Providing Energy Security to Remote Communities: An Analysis of Modular Energy Sources

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Electricity is a vital part of the modern world, but access to this resource is not equal across Canada. Many northern remote communities, particularly those in Nunavut, Quebec, and Northern Ontario, rely on expensive and inefficient diesel fuel for electricity and heating (Fig. 1) [1]. This has led to widespread fuel poverty, long-lasting power outages due to maintenance delays, and frequent fuel spills [2]. Energy insecurity in remote communities has been occurring for many years and is widespread in many provinces across Canada . Because these areas are not connected to the North American electrical grid, they must generate their own power. With improvements in technology, cheaper, more reliable alternatives to diesel are becoming available. The research presented here compares three modular energy sources to find the best solution to widespread energy insecurity: wind, solar, and small modular reactors (SMRs). Performance across five categories is considered: economic, health & safety, societal, environmental, and capacity. Impacts from decommissioning current diesel generators are beyond the scope of this research. The Canadian Government is currently considering SMRs as “primary alternatives” to diesel fuel as outlined in their Small Modular Reactor Action Plan [3]. However, SMRs are not viable alternatives for replacing diesel fuel in remote Canadian communities, so renewable sources like wind and solar should instead be considered, providing communities with cost-effective, safe, and reliable energy.

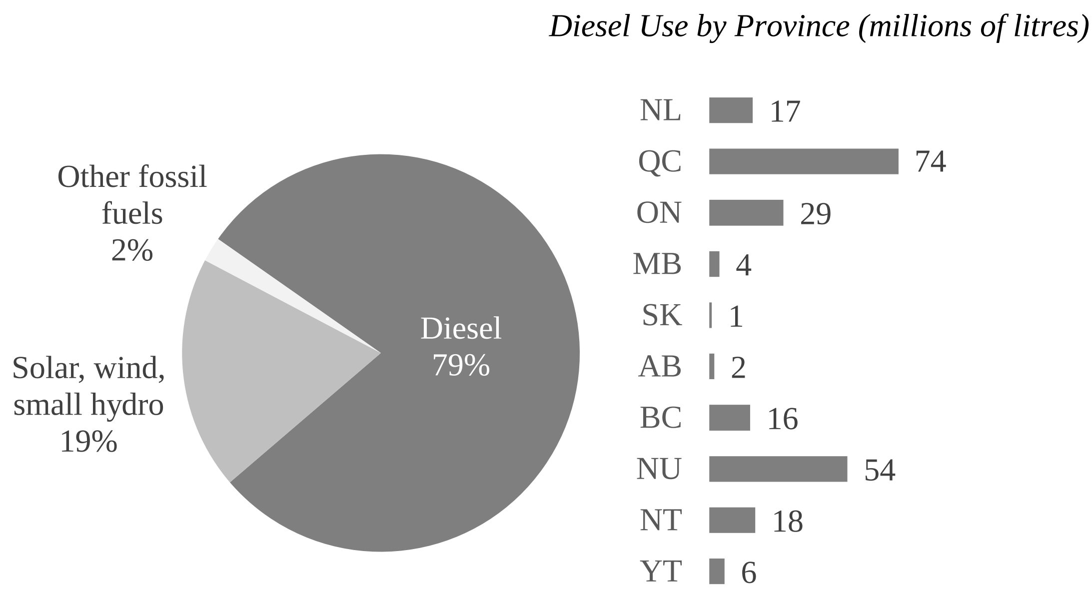

Fig. 1. Canadian Remote Community Electricity Generation Breakdown (2020) (source reproduced from [1])

There are approximately 200,000 people living in over 280 communities across Canada that are not connected to the North American electrical grid and are characterized as "remote" [4]. Due to the low population density in these areas and their surrounding geography, it is not technically or economically feasible to extend the energy grid to reach the communities. Instead, electrification projects rely on constructing mini-grids for small, self-sustaining generators to provide these remote communities with energy [5]. Historically, these communities have turned to diesel generators to meet their energy needs which have led to significant economic problems and maintenance challenges [6].

Diesel is expensive, risky, and inefficient but it has been the primary energy source in these remote communities for decades. Costs associated with the purchase, transport, and storage of fuel only cover a fraction of the "true" cost that these communities pay. There are serious health and environmental risks associated with diesel such as local air pollution and the over

1000 catastrophic spills that occur each year across Canada [7]. The inefficiency of diesel generators in cold, northern communities has led to prevalent fuel poverty, where households spend more than 10% of their income on utilities. To reduce fuel poverty rates and ensure these regions have affordable and reliable energy, the Canadian government must implement large subsidies [8]. Furthermore, many of the generators are also publicly owned and require parts and labour to be imported for repairs and maintenance, leading to delays and long-lasting power outages [5]. Replacing diesel fuel is a key step in providing communities with energy security, but alternative energy sources must incorporate local training to reduce maintenance delays.

SMRs are nuclear reactors that offer high standards in safety, energy reliability, and portability. While they are still in development and are not expected to hit the market until 2030 [9], they show promise as a potential energy source for remote communities. SMRs typically have a capacity under 300 megawatts (MW), whereas traditional reactors like the Bruce Generating Station in Ontario have capacities over 3000 MW. Due to their small size, they can be factory constructed and transported to sites, leading to better quality control and a safer, more efficient system overall [10].

To determine which energy source would best serve remote communities, each of the three options is assessed based on five factors: economic, societal, health & safety, environmental, and capacity. Performance against these 5 criteria is illustrated as a heat map (Table I) as either poor, average, or excellent.

The economic cost of a generator includes its implementation, maintenance, and operation expenses. These are combined into the Levelized Cost of Energy (LCOE) (Fig. 1) [11], [12]: the average price per kilowatt-hour (kWh) of electricity needed for a generator to break even over its lifetime. Energy costs are important aspects to consider when installing generators in remote communities since reducing fuel poverty allows communities to become more independent and sustainable.

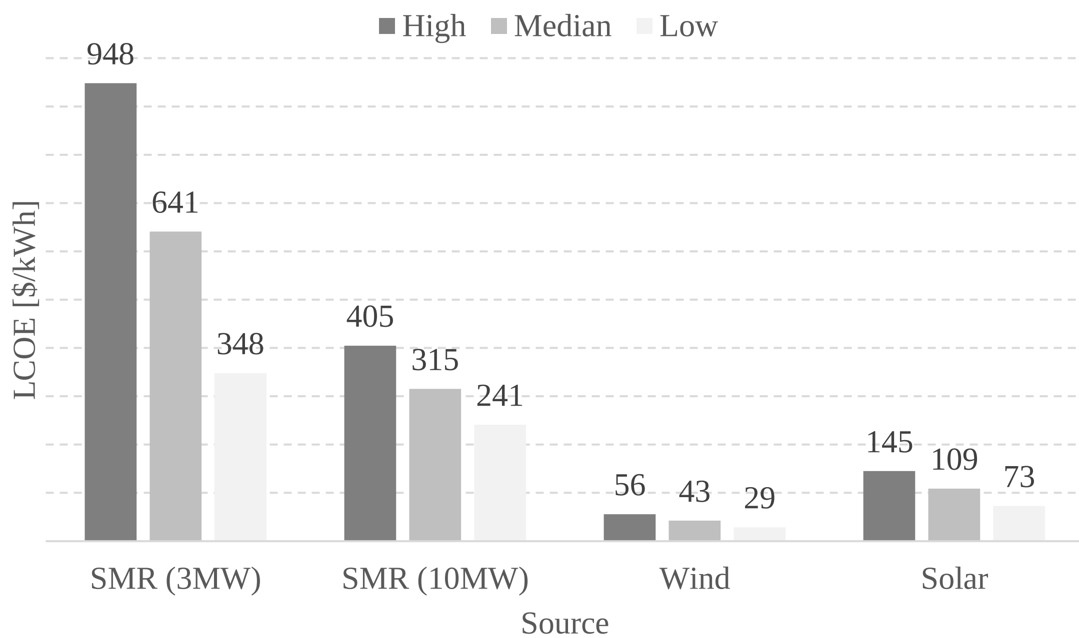

Fig. 2. Levelized Cost of Energy (LCOE) in Canada per kWh (source reproduced from [11], [12])

Currently, wind energy is the most cost-effective option available, and its cost/kWh is only expected to decrease over the next decade [6]. When SMRs are launched in 2030, they are expected to have a minimum LCOE of $241/kWh which would only increase fuel poverty in remote communities. SMR costs are also highest with lower capacity reactor installations (i.e. <= 3 MW), which makes them less feasible in smaller communities with lower energy demands.

Societal factors are arguably the most important because they identify the level of community independence and job opportunities that energy sources offer. While many diesel reduction projects have already been implemented in remote communities in other countries, many have also failed due to a lack of local personnel trained to perform adequate maintenance [5]. Many studies have identified the need to build local expertise to eliminate the delays that come with sourcing external assistance [1], [5], [13]. Wind and solar projects have already been implemented in remote communities through government grants and programs that also offer local training (Fig. 1) [1]. SMRs, on the other hand, will likely require an extensive network of expertise for maintenance when they first become available and require further testing during commissioning, limiting community independence [13]. Currently, remote communities in Canada rely on diesel imports as well as external assistance for the operation and repair of their diesel generators [5]. Wind and solar projects have proven that community-owned mini-grids are feasible and sustainable while SMRs will further limit community independence.

Health & safety factors consider the safety and quality of life of workers and people in the surrounding community. Establishing these needs as top priorities is a critical step when building local expertise, promoting job opportunities, and protecting the basic human rights of residents [2]. Both wind and solar excel in terms of safety by providing clean energy without generating harmful waste. SMRs also offer high safety standards compared to traditional nuclear reactors through passive safety systems which reduce the risk of severe accidents [10]. Reactor meltdowns are even physically impossible in approved SMR designs [9]. These three energy alternatives all offer high standards for safety and local health preservation, especially when compared to diesel fuel.

During the construction and operation of the generators, local and national impacts are important environmental factors to consider. Wind, solar, and SMRs produce virtually no airborne pollutants during operation. However, uranium mining, for SMR fuel, produces waste that can be radioactive and devastating to the environment if not managed properly [14]. In Canada, burying spent nuclear fuel remains the only method for disposal [15]. While the risks of environmental pollution from buried waste are low, there are known cases of water collecting in storage facilities and causing radioactive runoff [16]. SMRs may produce no carbon emissions during operation, but improper fuel management can still release harmful radioactive pollutants.

Capacity factors characterize a generator's ability to meet energy demands and operate reliably under varying seasonal and weather conditions. Most remote communities have an energy demand in the tens of MW which is entirely manageable for a small wind farm or an array of solar cells [13]. However, because wind and solar power generation are heavily reliant on weather conditions, incorporating energy storage technologies is critical to their success. Energy storage increases energy reliability by providing power on calm or cloudy days when energy cannot be generated and has been shown to improve overall project success [5]. SMRs, however, can operate at any time of day and independently of weather conditions [10].

The results of the comparisons across the five categories of interest are summarized in the heat map below (Table I).

Table I

Performance Comparison of Energy Sources

	Energy Source		
Factor	SMRs	Wind	Solar
Economic			
Societal			
Health & safety			
Environmental			
Capacity			

Legend: Poor, Average, Excellent

From this analysis, it is clear that wind power is the best alternative to diesel fuel in remote communities, closely followed by solar. However, site-specific conditions must be considered before implementation. For example, wind power would not be appropriate in areas where the wind speed is lower than 5 m/s on average [17]. The results from this study indicate that the Canadian government should focus on implementing renewable alternatives like wind and solar rather than rely on SMRs as primary alternatives to diesel fuel in remote communities.

Due to the shortcomings of SMRs in the economic, societal, and environmental categories, wind and solar are better alternatives for replacing diesel fuel in remote Canadian communities. The research presented here shows that, when SMRs become widely available in 2030, they will not be the cheap, reliable solution to energy insecurity that the Canadian government envisions. Instead, new policies must be developed for remote communities that put local training and job opportunities first. This means further developing wind and solar infrastructure and bringing renewable energy to northern Canada.

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