POLICY PRIMER

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Alternative Energy in The Canadian North

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Key Considerations

Purpose: explore alternative energy options in the Canadian North pursuant to the Department of National Defence's Energy and Environment Strategy and its MINDS Policy Challenges 2020-2021

Guiding question: How could climate change alter future defence requirements in the North and how could DND/CAF address climatic changes in the region? Alternative energy sources were examined in the context of this question to support Canada's defence role in the Arctic (MINDS challenge #4)

- Diesel is the primary source of energy for heat and electricity at isolated sites such as military bases in the North. The high annual cost of supplying diesel to these sites and logistical constraints which make transporting diesel to these sites difficult and costly are reasons why alternatives to diesel might be considered. The present difficulties in transporting diesel to isolated sites will likely be further exacerbated by climate change in the region.
- The alternatives to diesel generation include: renewables (solar, wind, hydroelectricity, biomass, geothermal, tidal), hybrid diesel-renewable systems, expanding the grid network, small modular nuclear reactors (SMRs) and increasing the efficiency of existing diesel generators/alternative fuels
- This primer highlights SMRs and increasing the efficiency of generators using existing fuels as comparatively underexplored options that invite further study

Introduction

The Government of Canada and many Northern stakeholders are actively considering alternative energy options for deployment in the Canadian North to complement or replace existing diesel generators. This comes amid the push to mitigate climate change and local environmental impacts, and in the context of the need for increased electricity generating capacity in the north for economic activity, growing communities, and military operations. Because diesel generators in the Canadian North do not contribute significantly to global climate change (Government of Canada, 2016), reducing reliance on these systems in the region will not actively contribute to greenhouse gas (GHG) abatement. Nevertheless, policies at all levels of government prioritize transitioning away from diesel generation in the North (Crown-Indigenous Relations and Northern Affairs Canada, 2019). Aside from producing GHG emissions, diesel generation also poses a risk to the local environment and human health from fuel spills and emissions, and climate change exacerbates logistical constraints associated with fuel supply. In some cases, alternative energy sources have the potential to alleviate the costs and challenges of transporting diesel fuel (Department of National Defence, 2019).

Macro-level institutional factors currently dictate that diesel power generation in northern communities remains the best option for electricity generation, despite its many drawbacks. This may change as climate change reduces the availability and increases the expense of shipping diesel to Northern communities (owing to shorter ice road seasons and environmental concerns over diesel fuel spills). Governments are considering alternative energy sources that are more resilient to supply chain disruptions over increasing their dependence on diesel to accommodate growth (Karanasios & Parker, 2018).

Alternatives to diesel need to be more reliable and cost effective, not simply better for the environment. Renewable energy technologies are becoming a cheaper means to generate electricity than fossil fuels in some contexts (Imelda, Fripp & Roberts, 2018) and Canada could significantly reduce its national greenhouse gas emissions consistent with its Paris Targets by widely implementing these technologies. Renewable technologies are cheaper to implement in developing countries than expanding electricity grids (Riley, 2016) and implementing renewables in the Canadian North could also be an option where expanding the electricity grid would be cost prohibitive or impractical. However, renewables have yet to prove more cost-effective and reliable than diesel generation in harsh northern conditions. Renewable energy technologies may need to be adapted to operate in the harsh northern environment, imposing additional constraints on their implementation in the north.. Non-renewable alternative energy options also warrant consideration as more cost effective, reliable, and environmentally friendly sources. Renewable energy, hybrid diesel-renewable systems, alternative fuels, increasing diesel efficiency, and expanding electrical grid infrastructure are the most readily-available alternative sources of energy. Furthermore, increasing the efficiency of buildings and energy conservation will reduce consumption of energy from diesel and alternative sources.

Renewables

Ensuring access to affordable, reliable, and sustainable modern energy is goal number 7 of the UN's 17 sustainable development goals (UN SDGs), and renewable energy accounts for more than half of the electricity generated in Canada (Karanasios & Parker, 2018). Alternatives to diesel-generating plants include the use of different fuel (e.g. natural gas), connecting to electrical grids, renewable energy, more efficient diesel generators, and small modular nuclear reactors.

Renewable technologies are challenging to implement in the Canadian North because they need to withstand extreme climatic conditions and are incompatible with existing local grids (Karanasios & Parker, 2018). Renewables also have associated environmental and social impacts that can make them difficult to implement. For example, wind developments cause bird and bat deaths, produce noise and affect the visual and aesthetic qualities of the landscape. Furthermore, renewable energy developments will have significant impacts on subsistence species that sustain northern peoples. If they have acceptable social and environmental impacts, renewables are viable alternative energy sources in northern communities and at remote sites.

The barriers to transitioning to renewable energy sources are primarily social and political in Southern Canada (Pischke et al, 2019), and there are additional environmental challenges for infrastructure (such as thawing permafrost) and logistical challenges (i.e. how do you transport large wind turbine blades to a small community or site that is only accessible by small plane?) in the Canadian North. The road network in the Territories is more limited than in southern Canada and port infrastructure is virtually non-existent. Both are necessary to economically transport large renewable energy infrastructure. Where it exists, road accessibility makes transporting large renewable energy infrastructure to industrial sites feasible. For example, the large wind turbines at the Diavik Diamond Mine were the longest load to ever travel by ice road. These turbines were transported initially by ship from Germany, offloaded in the port of Thunder Bay and then trucked to the mine. Communities and sites that are accessible by deep water port and road are the best candidates for wind turbine developments. The challenges associated with limited and inadequate transportation infrastructure can be alleviated by adopting smaller and more portable renewable energy infrastructure such as solar panels.

Solar panels can be transported individually or in small numbers relatively easily (even to remote sites) and assembled incrementally and integrated as part of a larger project (Thomson, 2019). Solar installations are a good source of renewable energy for part of the year in the north because there is complete or near 24-hr sunlight in the summer months. However, storing and generating solar energy during long periods of darkness during winter is a challenge (Carreau, 2019). Solar panels can be a reliable and abundant source of energy for isolated communities and remote sites when paired with other renewables and a good method of storing energy (Karanasios & Parker, 2018). Solar thermal installations have also been successfully implemented in the north (Nunavut Department of Environment, n.d.).

The Government of Canada is interested in adapting renewable technologies to the Arctic environment as a long-term alternative to diesel generation. The Department of National Defence (DND) has explored operationalizing small, ruggedized wind turbines for use at isolated DND/CAF locations where the transportation of diesel is already extremely costly and logistically constrained. However, DND considers reducing the environmental burden of diesel generation of equal importance. The department also acknowledges that there are some major challenges to overcome before wind turbines can be fully implemented as a source of alternative energy (DND, 2019), including climate change impacts on this infrastructure.

Geothermal potential, which could be used for heat and power, has been identified in some areas of the Canadian North. Sufficient temperatures have been found at great depths but the cold temperature of bedrock and permafrost are challenges to widespread application. Water from 50 – 130°C has been encountered during drilling and in pre-existing mine shafts. Low temperature geothermal from warm groundwater is used to keep the pipes in the city of Whitehorse from freezing during the winter (Governments of Yukon, Northwest Territories and Nunavut, 2011).

Furthermore, Nunavut may have the highest tidal energy potential in Canada but high costs of up-front investment and harsh northern conditions have prevented this technology from becoming established in the North (Nunavut Department of Environment, n.d.).

Storage is a significant consideration for renewable electricity generation. This is accomplished by using a reservoir to hold back water until it is needed to generate electricity for reservoir hydroelectric projects (Ingenium, 2020). Batteries and other forms of storage such as pumped hydroelectric and compressed air are needed to address the intermittency of other renewable sources, such as wind and solar (Gearino, 2019; Natural Resources Canada, 2019). Considering the high cost of electricity in the north, it is possible that the cost of electricity from renewable sources will be cheaper than that of conventional diesel generation (Sahar Zerehi, 2016). Ultimately, high costs of transport and cost of initial investment will determine the price of renewable electricity compared to electricity from diesel generators.

Global investment in renewables was greater than fossil fuels in 2015 (Fried, Shukla & Sawyer, 2017). Wind energy is currently the fastest growing renewable energy technology (Ibrahim et al., 2019). The cost of wind energy continues to fall and is the least cost option in many markets when adding new capacity to the grid (Fried, Shukla & Sawyer, 2017). Solar panels are also coming down in cost. The cost of electricity generated from renewable sources is now cost competitive or cheaper than from conventional fossil fuel sources (Imelda, Fripp & Roberts, 2018) and, if these trends continue, renewable energy will be the best option for increasing capacity globally (Fried, Shukla & Sawyer, 2017). This same cost competitiveness with fossil fuels is a precondition to assuring renewables a place in the Northern Canadian energy supply, and sustained investment and implementation of renewable technologies will continue to drive innovation that may prove beneficial for implementing renewable technologies in the Canadian North.

There is disparate access to renewable energy across Canada. Access to renewable energy through a grid network, particularly from large hydroelectricity developments, is available to some northerners (Thomson, 2019) but many isolated and remote communities depend on (and will continue to depend on) the electricity that can be generated on-site (Karanasios & Parker, 2018). As renewables continue to expand in Canada and globally, some northern communities and sites will have access to renewable energy through the expansion of electrical grids from southern sources (d'Entremont, 2020). Small-scale hydroelectric developments can sometimes meet the full demands of communities and remote sites and in some cases can generate surplus power that can be sold into the grid for revenue, but few isolated communities and sites have the ability to generate their power totally from renewable sources (Abboud, 2019). Communities that rely on solar, wind, or other renewable technologies will likely continue to use diesel generators to supplement their power needs at certain times of the year, and hybrid renewable-diesel or -LNG systems should be considered in cases where renewable energy cannot fully meet demand (Karanasios & Parker, 2018).

Biomass

Biomass is a renewable source of alternative energy. Wood is a common biomass fuel, but biomass fuel can be any liquid, solid or gas fuel that is derived from organic material that is generated on a renewable basis. Biomass is considered carbon neutral because an equivalent amount of carbon produced by burning is captured by a tree (or other organic material) to produce the same amount of wood (or other biomass fuel) that was burned as long as the forest regenerates (Government of Yukon, 2016; Northwest Territories Environment and Natural Resources, 2010). Wood stoves are extensively used for space heating in northern Canada and increased efficiency has already proved beneficial for residential applications (Northwest Territories Environment and Natural Resources, 2012). However, few commercial projects have been explored. Biomass can be used for both centralized heating and electricity generation. Biomass generating programs and facilities are already well-developed in Northern European jurisdictions, and Northern Canada has similar biomass potential. Wood waste from the forestry sector is commonly used as biomass fuel, when it is not in demand for other products,. Sustainable forestry practices and the expansion of the forestry sector in the north could further increase the potential of biomass (Government of Yukon, 2016; Northwest Territories Environment and Natural Resources, 2010). The cost of energy in the north is driving renewed interest in biomass as an alternative source of energy. Both the Yukon (2016) and Northwest Territories (2010 & 2012) have released biomass energy strategies.

Biomass can be readily integrated with other sources of alternative energy as well as with initiatives to increase efficiency and conserve energy. Efficient biomass systems can reduce dependence on diesel fuel and reduce energy costs, but sustainably harvesting wood from northern forests is more challenging than in southern forests because of the comparatively low growth rate (Northwest Territories Environment and Natural Resources, 2010).

Wood is still used today by many Yukoners to heat their homes and currently makes up 17% of the energy demand for heat in the territory. For example, abundant fuelwood is currently being sourced from beetle-killed trees near Haines Junction. Climate change is already causing the expansion of forest pests that are affecting large swaths of forest and tree deaths due to climate change mediated expansion of pests may create more opportunities to heat with biomass as part of broader forest management strategies. Wood for biomass fuel can also be sourced from sawmill waste and routine tree clearing activities. The Government of the Yukon has identified several challenges associated with biomass energy. For use in homes, older woodstoves need to be replaced with newer, more efficient models. Infrastructure and new expertise will be required to modernize and expand biomass energy and wood harvesting needs to occur in a sustainable manner. These systems should also conform to environmental standards for air pollution so that it does not pose a risk to human health or the environment. Biomass energy can increase resilience in energy systems that are vulnerable to fossil fuel price and supply, is safe to transport, unlike fossil fuels, and does not pose a risk to human health (Government of Yukon, 2016). Furthermore, money spent on wood biomass fuel sourced in the territories stays in the territories to the benefit of residents (Government of Yukon, 2016).

At present, biomass energy systems would only be viable in Nunavut using imported fuels. In the future, biomass potential may increase in some areas as the treeline expands northwards due to climate change and forest growth rates increase.

Hydroelectricity

Hydroelectricity is a viable option as an alternative energy source in the Canadian north. There is untapped potential for hydropower in the Canadian north and these projects also have a long history of successful implementation in the region, unlike other types of renewables (Thomson, 2019). Small hydroelectric plants were the first renewable energy option to be proposed and have been successful where they have been implemented (Karanasios & Parker, 2016; Karanasios & Parker, 2018). Transitioning to hydroelectricity from diesel generation can reduce the cost of electricity in the long term because it eliminates the need to purchase diesel fuel, which is a significant yearly expense and eliminates the chance of fuel spills (Abboud, 2019; Qulliq Energy Corporation, n.d.). Hydroelectric facilities also require very little maintenance compared to diesel generators (Qulliq Energy Corporation, n.d.). Hydroelectric potential in the north may further improve as precipitation increases due to climate change (Environment and Climate Change Canada, 2019).

Conventional hydroelectricity projects with dams and reservoirs alter the flow of river systems and have substantial environmental impacts including possible impacts on Indigenous subsistence economies. Run-of-river-type hydroelectric projects do not alter the flow of rivers and have significantly less environmental impacts than dams or reservoirs (Ingenium, 2020). Both storage-type and run-of-river-type hydroelectric developments have been proven to operate successfully in the north during winter as long as water levels are sufficient (Nunavut Department of Environment, n.d.). Hydroelectric facilities currently operate in Yukon and Northwest Territories as part of their energy grid (Thomson, 2019), and several locations have been proposed in Nunavut to meet the needs of resource activity (AECOM, 2011; Northwest Territories Industry, Tourism and Investment, 2012; Nunavut Department of Environment, n.d.). Large reservoir hydroelectric developments which offer electricity on demand and with greater associated environmental impacts have been proposed to meet the demands of larger centers such as Iqaluit (Qulliq Energy Corporation, n.d.; Ingenium, 2020). In the absence of resource development projects, however, there is often not a demand-side need for a dramatic increase in generating capacity to support smaller communities.

Transitioning to hydroelectricity or other alternative sources of energy, can remove the risk of fuel spills, an ever-present risk in communities that rely on diesel. For example, the community of Inukjuak in northern Quebec experienced a large fuel spill in 2015 while filling the diesel power plant tanks. It recently agreed to the construction of a run-of-river type hydro development which will replace diesel as a source of energy in the community and lower the cost of electricity. The community has also agreed to sell electricity to Hydro-Quebec which will generate revenue that can be re-invested in the community (Abboud, 2019).

Hydroelectric generation in northern communities has limitations and potentially negative impacts. Not all communities, resource development projects, or military bases are located in areas with hydroelectric potential and there are massive up-front costs associated with the construction of hydroelectric facilities (Abboud, 2019; Ingenium, 2020). Run-of-river developments need to be constructed in a river that does not freeze to the bottom during winter to allow year-round operation (Nunavut Department of Environment, n.d.). Furthermore, conventional hydroelectric dams dramatically alter freshwater and terrestrial ecosystems where they are located (Ingenium, 2020). For example, dams act as a barrier to migratory fish species (Ingenium, 2020). Climate change negatively affects dam infrastructure through permafrost degradation, increased precipitation, and melting snow and glaciers. Greenhouse gases from decaying material and methylmercury that ends up in the aquatic food chain which can seriously affect human health are produced by large hydroelectric reservoirs (Ingenium, 2020). Furthermore, the devastating effects of methylmercury on the health of residents in some Canadian Indigenous communities are well documented (Pirkle, Muckle & Lemire, 2016), and contaminants such as mercury can be transported long distances and accumulate at higher latitudes even in areas of limited industrial activity. High mercury concentrations can be found in recently impounded reservoirs because mercury naturally mobilizes from soils into aquatic ecosystems under these circumstances. This mercury then ends up in wild foods and poses a risk to human health (Pirkle, Muckle & Lemire, 2016).

Hybrid Diesel-Renewable Systems

Hybrid renewable-diesel systems which utilize both wind and solar technologies may represent the best way to implement renewable energy technologies in isolated northern communities. Hybrid diesel-renewable systems which use diesel generators during times when renewable technologies cannot meet demand allow communities to enjoy the benefits of reducing their dependence on diesel without the risks of relying solely on renewables, which are still being proven (Quitoras, Campana & Crawford, 2020). Furthermore, hybrid systems that rely on multiple sources of renewable energy such as wind, solar, and hydroelectricity can help to balance out the intermittency of these sources (Canada Energy Regulator, 2019a). Solar has great potential to power the Arctic during the summer months because many places experience a period of complete or near 24-hour sunlight; but the period of limited or no sunlight in the winter offsets this (Carreau, 2019). During this time, wind energy can supply a crucial source of power and offset use of diesel generators. Furthermore, a mix of renewable technologies can be expanded and combined to increase capacity as need grows or as communities rely less on diesel (Nunavut Department of Environment, n.d.), and LNG generators can be used as a substitute for diesel generators in a hybrid system.

The concept of hybrid diesel-renewable generating systems has been adequately proven in Alaska. Approximately 70 small communities in Alaska (of ~200) employ hybrid diesel-renewable systems which make use of a combination of solar wind and hydro (Sahar Zerehi, 2016) from which lessons can be learned and applied in the Canadian north. The community of Kugluktuk, Nunavut is slated for a hybrid diesel-solar plant which will make use of a storage plant to store energy (McKay, 2019) and Old Crow, Yukon has installed solar panels to offset their use of diesel during the summer months (Deuling, 2018). These hybrid diesel-renewable options are also applicable to resource development and economic activity in the north as well isolated military bases. The large-scale wind-diesel hybrid power facility at the Diavik diamond mine in the Northwest Territories proves that hybrid systems can be utilized to meet high electricity demand. The four turbines were designed to meet 10% of the mine's power needs but at times has supplied as much as 58% of those needs. This project was primarily driven by necessity because a mild winter delayed the opening of the ice-road that supplies the mine and forced the operators to fly-in several million litres of fuel (Kirby, 2014). This case illustrates the importance of diversifying energy sources to improve resiliency in remote locations. This is especially important in the context of climate change which will negatively impact the feasibility and cost effectiveness of transporting diesel to some remote sites.

Aside from reservoir hydroelectricity, relying completely on renewable energy requires significant storage capacity to meet demand at times when less power is being generated than what is needed. Although battery prices are falling, they still entail significant costs. Pumped hydroelectric, which stores energy as hydroelectric potential and releases it when it is needed, offers one solution, and compressed air is also being explored as a way to store energy and increase the capacity of renewables to displace diesel (Gearino, 2019; Natural Resources Canada, 2019). Compressed air storage is also being investigated as method of storing wind energy (and possibly solar) at industrial sites in the north (Natural Resources Canada, 2019), which supercharges diesel generators in hybrid wind-diesel systems to increase power and efficiency, and reduce fuel consumption and GHG emissions (Ibrahim et al., 2019).

More Efficient Fuels or Diesel Generating Technologies

Diesel is a significant local pollutant (when spilled or burned) and a large annual cost for isolated communities, resource developments, and military bases (Thomson, 2019; Department of National Defence, 2019). Storage and transport of this fuel poses a significant environmental risk, and diesel generators emit toxic pollutants that affect local environments and human health (Thomson, 2019). The noise from diesel generators can also be a stressor which contributes to other health issues.

Liquified natural gas (LNG) generators produce less GHGs than their diesel counterparts and are more efficient under certain circumstances (e.g. light loads vs higher optimal loads for diesel generators) (Thomson, 2019; Acosta, 2015). Shipping natural gas in the north remains a challenge, but small-scale LNG plants could supply local needs at a lower cost than larger developments. For example, a small-scale operator in Alberta is already shipping LNG by the truckload to Whitehorse and Inuvik and, although transporting LNG in the north by pipeline seems unlikely, cross water shipping is possible (particularly in the eastern Arctic) (JWN staff, 2017). Furthermore, both Yukon and Northwest Territories have large natural gas reserves that could be developed on a small scale to meet local needs (see Figure 1), with local natural gas currently in use in Inuvik and Norman Wells (Canada Energy Regulator, 2019b).

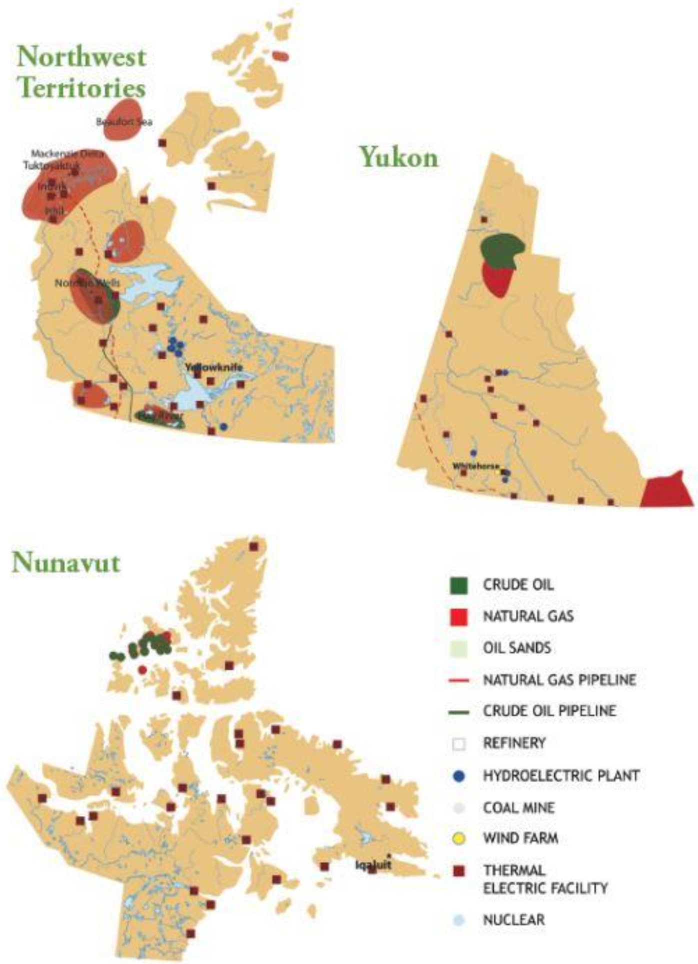

Figure 1: Location of Renewable and Non-Renewable Energy Resources and Infrastructure (Canada Energy Regulator, 2019b)

Globally, natural gas has been touted as a fuel to “bridge” the transition to renewable energy sources (Borunda, 2020) but leakage during the natural gas production process can be a significant source of GHGs (particularly methane) which makes natural gas less climate friendly than it seems (Brandt, Heath & Cooley, 2016). For the small-scale developments proposed here for production and use in the Canadian north, the GHG emission emitted during the extraction process is modest and should not be considered in the same context as emissions generated from the extraction process for the global use. Natural gas has clear local environmental and health benefits as an alternative to diesel and there are possibly economic and logistical advantages as well.

Methane, a potent GHG and with a global warming potential (GWP) that is 28-36 times that of CO_2 (United States Environmental Protection Agency, 2017) that is released from melting permafrost in the circumpolar Arctic, is a potentially globally significant source of GHGs to the atmosphere (Knoblauch et al., 2018). Methane captured passively or actively from melting permafrost, however, in a manner similar to the capture of biogas from landfills and agricultural operations is being investigated as a possible energy source (Hopkins, 2017; Soong, 2018).Active methods that require energy to extract methane from permafrost are not as climate friendly as passive collection (Hopkins, 2017) but still may ultimately provide a cleaner source of energy than diesel.

Diesel generators can be equipped with a bi-fuel technology that allows them to burn a combination of natural gas (up to 75%) and diesel. This technology allows diesel generators to be more environmentally friendly and cost effective to run, depending on the price of natural gas. Unfortunately, this same technology cannot be applied to allow natural gas generators to burn diesel. Diesel fuel and natural gas will likely be shipped by the same methods in the absence of pipelines (which are also subject to disruptions under certain circumstances), and will be subject to the same disruptions to supply. Natural gas is less of a spill risk than diesel during transport and storage, an advantage for communities and locations where there is concern over the risk of a diesel fuel spill (Acosta, 2015).

Increasing the efficiency of diesel generators, and other improvements, can reduce fuel consumption, GHG emissions, and other pollutants (often as a result of partial combustion of fuel). Diesel generators run optimally at 50-70% load, and lighter loads waste fuel and larger loads risk damage to the engine. Load banks may be used for light loads to consume excess energy and allow the engine to run at a higher capacity, but this also wastes fuel (Acosta, 2015). Increased efficiency can be achieved by matching output and load using automation and controls (Canada Energy Regulator, 2019b). Running generators at optimal loading and storing this energy for use at times when demand is too low to efficiently run the generator could help to alleviate some of the issues associated with running the generator at less than peak capacity and improve efficiency overall.

Various methods of storing energy were suggested in the section on hybrid diesel-renewable systems. Investing in energy storage capacity could also open the door to the integration of renewable technologies in the future. Using compressed air to supercharge diesel generators in hybrid diesel-wind systems (discussed in the previous section) may be used in any system that utilizes compressed air storage. Therefore, compressed air storage may be a good option for energy storage because it can also be used to supercharge diesel generators and further increase efficiency, although other storage methods may be more applicable in other situations. Waste heat can also be recovered from diesel generators and used to heat nearby buildings. Energy corporations in Nunavut and Northwest Territories have used waste heat to heat their facilities and nearby buildings since the 1990s (Governments of Yukon, Northwest Territories and Nunavut, 2011).

Increasing energy efficiency is another way to reduce the amount of fuel that is needed to supply heat and electricity to communities, resource development sites, and military bases in the North. New buildings should be constructed to a much higher standards and existing buildings should be retrofitted to make them more energy efficient, as outlined in the Canadian government's Pan-Canadian Framework on Clean Growth and Climate Change (Government of Canada, 2016). When the reduced cost to heat buildings in the North is taken against the cost of renovations or additional materials for new buildings, operators are likely to benefit from cost savings in the long run (Canada Energy Regulator, 2019b). Increasing efficiency in buildings also includes more efficient lighting (e.g. LED) and more efficient appliances (Government of Canada, 2016), but the cost of upgrading or replacing appliances in the north may not produce the same cost savings as in the south owing to high transportations costs. Increasing efficiency also positions communities positively to benefit from alternative energy sources such as renewable or hybrid systems, and can accommodate growth (i.e. greater electricity demand), but cost-benefit analysis needs to be undertaken to justify these actions in a northern context.

Small Nuclear Modular Reactors (SMR)

Small Modular Reactors (SMR) – nuclear reactors that are smaller in size and have lower power outputs than traditional nuclear reactors – have recently emerged as a novel technology which can be applied to supply power to small electrical grids or to sites in remote locations (Canadian Small Modular Reactor Roadmap Steering Committee, 2018). Although the idea of using small nuclear reactors for power dates back to the earliest days of atomic power (Ramana, 2015), there is a recent resurgence in interest about whether this highly complex, emerging technology could be used to supply power to isolated and remote communities, resource development projects, and military bases in the Canadian North. Renewed interest and investment could drive the necessary innovation to achieve modularity, but SMR technologies must be manufactured in a highly efficient manner and shipped to sites in a way that is cost competitive with other energy sources (Waters & Didsbury, 2012).

SMRs could be positioned to address the current challenges of supplying electricity in the Canadian North, where communities and sites need an uninterrupted supply of electricity in the winter for heat and where interruptions in power supply can prompt emergency evacuations. The average demand for communities in the North is about 1 MW – far less than most current SMR designs supply (e.g. the smallest SMR available in 2012 produced 25 MW) (Waters & Didsbury, 2012). The energy demand for a small community is probably similar to that of a small military installation (barring any extraordinary power demands for military equipment). Therefore, a much smaller reactor needs to be developed, in the range of 1 MW, to operationalize this technology in the Canadian north (Waters & Didsbury, 2012). Recent designs as small as 3 MW (and up to 300 MW) have been submitted to the Canadian Nuclear Safety Commission for review (Chung, 2019), and reactors as small as 0.2 MW are currently in development (World Nuclear Association, 2020). SMRs can be attached to a grid to meet the needs of multiple communities and sites or of a military installation, but this could be challenging in the North considering the impacts of climate change (e.g. thawing permafrost) on infrastructure in the region.

SMRs for use in the Canadian North should be developed with specific maintenance and reliability concerns in mind, given the limited availability of people with requisite technical skills. By contrast, diesel generators require less technological proficiency to operate. The military or resource extraction companies are more likely to have ready access to personnel who can operate SMRs, which in turn could be connected to communities through a grid. Additionally, SMRs may provide the opportunity for the development of technological proficiency for Northern community members (Waters & Didsbury, 2012).

SMRs are a potentially carbon-free energy source to meet the needs of communities, economic development, and the military in the north. Small reactors may be more economically attractive in the Arctic because of the high costs of other forms of energy. However, rushing to make nuclear reactors cheaper so that they can be deployed as more economical alternatives to diesel generators could exacerbate existing problems associated with nuclear power including accidents and the proper transport and storage of nuclear waste (Ramana, 2015).

In contrast to diesel generators (where transporting fuel to isolated sites and communities can be a significant challenge exacerbated by climate change), SMRs can operate for long periods of time without refuelling (Canadian Small Modular Reactor Roadmap Steering Committee, 2018). Nuclear reactors also can be used to desalinate sea water, an energy intensive process, and have been successfully used in this capacity in the past (Canadian Small Modular Reactor Roadmap Steering Committee, 2018; Reid, 2014). SMRs could provide the additional capacity needed to power greenhouses to increase food security in the North and can be used for hydrogen production for use either as a clean fuel or to provide buoyancy for airships (Canadian Small Modular Reactor Roadmap Steering Committee, 2018). The cost of manufacturing these reactors and transporting them to sites and communities, however, will be a determining factor in whether SMRs represent a more cost-effective solution than conventional diesel generation or other alternative energy sources.

Economic viability is not always the most important consideration in military settings such as submarines, where nuclear reactors allow vessels to remain at sea for protracted periods without refueling (Ramana, 2015). The US military is exploring very small modular reactors (vSMR) for use at forward and remote operating bases, with expeditionary forces, and to reduce their dependency on fossil fuels (supply can constrain operational capabilities) (Vitali et al., 2018). Mobile vSMRs can also increase resilience of domestic power grid infrastructure to disruptive foreign attacks (World Nuclear Association, 2020) and can provide power in emergency situations and other humanitarian assistance missions (Vitali et al., 2018; World Nuclear Association, 2020). Mobile vSMRs in the Arctic might be operationalized to respond in emergency situations such as power outages and, given their small size compared to diesel generators of comparable output capacity, they offer potential advantages in terms of portability.

The potential environmental impact of SMRs in the north also needs to be considered, especially in the context of the sensitive northern environment and the subsistence economies of Inuit and northern Indigenous peoples. Modern SMR designs are safer overall, but their safety needs to be assured specifically under the harsh conditions of the Arctic. A damaged or malfunctioning reactor can pose a threat to personnel operating in isolated locations with limited opportunities for response and evacuation. For example, a small nuclear reactor deployed by the US military in Antarctica performed poorly, caused significant contamination, and was decommissioned after only 10 years (half of its intended life span). The reactor exposed fourteen people to high dosages of radioactivity (McMurdo Station Radiation Dose Assessment Integrated Project Team, 2013) and a significant clean-up effort was required to remove contaminated soil from the site (Ramana, 2015; Reid, 2014).

The potential social and cultural implications of implementing SMR technology should also be assessed. Inuit, First Nations, and Métis peoples in the Canadian North engage extensively in subsistence activities as part of their traditional lifestyles. Even a nuclear accident that is not associated with a community has the potential to deleteriously impact subsistence economies and the health of northern ecosystems and residents. Accordingly, Northern communities have engaged in preliminary consultations to identify community concerns regarding SMRs in the north, including fears about the perceived risk of a nuclear accident, the disposal of nuclear waste, and worries that these reactors would leave lasting environmental impacts similar to historical industrial and military installations (such as the DEW line) (Neil, 2018). Nevertheless, Inuit participants accept that Canada is a leader in nuclear safety and expressed interest in training to learn to operate SMRs in the same way that community members are currently trained to operate diesel generating infrastructure (Neil, 2018). Indigenous consultation is considered integral to developing the Canadian SMR Roadmap and will have a critical impact on obtaining social licence for projects to proceed (Reed et al., 2018).

Expansion of the Existing Grid

Expansion of the existing grid network may be the most viable option and the best long-term solution to meeting energy demands for communities and sites that are proximate to existing electrical grid infrastructure. For example, much of the hydropower in Quebec is generated in the north (Canada Energy Regulator, 2019a), but small communities in Nunavik that are disproportionately affected by these developments receive no direct energy benefit from them (Thomson, 2019; Senécal & Égré, 1999). A proposed project would link the Kivalliq region of Nunavut to hydroelectricity by connecting five communities and two mines to the Manitoba power grid. This project is projected to reduce the cost of electricity in these communities by 50%, reduce local air pollution, and eliminate the risk of fuel spills (d'Entremont, 2020). Broadband connectivity would be extended to these communities along the same corridor via a fibre optic cable. Other studies propose that Yukon communities and sites could be linked to existing grid infrastructure in Alaska (Standing Senate Committee on Energy, the Environment and Natural Resources, 2015).

Large energy developments in the north such as large hydroelectric dams, wind farms, LNG generators, and small nuclear reactors may produce enough power for more than one community or site. Connecting these communities or sites through grids could bring cheaper, more reliable, and cleaner electricity to residents or industry to facilitate economic growth and meet increasing demand. Expanding grid network infrastructure remains very expensive, however, and communities are often long distances apart. Furthermore, the impacts of climate change challenge both the construction and maintenance of grid infrastructure. Hydroelectric dams and reservoirs, wind farms, and LNG projects have significant environmental impacts that must be considered, especially in the context of Indigenous subsistence economies and land claims agreements. SMRs have a small environmental footprint when operating correctly, but there is potential for widespread and long-term damage in the event of an accident.

Conclusion

Many communities and remote resource developments and military bases in the Canadian North are solely or primarily reliant on diesel generators for electricity and heat. Diesel fuel is expensive, difficult to transport, and poses a risk to the local environment and human health when spilled or burned. Despite these drawbacks, diesel has persisted as a source of energy in the region because alternative sources of energy are not perceived to be as cost-effective and reliable. The current and future cost of diesel, the desire to stimulate local economic growth, environmental awareness, and logistical challenges exacerbated by climate change are reasons why policy makers should consider alternative sources of energy. Supply chains are already interrupted by climate and environmental changes that threaten the energy security of communities and remote sites in Canada's North.

The price of alternative energy technologies is falling, and continued growth and investment may lead to innovation that addresses unique challenges in the North. The price of electricity generated from renewable sources is now cost competitive or cheaper than fossil fuel generation globally. Renewable technologies also increase resilience to supply chain interruptions. Solar energy is limited seasonally in the north but is still a good option for reducing reliance on diesel in the summer. Wind energy and hydroelectricity are available year-round, and various options are being explored to improve energy storage. Diesel-renewable hybrid systems that use both wind and solar are increasingly attractive options, as are various reservoir and run-of-river hydroelectric developments. Geothermal and biomass are other renewable alternative energy options with limited applicability in some regions.

Small modular nuclear reactors (SMRs) that can power the needs of a single community or site are still in development or in the process of licencing. Depending on location, this technology may not be cheaper than other forms of alternative energy but could bring other benefits. Despite persistent concerns about nuclear accidents, contamination, and human health that accompany SMR technology, Canada has one of the safest nuclear power programs in the world (Canadian Small Modular Reactor Roadmap Steering Committee, 2018) and safety concerns around the application of SMR technology in the north may subside over time (Neil, 2018).

This report also considers how improving the efficiency of diesel generators can be achieved. Furthermore, switching to generators that run on cleaner, cheaper fuels such as LNG is a relevant option to replace existing systems. Improving efficiency in buildings and reducing electricity consumption reduces the amount of diesel burned in communities and at remotes sites and frees up electricity that can be used to accommodate economic growth. Expanding grid networks can also deliver cheaper, more reliable energy to communities, resource development sites, and possibly military bases.

Alternative energy in the north needs to be cheaper, more reliable, and cleaner than diesel in order to take hold. There will not be one solution to the energy challenges in the North but many, given the varied needs and opportunities in communities and at remote sites for alternative energy. A combination of energy sources will increase resilience to climate change and supply chain disruption as Northern residents and actors operating in the region seize opportunities to achieve greater energy self-sufficiency, stimulate local and territorial economies, lower energy costs, and remain responsible environmental stewards.

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