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The Irony of Climate Science and the Race to Net Zero: A Carbon Footprint Investigation

by

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ABSTRACT

A carbon footprint investigation of the Kluane Lake Research Station (KLRS), which supports the advancement of climate science, is vital to identify the organization's large-scale contribution to climate change. A comprehensive measurement of KLRS's emissions profile enables the development of effective mitigation and management strategies to approach net zero carbon, in alignment with current IPCC projections. The GHG Protocol Standard was applied to evaluate KLRS's material emission sources and understand its energy demands and environmental impacts, supplemented with an economic analysis of mitigation efforts addressing its predominant direct contributor. The findings yielded 86 percent of KLRS's absolute emissions were scope 3 with 86 percent attributable to aviation, emphasizing the importance of decarbonization, extensive behavioural change, and global collaboration essential to progress this fundamental exploration whilst minimizing its impact. This signifies a critical juncture in addressing climate science's ironically high carbon signature and the synergistic pursuit required to realize carbon neutrality.

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AINA: Arctic Institute of North America

CH_4: Methane

CO_2: Carbon dioxide

CO_2e: Carbon dioxide equivalent

Defra: Department for Environment, Food & Rural Affairs

EF: Emission factor

FTE: Full time equivalent

GWP: Global warming potential

GCD: Great circle distance

GHG: Greenhouse gas

HGV: Heavy goods vehicle

HFC: Hydrofluorocarbons

H_2O: Water

IPCC: Intergovernmental Panel on Climate Change

kg: Kilogram, unit of mass

KLRS: Kluane Lake Research Station

km: Kilometre, unit of length

kW: Kilowatt, unit of power

kWh: Kilowatt hour, unit of energy

kWp: Kilowatts peak or installed kilowatt, solar electricity system rating

L: Litre, unit of volume

LPG: Liquefied petroleum gas, also known as propane

M: Thousand multiplier

MM: Million multiplier

MMBtu: Million British thermal unit, unit of energy

NEB: National Energy Board

NF_3: Nitrogen trifluoride

N_2O: Nitrous oxide

NPV:	Net present value
O&M:	Operation & maintenance
O_3:	Ozone
PFC:	Perfluorocarbons
pkm:	Passenger.kilometre
PV:	Photovoltaic
RF:	Radiative forcing
SDB:	Self-determination Benefit
SDG:	Sustainable development goals
SF_6:	Sulphur hexafluoride
t:	Tonne, unit of mass, equivalent to 1000 kg.
tkm:	Tonne.kilometre
UK:	United Kingdom
UN:	United Nations
UNFCCC:	United Nations Framework Convention on Climate Change
U of C:	University of Calgary
WEEE:	Waste electrical and electronic equipment
WhiteCAP:	Whitehorse Community Adaptation Project
WTT:	Well-to-tank
WWF:	World Wildlife Fund

CHAPTER 1: INTRODUCTION

As climate scientists race to understand the extent of the anthropogenic impact on our climate cycle, the transformation can most notably be observed in the Arctic, where temperatures over a 50-year period have increased at twice the global average (Intergovernmental Panel on Climate Change [IPCC], 2018a). The irony manifests in the importance of the research being conducted by the many climate scientists who brave the cold Arctic conditions to acquire critical data over an increasingly large geographic region. This data is imperative to reduce the knowledge gap and to help improve climate models and the ability to predict and respond to local and regional impacts (Arctic Monitoring and Assessment Programme [AMAP], 2017). However, the need to travel from far and wide to access these remote locations and to disseminate one's findings globally, further exacerbates the problem of rising greenhouse gas (GHG) emissions, making it more difficult to approach net zero carbon across the entire system. This capstone will focus on the Arctic Institute of North America (AINA) and their pursuit toward net zero carbon by evaluating the carbon footprint of the Kluane Lake Research Station (KLRS), through capturing the direct and indirect emissions, and developing a preliminary carbon reduction plan to further progress toward that goal. These solutions will be evaluated based on economic merit to determine feasibility as well as the environmental and social benefits.

1.1. BACKGROUND ON KLUANE LAKE RESEARCH STATION

The Kluane Lake Research Station is owned by the University of Calgary (U of C) and operated by the Arctic Institute of North America and is typically operational between the months of April and October. Due to its remote location, 220 km northwest of the city of Whitehorse, Yukon, it is off the grid and relies heavily on diesel power generation, propane tanks for heating and cooking and the long-distance transport of people and goods. Established in 1961, KLRS has long provided housing, support (both material and logistical) and sundry opportunities, due to the geological diversity of the surrounding landscape for researchers to explore from both national and international communities (Arctic Institute of North America [AINA], n.d.). Ideally situated next to the St. Elias Mountain Range and Icefields, the world's largest non-polar icefield, it is surrounded by the northern boreal forest and is positioned along Kluane Lake's south shore

(Arctic Institute of North America [AINA], 2017). In proximity to the Kluane National Park and Reserve, KLRS lies within the traditional territories of the Kluane, Champagne and Aishihik, and White River First Nations (Arctic Institute of North America [AINA], n.d.). KLRS continues to actively support the advancement of northern research and plays a pivotal role in furthering research on climate science and promoting sustainability initiatives within its host communities.

1.2. PURPOSE OF RESEARCH

Using methodologies outlined by the GHG Protocol Standard (Greenhouse Gas Protocol, 2019), major sources of carbon emissions were evaluated throughout KLRS's value chain to capture direct emissions related to the energy consumed during facility operations (scope 1 emissions) as well as indirect emissions associated with its upstream activities (scope 3 emissions). To complement the findings, a preliminary carbon reduction plan was developed to provide possible recommendations to enable the reduction of KLRS's carbon footprint including renewable energy solutions, energy efficiency products, carbon offset projects, and the arguably most important, behavioural change. Finally, an economic analysis was conducted in the form of a cost benefit analysis to address the station's largest contributor to scope 1 emissions.

A comprehensive understanding of KLRS's distribution of scope 1 and 3 emissions better enables them to set functional targets and prioritize initiatives to achieve their strategic goal of approaching carbon neutrality. As formulated by the GHG Protocol Standard, if you can't measure it, you can't manage it (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004), signifying the value one's carbon footprint has in progressing an organization towards effective emissions management and mitigation.

1.3. THE IMPACT OF CLIMATE CHANGE ON A LOCAL AND GLOBAL SCALE

From a global perspective, recent findings highlight the shifting state of the Arctic's climate including (Arctic Monitoring and Assessment Programme [AMAP], 2017):

1) an Arctic Ocean potentially free of sea ice during the summer months by the late 2030s;
2) the underestimation of the low-end Intergovernmental Panel on Climate Change (IPCC) projections for sea-level rise due to additional melt processes; and,

3) the far-reaching changes thought to be influencing weather in the mid-latitudes (Arctic Monitoring and Assessment Programme [AMAP], 2017).

On a local and regional scale, climate change impacts have led to numerous localities investing time and energy into creating adaptation plans to prepare for the gradual and extreme changes that will continue to transpire (Intergovernmental Panel on Climate Change [IPCC], 2018a). This will affect both the natural ecosystem and the human infrastructure developed to withstand the challenging climate, especially in the northern territories (Intergovernmental Panel on Climate Change [IPCC], 2018a). Climate-related risks do not depend solely on the rate and magnitude of global warming, but are also determined by geographic location, vulnerability and development, and the implementation of mitigation and adaptation strategies (Intergovernmental Panel on Climate Change [IPCC], 2018a). If executed, these strategies can reduce future climate-related risks through scaling and expediting mitigation measures and incremental and transformational change (Intergovernmental Panel on Climate Change [IPCC], 2018a).

As the Kluane Lake Research Station is situated in the Yukon territory, a review of the current and evolving territorial climate strategy with respect to mitigation and adaptation in response to climate change was conducted. Identification of the current measures being taken to reduce collective contribution and the impact of changing conditions affecting the Yukon's natural and built environment assists in setting a territorial baseline strategic action plan. This information is valuable for KLRS to align its own strategic goals with the Yukon, and in the process identify possible areas for collaboration, and positively contribute to reducing its own impact on the environment and the communities with which it interacts. Existing solar resource projects within the Yukon were also evaluated to understand the potential for success of solar photovoltaic (PV) installations within KLRS to supplant diesel power generation.

Due to the proximity of KLRS to Whitehorse, a review of the Whitehorse Community Adaptation Project (WhiteCAP) developed to respond to climate change (Hennessey & Streicker, 2011) was critical in understanding the importance of operational changes at KLRS that can indirectly impact local and regional communities. Members of the Whitehorse community and greater Yukon have experienced changing climate dating back to the 1940s from observed weather data (Hennessey

& Streicker, 2011). This has included warming temperatures (most notable in winter), the early arrival of spring break-up, the delay in freeze-up and the increasing number of days frost-free (Hennessey & Streicker, 2011). The developed plan details multiple scenarios of community changes from 2011 to 2050, assesses climate change impact risks and vulnerabilities and prioritizes adaptation plans, with some aspects of the established plan already implemented (Hennessey & Streicker, 2011). The five priority sectors identified were natural hazards (fire and flood), environment, infrastructure, and the security of food and energy (Hennessey & Streicker, 2011). In addition, a few case studies were reviewed to understand the common challenges facing remote northern communities, their movement toward reducing reliance on diesel, and active green energy projects within the Yukon, more specifically, within neighbouring communities of KLRS.

As the Arctic Institute has been a constituent of the University of Calgary since 1976, it endeavors to ensure its administration and operations are strategically aligned with, if not exceeding, the sustainability initiatives established within the U of C under the broader 2015 Institutional Sustainability Strategy framework (University of Calgary, 2015). As energy consumption continues to be the U of C's greatest source of GHG emissions (U of C Office of Sustainability, 2018), the university is focused on supporting initiatives to transition toward a low carbon economy, eventually striving to achieve net carbon neutrality (University of Calgary, 2019). One such achievement is the U of C's reduction in GHG emissions by 30 percent across all sites despite a 16 percent increase in the student population and incremental additions of built area over 180,000 square metres, when comparing 2018 actuals to 2008 baseline (University of Calgary, 2019). Although the latest GHG inventory posted a 32 percent decrease in GHG intensity per capita, this indicator excludes scope 3 emissions (U of C Office of Sustainability, 2018).

1.4. SCOPE 1 TO SCOPE 3 EMISSIONS OF KLUANE LAKE RESEARCH STATION

Scope 1 emissions capture all direct GHG emissions related to sources controlled or owned by the organization (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004). This includes the operation of buildings, equipment and vehicles owned or controlled by AINA and used at KLRS. Scope 2 emissions are those indirect GHG emissions generated from purchased electricity (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004), which was irrelevant for this study due to the research station being off the grid. Finally, scope 3 emissions are the remaining indirect GHG emissions that are optional with respect to reporting and are often overlooked, despite comprising a substantial share of an organization's carbon footprint (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004). These emissions result from the organization's activities but occur from sources outside of its control (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004). In application to this study, upstream activities indirectly related to KLRS included business-related travel of local and international users and employees, the procurement of goods and services and associated freight, employee commuting, and waste generated during operation. For comparison, a GHG inventory conducted by Kraft Foods found scope 3 emissions constituted greater than 90 percent of their collective scope 1, 2 and 3 emissions, emphasizing the importance of capturing its magnitude to further realize reduction efforts (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2011).

1.5. ENERGY, ENVIRONMENT AND ECONOMICS

This carbon footprint study is multi-disciplinary and will be anchored in energy, environment and economics. The first anchor evaluated was energy and its relevance to the Arctic Institute with respect to the unique circumstances that surround its mission and vision; "to advance the study of the North American and circumpolar Arctic…and to acquire, preserve and disseminate information on physical, environmental and social conditions in the North," (Murray, 2016, para.2) while "*Advancing Knowledge for a Changing North*" (Murray, 2016, para.2), respectively. The total direct and indirect energy needs of KLRS were identified to understand the operational requirements of the station. A comprehensive study was thought to enable KLRS to better prepare for and adapt to the inevitable changes that will transpire in the northern communities over subsequent decades.

These energy needs were analyzed and associated GHG emissions related to scope 1 and 3 categories were calculated to understand KLRS's carbon footprint and its impact on the environment, the second pillar studied. Of the seven GHGs covered under the Kyoto Protocol (United Nations Climate Change, 2019), those most applicable to this study were carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), with final results normalized to CO_2 equivalents (CO_2e) for comparative purposes. Potential avenues to reduce emissions were assessed with greater consideration given to those emissions generated within the direct operational control of KLRS that can be effectively managed, reduced or eliminated through investment in clean energy technology, energy efficiency and food sustainability initiatives. In addition, carbon offset programs for those emissions near impossible to reduce at source, such as business travel conducted to collect pertinent data at KLRS were briefly reviewed.

The third and final dimension evaluated was the economics of investment in a renewable energy system to help mitigate KLRS's reliance on fossil fuels. A cost benefit analysis of the replacement of the diesel-fired power generation system with a hybrid solar diesel power and battery storage system was conducted to understand the financial, environmental, and social benefits of shifting away from diesel. Incorporating the avoided costs of diesel, beyond fuel savings, provides a more comprehensive view of both energy systems and supports the development and execution of appropriate energy and environmental management strategies.

The findings can provide scalable learnings for the dozens of other remote research stations confronting analogous challenges in reducing their carbon signatures. Though the carbon footprint of KLRS may be miniscule in comparison to the generation at a global scale, these initiatives hold merit on being exemplary rather than contributing to a growing problem, especially with the rapid advancement and rising affluence of developing nations. Though these changes may have no near-term impact due to warming trends already "locked into the climate system" (Arctic Monitoring and Assessment Programme [AMAP], 2017, p. viii), changes now can ensure a future impact that is greatly reduced much sooner than century's end.

CHAPTER 2: BACKGROUND

This section will review the position of KLRS as a research station and community leader in sustainability, the climate strategies being progressed by both the Yukon territory and University of Calgary, with overarching targets established by the United Nations (UN) Sustainable Development Goals (SDG) for global benchmarking. In addition, the socio-economic challenges confronting many remote off-grid northern communities and the growing divergence from diesel leading to the greater adoption of renewable energy projects will be reviewed.

2.1. THE UNIQUE POSITION OF THE KLUANE LAKE RESEARCH STATION

The Kluane Lake Research Station is unique in its geographic setting and combined purpose. Although relatively remote and off the grid, it provides researchers easy access to the largest sub-polar icefield in the world, on the south shore of the Yukon's largest lake (Arctic Institute of North America [AINA], 2019). While located just north of the 60th parallel, its diverse subarctic landscape experiences short seasons of long summer days and long seasons of short winter days (Kluane First Nation, 2019b) bringing its own set of challenges, particularly from an energy perspective. KLRS aims to play a role in fostering both local and international relationships, from project collaboration and promoting sustainability initiatives within adjacent communities to supporting research to further climate science within the international research community. Through its grassroots initiatives, KLRS provides an ideal environment to safely experiment with both disruptive and conventional technologies to promote sustainability initiatives, with the latter's implementation potentially not fully quantified for the challenging northern winters. As KLRS operates for only half the year, a comprehensive understanding of harsh climatic challenges and how these might impact energy solutions with respect to pilot projects are somewhat limited by gaps in operational continuity. Despite limitations, KLRS initiatives still provide tremendous value over the active data collection months, which is currently representative of net facility use.

KLRS's location midway between Haines Junction and Burwash Landing, a grid-connected and off the grid community respectively, provides those at KLRS some semblance of understanding with respect to the struggles of living off-grid. The shared commonalities with local communities of Destruction Bay and Burwash Landing, such as receding shorelines at Kluane Lake, reliance on diesel fuel for electricity generation, and concerns for food and energy security primarily related to affordability, emphasize the vulnerability of those within northern Canada, with respect to extreme weather, satellite communication, and exposure to health and environmental risks of fossil fuel combustion for survival. ***As an ambassador of sustainability and a crucial facility in furthering the knowledge of climate science, the Kluane Lake Research Station should endeavor to progress toward being a leader in promoting low carbon intensity energy initiatives throughout its direct operations.***

2.2. THE YUKON'S CLIMATE STRATEGIES

2.2.1. Climate Impacts Observed Within the Yukon

The science has illustrated the climate change impacts observed in the Canadian North are accelerated and more substantial than in many other regions, with rates of warming more than double that of the global average (Government of Yukon, 2019a). Between 1948 and 2016, the average recorded temperature within the Yukon increased by 2.3 degrees Celsius with an average of 4.3 degrees Celsius observed over the winter seasons (Government of Yukon, 2019a). These temperature increases affect the Yukon and impact the amount of precipitation that falls each season, the thawing of the permafrost, accelerated melting of sea ice and glaciers, reductions in water quality due to material changes affecting lakes and rivers, and an increase in extreme weather events (Government of Yukon, 2019a). These impacts alter both plant and animal habitats with documented reductions in population or migration of species, which enables the northern movement of invasive species (Government of Yukon, 2019a). Those who live closest to the land experience and feel these cumulative effects the most, forcing many Indigenous groups within the Yukon to alter their traditional ways of life. These climatic changes can have detrimental impacts on the land's biocapacity, the physical infrastructure utilized by its inhabitants and cause deterioration in human mental and physical health (Government of Yukon, 2019a). As a part of the Yukon community, KLRS has experienced firsthand the early thaws of permafrost, receding glaciers, increased precipitation and average two degree warming over the last 70 years.

2.2.2. Government of Yukon Climate Strategies

In response to these changes, the Yukon Government has developed and continues to update its climate strategy, including mitigation and adaptation measures to reduce its contribution to climate change and limit the negative impacts felt by its citizens through building resilience. The latest report published in November 2018 was a *Climate Change Action Plan Update* prepared by the Climate Change Secretariat highlighting the progress of ongoing projects between the periods of January 2016 and June 2018, which specified the need for improved measurement and reporting of its energy consumption and consequent GHG emissions through establishing commitments that are measurable, costed and time-bound, and compared to recognized metrics (Climate Change Secretariat, 2018). A new strategy slated for release in late 2019 is proposed to increase public engagement and collaboration with transboundary First Nations and municipalities, establish more detailed and transparent targets, prioritize commitments through risk-weighted approaches, and place greater emphasis on the interconnection between energy, climate change and the growth of a green economy, further enabling the ability for communities within the Yukon to thrive (Climate Change Secretariat, 2018).

2.2.2.1. The Yukon's Greenhouse Gas Emissions

As per the Government of Canada's National Inventory Report submitted to the United Nations Framework Convention on Climate Change (UNFCCC), the Yukon's largest source of emissions in 2016 was road and air transportation at 62 percent, followed by space heating at 18 percent and the combustion of diesel at 12 percent (Climate Change Secretariat, 2018). Although a 2.6 percent increase in GHG emissions was observed between 2009 to 2016, a 13 percent decrease was recorded between its peak in 2011 compared to 2016 (Government of Yukon, 2019b). Since the 2009 baseline, road transport-related emissions increased by 14 percent with a 15 percent and 12 percent increase recorded in on-road diesel and on-road gasoline, respectively, compared to 2016; aviation gas or jet fuel increased by 32 percent over the same period (Government of Yukon, 2019b). These statistics capture the demand growth of Yukon residents, with similar trends seen both nationally and globally, emphasizing the mounting importance of the continuous monitoring and forecasting of GHG emissions.

2.2.2.2. Mitigation Strategies

In order to address some of the Yukon's most dominant emissions, the City of Whitehorse and Government of Yukon collaborated to launch a ridesharing program in 2016 to reduce transportation emissions and incentivize commuters to offset costs (Climate Change Secretariat, 2018) through promoting carpooling at least once a week (RideShark, 2019). Additional projects include improved energy efficiency within new infrastructure projects and boiler replacements with more energy efficient models at various elementary and secondary schools within the Yukon, the use of hydro power for space heating within government buildings fitted with secondary electric boiler systems during periods of low-demand, and enhancing waste diversion efforts through composting and recycling (Climate Change Secretariat, 2018).

Despite the need to improve the data quality, measurement and achievement of Yukon-wide emissions targets, two of twelve targets set within the electricity, transportation and building sectors in 2012 were met in advance of the 2020 end date (Climate Change Secretariat, 2018). This included a 20 percent reduction in emission intensity of power generated by grid-connected diesel systems and a five percent reduction in emission intensity for existing buildings Yukon-wide, including residential, institutional and commercial (Climate Change Secretariat, 2018). Microgeneration policies, increased hydropower generation capacity, and the implementation of residential and commercial energy incentive and rebate programs enable Yukoners to invest in systems to reduce energy consumption, its associated emissions and improve energy performance, with the potential to sell surplus energy back to the grid (Government of Yukon, 2019b). These examples and other moving targets need to be more rigorously progressed to ensure the impact on the Yukon and the global system is minimized.

2.2.2.3. Adaptation Strategies

In response to some climate change impacts already realized and those forthcoming, the Yukon government secured $2 million of funding in 2012 from the Crown-Indigenous Relations and Northern Affairs for adaptation projects up to 2016 (Climate Change Secretariat, 2018). This capital was spent on projects that reviewed how the changing conditions surrounding permafrost created new challenges for agriculture and impacted the integrity of highways with adaptation designs to preserve permafrost studied and implemented, the Yukon forest's vulnerability to climate change and the Mountain Pine Beetle's proliferation as dependent on variable climate scenarios, flood-plain risk mapping, and other initiatives including an innovative film and speaker series to improve communication of strategies and methods for climate change adaptation (Climate Change Secretariat, 2018). In addition, the Yukon government continues to collaborate with the Yukon College to create a standardized method for modelling climate change to improve trend and projection comparison (Climate Change Secretariat, 2018). Another $1.9 million was secured from the same agency for an additional thirteen adaptation projects over 2018 to 2021 (Climate Change Secretariat, 2018). These ongoing projects capture the importance of continued consideration and financial dedication to projects that proactively address climate risks.

2.2.3. Whitehorse Community Adaptation Plan

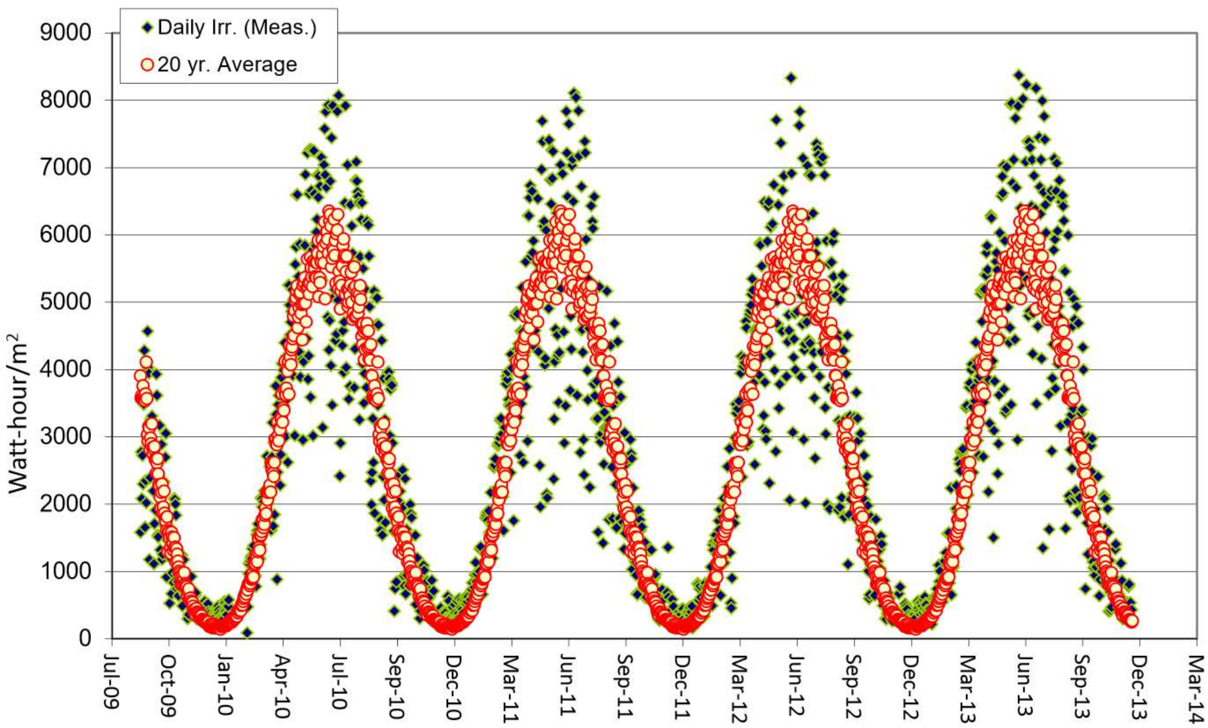
When evolving Whitehorse's Adaptation Strategy, its vision incorporated six key steps which included the preparation for both uncertainty and variability, the building of four foundational tenets (capacity, knowledge, resilience, and effective partnerships), and arguably the most important, the integration of sustainable development (Hennessey & Streicker, 2011). Immediate actions submitted for climate change adaptation included emergency backup power for critical buildings, public education on both agricultural opportunities and food-related security risks, as well as water conservation (Hennessey & Streicker, 2011). The mainstreaming of adaptation measures in response to climate change was thought to increase local resilience and ensure the strategic integration of sustainable development within policy development, positively impacting energy management, land-use regulations and infrastructure improvements (Hennessey & Streicker, 2011). As both the built infrastructure and natural ecosystems change due to climatic factors, proactive knowledge and capacity building are critical to prepare for hazards and circumstances of catastrophic flood to analyze current gaps, understand the thresholds at which the state of ecosystems shift, study analogous circumpolar regions, and monitor the changing landscape over the long-term (Hennessey & Streicker, 2011). The Yukon Northern Strategy Trust funded $120,000 for eight WhiteCAP implementation projects within Whitehorse in response to identified environmental and food security risks (Hennessey & Streicker, 2011). These included edible landscaping, community gardens, the preservation and storage of food, the detached study of invasive species and groundwater, permaculture workshops focused on energy and food resilience, and the communication of Whitehorse adaptation projects through educational signage and short films (Hennessey & Streicker, 2011). In addition, further limiting GHG emissions and enhancing energy security through alternative energy is a focus for Whitehorse, as both a mitigation and adaptation measure (Hennessey & Streicker, 2011).

These projects, from both the municipal and territorial level, highlight the progress the Yukon is making to manage observed changes and better prepare itself for uncertainties around what the future holds with respect to climate change.

2.2.4. Solar Energy Projects Within the Yukon

In addition to current mitigation and adaptation strategies, a review was completed of the Yukon Government's 2014 Solar Energy Pilot monitoring the performance of solar PV installations within three grid-connected demonstration sites at various tilt angles from vertical dating back to 2008, which included a separate roof- and ground-mounted installation within Whitehorse and one roof-mounted system in the community of Watson Lake, located along the northern border of British Columbia (Yukon Government's Energy Solutions Centre, 2014). Under the supervision of the territorial government's Energy Solutions Centre, the provision of renewable energy for electricity generation to supplement a share of each building's power demand was recorded to enhance the understanding of Yukon's solar resource quality and the technology's effectiveness in a northern climate, as well as allow for capacity building with respect to the technology's operational performance (Yukon Government's Energy Solutions Centre, 2014).

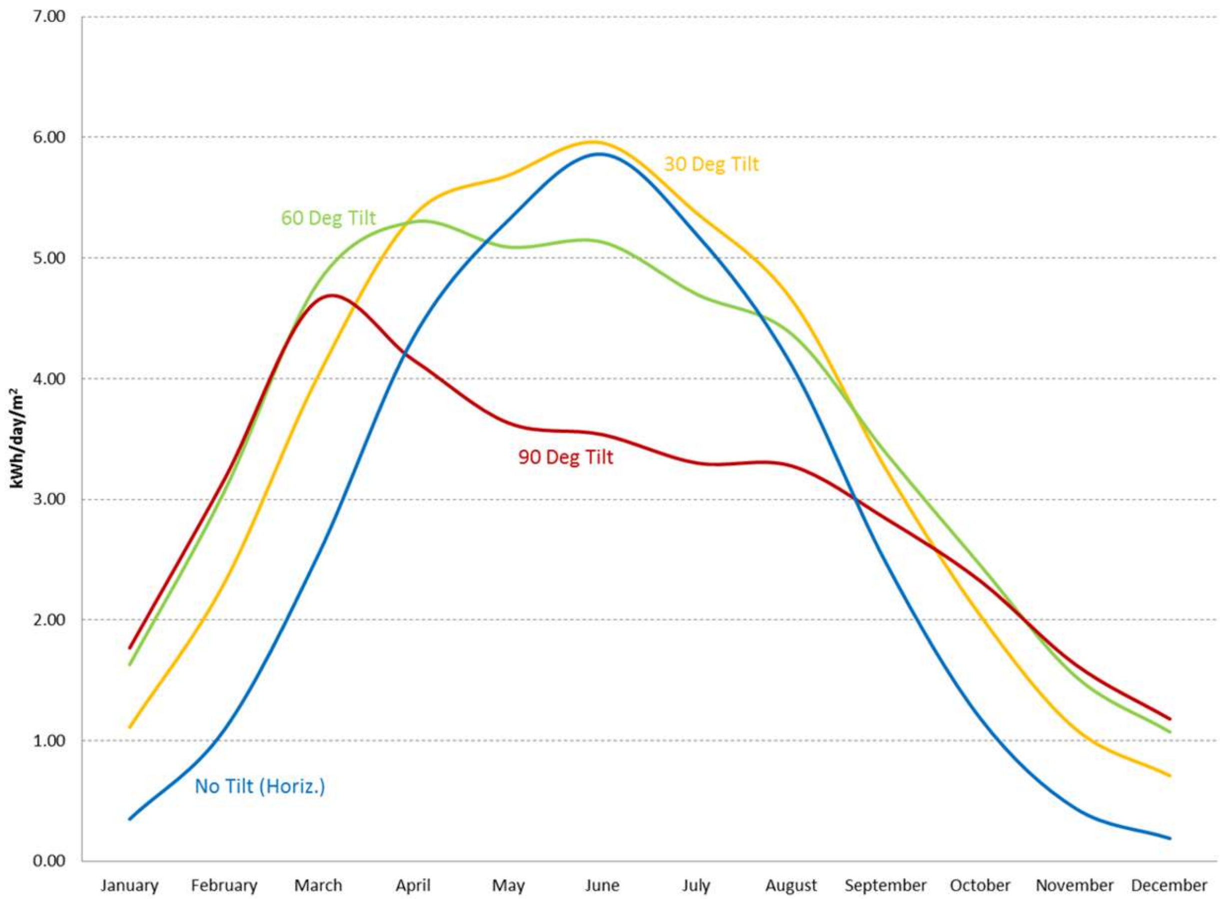
Figure 1. Whitehorse's Daily Average Solar Irradiance Measured on a Horizontal Surface



Source: (Yukon Government's Energy Solutions Centre, 2014)

Figure 1 captures annual cycles of solar irradiance collected between July 2009 and November 2013 from Whitehorse’s Yukon College demonstration site with daily average solar irradiance compared to the 20-year average collected by Environment Canada between 1974 and 1994 (Yukon Government's Energy Solutions Centre, 2014). The trends highlight the predictability and consistency of the solar resource within the Yukon (Yukon Government's Energy Solutions Centre, 2014). Though standard practice dictates measurement on a fixed horizontal surface, simulations suggest the Yukon’s ideal orientation is a strongly-tilted surface toward the southern hemisphere (Yukon Government's Energy Solutions Centre, 2014). This contributes to somewhat compromising the solar collection during mid-summer with increased solar collection throughout spring and fall, as illustrated in Figure 2 (Yukon Government's Energy Solutions Centre, 2014).

Figure 2. Effect of Tilt Angle on Solar Collection, Generated Using RetScreen®



Source: (Yukon Government's Energy Solutions Centre, 2014)

Simulations from PVSyst® and RetScreen® suggest annual maximums in solar collection can be achieved at tilt angles between 45 and 55 degrees in Yukon's southern and central regions (Yukon Government's Energy Solutions Centre, 2014), where KLRS is located. However, the report also submits the tilt angle will likely have a larger effect on the system's seasonal performance rather than its annual average performance (Yukon Government's Energy Solutions Centre, 2014). As evidenced, solar resources in the thick of Yukon winter are negligible due to snow-covered panels and limited hours of sun (Yukon Government's Energy Solutions Centre, 2014).

Despite the Yukon's challenging environmental conditions, positive results were recorded for the performance of the solar PV systems with the Yukon Government's installation at their main administration building performing 10 percent better on average than the simulation's projections over a five-year period between 2009 and 2013, producing an average annual PV of 1077 kWh/kWp with a 47 degree tilt angle from vertical (Yukon Government's Energy Solutions Centre, 2014). The increased performance was partially attributed to the above average solar resource over that period (Yukon Government's Energy Solutions Centre, 2014). The Yukon College’s re-commissioned PV system in Whitehorse performed comparatively to simulations at sub-negative two percent, believed attributable to shading effects generated by surrounding structures (Yukon Government's Energy Solutions Centre, 2014). An average annual PV of 825 kWh/kWp was produced between 2010 and 2013 at a 64 degree tilt angle from vertical (Yukon Government's Energy Solutions Centre, 2014). Finally, the Watson Lake community installation at the Space and Science Centre saw the system under-perform compared to simulations by 17 percent, during a more limited period between 2012 and 2013 (Yukon Government's Energy Solutions Centre, 2014). The reduced performance was believed due to significant snow coverage in the area resulting in poor winter performance, which is not accounted for in the simulation as it is dependent on satellite data, due to its location (Yukon Government's Energy Solutions Centre, 2014). However, it measured a comparable annual average PV of 991 kWh/kWp during this time with a 60 degree from vertical tilt angle (Yukon Government's Energy Solutions Centre, 2014).

All three systems recorded minimal operations and maintenance (O&M) costs over their respective time periods, except for the optional snow removal from modules (Yukon Government's Energy Solutions Centre, 2014). PV system installation costs have illustrated a steep downward trend dropping from a high of $17.10 per installed Watt at the main administration building in 2008 to a mid-range of $8.20 per installed Watt at Watson Lake in 2010 and $4.88 at the Kluane maintenance building in 2012, a partnered project with the government of the Kluane First Nation (Yukon Government's Energy Solutions Centre, 2014). Current estimated installation costs average between $2.50 and $3.50 per Watt (EnergyHub.org, 2019). The Yukon government permitted residents to sell surplus power back to the grid starting in 2015 which saw an influx of installations, making the Yukon the Western Canadian leader in operational solar panel units per capita as of August 2017, as per the Director of the Yukon Government’s Energy branch (Rudyk, 2017).

These results highlight the viability of solar energy technology within the Yukon and suggests their potential for longevity despite the harsh conditions they endure, with the Yukon College possessing solar panels in operation for more than 20 years. This data is relevant for KLRS and suggests similar installations would be successful within its location. Specific values of PV potential for locations adjacent to KLRS can be found in Appendix A: Cost Benefit Analysis from the PV and solar resources maps published within the Natural Resources Canada municipal databases.

2.3. REMOTE NORTHERN COMMUNITIES OF CANADA

There are more than 280 remote communities within Canada living off-grid (National Energy Board [NEB], 2019) with an estimated 170 reliant exclusively on diesel for power generation (Waterloo Global Science Initiative, 2016). The Yukon territories specifically, are not tied in to the North American natural gas pipeline distribution or electrical grid systems; however, there are four hydroelectric facilities supporting their territorial electricity grid, meeting 95 percent of their power demands through a renewable energy source (National Energy Board [NEB], 2019). Those communities not connected to the electricity grid rely heavily on diesel-fired power generation which is imported from Alaskan or Albertan refineries, by truck (National Energy Board [NEB], 2019). The widespread use of diesel fuel for power generation is due to its energy-dense properties and ease of storage with affordable and scalable generators that are simple to install and offer flexibility and reliability; important aspects within remote community settings (National Energy Board [NEB], 2019). However, fuel price volatility, high operating costs and GHG emissions, as well as external social impacts related to ecological and human health pose numerous challenges to communities reliant on it for survival (National Energy Board [NEB], 2019). This is encouraging the exploration and development of renewable energy projects within many off-grid communities to reduce their consumption of diesel fuel and consequent carbon emissions (National Energy Board [NEB], 2019).

The adoption of renewable energy powered microgrids are ideally located within areas of geographic isolation where remote communities do not have access to the electricity grid, largely due to the economics of supply (Waterloo Global Science Initiative, 2016). Comparatively, enabling these communities to generate their own renewable sources of power is more favourable economically, reducing the financial strain on rural populations of procuring diesel at high prices. The NCC Development, created by the chiefs from six northern Ontario First Nations communities, are progressing toward improving energy sustainability by implementing combined strategies of energy conservation, solar microgrid construction, and load management, to achieve a 50 percent reduction in fossil fuel dependence within remote First Nations communities (Waterloo Global Science Initiative, 2016). There is potential for these microgrids, operated using clean renewable energy, to reduce reliance on expensive sources of fuel and create socio-economic benefits for many of Canada's remote communities, provided resources are available to develop these systems (Waterloo Global Science Initiative, 2016). Section 2.3.2 will review some First Nations communities within the Yukon progressing toward similar goals.

2.3.1. Diverging from Diesel Study

A diverging from diesel study conducted by the Gwich'in Council International in 2016 endeavoured to discern true fossil fuel costs of powering northern Canada's remote off-grid communities and reviewed the value of alternative energy development through the realization of avoided costs benefits related to (Gwich'in Council International, 2016):

i) utility (mainly high operating costs associated with fuel and its transport);
ii) the generation of GHG emissions due to fossil fuel combustion through escalating federal carbon pricing and;
iii) social impacts attributed to environmental and health risks due to diesel fuel transportation, storage and combustion for home heating and electrical power generation (Gwich'in Council International, 2016)

Destruction Bay, a community within the Yukon and near to KLRS, was included in the study and though it reflects some of the lowest fuel costs per kWh compared to more remote communities in the North, such as Old Crow, Yukon which requires fuel to be flown in, provides some insight into the importance of looking at establishing a reasonable price for alternative energy projects that reduce fuel consumption, particularly diesel (Gwich'in Council International, 2016). With total utility costs estimated at $0.41/kWh (including fuel, overhaul, non-fuel O&M and capital), GHG costs between $0.01 and $0.05/kWh based on existing carbon tax structures of $10 and $50/tonne, and the additional consideration of social costs due to environmental and human health impacts between $0.0322/kWh and $0.1918/kWh, may increase the favourability of cleaner energy projects (Sullivan, 2017). The results of the study suggest diesel power's true cost within the remote Canadian north is often overlooked and is encouraging the exploration of opportunities of developing renewable energy within many off-grid communities to reduce their consumption of diesel fuel and consequent carbon emissions.

2.3.2. Renewable Energy Projects Surrounding Kluane Lake Research Station

The Kluane Lake Research Station resides on the traditional territory of the Kluane, Champagne Aishihik, and White River First Nations (Arctic Institute of North America [AINA], 2019). Both the Kluane First Nation and Champagne and Aishihik First Nation are self-governing in tripartite with the Yukon and federal governments (Kluane First Nation, 2019a) with settled land claims in 2004 and 1995, respectively; however, the White River First Nation remain a band with unsettled land claims, under the Indian Act (Government of Canada, 2011). The Kluane First Nation reside in Burwash Landing, the area historically used by the group as a summer camp (Kluane First Nation, 2019a), located 63 km NW of KLRS. The Champagne Aishihik First Nation reside in Haines Junction 63 km SW of KLRS, while the White River First Nation reside in Beaver Creek 233 km NW of KLRS, with road access year-round and more than 350 km from the closest service center (Government of Canada, 2013). Due to their geographic locations, the Kluane and White River First Nations are not connected to the territorial grid and are both reliant on diesel power generation (National Energy Board [NEB], 2019). However, due to the proximity of Haines Junction from a hydro power generating station, it is connected to the territorial grid, as illustrated in Figure 3 with specific attention to the SW rectangle. KLRS is represented by the upwards arrow.

The population appears to wildly fluctuate with a 2016 census indicating a population of approximately 70 people with 50 identifying as Aboriginal (Yukon Bureau of Statistics, 2018a) compared with a 2011 National Household Survey showing 80 of 95 inhabitants within Burwash Landing identifying as Aboriginal (Yukon Bureau of Statistics, 2015), a 37.5 percent decrease over five years, with oscillations exhibited in prior censuses. KLRS procures diesel fuel from Kluane

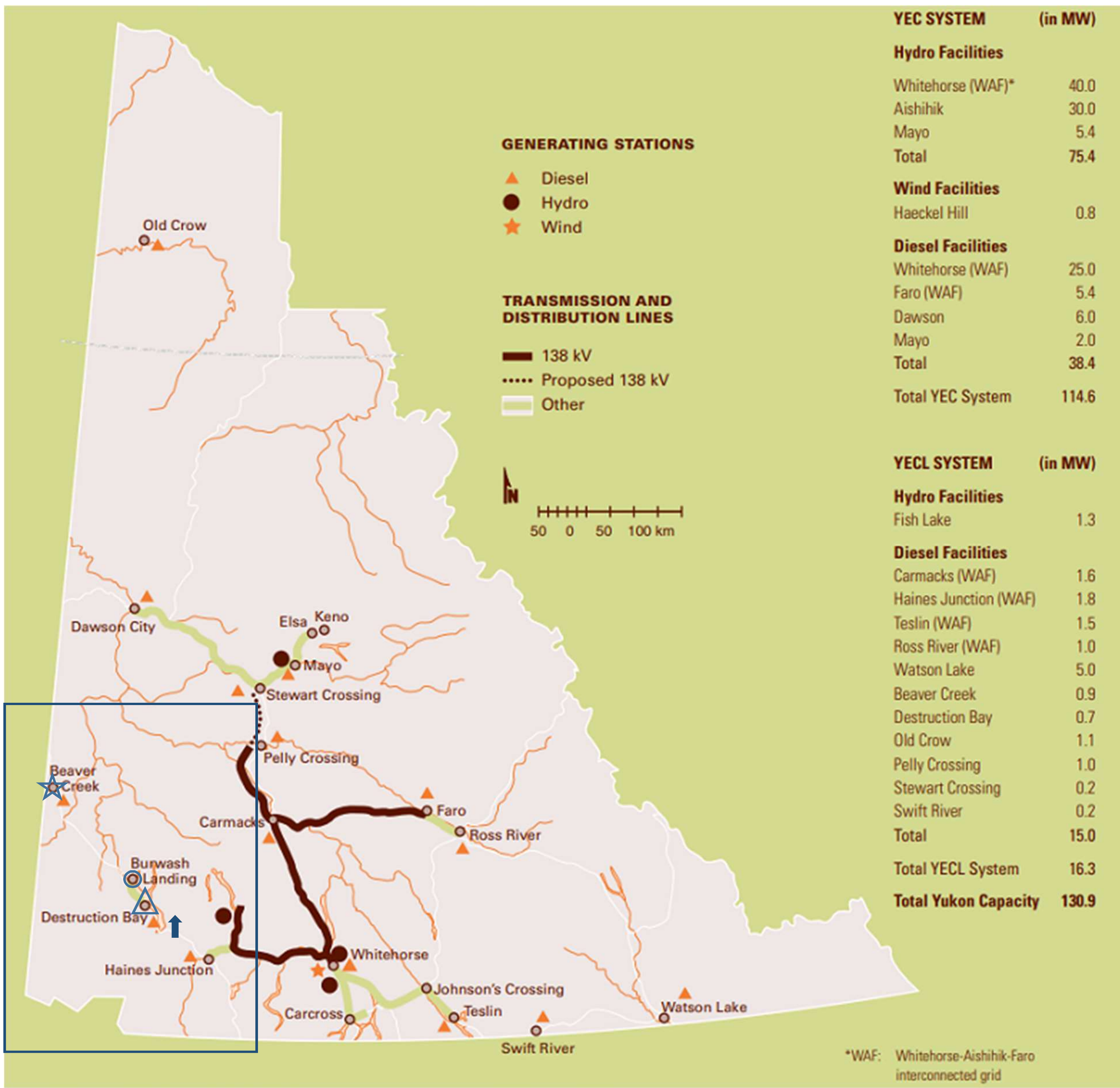
Energy out of Burwash Landing and continues to develop both customer and community partnerships with the First Nations community.

Figure 3. Yukon's Electrical Grids and Diesel, Hydro and Wind Generating Stations

Beaver Creek, Population: 93 ☆ Burwash Landing, Population: 72 O Destruction Bay, Population: 55 Δ

Community type: Settlement | Classification: Indigenous, First Nation

Main Power Source: Diesel | Secondary Power Source: N/A



Source: (National Energy Board [NEB], 2019)

The Northern REACHE or Northern Responsible Energy Approach for Community Heat and Electricity program, helps support the adoption of energy efficiency, renewable energy and associated capacity building through funding to progress sustainability and reduce the reliance on diesel fuel by northern communities, resulting in positive environmental and socio-economic benefits (Government of Canada, 2019a). The Yukon Government received the designated funding tabulated in Table 1 to support numerous projects; select First Nations communities are described in further detail below.

1) Kluane First Nation of Burwash Landing:

This funding was budgeted for the development of the Kluane Wind Farm, a renewable energy installation of three wind turbines with 100 kW capacity each and battery storage of 300 kWh (Government of Canada, 2019b; Government of Canada, 2019c; Government of Canada, 2019d).

2) Champagne-Aishihik First Nation of Haines Junction:

Funding from 2016/2017 was designated for a commercial building energy audit prior to 20 kW of solar PV systems being installed and additional energy saving measures being implemented (Government of Canada, 2019b).

In 2017/2018, funding was designated for energy efficiency retrofits at the Da Ku Cultural Centre, recommended from the previous year's assessment (Government of Canada, 2019c).

3) White River First Nation of Beaver Creek:

In 2017/2018, $97,900 in funding was designated for a similar commercial building energy audit prior to 20 kW of solar PV systems being installed and additional energy saving measures being implemented (Government of Canada, 2019c). An additional $45,800 was received the same year for a community green energy initiative to complete a feasibility study on district heating, heat recovery and diesel power generation (Government of Canada, 2019c).

Funding for 2018/2019 was budgeted for a study on how solar PV system integration would impact the grid in Beaver Creek (Government of Canada, 2019d).

Table 1. Select Northern REACHE Projects Within the Yukon Funded from 2016 to 2019

	Northern REACHE Projects			Total Funding [$]
	2016/2017	**2017/2018**	**2018/2019**	
Kluane First Nation	108,000	500,000	500,000	**1,108,000**
Champagne-Aishihik First Nation	110,333	136,600		**246,933**
White River First Nation		143,700	25,000	**168,700**
Total Funding [$]	**218,333**	**780,300**	**525,000**	**1,523,633**

Source: Adapted from various sources on the Indigenous and Northern Affairs Canada database (Government of Canada, 2019b; Government of Canada, 2019c; Government of Canada, 2019d)

Shedding light on these sustainable energy projects in First Nations communities surrounding the Kluane Lake Research Station emphasizes the importance of the research station moving away from diesel-fired power generation and becoming leaders in a territory that is focused on both climate change mitigation and adaptation, supported by investment in suitable infrastructure allowing it to move toward a lower footprint, address high operational costs and reduce the health effects attributed to diesel power generation.

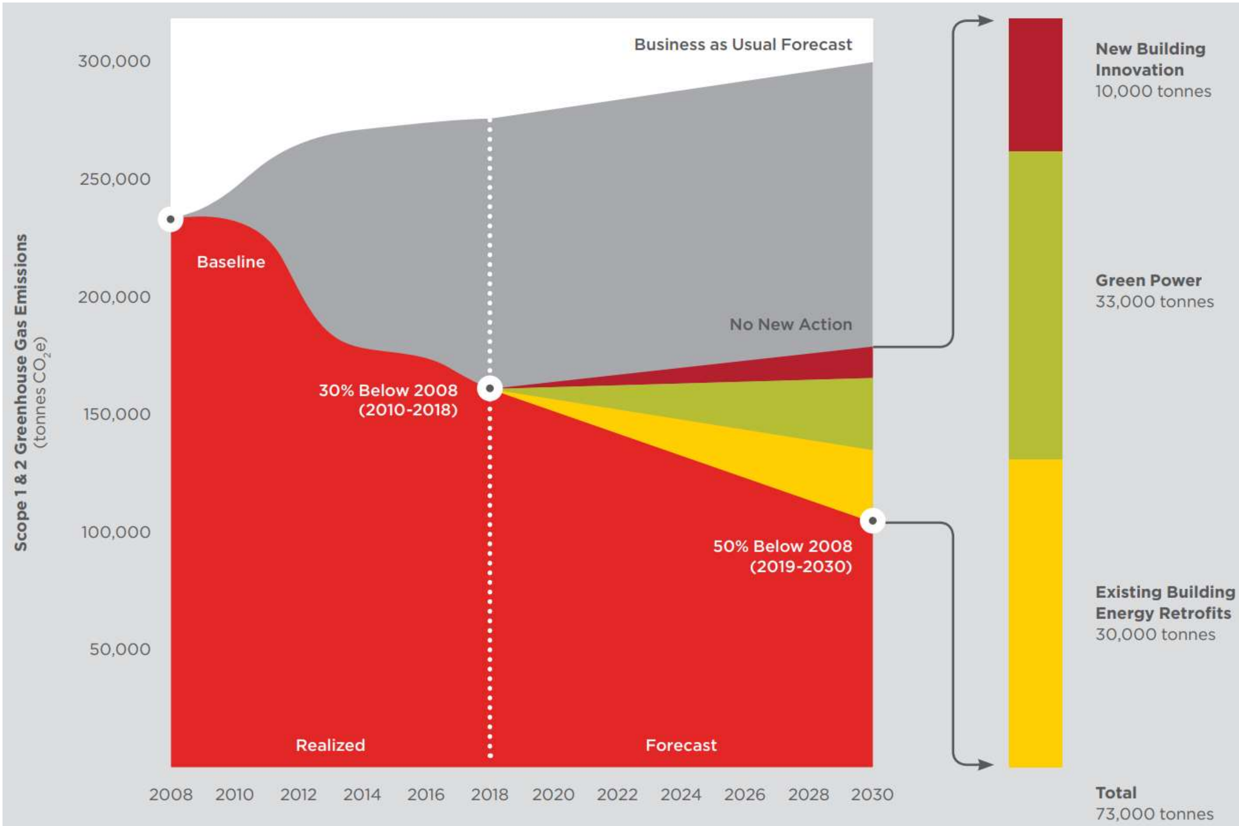
The Kluane N'tsi (Wind) Project is expected to displace more than 20 percent of the 160,000 litres of diesel fuel combusted annually between the communities of Burwash Landing and Destruction Bay for electricity generation, with a power purchase agreement with ATCO Electric Yukon and expected pricing equivalent to the avoided cost of diesel (Kluane Community Development Limited Partnership [KCDLP], n.d.). This project broke ground on National Indigenous Peoples Day on June 21, 2018 (Bullfrog Power, 2018) and is expected to begin electricity production in fall of 2019 (Croft, 2019). With Destruction Bay boasting a population of approximately 45 people (15 of Aboriginal identity) according to a 2016 census (Yukon Bureau of Statistics, 2018b), this project is helping move these Indigenous groups closer to their traditional beliefs as stewards of the land, embodying sustainability through limiting their environmental footprint (Bullfrog Power, 2018).

As KLRS is located in the Yukon, which has taken a territorial stance to combat climate change, a central part of the community engagement strategy will involve KLRS collaborating with local communities to support sustainability projects, progressively mitigating its own GHG emissions and proactively adapting its strategy in response to a changing climate. Strategic community engagement is exemplified by the CropBox initiative that KLRS has been involved with, which is a high-yield indoor hydroponics system developed to help improve northern food security, especially in remote communities.

2.4. UNIVERSITY OF CALGARY'S CLIMATE ACTION PLAN

As AINA is a research institute within the University of Calgary, it aims to strategically align itself with the U of C's 2019 Climate Action Plan which is actively working to measure, reduce and track its progress on cutting GHG emissions to achieve carbon neutrality on campus by 2050 (University of Calgary, 2019). The latest action plan serves as an operational roadmap to support the university's transition to a low carbon economy, strengthening campus resiliency while sparking innovation through updated strategies to mitigate emissions generated by campus operations and renewed targets aimed at the reduction of scope 1 and 2 emissions (University of Calgary, 2019). These targets are focused on behavioural change, a cleaner supply of green energy, and the reduction in energy demand (University of Calgary, 2019). Although the renewed targets notably exclude scope 3 specific goals, the action plan summary includes opportunities to act upon scope 3 emissions related to both purchasing and commuting, the renewal of zero-waste strategies through compost and recycling program expansion, as well as enhance engagement (University of Calgary, 2019). Further, it is worthwhile to note that although U of C includes scope 1, 2 and 3 emissions from sources in which U of C has direct operational control, it excludes financed air travel in its latest 2017/18 GHG inventory (U of C Office of Sustainability, 2018).

Figure 4. University of Calgary's Emissions Reduction Profile: 2008 Baseline to 2030



Source: (University of Calgary, 2019)

At a high level, the U of C's renewed targets aim to achieve a 35 percent reduction by 2025, 50 percent reduction by 2030 and a nearly 97 percent reduction by 2050, each compared to the 2008 baseline for total scope 1 and 2 emissions (University of Calgary, 2019). Figure 4 captures U of C's realized emissions reductions up to 2018 as well as those forecasted to meet the renewed targets. The 2019 Climate Action Plan named the U of C a Canadian leader among post-secondary institutions due to realized emissions reductions (University of Calgary, 2019). This successful reduction in GHG emissions was enabled through three key initiatives including the cogeneration unit installation on the main campus which recovers and reuses waste heat, the investment in building energy retrofits and new energy efficient buildings (University of Calgary, 2019). These investments are pertinent as 99 percent of total scope 1 and 2 emissions are from building operation, with an estimated utility cost avoidance of $4.8 million annually due to these reduction measures (University of Calgary, 2019).

These figures emphasis the financial returns of investing in energy efficiency, green energy and supporting the acceleration of a low carbon future, with an overarching emphasis on working together toward carbon neutrality. However, it is important scope 3 emissions are evaluated closely with targets also established to ensure some of the largest sources of emissions are not neglected.

2.5. SUSTAINABLE DEVELOPMENT GOALS

Various targets have been defined and indicators established with metrics to track the progress and achievement of various Sustainable Development Goals outlined by the United Nations (Roser, Ritchie, Ortiz-Ospina, & Mispy, SDG-Tracker.org, 2018a). The SDGs to be reviewed briefly look to ensure the global economy has access to clean and affordable energy and appropriate action is taken in alignment with the urgency of climate change, providing both opportunity and the ability to overcome present-day challenges (Roser, Ritchie, Ortiz-Ospina, & Mispy, SDG-Tracker.org, 2018a).

2.5.1. Sustainable Development Goal #7

As a fundamental component of our daily lives and responsible for continuous development, SDG 7 is affordable and clean energy (Roser, Ritchie, Ortiz-Ospina, & Mispy, 2018b). Energy has historically been transformative for people, planet and profit; however, its role in perpetuating climate change is too significant to disregard. The importance of ensuring the global economy has access to sustainable, reliable, affordable and modern energy (Roser, Ritchie, Ortiz-Ospina, & Mispy, 2018b) is critical to provide environmentally responsible growth opportunities and to help overcome complex challenges facing the world today. Some targets relevant to KLRS include improvements in energy efficiency, increasing percentages in renewable energy production for purposes of heating and cooking, electricity generation, and transportation, as well as investment in clean technologies (Roser, Ritchie, Ortiz-Ospina, & Mispy, 2018b).

2.5.2. Sustainable Development Goal #13

SDG 13 is climate action (Roser, Ritchie, Ortiz-Ospina, & Mispy, 2018c) and relates to both mitigation and adaptation measures. Due to greater availability, affordability and scalability of low carbon solutions, countries have the increased capacity to enhance the resiliency of their economies while reducing their climate impact through investment of renewable energy and other green technologies (Roser, Ritchie, Ortiz-Ospina, & Mispy, 2018c). Some targets relevant to KLRS include building both one's adaptive capacity and resilience to respond to climate-related disasters, integrating climate change into strategic planning, as well as capacity- and knowledge-building to address climate change with respect to mitigation, adaptation, early warning and impact reduction (Roser, Ritchie, Ortiz-Ospina, & Mispy, 2018c).

These targets and certainly more of the United Nations Sustainable Development Goals can be reviewed in KLRS's endeavour toward achieving carbon neutrality in their operations, which observe substantial alignment with those being progressed by the University of Calgary, the City of Whitehorse and the Yukon Government.

2.6. CARBON OFFSET PROJECTS

As climate change is non-localized and GHG emissions that accumulate in the atmosphere have global impacts, investing in carbon offset programs to offset KLRS's carbon footprint due to emissions generated from business travel is appropriate. There are numerous benefits of carbon offset programs beyond overall climate protection. These may include the promotion and safeguarding of biodiversity, supporting poverty reduction and human development, and advancing technology development by creating market conditions that benefit low-carbon sectors (Liu, Chen, & He, 2015). However, these benefits are dependent on programs selected for investment and can also face its own set of challenges. One such challenge highlighted in previous research suggests the cost-effectiveness of Alberta's Carbon Offset System may be an illusion and the commodification of offsets does not necessarily ensure neutral substitutability with true emissions reductions (Janmohamed, 2016). Another study, conducted in 2016, found 85 percent of the 7,700 Clean Development Mechanism offset projects evaluated, which is a mechanism developed from the Kyoto Protocol, had a low likelihood of assuring environmental integrity, such that emissions reductions were not over-estimated and have a component of additionality (Cames, et al., 2016). Thus, the importance of an accurate emissions calculation to understand one's footprint along with the careful consideration and selection of carbon offset projects are critical in the development and execution of effective strategies to veritably reduce overall emissions and maximize co-benefits.

In developing carbon offset programs, it will be prudent to carefully select projects that align with and further promote AINA's vision. Identifying ways in which carbon offset projects can help co-benefit some of the most vulnerable to climate change's impacts, including rural communities and Indigenous groups within the Yukon and Arctic, will help progress AINA's engagement of First Nations and Inuit within the dynamic north while advancing their research to meet the Arctic's diverse needs.

CHAPTER 3: METHODOLOGY

This section provides a detailed account of the process used to calculate the carbon footprint of the Kluane Lake Research Station including the:

- defined scope of work with system boundary detail,
- selection criteria for determining the applicable standard,
- source of conversion factors used and their applicability to the geographical area being studied and;
- source and quality of data collected.

Assumptions made during calculation are outlined in Section 3.6.3: Inputs & Assumptions and discussed in further detail under Section 4: Results. Due to the time constraints related to this project, a limited number of carbon reduction strategies were evaluated. As such, a cost benefit analysis was conducted comparing renewable energy system solutions to the existing diesel power generation system in place, which was anticipated to be the largest contributor of scope 1 emissions to the research station, due to the facility operational design. The detail provided in this chapter ensures the carbon footprint calculation is reproducible by AINA for purposes associated with KLRS and potentially within AINA's overseeing operations at the University of Calgary, including the ARCTIC Journal and international travel associated with the nature of the business. This will allow KLRS to:

- continuously monitor its carbon footprint compared to its 2018 baseline,
- refine assumptions to improve the precision and accuracy of data captured as well as the subsequent understanding of emission sources; and
- more efficiently track its organizational progress and the impact of implemented strategies toward GHG emissions reduction, with the hopes of achieving net zero carbon within an established time frame.

Only once the carbon footprint of KLRS is understood, can the organization set realistic goals and support capital investment initiatives to help them achieve their sustainability goals.

3.1. FRAMING OF CASE STUDY

Framing the case study requires the consideration of defining a scope extensive enough to provide AINA with insights into the carbon footprint of a key aspect of their organization while balancing time constraints imposed upon the study, within the six-month window.

3.1.1. Case Study Area Selection

Numerous aspects of the Arctic Institute of North America can be reviewed including the head office located within the University of Calgary Earth Sciences building and the administrative aspects associated with typical office operations, as well as the business travel accompanying a research institute. In addition, there is the physical dissemination of information through monthly publications of the ARCTIC Journal, which is distributed to a global network of subscribers. However, the careful consideration and ultimate selection of the Kluane Lake Research Station to focus this study included the diverse needs of the station and its unique purpose as a significant data hub in the heart of the Yukon, which attracts a wide variety of users that extend beyond national borders. As well, the location of the facility in a remote community within the northern territories highlights some of the unique issues facing the more than 280 Canadian communities disconnected from both the North American electricity grid and the pipeline network distributing natural gas (National Energy Board [NEB], 2019).

3.2. GOAL AND SCOPE DEFINITION & ESTABLISHING SYSTEM BOUNDARIES

The overarching goal of conducting a carbon footprint on the Kluane Lake Research Station is to understand its major sources of greenhouse gas emissions, both directly and indirectly related to its operations and subsequently assess its environmental impact. The intended application of the carbon footprint study is to help AINA and KLRS set strategic targets to progress toward its goal of achieving carbon neutrality. The target audience is the Kluane Lake Research Station, its parent organization the Arctic Institute of North America, and potentially other research stations faced with similar high carbon footprints owing to the nature and location of their respective operations.

Defining a scope that is too limited prevents AINA and KLRS from gaining a complete understanding of its operational risks. Building a comprehensive GHG inventory improves KLRS's understanding of its emission profile as well as captures the opportunities for optimization, helping to reduce potential exposure along its value chain (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013a). The importance of establishing an appropriate system boundary prior to carbon footprint calculation is to capture a baseline that accurately reflects the facility's daily operations, current utilization and peak annual user-days to circumvent underestimating the magnitude of its footprint and improve the repeatability of the calculations for subsequent comparative studies.

3.2.1. Temporal Boundary

The study's temporal boundary was set to 2018 spanning January 1, 2018 to December 31, 2018. This was not only based on the availability of a more comprehensive data set but is a better reflection of increased utilization and current user-days. Current strategies will be discussed below detailing operational changes administered to increase utilization of the research station. As such, the carbon footprint calculated from 2018 will serve as KLRS's operational baseline.

3.2.2. Operational Boundary

In establishing the operational boundary of the carbon footprint study, it was important to consider the principal purpose of the station to support the climate scientists and other researchers who use it as a base from which to conduct experimentation, to collect pertinent data from specific landmarks and to study the geological diversity of nearby landscapes. Due to this inimitable circumstance, it is important to include the activities of the users within the scope, as the station would not continue to exist without their patronage. The operational boundary is comprehensive to provide KLRS with a more complete picture of the risks and opportunities associated with its GHG exposure, reducing misinterpretation (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004) related to both direct operation of on-site facilities and the upstream activities associated with its user base, for both research and educational outreach. Offsite user activity while lodging at KLRS was not within the scope of this study. The organizational boundary was established during the selection of the case study area within the Arctic Institute of North America.

Recent strategies have expanded the use of the research station and its facilities to include educational outreach programs for impressionable youth, particularly those from within the Yukon. This additional element of youth engagement exposes the station to a broader range of clientele, allowing for experiential learning of firsthand impacts observed within the sub-arctic regions of the Yukon, related to climate change. This serves to increase the awareness critical to long-term sustainability to newer generations with shifted environmental mindsets and a greater willingness to embrace emerging technology to help tackle some of society's most arduous problems. One consequence is increased rates of resource consumption, from power generation to water usage and waste production, though accompanied by reduced rates of air travel due to the greater number of local clients.

A comprehensive approach was taken to compile KLRS's GHG emission inventory for the 2018 baseline. This approach was thought to improve relative accuracy between estimates as well as KLRS's understanding of their current emissions profile, helping to identify potential exposure or GHG liability along its value chain, due to heightened scrutiny of business practices with respect to GHG management and tightening environmental regulation intended to reduce emissions (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004). Capturing indirect emissions related to upstream activities across the value chain allows KLRS and AINA to better manage potential GHG risks (such as increased upstream costs) and identify reduction opportunities within direct operational control as well as those outside their sphere of influence (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004). It provides knowledge which enables the ability to derive potential solutions to mitigate impacts indirectly related to their operations, with the overarching idea considered that a GHG inventory that can't be measured can't be managed (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004). Thus, a carbon footprint has the potential to accelerate and measure initiatives to not only improve the optics of outwardly exhibiting sustainability as a station focused on furthering climate science, but to effectively reduce its impact as well.

3.3. GHG PROTOCOL STANDARD

Through a multi-stakeholder effort that saw the collaboration between the World Resources Institute and the World Business Council for Sustainable Development, among many others, two distinct yet connected standards have been developed since the Initiative's launch in 1998 (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004). The first detailed guide was developed for organizations to accurately and consistently quantify and report GHG emissions, known as the *GHG Protocol Corporate Accounting and Reporting Standard* (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004)in conjunction with the *Corporate Value Chain (Scope 3) Accounting and Reporting Standard* (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2011), which will be utilized extensively. The *GHG Protocol for Project Accounting* can be used to quantify emissions reductions that arise from GHG mitigation projects implemented through this research (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2005). The first two standards include information on collecting data pertaining to the research station, such as scope 1 emissions directly related to its operation and scope 3 emissions related to its value chain. The latter standard would be utilized once carbon strategies are in place to track reductions compared to the established baseline.

These corporate standards help organizations capture an accurate GHG inventory by utilizing simple, standardized and transparent approaches that can be consistently applied on a global scale (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004). Organizations can also use these guides to build effective strategies that enable them to manage their carbon footprint and reduce their GHG emissions. To be consistent with changes in international inventory practices, the UNFCCC and Kyoto Protocol require the accounting and reporting of seven GHGs within the standard, including CO_2, CH_4, N_2O, sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and the most recent addition, nitrogen trifluoride (NF_3) (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013a).

3.3.1. Factors Considered in Selecting the Standard

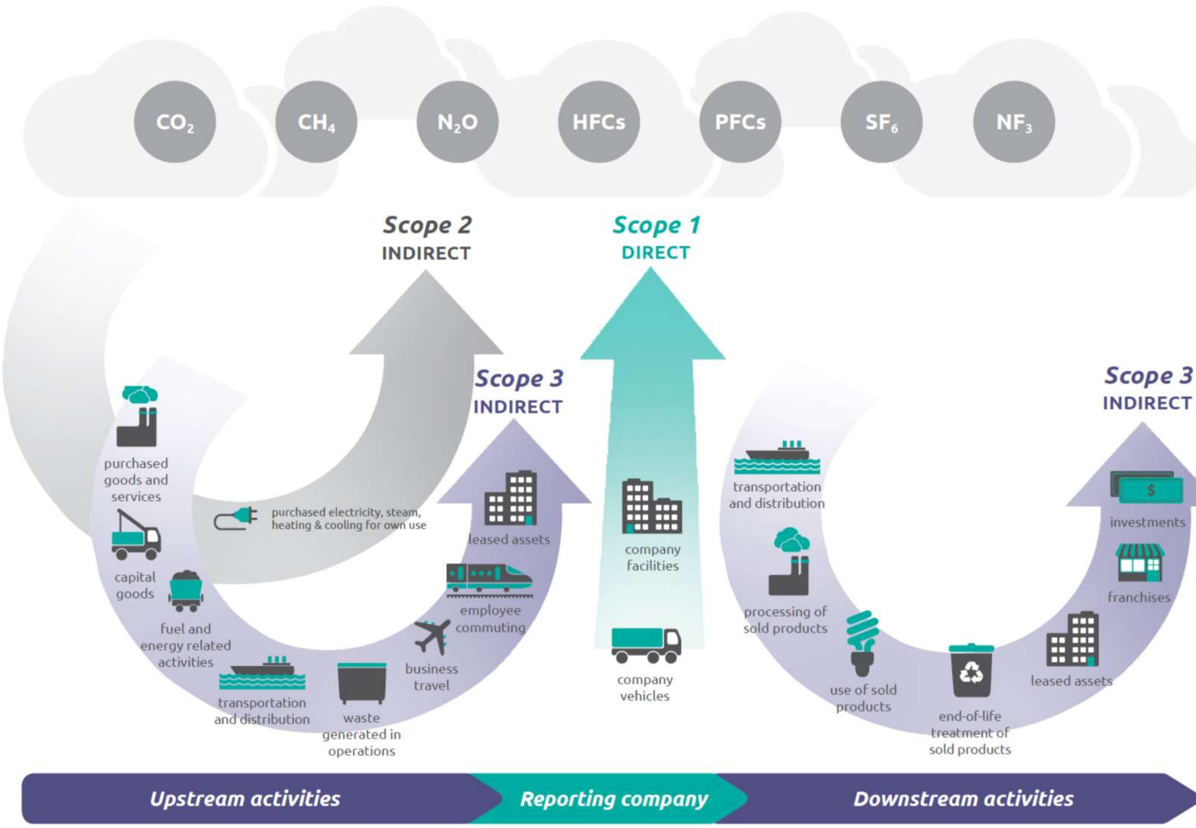
Numerous factors were evaluated in selecting the GHG Protocol Standard and its supplementary documentation to calculate the carbon footprint of the Kluane Lake Research Station. The CPD (previously known as the Carbon Disclosure Project) is a non-profit that operates a global disclosure process that measures and manages environmental impacts of companies, regions, states and cities using the GHG Protocol Standard as its framework (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2019), representing investors with assets worth over $100 trillion (CDP, 2019a).

In addition, the International Standards Organization 14064 began development in 2002 as an extension of their environmental management standard series and is an international standard for management of GHG activities related to inventories and verification (Wintergreen & Delaney, 2006). It was derived from and is generally consistent with the largely recognized GHG Protocol Standard, defining minimum compliance standards (Wintergreen & Delaney, 2006). Dating back to the early 2000s, companies recognized the importance of reporting scope 3 emissions related to their upstream and downstream businesses, including impacts to their bottom line (Price Waterhouse Coopers [PWC], 2008). As such, new standards were created in response to both market and stakeholder demands to more accurately capture supply chain impacts or those emissions from a company’s value chain, helping to expose often hidden emissions reduction opportunities (Price Waterhouse Coopers [PWC], 2008). Ultimately, this standard is open source and therefore accessible by businesses, governments and institutions globally, further enabling consistency of reporting. These standards are user-friendly, robust, and incorporate a multi-stakeholder process to rigorously test the standards through multiple drafts (Bhatia & Ranganathan, 2011).

3.3.2. Scopes and Emissions of the GHG Protocol Standard

The GHG Protocol Standard was used to account for the greenhouse gases produced as a result of scope 1 direct and scope 3 indirect emissions. Figure 5 schematically depicts the interplay between the three emissions scope categories. Scope 1 emissions related to the direct operation of KLRS owned buildings and vehicles such as fuel consumption was evaluated. Scope 2 indirect emissions related to purchased electricity did not apply to this study as the research station is not connected to the electricity grid. Scope 3 indirect emissions related to upstream activities within an organization’s value chain were also captured but are optional for organizations to report (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2011), with downstream activities also irrelevant to this study.

Figure 5. Scopes and Emissions of GHG Protocol Standard Throughout Value Chain



Source: (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b)

3.4. SELECTION OF EMISSION CALCULATION TOOL

The GHG Protocol Standard has a collection of online-hosted calculators available for the purposes of calculating emissions related to various sources. In selecting a calculation tool or emission factor database for use in calculating the carbon footprint of KLRS, various data quality indicators were considered based on reliability, completeness, and technological, temporal and geographical representativeness to remain as objective as practically possible (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2011). These same indicators were also applied to activity data inputs such as fuel volumes consumed to qualitatively assess the data and to consider subjectivity when able.

The 2018 UK Defra GHG Conversion Factor (UK Defra) worksheet was selected due to its temporal relevance, as it is updated on an annual basis with improved data if available, with a data requirement of less than five years (Department for Business, Energy & Industrial Strategy, 2018a). Its comprehensive database provides emission factors for pertinent GHG sources from a wide range of scope 1, 2 and 3 emission categories in detailed compartmentalization, by separate GHG and in CO_2 equivalents, with all datasets derived from credible sources and reviewed to ensure complete coverage of appropriate inputs and outputs related to an activity's life cycle (Department for Business, Energy & Industrial Strategy, 2018a). The technology requirement is that of average technology for which a range of coverage is available from best in class to pending technology (Department for Business, Energy & Industrial Strategy, 2018a). It is compatible with the GHG Protocol Standard which makes it applicable to the analysis methodologies employed within this study as well as allows for consistency in application across all three scopes, using global warming potentials (GWP) over the same 100 year time frame, as per the UNFCCC (Department for Business, Energy & Industrial Strategy, 2018a). This also ensures the combustion and life cycle emission factors used are also taken from the same technical, temporal and geographical representativeness (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2011). GWPs of methane (CH_4 = 25) and nitrous oxide (N_2O = 298) from the IPCC fourth assessment report were used for this methodology (Department for Business, Energy & Industrial Strategy, 2018a) as updated numbers presented in the IPCC fifth assessment report had not been formally recognized under the UNFCCC (CH_4 = 28 and N_2O = 265) (Myhre, et al., 2013).

The most significant limitation in the use of this tool was with respect to its geographical relevance as data coverage reflects average production within the UK market and Europe, rather than Canada (Department for Business, Energy & Industrial Strategy, 2018a). This should have minimal impact on emission factors from sources of stationary or mobile combustion as variances in fuel properties are negligible when comparing similar fuel grades, with emission factors for various fuels found to be comparable across multiple datasets. Fuel properties such as specific volume was recorded from supplier material safety data sheets when available for appropriate conversions. As well, several sources use UK Defra for emission factors related to aviation such as the GHG Protocol Calculation Tool for Mobile Combustion (Greenhouse Gas Protocol, 2015), the Carbon Zero calculator based out of Canada (CarbonZero, 2017), and the Fly Green calculator; the latter of which completed a thorough analysis between various calculation methods for air travel emissions (FlyGreen, 2019), suggesting the UK Defra tool has been more rigorously studied compared to other calculators. In addition, more modern fleets within western Europe can be approximated with those within western countries (FlyGreen, 2019). These emission factors can be updated in future for greater certainty of calculation. However, its methodology is well documented and continuous rigor goes toward annually updating these emission factors.

Overall, the UK Defra third party life cycle database is well-regarded and can be applied outside of the UK geography on a global scale (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], n.d.). It pulls from a variety of data sources including government publications, industry statistics, original research, and other reputable Life Cycle Analysis databases with datasets numbering more than 300, offering data from life cycle stages encompassing cradle-to-grave (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], n.d.). This conversion factor tool focuses on crude oil and natural gas-based fuels, as well as air and road applications (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], n.d.), which are all applicable to the system boundary defined by the carbon footprint calculation surrounding KLRS's overall operation. The tool offers improved data transparency through defined system boundaries, quality assurance, and is updated regularly with reliable and relevant data (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], n.d.).

3.5. DATA COLLECTION

A comprehensive dataset specific to KLRS consumption and user logs capturing the influx of individuals and their purpose for utilizing the research station can provide greater insight into its userbase, identify patterns within its GHG inventory and increase the accuracy of the calculated carbon footprint of the station. These are pertinent reasons for ensuring appropriate levels of rigor when collecting data throughout the operational year.

3.5.1. Type of Data Used

Data was collected from the operational records and travel logs maintained over the past year at KLRS as well as from records retrieved through correspondence with third party suppliers within the Yukon, to understand typical usage patterns and needs of the remote station. Scope 1 direct emissions were calculated based on primary activity data acquired through analyzing fuel volumes recorded on invoices with respect to facility operations. These included diesel, propane, and wood, as well as volumes of petrol purchased for mobile combustion by company vehicles. Data for scope 3 emissions were collected from facility-maintained logs of user information for 2018. The 2018 user days were confirmed to be in line with the high end of the historical average with potentially higher than average volumes of field schools, thought to represent the new normal. This time frame also captures the most comprehensive record of user data from individuals accessing KLRS ensuring a higher level of accuracy in carbon emission calculations. This includes the length of stay at the research station, size of group, lodger's origin by city and mode of travel to destination. Secondary data, which is defined as data derived from activities not specific to a company's value chain (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2011) was used when primary data was inaccessible due to third party limitations. This included the use of industry-average data for items purchased from local grocery stores in Whitehorse, such as GP Distributing, Superstore and Sobeys. Assumptions made during calculation and data interpolation conducted are recorded in Section 3.6.3: Inputs & Assumptions to capture uncertainties and identify knowledge gaps that may be addressed in future as energy consumption and activity logs are continuously monitored over the operational life of KLRS. This information will help to generate a comprehensive baseline for comparison and to better understand future impacts of GHG reduction projects.

3.5.2. Data Quality

Data quality will be evaluated using the same parameters addressed earlier under Section 3.4 regarding the selection of the UK Defra emission factor worksheet. The temporal and geographical representativeness have already been addressed in the previous section. The use of primary data capturing KLRS's 2018 operations and verified where possible through records obtained from third party suppliers within the Yukon ensures a "very good" score with respect to quality assurance is achieved with reliability and completeness of data (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2011). Where data quality can be improved is on business travel where flight routes have been assumed based on industry averages or most common flight paths, as well average passenger vans assumed for transport of groups larger than five people, in the absence of specific user data. Meticulous records of primary data will significantly improve the accuracy of the carbon footprint calculation and consequently improve KLRS's ability to track progress with respect to GHG reduction. However, secondary data allows for a more comprehensive understanding of the relative scale of its emissions profile with respect to scope 3 upstream activities, allowing KLRS to identify its risks and opportunities, and re-focus efforts for primary data collection, GHG reduction and supplier engagement (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2011).

3.6. CARBON FOOTPRINT CALCULATION

This section will provide an overview of calculation methods selected for the largest emitters based on initial screening. Using various decision trees outlined throughout the GHG Protocol Standard, calculation methods were selected dependent on the data available for each of the scope 1 and 3 emissions evaluated, as illustrated in Figure 6 of Section 3.6.2 for business travel (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b).

3.6.1. Scope 1 Emissions Calculations: Consumption of Fuel & Bioenergy

Scope 1 emissions typically correspond to the combustion of fuel from both stationary and mobile sources related to electricity or heat generation and the transportation of employees, goods or waste from KLRS owned buildings and vehicles, respectively (World Resources Institute

[WRI] & World Business Council for Sustainable Development [WBCSD], 2004). This study excluded the accounting of fugitive emissions that might occur during the unintentional release of fuel due to possible equipment leaks or operator error, etc. Scope 1 emissions are within the direct operational control of KLRS and therefore detailed records of fuel combusted should be consistently recorded to accurately calculate their carbon footprint. These volumes, along with combustion emission factors (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b) are used to determine the total emissions generated from the operation of infrastructure or vehicles.

The fuel-based method is the most accurate measure of emissions associated with stationary fuel combustion (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b). When considering transportation emissions related to KLRS owned vehicles, CO_2 is more accurately measured from fuel consumption, whereas CH_4 and N_2O, two GHGs associated with mobile source combustion, are best estimated using the total distance travelled (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b). This is because CO_2 emission factors related to the combustion of fossil fuels are primarily dependent on intrinsic properties such as the fuel's heating value, density and carbon content and less dependent on the combustion technology (Environment and Climate Change Canada, 2019). Conversely, fuel combustion generating CH_4 and N_2O emissions are largely technology dependent, thus more dependent on the type of engine installed than on the amount of fuel burned (Environment and Climate Change Canada, 2019). This same principle applies for the residential combustion of biomass such as firewood (Environment and Climate Change Canada, 2019).

Equation 1. Fossil Fuel Combustion Emissions Calculation

$$Emissions\ of\ fossil\ fuel\ combustion = Activity\ data\ [L]\ x\ Emission\ factor\ [kg\frac{CO2e}{L}]$$

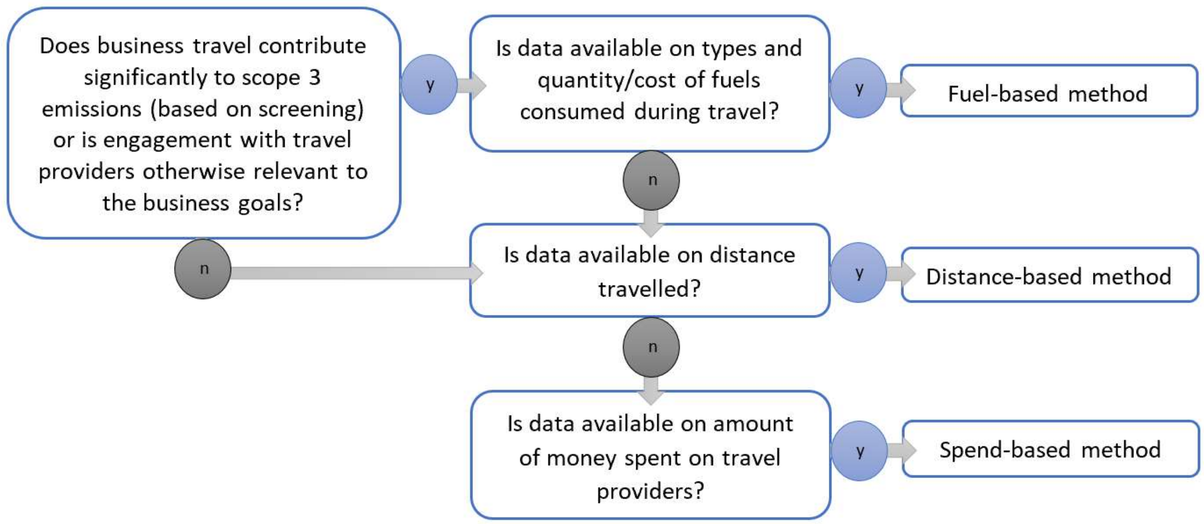
Source: Adapted from (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b)

The total emissions in units of kg CO_2e from the combustion of each fossil fuel was calculated using a simple multiplication illustrated by Equation 1. Activity data was recorded in units of litres of fuel combusted and the emission factor (EF) selected in units of kg CO_2e per corresponding activity taken from the UK Defra worksheet for the respective fuel, which can be found in Appendix B: List of Emission Factors.

3.6.2. Scope 3 Emissions Calculations: Business Travel

Being optional, scope 3 emissions are not a reliable tool for comparison between organizations; however, they create opportunities for innovation of an organization's GHG emissions management (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004). In accounting for scope 3 indirect emissions, activities most relevant to KLRS and their goals as a research institute should be reported, provided the information used is reliable. Though a full-scale GHG inventory life cycle analysis is not required for all KLRS operations and upstream activities, it is valuable to concentrate on the key activities thought to dominate the emissions profile (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004). These include third party transport-related activities such as business travel, the transportation of purchased fuels, materials or goods, and waste, employee commuting, waste disposal related to domestic and water waste generated during operations and well-to-tank (WTT) emissions related to the upstream extraction, production, refining and transportation of the purchased fuels and materials, known as life cycle emission factors excluding combustion (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004). The consideration of KLRS's value chain in conjunction with their business goals helps guide choices related to building a GHG inventory and selecting scope 3 categories most relevant to their organization (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004).

Figure 6. Decision Tree Analysis for Calculation Method Determination



Adapted from Source: (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b)

The largest anticipated scope 3 emission related to KLRS is business travel by aircraft due to the unique nature of the research station and its user base. Through application of the decision tree analysis outlined in Figure 6, the distance-based method was determined to be most suitable in capturing an estimate of the GHG inventory related to user and employee air travel through third party transportation operators without access to third-party primary data regarding fuel consumption or technology of aircraft; this technically captures a portion of a transportation company's scope 1 and 2 emissions (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2011). In the absence of individual flight manifests, journeys to KLRS were estimated by analyzing most common routes from user origin through tools such as Google flights and various other online mediums, with stopovers assumed through Vancouver, as is typical. Distance travelled was approximated using estimates based off typical flight paths using an online tool called the Great Circle Mapper (Meco Media & Communication UG, n.d.). The total distance traveled by guest on each leg of the trip from flight of origin was multiplied by the number of passengers in the group to determine the total passenger.kilometre (pkm), or the total distance traveled by passengers, for each leg. The great circle distance (GCD) is defined as the shortest route between two terminuses or points on a spherical surface, such as the earth, corresponding to a linking arc (Rodrigue, 2019). The great circle distance is inferred by the circumference between the two points effectively dividing the earth into halves (Rodrigue, 2019). By following the earth's sphericity, the shortest route is determined along the parallels, avoiding distortions created by projections onto plane surfaces (Rodrigue, 2019). Therefore, data based on the estimated distance traveled would be considered secondary data and though not industry-average data, exact flight paths are unknown and are therefore approximated. Distance-based methods apply equally to land-based travel for both users arriving at Whitehorse international airport to KLRS as well as employee commuting to site.

Including user travel for the purposes of accessing and utilizing the facility as a base for research as part of the scope 3 emissions calculation serves three purposes; it increases the relevance of KLRS's emissions footprint, improves recognition of its cost savings opportunities and it expands its ability to reduce its impact (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2004).

Equation 2. Business Travel by Air Emissions Calculation

$$Emissions\ of\ air\ travel = Activity\ data\ [pkm]\ x\ EF\ [kg\frac{CO2e}{pkm}]$$

Source: Adapted from (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b)

The total emissions related to business air travel was calculated using Equation 2 through the multiplication of activity data collected by pkm and the emission factor associated with the type of travel indicated by the activity data. Further detail will be provided in Section 3.6.3 reviewing the inputs and assumptions used to measure this significant aspect of KLRS's indirect operations.

3.6.3. Inputs & Assumptions

The following section will review some of the inputs and assumptions related to the calculation of the carbon footprint for KLRS's largest emission sources by scope 1 and 3.

3.6.3.1. Scope 1 Emissions: Stationary & Mobile Fuel Consumption

The activity data collected for calculation of scope 1 emissions at Kluane Lake Research Station was collected from monthly operational logs maintained by KLRS station management and verified with third party suppliers, through records pulled from their database as with Superior Propane or from review of invoicing as with Kluane Energy, where KLRS purchases 100 percent mineral diesel. The total volume of fuel consumed during 2018 operations is assumed equal to the total amount purchased as verified, apart from wood and petrol. No records were made available to verify wood volumes purchased from neighboring Bear Creek Logging Inc, located 50 km SE of the KLRS camp. However, multiple interviews with KLRS staff confirmed the 16 cords of beetle-killed Spruce Bark dry firewood recorded. Individual invoices from filling petrol with average biofuel blend (the standard purchased from local filling stations (Department for Business, Energy & Industrial Strategy, 2018b)) in the KLRS vehicles were unable to be verified by third party suppliers due to the magnitude and nature of the transactions. Therefore, there is potential that some gasoline used by KLRS vehicles may have been missed and thus underestimated in the current carbon footprint calculation. In addition, small volumes of propane purchased at retailers such as Canadian Tire on occasion by KLRS staff have not been captured in the analysis, such as for barbecuing or propane heaters purchased for block-heating of the generators during infrequent winter operation, and as such total propane volumes and associated emissions are also slightly underestimated; however, these volumes should not be significant and tracking can be improved in future.

Unlike fossil fuels, emission factor data for biomass wood logs were in units of kg CO_2e per kWh. The activity data collected for dry Spruce bark purchased from Bear Creek Logging was converted from units of volume to units of energy through the recoverable heat value of dry cord in units of MMBtu per cord taken from the Engineering Tool Box for the species of Spruce wood. The unit of MMBtu was then converted to kWh to calculate total emissions. Equations for wood combustion emissions are included in Appendix C: Wood Combustion Emission Calculations, along with the recoverable heat value of dry cord used.

3.6.3.2. Scope 3 Emissions: Business Travel by Air and Land

Various assumptions were made in order to estimate total business travel by air and land. These included:

- Users transit via most common routes listed on Google flights,
- Users transit through Vancouver international airport en route to Whitehorse,
- Gaps greater than two weeks between departure and arrival at KLRS indicate return travel to origin,
- Station users travel by economy seating,
- Users listed on separate lines of KLRS logs rent individual vehicle to travel to KLRS,
- Client groups greater than 5 travel by passenger van with 10 allocated per vehicle, otherwise travel is in an average size car; and
- Emission factors for average passenger van (up to 3.5 tonnes) and average car (unknown engine size) with petrol fuel used for land travel dependent on group size.

The activity data collected for calculation of scope 3 emissions related to business travel were derived largely from analysis of KLRS user logs outlining arrival and departure date, length of stay, affiliated organization if applicable, type of visit (research, field school, overnight school visit, and community service, etc.). Some assumptions were made to determine departure dates as some researchers frequented the station multiple times, at times returning home (potentially by plane) and others offsite for days or weeks at a time collecting glaciological data or trekking, but eventually returning to the station. Gaps away from the station for longer than two weeks were assumed to be return trips back to user origin. In some instances, user origin was not detailed, and further investigation was required with verification from KLRS management. This aspect of the study was data and time intensive, which can be greatly minimized through data collection when accommodation is booked or during user check-in. Additionally, a worksheet has been populated with common flight paths documented by leg which can automatically populate leg distance based on entry of airport codes to streamline future data collection efforts.

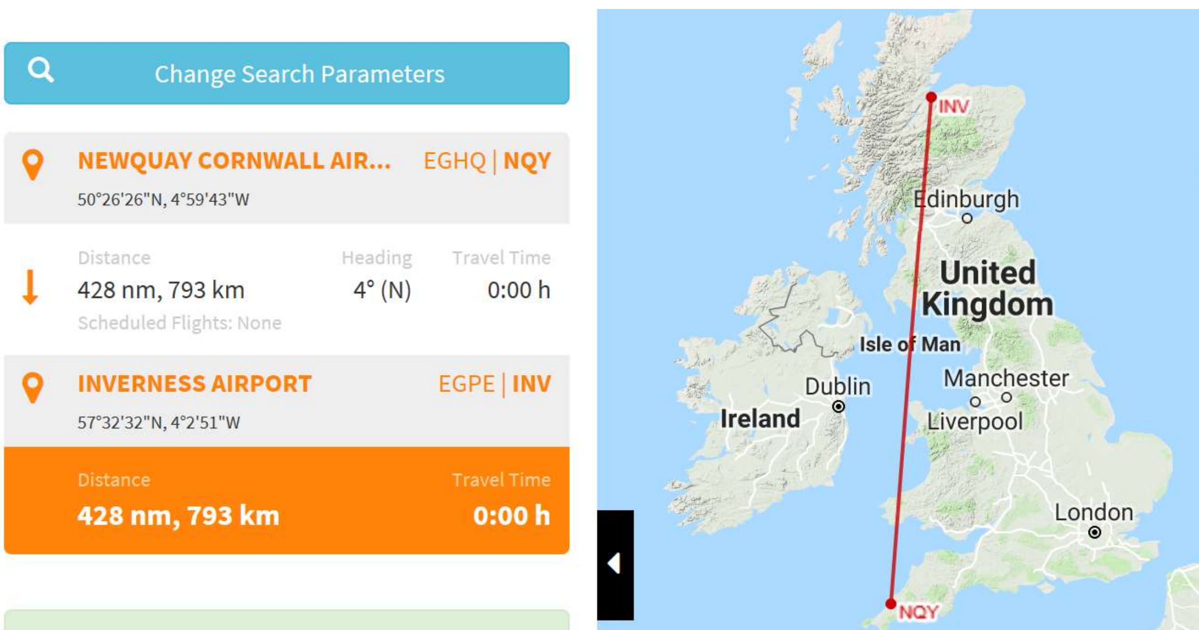
Assumptions made with respect to transit to final destination was detailed in Section 3.6.2. Rather than assuming direct flights to Whitehorse which are available from only select locations, greater accuracy was estimated with transit assumed through Vancouver. In addition, though class of travel is not known with respect to economy, business or first class, and average emissions factors are recommended for calculation if unknown (Department for Business, Energy & Industrial Strategy, 2018a), economy was assumed due to the nature of the travel and after discussions with KLRS station management deemed the most apt representation of the station's clientele; however, this could lead to underestimation of emissions if many fliers choose to upgrade to premium seating upon booking or check in. The exception is domestic hauls as they are only represented by average passenger emission factors.

In cases where dates overlapped on the user log and entries were on separate lines, assumptions were made user travel by car was made individually and not jointly, potentially inflating user travel on land. This is countered by groups larger than five assumed to have traveled in a van that can transport up to 10 passengers. However, this assumption might underestimate the amount of user travel conducted on land if larger groups rented more vehicles with less passengers allocated to each vehicle than assumed. Without detailed data, assumptions made for type of vehicle rented assuming average sized cars and vans, dependent on group size, could potentially under or overestimate land travel emissions. However, car emissions are likely underestimated as travelers who traffic the station are inclined to favour larger and more reliable vehicles while traveling on remote highways and to move gear and equipment. In future, number of vehicles rented, type and size of passenger vehicle can all be documented at check in to improve accuracy of emission calculations. In addition, groups picked up by KLRS staff would be captured by petrol fuel consumption records and could also result in overestimation of user emissions by vehicle.

The Defra emission factors are used widely on a global scale and are updated frequently to capture newer aircraft coming into operation within the United Kingdom, covering a range of aircraft of increasing efficiency, including variations within aircraft families, with assumptions of average load factors (flight occupancy), seating capacities which impact total available seats and passenger.kilometre proportions by aircraft made to estimate emission factors (Department for Business, Energy & Industrial Strategy, 2018a). An aircraft's technical performance impacts the aviation efficiency per pkm, but this measure is also largely dependent on an aircraft's load factor (Department for Business, Energy & Industrial Strategy, 2018a). Increasing square footage reserved per passenger reduces the overall passenger count that can be transported, with first class occupying more space than business class than economy, which is reflected by higher average emission factors per pkm for the prior than the latter (Department for Business, Energy & Industrial Strategy, 2018a). This is made increasingly more difficult to estimate on long-haul flights where seat orientation for first class passengers can be three to six times larger than that occupied by economy seating (Department for Business, Energy & Industrial Strategy, 2018a). However, assumptions are continuously evaluated and updated with validity checked as current data is made available and provides an idea of the magnitude of emissions produced due to air travel (Department for Business, Energy & Industrial Strategy, 2018a).

Using the 2018 UK Defra worksheet, emission factors were documented by domestic, short-haul and long-haul flights. International flights were introduced in the 2015 update to reflect flights between two countries outside of the UK and are defined to be average emission factors of the short-haul and long-haul flights (Department for Business, Energy & Industrial Strategy, 2018a). As such, they were disregarded and specific emission factors that fell within the domestic, short and long-haul flight categories were selected for use in calculation for improved accuracy and representation. Though the definition of domestic varies substantially from country to country based on its land mass, with Canada boasting significantly larger surface area than most other countries globally, domestic as per the Defra tool was defined as flights within the UK. As such, distances between UK airports were reviewed through map analysis of the more than 40 major domestic and international airports in the UK (Trainline PLC, 2019), with the furthest distance estimated to be between Newquay Cornwall Airport and Inverness Airport at 793 km, using the Great Circle Mapper tool referenced above in Section 3.6.2 and illustrated in Figure 7. Although further analysis reveals no direct flights exist between these two airports and a table calculating the weighted average passenger flight emission factors in the 2018 UK Defra Methodology paper documents the longest listed average flight length for domestic within the UK as 463 km, flight allocations were adapted to fit the Canadian context and flight distances under 800 km was established as domestic for the purposes of this study. This was further supported by an IPCC special report titled *Aviation and the Global Atmosphere* which categorized short haul (as reported categories were subdivided into short, medium and long-haul, this would represent domestic) as flight stages totaling 800 km or less, believed to represent less than a quarter of scheduled passenger operations, between 15 to 20 percent (Penner, Lister, Griggs, Dokken, & McFarland (Eds), 1999). Defra's categorization of short haul flights as those within Europe (less than 3700 km) and long-haul flights as those outside of Europe (>3700 km) (Department for Business, Energy & Industrial Strategy, 2018b) were applied similarly within this study with short haul assigned to flights between 800 km and 3700 km and long-haul flights greater than 3700 km. Appropriate emission factors were applied to each corresponding leg of all assumed passenger itineraries that stayed at KLRS. Specific emission factors used per pkm by flight class are listed in Appendix B: List of Emission Factors.

Figure 7. Great Circle Distance Between Furthest UK Airports



Source: (Meco Media & Communication UG, n.d.)

Finally, all emission factors listed on Defra's worksheet included an eight percent distance uplift factor applied to the calculated GCD which accounts for numerous factors including circling/stacking, congestion, delays, and indirect flight paths for logistical reasons (Department for Business, Energy & Industrial Strategy, 2018a), such as circumventing international air space (Department for Business, Energy & Industrial Strategy, 2018b). Options are available on Defra's worksheet to use emission factors with or without radiative forcing (RF), which is defined as the measurement of aviation's supplementary adverse environmental impacts such as high altitude emissions of water vapour, contrails, ozone (O_3), soot, sulphate, and NOx, with recommendations to include its influence when calculating air traffic emissions to more accurately replicate air travel's total climate impact, rather than just direct emissions of CO_2, CH_4 and N_2O (Department for Business, Energy & Industrial Strategy, 2018a). Though substantial scientific uncertainty still exists surrounding the magnitude of RF due to air travel in the troposphere or stratosphere, neglecting the factor contributes to significantly underestimating emissions related to non-CO_2 effects. Therefore, the UK Defra methodology which applies a multiplier of 1.9 to scale CO_2 direct emissions with respect to radiative forcing was used in this study (Department for Business, Energy & Industrial Strategy, 2018a).

3.6.3.3. Scope 3 Emissions: Grocery Emissions Including Freight

A regular weekly and occasional semi-weekly purchase made by KLRS with respect to goods is groceries. Three meals a day are prepared by a Red Seal chef at KLRS for users of the station, which include significant amounts of meat and dairy. Though not all aspects of material use are captured in this study such as operational maintenance expenses that may include hardware purchases, groceries were hypothesized to account for substantial emissions contributions due to the consistency and volume purchased, as well as the larger population served. These emissions as well as those related to freight logistics are well within KLRS's ability to employ effective strategies to reduce its emissions profile. The emission factor used falls under the material use category and is an average factor for the primary production of food and drink (from virgin stock), at 4060 kg CO_2e per tonne *(Department for Business, Energy & Industrial Strategy, 2018a)*. This cradle to gate emission factor accounts for the extraction, processing, manufacturing and material transport to the retailer, capturing the consumption of procured food and drink for both client and employee, based on origin of supply *(Department for Business, Energy & Industrial Strategy, 2018a)*.

Unable to collect every grocery invoice from 2018 prevented the extraction of precise masses for each load of delivered provisions to KLRS from the main distributor GP Distributing based out of Whitehorse. However, two invoices of KLRS's more substantial orders were procured from GP's accounting team, inputted into Excel and analyzed in detail. The itemized list contained a combination of mass, volume, and quantity and was subsequently converted to mass (in tonnes) to utilize the emission factor related to this specific activity. Where details were unavailable on the invoice, GP's 2017 product listing was used to evaluate its posted mass. For those products with masses unavailable on the listing, similar products from alternative grocers with an online presence such as Superstore or online reference mass calculators were used to determine the average mass of each purchased product. A list of the reference mass tools used can be found in Appendix D: Reference Mass Databases Used for Material Use Calculations. The expenditure in Canadian dollars excluding freight and the total mass of groceries from each invoice was tabulated and recorded in units of kg to determine the unit cost in $/kg from each order. A weighted average unit cost was calculated and used to convert the total 2018 provision expenditures into a mass in unit of tonnes for estimation of total emissions. As these two expenditures only represent orders purchased during the late summer months of August and September, it may skew estimates for orders purchased during spring, as costs can vary seasonally. However, it provides KLRS with a general understanding of the magnitude of their emissions related to food and drink.

Equation 3 outlines the calculation used to multiply the activity data or mass of the food and drink purchased in tonnes by the emission factor in kg CO_2e per tonne to calculate total scope 3 emissions related to the procurement of groceries for users and employees at the station.

Equation 3. Grocery (Material Use) Emissions Calculation

$$Emissions\ of\ groceries\ = Activity\ data\ [tonne]\ x\ EF\ [kg\,\frac{CO2e}{tonne}]$$

Source: Adapted from (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b)

Since the August 2018 invoice procured by GP Distributing included freight while the September 2018 invoice excluded freight (due to operational oversight) and without possession of invoices to appropriately account for freight charged during each transaction, the total cost listed on operational records was assumed to exclude freight (with exception to the invoices evaluated). This may overestimate total spend and therefore the total emissions related to the procurement of food and drink; however, the standard \$200 of freight per order suggested for application for minimum deliveries of at least \$100 are contradicted by a few orders below the anticipated minimum threshold of \$300. In addition, KLRS started to pick up orders at some point after \$200 freight was introduced. However, uncertainty as to when orders were picked up by KLRS on a go forward basis is unclear, if at all, during the 2018 operating season. Nonetheless, this confirmation was not received until August 8th and due to time constraints and the lingering uncertainty, it was determined recalculation would not provide additional value.

Equation 4 and Equation 5 capture the emissions calculation for average laden and unladen backhaul freights, respectively. Due to the retrospective nature of this study, information regarding the percentage of maximum capacity used to haul the goods within its carriage is unknown. As such, average laden loads for freight were assumed which reflects slightly less than 50 percent capacity. Activity data of average laden loads for groceries are measured in units of tonne.kilometre (tkm), which represent the total mass shipped by truck and the total distance traveled one-way from the warehouse to KLRS. Multiplied by the correlating emission factor provides the total emissions generated from average laden freight. Specific to the delivery of groceries, the heavy goods vehicle (HGV) reefer is only engaged when perishable or frozen goods are on board. Therefore, HGV refrigerated emission factors were selected for use for average laden hauls.

Equation 4. Freight (Average Laden) Emissions Calculations

$$Emissions\ of\ freight\ (average\ laden) = Activity\ data\ [tkm]\ x\ EF\ [kg\,\frac{CO2e}{tkm}]$$

Source: Adapted from (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b)

Unladen backhaul or zero percent laden represents freight calculated with no goods being transported, in this scenario, when groceries have been offloaded to KLRS and the HGV returns to base. Converse to average laden hauls, it is assumed the reefer is not engaged on the return trip and as such, HGV emission factors without refrigeration are used in calculation of scope 3 emissions related to unladen backhaul. The activity data used to calculate emissions for unladen backhaul is based only on the distance driven back to Whitehorse, as illustrated in Equation 5.

Equation 5. Freight (Unladen Backhaul) Emissions Calculations

$$Emissions\ of\ freight\ (unladen\ backhaul) = Activity\ data\ [km]\ x\ EF\ [kg\frac{CO2e}{km}]$$

Source: Adapted from (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b)

The selection of emission factors for both types of hauls was based on the average size of truck used for delivery as specified by the supplier. In the case of grocery deliveries made by GP Distributing, a rigid five tonne HGV diesel truck was used for transport. Similar information was collected from Superior Propane for propane with the difference being activity data for average laden hauls were converted from volumetric units of litre to tonne to reflect volumes of fuel purchased in its mass equivalent. Specific volumes were used for conversion obtained from either third-party suppliers or properties available in the UK Defra worksheet for 100 percent mineral diesel. Average truck weights used by Kluane Energy for diesel and Bear Creek Logging for wood were not confirmed by the respective suppliers, but the HGV used for diesel delivery was deemed comparable to propane delivery trucks and thus approximated with a higher degree of confidence. Articulated diesel HGV used for wood delivery is estimated with high confidence as well based on online research and the leverage of KLRS exposure with supplier offloads. Specific emission factors related to food and drink, as well as freighting goods by heavy goods vehicle for all types of hauls relevant to KLRS operation can be found in *Appendix B: List of Emission Factors*.

3.6.3.4. Scope 3 Emissions: Well-to-Tank Emissions

Well-to-tank emissions are the life cycle emissions of raw fuel sources prior to combustion capturing emissions related to its extraction, refining and transportation (Department for Business, Energy & Industrial Strategy, 2018a). Calculating WTT emissions provides KLRS with a greater understanding of the magnitude of emissions associated with its direct and indirect emissions, capturing more than just the activity itself but the upstream impacts, further enforcing the importance of accurately measuring the scope of activities. Well-to-tank emissions were calculated for the fuel combusted from KLRS's stationary and mobile sources (scope 1 emissions related to diesel, propane, wood (bioenergy) and petrol), as well as upstream activities related to air travel, land travel (passenger vehicle and employee commuting) and freight of both fuel and groceries. To calculate the emissions for each WTT category, the type of emission factor applied should correspond to the previous activity-based emissions used (on a volume, mass, distance, or energy basis) (Department for Business, Energy & Industrial Strategy, 2018a), such as per unit of L for fuel combustion, per unit of pkm for air travel, per unit of tkm for freight with average laden loads and per unit of km for unladen backhaul. A general equation to calculate well-to-tank emissions for each activity is listed in Equation 6 and is essentially the same formula as applied to calculate any corresponding scope 1 or 3 emission activity which uses fuel. Therefore, assumptions made for those activities would extend into WTT emission calculations.

Equation 6. General Well-to-tank Emissions Calculations

$$Emissions\ of\ WTT\ (activity)\ = Activity\ data\ [units\ of\ activity]\ x\ EF\ [kg\frac{CO2e}{units\ of\ activity}]$$

Source: Adapted from (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b)

Though not exhaustive of all calculations made throughout the carbon footprint study, the detail provided above captures the major scope 1 and 3 emissions calculated directly or indirectly impacting KLRS and its operations, ensuring calculations are replicable for KLRS to set targets and track progress to understand whether targets are being met.

CHAPTER 4: RESULTS & ANALYSIS

This section captures the major findings from the carbon footprint study of the Kluane Lake Research Station with respect to 2018 baseline emissions. The first segment evaluates the energy usage directly related to the operation of the research station, comprising the use of the station's buildings and vehicles, followed by the upstream activities of both users and station employees indirectly related to KLRS. The GHG inventory is reviewed to provide insight into the magnitude of KLRS's environmental impact with respect to emissions generated in conjunction with the combustion of fuel and travel to the station. The final section examines the economics of a preliminary carbon reduction plan to address the station's largest contributor to scope 1 direct emissions through a cost benefit analysis.

4.1. OVERVIEW OF 2018 BASELINE EMISSIONS

The GHG Protocol Standard's diagram highlighting the emissions related to an organization's value chain was adapted for the carbon footprint study of KLRS. As illustrated in Figure 8, the main GHG analyzed in this study was predominately CO_2 from fossil fuel combustion with CH_4 and N_2O relevant for combustion from mobile sources. These sources are directly related to the scope 1 direct emissions associated with operating KLRS owned buildings and vehicles. Of the 15 categories of scope 3 indirect emissions, those most relevant to KLRS included upstream activities related to business travel by air and land, purchased goods and services and their respective round-trip transport to site, fuel and energy related activities including the use of helicopters for geological sample collection, and waste generated during operations including water disposal. Due to the small number of station employees and the infrequent round-trip travel to site, employee commuting (travel not in a company vehicle) did not comprise a substantial portion of KLRS' footprint; however, an analysis was completed to confirm this hypothesis.

Figure 8. Scope 1 & 3 Emission Categories Most Relevant to KLRS

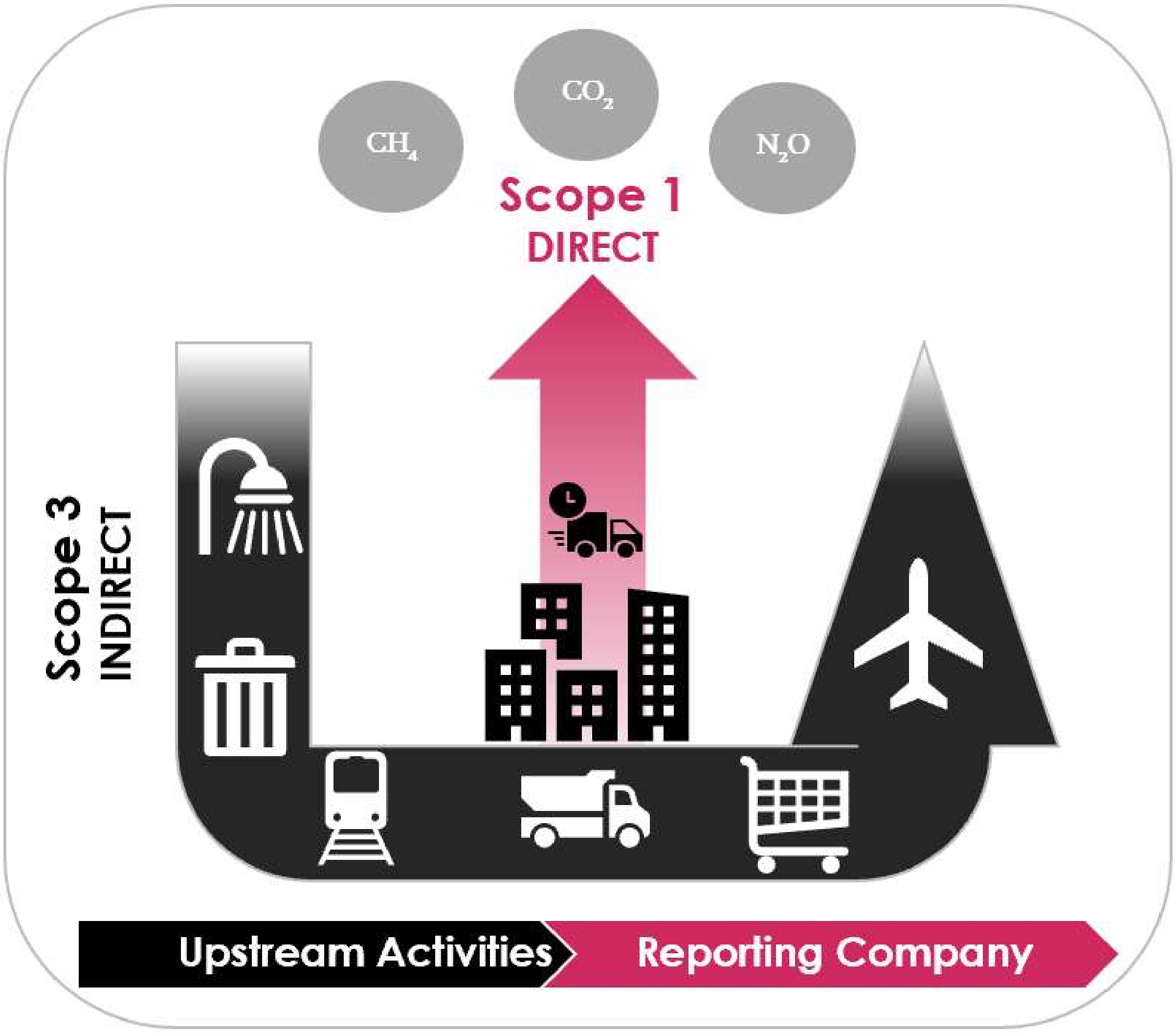
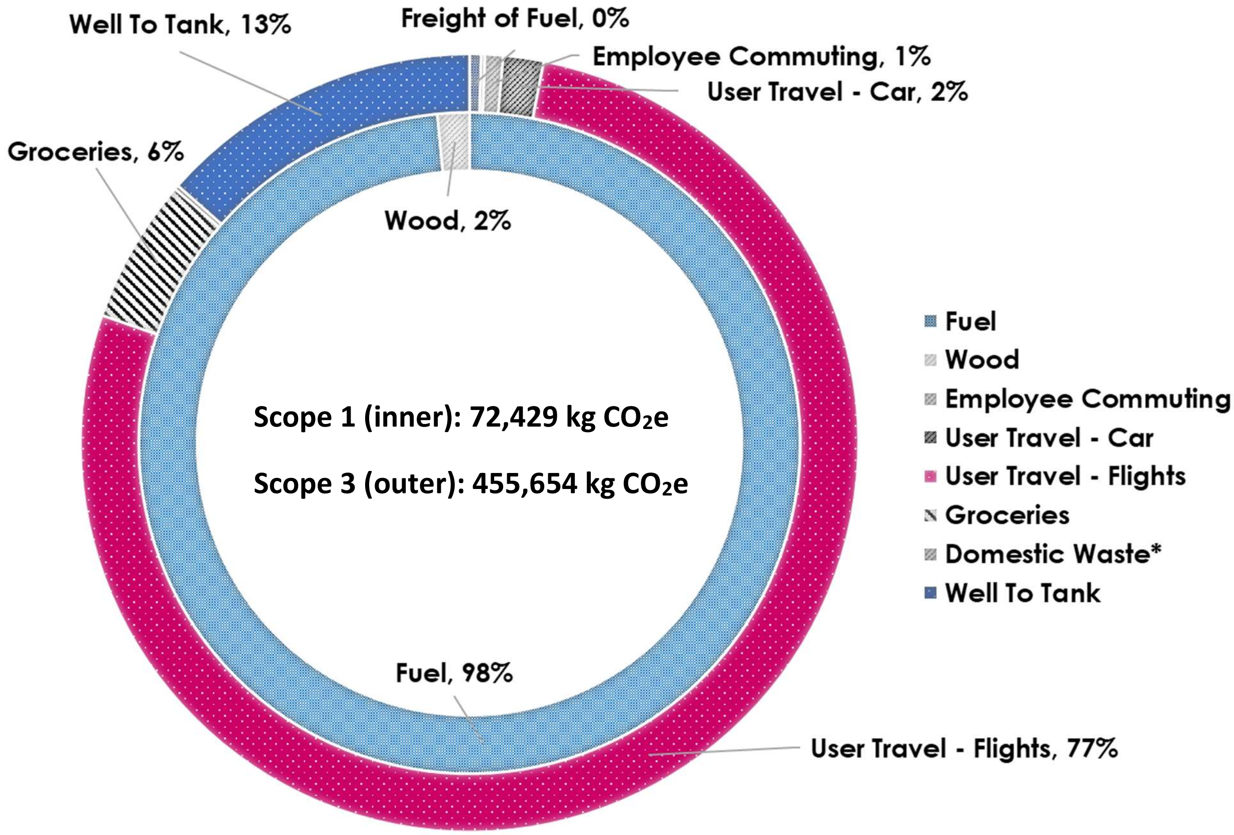


Figure 9 illustrates the results of the 2018 baseline emissions calculated reflecting the total carbon footprint of the research station within the scope of the study, with scope 1 direct emissions reflected in the inner donut and scope 3 indirect emissions captured by the outer donut. More than 86 percent of the 528,083 kg CO_2e in total emissions were scope 3, which is greater than six times the magnitude of its scope 1 emissions, further highlighting its dominance. Scope 1 emissions comprised predominantly of fossil fuel combustion at 98 percent with bioenergy completing the donut at less than two percent. Scope 3 emissions was primarily due to user air travel at 77 percent, followed by well-to-tank emissions at 13 percent and groceries at six percent including freight. User travel by car captured only two percent of the outer donut with employee commuting at one percent, and the transport of fuel capturing a visible wedge but not rounding up to one percent. Domestic waste including landfill, compost, recycling and transport of water disposal by septic truck did not register on the donut chart, in comparison to the other scope 3 emissions generated.

Figure 9. Overview of 2018 Baseline Emissions, Scope 1 (inner) & Scope 3 (outer)



Complementing the overview chart of KLRS's 2018 baseline emissions, Table 2 provides a detailed breakdown of the magnitude of each scope 1 and 3 emission category and the corresponding percentage based on cumulative scope 1 and 3 emissions. User travel by air yielded the largest proportion of total emissions at 67 percent with fuel trailing at 14 percent and associated well-to-tank emissions at 12 percent. Groceries including freight comprised five percent of total scope 1 and 3 emissions. To understand the contribution of upstream categories without the data skewed by the magnitude of air travel emissions, user air travel including its associated well-to-tank emissions was removed from the two right columns, and the data normalized to accentuate the relative magnitude of the other scope 3 emissions categories. The magnitude in units of kg CO_2e and percentage of total scope 3 emissions without air travel and associated WTT emphasize the dominance of groceries on KLRS's carbon footprint at 42 percent, with WTT emissions trailing at 35 percent (associated with fuel, freight, and user & employee travel on land) and user land travel at 12 percent.

Table 2. Total Scope 1 & 3 Emissions With & Without Air Travel [2018 Baseline]

	Includes Air Travel				Excludes Air Travel	
	Emissions [kg CO_2e]			%	Scope 3***	
	Scope 1	Scope 3	Total Scope 1 & 3	Total Scope 1 & 3	[kg CO2e]	%
Fuel	71,299	2,206	**73,505**	**14%**	2,206	3%
Wood	1,130	701	**1,831**	**0%**	701	1%
User Travel - Car		7,629	**7,629**	**1%**	7,629	12%
User Travel - Flights		352,081	**352,081**	**67%**		
Employee Commuting		3,408	**3,408**	**1%**	3,408	5%
Groceries*		27,344	**27,344**	**5%**	27,344	42%
Well To Tank		61,463	**61,463**	**12%**	22,888	35%
Domestic Waste**		822	**822**	**0%**	822	1%
Total	**72,429**	**455,654**	**528,083**	**100%**	**64,998**	**100%**

***Includes 338 kg CO_2e of material use emissions related to capital goods**
****Includes recycling and waste water disposal**
*****Excludes air travel and associated WTT**

The dominance of scope 3 emissions related to KLRS's value chain emphasizes the importance of a comprehensive understanding of KLRS's carbon footprint, with the magnitude of its emissions reinforcing the need to accurately capture and monitor the sources. The inability of measuring an emission source inhibits its ability to be managed, presenting a barrier for KLRS and AINA in methodically setting targets, implementing reduction initiatives and evaluating the effectiveness of incremental changes in pursuit of their strategic goal.

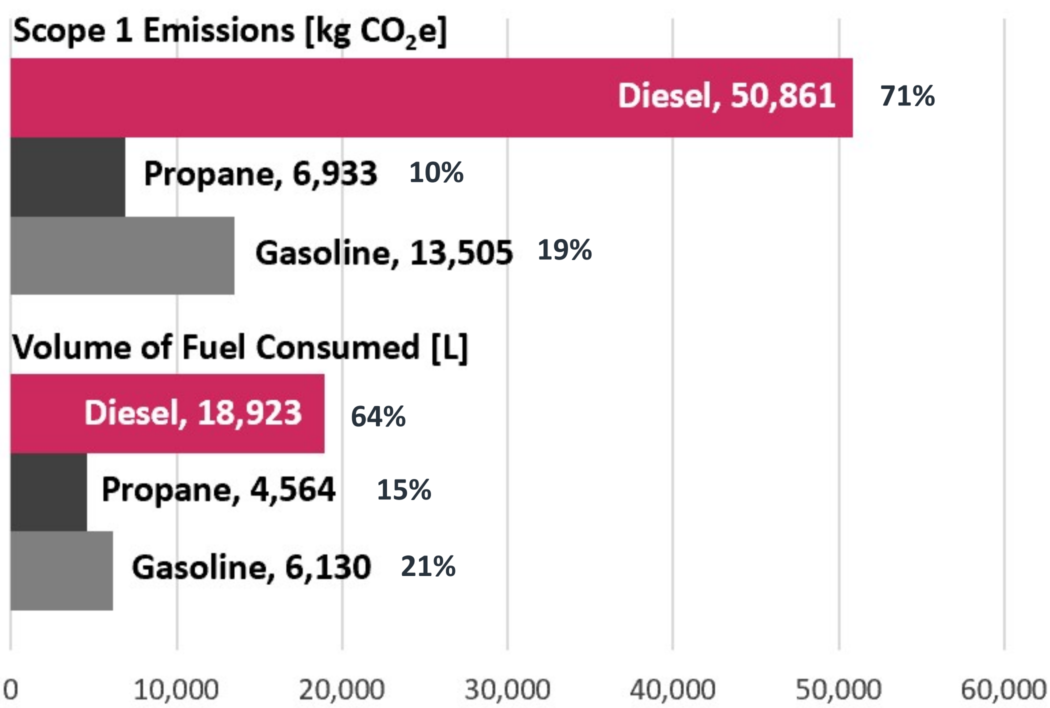
4.2. ENERGY & ENVIRONMENT

4.2.1. Scope 1 Emissions

As fuel (including biomass) comprised 100 percent of KLRS's scope 1 GHG emissions and contributed to 13 percent of scope 3 emissions related to well-to-tank upstream activities, a further breakdown was necessitated. The main sources of scope 1 GHG emissions directly related to fuel consumption at KLRS included diesel-fired electricity power generation, gasoline for the passenger van and truck to transport people and goods within the Yukon, propane used for heating water and cooking, and the firewood combusted for heat production.

Figure 10 plainly highlights the largest contributor of scope 1 emissions related to fossil fuel combustion calculated using the fuel-based method, as diesel combustion to generate electricity to power KLRS buildings, white goods and research equipment, with 18,923 L of consumed fuel and 50,861 kg CO_2e of GHG emissions generated. This equates to 64 percent of the combusted diesel producing 71 percent of emissions with propane producing the lowest ratio of emissions to fuel burned at 15 and 10 percent, respectively. Sandwiched between both fuels was gasoline, which at 21 percent of total annual fuel consumed produced 19 percent of scope 1 emissions. Keeping in mind this only captured six to seven months of operation over the relatively warmer spring and summer and is anticipated to be significantly higher during fall and winter operation.

Figure 10. Scope 1 Major Emissions [2018 Baseline]: Fuel Combustion



With diesel and propane fuel combusted from stationary sources within KLRS applications, the emission factors applied with a breakdown of CO_2, CH_4 and N_2O are estimated with a high degree of confidence and are tabulated in Table 3. Looking at the individual GHG emissions produced by diesel combustion, 98.60 percent of the 50,861 kg CO_2e was estimated to be 50,150 kg CO_2e

of CO_2, with only eight kg CO_2e of CH_4 and the 1.38 percent balance N_2O at 703 kg CO_2e. As the GWP of N_2O is between 10 to 12 times higher than that of CH_4 dependent on the IPCC assessment report GWP is based off, these values are significant and are magnitudes greater than both petrol and propane. Petrol produced a higher ratio of CO_2 to both CH_4 and N_2O with the combustion of gasoline (with average biofuel blend) generating 99.38 percent kg CO_2, and 0.31 percent for both kg CH_4 and kg N_2O. Propane had an even higher ratio of CO_2 to both CH_4 and N_20 with the combustion of propane generating 99.87 percent in kg CO_2, and 0.07 percent for both kg CH_4 and kg N_2O. As this table further suggests, since CO_2 makes up the largest proportion of emissions during fossil fuel combustion, a complete record of fuel volumes is critical to capture an accurate carbon footprint. However, the calculation of emissions of CH_4 and N_2O for mobile combustion of gasoline can be improved through record of distance traveled by vehicle, due to its dependent relationship with vehicle fuel efficiency technologies. Overall, simplifying record-keeping can provide greater assurance of completion rather than more rigorous data collection that may prove unrealistic, especially in the long term.

Table 3. Fossil Fuel Scope 1 Emissions by Greenhouse Gas [2018 Baseline]

Activity	Fuel	kg CO_2e	kg CO_2	kg CH_4	kg N_2O	% CO_2	% CH_4	% N_2O
Gaseous fuels	Propane	6,933	6,924	5	5	**99.87%**	**0.07%**	**0.07%**
Liquid fuels	Petrol	13,505	13,421	42	41	**99.38%**	**0.31%**	**0.31%**
	Diesel	50,861	50,150	8	703	**98.60%**	**0.02%**	**1.38%**

Table 4 captures the fuel consumed by KLRS in litres, wood volumes in cords and their attributable scope 1 emissions. Freight for each type of fuel delivered to site from various Yukon locations was also captured along with their associated scope 3 emissions. Without specific allocation data with respect to the size of each delivered load or insight into efficiencies within third party supplier logistical operations, average laden loads were assumed for delivery of the fuel to site and 0 percent laden or unladen backhaul was assumed for the return trip back to the originating warehouse. Cumulative one-way distances were tabulated reflecting total delivery distance over the year applicable to both types of hauls. In total, there were:

- five deliveries of diesel between 3030 and 4275 L during April and October 2018 inclusive,

- seven deliveries of propane volumes varying between 70 and 2600 L purchased during May and August 2018 inclusive, and;
- three separate hauls of wood over 2018 with a one-tonne truck making two hauls of three cords each and an articulated truck making one haul of 10 cords of beetle kill Spruce bark, purchased in February and September of 2018.

Table 4. Fuel Volumes, Freight and Associated Scope 1 & 3 Emissions [2018 Baseline]

	Fuel Consumed		Freight			
			Cumulative Distance	Scope 3 [kg CO_2e]		
	Volume [L]	Scope 1 [kg CO_2e]	One Way [km]	Average Laden	0% Laden	Total
Wood*	16	**1,130**	155	640	62	**701**
Propane	4,564	**6,933**	1,505	628	1,156	**1,784**
Petrol	6,130	**13,505**	-	-	-	**-**
Diesel	18,923	**50,861**	316	180	242	**422**
Total	**29,617**	**72,429**	**1,975**	**1,447**	**1,460**	**2,907**

***Unit of volume in cord, excluded from total volume**

This illustrates that though scope 1 emissions may appear small in comparison to scope 3 emissions, there are scope 3 emissions attributable to scope 1 activities; thus, emission dependencies require consideration when evaluating the overall footprint. In the case of fuel combustion, including bioenergy, scope 3 includes freight and well-to-tank upstream emissions. Though relevant, well-to-tank emissions will be discussed below in Section 4.2.2 under the major contributors to scope 3 emissions. All emission factors used in this study can be found in Appendix B: List of Emission Factors.

An energy audit conducted in 2014 by Dr. Andy Knight, a professor and interim department head of the Department of Electrical and Computer Engineering and the Transmission Electric Industry Chair at the Schulich School of Engineering within the University of Calgary, was reviewed in detail to identify operational synchronicities that may prove useful in understanding activities at the station and their impact on fuel consumption. Though the study investigates aspects of the station's electricity demand profile which correlate to the volume of diesel fuel consumed, some deductions can be inferred with respect to the other fuels, based on patterns observed and considering the nature of the station. Though no reliable correlation was determined between occupancy and KLRS's power use, as consumption is highly dependent on activities taking place on site (Knight, 2014), it can likely be assumed that increased traffic would result in increased volumes of propane for heating water and cooking food, increased petrol burned for transport of users to and from various destinations including Whitehorse international airport, and increased diesel consumption if power-hungry equipment is utilized. Although the past few years demonstrate decreased volumes in total propane purchased from Superior Propane (an 18 percent decrease from 2016 to 2017 and a further six percent decrease from 2017 to 2018), likely attributable to the broad efficiency improvements made at the station such as the installation of new hot water tanks, it highlights KLRS's ability to reduce its consumption despite an overall increase in user-days from approximately 900 to 2000 in 2017 to 2018.

Although wood volumes make up less than two percent of total scope 1 direct emissions related to bioenergy, it has been included as wood stoves have recently been installed in every building at KLRS. With increased usage of wood stoves, the expectation is wood volumes and their associated emissions will increase. However, the magnitude of increase is projected to be less than the corresponding decrease anticipated through the reduction of diesel fuel previously consumed to power the electric heaters on site and hence positively contributing to emissions reduction. The electric heaters installed at KLRS triggered notable spikes in power draws when active, based on data from the 2014 energy audit, thus a reduction in use also serves to improve overall efficiency of the diesel power generator system and reduce overall power demands (Knight, 2014). Net reduction is attributable to the higher emission intensity of diesel compared to that associated with the on-site combustion of bioenergy from trees, a formerly living source (Department for Business, Energy & Industrial Strategy, 2018b). As well, biomass emission factors used for wood logs set the value of CO_2 emissions at net zero countering the CO_2 absorbed during the growth of the bioenergy source, and therefore only account for CO_2 equivalent emissions from CH_4 and N_2O production (Department for Business, Energy & Industrial Strategy, 2018b).

4.2.2. Scope 3 Emissions

Some of the major contributors to scope 3 emissions within the Kluane Lake Research Station's operations are those due to business travel, well-to-tank emissions associated with fuel combustion in air and land travel and associated freight. This section will detail some of the major findings of the carbon footprint study and highlight some intricacies with the continuously shifting data due to the nature of the operation.

4.2.2.1. Business Travel

The major indirect emissions related to KLRS operations was round trip air travel mainly by station users, totaling 352,081 kg CO_2e. The distance-based method was used to analyze the emissions by domestic, short and long-haul flights, with radiative forcing and distance uplift incorporated into the emission factors used from the 2018 UK Defra source. Figure 11 illustrates the distribution of emissions by haul, that of the estimated 324 unique station users (plus four roundtrips by KLRS employees) in 2018 who traveled by airplane, 66 percent of emissions generated were from short haul flights which made up 69 percent of total great circle flight distances. Due to Canada's vast geography, domestic flights or those within national borders, are significantly longer than in many places around the world. Previously outlined in Section 3.6.3.2, as the upper limit for domestic hauls was set to less than 800 km, they constitute the smallest proportion of emissions at seven percent with four percent of the total distance traveled; despite having the highest emission factor per passenger.kilometre. This is attributable to the typically smaller aircraft used for domestic flights holding less passengers, less air time within more efficient airspace or cruising altitude and take-off and landing, with its higher fuel burn, encompassing a larger relative share of flight time (Clark, 2010). Long-haul flights rounded out at 27 percent of total emissions, comprising 28 percent of the distance traveled by station users.

Flights included four round trips in the 2018 fiscal year taken by KLRS staff between Calgary and Whitehorse, assumed through Vancouver, consisting of a domestic and short haul leg. With 32 percent of the total distance traveled (17,392 km) domestic and 68 percent short haul, emissions were not reported separately as they made up only one percent of total emissions related to air travel. Number of users in Figure 11 reflect station users and employees that embarked on the specific haul listed during each leg of travel.

Figure 11. Percentage by Haul of Scope 3 Emissions [2018 Baseline]: Air Travel

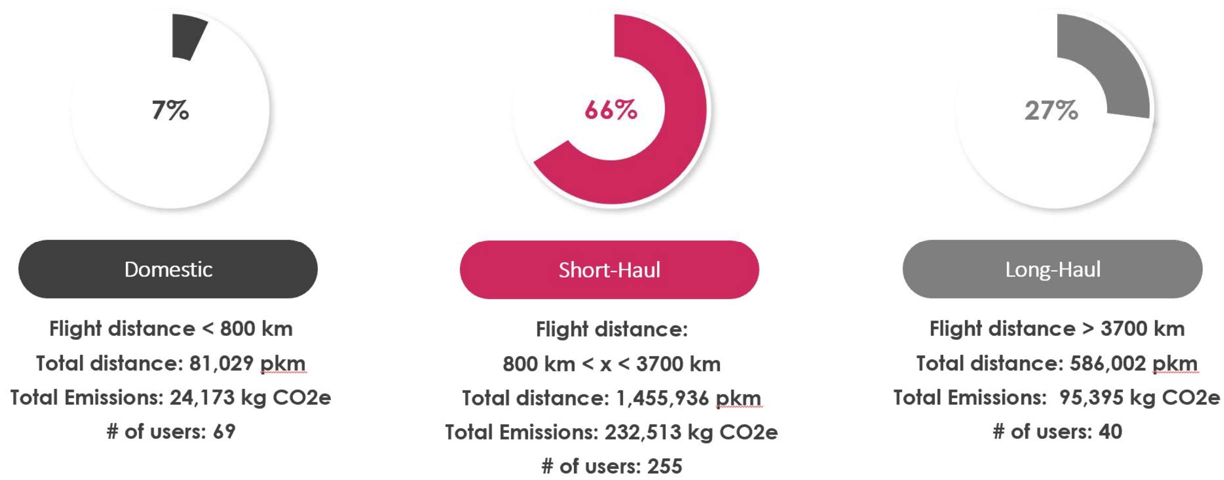
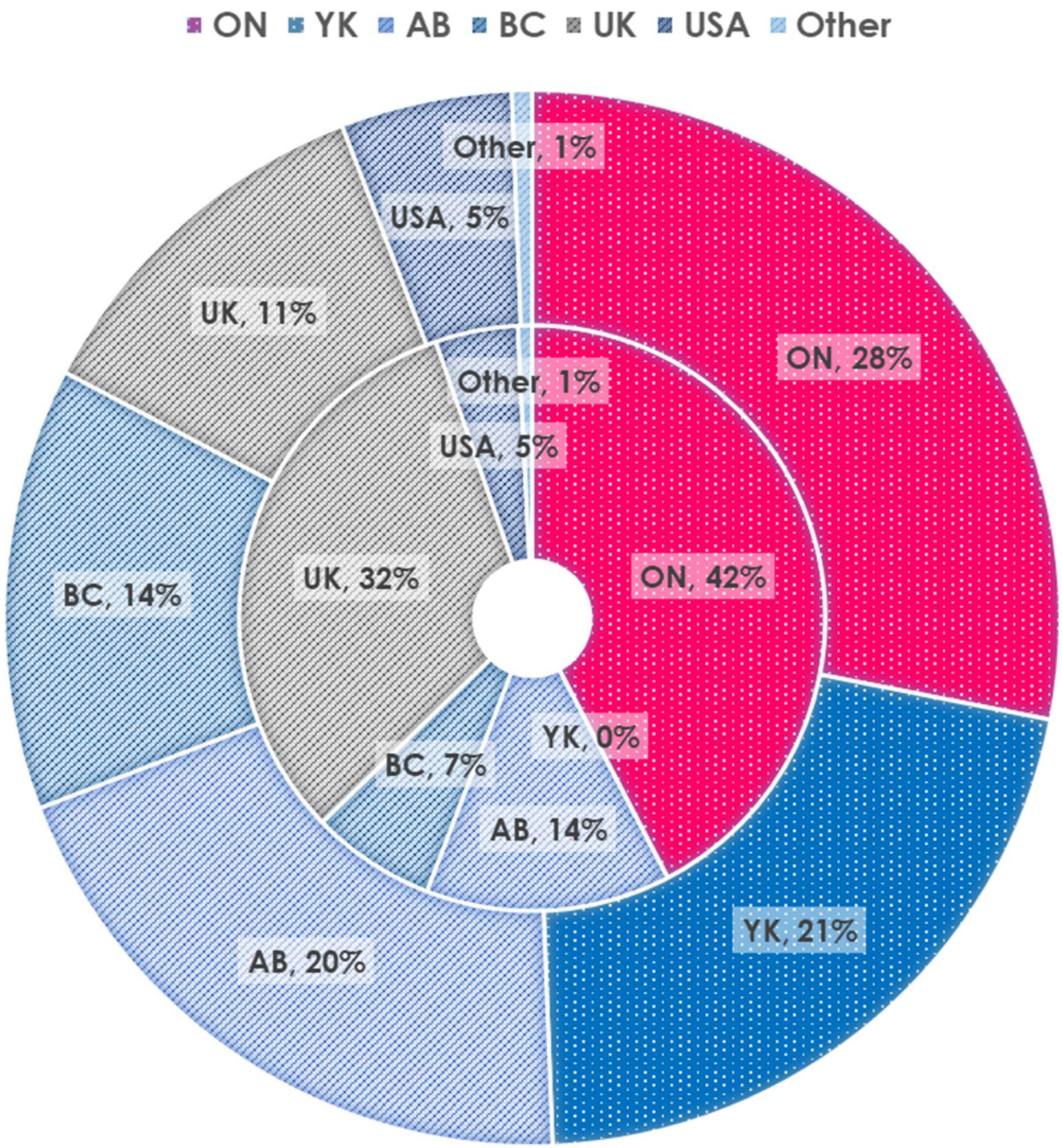


Figure 12 captures the proportionality of outbound user flights, excluding KLRS staff roundtrip travel, providing a visual representation between the distribution of users by origin (outer donut) and the great circle distance (inner donut) for KLRS's 2018 baseline. Based on the distribution of users by origin, in 2018:

- 28 percent of users originated from Ontario (ON), assumedly by plane with each leg of the flight falling under the short haul category;
- 21 percent travelled from various locations within the Yukon (YK) via land;
- 20 percent flew from Alberta (AB) with all flights from Edmonton also falling under the short haul category;
- 14 percent originated from British Columbia (BC) and typically fell within the domestic and short haul categories;
- 11 percent originated from the United Kingdom (UK), making up 96 percent of the logged long-haul flights. The remaining four percent of users on long-haul flights was derived from visitors at the University of Maine in the United States of America (USA);
- five percent of visitors from the USA encompassed users from Utah & Michigan of varying domestic and short haul ratios with those from Alaska assumed to have driven; and
- the remaining one percent of users from Quebec (QC) and the North West Territories.

From a great circle distance perspective, 42 percent of the total 2,105,575 pkm accumulated through air travel were from ON, 32 percent of total GCD were from the UK, 14 percent AB, seven percent BC, and five percent from various parts of the USA excluding Alaska. Thus, 64 percent of total pkm arose from domestic travel, in the typical definition such that all travel was within Canadian borders and the remaining 36 percent was international, with 83 percent of station users originating from within Canada.

Figure 12. 2018 KLRS User Distribution by Origin (outer) & by Great Circle Distance (inner)



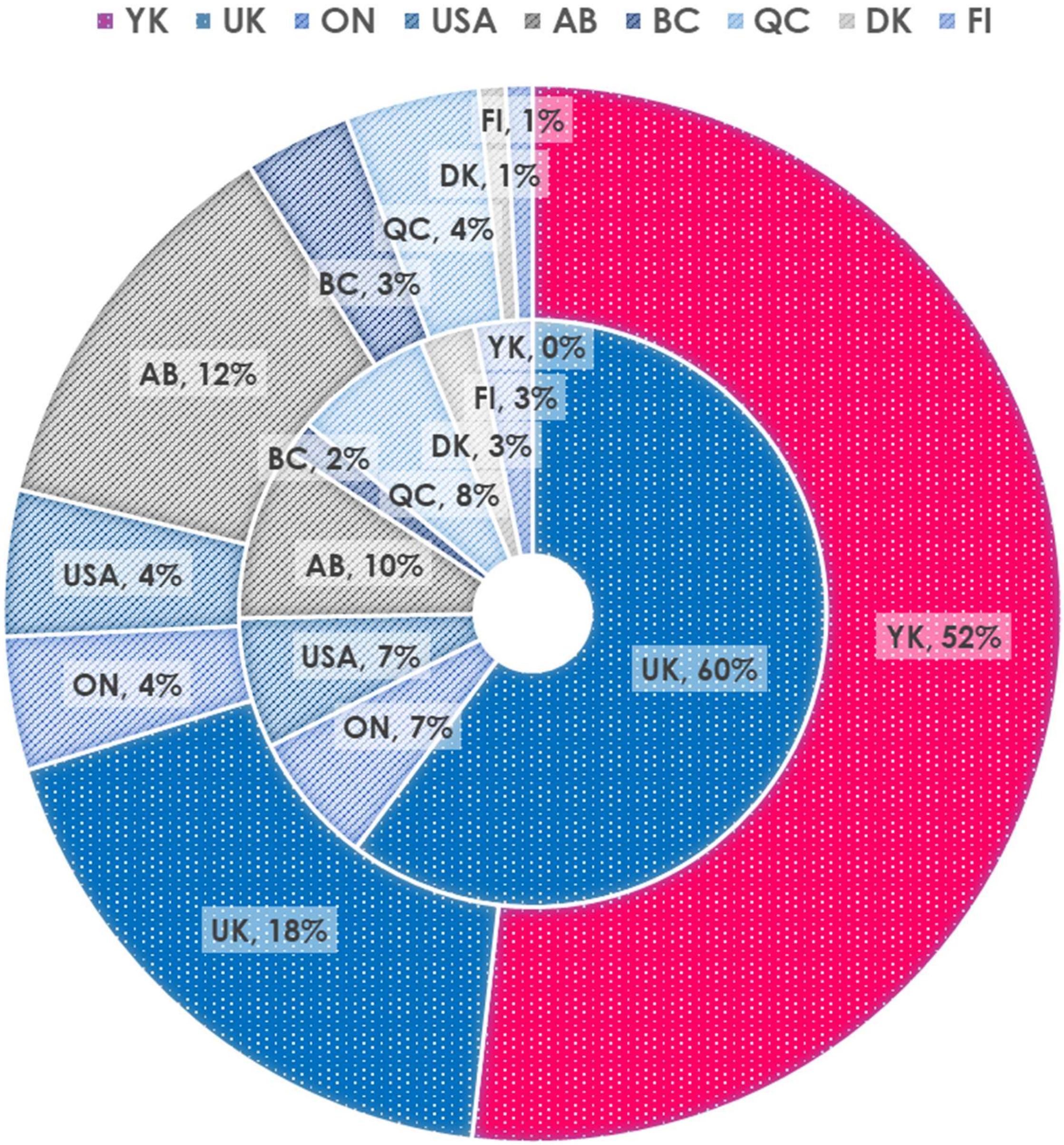
User Origin (outer): 324 users | GCD* (inner): 2,105,575 pkm | Emissions: 352,081 kg CO_2e

The user distribution by origin at KLRS will vary each year due to its changing client base, making it difficult to manage let alone predict scope 3 emissions outside of KLRS's direct control. This is especially important if carbon offset strategies are implemented to counter even a portion of these generated emissions. This drastic fluctuation is graphically depicted when comparing two distinct operational years, with Figure 13 capturing the same relationship as defined above, but for 2017's user base. Following a review of KLRS's 2017 user logs using the same process administered to 2018 user data, out of 245 total unique station users:

- 52 percent originated from the YK;
- 18 percent travelled from the UK;
- 12 percent from AB;
- four percent each from ON, QC, and various parts of the USA including Maine, New Mexico, California and Alaska;
- three percent originated from BC; and
- one percent from both Denmark (DK) and Finland (FI).

As the users within the Yukon would not have logged flight time, 60 percent of the total GCD traveled to KLRS was recorded by clients hailing from the UK, with AB making up 10 percent of the 1,357,070 pkm traveled in 2017, followed by QC at eight percent, and both the USA and ON at seven percent.

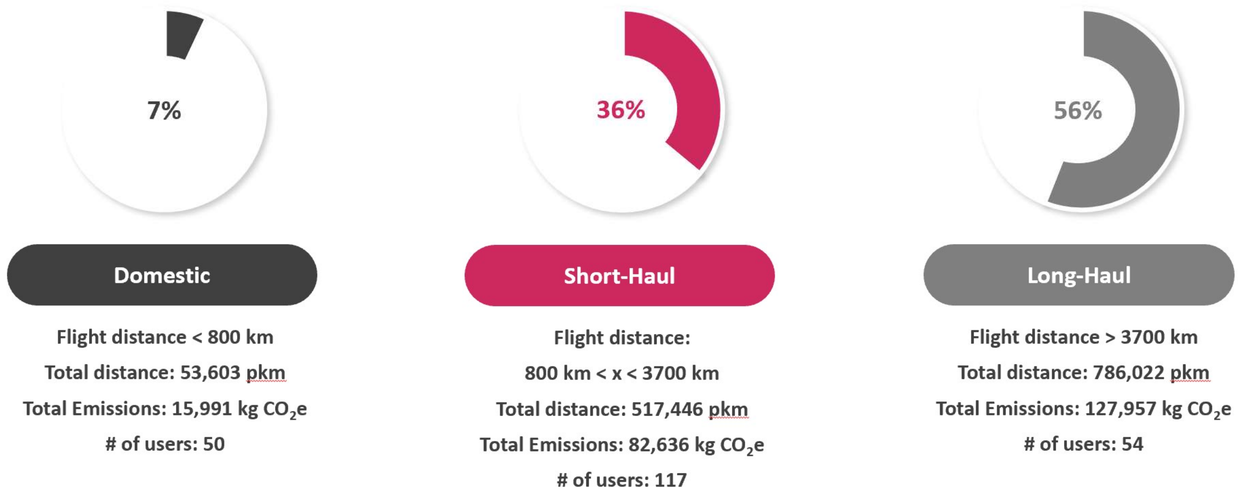
Figure 13. 2017 KLRS User Distribution by Origin (outer) & by Great Circle Distance (inner)



User Origin (outer): 245 users | GCD* (inner): 1,357,070 pkm | Emissions: 226,583 kg CO_2e

For comparison purposes, the 2018 UK Defra emission factors were used to calculate 2017 total emissions due to air travel and excludes air travel by KLRS staff, deemed negligible. To facilitate a fair comparison and meaningful data analysis, KLRS staff travel was also removed from the GCD tabulated for 2018.

Figure 14. Percentage by Haul of Scope 3 Emissions [2017 Operations]: Air Travel



Note: Due to rounding, total percentages do not equal 100.

The percentage of scope 3 emissions by flight haul for air travel from the 2017 operational user base is captured in Figure 14. Based on 2017 air travel activity, 56 percent of total emissions generated were due to long-haul flights as a result of the substantial percentage of users coming from overseas, 36 percent due to short-haul flights and seven percent again due to domestic. This comparison highlights the fluctuations and unpredictability of both total emissions profiles due to air travel and allocation with respect to haul; the possible exception being that domestic hauls will principally comprise the minority. However, 2017 recorded 55 percent less user-days at 901 compared to 2018's baseline of 2009 user-days, correlating to 36 percent less in total emissions.

4.2.2.2. Grocery Emissions

One unexpected finding was that emissions related to the material use of food and drink procured frequently at the station for consumption by both KLRS clients and employees made up a significant portion of the total scope 3 emissions at six percent or 27,007 kg CO_2e. This total included 18,995 kg CO_2e in emissions generated from material use over the 2018 calendar year and 8,012 kg CO_2e generated from associated freight of approximately 3.36 tonnes of provisions procured from GP Distributing, which represented 16 round trip hauls between May and September inclusive, tabulated in Table 5. The emissions attributable to groceries picked up from various retailers by KLRS staff are assumed to be captured in scope 1 emissions calculated based on total petrol volumes recorded in operational logs. The significance of freight with respect to groceries should be carefully considered when strategizing toward activities that support net zero carbon. Significant reductions in procurement of material goods with respect to provisions and frequency can effectively curtail associated emissions, as freight constituted at least 30 percent of emissions related to food and drink (excluding self-pickup). Scope 3 emissions attributable to average laden loads was more than four times larger than unladen backhaul due to the weight of its payload and the reefer being engaged to maintain the integrity of both frozen goods and non-perishables. A comparison between the total emissions generated from freighting groceries versus deliveries of fuel, wood logs, and waste water disposal via septic truck, found the scope 3 freight emissions related to groceries made up a substantially larger percentage of emissions, at 71 percent.

An important takeaway from this data is that due to GP Distributing's typical use of a five-tonne truck for deliveries despite the quantity of goods purchased, KLRS would benefit from picking up groceries ordered using their lighter vehicles. Not only would net savings be realized associated with freight, but less emissions would be generated due to the use of petrol instead of diesel fuel, the higher efficiency of transport and the improved allocation of loads, including the ability to avoid engaging a reefer to transport items through pre-packed coolers. This calculation assumes average laden hauls and does not consider possible efficiencies built into logistical planning by GP Distributing, in potentially off-loading orders in surrounding areas on the same journey.

Table 5. Material Use of Food & Drink and Associated Freight Emissions [2018 Baseline]

Material Use		**Freighting Goods (Groceries)**			
Food & Drink Procured		**Cumulative Distance**	**Scope 3 [kg CO_2e]**		
Mass [tonnes]	**Scope 3 [kg CO_2e]**	**One Way [km]**	**Average Laden**	**0% Laden**	**Total**
4.68	**18,995**	3,328	6,486	1,525	**8,012**

The two invoices obtained from GP Distributing were evaluated to better understand the proportions of provisions by food group on a mass basis. A clear distinction was evident in KLRS's dominant purchases for consumption during the three meals served daily. The distribution for each invoice was tracked separately on the radar chart graphed in Figure 15 to highlight the variability and to understand if any palpable patterns in procurement of provisions would arise from the limited data collected. Though, the two invoices analyzed represented 60 percent and 41 percent of the groceries procured in August and September by spend, respectively, with total spend of the combined invoices representing 16 percent of the annual grocery expenditures.

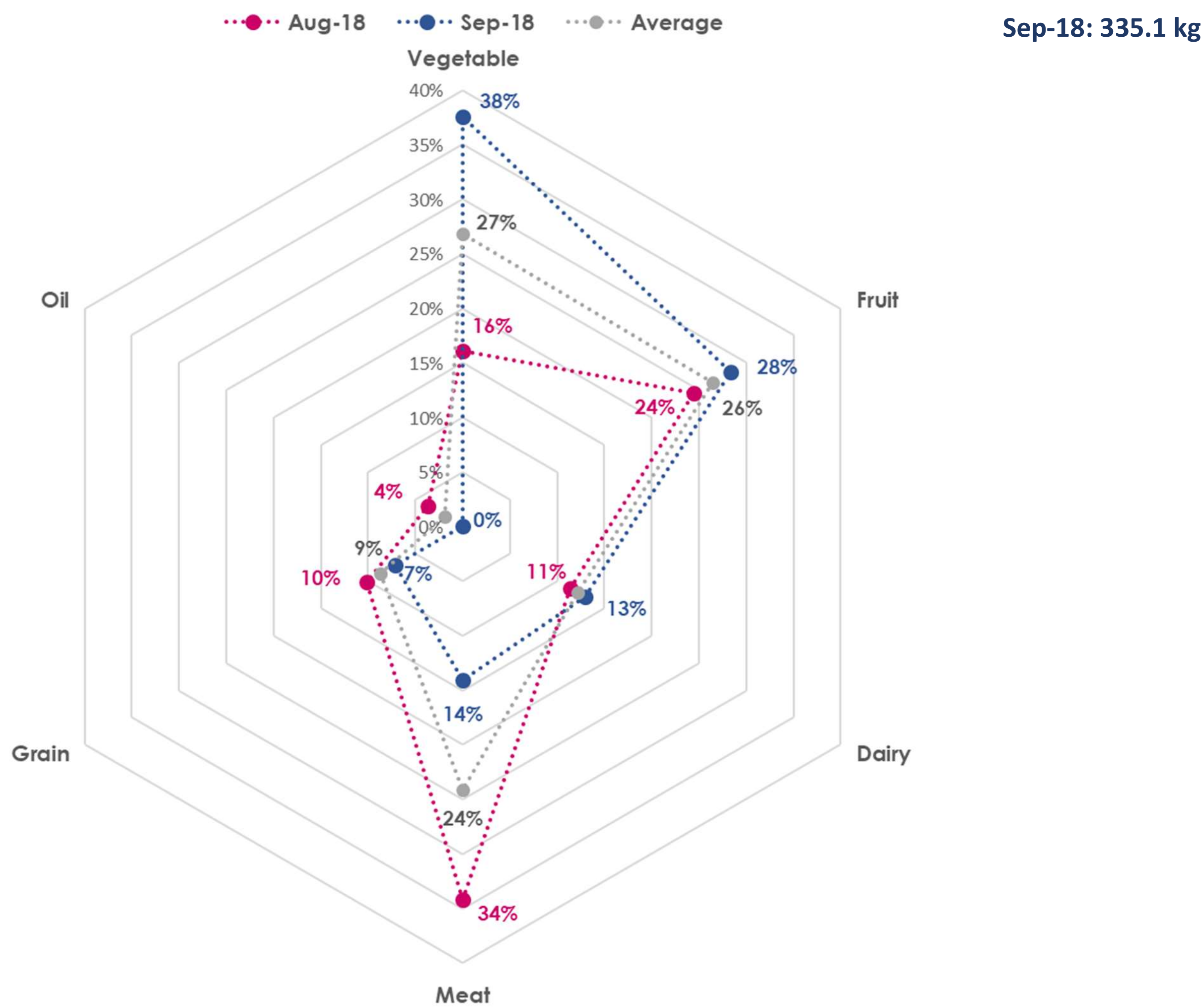
Of the food groups plotted, the three categories that appear to consistently dominate are:

- vegetables averaging 27 percent by mass,
- fruit averaging 26 percent by mass (though consistent over both orders),
- and meat averaging 24 percent by mass.

The quantity of dairy and grain purchases by mass also appear consistent averaging twelve and nine percent, respectively.

Although possibly a coincidence, on the September invoice when vegetables peaked at 38 percent, meat was noticeably lower at 14 percent and when meat peaked on the August invoice at 34 percent, vegetables were noticeably lower at 16 percent. Though this only captures a snapshot of KLRS's food distribution orders during the late summer and early fall months, it provides KLRS with some semblance of understanding of their carbon footprint with respect to current practices, providing insight into behavioural habits they have an opportunity to address and reduce, as elements under their direct control. With an increase in data collection and a more detailed database established, a more accurate carbon footprint can be calculated to facilitate an improved understanding of KLRS's food distribution allowing them to make more strategic decisions in alignment with sustainability principles and the practices it supports.

Figure 15. Distribution of Groceries by Food Group in 2018



This chart further sheds light on the progression of existing projects in the pipeline that can allow KLRS to support more sustainable food practices, such as prioritizing the garden when the season allows to grow their own vegetables at an earlier date or the potential roll out of the Crop Box hydroponics project, if available funding is obtained. If supported by a hybrid solar diesel storage system that can be scaled up to meet the power needs of the Crop Box project without impacting the electricity needs of the research station, it has the potential to reduce the scope 3 upstream emissions related to the material use of food and drink as well as the emissions associated with freight and WTT, by up to 20 to 40 percent; though the magnitude of reduction is also dependent on how it impacts delivery frequency with its effect on the amount of diesel fuel consumed for power generation another important consideration. The reduction in emissions based on material use and average laden freight would be directly proportional to the mass reduction in vegetables procured; however, it will have no impact on unladen backhaul emissions unless the frequency of delivery is also reduced. Although there is a correlation in reduced emissions related to freight, it would be less than the percentage reduction observed by material use emissions.

4.2.2.3. Well-to-Tank Emissions

At 13 percent of total scope 3 emissions, well-to-tank emissions are quite prevalent in that they arise whenever an activity involves the combustion of fuel. This encompasses all stationary and mobile combustion sources associated with generating electricity and heat, and the transportation of people, goods or waste products. Table 6 encapsulates the sources of well-to-tank emissions from the combustion of fuel based on known volumes procured and the estimated distance traveled by various transport mediums, from a small two litre engine to a 17 tonne HGV diesel truck. Total scope 3 WTT emissions due to fuel combustion from stationary and mobile sources operated by AINA was 17,326 kg CO_2e with WTT emissions associated with diesel fuel generating 68 percent of those emissions.

The cumulative annual distance traveled in 2018 due to freight from sources such as fuel, bioenergy, groceries and septic disposal and passenger travel by air, land and employee commuting, was also recorded. Scope 3 WTT emissions related to freight or travel totaled 44,136 kg CO_2e. Well-to-tank emissions related to air travel dominated at 87 percent of this total due to the magnitude of distance traveled. Exclusive of air travel, WTT emissions due to land travel by users (as seen in the right hand column) was greatest due to the distance traveled by users greater than 2.5 times that when compared to employee commuting. However, despite the total freight distance of groceries equating to only 19 percent of total distance traveled by users in land-based vehicles, the WTT emissions are nearly the same magnitude as user land travel due to the mass of the haul, and the size and type of truck used with an onboard reefer engaged 50 percent of the time. Employee commuting was estimated to contribute only 926 kg CO_2e due to travel in smaller-sized vehicles and the lower frequency of travel. The objective of this table was to highlight the associated well-to-tank emissions related to fuel sources and understand all contributing factors to KLRS's carbon footprint along its value chain.

Table 6. Scope 3 Well-to-tank Emissions With & Without Air Travel [2018 Baseline]

Activity	WTT - Fuel		WTT - Freight or Travel (F/T)		
	Total Volume Procured [L]	Scope 3 WTT - Fuel [kg CO_2e]	Total Distance [km]	Scope 3 WTT - F/T [kg CO_2e]	Scope 3 WTT - F/T** [kg CO_2e]
Diesel	18,923	**11,839**	631	**100**	**100**
Propane	4,564	**872**	3,010	**425**	**425**
Petrol	6,130	**3,657**			
Wood*	16	**958**	310	**167**	**167**
Fuel + Bioenergy Totals	**29,617**	**17,326**	**3,951**	**693**	**693**
User Travel - Air			2,122,967	**38,575**	
User Travel - Land			34,759	**1,951**	**1,951**
Employee Commuting			13,698	**926**	**926**
Groceries			6,656	**1,912**	**1,912**
Septic - Waste Water Disposal			252	**80**	**80**
2018 Total		**17,326**	**2,182,283**	**44,136**	**5,562**

***Unit of volume in cord. Fuel + bioenergy total volumes exclude wood**
****Excludes air travel**

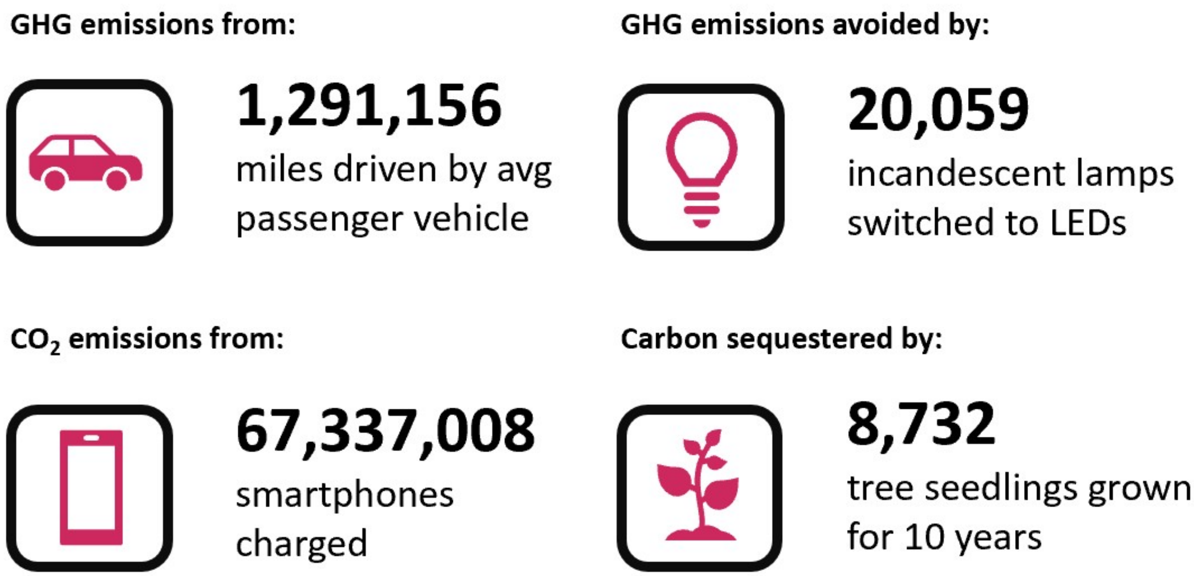
All other emissions calculated as part of the carbon footprint study will be included in Appendix E: Summary of Results of Carbon Footprint Calculation for completeness and transparency, but will not be reviewed in detail due to the vanishingly small footprint in terms of the magnitude of emissions in other categories.

4.3. EQUIVALENCIES

4.3.1. High Level GHG Equivalents to KLRS's Scope 1 & 3 Emissions

To understand the magnitude of the results, it was deemed valuable to compare the total scope 1 and 3 emissions to something a bit more tangible. Of the total estimated 528,083 kg CO_2e in GHG emissions for the Kluane Lake Research Station, four perceptible equivalents were compared in Figure 16, bearing in mind that 14 percent of the total emissions are scope 1 and 86 percent are scope 3. Using the United States Environmental Protection Agency Greenhouse Gas Equivalencies Calculator, the carbon footprint of KLRS was estimated to be equivalent to GHG emissions from 1.3 million miles driven by an average passenger vehicle, GHG emissions avoided by the conversion of 20.1 thousand incandescent lamps to LEDs, CO_2 emissions from the charging of 67.3 million smartphones, and the carbon sequestered by the growth of 8.7 thousand tree seedlings over 10 years (United States Environmental Protection Agency [EPA], 2018), which provides meaningful context of the size of KLRS's carbon footprint with scope 1 and 3 considered.

Figure 16. GHG Equivalents of Total Scope 1 & 3 Emissions for KLRS's Carbon Footprint



Source: Adapted from (United States Environmental Protection Agency [EPA], 2018)

4.3.2. Comparison of KLRS's 2018 Baseline to Yukon's GHG Intensity

To make a comparison more attributable to the geographic location of KLRS, it was worthwhile to compare the per capita emissions of a time-weighted station user from the 2018 baseline with that of an average Yukoner using the latest available data. When reviewing the per capita emissions of station users at KLRS with an average operating year of 183 days (typically between April and October, with more than 90 percent of user-days occurring between this time) and 2009 user-days recorded in 2018, there are approximately 11 weighted users per day over a typical operational period of six months. Of the total 528,083 kg CO_2e in GHG emissions generated through direct operations and indirect upstream activities over the 2018 reference year, a station user's GHG intensity was calculated to be approximately 48 tonnes of CO_2e in emissions generated per user over the six-month operational period. Based on the Yukon's 2016 per capita emissions, the National Inventory Report estimated the average Yukon resident generates 16.4 tonnes CO_2e over the entire year (Government of Yukon, 2019b). Though dividing this number in half to normalize the six months of KLRS operation is not an accurate representation of the average emissions per resident over six months, as significantly more emissions are likely to be generated during the shorter and colder months of a Yukon fall and winter, this assumption alone observes GHG emissions per weighted user at KLRS generating almost six times that of an average Yukoner. This is substantial given the goals of the research station and the clients who utilize it. It is worthwhile to note the National Inventory reports capture aviation fuel from domestic travel as required by the UNFCCC, though perhaps not exhaustive, making the comparison more relevant (Larsson, Kamb, Nassen, & Akerman, 2018).

With average annual diesel consumption estimated at 160,000 L between neighbouring communities of Burwash Landing and Destruction Bay for a community with a combined population of 115 people as of the 2016 census, as noted earlier in Section 2.3.2**,** the volume of diesel fuel allocated per person is approximately 1391 L. With 18,923 L of diesel fuel procured in 2018 and an average 11 station users per day, KLRS consumes approximately 1720 L per weighted user. Using the simplified assumption so the quantities are more comparable and normalizing to a six-month operational year, the average station user consumes almost 2.5 times the diesel compared to similar off-grid communities. This comparison highlights the impact of the forced inefficient operation of the diesel-fired power generation system and the variability of KLRS's power profile due to the diverse needs of its clients, as well as the ability for Burwash Landing and Destruction Bay to operate their diesel power station more efficiently due to economies of scale with a larger population base. This will be further discussed in Section 4.5: Economics.

4.3.3. Comparison of KLRS's 2018 Baseline to U of C's GHG Intensity

As the University of Calgary campus is aiming to become carbon neutral by 2050 and has made a Climate Action Plan noting strategic objectives to achieve that goal, there is scientific merit in comparing the Kluane Lake Research Station's carbon footprint to the U of C's most current GHG inventory, from April 1, 2017 to March 31, 2018 (2017/18). The U of C selected to account for emissions in its 2017/18 inventory from all sources within its direct operational control (U of C Office of Sustainability, 2018). As such, this confirms KLRS is excluded from the U of C inventory to ensure no double-counting of emissions prior to comparing both sets of inventories. Although the GHG inventory tabulates total greenhouse emissions, some valuable comparisons can be made from the overall results rather than components of campus operations with similar magnitudes to the Kluane Lake Research Station.

For ease of comparison, Table 7 contains important measurements from U of C's 2017/18 GHG inventory and their established baseline in 2008/09 (U of C Office of Sustainability, 2018). Though scope 3 emissions appear to be measured in both of U of C's GHG inventories, they are not comparable as a less comprehensive inventory was completed in 2017/18 and is therefore not a true reflection of emission reduction (U of C Office of Sustainability, 2018). Although total emissions by scope cannot be compared due to the significant difference in campus population (33.6 thousand full time equivalents (FTE) at U of C versus 11 FTE at KLRS), the GHG intensities can make for a valuable comparison, bearing in mind the lower occupancy of the research station (35 user accommodations) with just over 31 percent occupancy by calculated weighted user.

The GHG intensity from both scope 1 and 2 emissions and from all three scopes combined (total) were reviewed. When comparing scope 1 and 2 GHG emission intensities, KLRS's scope 1 GHG intensity is 6.58 tonnes CO_2e per FTE, almost midway between the U of C's 2008/09 baseline at 7.93 and their latest 2017/18 GHG inventory at 5.43. When scope 3 emissions are also accounted for, KLRS's total GHG intensity is 48 tonnes CO_2e per FTE, which is more than seven times when compared to both its own scope 1 GHG intensity and the U of C's total GHG intensity recorded in 2017/18, inclusive of all three scopes (excluding financed travel). However, when compared to the U of C's 2008/09 baseline which includes financed travel in their scope 3 emissions, KLRS's total scope GHG intensity is still more than 4 times the magnitude. This is attributable to a few factors including that most users travel by air to visit the research station and the university has a large campus population to distribute its emissions with financed travel only attributable to the university's employees.

Some notable observations included U of C's lack of inclusion of financed travel in the 2017/18 inventory which were included in their 2008/09 scope 3 emissions baseline, comprising 15 percent of scope 3 emissions in its baseline with commuting vehicles making up 50 percent (U of C Office of Sustainability, 2018). Being a commuter campus, U of C's 2017/18 GHG inventory scope 3 emissions only included commuting by car and bus, some of the solid waste generated during operations and some of the activities related to fuel and energy not recorded in scope 1 or 2 such as transmission and distribution losses (U of C Office of Sustainability, 2018) and is therefore, underestimating its scope 3 emissions making it difficult to perform an equivalent comparison. It is worthwhile to note the omission of financed business travel in the U of C's latest GHG inventory due to the high carbon signature of academics with respect to air travel, due to attendance at international conferences, research abroad as evidenced by typical users of KLRS and worldwide collaboration (Buchs, 2019), significantly underestimates their contribution to climate change and undermines their responsibility to proactively address steps to minimize their travel and associated impact.

Table 7. GHG Intensity Comparison of U of C's GHG Inventory & KLRS Baseline

	University of Calgary GHG Inventory			**KLRS Baseline**
	2008/09	**2017/18**	**Delta [%]**	**2018**
Scope 1 [tonnes CO_2e]	50,133	86,931	**73%**	72
Scope 2 [tonnes CO_2e]	189,822	95,181	**-50%**	-
Total Scope 1 & 2 [tonnes CO_2e]	**239,955**	**182,112**	**-24%**	**72**
Scope 3 [tonnes CO_2e]	88,621	42,453		456
Total Scope 1, 2 & 3 [tonnes CO_2e]	**328,576**	**224,565**	**-32%**	**528**
Campus Population [FTE]	30,249	33,558	**11%**	11
GHG Intensity - Scope 1 & 2 [tonnes CO_2e/FTE]	**7.93**	**5.43**	**-32%**	**6.58**
GHG Intensity - Scope 1, 2 & 3 [tonnes CO_2e/FTE]	**10.86**	**6.69**	**-38%**	**48.01**

Source: data populated from University of Calgary's 2017-2018 GHG Inventory (U of C Office of Sustainability, 2018)

4.4. UNCERTAINTY ANALYSIS

A high-level uncertainty analysis was conducted on scope 3 emissions found to largely contribute to the Kluane Lake Research Station's carbon footprint, focused on air travel and the procurement of provisions, to determine the spectrum at which assumptions may impact findings.

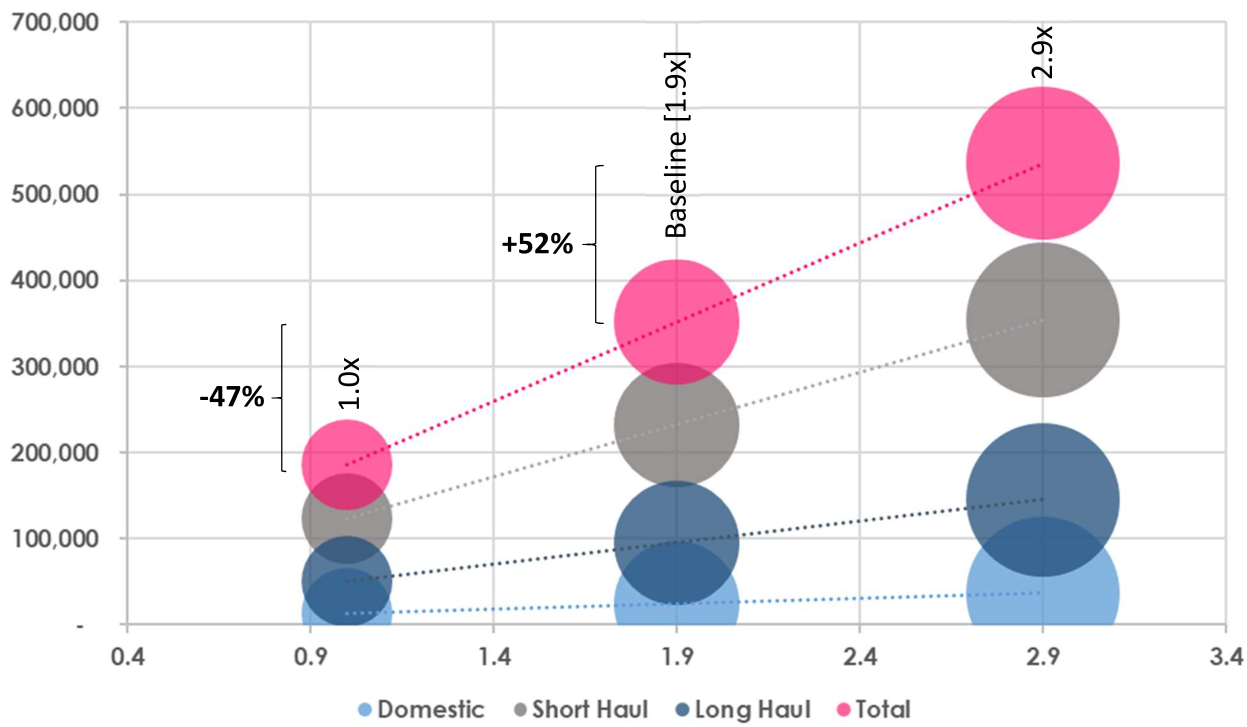
4.4.1. Business Travel Emissions by Air

Numerous assumptions were made in tabulating air travel emissions related to both user and employee travel. The four assumptions that likely had greatest influence on calculated air travel emissions included the:

- use of emission factors that account for radiative forcing,
- representative approximation used for travel via transit rather than direct flights,
- assumption all passengers travel in economy class and;
- domestic haul set at an upper boundary of 800 km for baseline rather than 463 km.

As previously mentioned, the impact of radiative forcing is still an active area of research. Although there is a wide range of factors that can be applied, from the exclusion of the effect aviation has on non-CO_2 climate change using emission factors without radiative forcing (Department for Business, Energy & Industrial Strategy, 2018b) up to multiplicative factors of 2.9 applied to CO_2 direct emissions; the baseline calculated applied the central estimate of 1.9 based on the most current research of aviation's impact for each forcing agent (CO_2, O_3, CH_4, water (H_2O), sulphate, soot, and contrails) derived by dividing the total radiative force without cirrus by the radiative forcing of direct emissions of CO_2 (Department for Business, Energy & Industrial Strategy, 2018a). The bubble chart in Figure 17 captures the essence of the distribution for each haul, from the lower limit which uses only direct emissions or a factor of 1.0 (without radiative forcing), the baseline which applies a factor of 1.9 represented by the middle set of bubbles and the upper limit using a 2.9 multiplier. This visually demonstrates the wide differential between air travel emissions with and without radiative forcing uplift from a total of 186,000 kg CO_2e without radiative forcing (a 47 percent reduction from the 2018 baseline of 352,081 kg CO_2e) up to 536,000 kg CO_2e (a 52 percent increase compared to baseline). Though the radiative forcing factor selected to calculate emissions related to air travel can largely impact the carbon footprint of KLRS, neglecting multiplicative impacts of aviation while an airplane operates within the upper troposphere and lower stratosphere has the potential to significantly underestimate one's true environmental impact.

Figure 17. Air Travel Emissions and the Influence of Radiative Forcing in kg CO_2e



To ensure a greater degree of accuracy in air travel emission calculations which already have substantial entrenched uncertainty due to the complex nature of its emissions within the upper atmosphere, more representative flight paths through typical in transit locations were assumed rather than direct travel from origination to Whitehorse in hopes of minimizing uncertainty and limiting the underestimation of air travel emissions within KLRS's carbon footprint. As such, an evaluation of the difference between direct flights compared to transit through the Vancouver international airport (baseline includes at minimum a flight stage that transits through YVR) was conducted to understand the magnitude of both the great circle distance and total emissions by haul. As expected, both GCD and its associated emissions would be reduced if direct flights were assumed due to optimal flight paths and the greater efficiencies obtained without having to embark on additional domestic or short haul flights in transit to the final destination. The percentages captured in Figure 18 was representative of both the total GCD measured in pkm for each haul, as well as the air travel emissions by haul in kg CO_2e. As a result, 23 percent of total flights were categorized as short haul and 77 percent fell within the long haul category, strikingly different from the distribution presented in Figure 11 at 66 percent and 27 percent short and long haul, respectively.

Figure 18. Percentage Distribution by Haul of GCD and Air Travel Emissions

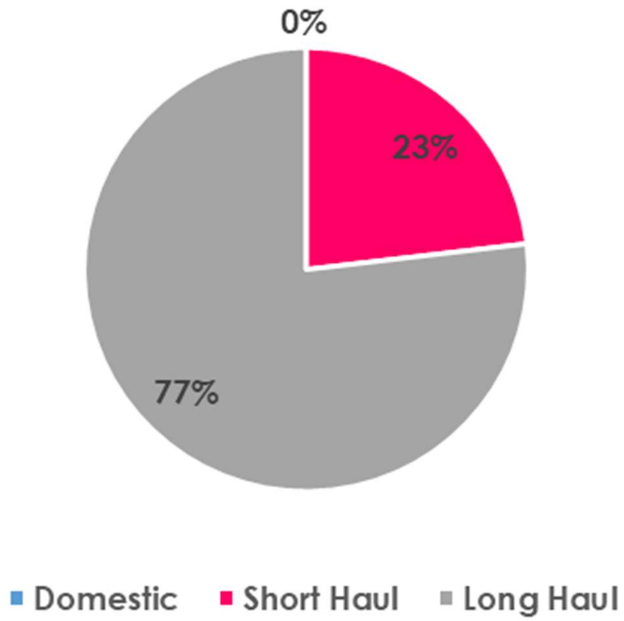


Table 8 contains the numerical distances from both direct flights as well as those via transit in the baseline. In comparing the total pkm and air travel emissions of direct flights to baseline, GCD decreased by 20 percent with emissions dropping by 22 percent, respectively. Looking at each individual haul, short haul flights decreased by 73 percent with long haul flights increasing by 122 percent, in both cases representing patterns observed by both GCD and emissions by haul. As both the table and figure illustrate, domestic hauls dropped to zero, which further accentuates the remote nature of the research station within the Yukon.

Table 8. Comparison of Direct Flights to Transit Through Vancouver [2018 Baseline]

		Domestic	Short Haul	Long Haul	Total	Delta
Direct	**GCD [pkm]**	0	392,222	1,302,982	**1,695,204**	-20%
	Emissions [kg CO_2e]	0	62,638	212,112	**274,750**	-22%
Transit [Baseline]	**GCD [pkm]**	81,029	1,455,936	586,002	**2,122,967**	
	Emissions [kg CO_2e]	24,173	232,513	95,395	**352,081**	
	Delta	**-100%**	**-73%**	**122%**		

Another assumption made attributable to all station users and KLRS staff was flight class. To better understand the impact the assumption that all individuals who traffic KLRS fly in economy class rather than using the average emission factor (without exact knowledge of the flight class selected), was reviewed to understand its influence on the total carbon footprint with respect to air travel. This will however only impact short and long-haul flights as only average emission factors are available for domestic flights, as per the asterisk in the table heading below. Table 9 captures the total emissions related to economy class as well as the average assumption when class type is unknown, as was the case in this study. The impact was predominantly observed on long-haul emissions where the emission factor was significantly larger due to the noticeable attribution in premium seating capacity allocated to business and first-class travel (Department for Business, Energy & Industrial Strategy, 2018a) with short haul flights using average emission factors posting only a two percent increase compared to economy (baseline) and long-haul flights increasing by 31 percent compared to baseline. Overall, the impact on total emissions of average emission factors compared to baseline was a nine percent increase. With the numerous factors that can potentially influence the carbon footprint due to air travel, data accuracy at the collection step can substantially improve calculations through minimizing unknowns.

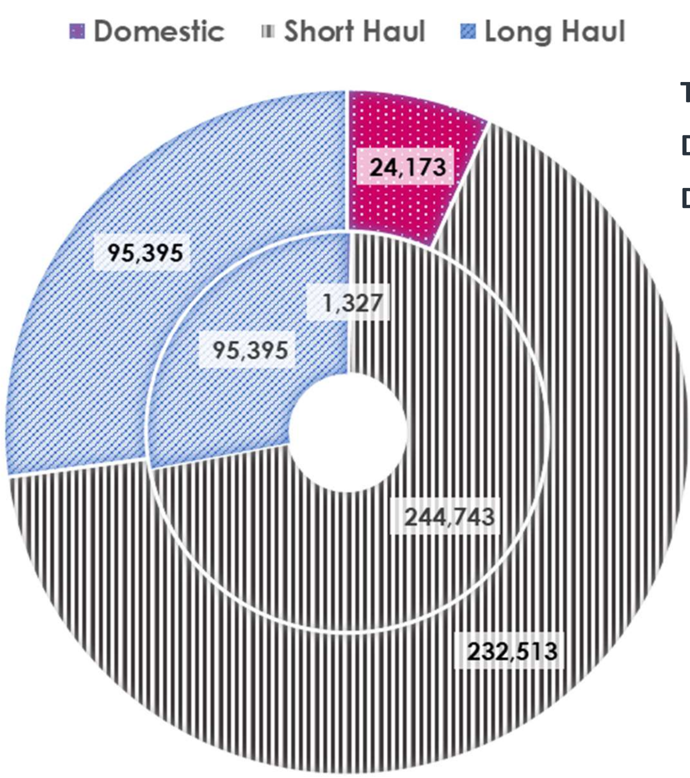
Table 9. Uncertainty Analysis of Flight Class on Air Travel Emissions

	Domestic*	Short Haul	Long Haul	Total
Distance [pkm]	81,029	1,455,936	586,002	**2,122,967**
EF - Economy [kg CO_2e/pkm]	0.29832	0.15970	0.16279	
Economy Total Emissions [kg CO_2e]	**24,173**	**232,513**	**95,395**	**352,081**
EF - Average [kg CO_2e/pkm]	0.29832	0.16236	0.21256	
Average Total Emissions [kg CO_2e]	**24,173**	**236,386**	**124,561**	**385,119**

***Average EF applicable for all domestic flights**

The 463 km distance arbitrarily set by various carbon calculators as it relates to the longest direct domestic flight between airports within the UK, as per Defra. Figure 19 captured the variance between setting domestic flights to less than 800 km (baseline) compared to 463 km to observe the magnitude this impacted emissions related to domestic and short haul flights, as this condition would have no impact on long haul flights greater than the defined 3700 km. The outer donut captures those emissions generated during each haul when domestic flights were set at an upper limit of 800 km and the inner donut reflects those calculated when domestic flights were categorized below 463 km. The most significant observation was the 95 percent drop in emissions related to domestic travel when comparing the baseline to the UK's guidelines with domestic passenger.kilometre dropping from 81,000 pkm down to sub-4500 pkm, which was perhaps predictable due to the geographic nature of Canada's vast landmass. Contrarily, emissions attributed to short haul flights increased by only five percent, the small change largely due to the prior dominance of short haul flights with the 77,000 pkm moving to the short haul category. Overall, total emissions related to air travel dropped by three percent compared to baseline, highlighting the minimal effect the selection of an 800 km boundary had on the overall carbon footprint calculated, which more accurately depicts domestic flights within Canada.

Figure 19. Impact of Domestic Flight Upper Boundary on Air Travel Emissions in kg CO_2e



Total Emissions of All Hauls [kg CO_2e]

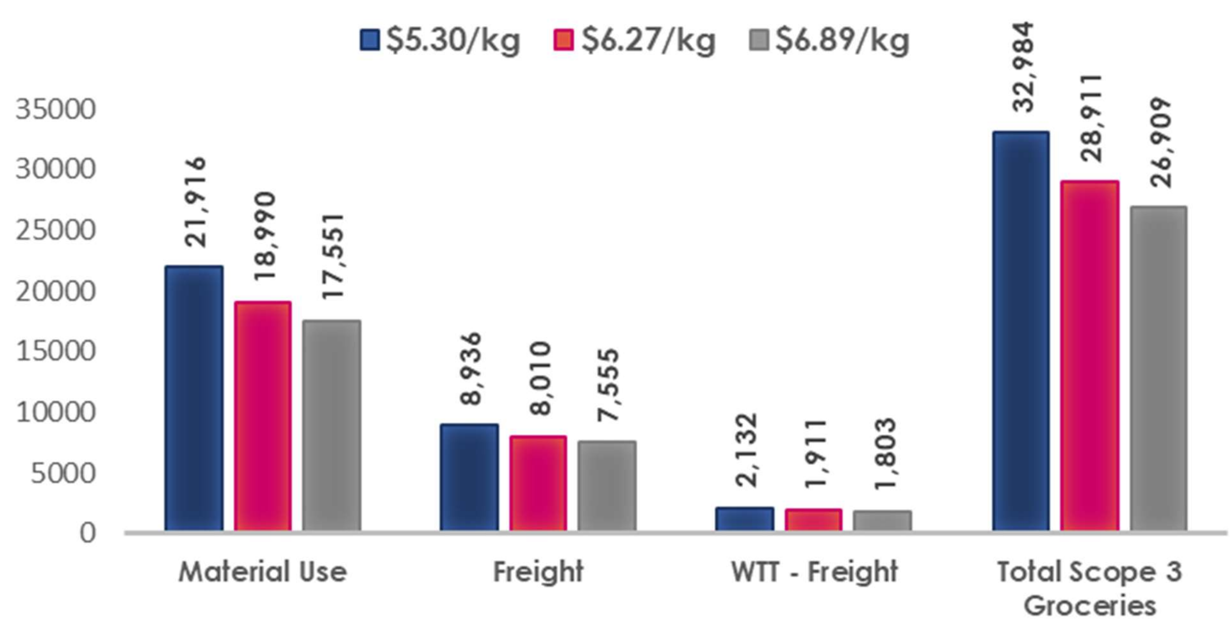
Domestic < 463 km (inner): 341,465

Domestic < 800 km (outer): 352,081

4.4.2. Grocery Emissions

To understand the impact of using the weighted average unit cost to convert operational expenditure to mass on the magnitude of scope 3 emissions related to material use of food and drink, the lower and higher unit costs calculated from the two invoices acquired from GP Distributing were used to calculate a lower and upper limit of scope 3 emissions within two knowns. Figure 20 highlights the distribution of emissions calculated with the lower unit cost of \$5.30/kg resulting in a total annual mass of 5.6 tonnes in groceries with \$6.89/kg calculating an annual mass of 4.32 tonnes. The largest observed change was in material use emissions as unladen backhaul emissions remain unchanged regardless of the mass delivered, thus abating the change in total freight emissions. Overall, the unit costs of \$5.30/kg and \$6.89/kg resulted in a 14 percent increase and seven percent decrease in total scope 3 emissions (material use, freight and WTT), respectively, in comparison to the \$6.27/kg weighted average used in the baseline.

Figure 20. Impact of Unit Cost Assumption on Grocery Emissions in kg CO_2e



Due to the uncertainty around the cost of freight applied to each invoice, supplementary analysis was conducted to understand the total reduction in scope 3 emissions with \$200 removed from 11 of the 16 deliveries made throughout 2018. Eleven instances were selected as freight from two of the known invoices had already been accounted for and the three invoices below the \$300 spend threshold were deemed negligible and unlikely to have been charged an additional

$200 in freight. As such, the $2200 in total freight-related spend is equivalent to an estimated total provision mass of 351 kg (using the $6.27/kg unit cost), corresponding to an estimated emissions reduction of 1425 kg CO_2e for material use (an eight percent drop when comparing total emissions including freight versus those excluding freight), 677 kg CO_2e in average laden hauls and 161 kg CO_2e in associated WTT emissions (the latter two equivalent to an eight or ten percent drop compared to total hauls including unladen backhaul or solely average laden emissions from each category, respectively). These results are captured in Table 10. Overall, this had little to no impact on the percentage of overall scope 3 emissions with groceries still comprising six percent of total scope 3 emissions, moving the needle by 0.4 percent.

Table 10. Impact of the Inclusion of the Cost of Freight on Grocery Emissions in kg CO_2e

	Material Use	Freight			WTT - Freight		
		Average Laden	Unladen Backhaul	Total	WTT Average Laden	WTT Unladen Backhaul	Total
$2200 Freight	- 1,425	- 677	-	- 677	- 161	-	- 161
Total Including Freight	17,570	5,810	1,525	7,335	1,387	363	1,750
Total Excluding Freight	18,995	6,486	1,525	8,012	1,548	363	1,912
Delta [%]	**-8%**	**-10%**		**-8%**	**-10%**		**-8%**

Although calculations typically contain ambiguity when examining elements often difficult to directly measure, the uncertainty analysis conducted provides a positive overall view of the data integrity. Its findings highlight some of the fluctuations observed due to assumptions made often impacting total GHG emissions within the upstream category by less than +/- 20 percent, apart from radiative forcing which has the most drastic impact on air travel emissions calculated; which is in itself an ongoing conscientious research effort to assimilate data to quantify causal mechanisms, understand feedback looks and model effects. Overall, this comprehensive study allows for a more accurate picture of KLRS's carbon footprint with recognition of impacts that are incredibly variable in nature.

4.5. ECONOMICS

As is often the case, diesel-fired power generation systems are often replaced in equal substitution due to the overall reliability of the system and its lower relative capital investment. However, as was highlighted in the diverging from diesel study discussed in Section 2.3.1, avoided costs of diesel are typically not considered when evaluating economics, often based solely on initial capital expenditure and project payout. This cost benefit analysis serves to compare the replacement of a diesel-fired power generation system to a renewable energy hybrid system capable of meeting current power needs, to understand the costs of addressing one of the largest sources of GHG emissions within KLRS's direct operational control. Numerous assumptions were made to model both hypothetical scenarios to understand variances over a similar time frame and enable a more equal comparison of different inputs. Inputs and assumptions used for the cost benefit analysis can be found in Appendix A: Cost Benefit Analysis.

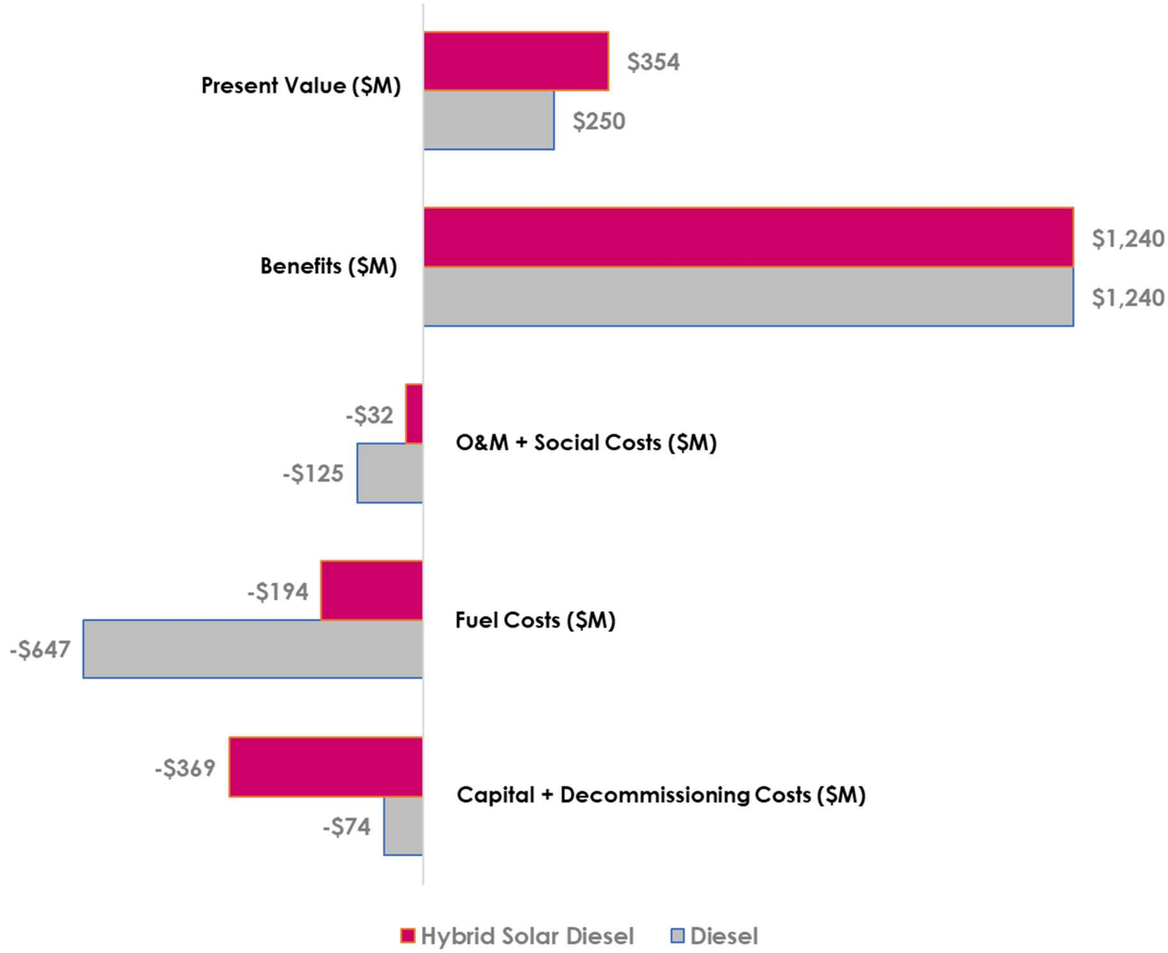
A 2014 energy audit conducted by Andy Knight of the University of Calgary was reviewed to evaluate the latest available data of the estimated average load on KLRS's diesel-powered generator system. Its analysis provided some understanding of both the regular and efficient power use at the station, along with its largest power draws, to analyze whether a hybrid solar PV diesel system with battery storage would be sufficient to replace the current diesel-fired power generation. As some uncertainty exists as to how the load demands may have changed between 2014 and 2018 with the upgrade of white goods to energy efficient appliances, the increase in user-days that may further strain the system while factoring in the inconsistent correlation observed between number of users on site and power demand (Knight, 2014), it was assumed that 2014 data was a relatively accurate reflection of current station demands, with additions and subtractions canceling out, and the recent installations of solar panels atop each housing unit contributing additional resources to support further reductions in power demands. To estimate the true load on the diesel generator system, a power factor of 0.8 was applied to the apparent work measured at KLRS based on typical averages seen for systems of this size and design (Nowicki, 2019). The same power factor was applied to both the average measurements recorded during regular and efficient operation, the latter believed to more accurately replicate the load of the system following the installation of a renewable energy system. As a further check on the application of 2014 power data to 2018 operation, the energy demand in 2018 was approximated based on the estimated consumption of diesel between the typical operational months, with the consideration of the system's forced inefficient operation to maintain minimum loads to avoid underloading the generator set. The current diesel-powered system is forced to operate inefficiently by continuously maintaining a minimum load on the generator even if electricity is not required, mainly through the use of inefficient fluorescent lighting within the mess hall and wash house, which consumes a visible percentage of power (Knight, 2014).

A cost benefit analysis was conducted to compare the capital and decommissioning, O&M, fuel and social costs to calculate the resulting net present value (NPV) between re-installation of the existing 20 kW diesel-fired power generation system (diesel) and a 24 kW hybrid solar diesel system with battery storage (hybrid solar diesel). A 30-year time horizon was used for evaluation with a six-month typical operational period assumed for its entirety to estimate equipment replacement frequency. This time frame saw the replacement of the diesel-powered turbine with the diesel system twice (every 10 years) and once with the hybrid solar diesel system due to its secondary role and less frequent/more efficient operation (at 15 years) as well as the replacement of the battery in the hybrid solar diesel once (at 15 years).

The capital costs (including 10 percent in decommissioning) for the hybrid solar diesel compared to the diesel system is almost 400 percent greater over the same time period, as shown in Figure 21. However, this has the potential to be offset over the 30-year time horizon with lower fuel and O&M costs. In comparison to the hybrid solar diesel system, the fuel costs of the diesel system are 233 percent greater and O&M including social costs are 294 percent greater. This is attributable to the estimated 70 percent reduction in diesel fuel consumption with respect to the hybrid solar diesel system with its zero-emission power generation when the solar panels are operational or actively charging the battery to harness the sun's energy rather than allowing it to dissipate. In addition, fuel cost volatility and carbon taxes can lead to escalating operating costs over a 30-year period, especially when a diesel genset is forced to run inefficiently which also contributes to higher costs associated with operation and maintenance. The $0.0322/kWh social cost attributed to the human health and ecological impacts related to the combustion of diesel further impacts the economics of the diesel system, although only marginally. Overall, the NPV of the hybrid solar diesel system was $354 thousand which was 41 percent higher than the diesel system at $250 thousand, using a three percent social time preference discount rate, a $1000 self-determination benefit, and a social cost of $0.0322/kWh for the diesel system, assumed as the base case for both scenarios. Social costs were not attributed to the hybrid solar diesel system due to the reduced operational frequency of the diesel-fired generator.

The three percent social time preference discount rate has been estimated for use in Canada, as per the Treasury Board, during circumstances concerning consumer consumption or where nominal resources comprise economic opportunity costs, in this instance, ecosystem and human health goods and services (Treasury Board of Canada Secretariat, 2007). This allows aspects beyond the fund's opportunity cost to be considered with the discount rate based on the projected consumption growth rate and the rate at which future consumption will be discounted (Treasury Board of Canada Secretariat, 2007). The self-determination benefit is defined as the estimated value members of a community would be willing to pay to remain within an existing location, with the stated preference method assumed to be based on contingent valuation as per the Treasury Board of Canada (Treasury Board of Canada Secretariat, 2007). This utilizes the willingness to pay principle which is a fundamental tool in the application of welfare economics (Treasury Board of Canada Secretariat, 2007).

Figure 21. CBA of Diesel Vs Hybrid Solar Diesel at 3% Social Time Preference Rate



A sensitivity analysis was conducted to understand how the assumptions made might impact the resulting NPV calculated and the self-determination benefit required to breakeven including the:

- Variance in discount rate assumed for both scenarios (three percent social time preference rate versus eight percent real rate, the latter used for evaluating Canadian regulatory interventions (Treasury Board of Canada Secretariat, 2007))
- Variance in social cost assumed on diesel system NPV based on minimum and maximum values recorded in research, as obtained from the diverging from diesel study ($0.0322/kWh versus $0.1918/kWh) (Gwich'in Council International, 2016)

Results are recorded in Table 11 which highlight numerous findings including the 18 percent reduction in the self-determination benefit for the hybrid solar diesel base case to breakeven compared to the diesel system, meaning each "resident" would spend less to remain in the current location. This same comparison at an eight percent discount rate reduces the difference between the NPV and self-determination benefit to break even, with the NPV of the hybrid solar diesel case 12 percent less than diesel and the self-determination cost to breakeven higher by five percent. Applying the same comparison at a social cost of $0.1918/kWh and a three percent discount rate realizes a 100 percent increase in the NPV of the hybrid solar diesel case compared to the diesel with a self-determination cost 27 percent less at breakeven. Again, the difference is less pronounced at an eight percent discount rate; however, the hybrid solar diesel case has an NPV 28 percent greater than the diesel system with a self-determination benefit seven percent less. These results emphasize how a larger burden placed on the diesel system with respect to its damage to human health and ecological effects, at $0.1918/kWh, has on economics.

Table 11. Sensitivity Analysis for Diesel Versus Hybrid Solar Diesel Cost Benefit Analysis

		Diesel		Hybrid Solar Diesel	
Discount Rate	**Sensitivity**	**NPV [$M]**	**SDB @ Breakeven [$M]**	**NPV [$M]**	**SDB @ Breakeven [$M]**
3%	**Social Cost = $0.0322/kWh**	250	696	354	571
8%	**Social Cost = $0.0322/kWh**	138	719	121	754
3%	**Social Cost = $0.1918/kWh**	177	785	354	571
8%	**Social Cost = $0.1918/kWh**	94	808	121	754

Note: All calculations made at $1000 self-determination benefit with the base case shaded

Something often missed in the economics of diesel power generation systems is the impact of social costs on communities and the long-term impact fuel consumption profiles may have on the future affordability and reliability of the systems in place. The diverging from diesel study in Section 2.3.1 emphasizes the importance of considering the additional adverse human health and ecological impacts associated with the burning of diesel fuel in off-grid communities and reflecting a fair price when evaluating clean energy projects to replace fossil fuel combustion (Sullivan, 2017). Though the replacement of a diesel system with a hybrid solar diesel system does not eliminate the need for diesel fuel, it significantly reduces a community's reliance on a product that generates a large carbon footprint by utilizing a renewable energy system when natural sources of power are available and effective, while still providing the reliability of power when solar resources are unavailable. The successful solar projects within the Yukon provides additional security of system reliability at KLRS, particularly during its typical operational months, which produces on average a total of 723 kWh/kW of PV potential over the six-month period.

Though several assumptions were made during evaluation, this cost benefit analysis captures the value of replacing the existing diesel power generation system with renewable energy solutions to progress the research station toward net zero carbon. Though the payout period of the hybrid diesel solar base case is less favourable at under eight years compared to less than one for the diesel system, the long-term environmental and human health benefits as well as the outward display of sustainability is invaluable within a northern remote community most susceptible to the risks of climate change, with perceptible changes already observed. Although the large upfront capital investment of the hybrid solar diesel system makes it more challenging to readily pursue compared with the small capital diesel genset systems, potential rebates might help offset these initial costs.

4.6. CARBON REDUCTION PLAN

A preliminary carbon reduction plan identified some components of renewable energy projects, energy efficiency initiatives and carbon offset projects that might be considered to help manage the GHG emission sources and mitigate the carbon footprint evaluated within KLRS's operation.

4.6.1. Renewable Energy Projects

As reviewed in Section 4.5: Economics, there are economic, environmental and social benefits to replacing fossil fuel combustion with renewable energy projects where feasible, while ensuring reliability of system performance when renewable energy sources are not active. Though activities are ongoing to progress the Kluane Lake Research Station toward renewable energy generation in all aspects of its operations rather than just the critical communications infrastructure, it is important to understand how its replacement might impact its current carbon footprint. A hybrid solar diesel system with battery storage could see up to 70 to 80 percent in both fuel savings and associated emissions reductions related to the direct combustion of diesel and indirect emissions related to its freight and associated well-to-tank (of both fuel and freight). This approximates one of five hauls could be sufficient to meet the station's needs in a typical operational year. Combined, an 80 percent reduction scenario in diesel fuel consumption would be nearly equivalent to the magnitude of scope 1 direct emissions attributed to on-site diesel combustion (51 tonnes of CO_2e) with 80 percent of total emissions reductions related to fuel combustion and the remainder related to its well-to-tank upstream emissions. The goal of carbon neutrality highlights the importance of promoting these initiatives and striving toward material reductions in diesel-fired combustion; however, capital investment is required to reset the energy balance.

4.6.2. Energy Efficiency

Energy efficiency projects allow for the continuous operation of appliances, vehicles, and buildings (residential or commercial) using less energy without sacrificing performance (Natural Resources Canada [NRCan], 2019), thus allowing for the increased conservation of energy. It is the swiftest, easiest and cheapest means of managing challenges related to energy security, economics and the environment as well as generating savings, supporting innovation and competitiveness, while reducing emissions and the requirement for new or incremental generating capacity (Natural Resources Canada [NRCan], 2019).

Energy efficiency projects at KLRS have the ability to reduce emissions related to the consumption of diesel fuel for power generation through the reduction in load demands on the system. Within the past few years, most white goods have been replaced with ENERGY STAR certified appliances known for their energy efficient operation. Although notable, the remaining initiatives, specifically the replacement of the 15 two lamp fixtures of 4ft linear fluorescent tubes in the mess hall and additional lighting in the wash house, Wood Building and outdoor lighting, will not be pursued at KLRS until after the diesel power generation system is eliminated as the primary source of power due to the requirement of the inefficient fluorescent lights to provide a continuous base load for the diesel generator operation. Options are available to replace these commercial lighting systems with smart LED systems with auto-dimming and occupancy-based lighting control to encourage zero waste and eliminate under- or over-lighting with the ability to reuse current fixtures, eliminating the need to rewire above-ceiling and replace the ballast which only serves to generate more landfill waste, as offered by Alec SmartLighting™ out of British Columbia (Alec SmartLighting, 2019). Under the Build in Canada Innovation Program, the federal government has selected this lighting control system for 2019 pilot installations within numerous government facilities (Alec SmartLighting, 2019). With these initiatives in the project pipeline and increased support in transitioning remote northern communities toward clean energy solutions with financial resources from provincial, territorial and federal governments, there is greater incentive for replacing the diesel-powered generator with a renewable energy system.

4.6.3. Carbon Offsets

Due to time constraints, carbon offset initiatives were not evaluated in detail for purposes of offsetting those emissions generated indirectly related to KLRS operations, particularly those related to air travel due to its domination of scope 3 emissions. Of note is the U of C's 2008/09 baseline GHG inventory which catalogued carbon offset initiatives undertaken by the U of C to offset its carbon footprint, which could be reviewed in further detail if KLRS is dedicated to actively pursuing a campaign toward carbon neutrality. During their baseline year, the U of C purchased 146 MWh in Renewable Energy Credits which was attributed to 133.3 tonnes of CO_2e in carbon offsets, as calculated using the Clean Air-Cool Planet Campus Carbon Calculator (Sustainability Tracking, Assessment & Rating System [STARS], 2016). Purchases related to Renewable Energy Certificates of which emissions reductions can be attributed to clean energy development mechanisms is an option typically selected to reduce scope 2 emissions related to electricity consumption, with the project source and vendor verified by a third-party (Sustainability Tracking, Assessment & Rating System [STARS], 2016).

It still stands that the optimal method to reduce one's own carbon footprint is to abstain from emissions intensive operations. Thus, targeted reductions at the emissions source remains the most productive way to truly progress toward net zero carbon with offsets potentially providing organizations involved in carbon intensive processes with a means of being absolved from the mounting pressure to address the magnitude of one's own emissions with strict limits believed necessary to ensure incentives exist and are effective enough to drive urgent change (Newell, 2011). As no technology currently exists to remove as much carbon from the atmosphere at the rate it is emitted, particularly from air travel in relation to this study, carbon offset strategies can help counterbalance some of the emissions generated. However, the time scales are often longer and demand growth often outstrips immediate benefits (Newell, 2011); thus while they form part of a complete and balanced portfolio of emissions reduction options, they should be treated as a temporary measure (Newell, 2011) to offset some of the baseload emissions associated with continued business operations.

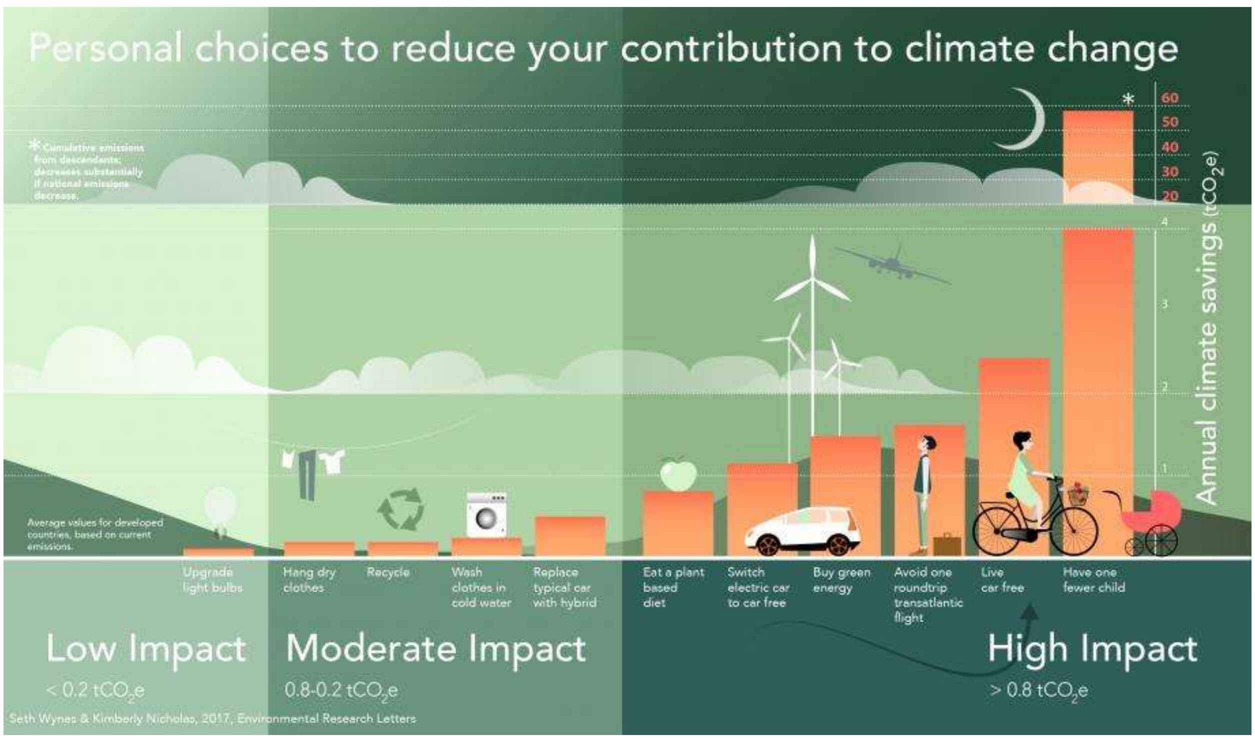
As realized during the carbon footprint study, not all emissions caused by KLRS's activities are avoidable; those unavoidable emissions can be compensated through offsets of global emissions reduction climate protection projects (First Climate, 2018a). Often located in developing countries, these clean development mechanism projects produce co-benefits to local communities, furthering the Sustainable Development Goals of the United Nations (First Climate, 2018b). However, supporting initiatives closer to home can improve KLRS's ability to monitor its impact and ensure an effective carbon offset project with increased investment confidence. KLRS can consider all possible ways to reduce its carbon footprint, strategically prioritizing projects that not only help progress it toward carbon neutrality but also supports a mindset change to systematically review its value chain and identify areas where change can be implemented organically. Once all of KLRS's emissions are offset, it would then be considered carbon neutral.

CHAPTER 5: DISCUSSION

By the very nature of its operation and geographical location, a research station located in the remote sub-polar Canadian north contributes considerable amounts of anthropogenic greenhouse gas emissions to the atmosphere, accelerating climate change and further affecting the ability for the earth to regulate itself. Thus, the importance of a comprehensive study of the Kluane Lake Research Station in all aspects of its operations to understand the direct and indirect sources of carbon emissions allows the station and AINA to better strategize the processes and projects it endeavours to pursue to have the largest impact on its footprint and progress it toward net zero carbon, in a meaningful timeframe. The GHG intensity calculated for the time-weighted average station user highlights the exorbitantly high emission rate KLRS produces in comparison to an average Yukon resident, due to the nature of its operation and its geographical appeal from a global audience. However, this newfound knowledge exposes the opportunity to not only further promote climate science but take a leadership role through the implementation of ongoing and future sustainability initiatives.

Figure 22 highlights the level of impact of specific personal choices with respect to its contributive reduction to climate change (Nicholas & Wynes, 2017). It was obtained from a comprehensive literature study completed at Lund University which concluded the four highest-impact lifestyle choices that an individual can take to noticeably diminish one's carbon footprint, which can be applied at KLRS in some form; though not all. The suggestions most pertinent to KLRS include the consumption of a plant-based diet, living car free which can be slightly revised to suggest improved logistical influence with respect to user land travel in ensuring greater frequency of carpooling, and avoiding air travel (Nicholas & Wynes, 2017). Although complete avoidance in air travel might not be realistic for a station that is remote in nature and dependent on user patronage, the potential to involve oneself in the logistical planning to reduce total great circle distance traveled and that which traveled on land, can have a notable cumulative difference. Switching from an omnivorous to a herbivorous diet which captures life cycle emissions from fertilizers, the fugitive production of methane from livestock, and the transportation of food, can save an estimated 0.8 tonnes CO_2e per person.year (Nicholas & Wynes, 2017). Being car-free for an entire year eliminates the generation of 2.4 tonnes CO_2e, with the avoidance of one transoceanic roundtrip flight saving 1.6 tonnes CO_2e (i.e. New York to London) or 2.97 tonnes CO_2e (i.e. Hong Kong to London) (Nicholas & Wynes, 2017). In comparison to the annual GHG emissions avoided through simple recycling, consuming a plant-based diet, avoiding one intercontinental roundtrip flight and going car-free can save approximately four, eight and eleven times more in avoided emissions, highlighting its significantly larger impact than what is often touted with simply encouraging recycling (Nicholas & Wynes, 2017). The focus on a plant-based diet as well as emissions due to air travel are relevant to the study of KLRS's carbon footprint as the air travel and groceries purchased, including freight and well-to-tank emissions combined, make up 92 percent of total scope 3 emissions.

Figure 22. Highest-Impact Lifestyle Choices to Reduce One's Carbon Footprint



Source: (Nicholas & Wynes, 2017)

Understanding the impact one's diet can have on the climate might influence the decisions made during the selection of provisions procured from retailers within the Yukon. Being more deliberate in the provision of meals on site focused on lower carbon signature plant-based options will significantly reduce the emissions generated from the production and procurement of meat alternatives. Lowering the percentage of meat offerings, either through meal rotations or days of the week supporting herbivorous diets, will also serve to enhance user awareness and normalize sustainability initiatives in more everyday aspects of KLRS's operations, with the potential to support more thoughtful practices outside of the station. This does not necessarily mean the station need coerce its clients and employees to avoid the consumption of meat; however, it can potentially encourage intentional behavioural change by reducing the consumption of meat and dairy or at least highlight the implications of choice.

As groceries comprised a sizeable portion of KLRS's scope 3 emissions, prioritizing an earlier start to its gardening initiatives, whether in the greenhouse or in the boxes adjacent to the mess hall, can reduce the tonnage required to be transported from Whitehorse to the research station, reducing scope 3 emissions related to its primary production, freight and well-to-tank emissions associated with delivery. Further, potential investment in initiatives such as the Crop Box project has the potential to pair renewable energy systems with the sustainable farming of vegetables that can provide innumerable rations to KLRS as well as neighbouring communities who may benefit from its operation, assuming a clean source of fuel to power the high-yield hydroponic agricultural system (Vertical Crop Consultants, 2017), doubly ensuring the provisions are ethically sourced**.** Though food waste is commendably minimized throughout KRLS's meal service with leftovers utilized in creative ways for later meals, some initiatives can be pursued to lower their carbon signature and implement more sustainable practices with respect to method of procurement and type of foodstuffs grown or ordered, of varying commitments of capital investment (gardening – lower, CropBox – higher). It is important to be mindful in the decision-making process to ensure choices made consider entire life cycles with the impact of generating residual carbon signatures understood.

Though waste disposal did not make up a substantial portion of KLRS's carbon footprint, its initiatives are important in the implementation of sustainable practices within their visible and background operations. Composting earlier in the season will reduce the amount of organic waste entering the landfill which has an emission factor 60 times greater than that of composting (Department for Business, Energy & Industrial Strategy, 2018b). To simplify the disposal of organic waste and eliminate the more labour-intensive process of composting using the e-composting balls at KLRS, there is the potential to invest in a backyard anaerobic digester. This not only produces compost that can be used in the garden, but also harnesses the energy produced from organic waste in the form of biogas. In addition, home biodigesters typically accept non-compostable organic waste, yard and animal waste often rejected in the backyard compost, due to the bacteria's enhanced ability to decompose meat, dairy and animal/human waste, reaching temperatures sufficient to kill most pathogenic bacteria and divert greater portions of organic waste from landfill; thus reducing the production of GHG emissions, with minimal, low-maintenance supervision (once commissioned) (HomeBiogas, 2017).

As the waste generated at KLRS is predominately food waste with approximately two to four kg of organic food waste produced daily, an opportunity to invest in an innovative clean tech system called the Home Biogas 2.0 or similar could help to convert organic waste into both liquid fertilizer and biogas fuel (Markham, 2017). The appliance can be installed within 20 metres of a cooking stove, which has a 1200 L capacity digester tank for water and activated bacteria and can accept daily maximums of 12 L of organic food waste to produce biogas for storage within a 700 L pressurized collection tank with an inline purifier (HomeBiogas, 2017). This system is reported capable of generating up to three hours of biogas for cooking and 12 L of fertilizer daily, assuming optimal operating conditions (temperature, waste inputs, etc.) (Markham, 2017). The only drawback is the need to maintain temperatures of at least 20 degrees Celsius with temperatures greater than 25 degrees Celsius ideal to ensure optimal performance for the anaerobes to promote effective decomposition and the production of gas (HomeBiogas, 2017). Temperatures below 20 degrees require the construction of a housing unit for the appliance for additional insulation and the installation of a heater to maintain ideal temperatures, with the potential to be installed inside of a greenhouse. However, the production of biogas from organic waste generated from KLRS operations can be used as cooking fuel which can effectively reduce the volumes of propane burned, thus reducing scope 1 and associated scope 3 emissions.

The comprehensive carbon footprint study enables KLRS to understand what aspects of their business can be improved upon, even for those emissions markedly minimal in comparison to the aviation footprint. Even though upgrading light bulbs is believed to be a low impact contribution to climate change, as highlighted by Figure 22 (Nicholas & Wynes, 2017), it should not be overlooked in KLRS's endeavor to approach net zero carbon; as the only way for KLRS to approach net zero carbon is to eliminate even the smallest sources of GHG emissions generated. As neighbouring communities surrounding KLRS progress on their journey toward sustainable baseload renewable energy and supplementary energy efficiency initiatives, it is critical that KLRS not only collaborate with but strive to be an exemplary facility that the surrounding communities can learn from, adapt their own systems to and can provide unbiased, evidence-based information in relation to sustainability and a low carbon footprint.

To support policy decisions, it is essential to have meaningful data on GHG emissions and trends, particularly in sectors that generate significant sources of emissions (Larsson, Kamb, Nassen, & Akerman, 2018). However, the UNFCCC only requires national GHG inventories to report emissions related to domestic flights, leaving those emissions generated from international travel largely unreported (Larsson, Kamb, Nassen, & Akerman, 2018). As an international air study suggests, this makes invisible a substantial portion of air travel emissions of which are associated with international travel; a believed contributing factor to the lack of policies decreasing absolute levels (Larsson, Kamb, Nassen, & Akerman, 2018). This narrative highlights the responsibility organizations such as KLRS must take to understand its user and employee air travel footprint to effectively manage its contribution and reduce its impact, particularly if this is an intentional omission at the national level. Though land transport alternatives exist (motorcar, bus, rail) to substitute some domestic and short-haul flights, few alternatives exist for longer haul air travel bar complete avoidance. It is believed less than 10 percent of total flights can be replaced with other modes, due to inadequate ground infrastructure and the need to circumvent physical obstacles (ie. mountains or water) with the consideration of length of trip, cost of fare, and service frequency ostensibly taking precedence over environmental considerations (Penner, Lister, Griggs, Dokken, & McFarland (Eds), 1999).

There is additional complexity in tracking scope 3 GHG emission reductions with respect to air travel due to potential reduction in user or employee air travel generally not a cause-and-effect relationship, in such that it does not directly translate into equivalent reductions of greenhouse gases emitted into the atmosphere, particularly if the unused seat is simply filled by another occupant and unless the empty seat created can effectively contribute to a long term aggregate reduction in air traffic (World Resources Institute [WRI] & World Business Council for Sustainable

Development [WBCSD], 2011). This further emphasizes understanding how one's changed behavior might be impacted by external forces but should not inhibit KLRS from endeavouring to address components of their own emissions profile. However, as it is difficult to impact global behaviour, starting with addressing one's own footprint and those within its organization, is hoped to make meaningful progress.

As decarbonizing air travel is both exorbitantly costly and challenging to scale, its growth needs to be curtailed with all aspects of air travel (business and personal) reduced to approach net zero carbon within the century (Buchs, 2019). Global collaboration within the academic and research sector, though closely aligned, is required to reduce the collective impact of business travel (Buchs, 2019). Some suggestions obtained from an article written by an Associate Professor from the University of Leeds in Sustainability, Economics, and Low-Carbon Transitions who has pledged to abstain from air travel, includes individuals performing an honest assessment of essential travel versus targets achievable through video-conferencing (Buchs, 2019). In addition, reviewing the potential for local students at Yukon College, academics or even residents, to participate in capacity-building to enable them to collect the necessary data and complete the fieldwork under the remote supervision of researchers far-removed, could be effective in reducing or eliminating air travel for purposes of data collection (Buchs, 2019). If travel is deemed necessary, looking at methods of travel with a lower carbon signature to reduce one's impact or evaluating whether the same work could be performed with a smaller team on-site, are possible reduction alternatives (Buchs, 2019). One great example is in Sweden, where a recent survey conducted by the World Wildlife Fund (WWF) Sweden Conservation group recorded one in four Swedes consciously selecting to abstain from air travel over the past year (Talmazan, 2019). These considerations need to be made when strategizing ways to reduce the overall carbon footprint, including scope 1 and 3 emissions generated by the Kluane Lake Research Station and its patrons. No other time has been more critical than now for the global community to converge to find common ground and discover innovative ways to work toward a unified goal of behavioural change and reducing humankind's influence on a changing climate. It will become increasingly important for individuals to take accountability for their actions and implement solutions that have measurable impact, rather than using the by-products of a changing system, albeit extreme weather events or the degree of glacier melt, to drive personal agendas in place of well-grounded scientific information. The data available is clear that the earth is not elastic and that a transition to a low-carbon economy is essential for preservation of the various ways of life to which humans are accustomed. Transition involves change and change involves work, with meaningful change requiring a global undertaking that will cross temporal and spatial boundaries for the benefit of all species that call earth home.

As referenced in the Lund University study, by 2050, individuals should not exceed annual per capita emissions of 2.1 tonnes CO_2e to realize a global temperature increase below the limit of two degrees Celsius (Nicholas & Wynes, 2017). This is a substantial carbon footprint reduction by individuals in the developed world, which currently sees an average of 22 tonnes CO_2e per capita in Canada (Climate Transparency, 2018), 16.8 tonnes CO_2e in the Yukon (Government of Yukon, 2019b), and 48 CO_2e per weighted user at KLRS. The latest IPCC reports found that net anthropogenic emissions of CO_2 on a global scale need to drop by approximately 45 percent by 2030 from 2010 levels in order to limit global temperature increases by 1.5 degrees Celsius, with net zero achieved around 2050 (Intergovernmental Panel on Climate Change [IPCC], 2018b). It is reported that limiting temperature increases to 1.5 rather than 2 degrees Celsius would further enable the achievement of the UN's Sustainable Development Goals and lessen adverse impacts on human health and welfare as well as ecosystems and the services they provide (Intergovernmental Panel on Climate Change [IPCC], 2018b). This year, Earth overshoot day, which calculates when humanity's competing demands for the earth's natural resources have exceeded its annual ecosystem regeneration budget, arrived on July 29, 2019, the earliest in history, suggesting the need for 1.75 earths to meet the current demands of its human inhabitants (Global Footprint Network, 2019), further highlighting the importance of a mindful behavioural shift. The data is clear that significant and systematic progress needs to be made for global targets to be met and net zero carbon to be achieved.

A particularly sensitive balance emerges between three seemingly conflicting goals including:

1. The desire of increasing occupancy at KLRS to generate revenue and ensure the station's growth and relevance;

2. Meeting the needs of the users who visit the site for purposes of collecting pertinent data to aid in valuable research, educational outreach to support experiential learning for youth, and community development through volunteer projects and;
3. Helping to support sustainability initiatives through the promotion and implementation of carbon reduction programs and enact effective change that will ensure carbon neutrality is achievable.

The Kluane Lake Research Station does not have to remain an ongoing irony in climate science research, through targeted investment, and the trialing and optimization of clean energy technologies, it can become an exemplary facility with ongoing reductions in its carbon footprint occurring symbiotically with sustainability initiatives. Through continuing to improve the accuracy of its carbon emissions profile and improving data collection to better reflect scope 3 emission allocations that actually contribute to its carbon footprint, it can better strategize and prioritize investment opportunities to reduce the carbon signatures most significant to its collective operation.

CHAPTER 6: CONCLUSIONS & RECOMMENDATIONS

This chapter concludes the carbon footprint study conducted on the Kluane Lake Research Station and will review the limitations, recommendations for next steps to improve visibility across its GHG inventory and ultimately reduce its footprint, as well as future research to complement and further investigate the findings of this study.

6.1. CONCLUSION

The findings of this carbon footprint study highlight the dominance of scope 3 indirect emissions from upstream activities related to the Kluane Lake Research Station, comprising more than 86 percent of the 528,083 kg CO_2e in total scope 1 and 3 emissions calculated. Coincidentally, 86 percent of the scope 3 emissions were generated from air travel including its associated well-to-tank emissions, with procured groceries including freight comprising 6 percent of scope 3 emissions. This data emphasizes the enormity of the task at hand and presents an opportunity for innovation, with collaboration inevitable to ensure the success of KLRS and enable it to overcome the challenges to achieve its strategic business goal of attaining carbon neutrality.

Considerable optimism exists that material change is imminent at the Kluane Lake Research Station with the engagement and desire by station management to incorporate sustainability principles into practice. Despite an entanglement of interests and varying degrees of control, further complicated by the balancing of client needs and supporting the valuable research conducted by climate scientists, there is opportunity for KLRS to make meaningful progress toward becoming a sustainability leader within the Yukon and exhibiting what an energy transition toward net zero carbon might look like. Pursuing these endeavours would be effective in reducing KLRS's carbon signature and better aligning the station's operations with the research that it supports, and the sustainable development goals of the University of Calgary, the Yukon Government and the United Nations.

Through the inclusion of air travel in its carbon footprint, KLRS is outwardly accepting responsibility for its contribution to climate change and the high carbon signature generated through its existence, improving the transparency of its operations and desire to address some of its more challenging emissions bases. Mitigating current impact levels requires a clearly defined scope, a bold strategy and an honest internal review of the demand reduction required of individuals, organizations and the global community, while providing ongoing support for outreach projects to ensure its remote northern neighbours also continue to benefit from their undertakings. As communities surrounding KLRS continue to transform their energy mix with a greater share of renewable power, it is a timely opportunity for KLRS to follow suit.

Climate science does not need to be an ongoing irony; those who support the instrumental research and have also actively contributed to the generation of substantial carbon signatures over the years, can become the change makers their work attempts to activate in the world. Publishing findings on environmental deviations observed due to anthropogenic induced climate change, without addressing one's own contribution, challenges the weight of an organization's merit without the support of initiatives that exemplify what a low carbon future might look like, especially for individuals who traffic the station.

This study highlights the importance of global collaboration to conquer climate change through addressing behavioural change, trialing low carbon technologies and finding novel and low impact means of productively advancing critical research and disseminating consequential findings. The race toward net zero carbon is not just the responsibility of one organization, such as KLRS, but is an urgent and collective journey of the global community. It is hopeful these findings can initiate meaningful change and provide scalable learnings for the dozens of other research stations and analogous organizations with similar high carbon signatures, with a critical reminder that what gets measured, gets managed.

6.2. LIMITATIONS

The limitations of this study primarily revolve around the data collected, assumptions made, and emission factors used for calculating KLRS's carbon footprint. Though the data collected was predominately primary data, some information was incomplete such that assumptions or interpolation was required for calculation which may contribute to variances in emissions calculated compared to actuals. This is limited mostly to data collected relating to scope 3 emission categories such as air and land travel, groceries, and freight. However, scope 1 emissions are limited in some capacity as the volumes of fuel procured do not necessarily translate to the amount combusted during KLRS's typical six-month operation. This section will briefly review those limitations that arise due to being outside of the scope of this study or within the scope of this study and limited by lack of available data or found to have negligible impact.

6.2.1. Outside of Scope Limitations

Some data relevant to KLRS's carbon footprint were outside the scope of this study and therefore excluded from the analysis. With respect to some of the more dominant scope 3 emissions, the current study excludes user offsite activities, only including one round-trip journey to and from the Whitehorse international airport to KLRS or from the originating location within the Yukon or Alaska (if assumed user traveled by land). This may understate potentially large carbon signatures from activities engaged in by specific researchers whom travel by helicopter to various glaciers to collect data, carrying equipment of substantial mass, or log significant mileage during day trips away from the station, thus leading to systematic underestimation of the intensity of scope 3 emissions related to user-dependent upstream activities. However, a carefully defined scope boundary with respect to user activities in which KLRS endeavours to take environmental accountability for its carbon footprint is critical to data collection initiatives, defining future strategies and the development of carbon reduction plans to approach net zero carbon.

Freight on passenger flights such as passenger luggage, seating and the galley (equipment associated with passenger service) (Department for Business, Energy & Industrial Strategy, 2018a) was also excluded as the scope of this study was limited to the macro-logistics related scope 3 emissions associated with client movements in and out of KLRS. Incremental scope 3 emissions associated with freight can be further studied to capture underrepresented emissions.

Finally, outside of scope emissions were excluded from this study. These include emissions generated through the production of CO_2 from combustion of biological sources, such as wood or the biofuel portion of petrol blends.

6.2.2. Inside of Scope Limitations Due to Limited Data Availability

With respect to freight calculated due to fuel and grocery deliveries, average laden hauls consisting of only KLRS procured goods was assumed which might over or under estimate emissions related to the size of load and allocation of haul; the dependence on whether the supplier made multiple deliveries to neighbouring businesses could re-distribute scope 3 emissions generated among those organizations. Those emissions related to groceries may be over or underestimated dependent on the accuracy of the weighted average unit cost calculation to convert total food and drink expenditures into mass. The mass was ultimately used to determine material use and hence scope 3 emissions, in addition to those associated with its freight and well-to-tank emissions.

As data was limited with respect to the small number of invoices analyzed for KLRS's procurement of food and drink, a clear understanding of the typical patterns for groceries purchased with respect to mass of goods delivered and quantity of goods purchased from the main food groups was restricted and therefore interpolated based on available data. It is acknowledged the mass may vary substantially month to month, driven by seasonal availability, occupancy and user demands; however, this can only be tracked retrospectively through accurate goods transfer receipts. Regardless of the true monthly variance, the category contributes heavily towards KLRS's scope 3 emissions.

The data collected on the cost basis during August and September may not be representative of costs or the percentage distribution of food groups ordered or available over the spring months between April to June. The operational period of KLRS is such that seasonal impacts across all evaluated categories were unable to be captured making it difficult to analyze historical averages to forecast what a true baseline year-round operation and its corresponding footprint resembles. It is important to be mindful that though individual impacts may be negligible in certain instances, they may have a more sizable cumulative impact when considering the magnitude of station users and thus must be considered.

In addition, average emission factors for the material use of food and drink were used. Averaging at a bulk order level over-simplifies the proportional emissions generated from types of food procured and does not offer the correct weighting of their individual impacts of varying severity (ie. emissions generated from meat are generally substantially larger than those from plants); thus, adding further uncertainty with respect to internal splits and the true magnitude of grocery-related emissions.

Lastly, the analysis of user logs became difficult at times to disassociate periods users were away from the station conducting field work, and gaps where researchers flew home, which became additionally complex with fluctuations in user numbers within the same group. This equally applies to user travel by passenger vehicle. Without specific details on travel dates, various flight stages of user travel and flight class, assumptions were made to calculate air travel emissions; data can be more accurately catalogued in future during user check in to reduce uncertainty related to scope 3 GHG inventories. As well, the number and type of vehicles driven to the research station from Whitehorse International Airport was also assumed based on arrival dates and group sizes; thus, reducing the accuracy of scope 3 emissions related to user travel.

6.2.3. Inside of Scope Limitations Found to Be Negligible

Though emissions factors related to fuel combustion of stationary and mobile sources are relatively consistent throughout databases irrespective of geographical location, the use of the UK Defra emission factors with respect to scope 3 upstream air travel emissions may cause the greatest variance due to Canada's substantial land size compared to the United Kingdom. This factor may impact the types of planes flown within national borders; however, the assumption of similar modern fleets within the western countries and the comparatively significant variance created by radiative forcing minimizes the impact of its geographical representativeness.

Acknowledging the limitations of the data, the methodology with respect to the UK Defra emission factors for air travel offers more sophisticated calculative techniques than that available through a government source in Canada. The granularity in emissions obtained by the incorporation of the 2018 UK Defra conversion factor tool better captures the magnitude of scope 3 emissions as opposed to its questionable applicability to describe internal Canadian upstream air travel and thus has limited impact on data associated with KLRS. In future, updated emission factors can be retrieved from Canada's National Inventory Reports or from sources that become available as Canada enhances its national inventory databases to produce something parallel to the annually updated UK Defra tool

6.3. RECOMMENDATIONS & NEXT STEPS FOR THE KLUANE LAKE RESEARCH STATION

There are several initiatives the Kluane Lake Research Station can consider for implementation within their operation to support their progress toward carbon neutrality while outwardly promoting sustainability. These recommendations for next steps are summarized below.

6.3.1. Green Energy Initiatives

KLRS's scope 1 direct emissions were almost entirely linked to onsite stationary fossil fuel combustion, suggesting that if given the appropriate financial resources to perform the transformation, renewable energy systems can substantially reduce the volume of diesel combusted to generate power, along with the associated scope 3 emissions related to freight and well-to-tank, which are well within KLRS's direct operational control. Reduction in the net amount of diesel burned complements decreasing the emission and particulate matter impacts to human health and the environment, while also reducing the frequency of noise pollution. Furthermore, the collection of pilot data of current renewable energy installations (on KLRS's critical communications infrastructure) through metering would provide KLRS greater insight into its operational performance throughout all seasons and improved understanding of potential system failures or shortfalls prior to its implementation on a larger scale and at a higher cost.

Carbon offset programs can be reviewed to counteract user travel in which the station does not have direct control; however, this should be considered a temporary measure to offset some of the baseload emissions associated with its operations. Though they can form part of the balanced portfolio, it is recommended they do not constitute the exclusive strategy.

As discussed with the station manager, energy efficiency projects on site would commence once renewable energy systems were installed, eliminating fluorescent lighting and enabling the ability for users and staff to turn off lights, if auto-dimming systems are not fitted. In addition, the potential for closed loop system design implementation, such as improved heat recovery to capture residual heat, would reduce volumes of propane required to heat water used in the wash house. In addition, the conversion of the diesel generator system to a combined heat and power system can also be reviewed.

6.3.2. Increased Station Utilization & Community Engagement

There are key strategic drivers for KLRS to maintain its adaptability while determining the optimal utilization of the station's facilities to engage with and promote more visits from local audiences, including the youth who can benefit from the experiential learning opportunities available within the geographic setting, serving to increase the station's user-days while simultaneously reducing its GHG intensity per weighted user, compared to its 2018 baseline.

Community engagement can be enhanced by potentially expanding the current summer student program to include the hiring of a neighboring First Nation youth leader to accelerate the roll out of on-site sustainability initiatives, such as composting or gardening, and potentially prepare them to operate CropBox projects within their own communities. Youth engagement and awareness are all part of long-term sustainability, with a willingness to embrace emerging technologies and a positive mindset to enact real change. This also presents beneficial opportunities for KLRS to acquire lessons from individuals whom boast innate qualities of sustainability through living in harmony with the environment and a worldly understanding of the ecosystem's needs. Finally, increased collaboration with neighbouring communities to support progression of low carbon initiatives can materialize co-benefits in the shared learnings of project failures and successes.

6.3.3. Implementation of More Rigorous Practices

The implementation of more rigorous practices can facilitate the development of responsible behaviours in station users and reduce the research station's reputational risk. Examples of these initiatives that can be progressed to reduce emissions within the direct control of KLRS include:

Energy Conservation: Encouraging responsible use of energy by directing users to power deemed essential electronic devices at designated solar-powered charging stations connected to user accommodations promotes efficient electricity use and avoids drawing off the main diesel power generation system (through connection to power bars within the mess hall). This can reduce the overall demand on the electricity system, volumes of diesel consumed, and ensure solar panels currently installed are more fully utilized.

Emphasis on Reduction, Reuse & Elimination: A shifted focus with greater emphasis on reducing and reusing can effect behavioural change and the cumulative reduction in water, fuel and power consumption, as well as reduce trip frequency for refuse disposal or recycling. This can include the elimination of single use plastics enforceable through the potential supply of reusable Tupperware for purposes of food storage to support user day trips. The slight adaptation to the common teaching of the “3 R’s” with the “6 R’s” by putting into practice the six steps that include first rethinking items being purchased and consumed, refusing to use certain products further empowering the consumer voice, reducing the amount of waste generated, reusing items to extend their service life, consciously recycling items that cannot be avoided from previous steps, and finally, replacing items with better alternatives once depleted (Kristine, 2019).

Waste Management Strategies: Composting initiatives earlier in the year or the use of a backyard anaerobic digestion system can reduce emissions generated due to organic waste being sent to landfill, expose users to additional waste to energy techniques to reduce their footprint, and reduce the amount of organic non-compostable waste sent to landfill. This would improve optics and promote mindfulness in recognition of the amount of food waste generated. In addition, excess compost produced can be donated to community gardens.

Elimination at Source: Gardening initiatives or capitalizing on CropBox initiatives to provide a greater surface area for harvesting vegetables for the station and neighbouring communities, assuming low emission energy source options are available to power the Crop Box**,** is a fitting example of eliminating GHG emissions at source. It effectively eliminates the upstream life cycle emissions associated with primary production, transport and freight of vegetables grown on site. Targeted reductions at the emission source remains the most productive way to progress toward net zero carbon.

Plant-Based Meals: Being more intentional with the types of food served through increased quantities and frequency of plant-based meals with corresponding reductions in meat consumption can stimulate productive conversations and normalize behaviours that effectuate material reductions in carbon footprints.

Through a number of small intentional actions, positive and mindful behavioural change associated with cognitive acceptance and adjustment to remote operations can be enacted for its range of users during short- and long-term visits for research, field school, educational outreach, and leisure; consequently, improving KLRS's subliminal messaging in its acknowledgement of the changing climate due to disruptive anthropogenic behaviours.

6.3.4. Partnerships with Responsible Local Suppliers

Continuing to procure goods from responsible local suppliers focused on implementing sustainability within their value chain and the supply chains they interact with can allow for the ease of data collection efforts and improve working relationships, due to common goals. In addition to boosting the local economy, it reduces emissions related to freight, creates engaged consumers and encourages responsible consumption. This is demonstrated through KLRS's purchase of wood from Bear Creek logging who procure a majority of firewood from beetle-killed Spruce bark trees surrounding Haines Junction and harvests approximately 25 percent of low-grade wood typically considered a waste product, converting them into wood chips for biomass burners within various Yukon communities (Hossack, 2018).

Alternatively, station managers can collaborate with various stakeholders to continue improving the quality and accuracy of data collected to better understand opportunities for optimization and better track their changing carbon footprint. Through engagement with suppliers, they can help build more sustainable practices and improve efficiencies within their business such as optimizing deliveries, tracking mileage, fuel efficiency and consumption, and minimizing waste within their operations. A simple adjustment could be during the procurement of groceries, where cardboard boxes used to transfer products picked up or delivered can be re-used for future pickups rather than dropped off at the nearest transfer station to be recycled.

There is the potential to understand the frequency of purchase and delivery schedules of neighbouring businesses or communities to limit the number of trips made by companies whose supply chain revolves around freight, as optimization of delivery can increase efficiency and reduce overhead and fuel costs. The shared use of trailers for freight and the consequent allocation of emissions related to the hauls among all recipients of delivered products, can develop KLRS's understanding of its carbon footprint and help reduce emissions generated by its own operations as well as positively impact the practices of others. However, this first requires improved understanding of current shipment practices, schedules and typical allocation of hauls.

6.3.5. Improved Inventory and Records Management

The improvement of the Kluane Lake Research Station's inventory and records management can enhance the accuracy of the carbon footprint calculation with respect to fuel consumption, user air and land travel as well as grocery inventories. Individual components are outlined below:

Fuel Consumption: Improved tracking of volumes at the start and end of the season can enhance the understanding of KLRS's actual fuel consumption during the operating season and increase the accuracy of scope 1 emissions calculated. This can also include improved tracking of both small and large purchases of fuel procured at local retailers. When evaluating mobile sources, odometer readings can be recorded to estimate total distance traveled in KLRS's owned and operated vehicles over the operational year, for enhanced estimates of CH_4 and N_2O emissions.

User Travel Records: Improved data collection for each booking with respect to user travel by air and land, such as an organizational roadmap, will reduce the uncertainty inherent in the carbon footprint calculation, through tracking flight class, in-transit flight stages, type of vehicle and total mileage amassed. Recording the percentage of each user's trip within the Yukon allocated specifically to accommodation at KLRS can improve their understanding of the carbon footprint attributable to the station and reduce the total amount of scope 3 emissions generated from air travel, particularly if the expedition was multi-purpose. It is important KLRS understands their maximum climate impact through the application of emission factors that account for radiative forcing; however, it is equally important they do not overstate the user influence, making it less realistic or even manageable for them to approach net zero carbon.

If KLRS or AINA decide to include user land travel during daily offsite visits while still checked in to KLRS and/or during extended windows when users are offsite on data collection efforts, then data needs to be collected from mileage or fuel recorded by vehicles used and not owned by KLRS, reiterating the importance of defining those activities occurring within the KLRS operational footprint.

Grocery Inventory: A more detailed grocery inventory and analysis of emission factors related to the type of food purchased (meat, veggies, fruit, vegetables, dairy, etc.) would provide greater perspective on KLRS's carbon footprint and potentially re-define how KLRS procures goods on a go forward basis. In addition, the pick-up of groceries in KLRS owned vehicles would reduce the

GHG emissions produced to minimize the inefficient use of large refrigerated trucks with reefers engaged during one leg of the journey and effectively avoid low percentage laden hauls. It is a worthwhile endeavour to apply additional rigor in the investigation of the quantities and the distribution of goods purchased to assist KLRS in the development of effective control strategies to reduce the frequency of deliveries and associated weight of goods.

Enhanced Logistical Management: The Kluane Lake Research Station can potentially take a more active role in the logistical management of user travel between Whitehorse and KLRS and assist in the development of journey management plans. This could serve to reduce the number of vehicles required for the purposes of travel to the facility, can be used as an initiative to support local business and ultimately reduce road traffic and exposure to road incidents. KLRS can continue to engage in efficient and effective practices of enhanced logistical planning to ensure each trip into town is meaningful and reduce future activity.

6.3.6. Empowering Collaboration Towards Air Travel Reduction

To address the dominant emissions of air travel will require active participation and collaboration between researchers, post-secondary institutions and global communities. KLRS can support initiatives that can eliminate or reduce air travel by participating in some of the more difficult conversations of differentiating between essential and non-essential business travel, for both its employees and client base. Understanding what components of research can be achieved through video-conferencing or a smaller team of researchers executing the field work might have a substantial impact on air travel emissions. Supporting capacity-building initiatives to enable data collection efforts to be conducted by students or academics associated with post-secondary institutions within the Yukon, enabled through remote supervision from researchers abroad, can also have meaningful impact. In addition, a review of alternative travel methods, particularly for domestic and short-haul flights, could also substantially curtail emissions generated due to air travel. Addressing the most dominant scope 3 emission for the Kluane Lake Research Station, due to its reliance on its user base, will require intentional action and substantial innovation.

6.3.7. Setting Science-based Targets

Setting science-based emission reduction targets can help KLRS and AINA commit to achievable targets without undermining or compromising the functionality of the facility as well as build a strategic business development plan to work toward achievement of that goal, including the necessary steps of validation, in alignment with climate science (Science Based Targets, 2019a). Science-based targets drive innovation through revamping operational practices and developing new technologies during the energy transition, increasing regulatory resilience through reduced uncertainty, and strengthening credibility of businesses with improved investor and consumer confidence (Science Based Targets, 2019b). This in turn offers companies a competitive advantage and improves overall profitability (Science Based Targets, 2019b). A 2018 study conducted by the CDP found that 53 percent of the 6937 companies responding to CDP questionnaires in 2018 acknowledged inherent risks to their businesses related to climate, with transitional risks such as policy changes and reputational risk perceived to be double that of physical risks, the latter related to rising global temperatures and extreme weather**;** this percentage was significantly higher when reviewing responses by the G500, at 82 percent (CDP, 2019c). A 2018 Global Climate Change Analysis report highlights that 77 percent of Canadian respondents ensure their business strategy integrates climate risk (CDP, 2019b). These statistics highlight the serious consideration of climate risk and its impact on business, but the real question is are we doing enough?

6.4. FUTURE RESEARCH

With a 2018 baseline established, future research may include setting realistic internal targets for GHG emission reduction and developing a strategy to identify and prioritize opportunities and track progress of carbon reduction initiatives. All sustainability initiatives under the direct control of the research station that can effectively eliminate or reduce emissions should be reviewed, and impact understood, with respect to GHG avoidance, such as the installation of hybrid solar power as a stand-alone system to power the entire research station or the Crop Box project. Future research can include understanding the requirement for expansion of a hybrid solar energy storage system to power both the station and support food security initiatives in remote northern communities, as well as test pilots for potential roll out beyond local borders. A detailed economic analysis performed on RETScreen® can provide more accurate estimates of diesel fuel savings and help optimize design. In addition, better understanding seasonal variations and their impact on KLRS's carbon signature would be beneficial to predict the potential intensifications and optimizations available if the station were to become fully operational year-round. Finally, further understanding of the relationship between increased wood burning and reduced electrical heater usage on the carbon footprint of the Kluane Lake Research Station, as well as all other residual impacts related to its substitution, could be reviewed.

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APPENDIX A: COST BENEFIT ANALYSIS

The following inputs and assumptions were made to model the cost benefit analysis evaluated over a 30-year time horizon reflecting six months of typical operation between April and October.

Diesel Power Generation System:

- **Diesel Generator service life**: 10 years as per KLRS historical lifetimes due to inefficient operation, dust, extended dormancy over winter and irregular maintenance schedule.
- **Installed Capacity:** 20 kW as per existing design, to manage short surges of power due to compressors within existing research equipment and freezers (Knight, 2014).
- **Efficiency:** 15%, as estimated through analysis of previous energy audits and 2018 fuel consumption volumes (Nowicki, 2019). Determined to be reasonable given typical operating conditions and falls just above the typical range observed in the energy factor with units of L per kWh.
- **Diesel consumption to approximate demand:** Based on 2018 volumes less October purchase (14,903 L) to simulate consumption during typical operation. Calculations approximate 0.67 L of fuel consumed per kWh of electricity generated.

Solar Photovoltaic Hybrid Diesel with Battery Storage:

- **Solar PV Installed Capacity:** 23.7 kW total capacity, which includes 64 panels of 370 W power (Power, 2019).
- **Solar PV Panels Service Life:** 30 years (US National Renewable Energy Laboratory [NREL], 2018)
- **Battery Storage:** 8-hour storage device assumed with 90% round-trip efficiency (US National Renewable Energy Laboratory [NREL], 2018)
- **Battery Service Life:** 15 years (US National Renewable Energy Laboratory [NREL], 2018)
- **Diesel generator service life**: 15 years based on short-term intermittent high efficiency operation (Nowicki, 2019).
- **Backup diesel generator installed capacity**: 20 kW

- **PV potential @ KLRS (April to September, inclusive):** 723 kWh/kWp as tabulated in tables below for Destruction Bay and Burwash Landing's monthly average PV potential (Natural Resources Canada [NRCan], 2017).
- **Efficiency:** 75% applied to product of peak sun hours and installed capacity to capture losses due to wiring, soiling, inverter, etc. and more accurately reflect demand (Nowicki, 2019).

Capital Costs:

- **Diesel generator (primary power & hybrid system):** $902/kW + 25% premium for remote community construction, approximated as natural gas combustion turbine (US National Renewable Energy Laboratory [NREL], 2018). [Primary: Year 0, 10, 20; Backup: Year 0, 15].
- **Solar PV panels plus miscellaneous:** $152,238**,** all in (Year 0). Costs include system design, project management, racking, electrical, shipping, labour and associated travel (Power, 2019).
- **Battery storage:** $69,159 with 25% premium applied for remote community construction [Year 0 and 15] (Power, 2019).

Operating and Maintenance Costs (Fixed & Variable):

- **Diesel generator for stand-alone system:** $3,326/year based on KLRS actuals from 2018 baseline operational cost. Higher cost than average due to factors cited under Diesel Power Generation System heading.
- **Diesel generator for solar hybrid system:** $19/kW-year estimate, approximated as natural gas combustion turbine (US National Renewable Energy Laboratory [NREL], 2018). Assumed higher efficiency operation results in reduction in operating cost in line with average.
- **Cost of Diesel Fuel:** Projection based on announced GHG policies within the Yukon starting in 2020, from the end-use prices of the transportation sector, reference case. Canada's Energy Future 2018 version was used which includes the federal carbon tax backstop (Government of Canada, 2017). Last ten years of projection was extrapolated based on current data set. 30% of the diesel consumed in the diesel case was assumed for the hybrid solar diesel case.

- **Solar System:** $18/kW-year estimate, approximated as commercial PV system (US National Renewable Energy Laboratory [NREL], 2018)
- **Battery Storage:** $9177/MW-year fixed + $2.793/MWh variable for an 8-hour storage device with a 15-year life and 90% round-trip efficiency (US National Renewable Energy Laboratory [NREL], 2018).

Decommissioning Costs:

- Assumed 10% of capital cost.

Social Costs:

- $0.0322/kWh taken from diverging from diesel study (Gwich'in Council International, 2016) and original cited source (Muller, Mendelsohn, & Nordhaus, 2011).
- $0.1918/kWh taken from diverging from diesel study (Gwich'in Council International, 2016) and original cited source (Machol & Rizk, 2013).

Assumptions:

- 0% average annual growth rate assumed based on building area available and current utilization.
- Population equivalent to accommodation capacity, 35 users and 5 employees.
- Consumption projected to remain constant based on 2018 average demand.
- $1000 self-determination benefit (Treasury Board of Canada Secretariat, 2007).
- Social time preference discount rate of 3% and real discount rate of 8% (Treasury Board of Canada Secretariat, 2007).

Monthly Average Photovoltaic Potential for Adjacent Community of Destruction Bay (NW of KLRS)

Territory	Municipality	Month	PV potential (kWh/kWp)			
			South-facing vertical (tilt=90°)	South-facing tilt=latitude	South-facing tilt=lat+15°	South-facing tilt=lat-15°
Yukon Territory	Destruction Bay	January	44	41	44	36
Yukon Territory	Destruction Bay	February	73	72	74	65
Yukon Territory	Destruction Bay	March	112	121	119	116
Yukon Territory	Destruction Bay	April	107	130	120	132
Yukon Territory	Destruction Bay	May	91	126	110	136
Yukon Territory	Destruction Bay	June	80	114	98	126
Yukon Territory	Destruction Bay	July	78	110	95	121
Yukon Territory	Destruction Bay	August	85	111	100	118
Yukon Territory	Destruction Bay	September	77	89	84	90
Yukon Territory	Destruction Bay	October	67	70	70	65
Yukon Territory	Destruction Bay	November	41	39	41	35
Yukon Territory	Destruction Bay	December	29	27	29	24
Yukon Territory	**Destruction Bay**	**Annual**	**884**	**1051**	**983**	**1064**

Source: (Natural Resources Canada [NRCan], 2017)

The PV potential surrounding KLRS is estimated to be greatest between March to September with 723 kWh/kWp of PV potential produced during KLRS's typical operational months (April through September). The months highlighted above captures approximately 68 percent of the annual solar irradiation in Destruction Bay. The total PV potential is slightly less below; however, Haines Junction is estimated to produce the same 723 kWh/kWp of PV potential during the months of April to September, inclusive, capturing approximately 70 percent of the annual solar irradiation during this six-month window.

Monthly Average Photovoltaic Potential for Adjacent Community of Haines Junction (SE of KLRS)

Territory	Municipality	Month	PV potential (kWh/kWp) South-facing vertical (tilt=90°)	South-facing tilt=latitude	South-facing tilt=lat+15°	South-facing tilt=lat-15°
Yukon Territory	Haines Junction	January	38	36	38	32
Yukon Territory	Haines Junction	February	68	68	70	62
Yukon Territory	Haines Junction	March	105	115	113	110
Yukon Territory	Haines Junction	April	102	127	117	129
Yukon Territory	Haines Junction	May	88	124	108	134
Yukon Territory	Haines Junction	June	79	116	98	128
Yukon Territory	Haines Junction	July	78	113	97	124
Yukon Territory	Haines Junction	August	85	113	101	120
Yukon Territory	Haines Junction	September	74	87	82	88
Yukon Territory	Haines Junction	October	60	63	63	60
Yukon Territory	Haines Junction	November	37	36	37	32
Yukon Territory	Haines Junction	December	25	23	24	20
Yukon Territory	**Haines Junction**	**Annual**	**838**	**1021**	**949**	**1038**

Source: (Natural Resources Canada [NRCan], 2017)

Cost Benefit Analysis of 20 kW Diesel-fired Power Generator [Years 0-19]

	General				Costs					Calculation based on 3% discount rate			Calculation based on 8% discount rate			NEB Cost Projection	
Year / Category	Population	Per capita energy demand [MWh/capita]	Annual average energy demand [MWh/year]	Total diesel volume consumed [GJ]	Capital costs of diesel generator [$]	O&M costs [$]	Decommissioning [$]	Diesel consumed [$] (Reference case)	Social costs [$]	Self-determination Benefit [$]	Net benefits (costs) [$ - given year]	PV of Net Benefits [$ - 2018 dollars]	Self-determination Benefit [$]	Net benefits (costs) [$ - given year]	PV of Net Benefits [$ - 2018 dollars]	Reference Year	Diesel Cost [2018 C$/GJ]
0	40	0.557	22	535	22,550	3,326		24,137	718	40,000	-10,730	-10,730	40,000	-10,730	-10,730	2020	44.81
1	40	0.557	22	535		3,326		22,758	718	40,000	13,199	12,814	40,000	13,199	12,221	2021	42.25
2	40	0.557	22	535		3,326		21,923	718	40,000	14,034	13,228	40,000	14,034	12,032	2022	40.70
3	40	0.557	22	535		3,326		21,955	718	40,000	14,001	12,813	40,000	14,001	11,115	2023	40.76
4	40	0.557	22	535		3,326		21,767	718	40,000	14,190	12,608	40,000	14,190	10,430	2024	40.41
5	40	0.557	22	535		3,326		21,707	718	40,000	14,249	12,292	40,000	14,249	9,698	2025	40.30
6	40	0.557	22	535		3,326		21,627	718	40,000	14,330	12,001	40,000	14,330	9,030	2026	40.15
7	40	0.557	22	535		3,326		21,497	718	40,000	14,459	11,757	40,000	14,459	8,437	2027	39.91
8	40	0.557	22	535		3,326		21,347	718	40,000	14,610	11,533	40,000	14,610	7,893	2028	39.63
9	40	0.557	22	535		3,326		21,217	718	40,000	14,739	11,297	40,000	14,739	7,373	2029	39.39
10	40	0.557	22	535	22,550	3,326	2,255	21,088	718	40,000	-9,936	-7,394	40,000	-9,936	-4,602	2030	39.15
11	40	0.557	22	535		3,326		21,002	718	40,000	14,955	10,804	40,000	14,955	6,414	2031	38.99
12	40	0.557	22	535		3,326		20,932	718	40,000	15,025	10,538	40,000	15,025	5,967	2032	38.86
13	40	0.557	22	535		3,326		20,883	718	40,000	15,073	10,264	40,000	15,073	5,542	2033	38.77
14	40	0.557	22	535		3,326		20,851	718	40,000	15,106	9,987	40,000	15,106	5,143	2034	38.71
15	40	0.557	22	535		3,326		20,813	718	40,000	15,143	9,720	40,000	15,143	4,774	2035	38.64
16	40	0.557	22	535		3,326		20,759	718	40,000	15,197	9,470	40,000	15,197	4,436	2036	38.54
17	40	0.557	22	535		3,326		20,700	718	40,000	15,257	9,230	40,000	15,257	4,123	2037	38.43
18	40	0.557	22	535		3,326		20,625	718	40,000	15,332	9,006	40,000	15,332	3,837	2038	38.29
19	40	0.557	22	535		3,326		20,555	718	40,000	15,402	8,784	40,000	15,402	3,569	2039	38.16

Cost Benefit Analysis of 20 kW Diesel-fired Power Generator [Years 20-30 Continued]

		General				Costs (Reference Case)					Calculation based on 3% discount rate			Calculation based on 8% discount rate			NEB Cost Projection	
	Category	**Population**	**Per capita energy demand [MWh/capita]**	**Annual average energy demand [MWh/year]**	**Total diesel volume consumed [GJ]**	**Capital costs of diesel generator [$]**	**O&M costs [$]**	**Decommissioning [$]**	**Diesel consumed [$] (Reference case)**	**Social costs [$]**	**Self-determination Benefit [$]**	**Net benefits (costs) [$ - given year]**	**PV of Net Benefits [$ - 2018 dollars]**	**Self-determination Benefit [$]**	**Net benefits (costs) [$ - given year]**	**PV of Net Benefits [$ - 2018 dollars]**	**Reference Year**	**Diesel Cost [2018 C$/GJ]**
Year	**20**	40	0.557	22	535	22,550	3,326	2,255	20,474	718	40,000	-9,322	-5,161	40,000	-9,322	-2,000	2040	38.01
	21	40	0.557	22	535		3,326		20,229	718	40,000	15,727	8,454	40,000	15,727	3,124	2041	37.56
	22	40	0.557	22	535		3,326		20,135	718	40,000	15,822	8,258	40,000	15,822	2,910	2042	37.38
	23	40	0.557	22	535		3,326		20,040	718	40,000	15,917	8,065	40,000	15,917	2,711	2043	37.20
	24	40	0.557	22	535		3,326		19,945	718	40,000	16,012	7,877	40,000	16,012	2,525	2044	37.03
	25	40	0.557	22	535		3,326		19,850	718	40,000	16,106	7,693	40,000	16,106	2,352	2045	36.85
	26	40	0.557	22	535		3,326		19,756	718	40,000	16,201	7,512	40,000	16,201	2,190	2046	36.68
	27	40	0.557	22	535		3,326		19,661	718	40,000	16,296	7,336	40,000	16,296	2,040	2047	36.50
	28	40	0.557	22	535		3,326		19,566	718	40,000	16,391	7,164	40,000	16,391	1,900	2048	36.32
	29	40	0.557	22	535		3,326		19,471	718	40,000	16,485	6,996	40,000	16,485	1,769	2049	36.15
	30	40	0.557	22	535		3,326	2,255	19,377	718	40,000	14,325	5,902	40,000	14,325	1,424	2050	35.97
	Total					**67,650**	**103,094**	**6,765**	**646,647**	**22,247**	**1,240,000**	**393,597**	**250,117**	**1,240,000**	**393,597**	**137,648**		

Cost Benefit Analysis of 24 kW Solar System with Backup Diesel and Battery Storage [Years 0-19]

	Category	General	General			Costs								Calculation based on 3% discount rate			Calculation based on 8% discount rate		
			Population	Per capita energy demand [MWh/capita]	Annual average energy demand [MWh/year]	Capital costs of solar system [$]	Capital costs of battery storage [$]	Capital costs for backup diesel generator [$]	O&M costs for solar system [$]	O&M costs for battery storage [$]	O&M costs for backup diesel generator [$]	Diesel consumed [$] (Reference case)	Decommissioning costs for solar, diesel and storage [$]	Self-determination benefit [M]	Net benefits (costs) [$ - given year]	PV of net benefits [$ - 2018 dollars]	Self-determination benefit [M]	Net benefits (costs) [$ - given year]	PV of net benefits [$ - 2018 dollars]
	0	0	40	0.321	13	152,238	69,159	22,550	426	219	380	7,241		40,000	-212,214	-212,214	40,000	-212,214	-212,214
	1	1	40	0.321	13				426	219	380	6,827		40,000	32,147	31,211	40,000	32,147	29,766
	2	2	40	0.321	13				426	219	380	6,577		40,000	32,397	30,538	40,000	32,397	27,776
	3	3	40	0.321	13				426	219	380	6,587		40,000	32,388	29,639	40,000	32,388	25,710
	4	4	40	0.321	13				426	219	380	6,530		40,000	32,444	28,826	40,000	32,444	23,848
	5	5	40	0.321	13				426	219	380	6,512		40,000	32,462	28,002	40,000	32,462	22,093
	6	6	40	0.321	13				426	219	380	6,488		40,000	32,486	27,207	40,000	32,486	20,472
	7	7	40	0.321	13				426	219	380	6,449		40,000	32,525	26,446	40,000	32,525	18,978
	8	8	40	0.321	13				426	219	380	6,404		40,000	32,570	25,711	40,000	32,570	17,597
Year	**9**	9	40	0.321	13				426	219	380	6,365		40,000	32,609	24,992	40,000	32,609	16,313
	10	10	40	0.321	13				426	219	380	6,326		40,000	32,648	24,293	40,000	32,648	15,122
	11	11	40	0.321	13				426	219	380	6,301		40,000	32,674	23,604	40,000	32,674	14,013
	12	12	40	0.321	13				426	219	380	6,280		40,000	32,695	22,931	40,000	32,695	12,984
	13	13	40	0.321	13				426	219	380	6,265		40,000	32,709	22,273	40,000	32,709	12,027
	14	14	40	0.321	13				426	219	380	6,255		40,000	32,719	21,631	40,000	32,719	11,140
	15	15	40	0.321	13		69,159	22,550	426	219	380	6,244	9,171	40,000	-68,149	-43,742	40,000	-68,149	-21,483
	16	16	40	0.321	13				426	219	380	6,228		40,000	32,747	20,407	40,000	32,747	9,558
	17	17	40	0.321	13				426	219	380	6,210		40,000	32,764	19,823	40,000	32,764	8,855
	18	18	40	0.321	13				426	219	380	6,187		40,000	32,787	19,259	40,000	32,787	8,205
	19	19	40	0.321	13				426	219	380	6,166		40,000	32,808	18,710	40,000	32,808	7,602

Cost Benefit Analysis of 24 kW Solar System with Backup Diesel and Battery Storage [Years 20-30]

			General			Costs								Calculation based on 3% discount rate			Calculation based on 8% discount rate		
	Category	General	Population	Per capita energy demand [MWh/capita]	Annual average energy demand [MWh/year]	Capital costs of solar system [$]	Capital costs of battery storage [$]	Capital costs for backup diesel generator [$]	O&M costs for solar system [$]	O&M costs for battery storage [$]	O&M costs for backup diesel generator [$]	Diesel consumed [$] (Reference case)	Decommissioning costs for solar, diesel and storage [$]	Self-determination benefit [M]	Net benefits (costs) [$ - given year]	PV of net benefits [$ - 2018 dollars]	Self-determination benefit [M]	Net benefits (costs) [$ - given year]	PV of net benefits [$ - 2018 dollars]
Year	**20**	20	40	0	13				426	219	380	6,142		40,000	32,832	18,178	40,000	32,832	7,044
	21	21	40	0	13				426	219	380	6,069	-	40,000	32,906	17,688	40,000	32,906	6,537
	22	22	40	0	13				426	219	380	6,040	-	40,000	32,934	17,188	40,000	32,934	6,058
	23	23	40	0	13				426	219	380	6,012	-	40,000	32,962	16,702	40,000	32,962	5,614
	24	24	40	0	13				426	219	380	5,984	-	40,000	32,991	16,229	40,000	32,991	5,203
	25	25	40	0	13				426	219	380	5,955	-	40,000	33,019	15,770	40,000	33,019	4,821
	26	26	40	0	13				426	219	380	5,927	-	40,000	33,048	15,324	40,000	33,048	4,468
	27	27	40	0	13				426	219	380	5,898	-	40,000	33,076	14,891	40,000	33,076	4,141
	28	28	40	0	13				426	219	380	5,870	-	40,000	33,105	14,469	40,000	33,105	3,837
	29	29	40	0	13				426	219	380	5,841	-	40,000	33,133	14,060	40,000	33,133	3,556
	30	30	40	0	13				426	219	380	5,813	24,395	40,000	8,767	3,612	40,000	8,767	871
	Total					**152,238**	**138,318**	**45,100**	**13,213**	**6,802**	**11,780**	**193,994**	**33,566**	**1,240,000**	**644,990**	**353,660**	**1,240,000**	**644,990**	**120,512**

APPENDIX B: LIST OF EMISSION FACTORS

The tables within this Appendix capture the emission factors used to calculate all categories of scope 1 and 3 emissions relevant to the carbon footprint of the Kluane Lake Research Station.

Scope 1 Emission Factors Used in Carbon Footprint Study

Scope Activity	EF	EF Unit	Category Description
Scope 1 - Combustion of Fossil Fuels & Bioenergy			
Diesel, 100% mineral	2.68779	$kgCO_2e/L$	Fuels | Liquid fuels
Petrol, average biofuel blend	2.20307	$kgCO_2e/L$	Fuels | Liquid fuels
Propane (LPG)	1.51906	$kgCO_2e/L$	Fuels | Gaseous fuels
Wood logs	0.01506	$kgCO_2e/kWh$	Bioenergy | Biomass

Source: Adapted from (Department for Business, Energy & Industrial Strategy, 2018b)

Scope 3 Emission Factors from All Categories Excluding Freight and Well-to-tank Activities Used in Carbon Footprint Study

Scope Activity	EF	EF Unit	Category Description
Scope 3 - Business Travel [Air]			
Domestic, average passenger	0.29832	$kgCO_2e/pkm$	Flights | With RF
Short haul, economy class	0.1597	$kgCO_2e/pkm$	Flights | With RF
Short haul, average passenger*	0.16236	$kgCO_2e/pkm$	Flights | With RF
Long haul, economy class	0.16279	$kgCO_2e/pkm$	Flights | With RF
Long haul, average passenger*	0.21256	$kgCO_2e/pkm$	Flights | With RF
Scope 3 - Business Travel [Land]			
Car, average	0.18368	$kgCO_2e/km$	Cars (by size) | Petrol
Van, average	0.24917	$kgCO_2e/km$	Vans | Average (up to 3.5t) | Petrol
Scope 3 - Material Use [Groceries]			
Food & drink	4060.1636	$kgCO_2e/tonne$	Primary material production (from virgin stock)
Scope 3 - Employee Commuting			
Car, medium-sized	0.19386	$kgCO_2e/km$	Cars (by size) | Petrol
Car, large-sized	0.28411	$kgCO_2e/km$	Cars (by size) | Petrol
Vans, Class III	0.3046	$kgCO_2e/km$	Vans | Class III (1.74 to 3.5t) | Petrol
Scope 3 - Waste Disposal			
Municipal solid waste	586.5313	$kgCO_2e/tonne$	Refuse | Landfill
Organic: food and drink waste	626.9729	$kgCO_2e/tonne$	Refuse | Landfill
Organic: food and drink waste	10.2586	$kgCO_2e/tonne$	Refuse | Composting
Plastics: PET	21.3842	$kgCO_2e/tonne$	Plastic incl. forming | Open loop
Aluminum cans and foil	21.3842	$kgCO_2e/tonne$	Metal excl. forming | Closed loop
Paper and cardboard	21.3842	$kgCO_2e/tonne$	Average: 78% corrugated & 22% carton board | Closed loop
Scope 3 - Capital Goods			
WEEE - fridges and freezers	3814.3675	$kgCO_2e/tonne$	Material use | Electrical items | Primary material production
WEEE - small (power equipment)	1759.6002	$kgCO_2e/tonne$	Material use | Electrical items | Primary material production
WEEE - all sizes	16.58	$kgCO_2e/tonne$	Waste disposal | Electrical items | Landfill

*used in uncertainty analysis

Source: Adapted from (Department for Business, Energy & Industrial Strategy, 2018b)

Scope 3 Emission Factors Used Related to Well-to-tank Upstream Activities

Scope Activity	EF	EF Unit	Category Description
Scope 3 - WTT: Fuels			
Diesel, 100% mineral	0.62564	$kgCO_2e/L$	WTT - fuels | Liquid fuels
Petrol, average biofuel blend	0.59665	$kgCO_2e/L$	WTT - fuels | Liquid fuels
Propane (LPG)	0.19102	$kgCO_2e/L$	WTT - fuels | Gaseous fuels
Wood logs	0.01277	$kgCO_2e/kWh$	WTT - bioenergy | Biomass
Scope 3 - WTT: Business Travel [Air]			
Domestic, average passenger	0.03267	$kgCO_2e/pkm$	WTT - flights | With RF
Short haul, economy class	0.0175	$kgCO_2e/pkm$	WTT - flights | With RF
Long haul, economy class	0.01783	$kgCO_2e/pkm$	WTT - flights | With RF
Scope 3 - WTT: Passenger Vehicle & Travel [Land]			
Car, average	0.04985	$kgCO_2e/km$	WTT - cars (by size) | Petrol
Van, average	0.06133	$kgCO_2e/km$	WTT - vans | Average (up to 3.5t) | Petrol
Scope 3 - WTT: Employee Commuting			
Car, medium-sized	0.05263	$kgCO_2e/km$	WTT - cars (by size) | Petrol
Car, large-sized	0.07722	$kgCO_2e/km$	WTT - cars (by size) | Petrol
Vans, Class III	0.083	$kgCO_2e/km$	WTT - vans | Class III (1.74 to 3.5t) | Petrol

Source: Adapted from (Department for Business, Energy & Industrial Strategy, 2018b)

Scope 3 Emission Factors Used Related to Freighting Goods

Scope Activity	EF	EF Unit	Category Description
Scope 3 - Freight of Propane & Diesel			
Freight, average laden haul	0.17927	$kgCO_2e/tkm$	HGV (all diesel) | Rigid (>17t)
Freight, unladen backhaul	0.7681	$kgCO_2e/km$	HGV (all diesel) | Rigid (>17t)
Scope 3 - Freight of Wood			
Delivery in F350 truck	0.51618	$kgCO_2e/tkm$	Vans | Class III (1.74 to 3.5t) | Diesel
Delivery in F350 truck	0.27491	$kgCO_2e/km$	Vans | Class III (1.74 to 3.5t) | Diesel
Freight, average laden haul	0.14054	$kgCO_2e/tkm$	HGV (all diesel) | Articulated (>3.5 to 33t)
Freight, unladen backhaul	0.64923	$kgCO_2e/km$	HGV (all diesel) | Articulated (>3.5 to 33t)
Scope 3 - Freight of Groceries			
Freight, average laden haul	0.5792271	$kgCO_2e/tkm$	HGV refrigerated (all diesel) | Rigid (>3.5 to 7.5t)
Freight, unladen backhaul	0.45835	$kgCO_2e/km$	HGV (all diesel) | Rigid (>3.5 to 7.5t)
Scope 3 - Freight of Septic Tank Waste Water Disposal			
Freight, average laden haul	0.3581	$kgCO_2e/tkm$	HGV (all diesel) | Rigid (>7.5 to 17t)
Freight, unladen backhaul	0.55083	$kgCO_2e/km$	HGV (all diesel) | Rigid (>7.5 to 17t)

Source: Adapted from (Department for Business, Energy & Industrial Strategy, 2018b)

Scope 3 Emission Factors Used Related to Well-to-tank for Freighting Goods

Scope Activity	EF	EF Unit	Category Description
Scope 3 - WTT: Freight of Propane & Diesel			
Freight, average laden haul	0.04268	$kgCO_2e/tkm$	WTT - HGV (all diesel) | Rigid (>17 tonnes)
Freight, unladen backhaul	0.18287	$kgCO_2e/km$	WTT - HGV (all diesel) | Rigid (>17 tonnes)
Scope 3 - WTT: Freight of Wood			
Delivery in F350 truck	0.12326	$kgCO_2e/tkm$	WTT - vans | Class III (1.74 to 3.5 tonnes) | Diesel
Delivery in F350 truck	0.06564	$kgCO_2e/km$	WTT - vans | Class III (1.74 to 3.5 tonnes) | Diesel
Freight, average laden haul	0.03346	$kgCO_2e/tkm$	WTT - HGV (all diesel) | Articulated (>3.5 to 33t)
Freight, unladen backhaul	0.15458	$kgCO_2e/km$	WTT - HGV (all diesel) | Articulated (>3.5 to 33t)
Scope 3 - WTT: Freight of Groceries			
Freight, average laden haul	0.13826	$kgCO_2e/tkm$	WTT - HGV refrigerated (all diesel) | Rigid (>3.5 to 7.5t)
Freight, unladen backhaul	0.10916	$kgCO_2e/km$	WTT - HGV (all diesel) | Rigid (>3.5 to 7.5t)
Scope 3 - WTT: Freight of Septic Tank Waste Water Disposal			
Freight, average laden haul	0.08518	$kgCO_2e/tkm$	WTT - HGV (all diesel) | Rigid (>7.5 to 17 tonnes)
Freight, unladen backhaul	0.13102	$kgCO_2e/km$	WTT - HGV (all diesel) | Rigid (>7.5 to 17 tonnes)

Source: Adapted from (Department for Business, Energy & Industrial Strategy, 2018b)

APPENDIX C: WOOD COMBUSTION EMISSION CALCULATIONS

This Appendix captures the equation and variables used to calculate the wood combustion emissions based on the available data, relevant to the carbon footprint of the Kluane Lake Research Station.

Equation Related to Wood Combustion Emissions

$$Emissions\ of\ wood\ combustion$$
$$= Activity\ data\ [cord]\ x\ Recoverable\ heat\ value\ \left[\frac{MMBtu}{cord}\right] x\ Energy\ conversion\ factor\ \left[\frac{kWh}{MMBtu}\right] x\ Emission\ factor\ [kg\ \frac{CO2e}{kWh}]$$

Source: Adapted from (World Resources Institute [WRI] & World Business Council for Sustainable Development [WBCSD], 2013b)

Variables & Conversion Factors Used:

Recoverable Heat Value of Cord [Dry Wood, Spruce]: 16.0 MMBtu/cord Source: (Engineering Toolbox, 2003).

Density of Dry Wood [Spruce, Canadian]: 450 kg/m^3 Source: (Engineering Toolbox, 2004).

Energy Conversion Factor: 293.0711 kWh/MMBtu Source: (Department for Business, Energy & Industrial Strategy, 2018b).

Volume Conversion Factor [Firewood]: 3624.556416 L/cord Source: (ConvertUnits.com, 2019).

APPENDIX D: REFERENCE MASS DATABASES USED FOR MATERIAL USE CALCULATIONS

The list found below are all online reference mass calculators used to estimate average masses for miscellaneous items and volumetric conversions on the grocery invoices analyzed, for calculation of the material use emissions for the Kluane Lake Research Station.

GP Distributing: (G-P Distributing Inc, 2017)

Real Canadian Superstore: (Loblaws Inc., 2019)

Food Facts Reference Database: (Reference, 2019)

Volumetric Conversions: (Aqua-Calc, 2019)

APPENDIX E: SUMMARY OF RESULTS OF CARBON FOOTPRINT CALCULATION

The tables within this Appendix capture results of all scope 1 and 3 emission categories calculated relevant to the Kluane Lake Research Station's carbon footprint.

Scope 1 & 3 Emissions Related to Combustion & Freight of Diesel & Associated Well-to-tank

Diesel Fuel Consumed		WTT - Fuel	Freight of Diesel: Cumulative Distance	Freight of Diesel: Scope 3 [kg CO_2e]			WTT - Freight: Scope 3 [kg CO_2e]		
Volume [L]	Scope 1 [kg CO_2e]	Scope 3 [kg CO_2e]	One Way [km]	Average Laden	0% Laden	Total	Average Laden	0% Laden	Total
18,923	**50,861**	**11,839**	316	180	242	**422**	43	58	**100**

Scope 1 & 3 Emissions Related to Combustion of Petrol Fuel & Associated Well-to-tank

Petrol Fuel Consumed		WTT - Fuel
Volume [L]	Scope 1 [kg CO_2e]	Scope 3 [kg CO_2e]
6,130	**13,505**	**3,657**

Scope 1 & 3 Emissions Related to Combustion, Freight of Propane & Associated Well-to-tank

Propane Fuel Consumed		WTT - Fuel	Freight of Propane: Cumulative Distance	Freight of Propane: Scope 3 [kg CO_2e]			WTT - Freight: Scope 3 [kg CO_2e]		
Volume [L]	Scope 1 [kg CO_2e]	Scope 3 [kg CO_2e]	One Way [km]	Average Laden	0% Laden	Total	Average Laden	0% Laden	Total
4,564	**6,933**	**872**	1,505	628	1,156	**1,784**	150	275	**425**

Scope 1 & 3 Emissions Related to Combustion & Freight of Wood

Wood Consumed		WTT - Bioenergy	Freight of Wood				WTT - Freight		
			Cumulative Distance	Scope 3 [kg CO_2e]			Scope 3 [kg CO_2e]		
Volume [cord]	Scope 1 [kg CO_2e]	Scope 3 [kg CO_2e]	One Way [km]	Average Laden	0% Laden	Total	Average Laden	0% Laden	Total
16	**1,130**	**958**	155	640	62	**701**	153	15	**167**

Scope 3 Emissions Related to Air Travel Predominately by Users Including Well-to-tank

Business Travel [Air]								WTT - Business Travel [Air]			
Great Circle Distance by Haul [pkm]				Scope 3 Emissions [kg CO_2e]				Scope 3 Emissions [kg CO_2e]			
Domestic	Short	Long	Total	Domestic	Short	Long	Total	Domestic	Short	Long	Total
81,029	1,455,936	586,002	**2,122,967**	24,173	232,513	95,395	**352,081**	2,647	25,479	10,448	**38,575**

Scope 3 Emissions Related to Material Use of Food & Drink, Freight & Associated Well-to-tank

Material Use		Freight of Groceries				WTT - Freight		
Food & Drink Procured		Cumulative Distance	Scope 3 [kg CO_2e]			Scope 3 [kg CO_2e]		
Mass [tonnes]	Scope 3 [kg CO_2e]	One-Way [km]	Average Laden	0% Laden	Total	Average Laden	0% Laden	Total
4.68	**18,995**	3,328	6,486	1,525	**8,012**	1,548	363	**1,912**

Scope 3 Emissions Related to User Land Travel Including Well-to-tank

User Travel [Land]						WTT - User Travel [Land]		
Distance Traveled [km]			Scope 3 Emissions [kg CO_2e]			Scope 3 Emissions [kg CO_2e]		
Car	Van	Total	Car	Van	Total	Car	Van	Total
15,759	19,000	**34,759**	2,895	4,734	**7,629**	786	1,165	**1,951**

Scope 3 Emissions Related to Employee Commuting in Personal Passenger Vehicles

Type of Passenger Vehicle	Number of Commutes	Total Distance Travelled [km]	Passenger Vehicle Scope 3 Emissions [kg CO_2e]	WTT - Passenger Vehicle Scope 3 Emissions [kg CO_2e]
Car, large	13	1602	455	124
Car, medium	14	6048	1172	318
Car, large	7	3024	859	234
Van, Class III	7	3024	921	251
2018 Total	**41**	**13,698**	**3,408**	**926**

Scope 3 Emissions Related to Organic & Inorganic Domestic Waste Disposal

Mass of Waste [kg]				Emissions [kg CO_2e]			
Organic: Compostable	Organic: Non-Compostable	Inorganic: Garbage Excludes Non-Compostable	Total	Compost	Organic Waste Landfill	Municipal Solid Waste Landfill	Total
Compost	Landfill	Landfill	Waste	Scope 3	Scope 3	Scope 3	Scope 3
341	79	701	**1,121**	3	50	411	**464**

Source: Data was adapted from 2018 KLRS waste management study (Montgomery, 2018)

Scope 3 Emissions Related to Recycling

Cans & Bottles			Cardboard	
Mass [kg]		Total	Mass [kg]	Total
Cans	Bottles	Scope 3 [kg CO_2e]	Cardboard	Scope 3 [kg CO_2e]
78	**9**	**2**	**826**	**18**

Scope 3 Emissions Related to the Procurement and Disposal of Capital Goods

Item	Material Use		Waste Disposal
	Weight of Item [kg]	Scope 3 Emissions [kgCO_2e]	
GE® 17.5 Cu. Ft. Top-Freezer Refrigerator	78	299	1
Hatco Commercial Pop-Up Toaster	6	11	0
MASTER Chef E-Star Water Cooler, Top Load	15	27	0
Total	**100**	**338**	**2**

Scope 3 Emissions Related to the Collection & Disposal of Waste Water

Waste Water	Cumulative Distance	Scope 3 [kg CO_2e]		
Volume [L]	One Way [km]	0% Laden	Average Laden	Total
11,830	63	70	267	**337**