Whapmagoostui Kuujjuaraapik Hybrid Power Plant Project

Environmental and Social Impact Assessment

Volume 3: Question Answer Document

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August 2, 2021

KWREC
Whapmagoostui Kuujjuaraapik Hybrid Power Plant Project

Environmental and Social Impact Assessment:

Volume 3: Answers to Questions and Comments

PESCA Environment
August 2, 2021

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☐ LIST OF APPENDICES

INTRODUCTION

Pursuant to the Environmental and Social Impact Assessment (ESIA) and Review Procedure established by the James Bay and Northern Quebec Agreement (JBNQA), Kuujjuaraapik Whapmagoostui Renewable Energy Corporation (KWREC) submitted an ESIA Study on April 23rd, 2021, for the project titled "Whapmagoostui Kuujjuaraapik Hybrid Power Plant Project" (WKHPPP) to the Regional Administrator. In accordance with JBNQA paragraph 22.6.10, this ESIA Study has been transmitted to the Provincial Review Committee (COMEX). Following their review, a series of questions and comments were addressed to KWREC to provide additional information and allow the COMEX to finalize their analysis and make a recommendation regarding this project. This document includes the answers and additional information in response to this series of questions and comments. To facilitate understanding, the answers are presented below, following the sequence and numbering determined by the COMEX.

1. CONTEXT

1.8 Alternatives to the project

QC-1. The proponent indicated that an alternative site (T1) was not selected due to concerns raised by certain interest groups, including hunters. In section 3.1, however, the proponent indicates that this site remains an alternative solution in the event of an adjustment to the project before its construction.

The proponent will be required to present in detail the concerns raised by the interest groups and land users regarding the alternative site (T1). The proponent will have to explain the rationale in retaining the alternative site (T1) as an alternative solution and explain the circumstances that would force the proponent to use this alternative site rather than the selected site.

The COMEX wishes to inform the proponent that an application to amend the Certificate of Authorization will have to be submitted to the Regional Administrator if an alternative location is selected after an authorization.

RQC-1. The alternative site (T1) is no longer an option for the project. The proponent confirms that no turbine will be installed on this site. The project under review by the COMEX is located on the two selected sites considered in the ESIA, i.e. sites T2 and T3a.

2. DESCRPTION OF THE ENVIRONMENT

2.3 Description of the components of the biological environment

Avian fauna

QC-2. This section presents the results of the bird inventory conducted in 2012 and 2013. However, the Ministère des Forêts, de la Faune et des Parcs (MFFP) considers that the validity of raptor migration data in the context of bird inventories, notably for wind turbine projects, is 5 years. Due to the presence of two species considered vulnerable in the Québec, the Peregrine Falcon and the Golden Eagle, it is strongly recommended that the proponent renew the raptor migration inventory for this project, before construction begins, to determine whether additional mitigation measures are required. The proponent must indicate the mitigation measures taken, if applicable.

For future reference, the proponent must take into consideration the validity period (5 years) for data collected during a bird inventory if the proponent later wishes to either expand the wind turbine

project or include additional wind turbines, all of which would increase the environmental impact of the project.

RQC-2. The proponent commits to conduct a raptor migration inventory in 2022, before construction begins. Based on the results, the proponent will discuss with the authorities to determine whether additional mitigation measures are required or not, depending on the risk for the Peregrine Falcon and the Golden Eagle. As mentioned in the ESIA, raptors would rarely be victims of collisions and WKHPP requires the installation of only two wind turbines.

The proponent also takes note of the validity period for any future reference.

Bats

QC-3. This section presents the results of the bat inventory carried out in 2013. However, since 2018, the MFFP considers that the data regarding the presence of bats species in a study area must be renewed at the beginning of each project, to be as current as possible. The MFFP therefore considers that the results of the 2013 bat inventory are no longer valid. In addition, the MFFP noted that this inventory was only partially compliant with the provincial protocol as only the fall migration period was covered during the 2013 bat inventory. The *Protocol for acoustic inventories of bats in the context of wind turbine installation projects in Quebec* (MRNF, 2008) stipulates that the bat inventory must also cover the breeding period.

Although the presence of bats could not be confirmed in the study area and, consequently, the impact of the project on bat species was considered minimal, with only partial results dating from 2013, a new impact assessment regarding bat species should be conducted. Moreover, the flight range of several bat species may extend further north than is currently known. The proponent must therefore carry out a new bat inventory before the construction of the project, in accordance with the *Protocol for acoustic inventories of bats in the context of wind turbine installation projects in Quebec*, to establish a new baseline. In the event of the presence of bats in the study area, the proponent will be required to submit appropriate mitigation measures. Regarding mitigation measures for bat populations, the promoter is invited to consult the article published by the MFFP in 2017[1].

For future reference, the proponent must take into consideration the validity period (1 year) for data collected during a bat inventory if the proponent later wishes to either expand the wind turbine project or include additional wind turbines, all of which would increase the environmental impact of the project.

RQC-3. The proponent commits to conduct a bat survey in 2022, before construction begins, in compliance with the provincial protocol but adjusted to take into consideration the size of the project and the northern context. Based on the results, the proponent will discuss with the authorities to determine whether additional mitigation measures are required or not, depending on the risk for bats, if these species are confirmed close to the turbines.

The proponent also takes note of the validity period for any future reference.

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[1] https://mffp.gouv.qc.ca/our-publications/bat-mortality-caused-by-wind-turbines/?lang=en

Fish

QC-4. It is specified that the fish inventory was carried out at three separate stations for a total fishing effort of 96 hours. Of these three stations, two stations were in two separate lakes and the third station was in a permanently flowing stream. The flowing stream selected for this study is, in fact, located north of the study area, outside the settlement area. In addition, the presence of Brook trout was confirmed during the fish inventory, however, the environmental impact study does not provide any details regarding at which site(s) this species was observed.

The proponent should focus on streams and waterbodies located within the project's area of influence. More specifically, the characterizations of lakes and watercourses affected by the construction and upgrading of access roads, as well as interconnecting lines. The proponent must therefore characterize, before construction begins, the sites where interconnecting lines cross watercourses or other waterbodies, notably if the installation of poles and anchors is planned in the shoreline, in the same way that it has undertaken to characterize fish habitat at the sites of the three watercourse crossings that were to be built before the start of the project. The result of the characterizations of the affected watercourses will help determine the need for mitigation measures.

RQC-4. The proponent commits to submit a characterization study with the application for a ministerial authorization under section 22 of the EQA. In accordance with section 46.0.3 of the EQA, this study will include the boundaries and the description of the ecological characteristics and functions of all the bodies of water (including watercourses and lakes) likely to be affected by the activities of the project (including construction and upgrading access road, as well as interconnecting line notably if the installation of poles and anchors is planned in the shoreline). Fish habitat will also be characterized at the sites of the three watercourse crossings to be built.

3. PROJECT DESCRIPTION

3.4 Implementation Phases

Construction and improvement of roads and work areas

QC-5. The proponent indicates that the watercourse crossings will be installed in accordance with the main standards of the *Regulation respecting the sustainable development of forests in the domain of the State* (RADF). Recall that Whapmagoostui/Kuujjuaraapik is located in the bioclimatic domain of the lichen woodland and the RADF must be applied in this territory. Therefore, the proponent must comply with RADF standards to protect fish and fish habitat when constructing watercourse crossings.

For example, the construction of a watercourse crossing is prohibited within the first 100 meters upstream of a spawning ground (section 89 of the RADF), and not within the first 50 meters as proposed by the proponent in section 6.3.2. The proponent must therefore incorporate the regulatory requirements of the RADF for all applicable types of work on the project that are governed by RADF standards.

RQC-5. The proponent will comply with the regulation in force on Category I land to protect fish and fish habitat when constructing watercourse crossings, including the RADF if applicable.

Transport and traffic

QC-6. The environmental impact study mentions that 800 m^3 of concrete will be required, the equivalent of approximately 100 trips of concrete mixers from a temporary concrete manufacturing site. However, the environmental impact study does not mention the location of that site or the characteristics of that cement plant.

The proponent must therefore provide the location of the temporary concrete manufacturing site, as well as the characteristics of the cement plant, including the duration of its operation, the methods of storing residual granular materials, the nearby presence of watercourses, waterbodies or wetlands and a wastewater management plan, including the location of the discharge point.

It should also be noted that the proponent must specify whether an application for a ministerial authorization, in accordance with paragraph 10, subparagraph 1, of section 22 of the EQA or a declaration of compliance (if eligible under the terms of section 127 of the Regulation respecting the regulation respecting the regulation of activities according to their impact on the environment (REAFIE)) would be required for the establishment of a cement plant. If a ministerial authorization should be issued, modeling the dispersion of air emissions from the cement plant may be required.

RQC-6. The concrete need is related to the turbine foundations, during a short period (few months). Consequently, the temporary concrete manufacturing plant will be located close to the work area to limit the transport. The preliminary location is along the road section to be built (55° 17.418'N; 77° 41.777'W). The model and characteristics of the mobile unit likely to be selected is presented in Appendix A. A declaration of compliance will be required for the establishment of this temporary concrete plant as it will comply with the terms of section 127 of the Regulation respecting the regulatory scheme applying to activities on the basis of their environmental impact (REAFIE):

- the plant will be established at the place indicated for a maximum period of 13 months after the declaration of compliance is sent;
- no granular residual materials will be stored;
- the plant will be located more than 30 m from a watercourse, lake or wetland;
- the water from washing operations will be collected and stored in a watertight pond, and the discharge point for wastewater from the pond will not be located in the littoral zone or on the shore of a lake, or in a wetland.

QC-7. It is also indicated that authorizations for the borrow pits will be obtained in advance. However, the environmental impact study does not provide an estimate of the required quantities of granular material (sand and gravel) or the location of the borrow pits. To assess the possible impacts (noise, dust, etc.), the proponent must submit an estimate of the quantities of granular material that will be required, as well as the location of the borrow pits.

In addition, the proponent must specify whether new quarries or sand pits will be required or whether the operating capacity of existing ones has been assessed. Where applicable, the proponent must assess the impact of the project on the latter.

RQC-7. The gravel required for the construction of WKHPPP will come from excavated rocks along the road access and at the turbine locations. No new quarry will be required. The proponent will need approximately 1,200 m^3 of sand for the construction of WKHPPP. An existing sand pit, located close to the project area and far from the communities, is likely to be used (55° 17.113'N, 77° 41.322'W). This sand pit is located at more than 1 km from the closest camp and more than 3 km from the village.

QC-8. In Appendix E (Section 4.11 *Workshop – Online Sessions with Cree Regional Entities*), the proponent states that the equipment will be transported by barge from Wemindji. The proponent indicates in section 3.4.2.3 of the environmental impact study that the components of the wind turbines will be transported by truck and boat.

What are the anticipated impacts of these transportation activities, including the potential impacts for the Cree Nation of Wemindji?

The proponent must validate that the road network can support and allow proposed traffic loads and dimensions. It will also have to confirm whether measures will be put in place to mitigate the effects generated by these transportation activities during the construction phase.

RQC-8. The transportation of the equipment by barge from Wemindji is no longer an option for the project. The equipment will be transported by boat directly from Montréal. There is no anticipated impact on the Cree Nation of Wemindji.

The proponent and the general contractor for the construction (TCI) had validated that the road network can support and allow proposed traffic loads and dimensions. As mentioned in the ESIA (section 3.4.2.2), priority has been given to the use of existing paths to access the sites of the wind turbines, instead of building new roads. Depending on the condition of existing roads, improvement work may vary from simple grading to localized widening of the road surface and correction of certain curves to improve road allowance.

4. PUBLIC CONSULTATION PROCESS

QC-9. The environmental impact study contains several references regarding the concerns of hunters and land users in the study area, but a detailed report is not included in Appendix E. The proponent must detail the meetings that took place with the tallyman, the concerns raised during these meetings and how they were addressed.

The Proponent must detail the meetings and consultations that took place with the general community, including suggestions and concerns raised during the Whapmagoostui First Nation General Assembly to be held in July or August 2021.

RQC-9. The project is located on Trapline GW00 and no tallyman is associated to this territory, located on Category I land. As mentioned in the ESIA, the proponent held meeting with different groups. Issues and Concerns raised during these meetings and how they were addressed by KWREC are detailed in Appendix E of the ESIA. The Regional Cree Trappers Association attended the online session with Cree Regional Entities on March 10th, 2021. Individual hunters, both Cree and Inuit, also had opportunities to ask questions, raise issues or concerns during workshops, surveys, or through the social medias. Detailed transcriptions were recorded during each meeting and could be provided to the Regional Administrator or to the COMEX, if required. It was not included in the public report to maintain a confidentiality level for all the attendees.

KWREC President Matthew Mukash presented the Project as an update to the community members at a General Assembly of the Whapmagoostui First Nation held on July 30th, 2021. The Assembly was informed that the Social Impact Assessment Public Consultation concerning the Project is complete and that a Final Report had been submitted to COMEX in April 2021, and that the Committee has submitted to KWREC nineteen (19) questions to be answered.

4.5 Main modifications to the project following public consultations

QC-10. The proponent indicates that it will consider the possibility of installing a fence and appropriate signage on the periphery of wind turbines sites for safety reasons and protection in relation with

possible ice fall. The proponent must indicate whether these measures have been retained and, if so, provide details on the size of the fenced area and access restrictions to the area. The proponent will also have to indicate whether the land users in the area have been consulted on the design of the fence.

RQC-10. The proponent will install a signage on the periphery of the wind turbines sites for reasons of safety and protection in relation with possible ice fall. This signage is commonly implemented in wind energy facilities as a Best Management Practice, specifically in Quebec due to weather conditions. A fence will be installed across the road leading to the turbines' site to restrict access to the area during construction and operation. Following common practice, it is not intended to have a fence around each turbine or around the whole area, but the proponent will continue to discuss with the community, including hunters/trappers and other land users, through the monitoring committee during construction and operation phases to assess its need. Should a fence be required or recommended, the proponent will consult the community, notably on its design and the size of the enclosed area.

6. ANALYSIS OF IMPACTS AND MITIGATION AND COMPENSATION MEASURES

QC-11. The environmental impact study does not present any mitigation measures for the temporary concrete manufacturing site. The proponent must specify whether mitigation measures are planned for the temporary concrete manufacturing site as well as for the maintenance and cleaning of the concrete mixers.

RQC-11. The concrete manufacturing activities will comply with the regulation in force and with the Best Management Practices. As mentioned in RQC-6, the water from washing operations will be collected and stored in a watertight pond, and the discharge point for wastewater from the pond will not be located in the littoral zone or on the shore of a lake, or in a wetland.

6.4 Impacts of the physical environment

Wetlands

QC-12. The proponent submitted a cartographic estimate of wetlands in the project area. The MELCC wishes to remind the proponent that all wetlands must be demarcated, with proper boundaries, in accordance with section 46.0.3 of the EQA. It should also be noted that any encroachment in a wetland will result in a request for a ministerial authorization under article 22, 1st paragraph, subparagraph 4, of the EQA.

If the project results in wetland losses, the proponent must demonstrate how they applied the avoid-minimize-compensate sequence. If, even after applying this sequence of actions, residual wetland losses occur, the proponent will be required to submit appropriate compensation measures.

RQC-12. The proponent commits to submit a characterization study with the application for a ministerial authorization under section 22 of the EQA. In accordance with section 46.0.3 of the EQA, this study will include the boundaries and the description of the ecological characteristics and functions of all the wetlands likely to be affected by the activities of the project. The proponent will demonstrate in the context of the application for a ministerial authorization the avoid-minimize-compensate sequence applied during the development of the project.

6.5 Impacts on the biological environment

Avian fauna

QC-13. The proponent states that the construction phase may disturb nesting birds in the study area. However, additional impacts could also be caused by deforestation. This project could result in the loss of nesting habitat for several bird species, including the Rusty Blackbird, a species likely to be designated threatened or vulnerable in Quebec, during deforestation near wetlands. However, no mitigation measures are presented in relation to deforestation. The proponent must plan mitigation measures to reduce impacts on nesting birds, notably that deforestation should be carried out outside the general bird nesting period in Québec, approximately from May 15 to August 15.

RQC-13. As mentioned in the ESIA, the use of existing roads helped limit the required vegetation clearing and the footprint of the project. The wind turbines will be located on rocky outcrops bare of tree vegetation and where shrub and herbaceous vegetation is sparse. This approach already allowed to reduce the impact on nesting birds. The proponent commits to conduct the vegetation clearing outside the bird nesting period, from May 15 to August 15, when possible. If clearing cannot avoid the bird nesting season, mitigation measures will be implemented to reduce the impact on nesting birds including a survey by a skilled and experienced observer to confirm the presence of nests prior to the start of the clearing.

QC-14. The proponent indicates that ptarmigan, an important species for the Cree, are present in the project area. Ptarmigans are likely to collide with the base of the wind turbine. There are measures that would mitigate impacts on this species (for example, the use of contrast paint for the base of the wind turbine). The proponent will be required to indicate what measures are planned to mitigate the effects on this species.

In this regard, we invite the proponent to consult the example from the following literature: https://onlinelibrary.wiley.com/doi/full/10.1002/ece3.6307

RQC-14. The proponent takes note of this comment and will use this opportunity to involve the communities in a solution to color the base of the turbines.

Terrestrial mammals

QC-15. This section states that the study area affects a portion of the wintering area of the migratory caribou of the Rivière aux Feuilles herd. However, it does not present an assessment of the impacts of the project on this species.

While it is true that this site is not particularly frequented by the species, the environmental impact study identifies the caribou as a species hunted in the study area. Hunting is one of the traditional activities that has been described as of great importance in the proponent's impact assessment. It would therefore be relevant to assess the possible disturbance and avoidance effect that the wind farm could have on the caribou and thus, its potential effect on hunting activities.

In this regard, we invite the proponent to consult the example from the following literature: https://onlinelibrary.wiley.com/doi/pdf/10.1002/ece3.2941.

RQC-15. The proponent takes note of this comment. The impact assessment on terrestrial mammals (presented in section 6.5.2 of the ESIA) takes into consideration the potential impact on the migratory caribou of the Rivière aux Feuilles herd. A specific attention has been paid through the ESIA process to the hunting and trapping activities, as one of the more important issues for the communities. The potential effect on hunting activities will be monitored through a follow-up carried out with hunters for the entire life of the project. The proponent will also continue to discuss with the Cree Trapper Association through the monitoring committee as well as with representatives of the local communities.

6.6 Impacts on the human environment

Land use

QC-16. The proponent has committed to do a follow up with hunters to assess the impacts on the Canada goose hunt in the spring and the Snow goose hunt in the fall. Will these inquiries be carried out annually and for the entire life of the project? Will these inquiries include asking about changes in geese migration such as changes in their behaviour or their trajectory?

RQC-16. The proponent commits to conduct this follow up with hunters every year for the entire life of the project. These inquiries will primarily focus on the potential effect on hunting activities and on their success (harvest). Please note that this follow-up will consider all the hunters, both Inuit and Cree.

Socioeconomic context

QC-17. Considering that the training program planned for 2022 will take place in Gaspé, the promoter must indicate what contributions will be done to support local candidates interested in taking this program outside their community.

RQC-17. The proponent has budgeted funds to cover the cost of the training program and will apply for the Cree beneficiaries to the Skill Development Program offered to employers by the Apatisiiwin Skills Development (department of the Cree Nation Government) and support admissible Cree beneficiaries for their application to the Cree School Board's Post-Secondary Program. A similar process will be undertaken for Inuit beneficiaries under the programs managed by the Sustainable Employment Department of the Kativik Regional Government and Kativik Iisarniliriniq (School Board).

6.7 Cumulative impacts

QC-18. In the section on cumulative impacts, the proponent cites two other wind projects located hundreds of kilometres from the site in question. However, in the consultation report (Appendix E, Section 4.11 Workshop – Online Session with Cree Regional Entities), the proponent mentions the Whapmagoostui First Nation's investment in the Eeyou Power project for wind projects south of the community. The proponent must adjust the cumulative effects section to consider the potential cumulative impacts of the project(s). Given that the current objective of the project is to provide, at most, between 40 and 50% of the electricity for the two communities from wind energy, the proponent will have to present how his project aligns with other potential projects. The proponent will also have to present the subsequent phases that could increase the proportion of electricity generated by his project and reduce the use of fossil fuels and GHG emissions.

RQC-18. WKHPPP is the only wind project planned for the communities of Whapmagoostui and Kuujjuaraapik. This project is aligned with the commitments and objectives, at Canadian and provincial levels, to implement an energy transition to fight climate change by reducing the use of fossil fuels and greenhouse gas (GHG) emissions. The Eeyou Power project is an on-grid project that will not be connected to the off-grid communities serviced by the proponent's project. They are no cumulative effect possible unless the communities are connected to the provincial grid. This is not foreseen before the end of the Project.

For the next phases of the project, only some exploratory studies have been completed to integrate additional wind, solar or biomass to the energy mix of the communities to further reduce GHG emissions.

The most recent study was completed by the Polytechnique School of Montreal in 2021 (See Appendix B). The study concluded that if full energy autonomy is the end goal, pathways that address both heating and power generation will be required. The subsequent phases will therefore likely be focused on the conversion of the communities' heating system to renewable energy. The proponent has no mandate on heating conversion in the communities and is not planning any additional renewable energy electricity generation. Should there be new renewable energy projects implemented, these should complement the installed wind energy production.

8. ENVIRONNEMENTAL MONITORING

QC-19. Although the 2013 bat inventory presented to the environmental impact study could not confirm the presence of bats in the study area, the MFFP recommends that bats still be included in the mortality monitoring program planned for avian fauna, regardless of whether these inventories are updated. In addition, the *Protocole de suivi des mortalités d'oiseaux et de chiroptères dans le cadre de projets d'implantation d'éoliennes au Québec* (MDDEFP, 2013 – French only), stipulates that mortality monitoring must be carried out during the first three years, but also every ten years during the entire operation phase of the wind farm. However, section 8.1 *Avian fauna* mentions that the follow-up planned by the proponent will only be carried out during the first three years of operation. The proponent must incorporate this clarification into its bird and bat mortality monitoring to ensure that monitoring is not limited to the first three years of operation.

RQC-19. The proponent commits to include bats in the post-construction mortality monitoring and to conduct this monitoring during the first three years, and then every ten years during the entire operation phase of the wind farm.

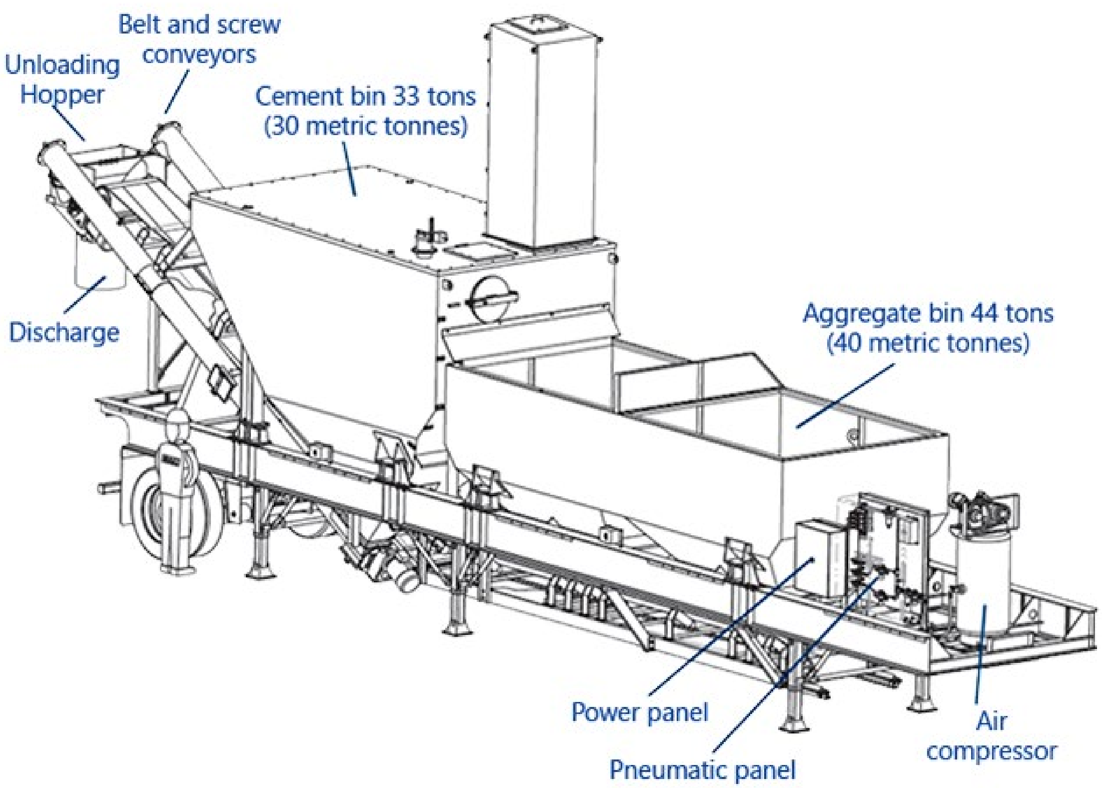
Appendix A Decumulative Mobile Batch Plant Brochure

BMH SYSTEMS DEC-50
DECUMULATIVE MOBILE BATCH PLANT

ASTEC™

BMH DEC-50 Decumulative Mobile Concrete Batch Plant

DEC-50 model is set to produce 65 yd3 (50 m3) per hour of dry mix material. Its size, quality of construction, quick set-up and versatility provides you absolute mobility to any job site.



No foundation required

- No aggregate handling required
- No crane required
- 1 day setup
- Export shipping container MODEC available

This decumulative mobile plant needs no concrete foundation and can be set-up and ready to use in a day. This is the perfect equipment for any contractor or job requiring batching concrete on site.

FEATURES

- Direct front-end loader charging of aggregates
- No foundation/erection required, blocking only
- Aggregate bin, 2 compartments, 44 tons (40 metric tonnes)
- Cement bin, single compartment, 33 tons (30 metric tonnes)
- Transfer belt, 30'' (760 mm) ribbed with 10 hp (7,5 kW) motor
- Cement delivery: 2 screw conveyors, 10'' (250 mm) diameter,
- Factory wired, plumbed and tested
- Electronic water meter, 2'' (50 mm)
- Air compressor, 5 hp (3,7 kW)
- Quick set-up time
- Decumulative batching
- Signal, brake and tail lights
- Telescopic legs
- Air brakes, single axle, double wheel and fifth wheel
- Low profile and high mobility batch plant 24' 0'' (7,3 m) long, with 10 hp (7,5 kW) motor

BATCHING CONTROL

- Manual

ELECTRICAL POWER

- Power panel 480 or 575 volts
- Other voltage available upon request

TRAVEL DIMENSIONS

- 55' 4'' (16.9 m) long
- 8' 6" (2.6 m) wide
- 14' 2" (4.4 m) high
- 32,000 lb (14,500 kg

OPTIONS

- Moisture probe
- Diesel generator
- Dust collector for cement bin
- Cement bulk bag handling system
- Computerized batch control system
- Cement bin extension, 11 tons (10 metric tonnes)
- Decumulative mobile cement bin, 33 tons (30 metric tonnes)
- Aggregate bin, 3 compartments with a total capacity of 44 tons
- (40 metric tonnes)

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Appendix B Study on district heating by the Polytechnique School of Montreal in 2021

District heating: a practical solution for reducing fossil fuel dependency in Quebec's remote communities

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Abstract

Fossil fuel dependency is a significant barrier to economic growth and self-sufficiency in remote communities. While renewable electricity integration is a common approach to reducing this dependency, investigation of low-carbon heating alternatives is lacking. The present study proposes district heating as a practical pathway to achieving significant reductions in greenhouse gas emissions. A district heating network is designed in QGIS and a simulation model developed in TRNSYS for the community of Whapmagoostui-Kuujjuarapik, Quebec. Generator waste heat recovery, excess renewable electricity and a centralized oil-fired boiler are all considered as heat sources in the model. Simulation results are compared with HOMER-optimized scenarios of hybrid wind-diesel-battery systems revealing that there is a point where district heating becomes the more economically feasible option.

Key Innovations

- Dynamic modelling of diesel generator waste heat recovery using a temporally and spatially accurate district heating load.
- Economic comparison of district heating to battery energy storage for high renewable energy penetration in remote communities.

Practical Implications

This paper demonstrates that consideration of heating alternatives at a community-scale is essential to achieving low-carbon energy systems in off-grid regions.

Introduction

Hundreds of remote communities across Canada rely solely on fossil fuels for both electricity production and heating (NRCAN, 2018). Most commonly, fuel for diesel generators and oil furnaces must be delivered by truck, barge, plane or some combination of the three, adding to the total carbon footprint of the fuel, as well as the price seen by consumers. The complicated chain of supply is also vulnerable to weather-based interruptions and creates a high potential for fuel spills. Thus, the transition to cleaner energy sources in these regions is not only important in terms of reducing greenhouse gas emissions, but also in developing autonomous and resilient local energy systems that do not rely on imported fuels.

In recent years, many studies have attempted to address these energy challenges in Canada; however, the absence of investigation into low-carbon alternatives that address the significant heating demand in cold-climate communities is notable. Rahman *et. al* (2016) evaluated the cost of electricity for seven renewable energy scenarios in a remote community but did not consider the heating demand. Thompson and Duggirala (2009) performed a similar study where heating was considered, but only constituted a minor portion of the total fossil fuel consumption. Other researchers have focused on optimizing battery or compressed air energy storage to maximize the penetration of variable renewable electricity (Guo *et al.*, 2016; Ibrahim *et al.*, 2011).

The potential for switching to less carbon intensive heating fuels such as natural gas, biomass or waste gasification was investigated by Yan, Rousse and Glaus (2019). Geothermal solutions such as borehole thermal energy storage and ground-coupled heat pumps have also been proposed as a suitable alternative (Giordano and Raymond, 2019; Gunawan *et al.*, 2020). These studies have all focused on individual residential heating systems, without exploring the need for overarching community heating strategies. One promising alternative that has yet to be widely investigated in this application, is district heating (DH).

DH systems consist of a network of underground pipes distributing hot water to individual buildings from a central heating plant. For over 100 years DH systems have served cities, universities and hospitals, among other applications (Werner, 2004). Technological advancement over time has seen DH network temperatures decrease, facilitating the use of lower temperature sources of heat such as shallow geothermal, solar thermal and waste heat recovery (Lund *et al.*, 2010). With the current pressure for energy systems to transition towards more renewable resources, the ability to harness alternative forms of thermal energy makes DH a prominent solution for low-cost energy generation (Persson and Werner, 2011).

On average in Canada, annual linear heat densities of 1.5 - 3 MWh/m are the threshold for economic feasibility of DH systems (Dalla Rosa *et al.*, 2012). Most remote communities are not densely populated and thus this threshold is likely not reached; however, there is further incentive to explore DH alternatives due to the high carbon-intensity of their energy systems. In addition, every community has a unique economic situation and access to different energy resources; it is therefore not possible to generalize whether DH is suitable based on a single characteristic such as linear heat density. Stephen et al. (2016) compared the potential of a DH system to decentralized boilers in Bella Coola, BC and found that DH was not economically competitive, while the town of Oujé-Bougoumou, QC has been successfully operating a DH system since 1993 (Rahman and Riddell, 2014).

The present study takes the Cree-Inuit village of Whapmagoostui-Kuujjuarapik in Northern Quebec and assesses the extent to which a DH system can reduce the community's dependence on fossil fuels. First, the hourly power and heating demand is estimated, and the baseline energy system characteristics are calculated. A DH system is modelled to determine the annual potential for generator waste-heat recovery using an hourly time scale. Next, a wind energy conversion system (WECS) is introduced to the DH model and the ability of the network to valorise excess wind energy is evaluated. Finally, these results are compared to the performance of a WECS with a battery energy storage system (BESS) on the basis of cost and emissions reductions. This work serves as the first step in determining the long-term energy savings and costs associated with DH in a remote community context and providing a measured comparison to other strategies for transitioning to a low-carbon energy system.

Methodology

The analysis performed for this paper can be roughly divided into six steps:

1. Creation of a 20-year hourly energy profile;
2. Layout of the DH network; pipe and pump sizing;
3. Modelling of DH with existing power plant;
4. Modelling of DH with wind-diesel hybrid plant;
5. Optimization of hybrid wind-diesel-battery system;
6. Lifecycle cost analysis of each system configuration

Community Energy Profile

Whapmagoostui-Kuujjuarapik (WK) is a half-Cree, half-Inuit community located at 55° North at the mouth of the Great Whale River leading into Hudson Bay. A previous study by the authors of this paper investigated in detail the space and water heating demand of WK (Pike and Kummert, 2021). In that study, residential archetypes were developed based on local construction standards and occupancy characteristics, with energy simulation performed in TRNSYS (Klein et al., 2018). The NECB 2011 baseline archetypes developed by CanmetEnergy (CanmetENERGY, 2017) were used for commercial and institutional buildings, with energy simulation performed in EnergyPlus (DOE, 2020). The simulation results were calibrated with fuel consumption data to develop an hourly thermal energy profile for the CWEC2016 typical meteorological year (ECC Canada, 2020). For electricity, Hydro-Québec, the provincial electric utility, and owner of the local diesel generation station, provided a 30-year hourly demand prediction based on previous years of measured data, the first 20 of which are used in the present simulations. Their dataset predicts a 27% growth in electricity demand over the next 20-years with the primary driver for growth being the construction of new housing. Heating demand is also assumed to grow, but only at half the rate of electrical demand due to warming temperatures and improved construction standards relating to envelope insulation. Annual totals for the 20-year period are shown in Table 1. Heating oil consumption is calculated assuming a boiler efficiency of 78% and hot water heater efficiency of 80%. The existing power plant consists of three CAT 3512, 1135 kW diesel generators which operate on a load following basis. The generator efficiency is modelled after the data presented in the generator data sheet (Caterpillar, 2019) and varies with the load. A minimum loading of 25% is considered, as well as an operating reserve of 10%.

Table 1: Energy Demand

	Year 1	Year 20	20-Year Average
Heating [GWh]	25.0	28.2	26.9
Electricity [GWh]	12.4	15.8	14.4
Heating GHG Emissions [tCO2eq]	8 270	9 330	8 920
Electricity GHG Emissions [tCO2eq]	9 690	12 110	11 120

This study is motivated by the fact that the heating load accounts for 45% of the building-related GHG emissions in WK. The consideration of heating alongside electricity when planning renewable energy projects in the community will lead to better economic outcomes and a more reliable and sustainable energy system.

District Heating Network Design

Data from the geographic information system software, QGIS (QGIS.org, 2020) was used to design the layout of the DH network. The use of this software permits the definition of spatial objects with individual attributes to characterize the infrastructure they represent. Every building in WK is assigned a polygon with attributes corresponding to the archetype, floor area, and peak heating load.

Figure 1: DH Plant and Service Zones

A bare lot of land adjacent to the existing diesel generation plant was chosen as the location for the central heating plant. Three independent coverage zones spanning the main village area were defined as shown in Figure 1. Distribution pipes were routed along main roads to reach all residential and commercial buildings in these zones. The sub-branches connecting each individual building to the main distribution line were routed based on the shortest possible distance. This network is not intended to represent the optimal DH system, but instead one that reaches the maximum number of customers without significantly lowering the linear heat density.

Maximum flow rates in the sub-branches were determined using a ΔT of 30°C and the peak heating load defined for each building. Nodes on the main branches were placed at each connection with a sub-branch, and the flow in the downstream pipe section was determined by the sum of the incoming maximum flows. These flow rates could then be translated to a pipe size that permits a maximum pressure drop of 200 Pa/m as is recommended for the design of DH networks (Natural Resources Canada, 2005). A safety factor of 5% was added to the flow rate to account for potential fluctuations in the heating load. The chosen pipe network is shown in Figure 2 and the piping parameters are shown in Table 3.

Table 2: Peak Zone Loads and Flow Rates

	Peak Demand [kW]	Peak Flow Rate [m3/hr]	Maximum Δp [kPa]
Zone A	1 968	56	671
Zone B	2 961	85	
Zone C	5 934	170	
Total	10 641	305	

Table 2 shows the peak demand and corresponding flow rate for each service zone. One should observe that the total peak demand is not the sum of the peak demand in the three branches, as these do not occur at the same time. This highlights one of the benefits of DH, in that the total installed heating capacity is reduced. The required DH pump capacity in kW is determined by multiplying the maximum flow rate leaving the central plant by the total pressure drop in the longest path considering supply and return pipe length. This gives a required pump capacity of 60 kW.

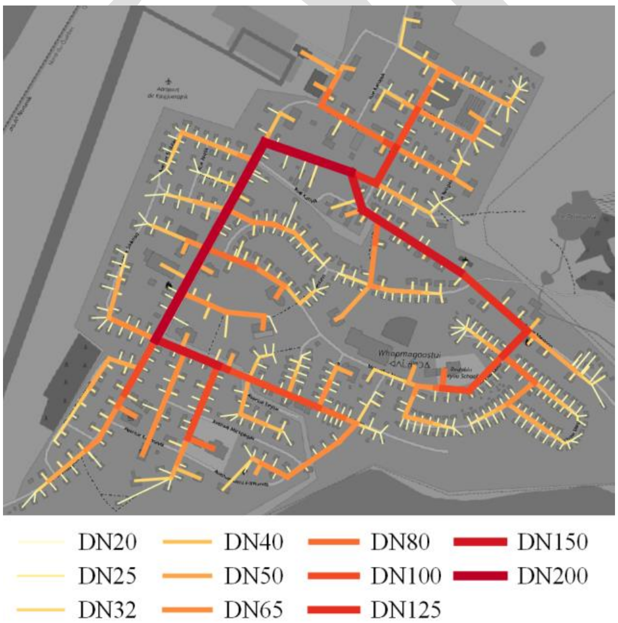


Figure 2: DH Network Design

The price per meter given in Table 3 is determined by aggregating data from studies and reports by Stephen *et al.* (2016); The Danish Energy Agency and Energinet (2016); and the Arctic Energy Alliance (2010).

Table 3: DH Piping Parameters

Pipe Size [mm]	Maximum Flow [m³/hr]	Required length [m]	Price [$/m]
DN20	0.54	8 420	320
DN25	1.1	2 570	320
DN32	1.8	1 430	350
DN40	2.7	1 120	375
DN50	5.8	2 600	400
DN65	12	2 360	450
DN80	21	770	480
DN100	36	880	550
DN125	65	480	630
DN150	110	530	700
DN200	248	750	860

District Heating with Existing Power Plant

TRNSYS modelling of the DH system was performed in two steps: the first was the simulation of the piping network to account for dynamic heating losses and pump energy requirements, giving the total loads seen at the central plant; the second step modelled the simultaneous electrical and heating energy demands to evaluate the availability of waste heat recovery and excess renewable electricity. Both simulations were performed at an hourly time step over a 20-year period, again using the CWEC2016 meteorological data.

Table 4: Equivalent and Actual Pipe Parameters

	Zone A	Zone B	Zone C
Equivalent			
Length [m]	221	304	387
Inner Diameter [mm]	235	286	404
Linear Heat Loss Coefficient [W m^{-1} K^{-1}]	2.8	3.2	5
Actual			
Length [m]	3 762	6 127	12 032
Volume [m³]	9.6	19.5	49.6
Weighted Average Velocity [m/s]	0.42	0.41	0.42
Peak Flow Rate [L/s]	18	26	53

The piping model consists of three loads, served by three equivalent pipe sections corresponding to the coverage zones mentioned in the previous section. The pipes are buried at 2 m depth and the working fluid is water. Ground temperature parameters were taken from data collected at the CEN climate station in Whapmagoostui-Kuujjuarapik (CEN, 2020). Equivalent properties of the pipes are determined according to the following logic. First, the equivalent diameter must be capable of serving the maximum volume flow at the weighted average peak velocity, such that the time delay of the system is maintained. Using the calculated inner diameter, the equivalent length is chosen to achieve the same total volume of water in the pipe. Finally, the total heat transfer rate, U [W/K], is determined for the original system and divided by the equivalent length to obtain the equivalent heat loss per meter. The characteristics of each equivalent pipe section and the actual pipe they represent are given in Table 4. Heat transfer rates and inner diameters of the actual pipe are based on the Logstor Series 3 bonded pipe system (Logstor, 2020).

Hourly heating demand for each service zone is determined based on the total floor area of each building archetype contained within it. A single pump and heat supply provide the hot water flow to the three pipes so the flow through each pipe section is calculated based on the fraction of total heat demand allotted to that section. Pump power is assumed to vary linearly with the required flow rate, to account for the presence of control valves, which increase resistance to flow when branch loading is uneven. A minimum pump turndown ratio is defined at 15%, the result of which can be seen in Figure 3. During the summer, heating demand is often less than 15% of the peak demand, so we see return temperatures increase, as a smaller fraction of the energy carried by the heating fluid is removed. There is also a decrease in the supply temperature, which occurs because the lower flow rates mean that the fluid spends a longer time in the pipe and therefore experiences a greater temperature drop, despite the warmer ground temperatures. The total heating load, accounting for pipe losses, is the heat input required to raise the heating fluid from the return temperature to the setpoint of 80°C.

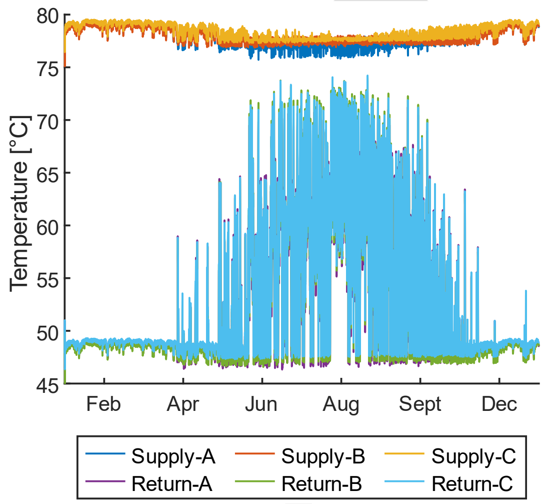


Figure 3: DH Network Supply and Return Temperatures

Table 5 shows the increase in energy requirements associated with the DH system. The DH pump contributes to the electric load, while the piping losses increase the heating load.

Table 5: Annual Pumping Energy and Heat Loss

	Pump	**Heat Losses**
Energy [GWh/year]	1.56	2.04
Percent of Base Load [%]	0.5%	7.6%

Next, the DH-adjusted heating and electricity loads are used as an input for the central energy plant simulation. Heat rejection (HR) performance data provided in the generator data sheet (Caterpillar, 2019) are used to populate the TRNSYS Type 907 internal combustion generator component (Thermal Energy System Specialists, 2012). This component reads a text file containing the generator's mechanical and electrical efficiency, exhaust flow rate, and the fraction of total heat rejected to each of five waste streams at a series of part load ratios (PLR), and determines via linear interpolation the appropriate values for the PLR called at the current time step. Apart from the hourly fuel consumption, most generator data are only provided for high part load ratios and thus, some assumptions must be made. The total efficiency for other PLRs can be calculated by dividing the power output by the total energy contained in the fuel assuming a density of 839 g/L and a higher heating value of 45.8 MJ/kg. Waste heat fractions are assumed to follow a quadratic relationship with the output power, while the exhaust flow rate is assumed to follow a linear relationship with the fuel consumption rate. Temperature impacts on generator performance have not been considered.

Table 6: Generator Performance Parameters

Output Power [kW]	1 135	851	625	505	312.5
Mechanical Efficiency [%]	0.37	0.37	0.35	0.34	0.29
Electrical Efficiency [%]	0.90	0.90	0.90	0.90	0.90
Jacket Water HR [kW]	763	592	493	434	355
Exhaust HR [kW]	1 083	792	610	508	379
Exhaust Flow Rate [kg/s]	2.14	1.83	1.66	1.56	1.42

Only the jacket water cooling loop, and the exhaust flow are considered as potential sources of waste heat recovery; the former because jacket water heat recovery is a well understood practice, and the latter because the largest portion of waste heat is present in the exhaust flow. Additionally, a minimum exhaust outlet temperature of 180 °C is set to prevent corrosion effects in the exhaust pipe, thereby limiting the available heat recovery. The relevant generator performance parameters are listed in Table 6.

District Heating with Wind-Diesel Hybrid Plant

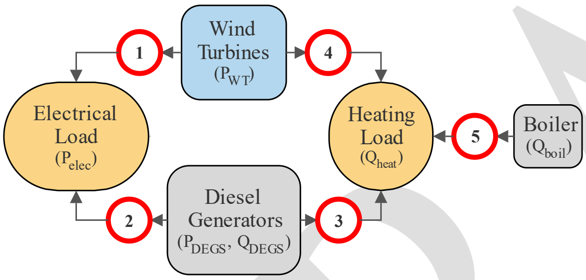
Another set of simulations were performed to determine how the presence of a WECS can contribute to reducing the total requirement for fossil-fuel generated heat. In HOMER Pro (HOMER Energy LLC, 2017), the DH-adjusted electrical load was simulated over a 20-year period for hybrid systems that include 1-17, 800-kW wind turbines. At each time step the available wind energy is calculated and applied towards the electrical load, with the diesel generators (DEGS) dispatching when the wind energy is not sufficient. The operating reserve required from the DEGS and BESS is equal to the total useful wind output plus 10% of the load.

The hourly results of the HOMER simulation are then used as an input to the TRNSYS DH model, with the same heat recovery logic as described in the previous section. When the available wind power is greater than the existing demand, it is also converted to heat by simple resistance heating. Wind data is taken from the CWEC2016 typical meteorological year (TMY) and extrapolated to the hub height of an Enercon E-53 turbine, the parameters for which are shown in Table 7 (ENERCON, 2015). To validate the acceptability of using the TMY, a simple hybrid wind-diesel model was run using the CWEEDS on-site wind data from 1998-2017 (ECC Canada, 2020). The same model run with the CWEC2016 data showed only a 4.4% difference from the 20-year average power generation and only a 2.6% difference from the 20-year average useful power.

Table 7: Wind Turbine Parameters

Turbine Rated Power [kW]	800
Hub Height [m]	60
Power Losses [%]	30
Cut-in wind speed [m/s]	2
Cut-out wind speed [m/s]	25
Annual average wind speed at hub height [m/s]	7.9
Shear coefficient	0.26

Figure 4 shows the energy flows and the dispatch priority for each source.



1. $P_{WT,used} = \max(P_{WT}, P_{elec})$
2. $P_{DEGS} = P_{elec} - P_{WT,used}$
3. $Q_{DEGS,used} = \max(Q_{heat}, Q_{DEGS})$
4. $Q_{WT,used} = \max(P_{WT} - P_{WT,used}, Q_{heat} - Q_{DEGS,used})$
5. $Q_{boil} = Q_{heat} - Q_{DEGS,used} - Q_{WT,used}$

Figure 4: Energy Flow Algorithm

HOMER Wind-Diesel-BESS Optimization

HOMER Pro is a techno-economic optimization software designed specifically for micro-grids that integrate renewable energies. It is used in the present study to create a point of comparison for the DH network model. A renewable energy project is currently in development for WK that will see the construction of three 800 kW wind turbines, the power generated being sold to Hydro-Québec who will install a battery energy storage system to maximize the usable wind energy. The system defined in the optimization process is based on this premise. For renewable electricity fractions increasing from 15 to 95%, we identify the combination of 800 kW wind turbines and battery storage that minimizes the net present cost of electricity supply for the next 20 years. The wind data and turbine parameters used in the HOMER simulations are identical to those used in the previously described scenario. Further details on the economic parameters are found in the next section.

Lifecycle Cost Analysis

The Levelized Cost of Energy (LCOE) refers to the average cost per kWh of energy generation. It can be calculated by dividing the annualized cost of the system by the average energy load over the 20-year period (NREL, 2020). For our purposes we extend this definition to apply to both electricity and heating. Only the base energy load is considered, such that DH pipe losses, pumping energy and un-used wind power generation do not artificially decrease the LCOE; ie. all scenarios produce the same amount of useful energy. The cost of capital used in the simulations is 5.21%, which is comparable to the loan rate obtained in a previous financing submission by the Kuujjuarapik-Whapmagoostui Renewable Energy Corporation (Schiettekatte, 2020). The values in Tables 8 and 9 are aggregated from previous studies and reports, and adjusted to account for inflation and the present study location (Lin, 2008; Forcione and Saulnier, 2003; Forcione and Delorme, 2008; Guo *et al.*, 2016).

Table 8: DH Equipment Parameters

Oil-fired boiler capital cost [k$/MW]	200
Boiler plant capital cost [k$/MW]	200
Central boiler efficiency [%]	85
HEX capital cost, 850 kW [k$]	30
HEX capital cost, 5100 kW [k$]	350
HEX piping and install cost [k$]	975
Pump capital cost [$/kW]	1 000
Residential connection cost [k$]	11.5
Number of residential connections	400
Commercial connection cost [k$]	23
Number of commercial connections	77
Lifetime of DH Plant and Equipment[a] [yr]	20
Adjustment for remote location [%]	20
Engineering and administration [%]	20

[a] It is assumed that a back-up pump will be installed such that their combined lifetime is 20 years

Table 9: Power Generation System Parameters

Turbine capital cost [M$]	4.01
Turbine replacement cost [M$]	2.4
Turbine O&M cost [k$/yr]	54
Turbine lifetime [yr]	15
Battery energy storage capital cost [$/kWh]	570
Battery lifetime [cycles]	3 500
Battery lifetime [yr]	10
Converter capital cost [$/kW]	594
Converter O&M [$ $kW^{-1}yr^{-1}$]	12
Converter lifetime [yr]	10
Inverter efficiency [%]	90
Rectifier efficiency [%]	95
System transformation (engineering design, electrical control centre) [k$]	990

It is unknown when Hydro-Québec plans to replace the existing diesel generators, so in all scenarios it assumed that new generators are purchased in the first year. The starting price of diesel and heating oil is 1.60 $/L and increases at a rate of 3% per year. These values are taken from Hydro-Québec's most recent report on the conversion of the Inukjuak power plant to small hydro (Hydro-Québec Distribution, 2019). The previous tables give a summary of the capital and operation and maintenance (O&M) costs associated with each type of equipment used in the simulation scenarios as well as the expected lifetime. O&M costs for heating systems within individual buildings are assumed to remain the same for all scenarios and are not included in the net present cost calculation.

Results

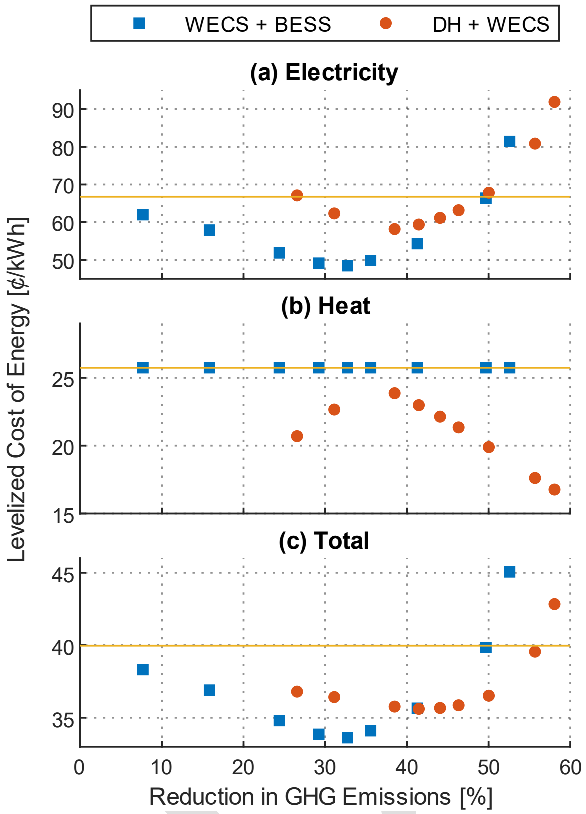


Figure 5: Levelized cost of (a) electricity, (b) heat and (c) total energy for decreasing GHG emissions; yellow line represents baseline cost

In Figure 5 the LCOE for electricity, heating, and the weighted average combination of the two is shown for different levels of GHG emission reductions achieved by the HOMER-optimized BESS strategy (WECS + BESS), and the DH strategy (DH + WECS). An overall LCOE of \$0.40/kWh is found for the baseline scenario, represented by the horizontal yellow line. This estimate is appropriate given that the calculated LCOE of electricity, \$0.67/kWh, corresponds well to Hydro-Quebec's reported avoided cost of energy, \$0.66/kWh (Hydro-Québec Distribution, 2018) and that the heating portion only considers the cost of heating oil.

We observe that the wind energy and battery storage strategy gives the best return on investment up to a total GHG reduction of 41%. Beyond this point DH is the more economical alternative and even has a lower LCOE than the base scenario up to a total GHG reduction of 55%. Both scenarios become rapidly more expensive beyond 50% GHG reductions, indicating the overall limitations of each strategy due to the misalignment of energy demand and wind energy availability. For this reason, simulations are not performed for GHG reduction scenarios over 60%.

In the heating LCOE curve for the DH strategy we see the conflicting effects of adding additional turbines. For each additional turbine, the excess wind energy available for heating purposes increases, but the generator load decreases and, consequently, so does the recoverable waste heat. Beyond the addition of the third turbine, it appears that each turbine produces more excess energy that is usable for heating than it takes away from the heat recovery potential.

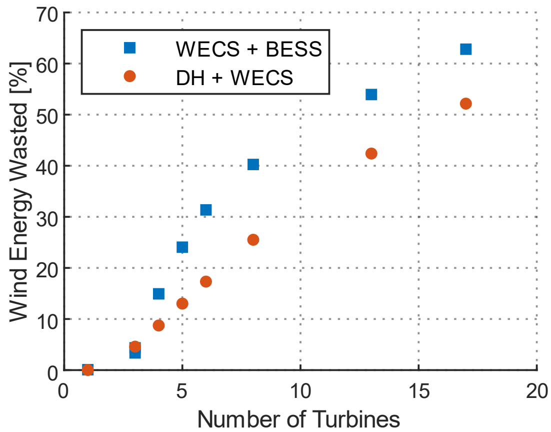


Figure 6: Percent of total wind energy wasted

In Figure 6, we see that for scenarios involving more than two wind turbines, DH consistently utilizes a greater portion of the wind energy than battery energy storage. Even so, the percentage of wasted energy is high, and thus it is likely that some combination of BESS and DH would be an ideal solution to minimize wasted energy. Additionally, if one wanted to increase renewable energy penetration in the BESS scenario, it would be prudent to convert some building level heating systems to electricity or dual-fuel heating. For the DH solution, the next strategy to explore would be thermal energy storage, which would allow for the excess wind energy seen in Figure 6 to be stored for heating demand periods that do not align with wind availability.

The cost of fuel for heating and electricity makes up 94% of net present cost (NPC) for the baseline scenario, and 75% and 62% of the optimal BESS and DH scenarios, respectively. It is therefore of interest to see how changing the price of fuel over the 20-year period changes the results. Figure 7 shows how the model results would be affected by increasing or decreasing the growth rate of the price of fuel. Here, the growth rate is varied from 1% (SC1) to 5% (SC5), with the initial assumption of a 3% growth rate shown by the dotted lines. The BESS has not been re-optimized to account for these changes.

As expected, the two alternative energy strategies are less affected than the baseline by the changes in fuel price. This makes the alternatives slightly less attractive in SC1 and slightly more attractive in SC2, as compared to the original fuel price assumption. For an NPC that does not exceed the baseline, 50% GHG reductions could be achieved in SC1, while 60% could be achieved in SC2. The point at which DH becomes more economically feasible than the BESS solution remains at about 40% GHG reductions for either scenario.

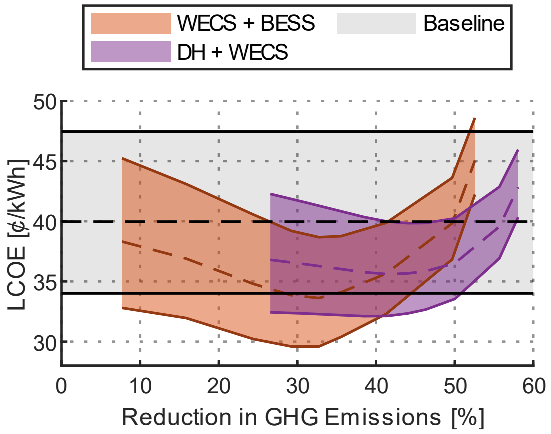


Figure 7: Levelized cost of energy (total) for the confidence interval of fuel price growth rate of 1-5%

Discussion

Motivating further exploration of alternative heating strategies is the main goal of this research, and its importance has been well supported by the results presented. Although there could be variability in the economic parameters, DH clearly has the potential to significantly reduce GHG emissions, while also creating a more affordable energy system for Whapmagoostui-Kuujjuarapik.

As mentioned previously, investigation of the effects of partially electrifying heat demand or adding thermal storage could reveal even more cost-effective solutions to the fossil-fuel dependency challenge. Both solutions would enable the use of additional wind energy and decrease the overall energy waste. It is also worthwhile to note that the DH strategy was based on a preliminary, non-optimized network design. It is therefore possible that the heat losses attributed to the service pipes for buildings at the periphery of the network, are more significant than the fuel savings achieved by connecting those buildings. Other optimization strategies, such as sizing the central boiler to meet only a portion of the peak load, while leaving individual heating systems to cover the remaining load, could also make DH a more cost-competitive solution. Another consideration for future work would be the use of heat pumps in place of resistance heating with excess wind energy, as the efficiency of cold-climate heat pump technology is rapidly improving (NRCAN, 2015). Finally, in order to reach net-zero, biomass imported from southern Cree territories could be used in a central cogeneration plant as a dispatchable fuel in place of diesel.

The renewable energy configurations investigated in this study achieve GHG emission reductions of up to 58%. However, in the interest of determining the most effective strategies for fossil-fuel reduction, it would also be prudent to look at energy-saving measures such as insulation to see how their cost-benefit ratios compare. Additionally, although it was shown that significant waste heat is available for use in the current system, the actual policy behind the use of it and the effect on other energy subsidies could be complex and must be further explored.

Conclusion

Presently, all waste heat produced at the Whapmagoostui-Kuujjuarapik generating station is lost to the surrounding environment. This study found that when a portion of this heat is captured for use in a district heating system, the annual heating load that must be met by boilers can be reduced by over 55%. Despite a slight increase in the energy consumed for the operation of distribution pumps and heat losses in the network, this recovered heat corresponds to a reduction in total GHG emissions of 27%. Furthermore, this is achieved at an LCOE of $0.37, which is 8% lower than the baseline system.

Next, DH was compared to the optimized BESS scenarios on its capacity to valorise excess wind energy. Although the lowest LCOE is achieved with a BESS giving a GHG reduction of 33%, DH performs better for GHG reduction targets beyond 41%. These results demonstrate the strong potential DH has as an alternative energy strategy in fossil-fuel dependent communities especially until BESS becomes a more affordable technology.

The results of this study do not diminish the positive impact of renewable electricity generation, but they do provide motivation for communities to look at alternative heating strategies in parallel with renewable electricity to determine the best long-term strategy for reducing the consumption of fossil fuels. If full energy autonomy is the end goal, pathways that address both heating and power generation will be required.

Acknowledgement

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References

Arctic Energy Alliance (2010) *NWT Community Wood Pellet District Heating Study*.

CanmetENERGY (2017) *NECB 2011 Baselines*.

Caterpillar (2019) 'Cat ® 3512 Diesel Generator Sets', pp. 1–5.

CEN (2020) 'Climate station data from Whapmagoostui-Kuujjuarapik Region in Nunavik, Quebec, Canada, v. 1.5 (1987-2019)'. Nordicana D4.

Dalla Rosa, A. *et al.* (2012) 'District heating (DH) network design and operation toward a system-wide methodology for optimizing renewable energy solutions

(SMORES) in Canada: A case study', *Energy*, 45(1), pp. 960–974.

DOE (2020) 'EnergyPlus'.

ECC Canada (2020) *Engineering Climate Datasets*.

ENERCON (2015) *ENERCON product overview*. Aurich, Germany.

Forcione, A. and Delorme, L. (2008) *Jumelage éolien-diesel - Mise à jour des VAN optimales pour les réseaux du Nunavik et des Îles-de-la-Madeleine*.

Forcione, A. and Saulnier, B. (2003) *Systèmes jumelés éolien-diesel au Nunavik - Établissement des configurations et VAN optimales pour les quatorze villages – Mise à jour 2004*.

Giordano, N. and Raymond, J. (2019) 'Alternative and sustainable heat production for drinking water needs in a subarctic climate (Nunavik, Canada): Borehole thermal energy storage to reduce fossil fuel dependency in off-grid communities', *Applied Energy*, 252.

Gunawan, E. *et al.* (2020) 'Alternative heating systems for northern remote communities: Techno-economic analysis of ground-coupled heat pumps in Kuujjuaq, Nunavik, Canada', *Renewable Energy*, 147, pp. 1540–1553.

Guo, L. *et al.* (2016) 'Optimal design of battery energy storage system for a wind-diesel off-grid power system in a remote Canadian community', *IET Generation, Transmission and Distribution*, 10(3), pp. 608–616.

HOMER Energy LLC (2017) 'HOMER Pro'. UL LLC.

Hydro-Québec Distribution (2018) *Coûts évités - Demande relative à l'établissement des tarifs d'électricité pour l'année tarifaire 2019-2020*.

Hydro-Québec Distribution (2019) *Demande Relative à la Conversion du Réseau Autonome d'Inukjuak à l'Énergie Renouvelable: Aspect - Contrat d'Approvisionnement*.

Ibrahim, H. *et al.* (2011) 'Potential of a hybrid wind-diesel-compressed air system for nordic remote canadian areas', *Energy Procedia*, 6, pp. 795–804.

Klein, S. A. *et al.* (2018) *TRNSYS 18 - A TRaNsient SYstem Simulation Program, User Manual. Version 18.2.* Madison, WI, USA: University of Wisconsin-Madison.

Lin, C.-S. (2008) *Capture of Heat Energy from Diesel Engine Exhaust*. Fairbanks, AK.

Logstor (2020) *Product Catalogue District Energy*.

Lund, H. *et al.* (2010) 'The role of district heating in future renewable energy systems', *Energy*, 35(3), pp. 1381–1390.

Natural Resources Canada (2005) *Clean Energy Project Analysis*, *Development*.

NRCAN (2015) *Clean Energy Fund Public Project Report: Cold Climate Heat Pump Development and Demonstration*.

NRCAN (2018) *Remote Communities Energy Database | Natural Resources Canada*.

NREL (2020) *Simple Levelized Cost of Energy (LCOE) Calculator Documentation*.

Persson, U. and Werner, S. (2011) 'Heat distribution and the future competitiveness of district heating', *Applied Energy*, 88(3), pp. 568–576.

Pike, A. and Kummert, M. (2021) 'An archetype-based energy modeling approach for a remote, subarctic community', *Manuscript submitted for publication*.

QGIS.org (2020) 'QGIS Geographic Information System'. QGIS Association.

Rahman, M. M. *et al.* (2016) 'A hybrid renewable energy system for a North American off-grid community', *Energy*, 97, pp. 151–160.

Rahman, R. and Riddell, C. H. (2014) *Feasibility analysis of wood-biomass energy generation for the off-grid community of Brochet in North-west Manitoba, Canada*.

Schiettekatte, J. (2020) 'Personal Communication'.

Stephen, J. D. *et al.* (2016) 'Biomass for residential and commercial heating in a remote Canadian aboriginal community', *Renewable Energy*, 86, pp. 563–575.

The Danish Energy Agency and Energinet (2016) 'Technology Data - Generation of Electricity and District heating', p. 414.

Thermal Energy System Specialists (2012) 'TESSLibs 17 - Component Libraries for the TRNSYS Simulation Environment'. Madison, WI, USA.

Thompson, S. and Duggirala, B. (2009) 'The feasibility of renewable energies at an off-grid community in Canada', *Renewable and Sustainable Energy Reviews*. Pergamon, pp. 2740–2745.

Werner, S. (2004) 'District Heating and Cooling', *Encyclopedia of Energy*, pp. 841–848.

Yan, C., Rousse, D. and Glaus, M. (2019) 'Multi-criteria decision analysis ranking alternative heating systems for remote communities in Nunavik', *Journal of Cleaner Production*, 208, pp. 1488–1497.

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