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De-Risking Wood-Based Bioenergy Development in Remote and Indigenous Communities in Canada

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Abstract: Remote and Indigenous communities in Canada have a unique opportunity to mobilize the vast amount of wood-based biomass to meet their energy needs, while supporting a local economy, and reducing greenhouse gas (GHG) emissions. This study realized in collaboration with five remote and Indigenous communities across Canada investigates the main barriers and potential solutions to developing stable and sustainable wood-based bioenergy systems. Our results highlight that despite the differences in available biomass and geographical context, these communities face common policy, economic, operational, cultural, social, and environmental risks and barriers to developing bioenergy. The communities identified and ranked the biggest barriers as follows; the high initial investment of bioenergy projects, the logistical and operational challenges of developing a sustainable wood supply chain in remote locations, and the limited opportunities for community leadership of bioenergy projects. Environmental risks have been ranked as the least important by all the communities, except for the communities in Manitoba, which ranked it as the second most important risk. However, all the communities agreed that climate change is the main environmental driver disturbing the wood-based bioenergy supply chain. To de-risk the wood-based bioenergy system, we suggest that stable and sustainable supply chains can be implemented by restoring community-based resources management supported by local knowledge and workforce. Using local knowledge can also help reduce the impacts caused by biomass harvesting on the ecosystem and avoid competition with traditional land uses. Including positive externalities to cost benefit analysis, when comparing bioenergy systems to existing energy installation, will likely make bioenergy projects more attractive for the community financially. Alternatively, supporting co-learning between partners and among communities can improve knowledge and innovation sharing.

Keywords: biomass; climate change; community-based management; off-grid community; traditional knowledge

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1. Introduction

Biomass makes up 10% of the world's energy supply [1]. Biofuels and wastes account for approximately 50% of the global total primary energy supply of renewable sources [2]. Global biomass utilization is projected to increase substantially over the next 10 years largely due to new policies with the objective of increasing energy security and reducing greenhouse gas emissions [3].

Canada has the largest amount of biomass per capita in the world [4], and approximately 6.5% of the world's bioenergy potential [5], with 9% of the world's forests. Canada is the world's third biggest exporter of timber [6]. Approximately 4% of Canada's total energy supply was produced by biofuels and waste in 2018 [2]. Remote and Indigenous communities in Canada are often surrounded by large, forested areas and therefore are well positioned to tap into this vast biomass resource to meet their energy needs [7]. According to the Remote Communities Energy Database [8] the number of remote Indigenous communities in Canada is 169 with an approximate population of 113,439, for a total of 276 remote communities with a population of ~196,138 across Canada with many of these inhabitants living in or around the boreal forest. Remote and off-grid communities are defined as communities with 10 or more dwellings that are not connected to the North American electricity grid or natural gas infrastructure [9] and therefore face many challenges to access affordable and clean energy. Approximately 73% of remote communities in Canada are reliant on fossil based diesel fuel to meet their heating and electricity needs [8]. The burning of these fossil fuels has negative impacts on human's health and well-being, and on the environment, as well as contributes to climate change. In some cases, diesel generation limits the communities' ability to thrive and grow due to the limited output of generators as well as complicated governance and decision-making process by multiple levels of government as well as utility companies [10,11].

The Forest Bioeconomy Framework for Canada and the Pan Canadian Framework on Clean Growth and Climate Change outline that given their proximity to forest resources, Indigenous community leadership and stewardship are expected to play a key role in Canada's transition to the low carbon economy [12,13]. The development of clean energy systems, energy independence, economic development, revenue and job generation, and community resilience are often goals mentioned when remote Indigenous communities discuss their plans for an energy transition [14].

Many of the aforementioned socio-economic and environmental benefits may, however, be far from reach because the wood-based bioenergy supply chain is generally complex and not yet mature in Canada [7,10]. The supply chain management is complex as it encompasses the entire biomass value chain, from the selection and quality of the feedstock to resource harvesting, collection, processing, storage, and its transportation to the point of ultimate conversion. The upstream processes related to the mobilization of biomass have not been fully understood and barriers along the biomass supply chain are often under documented [15]. This lack of understanding could jeopardize initial wood-based energy investments, as well as any other type of investment that would require biomass mobilization.

Previous studies have discussed challenges to bioenergy projects [16–19], meanwhile the number of publications providing the experiences of the Indigenous communities in Canada in developing bioenergy projects is limited. Bullock et al. [10] documented perspectives of Indigenous business leaders while Zurba and Bullock [20] explored the impact of bioenergy development on the wellbeing of Indigenous peoples in Canada. Rezaei and Dowlatabadi [21] explored the energy system goals of remote and Indigenous communities in British Columbia. Madrali and Blair [22] documented the experiences of nine Indigenous communities in Canada related to bioenergy system design, operations, fuel quality and supply, and trained capacity.

In collaboration with five remote and Indigenous communities located in central and western Canada, this study analyzes and identifies the potential risks and challenges related to the wood-based biomass supply chain for each community. Additionally, we provide contextual and real-world operational information on the energy needs and bioenergy systems development of each community, and outline strategies for de-risking or mitigating these risks at the community level. These communities have been specifically chosen because they are at varying stages of planning and implementing their wood based-bioenergy programs and present distinct environmental contexts.

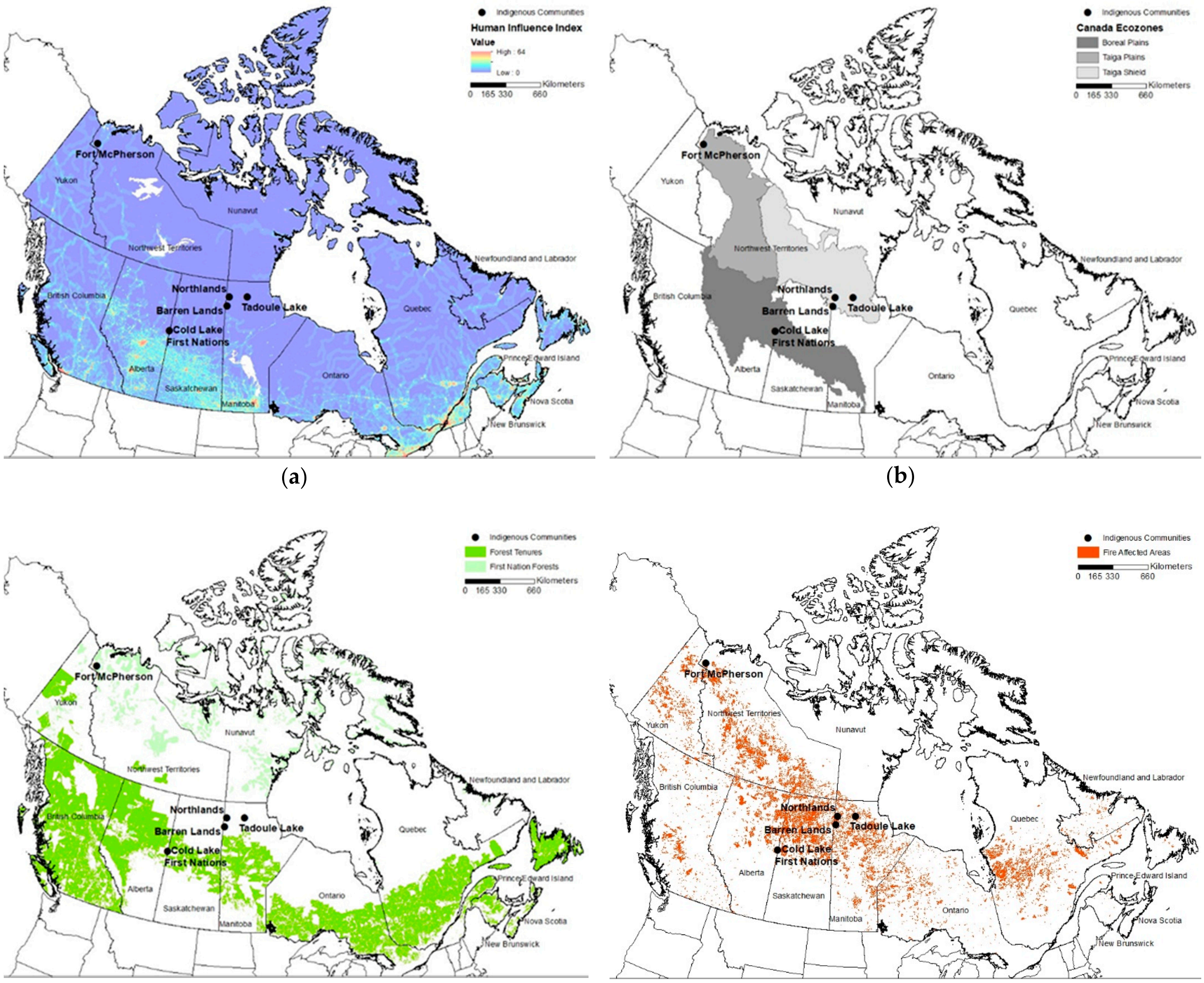
2. Materials and Methods

2.1. Geographical Context

All the communities consulted are located within the boreal forest in western and central Canada. From west to east, the five communities include: Fort McPherson, in Northwest Territories, Cold Lake First Nations in Alberta and Barren Lands (Brochet), Northlands (Lac Brochet), and Tadoule Lake (Sayisi Dene) in Manitoba (Figure 1). The communities included in this study are located on Treaty 11 (Fort McPherson), Treaty 6

(Cold Lake First Nations), and Treaty 5 land (Northlands, Barren Lands, and Tadoule Lake). Honoring the treaty relationship is fundamental for ongoing co-operation and partnership with Indigenous peoples. A treaty is an agreement which was made in a sacred trust between the Indigenous Peoples of Canada and the Crown. First Nations Treaties are "negotiated agreements that clearly spell out the rights, responsibilities, and relationships of First Nations and the federal and provincial governments" [23].

Fort McPherson is a remote community located in northern Northwest Territories, with no access to the electricity grid or natural gas infrastructure and little human disturbance or development (Figure 1a). The community is located at the northern extension of the Taiga Plains Ecozone on the Arctic Coast (Figure 1b). This ecozone has a subarctic and semi-arid climate, with 250–600 mm of precipitation a year and mixedwood forest areas dominated by white and black spruce, lodgepole pine, balsam poplar, tamarack, white birch, and trembling aspen [24].



(**a**) (**b**)

(**c**) (**d**)

Figure 1. Map of Indigenous communities, including: (**a**) the human influence index for Canada, which is shown to illustrate the remoteness of the communities where red indicates highly developed areas [25]; (**b**) Canada's ecozones in the study area [26]; (**c**) Canada's forest tenures and First Nation Forests [27]; (**d**) burned areas (1986–2019) [28]. First Nations Forests are classified as treaty settlement lands, which includes non-forested and forested lands. Most of the communities do not have access to forest tenures and some of them (Manitoba) use salvaged fire residues to supply their boiler.

Cold Lake First Nations is an on-grid community in Alberta, which is close to dense human development and natural resources extraction facilities including forestry and oil and gas activities, as well as the Cold Lake Air Weapons Range, which is in the middle of their traditional territory (Figure 1a). The Cold Lake First Nations is found in the Boreal Plains Ecozone (Figure 1b). This ecozone receives around 450 mm of rain annually, with white spruce, black spruce, balsam fir, tamarack, and jack pine found in peatlands, and white birch, balsam poplar, balsam fir, and trembling aspen being the most dominant broadleaf tree species [24].

Northlands, Barren Lands, and Tadoule Lake are three remote and off-grid communities in Manitoba. The three communities are in the Taiga Shield Ecozone (Figure 1b), which is characterized by a subarctic climate, an average of 250–500 mm of precipitation per year, and open black spruce stands with alder, open mixedwood areas with white spruce, balsam fir and trembling aspen, and fens and bogs with willows and tamarack [24].

2.2. Energy Context and Type of Feedstock

All five communities have a different geographical context that influences their needs, resources, and objectives for their energy programs. They are also at varying stages of planning and implementing their bioenergy programs. Fort McPherson and Northlands are the only communities that currently have biomass boilers. Fort McPherson has a population of approximately 700, and an energy demand of approximately 3600 MWh/year [29,30]. Currently, electricity is generated by imported diesel and the majority of heat is generated by imported heating oil, wood pellets in wood stoves installed in individual buildings and homes, and a small district heating system that captures heat from diesel generators and redistributes it to several large buildings [31,32]. Fort McPherson is considering several biomass feedstock options, including shipping pellets or harvesting willow adjacent to the community, clearing vegetation from highway right-of-ways and from the community wildfire protection plan, collecting residues from the local sawmill, or shipping in pellets [30]. Fort McPherson had an 85 kW biomass boiler installed in 2013 [30].

Cold Lake First Nations is connected to the grid with access to natural gas and electricity [9]. However, the community is currently investigating the potential of using biomass delivered by energy companies operating on their land and having a willow plantation double as a wastewater treatment strategy, and a biomass source. The population of this community is greater than 875 spread over four reserves, with an annual energy demand of 5510 MWh/year [29,33].

Northlands, Barren Lands, and Tadoule Lake are all considering harvesting fire residues from nearby burnt stands and harvesting from nearby forestry management units as a backup [34]. The populations of these communities are 728,624 (241 off-reserve), and 324, respectively [29]. The approximate energy demand in Northlands is 4765.6 MWh/year, 3522.7 MWh/year in Barren Lands, and 2865.4 MWh/year in Tadoule Lake [35]. Each community currently generates electricity with imported diesel and heat from heating oil and wood stoves installed in individual buildings and homes [34,36]. Northlands also generates heat using an in-lake geothermal system, electricity with a 282 kW solar array, and 2 $\times$ 1.5 MW biomass boilers that were installed in 2019 [35,36].

2.3. Data and Approach

The methodology used in the study combines a mix of consultation with the communities, operational data curation, and grey literature. Reports and data were sent to the authors from community consultants for the five participating communities. Reports gathered from the communities were curated and analyzed to identify the risks, gaps, and challenges unique to each community. Following the analysis and curation of the data provided by the communities, the risks and barriers to bioenergy supply chains were divided into four categories: Environmental, Policy and Economic, Social and Cultural, and Logistic and Operational and summarized in Figure 2. Representatives and consultants from the communities were asked to validate the risks and challenges and rank each of the risk categories from 1 to 4, with 1 being the category that represents the most risk for a given community and 4 the least amount of risk. Their responses have been included in Table 1. Comments from the community consultants on risk and barriers to bioenergy supply chains and potential mitigation techniques have been detailed in the results and discussion sections as direct quotes in italics.

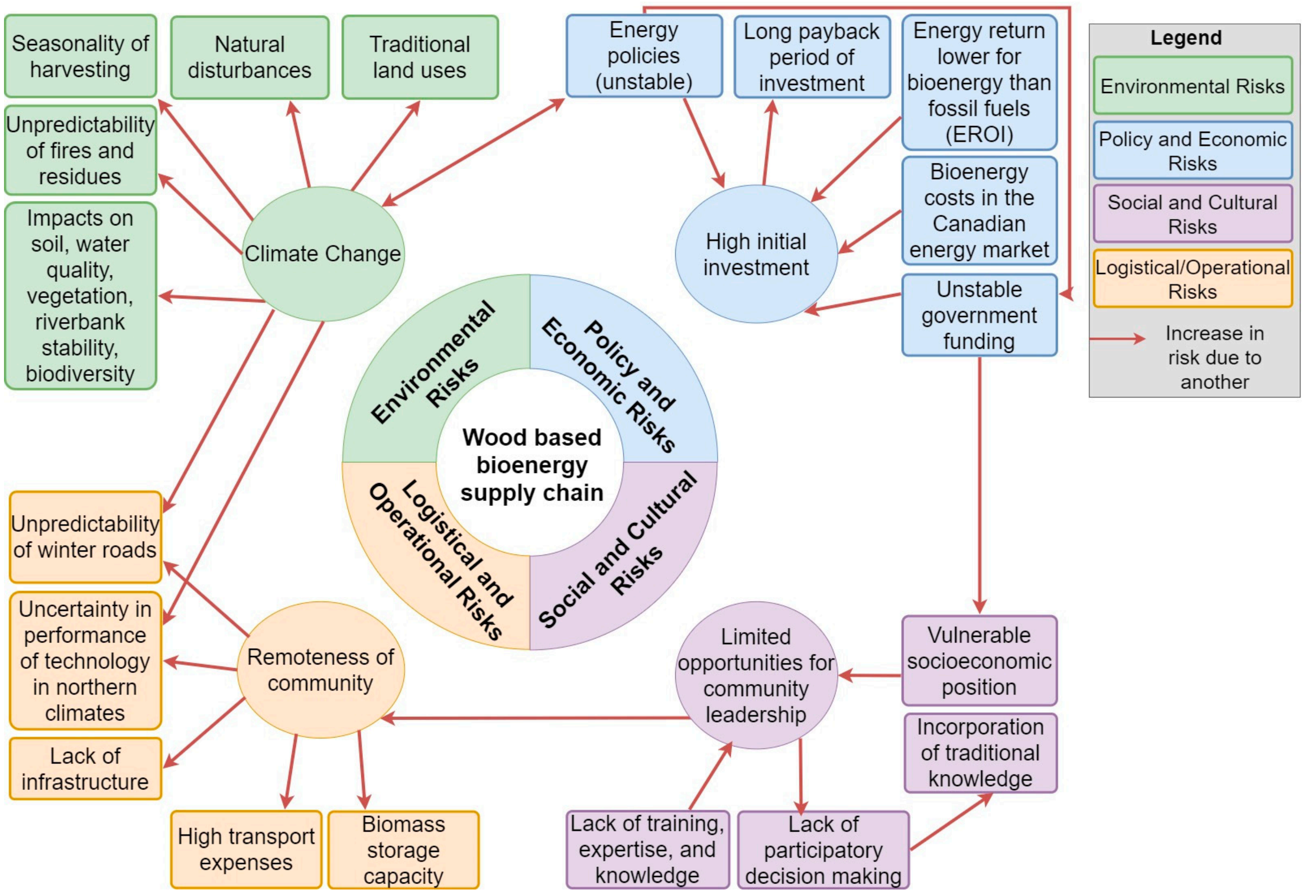


Figure 2. Risks and barriers to wood-based bioenergy projects in remote and Indigenous communities. Colour is used to represent the category of risk. The impact of one risk on another have been incorporated as arrows. The main drivers in each risk category are included in circles.

Table 1. Risk categories ranked by the representatives from Fort McPherson NWT, Cold Lake First Nations AB, and Northlands MB. 1 is the category that represents the highest risk and 4 the lowest.

Communities	Policy and Economic	Logistical and Operational	Social and Cultural	Environmental
Fort McPherson, NWT	1	2	3	4
Cold Lake First Nations, AB	1	2	3	4
Northlands, Barren Lands, and Tadoule Lake, MB	1	3	4	2

3. Results

3.1. Policy and Economic Risks

All the communities have reported that high initial investments and energy market competition are the main barriers in developing cost efficient bioenergy supply chains (Table 1; Figure 2). This is also valid for communities connected to the grid, see below. As a result, all of the communities in this study depend on federal and provincial funding to start and manage their bioenergy project. In addition, the process of writing a proposal to request the funding can be difficult and may not be achievable without the support of external consultants or additional training for some communities.

In Cold Lake First Nations, which is the only community connected to the grid, the current cost of electricity produced from natural gas is $21.25/GJ and a combined heat and power (CHP) system utilizing salvaged wood supplied by the oil and gas industry is estimated to cost between $27/GJ to $50/GJ [33] (all costs are in CAD$).

> *The most significant risk to the project is the initial investment for the biomass boiler system. Without external funding, the initial capital outlay will be difficult to raise internally given current natural gas prices and the estimated payback period for the bioenergy system.*

Another aspect of high investment is related to district energy systems, as stated by the Manitoba communities' consultant:

> *District energy heating systems will have a higher cost than individual heating systems for each building (whether diesel or biomass).*

Energy market competition also presents itself as a risk to some communities. When considering bioenergy systems, communities need to take into account costs associated with biomass transportation, boiler maintenance, repairs and malfunctions. In Fort McPherson, fossil fuel prices are competitive with bioenergy heating costs due to the high transport costs of pellets:

> *Diesel fuel heating is very competitive, especially considering today's diesel prices. Pellet pricing and shipping cost on the Dempster Highway have been on a steady increase last few years.*

Having a low energy return on investment (EROI) could be a barrier to bioenergy projects, as fossil fuels are thought to have an advantage over bioenergy due to having a higher energy content than biomass resources [37]. EROI refers to the ratio of energy created by a process compared to the energy used in the process [38].

3.2. Logistic and Operational Risks

Each community is facing a different energy transition and has a distinct geographical context, which represents unique logistical and operational challenges. Most of the communities have reported risks inherent to biomass harvesting, maintenance, storage and transportation as the second main barrier to an efficient biomass supply chain. Most of the risks identified are tied to the remoteness of the communities including difficulty in accessing the feedstock and implementing new technologies in cold weather where winter could be particularly harsh on the infrastructure and equipment. For example, unpredictability in shipping and high transport costs for importing pellets into remote communities is a risk for all of the remote communities in Manitoba and the Northwest Territories. Fort McPherson, which is the most remote community, is shipping pellets from Alberta or British Colombia, which is a costly 2000 km to 3000 km journey. Transportation is further complicated by the use of winter roads or crossings, which are restricted by the short amount of time each year that the ice is thick enough to support larger shipments. However, it should be noted that many of these transportation and logistical related risks also apply to diesel, for remote communities like the Manitoba communities:

> *These risks can only be understood in comparison to currently existing diesel systems. Every one of these risks applies to both.*

Despite the abundance of biomass available nearby, communities have reported logistical challenges accessing the local feedstock. The absence of forest management units in proximity to a community, such as for the communities in Manitoba, can deprive communities of important infrastructure for biomass harvesting operations such as roads (Figure 1c). Cold Lake First Nations is connected to the electrical grid and does not face the same transportation barriers and challenges that the four remote communities do. However, they have reported that the accessibility to biomass is constrained by the oil and gas infrastructures and by the presence of a military base, which overlap with their traditional land, and do not allow community led forestry operations. Having limited access could add to transport costs for building roads, delays in maintenance, and therefore interruptions in energy supply and profitability.

Having limited financial resources can also be restrictive for expansion of infrastructure and equipment, such as harvesting technology, transport vehicles and storage facilities to optimize the biomass supply chain. Furthermore, biomass boilers in remote and rural communities are relatively new and maintenance is an essential component for reliable and safe operation. In Fort McPherson there is concern about the realities of performing maintenance on boilers in remote locations:

> *Professional maintenance costs are very high. Major delays to get vital parts for operations. No room for these errors when profit margins are so marginal when competing with fossil fuels.*

Inefficiencies of conversion technologies could occur in any of the communities when biomass fuel does not meet the specifications of the equipment or equipment is not maintained. For example, when wood chips have high moisture content, less energy or heat is generated in a boiler. One piece of infrastructure that the communities have often mentioned as a concern is a proper storage unit for harvested biomass or storing biomass fuels. While the use of enclosed storage facilities or covering chips with tarps can reduce moisture content and losses through degradation, some storage options come at a high cost that communities cannot afford.

3.3. Social and Cultural Risks

Among social and cultural barriers, limited opportunities for community leadership have been identified as the third main barrier. This is in large part due to their vulnerable socioeconomic position, a lack of training and expertise, and complicated land ownership arrangements which limit their capacity to manage their own resources. Many Indigenous communities across Canada are in an unstable or vulnerable economic position, with a 15% unemployment rate on average for Indigenous people in 2015 [39] compared to 7% for Canadians on average [40]. The unemployment rates for the communities consulted in this study are all higher than these averages, ranging from 18% to 50% [29]. Their median employment income in 2015 was below the average for Indigenous people [29]. Therefore, with such high unemployment rates and low incomes, it is crucial to involve community members and develop local expertise (harvesting biomass, project management, or equipment maintenance) to ensure that community capacity is built and bioenergy developments provide socio-economic benefits to the communities. The Cold Lake First Nations representative stated how this lack of local expertise and training can become a barrier to bioenergy projects.

As mentioned above, some communities have struggled to access biomass as a feedstock within or at proximity to their land. The lack of ownership or Indigenous led management of resources can reduce their capacity to lead bioenergy projects. When resources are not solely owned or managed by an Indigenous community, management becomes more complicated, as decisions, objectives, and benefits are shared between owners. The majority of communities (Alberta, Saskatchewan, and Manitoba communities) do not have access to nearby sources of biomass from treaty settlement lands, where First Nations have law-making authority and resource rights including harvesting (Figure 1c). In some cases, such as Cold Lake First Nation in Alberta which is located on the Cold Lake oil sands deposit, other more lucrative land uses can compete with the rights of biomass harvesting for bioenergy.

A bioenergy project can also fail if it does not have the support of the community, which is a barrier for Cold Lake First Nations:

The project (i.e., Bioenergy) utilizes an unconventional approach, which may face opposition by the community and leadership.

Community support can also be lost if they do not agree with the source of the biomass. Harvesting biomass for bioenergy could create competition with traditional land use activities, which all five communities take part in, such as hunting, fishing, and trapping. Harvest could also degrade the land where these activities take place. Preferences for biomass sources could also limit feedstock supply available for a bioenergy system. Some of the communities included in this study (Northlands, Barren Lands, Tadoule Lake) preferred to harvest from fire damaged stands rather than disturb an intact and living forest.

3.4. Environmental Risks

Environmental risks have been ranked as the least important by all the communities except for the Northland communities, which ranked it as the second most important risk (Table 1). However, all the communities agreed that climate change is the main environmental driver disturbing the wood-based bioenergy supply chain. Climate change can directly impact the access, quality and the quantity of biomass and indirectly through the added vulnerability to community infrastructure. All the communities are exposed to a risk of wildland fire with the communities in Alberta and Manitoba being the most at risk (Figure 1d). Cold Lake First Nations is concerned about what an increased risk of fire could mean for their communities:

Climate change and the occurrence of forest fires would present a risk to the project and the community.

For the Northland community, who plans to use fire residues as their main biomass feedstock, the impacts of climate change on the fire risk are of high importance. As fire frequency and severity is directly impacted by climate change, the communities need to integrate the impact of climate change on their biomass harvesting needs (including the quantity, quality, and the accessibility of the feedstock). However, it is difficult to plan when using fire residues as a feedstock source:

Each individual fire is unpredictable, and the extent of fires in each year is unpredictable which influences the quantity of wood available as a feedstock and its moisture

Climate change can also exacerbate the logistical risks related to hauling and transportation of biomass in northern and remote communities. Thawing of permafrost in northern Canada is predicted to negatively impact infrastructure as many stable surfaces for buildings and roads become unstable. Therefore, the risk of climate change in the arctic communities and for the communities relying on ice roads for biomass transportation (Fort McPherson, Manitoba communities) will be higher than community's further south. For the communities in Manitoba, if wood is being hauled across a lake, transport is limited to when the lake is firmly frozen, or when a barge is available in the summer. Additionally, transport is often done when the ground is frozen and there is snow covering the ground to ensure any vehicles used do not damage the soil or the vegetation. These transportation risks also apply to the transportation of diesel in the Manitoba communities:

Diesel fuel must be trucked in over winter roads. With the predicted reduction of the number of very cold days (and the reduction in sustained cold periods, we should expect that the winter road season will become shorter and less predictable. As well, it is probable that the amount of snowfall will become more erratic i.e.,: that there will be instances of "unusually" heavy snowfall, which also shortens the winter road season. These effects have been seen already in the winter road system for these three communities. These problems can be expected to get worse.

In addition to the stress on the landscape associated with climate change and natural disturbances, the communities have acknowledged that biomass harvesting and transportation can also increase the pressure on the environment such as soil and water quality and habitat for wildlife. For example, reports from Fort McPherson show that the removal of willow from riparian areas near the Peel River can increase erosion, bank instability, and change downstream flows [41]. Harvesting methods could impact all communities, as stated by the Manitoba communities' consultant:

> *Impacts on soil, water quality, vegetation, riverbank stability, biodiversity are dependent on how harvesting and transportation is done. If mechanized means are used (roads built for harvesting, feller–bunchers used for felling, logging trucks used for transport) the environment will be badly damaged and will be very slow to recover (at least 50 to 100 years).*

4. Discussion and Recommendation

Some of the barriers and risks identified in this study have already been documented in the literature while others are unique to the communities consulted. Recent wood-based bioenergy studies involving Indigenous communities have reported that the leadership of Indigenous communities to start and manage bioenergy projects is limited, especially given the large capital investments needed [10,22]. These high costs can restrict access to bioenergy technology for many communities unless external funding sources are procured [10,30]. Particularly, smaller Indigenous communities often have limited money to spend on bioenergy infrastructure or training to develop technical and managerial skills needed to manage bioenergy projects [10,42,43].

The lack of ownership or management of natural resources by and for the communities have been documented as complex, thus reducing their capacity and leadership to lead bioenergy projects. For example, many land or resource management titles can be tenure based, meaning that the Crown holds the land in trust for an Indigenous community [44], or resources can be collectively managed or owned by Indigenous communities and non-Indigenous corporate owners, fragmenting ownership [45]. When resources are not solely owned or managed by an Indigenous community, management becomes more complicated, as decisions, objectives, and benefits are shared between owners.

Yet, Indigenous communities are often only marginally included in collaborative resource management [20]. Exclusion from resource management has led to rejection of renewable energy projects in the past because the final decision about the system and profit lies with the energy provider [21]. An absence of participatory decision making can also lead to a lack of understanding of bioenergy and the positive and negative impacts of biomass supply chains on local environments and land uses, leading to failure or rejection of a project [46,47]. Meanwhile, a shift towards more collaborative management has seen more Indigenous led projects, with an 140% increase in national wood supply held in Canada by Indigenous interests since 2003 [48]. In 2020, it was estimated that about 152 Indigenous communities own part of, or all of, clean energy projects (wood, solar, or wind) [49].

This study highlights that environmental risks can impede the development of sustainable biomass supply chains as well. Zurba and Bullock [20] have documented that communities may reject certain sources of biomass due to the size of their footprint, or negative impacts to the environment. All of the communities consulted in this study are using biomass feedstock that are compatible with their bioenergy needs as well as with their local environment and traditional land use. However, these communities are particularly vulnerable to climate change because of their geographical locations in western and central boreal forests of Canada. Climate change is already affecting northern and western Canada faster than the rest of the country and this trend will become more pronounced over time [50]. With increasing temperatures and drought, increases in fire frequency and size is occurring [51], stressing sustainable and reliable management of biomass supply chains [7,52]. The unpredictable nature of fires, such as where a fire will happen or when, can disrupt the supply of biomass for individual communities into the future. The amount of biomass that can be salvaged after fire is also highly variable and unpredictable across different fires, stand conditions, and seasons [7,53]. Despite these uncertainties, fire residues and insect damaged stands can represent substantial and competitive sources of feedstock across Canada [54].

While the communities already experience the impacts of climate change on their environment and traditional living [55], climate change could exacerbate many of the risks mentioned above and therefore needs to be carefully integrated into the development of biomass supply chains.

De-Risking Wood-Based Bioenergy Development

Strategies for mitigating the risks mentioned above are discussed below and summarized in Table 2. The risks related to the high initial investment required to switch from diesel can be partially offset by including positive externalities of bioenergy development such as local job creation, climate change mitigation opportunities, energy self-sufficiency using local biomass resources, and the well-being of the community. As such these projects are expected to support the creation of 642 employment days in Fort McPherson [56], and 50 seasonal and full time local jobs between the 3 Manitoba communities [36]. In addition, the avoided cost of cleaning up soil contamination from diesel spills in the communities should not be ignored [57]. For example, in Northlands, Barren Lands, and Tadoule Lake, the cost of cleaning up soil and groundwater contamination from diesel spills is \$0.20 to \$0.50/L for every litre of diesel trucked in [36].

Table 2. Key risks from the four risk categories with suggested mitigation strategies.

Risk Category	Key Risk	Mitigation Strategy
Policy and Economic	High initial investment	• Include positive externalities in cost benefit analyses (e.g., jobs and revenues creation, avoided cost of oil tanks leakage and clean up, avoided cost of health issues). • Procure long term external funding source. • Develop community-based entrepreneurship
Logistical and Operational	Remoteness of communities	• Utilize local sources of biomass to reduce transportation risks and costs as well as to create economic opportunities such as jobs and revenue creation. • Co-learning and information sharing with other communities with similar objectives or challenges
Social and Cultural	Limited opportunities for community leadership	• Restore community-based resource management supported by local knowledge and workforce. • Train local workforce on how to harvest biomass, install and maintain machinery, and manage bioenergy projects. • Implement asset-based community development to identify assets and strengths in the community • Identify champion to promote bioenergy project
Environmental	Climate change	• Integrate climate change impacts in wood based bioenergy development and biomass chains • Utilize local knowledge to reduce the risk of damage from biomass harvesting practices, reduce competition with traditional land uses, and potential degradation to the ecosystem. • Use local feedstock to mitigate biomass supply chains disruptions.

Quantifying some of these socioeconomic and environmental benefits at the beginning of a project is difficult [58] but early cost–benefit analysis can provide some indication of where and how to mitigate the costs related to bioenergy projects.

Bioenergy systems can be competitive with fossil fuel scenarios for remote communities with local sources of biomass. The costs associated with producing biomass sources for bioenergy are projected to be equal or less than diesel in remote communities that are not connected to the grid. In Fort McPherson the cost of using imported heating oil is $45/GJ, $62/GJ for imported diesel, between $29/GJ and $41.52/GJ using imported wood pellets and estimated to be between $34 and $56/GJ using local wood chips [32,59,60]. In the northern Manitoba communities, the cost to produce electricity using diesel is approximately $277.78/GJ, and it has been estimated that a CHP biomass boiler system could produce electricity for $166.67/GJ while generating heat at the same time in Northlands, for $172.22/GJ in Barren Lands, and $194.00/GJ in Tadoule Lake [35].

In addition to reducing productions costs and increasing energy return, utilizing local sources of biomass can also reduce logistical and operational risks by reducing transport distances and costs. Based on feedback from the remote diesel dependent communities in Manitoba, the EROI can also be higher than fossil fuels for locally harvested biomass-based systems:

> *EROI for biomass–based systems is lower than for fossil–fuel based systems in non-remote areas (where infrastructure already exists, and transportation costs are lower). It is not lower for remote communities. As you know, there are approximately 250 diesel-dependent communities in Canada. EROI for biomass–based systems can be expected to be competitive with fossil–fuel based systems in these communities. For those that are below the tree–line, EROI for biomass–based systems can be expected to be higher than for diesel-based systems, particularly if the costs of contamination cleanup are included.*

Restoring community leadership is crucial to de-risking the biomass supply chain. In particular, all communities voiced that social and cultural risks, can and should be mitigated by including locals in decision-making and ensuring that proper training is made available. Resource governance has been evolving, with an emphasis on public participation and bilateral engagement with Indigenous communities [61,62]. This includes shared or agreed upon management objectives that encompass local risks and needs, as well as regional goals, with Indigenous communities having the final decision-making power. Indigenous community led bioenergy projects should also include the integration of traditional knowledge to reach the multiple socio-economic, cultural, and environmental benefits of renewable energy solutions. Including traditional knowledge in assessment and planning allows for valuable longer-term observations to be included in risk assessments, for cultural values to be incorporated into energy projects, and increases participation, which results in further understanding of bioenergy systems. To complement traditional knowledge, asset-based community development (ABCD) approach can be of particular interest to evaluate and mobilize existing assets and resources within the community to support bioenergy development. The premise of ABCD is that communities can lead the development and management process themselves by identifying and mobilizing existing, but often unrecognized assets and thereby creating socio-economic opportunities and expertise [63]. Considering the human dimension as well as the social capital of the community is therefore crucial to ensure the success of a bioenergy project.

Using traditional knowledge in community based resource management can help increase local participation, support, and reduce the environmental impact of harvesting biomass for bioenergy. For example, communities in Manitoba are using traditional harvesting practices to reduce degradation or damage to vegetation and the soil. These include hauling of harvesting biomass using snowmobiles and light trucks and trailers rather than heavier equipment and transporting harvested biomass in the winter once the ground is frozen and covered by snow. In these communities, biomass is also stored on site in a pyramid or tipi shape to further prevent damage to the ecosystem during harvest and to accelerate the drying process of the biomass (Figure 3).

Figure 3. Example of biomass stacking following harvesting on burn sites in Northlands (Photo: courtesy of Bruce Duggan, Boke Consulting).

Community support for bioenergy projects can be increased by balancing environmental concerns of stakeholders as stated by Fort McPherson:

> *Develop a plan for harvesting biomass which would mitigate the impact of climate change for all interest groups and stakeholders to maintain the general community support for the project.*

And Cold Lake First Nations:

> *Bioenergy projects that do not address their potential environmental impacts as well as climate change mitigation potential for all interest groups and stakeholders run the risk of losing community support. Once community support for a bioenergy project is lost, community leadership is lost too, both of which make a project more likely to fail.*

In addition, finding individuals in the community with appropriate training, and training community members to harvest biomass, to install, maintain, and manage a biomass boiler system will help restore community leadership and support. Cold Lake First Nations and Fort McPherson [36] have expressed the need for a trained community champion, or a person that can lead and manage a bioenergy project:

> *Cold Lake First Nations will require a trusted and capable partner as well as a community champion to progress the project from a development phase into operations.*

Moreover, with the advances in technology and multidisciplinary data coming from Forestry 4.0, bridging traditional knowledge and western science will be key to improving decision support systems that are able to monitor and track effectively the different operations and their impacts along the wood supply chain [64]. Forestry 4.0 includes developing technologies such as remote sensing to quantify forest resources, wireless communication networks to share this information from remote locations, and automated technologies for harvesting [65]. Utilizing these new technologies will also help to reduce logistical and operational risks, with more data available on biomass sources and on transportation routes.

Finally, another way to reduce the risks associated with bioenergy systems in remote and Indigenous communities is through collaboration and information sharing between other communities with similar objectives. Capacity building among communities and organizations through knowledge and data sharing can avoid bottlenecks and thus save on time and money. Sharing expertise and success stories from more advanced projects and the creation of 'sister communities' can decrease risks by informing communities of potential challenges from all four risk categories so that they can be better prepared. Synergies and collaborative approaches are indeed crucial to developing a successful bioeconomy in remote and Indigenous communities.

5. Conclusions

Remote and Indigenous communities in Canada are in a unique position to take advantage of the development of wood-based bioenergy projects with many socio-economic and environmental benefits. In this study, we have collaborated with five remote and Indigenous communities to document the potential risks and barriers along the biomass supply chain. Our results highlight that remote and Indigenous communities share some common challenges and barriers in developing bioenergy projects but also that each community is unique with different needs. Ignoring these challenges and not considering the uniqueness of each community could jeopardize these initial wood-based energy investments, as well as any other type of investment that would require biomass mobilization. Implementing sustainable and cost-efficient biomass energy systems will require community-based solutions, as well as long term collaboration with government, bioenergy experts, and other communities. Since the landscape and its resources are changing rapidly, these communities who are particularly exposed and vulnerable to climate change will have to develop adaptive supply chains to integrate their renewable bioenergy systems with traditional land-uses. If these communities can successfully overcome these challenges, they can create a reliable, cheap source of energy or heat, allowing them to become self-reliant, while reducing Canada's GHG emissions. This project is related to the development of the bioenergy sector in the context of remote and Indigenous communities, but we believe that the understanding of the challenges as well as the applications of the solutions identified are relevant to advance the bioenergy sector in Canada at large.

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