apparent. Alberta and Quebec have season-lengths losses under 30% and remain operational for over 100-day season-lengths (106 in QC and 107 in AB). BC has greater season-length losses of 38% and drops slightly below an average 100-day season to 96 days in the 2080s under high-emissions yet remains resilient compared with Ontario and the US Midwest season-length declines of 60% dropping well below the 100-day threshold to 46 days. The major declines in season-length combined with required snowmaking increasing of 545% and 355% respectively, result in up to total losses of the ski tourism market in Ontario and losses to 92% of the US Midwest market (Scott et al. 2019; 2021). The US Northeast fares slightly better with 45% decrease in season-length and 308% increase in snowmaking production (Scott et al. 2019) but results in a season-length of only 67 days which does not meet economic viability criteria. While Quebec and Western Canada remain more resilient to season-length losses, snowmaking needs still increase significantly in both regions (+377% in QC and +401% in AB) though differences lie in snowmaking capacity which is estimated at 90% for Quebec and only 25% for western Canada currently. Both regions maintain similar percentage of regional ski areas based on the above economic viability criteria. Overall, this demonstrates that within North America there will remain a Western and an Eastern ski tourism market, but that Canada might see a net increase in ski tourists as demand patterns shift to respond to changing supply availability. Considering the US ski tourism market of 55 million average annual skier visits (NSAA 2020) is significantly larger than Canada's 19 million (CSC 2019), this could have major implications for resort and surrounding community infrastructure.

Internationally, comparing Western Canada to key ski markets including the origins of skiing in Scandinavia, the heart of ski culture in the European Alps, and new Asian markets demonstrates a contraction of the entire international ski tourism market supply due to climate change (Steiger et al. 2019). Scandinavia shows comparable results to Western Canada with over 70% of Norway's ski areas remain economically viable (over 100-day season-length and operational during the December holiday period) over high-emissions scenarios by end of century. Under the same future context, even after losing nearly half its baseline season-length, Sweden maintains an average season-length of 104 days and snowmaking increase of 353% (Rice et al. 2019) which are comparable to Western Canada averages. In Europe, Austria's famous Tyrol region was projected by Steiger (2010) for 85% reductions in season-length under high-emissions long term horizons which would have detrimental impacts to the ski economy and culture, suggesting less resilience to climate change than Western Canada. China's large and diverse ski tourism market, already highly dependent on snowmaking (baseline of 187cm), averages a 117-day season which could contract by up to 61% under high-emission long term futures, all though China's intra-regional variance suggests regions such as Heilongjiang may outperform Western Canada while Xinjiang, Qinghai and Jilin are more vulnerable (Fang et al. 2019).

These variable risks across continental and international scales will shift demand patterns as skiers transfer from climatically vulnerable regions to relatively resilient areas (Scott et al. 2008, 2012; Steiger et al. 2019). This redistribution of global demand pressures to relatively resilient ski tourism markets such as Western Canada, Sweden or Norway may be constrained by infrastructural (lift capacity), terrain (skier intensity) limitations and tourist behaviour. These alterations in terms of supply, but loss of terrain in some markets and crowding in others, may disrupt global tourism patterns both geographically and temporally. How the industry responds to the direct and indirect risks of climate change will influence the future of skiing locally, and have implications for winter sport participation and culture, and local mountain communities dependent on snow tourism.

2.5 Conclusions

The results of this study demonstrate Western Canada has relatively low physical climate risks, compared with national, continental, and international studies, yet still is projected to experience shortened seasons and increased snowmaking requirements to maintain ski tourism operations. Greater impacts are projected in southern, coastal, and high plateau sub-regions. SkiSim2.0 results highlight snowmaking as an essential tool for this region to respond to later snowfall, earlier spring warming and mitigate mid-season weather variability risks, yet low snowmaking capacity suggests a need for future research on this as an effective adaptation within Western Canadian contexts (Scott et al. 2022b). Furthermore, Western Canada home to the "powder highway" of ski resorts, visitor expectations of powder skiing versus a future experience of machine-made snow may result in changing tourist patterns or a need to rebrand the Western Canada ski experience. In addition to skier perceptions of climate adaptations, skiers' response to compounding climate impacts remains uncertain and represent priority research areas (Knowles 2019; Scott et al. 2019b. 2020; Steiger et al. 2019). Further research is needed to understand the dynamics of market contraction, skier congestion, spatial substitutions (and associated emissions), impact of small grassroots ski area loss and next generation sport participation trends, and how successive warm winters may influence tourist behaviour. While SkiSim2.0 does not simulate demand, seasonal tourism shifts or indirect implications of climate change, the comparable analysis of North America's continental ski tourism supply-side climate risk allows for a system-wide perspective which may help ski tourism businesses, destination communities, and winter sport organizations project skier pattern shifts and respond appropriately. Combining this foundational climate risk research with future research that engages sport and tourism industry leaders, adaptation technology developers, tourists, and community stakeholders in the research process with decision-based methodologies such as narratives, adaptation pathways and transition management (Burch 2019), will improve industry climate risk awareness (Abegg et al. 2017; Gössling et al. 2012, Knowles & Scott 2020) and inform evidence-based climate resilient transformations in ski tourism.

Chapter 3

Sustainability of Snowmaking as Climate Change (mal)Adaptation: An Assessment of Water, Energy and Emissions in Canada's Ski Industry

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As climate change continues to impact the snowpack in ski areas globally, operators rely increasingly on snowmaking to maintain ski seasons and visitor experience. Increased reliance on machine-made snow has implications for the sustainability of ski tourism. This study provides the first national estimate of water, energy, and CO_2 emissions and projected changes under low (RCP2.6), mid (RCP4.5), and high emission (RCP8.5) climate futures by the 2050s. A central estimates of snowmaking efficiency found Canada currently uses 478,000 megawatts (MWh) of electricity (with 130,095 tonnes of associated CO_2 emission) and 43.4 million m^3 of water to produce over 42 million m^3 of technical snow. With snowmaking production requirements projected to increase between 55% and 97% by 2050 across low to high emission climate futures, energy and water use will increase proportionally. In contrast, future emissions associated with increased snowmaking would nonetheless decline substantially as provincial electricity grids are decarbonized under current policy targets. Regional differences in snowmaking requirements and emissions caused by provincial electricity-grid emission intensity and their important implications for ski tourism sustainability and snowmaking as (mal)adaptation are discussed.

3.1 Introduction

Since its development in 1952, snowmaking technology has been widely adopted by the ski industry and has substantially increased ski areas' resilience to adverse weather and climate variability as well as extended the ski seasons in many regional markets (Scott et al. 2022b; Steiger et al. 2019). Massive investments have made snowmaking an integral part of the ski industry in most regional markets over the last 25 years, providing a competitive advantage in the ski tourism marketplace. As climate change accelerates and natural snowpack decreases in mountain regions (Hock et al. 2019), ski industry leaders intend to further invest in improved and higher capacity snowmaking as a climate change adaptation strategy (Abegg et al. 2017; Hopkins 2014; Knowles 2019; Steiger et al. 2019; Trawöger 2014). Investment in snowmaking is expected to grow at a 4.6-5.7% annual rate globally over the next decade (PMR 2018). High confidence in advanced snowmaking and a tendency to discount future impacts (Bicknell & McManus 2006) has resulted in what Berard-Chenu et al. (2022) characterize as "a headlong rush to a technical adaptation to climate change" without an understanding of climate or carbon risks. The need for research on climate responses (Klein 2017), including their effectiveness, sustainability, and equity has been repeatedly emphasized for the tourism sector (Scott & Gössling 2022).

The climate change and ski tourism literature, across a range of methodologies and locations, concludes that climate change represents a significant risk to the ski industry and related tourism because of reduced and more variable natural snow and the need for increased snowmaking to remain operational especially under higher emission scenarios (Fang et al. 2019; Knowles et al. 2023a; Rice et al. 2021; Scott et al., 2019ab, 2021, 2022a; Steiger et al. 2019; Spandre et al., 2015, 2017, 2019). Just as the climate risks in the ski industry are not evenly distributed spatially, snowmaking capacities, requirements, effectiveness, and impacts vary widely across regional, national, and international markets (Scott et al. 2022b; Steiger et al. 2019). This intra- and inter-market variability demonstrates the need for place-context specific analysis of snowmaking as an adaptation strategy (Scott et al. 2022b).

With industry-wide confidence in snowmaking as a central climate change adaptation strategy, multiple analyses pointing to the increased requirements for snowmaking under all future climate scenarios, and industry and external concerns over snowmaking sustainability, there has been a surprising lack of research evaluating the water, energy, and related greenhouse gas (GHG) emissions used in snowmaking (Berard-Chenu et al. 2022; Morin et al. 2021; Scott et al. 2022b; Steiger et al. 2019). Despite this gap, the media (Knowles & Scott 2020) and several publications have suggested that snowmaking represents maladaptation (Aall et al. 2016; de Jong 2015; Hopkins 2014), citing primarily water-use conflicts and energy consumption (and presumed GHG emissions) (Dunstan 2019; Hopkins 2014). Other research on snowmaking sustainability has examined impacts on biodiversity and soils (Casagrande Bacchiocchi et al. 2019), potential impacts of snowmaking additives such as Snowmax on vegetation and potentially human health (Lagriffoul et al. 2010), financial costs and equity of access (Damm et al. 2014), and path dependency reducing incentives to use other adaptation strategies (Morin et al. 2022). Others have identified high variance in snowmaking systems, regional socio-ecological contexts, and the scale of tourism system boundaries (including associated emissions) as reasons why snowmaking may represent effective adaptation in some locations (Faney et al., 2010; Scott et al., 2022b). Scott et al.'s (2022b:1) review of snowmaking sustainability concluded that "…snowmaking is highly place-context specific, varying at the individual operator and regional market scales, and represents a continuum from successful (and sustainable) adaptation to maladaptation."

As ski industry executives across North America express plans to expand snowmaking capacity in the future (Knowles 2019) and recognize the importance of snowmaking sustainability (NSAA 2023, VEIC 2022), there is a pressing need for research on snowmaking as climate change (mal)adaptation, including the current and potential adaptive capacity, limits and thresholds (physical, economic, social) under future climate scenarios and emission reduction targets, and co-benefits for tourism and local economic development. The broader business community is increasingly pressured by governments, the financial sector, and environmental organizations for transparency and integrity of reported emissions and physical climate risk (HLEG 2022; Orazalin et al. 2023).

This study provides the first national analysis of snowmaking's environmental sustainability as an adaptation strategy. Snowmaking water and energy use, as well as associated CO_2 emissions, are estimated at 136 Canadian ski areas, across four regional markets (Alberta, BC, Ontario, and Quebec) and the national scale in a baseline (1981-2010 climatology and current electricity grid emission intensity) and mid-century (2050s climatology) under low (RCP2.6), mid (RCP4.5) and high (RCP8.5) emissions futures (with decarbonized electricity based on current policy targets).

3.2 The Ski Industry and Factors Influencing Snowmaking Sustainability in Canada

3.2.1 Regional Ski Industry Characteristics & Snowmaking Reliance in Canada

Winter mountain destinations are a key part of Canada's tourism sector, with 237 ski areas currently operating and hosting on average of 18.2 million skier visits (see Table III-1), including 2.7 international visits (pre-COVID decadal average CSC 2019). The Canadian Ski Council (2023) estimates the Canadian ski industry economic impact at over $4 billion CAD and employs over 35,000 people. Pre-COVID industry estimates projected a 13.3% market growth by 2030 (CSC 2019).

Canada's vast landscape provides a diverse skiing experience from Pacific to Atlantic coasts. This study focuses on 136 ski areas from the four largest regional markets in Quebec (QC), Ontario (ON), Alberta (AB), and British Columbia (BC) (Table III-1) which make up over 96% of Canada's skier visits and skiable terrain (CSC 2019). Ski areas that do not report any skiable terrain with snowmaking coverage were not included in the analysis, as there is no way of knowing if they plan to add snowmaking capacity in the future. These are typically smaller ski areas and as such underestimation of water-energy-emissions related to snowmaking is minimal.

Table III-1. Characteristics of Provincial Ski Markets

Province or Region	***Total Number of Ski Areas***[2]	***Total Skiable Terrain in Acres***[1]	***Average Annual Skier Visits***[2]	***Ski Areas Included in This Study***		
				Number of Ski Areas	**Skiable Terrain in Acres**[1]	**Percentage of Terrain with Snowmaking**[1]
Alberta	32	21,673 (22.4%)	2,329,200 (12.8%)	26	19,209	31%
British Columbia	40	64,989 (67.2%)	5,927,900 (32.6%)	38	54,908	14%
Quebec	75	5,837 (6.0%)	5,988,100 (32.9%)	39	5,837	76%
Ontario	61	2,351 (2.4%)	3,211,100 (17.6%)	33	2,341	95%
Atlantic, Prairie, Northern Regions[3]	29	1,764 (1.8%)	722,500 (3.9%)	Not Included in Analysis		
National Total	**237**	**96,651**	**18,178,800**	**136**	**93,284**	**24%**

[1] *Compiled from multiple sources, including: OnTheSnow 2022, SkiResorts 2022. Non-reporting ski areas are not included in the total skiable terrain acres, and total provincial ski terrain is slightly underestimated as a result.*
[2] *Canadian Ski Council (2019), 2008-2019 10-year average.*
[3] *Atlantic region includes New Brunswick, Newfoundland, Nova Scotia, Prince Edward Island, Northern region includes Northwest Territories, Nunavut, Yukon, and Prairies include Manitoba and Saskatchewan.*

Eastern markets have relied extensively on snowmaking for over two decades. Almost all ski areas in these regional markets report some snowmaking capacity, and overall, 76% and 95% of terrain in Quebec and Ontario has snowmaking (CSC 2019; OnTheSnow, 2022). These regions are key domestic markets and are known for shorter seasons, commencing near the Christmas holidays, and typically lasting through the end of March. Analysis by Scott et al. (2019b) finds baseline average 137-day season for Quebec and 117 days for Ontario ski areas. Under climate change, Quebec is projected to remain more resilient, maintaining over a 100-day season even under high emission scenarios in late century, whereas Ontario's average season length could decline up to 60% in the same scenario (Scott et al. 2019b). All climate change scenarios have projected substantial increases in snowmaking requirements in Ontario and Quebec to maintain even these shortened ski seasons.

Western Canadian skiing, centred around large resorts in the Rocky and Coastal Mountains, is a key part of Canada's international tourism brand attracting over 2 million international skier-visits (CSC 2019). This region, often referred to as the "powder highway", is known for its high mountains, and fresh deep natural snow that is the foundation for long ski seasons (155 days on average [Knowles et al. 2023a]) and includes a wide range of ski areas from multi-national conglomerate owned resorts, such as BC's Whistler Blackcomb, to small volunteer run hills like Alberta's Spring Lake Ski Hill. With 86,000 skiable acres, Western Canada has a much lower percent of terrain covered by snowmaking (31% in Alberta and 14% in

BC) than Eastern Canada. While significantly less coverage by percentage of skiable terrain, both Alberta and BC's snowmaking covered terrain is still larger than Quebec and Ontario combined. Average ski seasons in this region are projected to decline between 14% and 33% respectively under mid-century low and high emission futures, with substantial increases in snowmaking requirements as well (Knowles et al. 2023a).

3.2.2 Snowmaking Energy Use and Emissions Intensity in Canadian Markets

GHG emissions associated with snowmaking have been widely criticized (e.g., Clement et al. 2015; De Jong 2015; Duglio & Beltramo 2016; Hopkins 2014; Rivera et al. 2006) but are highly dependent upon energy sources as well as snowmaking system efficiency (Scott et al. 2022b). In Canada, the electricity generation sources, and associated emission intensity, vary substantially across the provinces (CER 2022). Of the four ski markets included in this study, Alberta has an electricity grid dominated by natural gas and coal and thus has one of Canada's highest carbon emission intensities at 670g CO_2e per kWh (carbon dioxide equivalent [CO_2e] per kilowatt hour [kWh]). Conversely, Quebec's electricity, sourced from 94% hydropower and 5% wind-power, is one of the lowest carbon intensities of any jurisdiction in North America at only 1.5g CO_2e per kWh (CER 2022). The two other regional ski markets in Ontario and BC have diverse energy portfolios that include hydro, wind, natural gas, and nuclear (Ontario) with emission intensities that are in the lowest quartile of jurisdictions in North America (at 30g CO_2e and 19.7g CO_2e per kWh respectively) (CER 2022).

Importantly, any analysis of the sustainability of increased snowmaking under future climate change scenarios must also consider how emissions associated with energy use will also evolve over the same time horizons. The emission intensity of provincial electricity grids will change substantially in the decades ahead as Canada decarbonizes its electricity sector to achieve its Paris Climate Agreement targets (CER 2022). Since 2005, the carbon intensity of Canada's electricity has declined by 45% (from 220g CO_2e to 120g) (CER 2022). All scenarios set out by the Canadian Energy Regulator, including the current policy scenario, would result in at least a 78% reduction of electricity emission intensity (to 27g CO_2e) by 2030 (from 2019 levels) with further reductions (to 8g CO_2e) by 2050. It should be noted that some Canadian ski areas use off-grid electricity ranging from low or no emission renewable production to diesel generators with up to 2709g CO_2e/kWh (EPA 2020), but the extent of non-grid electricity use is unknown and not included in this analysis.

3.2.3 Water Use and Consumption from Snowmaking

Increasing water demands from snowmaking are a key concern as climate change accelerates (Berard-Chenu et al. 2021; De Jong 2015; Spandre et al. 2019), including potential negative impacts on downstream hydrological systems and conflict with other water users. Substantial water requirements for snowmaking have been identified in multiple studies (Gerbaux et al. 2020; Morin et al. 2022; Soboll & Schmude 2011; Vorkauf et al. 2022). For example, a case study in Switzerland (Vorkauf et al. 2022) found up to 114,000m^3 of water used for snowmaking in an average season at a single ski area, with water use more than tripling during the snow scarce 2017 season which was considered an analogue for future climate change scenarios. Other case studies in the French Alps range from 600,000m^3 to 1.6 million m^3 of water used by ski areas (De Jong 2015; Gerbaux et al. 2020) with Gerbaux et al. (2020) projecting a 15% increase by 2050 if snowmaking infrastructure remained at current capacities.

Scott et al. (2022b) emphasizes the distinction between *water consumptio*n as water that is used and not returned to its original source or watershed for potential future uses, versus *water use* which is the temporary application of water resources that return to their original source for additional usage. Morin et al. (2022) similarly note that frequent comparisons between snowmaking and agricultural irrigation water consumption are misleading. Water consumed or lost through evaporation and sublimation during the snowmaking process varies among snowmaking systems and with meteorological conditions (mainly temperature, humidity, and wind). Case studies in the US found between 0 and 11% water loss (Eisel et al. 1988), while a study of Swiss ski areas found 7-35% (mean 21%) losses (Grunewald & Wolfsperger 2019). Faney et al. (2010) cites a US industry standard of no more than 20% losses for new snowmaking installations. From a ski industry perspective, additional water may be lost due to machine made snow falling outside the desired skiing terrain (Eisel et al. 1988; Spandre et al. 2017) but this inefficient water use is not consumed as it is not lost from the watershed. Studies by Morin et al. (2022) in the French Alps of potential disruption to local hydrological cycles downstream by snowmaking concluded that the effect of snowmaking was neutral, mainly shifting water cycle temporal patterns and with limited spatial water transfers (usually within the same watershed). This literature demonstrates that water use results are site-specific with consumptive losses depending on weather conditions, snowmaking infrastructure, and watershed conditions.

The sustainability of water use for snowmaking also depends on the water source, regional water security and prone-ness to drought, all of which range widely across Canada's ski tourism market. While Scott et al. (2022b) considered groundwater usage maladaptive, there is no known case of ground water use by the ski industry in Canada. Across Canada the water sources for snowmaking range from purpose-built reservoirs in all regional markets, many of which have co-benefits for summer recreation or spring freshet flood control, to natural water bodies of water that range from the Great Lakes in Ontario to alpine and glacial melt lakes and rivers in Alberta and BC. Water use for snowmaking has received increased scrutiny in the Canadian media in recent years (e.g., Climenhaga 2023; Peipert 2022).

3.3 Methods

3.3.1 Current and Future Snow Production Requirements

Estimates of snowmaking requirements (depth in cm) at the 136 ski areas in the four markets were derived from the SkiSim2.0 model (Scott et al. 2003; Steiger 2010). This ski operations model has been applied in studies across the world to analyze climate change risks, including ski season length, key dates of operation, natural snowfall, and snowmaking requirements (e.g., Fang et al. 2019; Rice et al. 2021; Scott et al. 2021; Steiger & Abegg 2018). Further details on SkiSim2.0 methodologies and complete climate risk results for the four regional markets included in this study can be found in Scott et al. (2019) and Knowles et al. (2023).

SkiSim2.0 uses daily weather data obtained from the Meteorological Service of Canada (2017) and the National Oceanic and Atmospheric Administration (NOAA, 2018) for the baseline period of 1981–2010. These are then compared with snowmaking requirement in 30-year periods under future climate scenarios. Projections for the three emissions scenarios used in this analysis (RCP2.6, RCP4.5, RCP8.5) were developed using an ensemble of climate change projections prepared for the IPCC Fifth Assessment Report (2014) by the World Climate Research Programme’s CMIP-5 for mid-century (2040-2069). The Long Ashton Research Station (LARS) stochastic weather generator (Semenov & Stratonovitch, 2010) is used to downscale the ensemble monthly temperature and precipitation projections to the daily resolution using the baseline distribution (variability and extremes) in the local climate station data.

The SkiSim2.0 output variable used for this analysis is the amount of produced snow (depth in cm) that is required to maintain a continuous ski season between Dec 15 – Mar 31 in Ontario and Québec and Dec 15 - Apr 15 in Alberta, BC. Note that this continuous season is shorter than the observed season in some ski areas that experience substantial natural snowfall that can extend skiable conditions into April or May in Alberta and BC. The analysis assumes that snowmaking operations aim to provide a reliable snow base for the self-defined main season only to be resource- and cost-efficient. The SkiSim2.0 model assumes snowmaking is done at a relatively high snow-water density (400 kg/m^3) that is durable for the season and snow grooming. Some ski areas may produce less dense snow, which would increase the depth of reported machine-made snow, but not its water content.

Snow production volumes at the 136 ski areas are then estimated by combining required snowmaking depth (cm) from SkiSim2.0 with the skiable terrain covered by snowmaking (number of acres, as reported in OnTheSnow [2022] or the ski area websites). Annual and 30-year average snow production is calculated in acre-feet, which is a common performance indicator used in the North American ski industry, as well as m^3 which is a common indicator in Europe.

3.3.2 Water Requirements for Snow Production

The water requirements to produce the estimated machine-made snow requirements at the 136 ski areas were calculated using the water use to snow ratios available the academic literature and industry reports. Because snowmaking systems and terrain conditions vary substantially across ski areas and data on water use at individual ski areas is not available, it is necessary to consider a range of water use ratios for snow production. Consequently, three water use estimates were developed for this analysis, including efficient and inefficient scenarios, as well as a central estimate based on the average in the literature (Table III-2).

The methods used to estimate snowmaking water use vary in the literature (including volumetric field tests and water intake monitoring), which contributes to variable estimates of the most efficient and inefficient water use ratios. The most efficient water use (m^3 water/m^3 snow) reported in the literature range from 0.46 at European sites (Rixen et al. 2011) to 0.48 and 0.61 at US sites (NSAA 2010, Faney et al. 2010). A literature average of 0.52 m^3/m^3 snow was used for the efficient scenario in this study. The snowmaking water use reported in the sustainability reports of two ski areas in the study (Grouse Mountain, BC, and Blue Mountain, ON) are in this efficient range (at 0.50 to 0.55 m^3 water/m^3 snow). At the other end of the range are the most inefficient water use ratios reported, including 0.65 (Rixen et al. 2011), 0.70 (NSAA 2010), and 1.23 (Faney et al. 2010). A conservative ratio of 1.12 m^3/m^3 snow, which was the average of the most inefficient quartile in Faney et al.'s (2010) analysis at 22 US locations, was used to represent the inefficient scenario. A central estimate was also included in the study. It is based on an average of the literature (0.76m^3/m^3 snow) and is considered slightly conservative, because much of the literature is a decade old and many snowmaking systems in Canada have been improved through more efficient snow cannons and system automation. A recent analysis of 15 ski areas in QC found the average water use to be 0.62m^3/m^3 snow (VEIC 2022); supporting this assumption that the central estimate is slightly conservative.

The three water use scenarios reflect the uncertain distribution of snowmaking efficiency across Canada, including the range of water loss due to variable temperature-based evaporation and sublimation, nozzle efficiency, water pipe leaks, ski terrain and other factors (Eisel et al. 1988; Morin et al. 2022; Spandre et al. 2017). Each of the three scenarios assumes that all 136 ski areas in the study utilize water at the same specified ratio. This simplification is a limitation of the study, as ski areas have very individual water use to snow production ratios from across the spectrum. If more widespread analysis of water use at ski areas is completed by the Canadian ski industry, this range and the central estimate could be improved and a more robust estimate of inter-annual variability in water use also completed.

Table III-2. Range of Water and Energy Use Intensities for Snow Production

Snowmaking Efficiency	**Water Use**[1]			**Energy Use**[2]
	Gallons/Acre-Foot	m^3/Acre-Foot	m^3/m^3 snow	kWh per m^3 snow
Efficient	170,000	643.5	0.52	4
Central Estimate	250,000	946.3	0.76	11
Inefficient	365,000	1381.6	1.12	18

[1] *Faney et al. 2010, NSAA 2010, Rixen et al. 2011.*
[2] *NSAA 2010, 2023, VEIC 2022, Rixen et al. 2011, Stanchak 2010.*

3.3.3 Energy Consumption for Snow Production

Snowmaking systems are similarly varied in terms of energy efficiency, with new and recently retrofitted systems significantly more efficient. Ski areas have reported energy savings of up to 50-80% during retrofits (Faney et al. 2010; Rogstam & Dalhberg 2011; Stanchak 2010). Because energy use data at individual ski areas is not available in Canada, it is also necessary to consider a range of energy efficiency scenarios for snow production. Three energy use estimates were developed for this analysis, including efficient and inefficient scenarios as well as a central estimate based on the average in the academic-industry literature (Table III-2).

The methods used to estimate the energy efficiency of snowmaking in the literature vary in North America and Europe. In North America industry reporting express energy use as kWh / 1000 gallons of water pumped (see NSAA 2023 for recommended key performance indicator).

European studies like Rixen et al. (2011) report energy use as kWh / m^3 of snow produced. As studies of water loss in the process of snowmaking demonstrate (Eisel et al. 1988; Grunewald & Wolfsperger 2019; Morin et al. 2019, 2022; Spandre et al. 2017), measuring snow produced accurately is much more challenging than measuring water intake into a snowmaking system. This analysis adopts the approach of estimating energy use based on the volume of water pumped through a snowmaking system, which is common to the North America literature and industry reporting.

The three energy efficiency scenarios were applied to the volume of water (kWh / m^3) required to produce the volume of snow estimated by SkiSim2.0 at each ski area. The most efficient energy use reported in the literature ranged from 2.4 (Rixen et al. 2011 converted to water pumped) to 5.5 (Stanchak 2010), with a recent NSAA (2023) report reporting 4.0 as their US industry estimate. The most recent NSAA (2023) industry estimate was adopted for the efficient scenario in this study, as decade or more old North America studies likely underestimate current energy efficiency to some extent. Inefficient systems are reported by the NSAA (2010, 2023) and Stanchak (2010) as high as 17.1 to 19.8kWh. An average of 18kWh per m^3 was used to represent the inefficient scenario (Table III-2). A central estimate was also included (11kWh). Because it is based on an average of the literature, which is mostly a decade old and does not represent the large investments in system improvements in the 2010s, it likely overestimates average energy use to some extent. The only Canadian estimate of energy use for snowmaking reported an average for 15 ski areas in QC (VEIC 2022) that was close to the value used to represent the efficient scenario in this analysis.

One limitation of the analysis is that the estimates of change in energy use for snowmaking under climate change do not include increased energy requirements associated with snow production at warmer average temperatures. The projections of snowmaking requirements (annual average depth) obtained for the four regional markets from Scott et al. (2019b) and Knowles et al. (2023a) do not provide insight into how much snow is produced at what temperature. As such, the study underestimates energy use increases associated with future snowmaking. Future research should endeavor to quantify the impact of snowmaking at higher temperatures on energy use and associated GHG emissions.

3.3.4 Carbon-Dioxide Emissions

The baseline CO_2 emissions associated with total electricity used for snowmaking production was then calculated for each ski area using the 2020 carbon intensity of its provincial electricity grid (Table III-3). Emissions related to future energy requirements for increased snowmaking in the 2050s climate scenarios were estimated using current policy for electricity grid decarbonization, set out by the Canada Energy Regulator's net-zero 2050 targets (CER 2022).

Table III-3. CO_2 Emission Intensity of Provincial Electricity Grids

Province	*Current Grid Intensity (gCO_2e/kWh)[1]*	*Future Grid intensity (2050) Based on Current Policy Scenario (gCO_2e/kWh)[1]*
Alberta	670	13.4
British Columbia	19.7	0.4
Ontario	30	0.6
Quebec	1.5	0.1

[1] *Canada Energy Regulator (2022)*

3.4 Results

3.4.1 Snow Production Requirements

The results demonstrate an increase in snowmaking requirements (depth of machine-made snow) from baseline levels across all regional markets and under all climate change scenarios for the

2050s (Table III-4). Ontario is projected to require the greatest increases from 83.5cm currently to between 156.5cm (RCP2.6) and 200.2cm (RCP8.5) by mid-century. Western provinces see similar percentage increases but result in differing snowmaking requirements across low (BC – 97.6cm and AB - 133.1cm), middle (BC - 106.2cm and AB - 146.6cm) and high emission (BC - 112.9cm and AB - 156.2cm) futures. Despite a 33 to 109% increase in required snowmaking in the 2050s, Quebec remains the least reliant on machine-made snow (remaining under 100cm/year even in the RCP 8.5 scenario for the 2050s).

Table III-4. Modelled Snow Production Requirements

Region	Baseline (1981-2010)			2050s (Average Annual Depth)		
	Average Depth (cm)	Total in Acre-Feet	Total in m^3	RCP2.6 (%Δ)	RCP4.5 (%Δ)	RCP8.5 (%Δ)
National	**69.8**	**45,939**	**56,664,805**	**+55%**	**+76%**	**+97%**
Alberta	87.4	17,938	22,125,736	+52%	+68%	+79%
British Columbia	70.7	16,030	19,772,194	+38%	+50%	+60%
Ontario	83.5	5,356	6,606,640	+87%	+119%	+140%
Quebec	45.6	6,615	8,160,235	+33%	+59%	+109%

The volume of required snow production is calculated from the average annual depth of snow required by ski area operations and area of skiable terrain snowmaking is applied to. Overall, the Canadian ski tourism market currently requires over 56.6 million m^3 of snow produced annually and by 2050s can expect production to grow to between 87 million m^3 to 111 million m^3 depending on the climate scenario (Table III-4). Table III-4 demonstrates the large regional differences. Eastern ski markets require much less total snow production because of their much smaller area of terrain with snowmaking (see Table III-1). Quebec ski areas cumulatively have 4462 acres of skiable terrain covered by snowmaking and require the least amount of machine-made snow (8.1million m^3) in the baseline period. The volume of snow production in Quebec grows to between 10.8 and 17 million m^3 under low and high emission scenarios respectively.

While Ontario has 95% of its skiable terrain covered by snowmaking, the small total area (2221 acres) results in the lowest required baseline snow production of 6.6 million m^3. Alberta and BC both have lower coverage of snowmaking (averaging 31% and 14% of ski terrain respectively) but a much larger area of skiable terrain covered by snowmaking (6,023 and 7,440 acres respectively), resulting in large snow production volumes. Alberta's 22.1 million m^3 and BC's 19.7 million m^3 baseline snow production is higher than Quebec and Ontario's requirements under even the 2050s high emission scenario. While projected increases in snowmaking requirements in Alberta and BC are lower than in the eastern provinces, their larger area are the primary driver of national increase in snow production under climate change.

3.4.2 Water Use

Based on the central estimate ratio of 0.76m^3 water for every m^3 of snow produced (Table III-2), snowmaking across Canada's ski industry currently uses on average 43.4 million m^3 of water annually. This is equivalent to the water contained in over 17,300 Olympic sized swimming pools. Of this water-use, approximately 15% is lost (based on literature estimate of average water losses during snowmaking) through leakage, sublimation, and evaporation. It is uncertain what percentage of this 6.5 million m^3 in water is lost through evaporation, which could result in the transfer of water out of the local watershed it was sourced from. In the baseline period, water requirements for snowmaking could be up to 50% more than the central estimate if all ski areas in Canada operate at the level of inefficient snowmaking systems (65.3 million m^3 annually) or 40% less if all ski areas operate at the level of highly efficient systems (25.9 million m^3 annually).

By mid-century national water use for snowmaking in the central-estimate scenario is expected to increase by 54% in a low emission scenario (66.7 million m^3 annually) to 81% under high emissions (81.1 million m^3 annually) if the average water efficiency of snowmaking systems across Canada remains unchanged (Figure II-1). Water use reductions could be achieved if all snowmaking systems were upgraded to high efficiency. In the efficient water use scenario in the 2050s water use is only 4% to 23% higher than the baseline central estimate (45.3 to 53.4 million m^3 annually under low and high emission scenarios respectively) (Figure II-1).

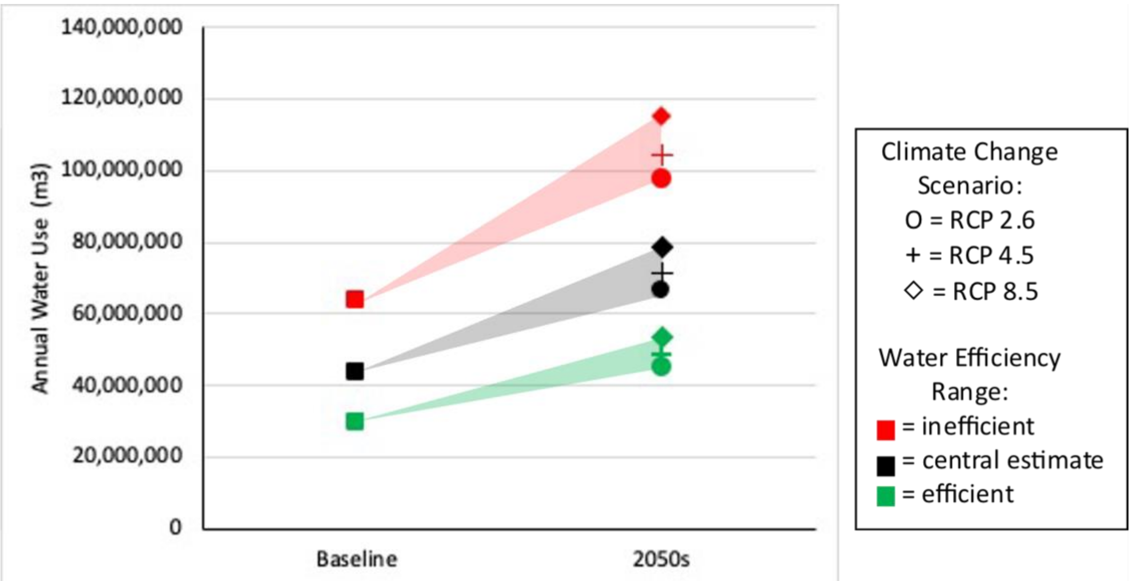

Figure III-1. National Water Use from Snowmaking

Regional water requirements for snowmaking are dominated by the much larger ski terrain in western Canada. Figure III-2 reveals the regional patterns of water use and projected change under the three climate change scenarios. The central estimate for water use efficiency is shown, but the same spatial patterns hold under efficient and inefficient water use scenarios. With the lowest snowmaking requirements in the baseline and future climate scenarios, Quebec represents the lowest water user across all central estimate scenarios (8.4 to 13.1 million m^3 under low and high emissions scenarios respectively). Ontario has a lower baseline water use than Quebec (Figure III-2), but larger increases in snowmaking requirements result in Ontario surpassing Quebec under all climate change scenarios for the 2050s. Western Canada's baseline water usage is triple that of Eastern Canada. Water use in Alberta increases more than BC under all climate change scenarios (+65% to 82% versus +26% to 39%), but increases are less than in the eastern ski markets. As a result, the proportion of national water use for snowmaking in western ski markets declines from 73% in the baseline to between 71% and 66% in low and high emission scenarios for the 2050s.

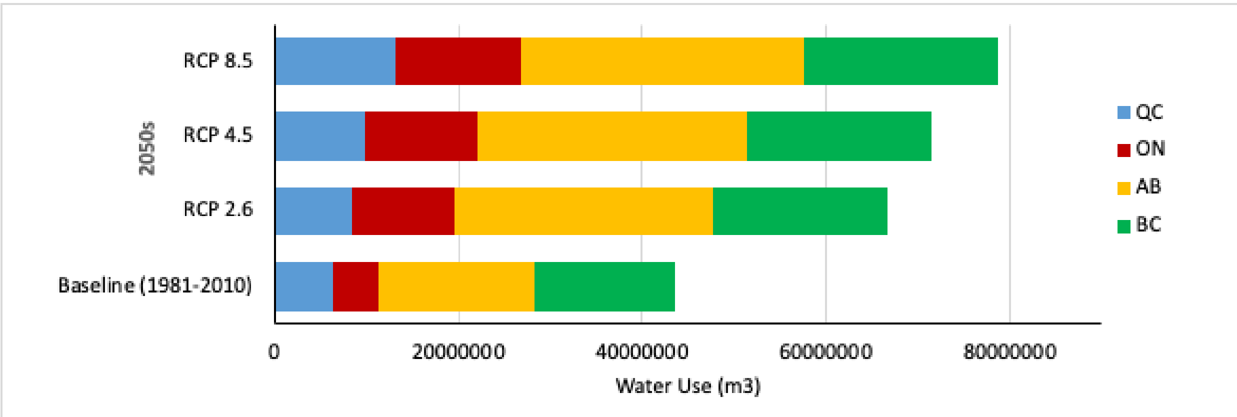

Figure III-2. Regional Water Use from Snowmaking - Central Estimate

3.4.3 Energy Consumption

Based on the central estimate of energy efficiency for snowmaking of 11kWh per m^3 of snow produced, Canada uses an average of 478,000 megawatts (MWh) annually for snowmaking in the baseline period. That electricity consumption is approximately equal to the annual consumption of 43,000 Canadian homes. Snowmaking energy-use in the central-estimate is projected to increase with snow production requirements across all climate change scenarios (54% - RCP2.6, 65% - RCP 4.5, 81% - RCP 8.5) (Figure III-3). If all snowmaking infrastructure in Canada could be upgraded to high energy efficiency by the 2050s (i.e., 4kWh per m^3 of snow produced), energy consumption could be 16% less (RCP 2.6) to 9% more (RCP 8.5) than baseline central estimate usage, despite large increases in snowmaking requirements.

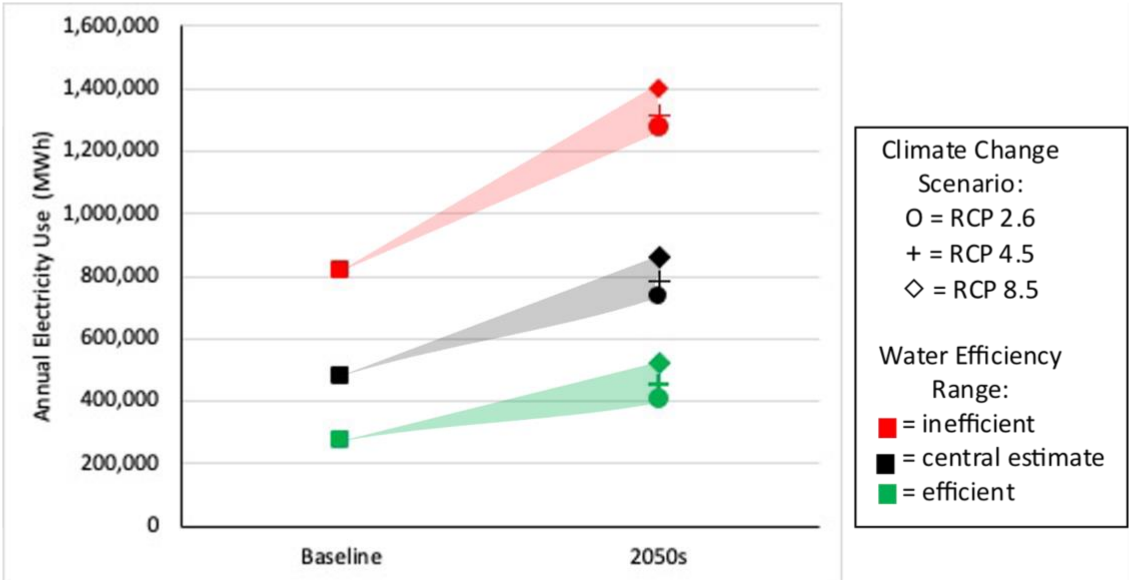

Figure III-3. National Energy Use (MWh) from Snowmaking

Regionally, the distribution of electricity use for snowmaking is proportionately similar to water use. In the central estimate electricity efficiency scenario, Alberta has the highest baseline energy consumption at 186,600 MWh, followed by BC (166,700 MWh), Quebec (68,800 MWh) and Ontario (55,700 MWh) (Figure III-4). With differential regional increases in snowmaking requirements under climate change, the regional proportion of energy use for snowmaking also changes. In the baseline period, western regional markets use 74% of the electricity required for snowmaking across Canada. This proportion declines to between 71% and 66% (RCP2.6 and RCP8.5 emission scenario respectively). Ontario is projected to experience the greatest rate of increase (122-173%) and BC the lowest (27-39%).

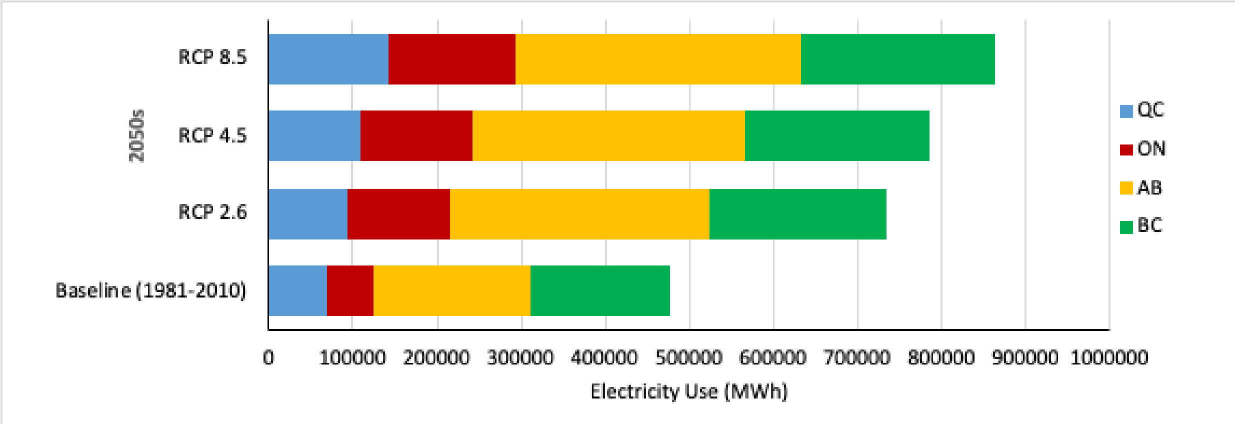

Figure III-4. Regional Electricity Use (MWh) from Snowmaking - Central Estimate

3.4.4. Carbon-Dioxide Emissions

CO_2 emissions associated with the electricity use for snowmaking vary substantially across the regional markets because of the CO_2 intensity of electricity production in each province. Unlike the provinces of BC, Ontario, and Quebec, Alberta's current electricity grid is primarily fossil fuel based. All four provinces have stated policies to decarbonize their electricity grid by 2050, and this is most impactful for future emissions related to snowmaking in Alberta.

In the baseline period, snowmaking in Canada is estimated to cause the emission of between 87,695 (efficient snowmaking scenario) and 191,994 (inefficient snowmaking scenario) tonnes of CO_2 equivalent annually, with a central estimate of 130,095 tonnes of CO_2. With an electricity grid carbon intensity of 670gCO_2e per kWh, Alberta causes 96% of the national snowmaking emissions in the baseline period, despite producing only 39% of machine-made snow nationally (Figure III-5). Currently, Alberta's required snowmaking produces over 125,000 tonnes of CO_2e annually (central estimate), which equates to the annual emissions of more than 8800 Canadians (at 14.2 tonnes CO_2e each [Akenji et al. 2021]). This stands in sharp contrast to emissions of only 103 tonnes CO_2e in Quebec, where its hydro and wind powered electricity grid limits snowmaking related emissions to the equivalent of the annual emissions of only 7.25 Canadians.

Under current policy to decarbonize electricity grids by 2050, future emissions resulting from snowmaking would decrease massively, even as snowmaking requirements increase substantially. Even under highest emission scenario (RCP8.5) with 81% increase in national snowmaking requirements, annual emissions associated with snowmaking would decrease 96% to 4721 tonnes CO_2e by 2050 if provincial targets are met. Despite large overall reductions in snowmaking related emissions nationally, provincial disparities will remain, with Alberta snowmaking remaining responsible for approximately 96-97% of national emissions in the current policy scenario.

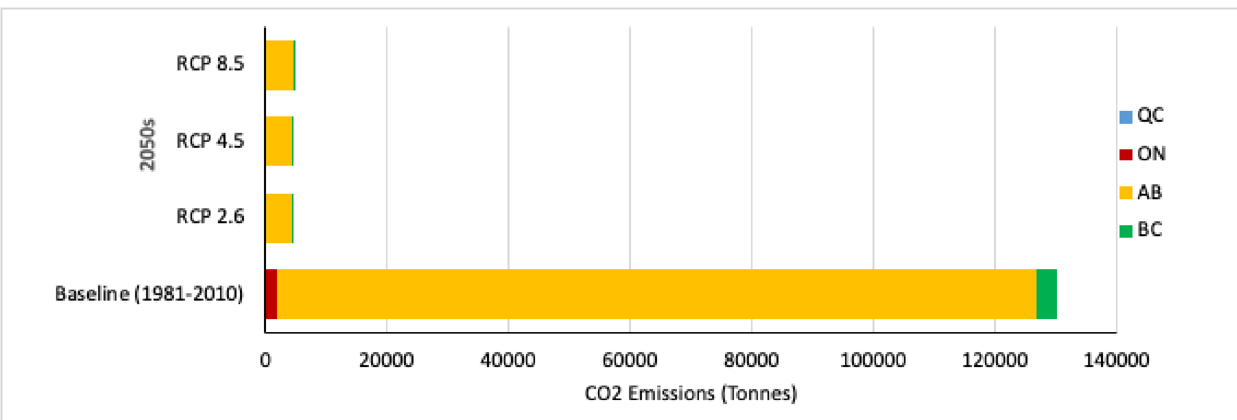

Figure III-5. Regional CO_2 Emissions from Snowmaking - Central Estimate with Current Mitigation Policy for Provincial Electricity Grids.

3.5 Discussion

This analysis of water, energy, and emissions associated with snowmaking is the first of its kind at a national and regional market scale. It provides new insights on the sustainability of sport and sport tourism and specifically the climate change adaptation-mitigation nexus and potential limits to snowmaking adaptation (water access, costs to expand and decarbonize snowmaking operations, re-naturalization of ski terrain where adaptation limits are exceeded). The results reinforce Scott et al.'s (2022b) emphasis on the need for place-context specific analysis of snowmaking as a climate change (mal)adaptation. Per skier day water-energy-emissions intensity also enable comparisons with other tourism products and how emissions associated with snowmaking adaptation can in some place-contexts reduce total emissions from the tourism system. The findings also provide insight into the future competitiveness of Canadian destinations in the international ski tourism marketplace. Each are discussed further below.

Analysis of water-energy-emissions intensity per skier day provide additional insight into the comparative environmental sustainability of snowmaking enabled ski tourism across Canada's regional markets. Table III-5 presents the estimated changes in water-energy-emissions intensity per skier visit from the baseline to the three climate change scenarios. On a per skier visit basis, baseline water and energy use are seven and nearly eight times higher in Alberta than in Quebec. Carbon emissions per skier visits are over 10 times higher in Alberta than in any of the other three regional markets (7,370 gCO_2e in Alberta versus 554 gCO_2e in BC, 520 gCO_2e in Ontario, and as low as 17gCO_2e in Quebec). Skier day water and energy intensity increase in all regional markets in all climate change scenarios. The disparity between Alberta and the other three provinces emphasizes the influence of regional electrical grid composition in assessing snowmaking as maladaptation or successful adaptation. These projections assume skier visits, skiable terrain, and snowmaking coverage remain at current levels, but as climate change progresses, changing skier behaviours such as geographic substitution may influence the per skier water-energy-emissions intensity. Further research on skier responses to climate change and preferences for climate adaptations such as snowmaking are needed to refine these projections in any regional ski tourism market.

Table III-5. Intensity of Snowmaking Water-Energy-Emissions Per Skier Visit (Central Estimate)

	Baseline	2050s RCP 2.6	2050s RCP 4.5	2050s RCP 8.5
				Water (m^3)
National	***2.5***	***3.8***	***4.1***	***4.5***
Alberta	*7.3*	*12.0*	*12.6*	*13.2*
BC	*2.6*	*3.2*	*3.4*	*3.6*
Ontario	*1.6*	*3.5*	*3.8*	*4.3*
Quebec	*1.0*	*1.4*	*1.7*	*2.2*
				Energy (kWh)
National	***27.4***	***42.0***	***45.0***	***49.5***
Alberta	*80.1*	*132.4*	*138.4*	*145.3*
BC	*11.5*	*35.5*	*37.1*	*39.0*
Ontario	*17.4*	*38.2*	*41.7*	*47.0*
Quebec	*11.5*	*15.5*	*18.2*	*23.9*
				Emissions (gCO_2e)
National	***7452.6***	***245.9***	***257.2***	***270.5***
Alberta	*53,681.3*	*1,774.2*	*1,854.3*	*1,947.3*
BC	*554.2*	*14.0*	*14.6*	*15.4*
Ontario	*520.6*	*22.9*	*25.0*	*28.2*
Quebec	*17.2*	*0.5*	*0.6*	*0.7*

Water use for snowmaking across Canada expands from the baseline central estimate of 43.4 m^3 to as high as 78.6 million m^3 in a high emission 2050 scenario. Although Canada is estimated to hold 7% of the world's renewable freshwater supply (ECCC 2023), the opportunity costs of water use, consumption, and user conflict occur at a local scale, and the availability of water for snowmaking will differ regionally and at the destination scale.

Ontario and Quebec are comparatively water rich regions, with low risks of drought or water insecurity even in high emission futures (NRCan 2018). Contemporary water use per skier day is the lowest in the country in these regional markets, but more than doubles under climate change. In Ontario, each ski area on average requires access to approximately 154,000m^3 of water annually. If this increased to 416,000m^3 in high emission future, ski areas may encounter regulatory constraints. For example, current permits for ski areas along Ontario's Niagara Escarpment allow between 25,000m^3 to 35,000m^3 per day of surface water use each (Ontario 2022). While future snowmaking needs could be met with 12-17 days at full allotment, it is unclear how close some ski areas are to reaching their allowable daily water withdraws or how permits for seasonal water withdrawals may change as other water users' needs evolve in response to changes in climate and population growth.

While coastal and northern BC remain at low risk of drought and water insecurity, the interior high-elevation plateau is expected to become much drier and warmer under by mid-century (NRCan 2018). Similarly, Alberta's Rocky Mountain region is projected to remain much wetter than the rest of the province under RCP2.6-8.5 scenario (NRCan 2018). Drier and warmer climate are increasing the length and intensity of forest fire seasons across Alberta and BC (NRCan 2023). Snowmaking reservoirs may support the wildfire response, providing helicopters with easy access to stored water in remote areas and snowmaking infrastructure can be adapted to enhance firefighting efforts. Conversely, these regions are also key agricultural areas, and BC is reliant on hydropower, which may portend future water conflicts. Future access to water for snowmaking highlights the complex mitigation-adaptation nexus, wherein higher emission scenarios may result in changing rates of both water availability and use-requirements, and influence adaptation needs and capacity simultaneously.

Snowmaking energy use, costs, and emissions are important factors in ski area financial viability and reputation, both currently and in the future, as they seek to operate in climate impacted conditions and achieve emission reduction targets set within the tourism sector and by governments. The climate resilience offered by snowmaking and the associated direct operational and indirect travel emissions also reveal important complexities at the adaptation-mitigation nexus. Increased snowmaking in regional markets with very low electricity emission intensity represents not only an adaptation strategy for the ski areas but can support mitigation at the tourism sector scale. The average per skier day CO_2 emissions associated with snowmaking (baseline, central estimate) in Quebec (17.2 gCO_2e) and Ontario and BC (520.6 and 554.2 gCO_2e respectively) compare very favourably to emissions associated with other tourism activities, such as one day on a cruise ship (102,500gCO_2e [Tourism Dashboard 2023]) or a nearby shopping trip where the purchase of even one pair of jeans represents between 33.4 and 90.3 CO_2e (Luo et al. 2022). Quebec's estimated current 103 tonnes of CO_2 emissions (baseline, central estimate) related to snowmaking helps make possible nearly 6 million skier days and related economic benefits, generally with limited transportation related emissions, primarily driving due to local and regional market (CSC 2022). Driving that is increasingly by electric vehicles, further reducing associated trip emissions. If this snowmaking was not maintained and the diminished ski season and ski conditions in the Quebec market forced skiers in the province to travel to ski elsewhere, emissions related to winter tourism would increase dramatically. For example, if only 65 people decided to fly round trip from Montreal to Vancouver to ski at nearby Whistler (estimated at 1.6 tonnes CO_2e each based on Atmosfair.com), they would be responsible for similar emissions as Quebec's current entire provincial snowmaking.

Importantly, emissions associated with snowmaking are projected to decline dramatically as provincial electricity grids are decarbonized over the next three decades (according to current policy targets – CER 2022). The emissions intensity of provincial electricity grids is a key determinant in the capacity to decarbonize snowmaking and ski operations. The current 800%

gap between Canada's least and most carbon intense provincial electricity grids far overshadows any energy efficiency gains possible through snowmaking system upgrades. For ski areas in jurisdictions with electricity grids that have high emission intensities, achieving emission reduction targets compatible with national pledges and the Paris Climate Agreement would only be possible by investing in onsite or locally dedicated renewable energy sources. Such additional investments and an increased price of carbon (the minimum price for carbon emission in Canada increases from CAD 65/tonne CO_2e in 2023 to 170/tonne CO_2e by 2030 – ECCC 2023) represent a large added cost and carbon risk relative to ski areas in regions with low carbon electricity grids.

Investment in snowmaking is one of the largest capital expenses for ski areas. For ski areas in the Ontario and Quebec markets, where most ski terrain is already covered with snowmaking, this is a sunk cost. Because many ski areas in BC and Alberta have limited terrain with snowmaking, they may increase climate resilience through further snowmaking investments. While snowmaking is common in the Eastern provinces, Western Canada is traditionally marketed as powder and natural snow, and it is unclear whether machine made snow will be considered an adequate substitute by skiers (particularly expert and long-haul ski tourists) (Mariani & Scalise 2022). With climate induced geographical substitution projected, future research on region specific skier perceptions of snowmaking is suggested prior to investment as this plays an important role in managing the adaptation-mitigation nexus. Financing large snowmaking systems expansions and retrofits favours ski conglomerates and larger ski areas where snowmaking is well integrated into the local economies, including real estate and tourism development (Morin et al. 2022; Scott et al. 2022b). For small community-based ski areas or ski areas in climatically vulnerable locations, particularly in an era of increased climate risk awareness in the financial community, the cost and investment in adaptation infrastructure is a much greater challenge that is likely to disproportionately impact their viability. Studies point out that the loss of grassroots ski areas, such as small independent ski areas near to major urban markets and volunteer run ski areas in remote communities where many people learn to ski, would adversely impact access to winter sport and outdoor recreation, reducing health and social wellness benefits and diminishing future ski demand (Scott 2006, Knowles 2019).

High emission scenarios that would cause substantial increases in water and energy requirements, also test the limits of snowmaking as a climate change adaptation. See Scott et al. (2019b) and Knowles et al. (2023a) for discussion of where snowmaking may not be able to reliably provide sufficient snow for viable ski operations in Eastern and Western Canada. These studies examine the ability to physically produce sufficient snow product and do not assess the financial costs (operational or new infrastructure) associated with this adaptation path. In exceeding physical or economic thresholds, Morin et al. (2021) and Scott et al. (2022b) both point out the potential for lock-in and path dependency, wherein snowmaking becomes a barrier to transformative shifts to more climate resilient or sustainable tourism and destination communities.

Regardless of future investment in expanded and more efficient snowmaking in Canada, there will be a contraction in the number of operating ski areas under moderate and high emission scenarios, and perhaps even in a low emission future (Scott et al. 2019b, Knowles et al. 2023a). This has important implications for the ski industry and destination communities. Recognizing this probable outcome Scott et al. (2022b) highlighted the need to examine and prepare for the future adaptation opportunity for ecological restoration in former ski terrain (which can also present a carbon-sequestration opportunity). While the impacts of snowmaking on localized biodiversity, soil, erosion, and other impacts to ecologically fragile alpine areas have been examined to some extent (Casagrande Bacchiocchi et al. 2019), very little is known about the rewilding of ski terrain abandoned decades ago or the success at ecological restoration attempts at former ski areas. This research gap should be addressed in preparation for future opportunities associated with the closure of some ski areas.

3.6 Conclusions

Results from this study align with research findings that climate change will result in increased snowmaking production to maintain operations across Canada and the broader North American market (Knowles et al. 2023a; Scott et al. 2019b). Nationally, water and energy use, currently estimated at 43.4 million m^3 and 478,000 MWh respectively, will increase proportionally if the terrain coverage and average snowmaking efficiencies remain static. Based on the current electrical grid carbon intensity, snowmaking in Canada results in 130,000 tonnes of CO_2e emissions annually. While national average snow production increases between 55% and 97% are expected based on low to high emission scenarios (RCP 2.6 to 8.5), future water and energy-use, and carbon emissions will also be influenced by a several other factors, including upgrades in snowmaking technology, increases in terrain covered by snowmaking, and electricity grid decarbonization. Canada's decarbonization policies for its provincial electricity grids mean that even with more snowmaking, annual emissions in the future are anticipated to be less than the current baseline.

Snowmaking in a warming Canada proves to be an adaptation that changes dynamically across regions. The vast regional differences in water-energy-emissions intensity demonstrate that the national scale is too coarse to report on environmental sustainability of snowmaking as a climate change adaptation.

This analysis provides new insights into the climate change adaptation-mitigation nexus in the tourism sector. Snowmaking as an adaptation is intricately linked with mitigation efforts both in terms of physical climate futures, decarbonized electricity, and future travel patterns. The multitude of variables influencing future snowmaking viability and sustainability, which in addition to climate change, water availability, and energy sources, include the cost of infrastructure, carbon pricing, skier perceptions, and changing demographics. While this research provides an essential first evaluation of the environmental impacts of snowmaking, and its potential sustainability, changes in emissions and water use will need to be re-assessed dynamically alongside destination-level sustainable development as climate change accelerates and decarbonization targets are pursued.

Chapter 4

Advancing Ski Tourism Transformations to Climate Change: A Multi-Stakeholder Participatory Approach in Diverse Canadian Mountain Destinations

Knowles, NLB., Scott, D. (submitted August 18, 2023). Advancing Ski Tourism Transformations to Climate Change: A Multi-Stakeholder Participatory Approach in Diverse Canadian Mountain Destinations. Annals of Tourism Research Empirical Insights.

This manuscript has been modified for use in this dissertation.

Canadian ski tourism destinations face increasing climate and carbon risks yet are not currently prepared to adapt to climate change or a decarbonized future. Considering the urgency of climate change and complexity of tourism systems, mountain destinations need research identifying stakeholder-held climate and carbon risk perceptions, wider socioeconomic determinants of climate preparedness, and opportunities to accelerate climate decision-making and responsiveness. Using socioeconomic system frameworks, this research analyses academic literature, climate action plans, and diverse industry, government and community stakeholder narratives on climate change and climate responsiveness in five Canadian mountain tourism destinations. Despite diverse localized climate and carbon risks, results highlight patterns impeding climate preparedness including rapid tourism growth, recreation resource corporatization, externalized climate action and sustainability, inequities, and lack of aspirational collective visioning. Conversely, stakeholders' pluralistic tourism and recreation values, sense-of-place, and interdependent relationships reveal pathways for mountain tourism destinations to transform towards climate resilient, sustainable, and just futures.

4.1 Introduction

Climate change will have transformative impacts on mountain and ski tourism worldwide, affecting natural, cultural, and built resources relevant to tourism supply and lead to temporal and geographic shifts in demand patterns (Steiger et al. 2019, 2022). Literature assessing physical climate risks to Canadian ski operations (Knowles et al. 2023; Scott et al. 2019) shows patterns of declining ski season length, more variable conditions, and increasing reliance snowmaking. Snowmaking sustainability and whether it is maladaptive with respect to GHG emissions and future water security remain important place-based uncertainties (Scott et al. 2022, Knowles et al. 2023b). Decarbonizing air travel-based ski tourism consistent with net-zero targets set by the tourism sector and the Government of Canada, represents even larger carbon risks. Despite awareness of important climate and carbon risks and decades-long conversation on sustainability research, policy and action (Scott & Gössling 2021), Canada's ski industry and mountain destinations are not currently well prepared to respond to the multi-faceted climate challenge, with far-reaching consequences for sport, culture, livelihoods, infrastructure, and quality-of-life in ski tourism-dependent communities across every regional market (Scott et al. 2019; Knowles et al. 2023a; Steiger et al. 2022). Considering the urgency of climate change and complexity of tourism responses, mountain destinations need research to accelerate climate adaptation and mitigation, including understanding stakeholder risk perceptions, just decision-making processes, and wider socioeconomic drivers and barriers of climate action (Bellato et al. 2022; Hussain 2021; IPCC 2014; Klein 2017; Steiger et al. 2022).

With goals of informing decision-making and advancing climate resiliency in mountain destinations amidst dynamic, complex, and uncertain futures, stakeholder narratives and socioeconomic systems approaches may be useful to better understanding how climate adaptation, mitigation and broader sustainability transformations are inhibited or enhanced (Klein 2017; Wise et al. 2014). Systems thinking which embraces the 'wicked problem' of climate change (e.g., Blokland 2019; Williams & van t' Hof 2016) and complex nature of tourism (e.g., Bellato et al. 2022), has not yet been applied to understand the mountain tourism-climate change nexus. Existing literature has largely focused on measuring and managing direct quantitative climate impacts on ski tourism (Steiger et al. 2019), yet barriers to climate action often extend beyond direct environmental or operational impacts to social, economic, and institutional factors (Klein 2017; Wise et al. 2014; Werner et al. 2021). Furthermore, climate actions are rarely taken in response to climate change alone, and a clearly identifiable and rational decision-maker with the mandate to unilaterally act rarely exists (Wise et al. 2014). How diverse ski tourism stakeholders understand and respond to climate change risks and sustainability transformation opportunities will define the industry's future and that of Canada's remote, rural mountain communities dependent on tourism. A participatory narratives approach that invites diverse stakeholders to identify climate-tourism impacts relevant to their destination may inform pluralistic understandings of risk, situate climate change within broader socioeconomic systems and decision-making processes, and enable new solutions to emerge (Krauß 2020).

Understanding mountain tourism's climate risk and responsiveness plays out in multi-stakeholder settings as part of larger socio-ecological systems (Bellato et al. 2022; Hussain 2021; IPCC 2014; Steiger et al. 2022). Accordingly, this study adopts a complex systems framework (based on Goodman 2002; Hassmiller & Kuhl 2020; Lich et al. 2017; Stave 2010) to analyse multi-stakeholder narratives (Bosomworth & Gaillard 2019; Werner et al. 2021) on climate change in five Canadian mountain tourism destinations to examine the patterns, structures and mental models contributing to climate inaction, and discuss potential action entry points and levers to transform mountain destinations towards a climate resilient, decarbonized and sustainable future. The study contributes to what Klein (2017) defines as fourth generation climate adaptation research, investigating social and institutional barriers and pathways to effective climate action.

4.2 Methodology

This study uses a mixed-method approach, analyzing (1) quantitative climate and tourism scenarios; and (2) qualitative multi-stakeholder narratives, through a (3) complex systems framework to understand dynamic socioeconomic processes driving climate and carbon risks within and across five ski tourism destinations in Canada and inform future responses. The methodological process is outlined in Figure IV-1 and discussed in detail below.

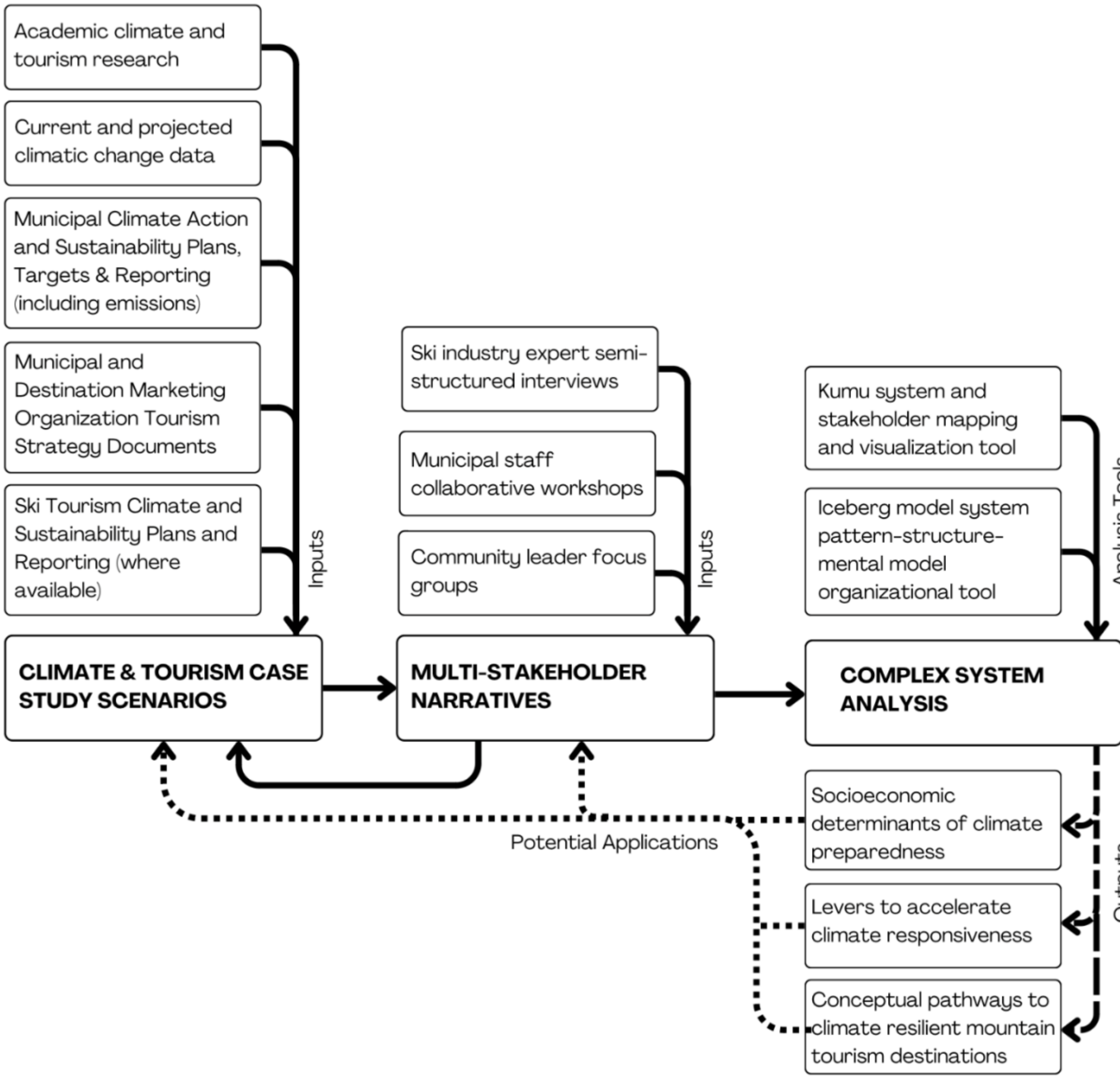

Figure IV-1. Mixed method approach.

4.2.1 Case Study Scenario Development

Across Canada, 237 ski resorts cover over 90,000 acres and host around 20 million skier visits each year (CSC 2019). British Columbia (BC), Alberta, Ontario and Quebec represent 96% of skiable terrain and skier visits (CSC 2019). This study collaborated with five communities chosen as prominent ski destinations to explore the climate change-tourism intersection within these key provincial markets: Whistler, BC; Revelstoke, BC; the Bow Valley (including Canmore, Banff, and Lake Louise), Alberta; Collingwood, Ontario; and Tremblant, Quebec. In all five case studies, skiing is a major component of the local community, culture, and economy, with established and/or growing four-season outdoor adventure tourism industry and close connections with a nearby large urban source market (see Table IV-1). Despite many similarities, these case studies also represent very different tourism and climate change realities and exist within diverse social, political, and environmental contexts, resulting in varying projected climate impacts, carbon emission sources, and potential responses to climate change. With diverse destination characteristics, the case studies provide opportunities to identify and compare systemic climate change drivers, and barriers and opportunities to sustainability transformations which may be transferable to other Canadian or international mountain destination contexts.

Table IV-1. Case study destination tourism profile.

	Whistler[1]	**Revelstoke**[2]	**Bow Valley**[3,4,5*]	**Collingwood**[6**]	**Tremblant**[7]
Residents ***% growth since 2016***[9]	13,982 *+19%*	8,275 *+9.4%*	24,295 *+6% Banff* *+14% CM*	34,201 *+13.8% ToC* *+33% TBM*	10,992 *+14%*
Private Dwellings ***Permanent occupancy %***	10,065 *56%*	3,739 *90%*	12,460 *89% Banff* *74% CM*	20,612 *85% ToC* *59% TBM*	8,783 *61%*
Average Dwelling Value ***% above Canadian Average***	$1,644,000 *+166%*	$678,000 *+10%*	$812,000 Banff $943000 CM *+31% Banff* *+52% CM*	$778,000 ToC $1,202,000 TBM *+26% ToC* *+94% TBM*	$760,000 *+23%*
Annual Visitors ***Daily Visitors***	3,480,000 *24,000*	768,400 *5,000*	4,120,000 *24,000*	2,500,000 *13,000*	3,000,000 *20,000*
Provincial ski visits/year[8] **2015-19** **2009-14**	British Columbia 6,180,000 5,890,000		Alberta 2,360,000 2,350,000	Ontario 3,295,000 3,250,000	Quebec 5,895,000 6,120,000
Nearest City ***Airport*** ***Population*** ***Distance***	Vancouver *YVR* *2,800,000* *135km*	Kelowna *YLW* *400,000* *200km*	Calgary *YYC* *1,600,000* *130km*	Toronto *YYZ* *5,900,000* *150km*	Montreal *YUL* *4,100,000* *150km*

Tourism Source Markets	40% BC 28% Canada 18% USA 6% Aus/NZ 4% Europe 3% Asia	64% BC 15% Alberta 9% Canada 6% USA 6% Int'l	29% Alberta 55% Canada 6% Europe 6% USA/Mex 2% Asia 2% Aus/NZ	99% Ontario 1% Canada	61% Quebec 20% Canada 9% USA 7% Europe 1.5% Asia 1.5% S America
Average Visit					
Group Size	1.9	1.9	3.5	2.5	3.1
Length of Stay	N/A	2 nights	4.6 nights	1.8 nights	3 nights
Visitation Seasonality	45% Winter 55% Summer	N/A	22% Winter 25% Spring 36% Summer 18% Fall	22% Winter 20% Spring 28% Summer 30% Fall	31% Winter 17% Spring 31% Summer 20% Fall

**Includes the Town of Collingwood (ToC) and The Blue Mountains (TBM)
*Includes Banff and Canmore (CM)
[1] RMW (2023)
[2] Destination Revelstoke (2019)
[3] Thornton (2016)
[4] Alberta (2022)
[5] BLLT (2021, 2023)
[6] Grey County (2022)
[7] Watson (2016)
[8] CSC (2019)
[9] Statistics Canada (2021)

Current and projected climate, carbon, and tourism scenarios were identified for each case study based on a review of scientific literature, industry climate and sustainability plans, and municipal tourism data and climate action plans. The literature review included recent climate change and ski or mountain tourism studies in Canada (Knowles 2019; Steiger et al. 2019; 2022), including a specific focus on destination and regional-scale SkiSim2.0 results projecting ski industry specific climate change impacts (Knowles et al. 2023ab; Scott et al. 2019, 2022). Additional climate impacts, such as changes in average seasonal temperature, first and last frost, extreme hot days, and snowpack, were summarized from the Canadian Climate Atlas (2023) (downscaled to local scale). Both SkiSim2.0 and Canadian Climate Atlas outputs are derived from the World Climate Research Programme's CMIP-5 and CMIP-6 climate change scenarios, including a low and emissions future (RCP4.5 and 8.5 respectively) across both mid- (2050s) and late-century (2080s) timeframes. Case study GHG emission baseline inventories and future targets were collected using available academic research (Knowles et al. 2023), industry (CSC

2018, 2019; NSAA 2021) and municipality climate reports and sustainability plans (e.g., Blue Mountains 2023; Revelstoke 2018). Available community (including population, second-homeowners, employment etc. [Statistics Canada 2021]) and tourism data (including tourist demographics, source market, projected growth, etc.) (e.g., Alberta 2022; BLLT 2021, 2023; Destination Revelstoke 2019; RMW 2023; Thornton 2016; Watson 2016) were incorporated into climate and carbon scenarios (e.g., seasonality, potential crowding), and used to estimate data missing from industry and municipal reports (e.g., scope 3 tourist transportation emissions), and calculate comparative metrics (e.g., per resident emissions) (Table IV-2). These climate, carbon, and tourism scenarios were then used to inform stakeholder conversations and analysed through the system framework that guided the stakeholder engagement (Figure IV-1).

4.2.2 Multi-Stakeholder Narrative Collection

Informed by participatory (Bosomworth & Gaillard 2019) 'multi-stakeholder' and 'transformation-oriented' (Werner et al. 2021; Wise et al. 2014) pathways approach, this research engaged 38 ski industry experts, local government officials, and community stakeholders involved in climate action across the case study destinations through five semi-structured interviews, twelve collaborative workshops (8-18 participants each) and four focus groups (3-5 participants) over June 2022 to April 2023. Williams and van t'Hof (2016:35) define stakeholders as "people or organizations with an interest in the (wicked) problem and its (re-)solution" and calls for involving stakeholders in the iterative process of system conceptualization, including identifying relevant elements, stakeholders, and their relations, contextualizing current scenarios and generating potential systemic changes (Hassmiller & Kuhl 2020; Stave 2010). Werner et al.'s (2021) multi-stakeholder pathways development approach stresses the social and institutional components of climate change decision-making and attempts to include multiple climate change drivers, and stakeholders with conflicting and contested knowledge, interests, goals, and values (Bosomworth & Gaillard 2019; Krauß 2020; Libarkin et al. 2018). Rather than discredit "non-expert" insight, multi-stakeholder approach understands personal values, experiences, relationships, and objectives influence climate risk perceptions and responses (Libarkin et al. 2018), thus recognizing and including non-scientific, local, or experience-based knowledge may consequently allow pluralistic understanding of risk, promote collaborative learning, and allow new solutions to emerge (Bosomworth & Gaillard 2019; Hassmiller & Kuhl 2020; Krauß 2020; Williams & van t'Hof 2016).

Consistent with Werner et al.'s (2021) transformation-oriented approach and Wise et al. (2014) pathways of change and response, this analysis does not assume current tourism system structure or functioning to necessarily be satisfactory nor aim to maintain the status quo and combines both incremental strategies to address proximate climate risks and transformative strategies to tackle systemic causes. Therefore, participants were asked to identify: (1) current and future climate impacts in their region or position, (2) carbon sources and responsibility for these emissions, (3) current or planned solutions including adaptation, mitigation, and sustainability (4) aspirational future vision for the destination, (5) opportunities, challenges, trade-offs, and co-benefits to achieving their desired future (Appendix A). Participants were then exposed to their respective case study climate and tourism scenarios and asked for their reactions and relevancy to the unique social, economic, and environmental realities of their position and destination community (Bosomworth & Gaillard 2019). All stakeholder narratives were recorded, transcribed, coded based on stakeholder type (industry, municipal, or community) and by case study region, and analysed through the systems framework described below.

4.2.3 Complex System Analysis

Considering pathways of change and response are components of dynamic, multi-scale, socio-ecological systems (Werner et al. 2021; Wise et al. 2014), case study climate and tourism scenarios and multi-stakeholder narratives were analyzed concurrently with two complex systems analysis tools:

(1) Following Goodman's (2002) iceberg model, case study scenario content and multi-stakeholder narrative themes were coded and analyzed, identifying *events;* observable or current climate and carbon risks, and existing solutions in place, *patterns;* common events or perspectives between case studies, stakeholder groups, geographic regions, *structures;* socio-economic institutions upholding patterns and events, and *mental models;* stakeholder-held assumptions, beliefs, and values shape cultural institutions and inform decision-making. This process highlighted values-based language and logic used by participants and the literature that influence decisions and capacity for transformation (Gorddard et al. 2016).

(2) Kumu system mapping software visually displayed stakeholder-identified climate and carbon risks, sources, and drivers. This process revealed climate change and tourism interactions, flows and causal loops, and situated climate events, patterns and structures identified above, within mountain destinations' socio-ecological systems (Lich et al. 2017; Stave 2010). Kumu software was also used to visualize actors and their relationships identified throughout the data and narratives collection processes. This relational mapping (Hassmiller & Kuhl 2020) helped situate participants within the system-wide social structure to better understand climate and tourism decision-making, including perceptions of power and influence.

Together the system analysis tools allowed exploration and visualization of both broad social networks and system-wide socioeconomic determinants of climate preparedness and deep structural values-based influences on climate decision-making. Following Wise et al.'s (2014:334) call to not only consider incremental actions or 'technical fix' type solutions to climate risk, but also to "use responses of people to the current impacts of climate change as a way to reflect on and reconsider the social norms and societal values that underlie existing problems", the system analysis sought to identify mountain tourism path dependencies, vested interests, values, or institutions constraining societal responses to change and those providing levers for social innovation and enhancing potential pathways to climate resilient, decarbonized, and sustainable futures (Werner et al. 2021).

4.3 Results

4.3.1 Stakeholder Perceptions of Climate and Carbon Risk

The system analysis of case study scenarios and multi-stakeholder narratives support academic evidence that mountain tourism and outdoor recreation destinations across Canada are experiencing climate change impacts (Table IV-2). Stakeholder narratives align with modelled climate impacts on current and future local ski tourism operationality (e.g., Ontario stakeholders noted shortened and more uncertain ski seasons, while Alberta stakeholders felt ski season climate impacts were limited thus far). Participants further identified what Scott and McBoyle (2007) termed the 'urban backyard phenomenon' wherein source market climate impacts influence tourists' behaviour (e.g., warm temperatures or rain in Toronto, Montreal, Vancouver discouraging visitation to Collingwood, Tremblant, or Whistler respectively). Eastern Canadian participants suggest such conditions might encourage travel to Western Canada which is perceived as more climate resilient. This aligns with climate projections showing parts of Ontario's ski tourism may not be economically viable by mid-century under high emissions scenarios and with academic discussions on potential spatial substitution by tourists to more resilient destinations in Quebec, Alberta and BC which are projected to maintain over 100-day season on average (Knowles et al. 2023a; Scott et al. 2019). Conversely, stakeholders noted longer summers and urban heat encourage visitation to mountain destinations, shifting seasonality and growing green season tourism. Stakeholders, particularly in Western Canada, identified increasing summer climate risks such as forest fires, extreme heat, flooding, and drought. Complex and compounding climate impacts and potential adaptation and mitigation strategies including tourist behaviour, industry adaptations, governmental policy may alter the effectiveness and relevancy climate risks across time and space, remain important uncertainties and concerns for stakeholders.

Stakeholder climate responses focus on what one participant described as "low-hanging fruit" prioritizing cost reductions, such as building retrofits, energy efficiency and marketing actions such as recycling programs. These responses do not meet the scale or scope required to adapt to projected climate change or emission reduction commitments. For example, municipal and industry climate plans use language consistent with Canada's policy targets for net-zero by 2050 (CER 2022), targets do not meet these standards (Table IV-2), and stakeholders emphasize concern over climate action plans still in preliminary planning or development phases, unlikely to be fully implemented, or with full compliance would still not achieve desired decarbonization targets. Furthermore, municipality and industry reports demonstrate a collective failure to account for scope 3 transportation emissions from tourism, which constitute a large proportion of destination emissions, particularly in Western Canadian destinations reliant on international tourism markets. This alone is identified as a key barrier to meeting climate targets, consistent with academic concerns surrounding tourism decarbonization (Gössling & Lyle 2021). Beyond direct carbon emissions, stakeholders have limited awareness or concern on carbon emissions outside their perceived scope of responsibility or how a decarbonizing economy will impact tourism systems. Systems analysis demonstrates how individual, destination, or organization-scale decarbonization initiatives may export or increase emissions across the system or how climate resilient destinations may see a rise in visitation and resulting emissions. Similarly, stakeholders did not identify cases where adaptations, such as snowmaking, which increase destination-scale emissions to maintain local tourism resources, may result in less system-wide emissions than tourist spatial substitution would (see Knowles et al. 2023b, Scott et al. 2022).

Overall, stakeholders had more interest in mitigation than adaptation, with actions such as snowmaking or four-season diversification considered part of operational planning to maintain tourism growth rather than explicit climate action. All participants, including municipal stakeholders with access to tourism, climate, and sustainability information, commonly highlighted lack of relevant climate information and inability to accurately account for tourism-based climate and carbon risks as a major barrier to climate action, yet were largely unaware of available academic research and climate change data suggesting a disconnect between science and decision-makers (Scott & Gossling 2022). Many participants are considered experts and leaders in their respective communities and roles, yet participants all frequently discredited their *own* climate and sustainability understanding, including their lived experiences, observations, and ideas, instead conveying narratives of uncertainty, and looking to perceived as experts including scientists, government policymakers and executive-level industry leaders for authority on decision-making and planning.

Table IV-2. Climate and carbon risks for tourism and outdoor recreation seasonality across low to high emission futures by 2050.

	Whistler	Revelstoke	Bow Valley	Collingwood	Tremblant
Temperature[1]					
Winter Average Current	-4.8ºC	-5ºC	-9.7ºC	-5.4ºC	-11ºC
RCP4.5	-3.3ºC	-3.4ºC	-8ºC	-3.1ºC	-8.7ºC
RCP8.5	-3ºC	-3.1ºC	-7.7ºC	-2.9ºC	-8.5ºC

Summer Average Current	11.4ºC	16ºC	11.6ºC	19ºC	17.2ºC
RCP4.5	13.2ºC	17.9ºC	13.4ºC	20.8ºC	18.9ºC
RCP8.5	13.5ºC	18.2ºC	13.7ºC	21.1ºC	19.2ºC
Precipitation[1]					
Winter Total Current	503mm	334mm	120mm	243mm	234mm
RCP4.5	531mm	356mm	130mm	264mm	256mm
RCP8.5	531mm	356mm	130mm	266mm	260mm
Summer Total Current	176mm	202mm	197mm	215mm	298mm
RCP4.5	165mm	202mm	199mm	219mm	305mm
RCP8.5	169mm	205mm	199mm	218mm	304mm
Ski Tourism Impacts[2,3]			*	**	
Season Length Current (days)	210	172	164	115	143
RCP4.5	207	153	144	97	124
RCP8.5	203	148	137	79	121
Snowmaking[4]			*	**	
Current Depth (cm)	0.1	85	58	61	25
RCP4.5	5	158	110	210	33
RCP8.5	15	177	125	276	49
Current Water Use (m^3)	2,500,000	388,000	5,008,000	1,893,000	880,000
RCP4.5	2,555,000	391,000	9,022,000	4,818,000	905,000
RCP8.5	2,558,000	400,000	8,953,000	5,383,000	1,337,000
Current Energy Use (kWh)	27,985,000	4,268,000	55,096,000	20,824,000	9,725,000
RCP4.5	28,107,000	4,301,000	99,242,000	53,007,000	9,952,000
RCP8.5	28,384,000	4,392,000	98,486,000	59,218,000	14,709,000
Current Emissions (tCO_2e)	551	84	36,914	625	35
RCP4.5	11	1.7	1330	32	0.3
RCP8.5	11	1.7	1319	21	0.4
Summer Tourism Impacts[1]					
Extreme Heat Current (days)	2	11	0	10	5
RCP4.5	5	20	2	23	14
RCP8.5	6	22	3	25	16
Shifting Seasonality[1]					
First Frost Current	Sept 15	Oct 1	Aug 30	Oct 20	Sept 19
RCP4.5	Sept 13	Oct 13	Sept 13	Nov 1	Oct 1
RCP8.5	Sept 29	Oct 16	Sept 14	Nov 3	Oct 2
Last Frost Current	June 7	May 3	June 15	May 2	May 22
RCP4.5	May 21	April 16	May 29	April 23	May 13
RCP8.5	May 18	April 14	May 26	April 22	May 11
Electricity[5] Carbon Intensity	British Columbia		Alberta	Ontario	Quebec
Current (gCO_2e/kWh)	19.7		670	30	1.5
NZ 2030	4.5		154.7	6.9	0.3
NZ 2040	2.4		80.4	3.6	0.18
NZ 2050	0.4		13.4	0.6	0.03
Reported Emissions					
Municipality (tCO_2e)	(Whistler) 109,000	1050[11]	6,900 (CM)	3,300 (ToC)	1800
Community (tCO_2e)	(Squamish) 97,000	N/A	270,000[9] (CM) 425,000[10] (B)	200,000[8] (ToC)	51,700
Ski Area[6] (tCO_2e)	N/A	N/A	N/A	2,459	2,872
Estimated Annual Tourism Transportation Emissions (tCO_2e)* **	101,872	33,324	63,048	61,800	59,806
Emission Reduction Targets	Whistler		Canmore	TBM	
Baseline Year	2005	2007	2015	2005	2008
2030	-50%	-20% (2020)[11]	-30%	-30% (2025)	-37.5%
2050	-80%		-80%[9]	-80%[7,8]	-100%
	(Squamish)		Banff	Grey County	
Baseline Year	2010		2016	2018	
2030	-45%		-31%	-30%	
2050	-100%		-83%	-50% (2035)	

*Includes 4 Bow Valley ski areas, **Includes 5 Collingwood ski areas

***Estimated based on visitation, urban source market distance, average length of stay and average group size (Table 1) and average emission rate of 206g CO_2/km (ECCC 2018)

[1] Climate Atlas (2023)

[2] Scott et al. (2019)

[3] Knowles et al. (2023a)

[4] Knowles et al. (2023b)
[5] CER (2022)
[6] NSAA (2022)
[7] Blue Mountains (2022)
[8] Collingwood (2023)
[9] Canmore (2018, 2022)
[10] Banff (2019)
[11] Revelstoke (2018)

4.3.2 Socioeconomic Determinants of Climate Preparedness

Social Structure & Decision Making

Participants uncovered a diverse stakeholder network (Figure IV-2) within and extending beyond destination boundaries as influencing climate decision-making and preparedness. The tourism industry ranges from local businesses to international corporations. Beyond direct hospitality operators and specialized products and services (e.g., alpine guides), tourism relies on private, public, and natural resources, cultural heritage, social services, governmental and non-governmental organizations, basic amenities (e.g., grocery stores, electricity providers). Participants also identified external stakeholders including foreign governments, airlines and other transportation networks, agriculture and energy industries, manufacturing which influence destination-system climate impacts and preparedness. Participants consider these indirect stakeholders as often difficult to influence and incorporate into climate and tourism planning, outside their scope of responsibility, and expressed challenges working across geographical- and political-scales. For example, the Bow Valley has strong community engagement in climate action with innovative initiatives in public transit, circular economy, and sustainable affordable housing, yet stakeholders feel hindered by provincial and regional policymakers who influence electricity grid carbon intensity and waste management systems. BC and Quebec feel provincial governments are supportive and generally hold aligned goals and values, while participants in Ontario expressed mixed response to provincial climate action. Within stakeholder groups, individuals often hold unique perspectives of the climate-tourism system.

Residents for instance, include long-term locals, seasonal or transient workers, second homeowners, which all have different relationships to the local tourism industry and perspectives on climate change. Municipality, and community stakeholders alike reference how high social cohesion, fast communication channels and a strong connection to place in small rural communities make sustainability communication and engagement relatively easy amongst residents. All participants identified community-members, tourism staff and other stakeholders with strong personal sustainability values as driving sustainability initiatives from bottom-up. Conversely, all participants identify top-down decision-making hierarchies wherein organization, business or municipality climate action depends on manager and executive support. Where sustainability decision-making roles are held by community-members and integrated into wider operations and financial departments, organizations (both municipal and industry) see greater depth, creativity, and engagement in climate solutions than when these management and decision-making roles are held by external stakeholders e.g., exported to a corporate headquarters or placed in marketing or communications departments (see corporate consolidation below).

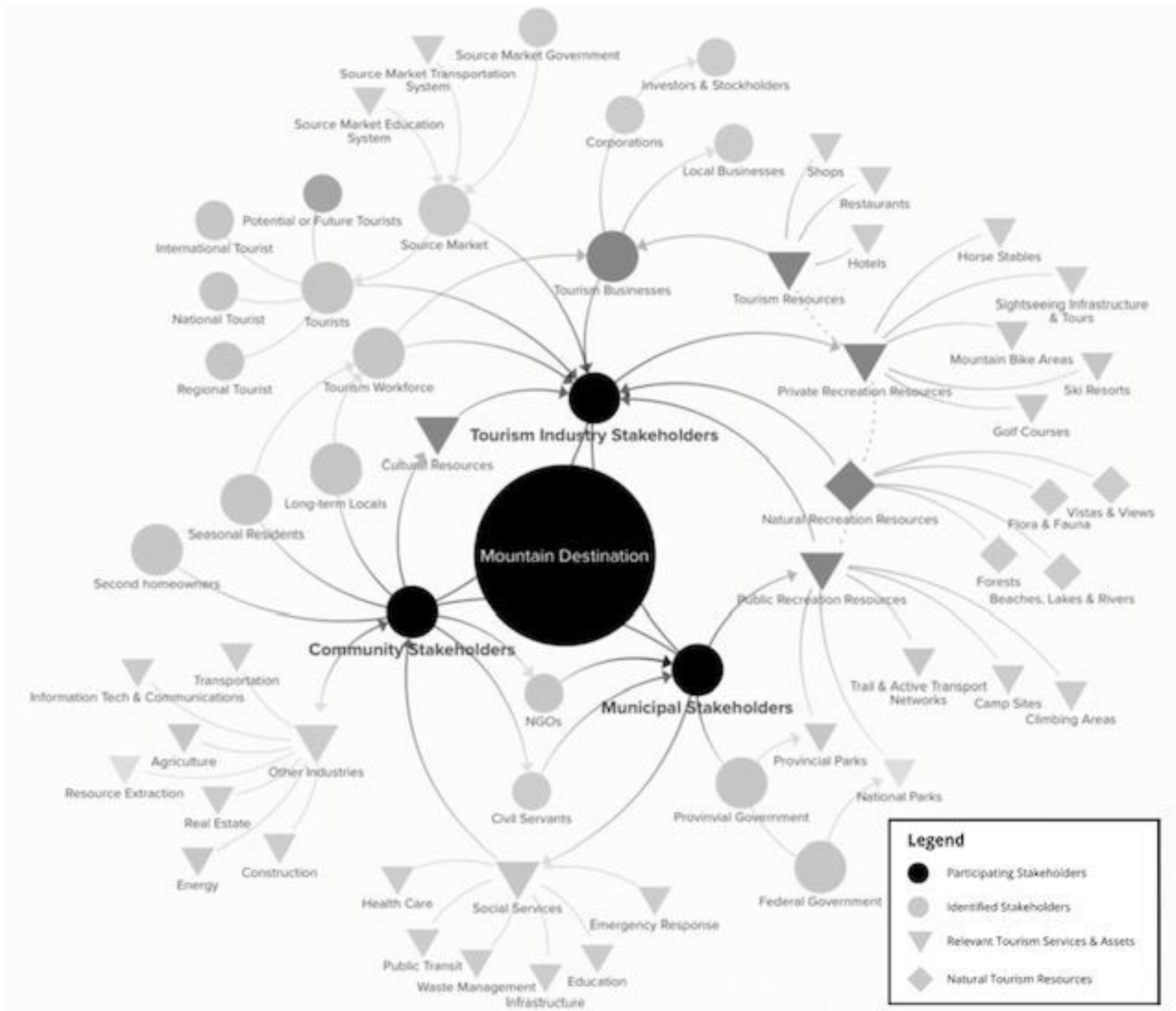

Figure IV-2. Stakeholder map of relationships within Canada's ski tourism mountain community systems

Similarly, *tourists* share common traits of travel to experience the destination's cultural or recreational activities yet vary in terms of place-of-origin (regional to international), length-of-stay (day trip to seasonal), level-of-skill or interest in recreation activities (beginner to expert). Participants noted source market education, governments, and cultural norms influence how visitors interact with existing or proposed tourism and municipal climate action strategies (e.g., buy in and engagement, communication, and signage). While all participants cite rising conscious and responsible tourists, stakeholder narratives paradoxically placed responsibility on tourists via frequent references to how "vacation mindset" means visitors will not choose sustainable options if added effort is required. Tourist and transient seasonal worker populations with diverse interests, understanding and languages make awareness, education, and participation in municipal or industry sustainability initiatives, (e.g., seasonal public transit schedules) challenging especially with vastly different destination-scale sustainability programs (e.g., local recycling and compost protocols) and visitor profiles.

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Corporate Consolidation & Geographic Diversification

Stakeholders note shortened and more inconsistent winter conditions are affecting ski areas, including reduced revenues from periods of inoperability, increased operating costs from adaptations such as snowmaking, and investment in diversifying and expanding summer tourism products and services. Ski visits across Canada declined from 18.6 million (2009-2014 annual average) to 18.4 million (2015-2019) with declining visitation in Quebec and static visitation across Alberta and Ontario (CSC 2019). In contrast, Canadian Ski Council's pre-COVID growth projections were set at 13.3% growth by 2030 (CSC 2018). Stakeholders explained how private or community-owned ski areas are financially disadvantaged while corporate ski area conglomerates use this as an opportunity to grow revenues by either purchasing local ski areas and resorts or bringing them into multi-resort pass programs. Multi-resort pass programs incentivize pre-season purchases by promoting discounts for early purchase and increasing day ticket prices drastically (up to over $200/day) to ensure sunk revenues before seasonal weather variability is known. In this way, ski corporations gain volume-based revenues security from pre-purchased multi-resort season passes and spread their climate risks geographically by encouraging passholders to visit climate resilient destinations.

Multi-resort ski passes, and related marketing, encourage higher ski tourism emissions when skiers travel to distant resorts. As more people travel farther to "take advantage of free skiing offered by multi-resort passes" scope 3 emissions increase but are not currently considered in ski industry or municipal carbon accounting. Industry disconnection to this feedback-loop is demonstrated in a 2023 press release on "climate action" by Vail Resorts CEO stating "*we have a bold commitment to hit net-zero by 2030, so that's net-zero emissions, landfill waste and habitat impact. And when we make investments, we are focused on efficient snowmaking and things that can help mitigate climate change and variability in the weather. Having guests commit in advance and geographic diversity also helps. If our guests in [San Francisco] don't feel like going to Tahoe because of too much or too little snow, they have other choices like Park City Utah, Colorado, or Whistler"* (Wahba 2023). Corporate consolidation and geographic diversification links to the dynamic adaptation-mitigation nexus and could be considered (mal)adaptation wherein adaptation approaches (flying to climate resilient destinations), increases absolute emissions thus exacerbating climate impacts and adapt requirements.

Community and municipality stakeholder participants suggest corporate consolidation strategies create monopolies and power imbalances where a few transnational tourism companies control destinations by privatizing and monetizing recreation and natural resources that were previously public domain (e.g., trails) and encouraging policy decisions made in favour of profit margins and foreign investors over local stakeholder wellbeing or ecological integrity. While industry stakeholder rhetoric suggests economic benefits trickle down to destinations, community and municipality stakeholders argue the majority of economic benefits are lost, aligning with Higgins-Desboilles et al. (2019) argument on multi-national tourism corporations' propensity to leakages. Climate action is also consolidated into overarching climate action plans (uniform climate plans for all resorts despite drastically different environment, climate, social and political systems), and decision-making shifted from destination-based grassroots initiatives to corporate executives.

Tourism Growth & Sustainability Finance

In addition to climate change and related impacts on tourism seasonality, Canadian mountain destinations are experiencing patterns of rapid growth in recreational users, resident populations (including amenity migration and digital nomads) and a post-pandemic rebound in most tourism market segments. Participants identified this growth as driven by COVID-19 pattern shifts (e.g., interest in outdoor recreation, nature-based activities, mental and physical well-being experiences, digital nomad tendencies), multi-resort ski pass incentives, and by climate change including increasing summer heat, and limited urban greenspace. These combined climate-tourism system changes may have complex and cascading implications for other social, economic, or ecological sustainability objectives. Community participants link this growth and shifting seasonality to social and ecological pressures which impact destination health community well-being or tourist experiences and could be defined as *over-tourism* (Higgins-Desboilles et al. 2019; UNWTO 2018). Manifestations include traffic, congestion, and related carbon emissions; pressure on local social services; crowding and impact on recreation amenities (e.g., mountain bike participation growth and trail maintenance); ecological impacts (particularly with earlier springtime participation); and increasing housing, and recreation costs. Municipal stakeholders, who often also identify as community-members, share similar personal sentiments on how growing tourism inhibits climate action. Municipal funding is often determined based on permanent resident populations, yet tourism-based municipalities must maintain infrastructure and services including sustainability programs (e.g., recycling programs), for growing visitor populations that in all cases outnumber residents several fold.

Despite over-tourism concerns, municipal tourism plans, destination marketing organizations and tourism industry strategy documents project and encourage further tourism growth for a "sustainable economy", while industry or municipality climate action strategies do not address how decarbonization targets may be achieved with increased visitation and tourism development. Like most tourism systems, tourism and climate policy at the destination- and national-scale are not coherent (see Becken 2019). Community leaders expressed concerns that industry and municipality decisions on climate mitigation and adaptation often result in investments sustaining revenue generating aspects of outdoor recreation and tourism economy over social or ecological destination well-being and prioritize visitor and second-homeowner interests and over residents. For example, Ontario community stakeholders expressed concerns for large spending on snowmaking adaptation and question its physical thresholds, future climatic viability in the area, and potential repercussions on community water security and ecological impacts. Alberta community-members gave examples of development decisions prioritizing hotel accommodation growth over ecological concerns including biodiversity and carbon sequestration and urgent social needs such as affordable housing for residents and tourism workers.

Participants from all three stakeholder groups highlight cost as a major barrier to climate action. Community participants focus on individual-scale sustainability acts, such as buying local organic food, switching to electric vehicles, or retrofitting houses for energy efficiency and renewable energy are often cost prohibitive to residents. Working with small budgets, slow moving decision approval processes, and short electoral-based timeframes, municipal stakeholders broadly feel constrained in their ability to implement effective, intersectional, and transformative climate action. Industry stakeholders and documents suggest sustained tourism revenue growth is needed to fund sustainability initiatives. These perspectives either explicitly or indirectly refer to the "business case" for climate action which prioritizes cost reduction initiatives such as energy efficiency, adaptations such as snowmaking which protect existing assets or marketable sustainability initiatives to limit reputational risks and enhance profitability. While industry stakeholders are aware of tourism's direct reliance on stable climates and natural environments as recreational and tourism assets for revenue generation, nature, climate, and sustainability, they are predominantly seen as an externality to operating budgets, revenue generation and strategic plans. Tourism industry's perceived financial barriers to climate action can be seen through strong reliance on pay to pollute systems (e.g., carbon offsets) and government grants for sustainability initiatives even amongst international ski corporations.

Affordability & Accessibility

Beyond specific climate action and sustainability costs, participants identify rapidly growing visitor and resident (including amenity migration, digital nomads or second homeowner) populations as driving up living costs. These stakeholders are considered to have a higher average income and greater willingness to pay than long-term local community-members. For example, 53% of Canadian skiers have an annual household income over $100,000 (CSC 2019), relative to only 5% of Banff households, 10% in Tremblant and Revelstoke, 12% in Whistler and Collingwood, 14% in Blue Mountains, and 18% in Canmore (Statistics Canada 2021). Community and municipality stakeholders see this socioeconomic divide exacerbating equity, accessibility, and inclusion challenges in recreation and tourism, and intersecting with climate justice. Transportation and housing were two major examples provided by stakeholders to explain this barrier to climate preparedness.

Transportation: Whistler, Bow Valley and Collingwood participants noted destinations have or are reaching vehicle-based carrying capacity, including parking at ski areas, trailheads, beaches, congestion in community downtowns, traffic and commute times, and wear on road infrastructure, well before ecological or social carrying capacity of recreation and tourism resources. Participants, specifically community and municipality stakeholders consider transportation a climate justice challenge wherein populations able to fly or drive to and within destinations emit carbon at high rates while gaining multi-faceted benefits (participants noted mental and physical health, cultural exchange, education, connection to nature, and sustainability benefits) of outdoor recreation, time in nature and tourism amenities. No case studies have convenient, reliable, or affordable public transportation linking destinations and their nearest major urban area, thus large populations face barriers accessing destinations and recreation resources due to personal vehicle ownership, rental, and fuel costs, or inefficient, unavailable, or inconvenient public transportation. Community participants from across the case studies emphasize this point stating variations of "*I can see the ski hill from my window but there's no* *way to get there", "You could probably take a bus, but it would take a really long time and be super inconvenient", "There's so much opportunity for green transportation to get that new population of people who want to ski outside but that barrier to entry is multi-layered. Having to take multiple busses for multiple hours is not going to get more diversity into these sports*". Those who cannot afford the cost or time of transportation are excluded from outdoor recreation and tourism's positive experiences and are simultaneously the same populations who are most vulnerable to climate impacts. As climate change impacts accelerate, destination spatial substitutions will exacerbate transportation emissions and inequities as tourists travel farther to climate resilient destinations.

Destination response to transportation emissions and inequities, range from helping (e.g., Bow Valley's free and, in some cases, mandatory public transportation to popular recreation destinations) to hindering (e.g., Collingwood increased parking costs and added reservation requirements for recreation sites) the joint climate-accessibility-affordability challenge. Stakeholders from all study areas expressed success with active transportation networks (e.g., multi-use trails, main streets closed to cars) reducing destination scale transportation emissions while bolstering tourism and community well-being. Participants highlighted sustainable transportation solutions needed to be recreation-friendly including access to trailheads, seasonally appropriate gear (e.g., mountain bikes, skis) and low-density use. Industry participants felt transportation is the municipality's responsibility, while municipality and community-members feel there needs to be stronger public-private partnerships with private tourism and recreation resource owners (e.g., golf courses, ski resorts, hotels) taking greater responsibility on how consumers they profit from reach and travel within the destination. All stakeholders identify major barriers to sustainable and equitable transportation from provincial and federal initiatives which include increasing highway capacity (e.g., doubling the Rogers pass highway to Revelstoke) and a reduction in public transit services (e.g., reduced bus services to Collingwood), while municipal participants emphasize challenges working across jurisdictions and industries to create cohesive transportation networks and encourage greater collaboration and communication.

Housing: Community and local government participants express concern that growing interest in mountain destinations is putting pressure on expensive and at-capacity housing markets (for example average housing values in case study communities range from 10% to 166% above Canadian averages -see Table IV-1). For example, Blue Mountain (2022) community identifies "three unavoidable truths": climate emergency, fast-growing populations and unattainable housing as key challenges to sustainability planning and a liveable future. Local homeowners are often incentivized by financial opportunities of high-cost short-term rentals over providing affordable long-term rental accommodations to the local tourism workforce, while large second homes owned by vacationers sit unoccupied (yet contributing emissions from heating/cooling) much of the year. Without attainable housing, long term residents and tourism workforce are pushed out of destinations which is noted as leading to increasing commute related emissions, decreased community cohesion, and exacerbating inequities within tourism systems. Tourism industry perspectives responded with the need for more development, yet community participants highlight decisions on development and land use prioritize tourism (increase in hotel and condo development), and rarely address affordable housing. In areas experiencing rapid development (e.g., Collingwood, Canmore), community participants are concerned sprawl and land-use change has negative ecological impacts, reduces carbon sequestration abilities, and degrades natural recreation assets which are driving tourism growth in the first place. In other areas where further development is limited by landscape or policy (e.g., Banff is limited by national park regulations), municipality stakeholders note destinations have more tourists than staff to support them and the town.

All participants highlighted mountain tourism's reliance on low-income seasonal workers who, like tourists and amenity migrants, are drawn to the benefits of living, working, and recreating in mountain destinations. Municipality stakeholders, who emphasize waste as a key scope 3 emission source and cost, discuss how low pay combined with short term nature of employment mean tourism workers often purchase cheap goods (including furniture, small appliances, recreation gear) which often end up in landfills following the season. Banff identified this causal loop as an opportunity to assist living affordability while reducing waste-based emissions by creating a sharing-economy style "library-of-things" and a reuse centre for larger items such as furniture. Community and municipal stakeholders also note energy volatility including housing electricity and heating, and gas for vehicles contribute most to high living costs, yet climate solutions such as solar panels on homes or electric vehicles which are advertised as reducing costs over time, often come with an upfront investment that is prohibitive to most. Participants all suggested climate solutions must be affordable and accessible to action at scale and help address affordability and accessibility, such as investing in renewable energy on low-income housing to create long-term cost consistency while reducing housing and transportation emissions.

4.3.3 Opportunities to Accelerate Climate Responsiveness

Analysis of community, local government, and industry narratives, and language and rhetoric found in climate action plans and tourism strategies, revealed dominant mental models upholding existing climate-tourism system structures and patterns (Figure IV-3). Expressed confidently by stakeholders or conveyed as obvious assumptions (e.g., "well *of course* you wouldn't expect a ski area to spend money on sustainability willingly") or seen through success (e.g., GDP growth), these mental models represent the status quo about the purpose and value of tourism, roles and responsibility for climate action and sustainability, and future pathways for mountain tourism. Dominant narratives can be seen in examples like Banff and Lake Louise Tourism (2023) business plan and annual report, "*As communities with economies reliant on tourism, BLLT is committed to rebuilding our industry with a shared vision and commitment to working with our members and stakeholders to ensure long-term resilience and viability of the economy, community and environment*". Their mandate highlights the community as dependent on tourism's economic outputs goals to sustain growing year-round demand and encourage visitors to spend more. On tourism's responsibility for climate action, a Whistler participant explains "*we are considering purchasing offsets, but the [local carbon offset project] wouldn't have enough offsets to provide coverage for our emissions*" without acknowledging how this may indicate tourism is exceeding local to global emission thresholds. The Blue Mountains revitalization strategy provides examples of sustainability language used within economic growth rhetoric including key objectives "*have a healthy, sustainable and mixed commercial environment in the Commercial Core Areas*" and "*capitalize on the natural heritage assets*".

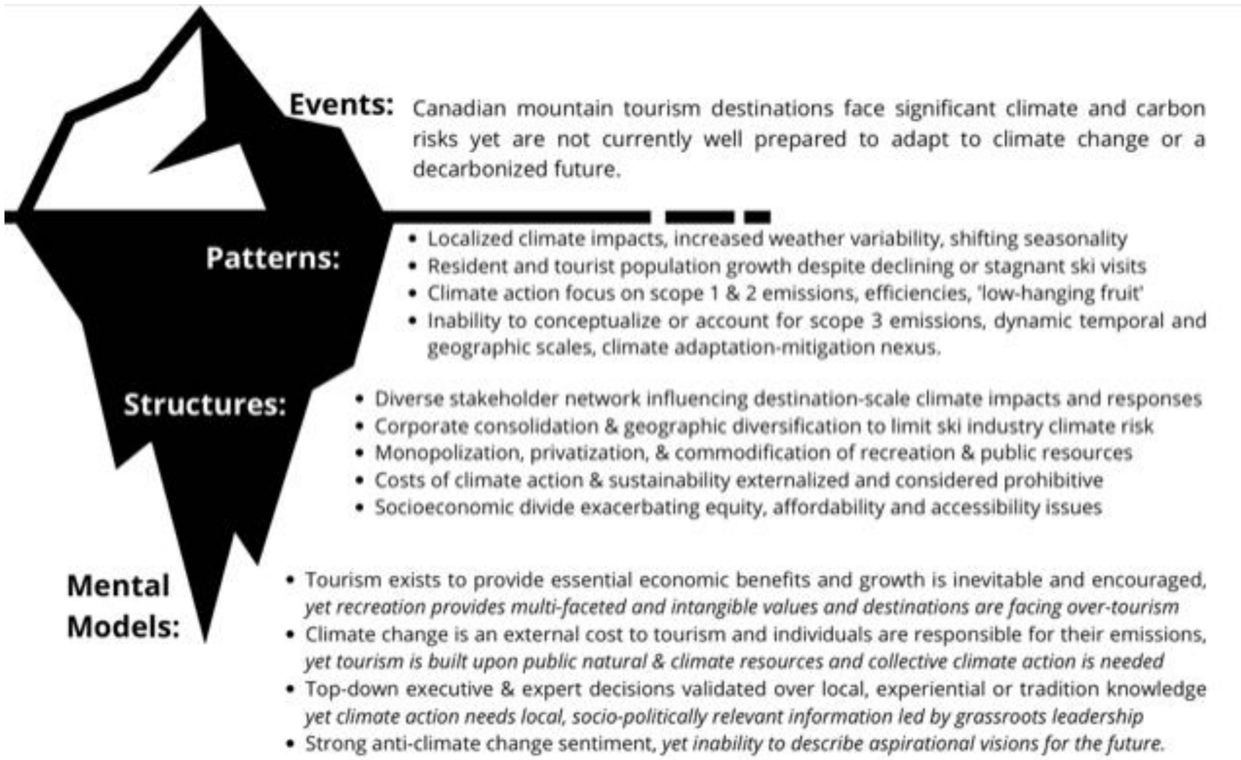

Figure IV-3. Synopsis of ice-berg model analysis of multi-stakeholder narratives and case study scenarios.

Alongside dominant narratives, participants and stakeholder documents often hold multiple values or rationalities which are paradoxical in nature. Examples of counter perspectives include stakeholder identification of tourism's multi-faceted and intangible value (including local cultural or community identity, mental and physical health, personal growth, social cohesion, public land protection, ecosystem services and intercultural exchange) for both visitors and residents. Place-based stewardship, integrated sustainability and collaborative action can also be seen through examples such as: focus group participant: *"Banff is a model environmental community where everything we do is guided by a goal to preserve this special place",* Whistler's Community Vision: *"We are a place where our community thrives, nature is protected and guests are inspired*", The Town of Blue Mountains guiding questions: *"How* *might we build upon the unique attributes of the Town of the Blue Mountains while creating a shared path towards a future of increased livability, vibrancy and health of all living systems in our community?"* or Ski Station Mont Tremblant President and CEO website statement "*new ways of ensuring sustainability affect both our environment and our children, and this makes us very proud*". While these counter perspectives were often expressed hesitantly or hopefully in stakeholder narratives (e.g., community and municipality linking equity, affordability and accessibility to climate change, or industry statements such as "*if only* public and private sectors could truly collaborate"), as buzzwords in municipal and industry strategies (e.g., regenerative tourism, circular economy frameworks within overarching growth-based tourism strategy), and small-scale grassroots initiatives (e.g., Banff's free public transit, library of things), they represent transforming hegemonic narratives and structures upholding climate unpreparedness and potential opportunities to accelerate climate responsiveness.

4.4 Discussion

"Some people believe sustainability means to maintain the status quo, when, in fact, the status quo is not currently sustainable" stated Henderson (2013:68) regarding leisure activities broadly. In exploring multi-stakeholder risk perceptions in Canada's mountain tourism destinations, narratives demonstrate growing climate awareness, yet there remains a significant gap between hegemonic mountain tourism socioeconomic system structure and functioning, and the actions and change needed to adapt to anticipated warming and meet decarbonization targets as set out by Paris Climate Agreement or Canada's net-zero plan. Moving beyond sustaining the status quo, the following discussion explores entwined ecological, social, and economic tensions identified in the results as potential levers to re-envision mountain tourism systems in alignment with climate resilient, decarbonized, and sustainable futures.

4.4.1 The Value and Purpose of Tourism: Why and For Whom?

Redefining purpose and value are the most effective levers for systemic change (Fletcher et al. 2019). Economic valuation currently dominates both tourism policy and planning (e.g., spending, jobs, GDP growth) and climate action (climate mitigation or adaptation costs) in Canada's mountain destinations. Driven by economic metrics of success, mountain tourism is increasingly monopolized by corporate tourism businesses and predicated on continued visitation and spending growth (Higgins-Desboilles et al. 2019; Hussain 2021). Tourism growth is marketed as a revenue source (profits or tax), yet Pollock (2019) notes few destinations globally have clear sense of where tourism income goes, let alone direct and indirect costs associated with servicing (growing) tourism. Tourism industry narratives centre around the idea that economic benefits trickle down into local economies, which community stakeholders conversely feel are extracted and exported outside destinations (Hussain 2021; Pollock 2019). Municipal narratives paradoxically suggest tourism spending is essential for destination economies yet identify large visitor populations and growing impact on infrastructure and services a major barrier for climate funding and action.

With growing mountain tourism, academia emphasizes direct carbon-emission limits to tourism growth (Becken 2019; Scott & Gössling 2022; Scott 2021), and more complex climate-growth interactions such as tourist spatial, temporal, and activity substitutions, corporate structure, and path dependencies (Gill & Williams 2011; Steiger et al. 2022). While industry and municipality stakeholders remain disconnected on this growth-decarbonization paradox, community-members holding over-tourism concerns suggest wider socio-ecological limits to growth. Defined by the UNWTO (2018;4) as "the impact of tourism on a destination, or parts thereof, that excessively influences perceived quality of life of citizens and/or visitors in a negative way" over-tourism can be seen here via congestion and impact on recreation infrastructure, pressure on community housing resulting in resident displacement in favour of high-paying short-term rental income (Fletcher et al. 2019), as well as multinational corporations homogenizing and privatizing natural and public recreation resources (Fletcher et al. 2019; Higgins-Desboilles et al. 2019). With tourism growth and climate change implications negatively impacting natural and cultural heritage, Steiger et al. (2022) warns destinations to carefully assess their fragile mountain landscape's socioecological carrying capacity. Concern must also be given to which measures are used to combat over-tourism as increasing fees (e.g., parking costs) or exclusivity (e.g., limiting ski or golf area capacity) can exacerbate inequity, affordability, and accessibility problems (Hall 2009; Higgins-Desboilles et al. 2019). Higgins-Desboilles et al. (2019) therefore calls to reorient local community's rights to well-being over tourists' rights to vacation and tourism corporates to make profits, while Büscher and Fletcher (2017) assert tourism requires a radical shift from privatizing activity to one founded in and contributing to the common.

As contemporary sustainable tourism scholarship increasingly questions tourism growth (Büscher & Fletcher, 2017; Fletcher et al. 2023; Hall, 2009, 2010), tourism's purpose for existence and indicators of success are also questioned (Fletcher et al. 2019). Sustainability transformations emphasize the importance of creating spaces in research, policy, and practice to integrate multiple values for and of sustainability into economic narratives including aspects of human and natural systems which are not amenable to pricing, valuation, or markets (Krauß 2020; Higgins-Desboilles et al. 2019). When asked what value outdoor recreation and tourism provides participants and destinations, narratives ranged from mental and physical health to community and intercultural exchange to recreation opportunities, passion, and personal challenge to cultural and natural heritage conservation, to qualitative economic benefits including enjoyable jobs, and entrepreneurial opportunities. Mountain tourism is thus well positioned to incorporate and prioritize stakeholder-held pluralistic values linking tourism, climate change and sustainability (Higgins-Desboilles et al. 2019; Krauß 2020). This could include emerging indicators of success, such as post-consumerism, universal basic services, nature's contributions to people, buen vivir, happiness index which offer potential to create more diverse and resilient economic systems that are aligned to ecological integrity and social justice (Higgins-Desboilles et al. 2019; Wyborn et al. 2020). Some municipalities and destination marketing organizations use transformative language surrounding climate change and tourism (e.g., circular economy, regenerative tourism). These campaigns reflect a "veneer of sustainability presented to gain support for tourism while the growth agenda is still at the core of tourism policy and planning" (Higgins-Desboilles et al. 2019). Mountain tourism stakeholders engaged in this study were hesitant to move beyond economic valuation, however pluralistic approaches to valuing tourism may prove beneficial as industry, municipality and community stakeholders noted competing industries, such as resource extraction sectors, do not provide the same social or environmental benefits as tourism and outdoor recreation.

4.4.2 The Role and Responsibility for Climate Action: How and By Whom?

While tourism may perform well against other industries using pluralistic valuations, Duffy (2015:533) provides an important reminder that tourism is often falsely presented as a “clean industry that stands in contrast to heavy industries, able to provide more environmentally sustainable forms of economic development”. Sustainable economic development narratives reinforced by international tourism organizations, has led a global pattern of communities, including Canadian mountain towns, to shift away from extractive industries towards tourism and recreation (Gosnell & Abrams 2011; Knowles 2019; Nepal & Jamal 2011) without regard for systemic climate implications from both exporting existing industries and growing tourism sector impacts. For instance, as tourism development displaces agriculture in Collingwood, the region loses local food sources and carbon sinks while increasing food transportation emissions. As recreation groups lobby to reduce logging in Revelstoke in favour of recreation space, resource extraction is pushed onto more vulnerable and out-of-sight regions, including Northern Canada and the global south. Assigning voluntary (e.g., Municipal Natural Asset Initiative [Segal 2022], ESG reporting), regulatory (e.g., Canada's carbon pricing strategy [ECCC 2018]) or market-driven (e.g., stock market climate risk reporting [Mazzacurati et al. 2018]) capital values to environmental (and social) impacts has been a common approach to bring these externalities into economic narratives and build a “business case” for climate action and sustainability. The business case for climate action perspective considers economic value and carbon emissions to be a “neutral-valuation-methodology” (Wyborn et al. 2020) able to recognize and capture multi-scalar environment and climate risks and use market-logics to solve the climate crisis.

Conversely, long ago the IPCC's ARII (1995:50) warned of non-monetary value and climate change risks, stating “monetary valuation should not obscure the human consequences of anthropogenic climate change damages because the value of life has meaning beyond monetary valuation”. More-recently IPCC AR5’s (2014) conceptual risk framework identifies exposure as “something of value is at stake, recognizing the diversity of values”. An economic-only value (and thus risk) conceptualization likely prioritizes protecting areas, infrastructure or people with significant resources and capacity (tourists and tourism assets) over more vulnerable places and people (natural areas and community-members) and faces challenges assessing and quantifying relative risk across and between non-comparable (particularly non-monetary) values (Folkersen

2018; van den Bergh & Botzen 2015) obscuring pluralistic stakeholder-held tourism values noted above. Acknowledging tourism and destination emission reductions to levels compatible with Paris Agreement targets is essential, mitigation-only approaches to climate action may face similar challenges. Stakeholder narratives suggest the race to "net-zero" is pushing individuals and organizations to reduce or export their scope of responsibility, decouple emission reduction from economic growth, prioritize net emission reduction over other environmental or social values including climate adaptation, and compete rather than collaborate to achieve these goals. Case study examples include externalizing scope 3 transportation emissions (Gössling & Lyle 2021; Scott & Gössling 2022, 2021), reliance on pay-to-pollute systems (e.g., often ineffective forest-based carbon offsets [Greenfield 2023]) and blaming individual tourist's with "vacation mindset", for ineffective sustainability programs (e.g., recycling, compost).

This reductionist approach to climate responsiveness fails to capture how tourism destinations derive direct, yet often non-monetary value and cannot be sustained independently of their wider socio-ecological system (Hall 2011; Pollock 2019) including natural, cultural, public recreation resources, social services, and stable climates. Rather than considering climate and sustainability a cost, regenerative tourism and tourism living-systems research identifies *place* as the central organizing concept and suggests situating tourism within the destination it's built upon to ensure net benefits (Bellato et al. 2022; Pollock 2019). While Pollock (2019) believes this requires crossing an "ontological threshold", destination stewardship approaches suit vastly different climate, carbon, ecological and social contexts identified for case-study destination and build off strong community-based sense-of-place values to apply integrated climate-sustainability solutions relevant to enhancing destination health thus sustaining the characteristics attracting residents and tourists. Acknowledging how reciprocal relationships between tourism stakeholders, landscapes, and non-humans co-create tourism destinations aligns with the increasingly recognized power of nature, Indigenous and local knowledges and need for equity and justice in climate adaptation and mitigation (Pollock 2019; WASP 2023). Prioritizing destination stewardship over tourism growth can be seen as a departure from competition, profit, and efficiency as the driving force for sustainable innovation (Bellato et al. 2022) and instead shifts tourism-climate responsiveness to collective responsibility and collaborative action.

4.4.3 Pathways for Mountain Tourism: Towards What Future?

Transformative change seeks to shift perceived values and role of tourism in society and aims to redefine tourism's success relative to ecological sustainability and ethical principles (Werner et al. 2021; Westley et al. 2013). While existing sustainability practices identified (e.g., recycling, energy efficiency) are essential, they may have, as Pollock (2019) said, "deluded us into thinking we can continue business-as-usual... and defer the moment we have to make systemic change." Tourism entrenchment in global socio-economic systems, as seen through system mapping, mean transforming tourism systems is impossible in isolation from wider societal sustainability transitions (Higgins-Desboilles et al. 2019). While tourism is well positioned to incorporate pluralistic values and mobilize collective action from diverse stakeholders necessary for sustainability transformations, negative climate rhetoric and self or collective doubt on solving climate change prevalent across all participant narratives is a major barrier. When asked about innovation and transformation, participants focused on technological innovation (e.g., electrifying vehicles) while generally considering social, political, or economic structures as static or impossible to shift.

Paradigm shifts require a collective re-envisioning of tourism (Higgins-Desboilles 2018; Hussain 2021), challenging and moving beyond prevailing sustainable tourism assumptions, structures, and strategies (Pollock 2019) to what Wright (2010) calls "real utopias" (Fletcher et al. 2023). While participants were able to articulate concerns over climate risks and barriers to achieving Paris Agreement targets or other sustainability objectives, they were unable to describe their aspirational vision for a sustainable future community, industry, destination, or tourism-system using positive language. Despite diverse experiences, ideas and visions, many stakeholders expressed imposter syndrome, downplaying their own idea’s viability assuming variations of "if it was a good idea and could actually work, it would already be implemented" or "there must be something I don't know" about potential creative solutions and future pathways. This lack of imagination and negative rhetoric suggests a strong path dependence inhibiting the collective creativity required to think beyond current systems, envision potential alternative future states, illuminate possible solutions, and ultimately transform values and governance arrangements to adapt and attain the desired future (Fletcher et al. 2023; Higgins-Desboilles et al. 2019; Hussain 2021; Pollock 2019).

4.5 Conclusions

Canada's mountain tourism systems both drive and are impacted by climate change and face impending climate change and climate response-induced transformations. In an increasingly decarbonized, warmer, and complexly stressed world, ski tourism will have to justify its existence (e.g., who is tourism benefiting?) and operations (e.g., snowmaking amidst drought, scope 3 transportation emissions) to diverse stakeholders (Higgins-Desboilles et al. 2019). While industry, municipal and community stakeholders across the five case studies are aware and concerned about current destination-scale climate impacts, there was a common inability to conceptualize long-term changes (e.g., mid to late-century), limited understanding of temporally and geographically dynamic socioeconomic interactions between climate change and broader tourism systems, and uncertainty on how to move forward. Tourism's climate resiliency and sustainability transformations are currently hindered economic-centric valuation and monitoring, externalized climate action and sustainability, and lack of collective aspirational visions for sustainable destination futures. Multi-stakeholder narratives and a complex systems mapping approach provided an opportunity to see pluralistic values and risk perceptions, build collaborative networks across wide-ranging stakeholders, and identify creative intersectional levers for change. As mountain tourism stakeholders face or pursue transformation, future research may seek to explore other stakeholder perspectives and emerging paradoxes, including the following. How can tourism shift away from growth while simultaneously addressing inequities present in climate change and tourism or outdoor recreation? How can destination stewardship harness sense-of-place values prevalent within communities without NIMBY actions exporting emissions or socio-ecological degradation onto more vulnerable people and places? How can destinations collectively vision localized sustainability transformations while entrenched in global corporate and commodified economies? How can diverse tourism stakeholders best contribute their knowledge, experience and expertise actualize sustainability transformations? These challenging and uncomfortable questions are particularly important as scholars contribute to emerging dialogues on climate justice and tourism.

Chapter 5
Dissertation Summary and Conclusions

5.1 Summary of Dissertation Findings

The three studies that comprise this dissertation investigated 8 research questions, as outlined in section 1.4, to identify the state of climate and carbon risk and responsiveness across Canada's ski and mountain tourism destinations. The primary focus of this dissertation was to enhance climate risk understandings, highlight the interface of adaptation and mitigation, inform decision-making amongst ski tourism stakeholders, and identify pathways to meet a climate change impacted yet decarbonized future. The following sections outline the objectives of each study and describe how these objectives were met. The chapter also summarizes the empirical, methodological, and conceptual contributions to the climate change and tourism literature, the practical implications for mountain destinations and society, and finally propose an agenda for future research.

5.1.1 Climate Scenario Modelling (Chapter 2)

Research Questions: (RQ1) What are the current and future physical climate impacts for British Columbia and Alberta ski areas? (RQ2) How do these climate risks in Western Canada compare to other regional markets across national and international scales?

> *Objective 1:* Model current baseline ski conditions and projected impacts of climate change on key industry-specific indicators across a range of potential future emission scenarios and timelines.
>
> Objective 2: Assess implications for future ski area operability at the regional market-scale including market capacity and economic viability.

Objective 3: Discuss Western Canada's intra-regional patterns of climate risk (*Objective 1* and *2)* and compare relative inter-regional climate risks across Canada and other continental and international markets.

Using historical daily weather data (NOAA 2018) identified as representative of each of Canada's western ski areas, common ensemble climate scenarios (CMIP-5 and CMIP-6 [IPCC2022a]), and SkiSim2.0 (Scott et al. 2003; Steiger 2010), the first study modelled Western Canadian ski tourism sector climate risks currently (baseline) and short (2050s) and long-term (2080s) projections under mid (RCP4.5, SSP245), upper-middle (SSP370) and high (RCP8.5, SSP858) emission scenarios. To the author's knowledge, this was the first study published in a peer-reviewed journal to provide climate change and ski tourism operation analysis in this geographical region, and completed coverage required for a national scale understanding of climate risk across Canada's major ski tourism markets. The study found that even mid-range-emission scenarios (RCP4.5 & SSP245) which are considered the most likely by climate scientists (Tollefson 2021), the regional 155-day baseline season length (156 days in BC, 153 days in Alberta) is projected to decline 14% by mid-century and 19% by late century, while under the same scenarios, snowmaking requirements are expected to increase 126% by mid-century and 169% by late century from a 64cm regional baseline (BC baseline of 55cm, Alberta baseline of 76cm) ***(RQ1; Objective 1)***. More pronounced impacts are projected under longer-term, high-emission scenarios. Evaluations of operational impacts and economic viability demonstrate that Alberta remains more resilient with over 80% of ski areas meeting thresholds of a 100+ day season and greater than 70% probability of operation during the New Year Holiday even under long-term high emission scenarios (RCP8.5 & SSP585, 2080s). Only 65-70% of British Columbia ski areas meet the same criteria in these conditions with ski areas in low latitudes and coastal regions notably more vulnerable ***(RQ1; Objective 2)***. Compared with national, continental, and international studies using the same methodologies, Western Canada has relatively low physical climate risks ***(RQ2; Objective 3).*** The study proposes investigation into demand-side responses to climate change including implications of successive warm winters and market contraction on tourist behaviour within and outside of Western Canada, and tourist perceptions of snowmaking as a climate adaptation in a region known for its natural powder snow.

5.1.2 Research for Adaptation (Chapter 3)

Research Questions: (RQ1) How much water-use, energy consumption and carbon emissions stem from snowmaking at the tourist, destination, region, and national scale? (RQ2) How could accelerating climate change and Canada's decarbonization targets impact future snowmaking water-use, energy consumption, and carbon emissions? (RQ3) At what scales (geographically, temporally, spatially) can snowmaking in Canada be considered a climate (mal)adaptation?

Objective 1: Develop the first snowmaking sustainability assessment tool to quantify water, energy, and carbon emissions from snow production.

Objective 2: Use tool *(Objective 1)* to estimate the sustainability of Canada's snowmaking (including metrics of water-use, energy consumption and carbon emissions) at the individual tourist, destination, provincial and national scales, currently and across a range of potential future scenarios.

Objective 3: Discuss the role of snowmaking as a (mal)adaptation in the context of the Canadian ski tourism system including the dynamic nature of adaptation, the adaptation-mitigation nexus, tourism system boundaries, and the scale(s) at which environmental sustainability can be assessed.

This study advances methodological approaches to evaluate snowmaking as a sustainable climate adaptation by developing ratios of water-use (m^3) and energy consumption (kWh) per snow produced (m^3) adjusting for low, central, and high efficiency snowmaking systems. Based on existing academic literature, industry reports, and self-reported snowmaking data from ski areas, this tool can be applied across scales, geographical regions, and future climate and carbon scenarios ***(RQ1; Objective 1).*** This tool was then applied in the major Canadian ski tourism markets, assuming central efficiency systems and using SkiSim2.0 results on snowmaking requirements from Alberta, BC (Chapter 2), Ontario and Quebec (Scott et al. 2019b) as the input. The study found that snowmaking in Canada currently uses 43.4 million m^3 of water and 478,000 megawatts (MWh) of electricity (with 130,095 tonnes of associated CO_2 emission) and to produce over 42 million m^3 of technical snow annually ***(RQ1; Objective 2)***. By mid-century, national average snow production increases between 55% and 97% are expected based on low to high emission scenarios (RCP 2.6 to 8.5) (Chapter 2, Scott et al. 2019b), with water and energy use increasing proportionally. Despite growing snow production, associated emissions would decline 96% to 4721 tonnes CO_2e if Canada Energy Regulator's (2022) policy targets for net-zero by 2050 are achieved ***(RQ2; Objective 2)***. Large regional differences in water-energy-emissions intensity demonstrate that the national scale is too coarse to report on environmental sustainability of snowmaking as a climate change adaptation, and this study suggests adaptation is dynamic requiring frequent re-assessment alongside changes in snowmaking infrastructure and technology, climate change, water availability, energy sources and electricity emission intensity ***(RQ3; Objective 3)***.

5.1.3 System Transformation (Chapter 4)

Research Questions: (RQ1) What do diverse ski tourism stakeholders perceive as current and future climate and carbon risks for mountain tourism destinations? (RQ2) What other socioeconomic determinants are contributing to the current state of climate preparedness in ski tourism destinations across Canada? (RQ3) Which stakeholder perspectives enhance versus inhibit destination climate resilience and sustainability, and how can these narratives be used as levers to accelerate climate responsiveness?

Objective 1: Engage diverse stakeholders from Canada's ski tourism system (including tourism industry experts, municipality staff members, and community leaders) in participatory research methods (including interviews, workshops, and focus groups) to collect qualitative narratives on climate change risk, response, and resilience in mountain tourism systems.

Objective 2: Situate climate and carbon risks and responses within the mountain tourism socioeconomic system including linking qualitative stakeholder risk perceptions, relationships, and decision-making influences (Objective 1), with quantitative climate risk and responses (Chapter 2 & 3 results), and the broader literature (including academic, industry reports, municipal policy documents).

Objective 3: Conceptualize gaps between climate risks and existing responses and potential levers for transformative change in research, theory, policy, and action that could enable pathways towards climate resilient futures in Canadian mountain tourism destinations.

The third study added qualitative narratives of climate and carbon risk to ski tourism through interviews, workshops, and focus groups with diverse stakeholders including tourism industry experts, municipality staff members, and community leaders from five major Canadian ski tourism destinations. Results demonstrate varied climate and carbon risks across the study area. While stakeholders are aware of and concerned about current destination-scale climate and carbon risks, narratives demonstrated a shared inability to conceptualize long-term changes (e.g., mid to late-century), limited understanding of temporally and geographically dynamic socioeconomic interactions between climate change and the broader tourism system, and uncertainty on how to move forward. ***(RQ2; Objective 1)***. Situating multi-stakeholder perspectives alongside climate scenario modelling (Chapter 2) and research for adaptation (Chapter 3) within the wider mountain tourism system, revealed stakeholders, relationships, and socioeconomic determinants of climate and carbon risk that may previously have been considered outside the scope of ski tourism boundaries. Themes include shifting tourism seasonality, increasing tourism and outdoor recreation participation urban to rural amenity migration, and transient populations, corporate structure and commodification of natural and public resources, externalization of climate change and sustainability costs, equity in affordability and accessibility, transportation infrastructure and scope 3 emissions ***(RQ1; Objective 2).*** Climate resiliency and sustainability transformations are currently hindered by an economic-centric valuation of tourism, top-down expert driven decision-making, externalization of climate action and sustainability, and lack of a collective aspirational vision for sustainable destination futures. Multi-stakeholder narratives and a complex systems mapping approach provided an opportunity to see pluralistic values and risk perceptions, build relationships and collaborative networks across wide ranging stakeholders, identify intersectional levers for change and conceptualize pathways to re-envision mountain tourism ***(RQ3; Objective 3)***.

5.2 Contributions to Climate Change and Tourism Literature

This dissertation makes key conceptual, methodological, and empirical contributions to the climate change and tourism literature. While programs of research often begin with generalized conceptual frameworks and then seek to use innovative methodologies to provide empirical evidence to deductively prove or disprove hypothesized conceptual frameworks. This dissertation took the opposite inductive reasoning approach, drawing on specific empirical evidence and exploratory methodologies to develop a conceptual theory of transformation for mountain destinations (see Figure V-1).

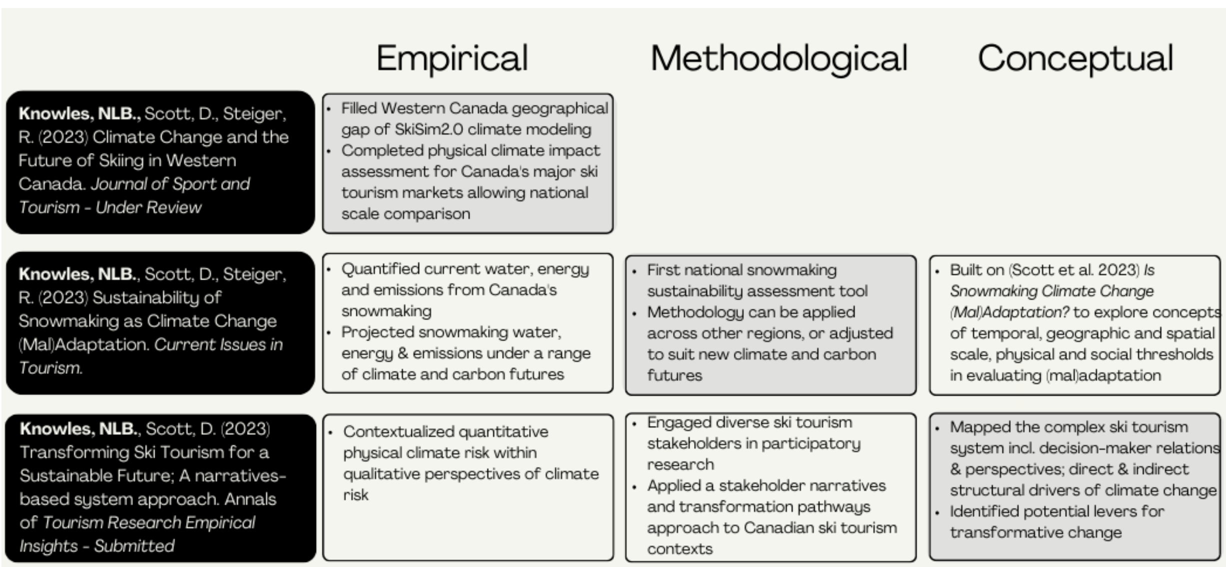

Figure V-1. Empirical, methodological, and conceptual contributions to the literature.

The first study (Chapter 2) used existing conceptual frameworks of physical climate risk, SkiSim2.0 climate modelling methodologies, and a common set of ensemble climate scenarios from *Coupled Model Inter-comparison Project (CMIP*) Phase 5 that have been applied in similar studies in North America (e.g., Scott et al. 2019b, 2021) and internationally (e.g., Abegg et al. 2015; Fang et al. 2019; Rice et al. 2021; Scott et al. 2022a; Steiger & Abegg 2018; Steiger &

Stotter 2013). By applying SkiSim2.0 to analyze 66 of the 74 Alberta and BC ski areas which represent Canada's largest ski tourism market and an international destination, this study fills an important regional gap in the empirical physical climate risk assessment literature (Scott et al. 2019b). Beyond providing destination scale and intra-regional industry-specific climate risk information, filling this geographical gap enables cross-regional comparisons, which is a priority identified by Steiger et al. (2019). These results provide key empirical evidence to shape conceptual discussions on relative climate risk, destination and tourism-system boundaries, and dynamic system responses to climate change.

The second study (Chapter 3) focuses on a new methodological contribution to the literature with the first national snowmaking sustainability assessment. Snowmaking has and continues to be the central climate change adaptation strategy for the ski industry to increase resilience to adverse weather and climate variability and extend season lengths (Abegg et al. 2017; Hopkins 2014; Knowles 2019; Steiger et al. 2019; Trawöger 2014). As research shows increasing reliance by ski areas on snowmaking to remain operational under all climate futures (e.g., Fang et al. 2019; Chapter 2 - Knowles et al. 2023a; Rice et al. 2021; Scott et al., 2019ab, 2021; Steiger et al. 2019; Spandre et al., 2015, 2017, 2019), media (Knowles & Scott 2020) and some publications suggest snowmaking is inherently maladaptive (Aall et al. 2016; de Jong 2015; Dunstan 2019; Hopkins 2014). A lack of research evaluating the water, energy, and related greenhouse gas (GHG) emissions used in snowmaking as noted by Berard-Chenu et al. (2022), Morin et al. (2021), Scott et al. (2022), and Steiger et al. (2019) suggest that the (mal)adaptation debate surrounding snowmaking is largely anecdotal. Using the results from Chapter 2 and Scott et al. (2019b), this study assesses water, energy and associated carbon emissions stemming from snowmaking in Canada. This methodology is transferable across geographies, and can be adapted to suit changing climate, carbon, and snowmaking technological futures, while the empirical results allow more informed and nuanced discussions of snowmaking as a climate (mal)adaptation. This research builds off Scott et al.'s (2022) theoretical paper entitled "Is snowmaking climate change (mal)adaptation", to further explore and provide new insights for the research *on* adaptation (Klein 2017) including: adaptation outcomes at various temporal and spatial scale; physical and social thresholds of adaptation; the adaptation-mitigation nexus; and adaptation within complex and dynamic socio-ecological systems.

The final study (Chapter 4) builds upon the conceptual discussions on climate adaptation of Chapter 3 and the empirical climate risk evidence of Chapter 2 to engage stakeholders in participatory methodologies that situates the climate and carbon risks and responses within the wider ski tourism socioeconomic system. The narrative-based results of this approach add to the body of literature on qualitative stakeholder climate and carbon risk perceptions in ski tourism (Knowles 2019, Dawson et al. 2011; Dawson & Scott 2013; Pickering et al. 2010; Rutty et al. 2015, 2017), while the application of systems-thinking and transformation pathways as theoretical frameworks have yet to be applied in the ski tourism context. These conceptual lenses embrace the complex and dynamic nature of climate and tourism systems, building on past research to create more interdisciplinary, integrative, and holistic pathways, as is recommended in Seeler's (2020) research agenda for sustainable tourism and Steiger et al.'s (2022) assessment of mountain tourism. The ecological, social, and economic tensions identified through the multi-stakeholder narratives and complex systems thinking analysis led to conceptual links to the rapidly growing body of innovative tourism futures and transformation literature including regenerative tourism (Bellato et al. 2022; Hussain 2021; Pollock 2019), de-growth tourism (Fletcher et al. 2019; Higgins-Desboilles et al. 2019), post capitalist tourism (Fletcher et al.

2023). This research therefore provides a first discussion of these concepts in the context of ski tourism leading to novel questions for future research.

5.3 Practical Contributions

As tourism emerges from the unprecedented COVID-19 pandemic shutdowns, tourism scholars are calling for the industry to use this unique opportunity to transform rather than return to pre-COVID normal which was incompatible with a warmer and decarbonized future (Fletcher et al. 2020; Hussain 2021; Scott 2021). Despite the growing awareness of the potential impacts of climate change on ski tourism, most winter sport and tourism organizations could be classified as in a *problem state* (Orr & Inoue, 2018), unprepared and unable to mitigate, manage, or adapt to current and future climate impacts (Knowles et al. 2020; Scott et al. 2012, Scott 2021). Research on ski industry management perspectives from alpine regions across the globe, including North America, shows varied levels of climate risk awareness and concern, a focus on future rather than current climate risks, and limited industry engagement in climate change mitigation and adaptation (Bicknell & McManus 2006; Gössling & Scott 2018; Hoy et al. 2011; Knowles 2019; Morrison & Pickering 2014; Steiger et al. 2019; Trawöger 2014; Wyss et al. 2014; Wolfsegger et al. 2006). Considering misinformation, lack of decision relevant information, and perceptions of uncertainty, a predominantly negative (disaster) rhetoric and a disconnect between researchers and practitioners have been identified as barriers to ski industry climate responsiveness (Abegg et al., 2017; Bicknell & McManus 2006; Gössling et al., 2012; Gössling & Scott 2018; Knowles & Scott 2020; Scott & Becken, 2010; Scott et al. 2016; Steiger et al. 2019, 2022; Trawöger, 2014; Wolfsegger et al., 2008). This research aimed to fill important knowledge gaps, provide solution focused results, and enhance communication channels throughout the Canadian ski tourism stakeholder network.

Western Canadian industry members and destinations are hindered by a lack of research and projections on climate impacts locally (Steiger et al. 2019; Fang et al. 2017). Chapter 2 provided the first climate change and ski tourism operation analysis in the Western Canada region providing an essential baseline analysis of climate risk across a range of potential future scenarios. This research reduced perceptions of uncertainty (Steiger et al. 2022) and set the foundation for informed discussions on effective climate response strategies for mountain tourism industry members as well as winter sport, recreation and broader destination and community planning. This research can be useful in decision-making on climate responsiveness and future tourism investments and infrastructure in this region. In BC specifically mountain resorts are a key development strategy for rural and remote communities (2012), with expansion of the $1.4 billion ski tourism market a central pillar (BC 2015). This research may therefore provide useful insights on climate change to communities, municipal and provincial governments (e.g., Ministry of Tourism) and may be extrapolated to better understand the future feasibility of proposed ski resort developments including Valemount, Garibaldi, Sasquatch, and Zincton. Beyond the localized results, understanding of the Western Canadian ski market's climate risk may help ski tourism businesses, destination communities, and winter sport organizations across Canada understand the relative risks, and respond appropriately to changes in supply and demand pattern. Internationally the comparable results of this research with other international markets can provide guidance on broader tourism and climate strategies, while the methodologies used can be exported to other regions such as South America to support multisector climate planning (Navarro-Drazich et al. 2023; Steiger et al. 2019, 2022).

In responding to climate change, a large body of research suggests that the ski industry’s reliance on (Fang et al. 2019; Knowles et al. 2023a; Rice et al. 2021; Scott et al., 2019, 2021;

Steiger et al. 2019; Spandre et al., 2015, 2017, 2019) and massive investment in (PMR 2018 Abegg et al. 2017; Hopkins 2014; Knowles 2019; Steiger et al. 2019; Trawöger 2014) snowmaking technology is expected to grow significantly over the next decade. As the ski industry pursues what Berard-Chenu et al. (2022) characterize as "a headlong rush to a technical adaptation to climate change", Chapter 3 provides an empirical analysis of snowmaking water and energy use, and emissions across Canada. These are crucial factors in ski area viability and reputation, will be especially relevant as they seek to operate in climate impacted conditions and achieve emission reduction targets set within the tourism sector and by governments. The results of this study demonstrate that sweeping negative characterizations of snowmaking (Aall et al. 2016; de Jong 2015; Dunstan 2019; Hopkins 2014) are neither useful nor accurate, and instead this research provides empirical evidence to aid industry stakeholder decision-making surrounding snowmaking at a regional and destination scale. The adaptation-mitigation nexus is complex and only with a systems perspective can trade-offs and unintended consequences be understood. This research also encourages industry and destination stakeholders to look beyond business-as-usual operating strategies and understand the dynamic and integrated nature of responding to climate and carbon risks with snowmaking including its effectiveness, sustainability, and implications across a range of timelines, carbon scenarios and geographical contexts.

While contemporary quantitative climate risk discourse often aims to define and isolate components of climate change and the associated risks and responses (Krauss 2020), climate actions are rarely taken in response to climate change alone and a clearly identifiable and a rational decision-maker with the mandate to make decisions rarely exists (Smit & Wandel 2006; Wise et al. 2014). Diverse stakeholder participation was therefore a key focus of Chapter 4, including sharing research results and collecting insights through participatory methods to ground quantitative climate risks (Chapter 2) and responses (Chapter 3) within broader qualitative socio-ecological contexts. A narratives approach that invites all actors to identify and define the climate (or sustainability) risks relevant to them, allowing stakeholders the agency to direct the research to suit their needs, ensuring more applicable research (Krauss 2020; Steiger et al. 2022). The results of this chapter provide evidence of how ski tourism is embedded in the natural environment, climate, and social structures, which may be beneficial to Canadian destinations pursuing or interested in engaging in tourism innovation and transformation, such as Canmore's Regenerative Tourism Framework (Canmore 2021) or Banff's Circular Economy Roadmap (RCA 2020). The themes which emerged and resulting discussions may help industry stakeholders and destinations alike understand and incorporate more pluralistic concepts of value, identify thresholds or limits to growth, and redefine *sustainable* tourism to meet the long-term needs of the entire mountain socio-ecological system (Higgins-Deboilles et al. 2018; Fletcher et al. 2020; Pollock 2019).

Presenting climate and carbon risks using models, adaptations, language, and contexts applicable to practitioners and stakeholders (Bisaro & Hinkel 2018; Steiger et al. 2022) may encourage communication and collaboration (Knowles & Scott 2020) and allow decision-makers to see ecological, social, and economic interactions as opportunities for thinking and acting differently (Gillard et al. 2016). For example, sharing relevant climate risk (Chapter 2) and adaptation impact (Chapter 3) with different stakeholder groups across diverse regions (Chapter 4), created a multi-directional knowledge co-creation network wherein participants enhanced climate responsiveness by identifying, brainstorming, and troubleshooting climate action strategies, identified additional stakeholders holding aligned values, complementary goals or relevant expertise (e.g., providers of affordable housing) and were able to request climate and tourism data and analysis relevant to their needs. Stakeholder reactions to Chapter 2 and 3 results suggest that large, intangible metrics (e.g., annual volume of water used in snowmaking, percent change in ski season length, terrain-days) and long-time horizons are challenging to understand, contextualize or act upon, whereas simple and destination-scale metrics (including season length losses in days, lift and terrain crowding, number of extreme heat days) or results presented using equivalency and comparative examples (e.g., how many flights equal annual snowmaking emissions, Alberta versus Ontario season length losses) elicit better comprehension. This resulted in wide-ranging stakeholders including non-profit organizations (including Protect Our Winters Canada, Climate Caucus, Columbia Mountain Institute, Canadian Mountain Network), industry associations (including HeliCat Canada, Canadian Ski Council), governmental organizations (e.g., Sport Canada's Sport Participation Research Initiative) and academic institutions (e.g., University of Lausanne - Institute of Sport Sciences, Universidad Nacional de San Martin) engaging with and collaborating throughout the broader dissertation research agenda. Research results were shared with these organizations through white paper reports, conversations, webinars, seminars, lectures, conferences, and presentations, and to a wider public audience through social media, blogs, and other public-facing channels such as *The Conversation.*

Mainstream media is also a primary source of climate change information for ski tourism stakeholders (Knowles & Scott 2020; Trawöger 2014; Wolfsegger et al. 2008). Considering reports of misinformation (Scott & Steiger 2020), simplifications or incorrect extrapolations (Gössling et al. 2012; Scott & Becken 2010), and biased or exaggerated coverage (Abegg et al. 2017), this dissertation took a proactive approach to controlling the public media narrative. Ski tourism research suggests communication strategies, including preparing research for public and media consumption, direct dissemination of new studies to local/regional industry and destination stakeholders, ski industry meetings and trade journals, or harnessing online and social-media platforms will enhance climate risk knowledge mobilization and industry application (Knowles & Scott 2020; O’Neill et al., 2014). Therefore, throughout the research process, concerted effort was made to connect directly with both media and the wide-ranging ski tourism stakeholders. For example, Scott et al.'s (2022) paper entitled *Climate Change and the Future of the Olympic Winter Games: Athlete and Coach Perspectives*, which used SkiSim2.0 results from Chapter 2 alongside a survey and was conducted as complementary research to this dissertation, reached international media including interviews with the New York Times, BBC, the Guardian, NBC, Sports Illustrated, Climate Network, CBC and viewership as high as 2.2 billion. Following this media surge, the International Olympic Committee director Christophe Dubi, citing Scott et al.’s (2022) evaluation on the future of the Winter Olympic Games, announced "we have preliminary results of leading academic research on the impact of climate change, which shows a potential reduction in a number of climate reliable hosts in the future", before postponing the decision on the 2030 host city (Carpenter 2022). The Taylor & Francis press office selected Chapter 3 for a press campaign which was released on June 8, 2023. After only one month, this article achieved coverage in 92 news outlets including National Geographic, NBC, and Yahoo! News, and is currently ranked as the 12th highest Altmetric Attention impact score (62) from all Current Issues in Tourism articles ever published, the highest score for 2023 and in the top 20 of all Taylor and Francis articles published in June 2023. This demonstrates the power of media and academia collaborations to ensure accurate climate change information reaches a broad and diverse public audience. Similar media and research dissemination strategies will be used with Chapter 2 and 4 as they proceed through the publication and dissertation process with the aim of fostering further collaborations, implementation and knowledge sharing opportunities.

5.4 Opportunities for Future Research

As the urgency and complexity of the climate crisis grows ever more apparent, the timelines to achieve the aims of the Paris Agreement serve as a striking reminder: there are less than 30 years to fundamentally transform global tourism into a decarbonized and climate resilient sector. The "wicked" challenge of climate change within the complex socio-ecological tourism system emphasizes the responsibility of all stakeholders in creating and implementing a more sustainable pathway forward (Bellato et al. 2022; Blokland 2019; Hussain 2021; Jakulin 2016; Pollock 2019). To more fully understand these multifaceted challenges and the complexities associated with tourism’s climate change response demands new research approaches that allow for pluralistic understanding of climate change risk, inter- and transdisciplinary collaborations, decision-centred approaches, and consideration of compounding impacts and non-linear system responses (Bosomworth & Gaillard 2019; Klein 2017; Krauss 2020; Steiger et al. 2022; Werner et al. 2021; Wise et al. 2014). In the past decade, climate change and tourism publications having grown three-fold, yet the limited responsiveness by the sector suggests a need to shift from awareness raising to research on engagement and implementation within the tourism sector (Scott 2021). For researchers this means increasing the quantity of research, (currently only 1–3% of research output, as measured by the content of high-ranking tourism journals) (Scott 2021) and ensuring research methodologies and dissemination strategies meet the scope and scale of this industry’s unique climate challenges. By harnessing broad input from tourism scholars and diverse sector stakeholders, and engaging across academic disciplines and socioeconomic sectors, research on the impacts of accelerating changes in climate and the low carbon transition can be mobilized into destination planning, policy, business operations, and traveller behaviour to inform and accelerate climate action throughout the tourism sector. The following discusses some of the key empirical, methodological, and theoretical areas of future research which emerged from the processes and findings of this dissertation:

5.4.1 Empirical: Emerging Markets, Global Risk & Emissions

There are persistent regional information gaps where the global south, including emerging ski tourism markets such as Asia, South America, and the Middle East, lack climate change and tourism research (Fang et al. 2017; Navarro-Drazich et al. 2023; Steiger et al. 2019, 2022). These regions are expected to experience large future tourism growth (Fang et al. 2017), and thus could benefit from proactive understandings of physical climate risks and evaluations of the effectiveness of adaptations to proactively guide decision-making on tourism planning and investment (e.g., potential water use conflicts as climate change accelerates). Exporting the SkiSim2.0 methodology (Chapter 2) and empirical snowmaking analysis (Chapter 3) would support capacity building in tourism research and climate responsiveness amongst practitioners and destinations. Furthermore, filling these gaps would allow global-scale industry-specific climate risk analysis and provide greater understanding of potential supply and demand shifts to prepare destinations for potential issues identified through this dissertation in the Canadian context such as over-tourism, development, and cost of living challenges in climate resilient regions, and climate adaptation, four-season diversification, and restoration of former ski terrain in climate impacted areas. As these adaptations and transformations begin, whether autonomous or planned, research *on* adaptation (Klein 2017; Scott & Becken 2010; Loehr & Becken 2021) such as Chapter 3 can explore how snowmaking and other ski tourism adaptations perform currently and in future climate change scenarios, including dealing with compounding and chronic stressors, working within changing or future societal contexts, and testing the thresholds of (mal)adaptation, such as changes in energy efficiency and associated GHG emissions from operating snowmaking at higher temperatures. In doing this, empirical analysis of mountain tourism emission sources and quantities would assist adaptation decision-making and enhance understanding of ski tourism's path to enter the decarbonized economy of the future. Collectively, presenting future empirical climate and carbon risk and adaptation analysis results using tangible, destination- and short-term scale metrics alongside comparisons and equivalent examples would enhance knowledge mobilization between researchers, practitioners, and policymakers.

5.4.2 Methodological: Situating Quantitative Research in Qualitative Systems

As research increasingly views climate change across scales and as constructions of interconnected socio-ecological systems, methodologies, and frameworks such as geography which work across natural and social sciences, open new arenas to investigate the mechanisms driving global climate change in tourism as well as identifying and mobilizing responses (Bjurstrom & Polk 2011; Haarstad 2014). Considering the dynamic nature of climate and carbon futures, future quantitative climate research may be enhanced from the input of the qualitative results, to guide feasibility, application, and thresholds. For example, indicators such as *economic viability, lift-capacity, skier intensity,* and *terrain days* and operating thresholds such as *100-day season rule* or *30cm minimum snow-depth* found in Chapter 2's SkiSim2.0 climate modelling could be enhanced using input from diverse stakeholders to suit nuanced, regional, or business-model-specific contexts and changing realities like shifting seasonality. Furthermore, expanding on demand-side climate response research such as work by Rutty et al. (2015, 2017), Dawson et al. (2011) and Dawson & Scott (2013) could enhance quantitative evaluations of climate risks (e.g., what are tourist thresholds for crowding or over-tourism, and how does this compare with industry or community perspectives? what are skiers' responses to compounding marginal seasons? [Chapter 2]), adaptations (e.g., will increasing snowmaking, as projected by SkiSim2.0, satisfy visitor expectations in regions such as the "Powder Highway" of Western Canada? [Chapter 3]) and development of effective industry and destination specific climate responses (e.g., what would encourage tourists to support transformations to transportation systems? [Chapter 4]). These insights could be applied to climate models to suit specific circumstances, as was done successfully by Scott et al. (2022) to tailor the SkiSim2.0 models to account for safe and fair competition conditions required for the Olympic Winter Games as identified by elite athletes and coaches. Considering climate change is and will continue to be fraught with trade-offs and synergies with other sustainability objectives (Nerini et al. 2019), the more social and environmental externalities can be brought into quantitative research from the onset, the more applicable and relevant the research will be to practitioners. Additionally, participatory methods can be enhanced by incorporating the perspectives of more stakeholders, with a particular emphasis on including local and Indigenous knowledge (WASP 2023) and using positive rhetoric to lead the tourism industry (Hussain 2021).

5.4.3 Conceptual: Pathways Forward

In alignment with broader tourism research finding an absence of viable plans to adapt to suit warmer futures and reduce emissions to be part the net-zero economy by 2050 (Scott & Gössling 2022; Gössling & Scott 2018; Scott et al. 2016; Lenzen et al. 2018), this dissertation, specifically Chapter 4, brings to the forefront important questions on the role of tourism amidst climate change and conceptual pathways for the future. Sharpley's (2020) review of two decades of research on sustainable development through tourism concludes that while academic and policy circles continue to align the two, there is little evidence of this happening in practice and a growing uncertainty on whether sacrifice-free decarbonization and sustainability solutions exist for tourism as has been promoted via the sustainable development narrative. With this realization has come a growing resurgence of new theoretical frameworks from which climate resilience and justice may be achieved with and through tourism, including but not limited to conscious travel (Hussain 2021), regenerative tourism (Bellato et al. 2022; Pollock 2019), de-growth tourism (Higgins-Desboilles et al. 2019; Fletcher et al. 2019), post capitalist tourism (Fletcher et al. 2020). Research exploring these theories within and across the ski and mountain tourism context may be of interest to mountain destinations, especially as communities reach social and environmental thresholds and seek to move beyond tourism as solely a job creation and economic growth engine lens to define how tourism could be a vector of positive change (Hussain 2021). With the broader economy pluralistic indicators of success such as post consumerism, universal basic services, circular economy, nature's contributions to people, happiness index are emerging (Pascual 2020; Wyborn et al. 2020). Future research could explore incorporating these metrics into the tourism sector to assess stakeholder identified tourism value-adds such as health and well-being, recreation infrastructure, ecological conservation, social-cohesion, cross-cultural exchange, education among others (Krauss 2020; Higgins-Desboilles 2018; Fletcher et al. 2020). This leads to further theoretical questions of what and who is sustainable tourism sustaining? How can tourism decarbonize and address over-tourism while simultaneously increasing equity and accessibility to achieve climate justice? How might tourism look if conceptualized from a standpoint of contributing to the common good? By whom and how might sustainability transformations occur? (Buscher & Fletcher 2017; Higgins-Desboilles

2019; Fletcher et al. 2019). As this dissertation demonstrates, the vast socio-ecological contexts within which tourism exists means the answers will likely vary significantly by destination resulting in what Wright (2010) deems a constellation of utopias rather than an overarching sustainable tourism framework (Fletcher et al. 2020).

Finally, as climate and tourism researchers begin to ask the tourism sector to transform itself amidst rapidly changing external contexts, we as researchers in this field must be reflective of our own role and the need to transform to stay relevant amidst change. Considering that the academic call to climate action has not yet been heard by tourism stakeholders, the process and results of this research suggest the academic community can aid ski tourism and mountain destinations by better disseminating research, mobilizing existing knowledge, and fostering shared learning (Loehr & Becken 2021). In an age of short attention spans, inflammatory news cycles, and clickbait headlines, not to mention artificial intelligence, it is no surprise that lengthy academic articles with discipline specific jargon held behind pay-walled journals are not reaching public audiences let alone implementation (Knowles et al. 2023; Sharpley 2020). As tourism and sustainability theories seek to incorporate more pluralistic metrics of success, researchers and research institutions can as well move beyond the prestige of publication metrics to measure success of our research by societal impact, dissemination to relevant stakeholders, and implementation (Knowles et al. 2023; Ravenscroft et al. 2017). Thus, key questions for future research practitioners aiming to enhance climate action in tourism systems include: how can academia best listen to the actors on the ground to ensure the right research questions are being asked in the first place? What communication channels can be built to foster multi-directional dialogues and diverse stakeholder engagement in the research process from the onset?

Amidst this rapid, and often visual-based, communication era what mediums can best convey accurate and applicable research findings to stakeholders and decision-makers?

5.6 Reflections and Concluding Remarks

Like ski tourism markets globally, Canada's mountain destinations will continue to face accelerating climate change, with cascading implications across their often-fragile alpine ecosystems and small remote communities. Experiencing the natural beauty and mountain culture is what draw tourists and residents alike to these locations, thus the tourism industry and its stakeholders have a vested interest in sustaining local socio-ecological systems. While tourism is often presented as a clean industry able to provide sustainable forms of economic development (Duffy 2015), tourism is a significant sector in the growth-based patterns of global production, trade, finance, and consumption (Higgins-Desboilles, 2018; WTTC 2020), which are some of the primary drivers of sustainability challenges (climate change, biodiversity loss, inequity) (Hüttel et al. 2020; IPBES 2019; IPCC 2014; Wiedmann et al. 2020). The visceral impacts of climate change on Canada's ski tourism sector, combined with international and national obligations to the Paris Agreement in the next 27 years, make it clear that continued business-as-usual growth of tourism does not align with a decarbonized economy. Rather than growing continually *bigger*, mountain tourism stakeholders must investigate destination carrying capacity within their specific socio-ecological contexts and seek alternative pathways to instead become *better*. In finding better pathways forward, this dissertation and aligned research outlined in Figure I-1 seeks to provide Canada's mountain tourism sector with essential understanding of current and potential climate and carbon risks, adaptation effectiveness and situate climate change within the wider tourism system. Ultimately this research aims to inspire destinations to move beyond reacting to climate change and sustaining tourism, to reimagine tourism to proactively serve the needs of the mountain communities and environment upon which it is built.

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Appendix A

Semi Structured Interview/Focus Group/Workshop Guide:

1) Introduction and Verbal Consent

Hello. I'm Natalie Knowles. I am conducting research about climate risks, carbon risks and implementing effective climate responses within your community. This interview/workshop/focus group is part of my PhD research at the University of Waterloo, Canada. I'm working under the supervision of Dr. Daniel Scott of University of Waterloo department of Geography and Environmental Management

Thank you for your interest in participating in my research. Have you had time to read the Letter of Information I sent you?

[*If the participant responds that they have read the LOI*]

Great, then I would like to take a moment to review some main points from the Letter of Information before we continue. [*Proceed to review the highlights of the LOI, be sure to include risks and what will happen with their data and confirm the important points about voluntary participation and withdrawal listed below.*]

- You have been invited to participate because you have been identified as an industry expert, municipal policy maker or community activist in local climate change issues and we want to better understand your perspectives and ideas on how to create climate solutions that work within your local ecological and socio-political environment as well as within an uncertain future. With climate conditions continually changing due to forces beyond the scope of a single small rural community and tourism sector, this study seeks to understand what factors (past, current, and future) may contribute to effective climate action from the perspective of industry experts, municipal policy makers, community activists and how this may impact climate action plans within your community, other destinations, and the wider Canadian ski tourism market.
- Participation in the study will consist of in a **one hour interview/focus group/workshop** in which you will be asked questions about 1) the current and future climate impacts in your community, 2) the sources of carbon emissions and any current or future regulatory or social pressures to decarbonize, and 3) the challenges, opportunities, trade-offs, co-benefits and limitations of current or potential future climate responses including adaptation and mitigation initiatives in your community. Participation is entirely voluntary, with freedom to decline to participate at any point. We are not collecting any personal information. Your identity will be confidential, and responses will be aggregated with the responses of other participants. Information will be attributed to a sector or a community but never both, to warrant anonymity.

- Your participation in this study is voluntary. You may decide to leave the interview at any time by verbally stating you no longer wish to participate. Any information and responses you provided up to that point will not be used, and the recording of your interview will be deleted from record. You may decline to answer any question(s) you prefer not to answer by stating so while continuing to participate in the remaining questions of the interview. Your identity is confidential, in that your name will be coded and shared separately from your recorded interview and we do not ask for any other identifying information. Once you have participated in the interview you may withdraw your consent to use your responses at any time up until publication of the results. You will be informed of the results prior to publication and updated on the final date as to which you may withdraw participation from the study.
- There are no known or anticipated risks associated with participation in this study. If a question, makes you uncomfortable, you can choose not to answer. See above for more details on voluntary participation.
- No personal information will be collected, and your identity will be confidential. Interview responses and other electronic data will be retained for a minimum of 7 years, after which they will be destroyed. Data will be stored in an encrypted folder on my password protected laptop. Only the research team will have access to study data. No identifying information will be used in my thesis, or any presentations or publications based on this research.

[*If the participant responds that they did not read the LOI in advance, then proceed to go through the full LOI in detail with the participant and confirm the important points about voluntary participation and withdrawal listed below*.]

Confirm the following to the participant:

- Your participation in this study is voluntary.
- If you do not want to answer some of the questions you do not have to, but you can still be in the study.
- You can decide to stop at any time, even part-way through the interview for whatever reason.
- If you decide to stop during the interview, we will ask you how you would like us to handle the data collected up to that point, whether returning it to you, destroying it or using the data collected up to that point.
- You can ask to remove your data from the study up until approximately **April 2023.**
    - After the research is published, it will not be possible to pull out your data.
    - This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board.

Do you have any questions or want me to go over any study details again?

Consent questions: (Documentation I obtained oral consent by audio recording the consent questions for each participant at the beginning of each interview.

Do you agree to participate in this study?
If yes,

- Would you like a copy of the study results? If yes, where should we send them (email, mailing address)?
- Do you agree to audio recording?

If no, "thank you for your time".

Introductory Questions
What is your position e.g. municipal staff? What led you to your current position?
How long have you been living/working in your community?
Why are you interested in climate change?

2) Stakeholder Climate Risks

What would you consider a "normal" winter/seasons?
What changes have you seen in your lifetime/career/time in the destination?
What climate change risks are you concerned about? What will the implications of those identified risks be on other aspects of the local socio-ecological system?
What is driving those risks?
What adaptations are currently in place? Are these adaptations successful? Under what conditions? What other adaptations would you suggest?

3) Stakeholder Carbon Risks:
What carbon risks are you concerned about? Regulatory changes? Social pressures? What will the implications of those identified risks be on other aspects of the local socio-ecological system?
What is the source of carbon risks?
What mitigation strategies are currently in place? Are these mitigations successful? Under what conditions?
What other mitigations would you suggest?

4) Conflicting Goals & Contested Values (multi-stakeholder based)

Who do you feel is responsible to respond climate and carbon risks in your community?
What other stakeholders directly or indirectly influence climate and carbon risks and responses in your destination?
Do you feel your perspectives align with other stakeholders (industry expert, municipal policy maker, community activist, others)? If not where do you think the differences exist?
Do you feel your perspectives align with other ski tourism destinations across Canada? If not, where do you think the differences lie?

What have you learned in your position or through your experiences that is important to think about when choosing climate actions and creating a climate strategy?
What information, knowledge or perspectives are missing that is hindering the effectiveness of climate responses?
Who else needs to be involved in creating and implementing climate action, responsiveness and solutions in your community?
What communication channels or information inputs could be created to allow for those voices, perspectives, ideas and knowledge to be incorporated?

5) Aspirational Vision (transformation-oriented approach),

What is the future you wish to see in your community, in 2030, 2050 and 2080? What are you working towards and if achieved what will that look like? Co-benefits? Trade-offs?

6) Potential Pathways and Barriers: Backcasting no regrets strategies (transformation-orientated approach)

How do we get to the desired future (identified in step 5)?
If you had no limitations, what would the top action you would implement to achieve the desired future?
What strategies, resources, support, stakeholder involvement would be needed to meet that objective?
What is stopping this from happening right now? What barriers do you foresee?

7) Response and Reactions to Case Study Scenarios

*Show participant(s) relevant case study scenarios including current, and future short (2050s) and long (2080s) time horizons and high (RCP8.5/SSP585) and low (RCP4.5/SSP124) emissions data, decarbonization targets, tourism projections etc. (see Table IV-2) and discuss the following:
How likely do you envision these scenario to be in terms of climate impacts?
How likely to you consider these scenario to be in terms of (de)carbonization?
How likely to you consider these scenario to be in terms of tourism futures?
How do these align with participant aspirational visions and identified pathways or barriers?
Is there other relevant information, sources, stakeholders which would enhance the case study scenarios, climate risk responsiveness or pathways to climate resilient mountain destinations?

Glossary

Edit all these to AR6 version IPCC Glossary (IPCC 2023b)

Adaptation	"In human systems, the process of adjustment to actual or expected climate and its effects, to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects. S" (IPCC 2022c:2898). Adaptation can be spontaneous or planned and can be carried out in response to or in anticipation of changes in conditions (IPCC 1995).
Climate	"[T]he average weather -or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities- over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (WMO). The relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system" (IPCC 2022c:2902).
Climate Change	"A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note: The United Nations Framework Convention on Climate Change (UNFCCC), defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes." (IPCC 2022c: 2902)
Decarbonization	"Human actions to reduce carbon dioxide emissions from human activities." (IPCC 2022c: 2905)
Equity	"The principle of being fair and impartial, and a basis for understanding how the impacts and responses to climate change, including costs and benefits, are distributed in and by society in more or less equal ways. Often aligned with ideas of equality, fairness and justice and applied with respect to equity in the responsibility for, and distribution of, climate impacts and policies across society, generations, and gender, and in the

	sense of who participates and controls the processes of decision-making." (IPCC 2022c: 2908)
Impacts	"The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather/climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, health and well-being, ecosystems and species, economic, social, and cultural assets, services (including ecosystem services) and infrastructure. Impacts may be referred to as consequences or outcomes and can be adverse or beneficial." (IPCC 2022c: 2912)
(Climate) Justice	"Justice that links development and human rights to achieve a human-centered approach to addressing climate change, safeguarding the rights of the most vulnerable people and sharing the burdens and benefits of climate change and its impacts equitably and fairly" (IPCC 2022c: 2912)
Maladaptation	"Actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas (GHG) emissions, increased, or shifted vulnerability to climate change, more inequitable outcomes, or diminished welfare, now or in the future. Most often, maladaptation is an unintended consequence" (IPCC 2022c: 2915).
Mitigation	"A human intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC 2022c: 2915).
Net-zero emissions	"Net-zero emissions are achieved when anthropogenic emissions of greenhouse gasses are balanced globally by anthropogenic removals over a specified period (IPCC 2018; 555).
Over-tourism	"The impact of tourism on a destination, or parts thereof, that excessively influences perceived quality of life of citizens and/or visitors in a negative way" UNWTO (2018: 4).
Pathways	"The temporal evolution of natural and/or human systems towards a future state. Pathway concepts range from sets of quantitative and qualitative scenarios or narratives of potential futures to solution-oriented decision-making processes to achieve desirable societal goals. Pathway approaches typically focus on biophysical, techno-economic and/or socio-behavioural trajectories and involve various dynamics, goals, and actors across different scales." (IPCC 2022c: 2917)
Risk	"The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential

	impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social, and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species… In the context of climate change responses, risks result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the Sustainable Development Goals (SDGs). Risks can arise for example from uncertainty in the implementation, effectiveness or outcomes of climate policy, climate-related investments, technology development or adoption, and system transitions.” (IPCC 2022c; 2921)
Risk Perception	“The subjective judgment that people make about the characteristics and severity of a risk” (IPCC 2022c: 2921)
Sustainability	“A dynamic process that guarantees the persistence of natural and human systems in an equitable manner” (IPCC 2018;559)
Tourism	“Refers to the activity of visitors” (UNWTO 2008: 10)
Tourist	A person taking “a trip to a destination outside their usual environment, for less than a year, for any main purpose (business, leisure, or other personal purpose) other than to be employed by a resident entity in the country or place visited” (UNWTO 2008: 10)
Transformation	“A change in the fundamental attributes of natural and human systems” (IPCC 2022c: 2925)
Transition	“The process of changing from one state or condition to another in a given period of time. Transition can occur in individuals, firms, cities, regions, and nations, and can be based on incremental or transformative change” (IPCC 2022c: 2925
Well-being	“A state of existence that fulfils various human needs, including material living conditions and quality of life, as well as the ability to pursue one’s goals, to thrive, and quality of life, as well as the ability to pursue one’s goals, to thrive, and feel satisfied with one’s life. Ecosystem well-being refers to the ability of ecosystems to maintain their diversity and quality” (IPCC 2018; 560)