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Northern Lights

by Mariano Arriaga, Claudio A. Cañizares, and Mehrdad Kazerani

Access to energy in some of the world's remote communities is still restricted; these locations only have access to simple and inexpensive local energy sources such as biomass for cooking, and kerosene lamps or candles for lighting. The World Bank and the International Energy Agency (IEA) perceive this energy deficit as a major obstacle to achieve community economic development, as well as access to health services and clean water resources. Electricity is a flexible modern energy source that is considered as one of the main driving forces that stimulate community development and access to basic services in remote locations. Governments, private institutions, and non-government organizations have gradually recognized these energy needs and have established electrification programs at national and regional levels that aim at the gradual electrification of remote locations. The IEA estimates that 1.3 billion people worldwide have no access to electricity and that their interconnection to the existing electric grid is unfeasible under a 5-10 year timeframe. Most of this population (93%) is located in Africa (587 million) and Asia (675 million), while the remaining (7%) is distributed in Latin America (31 million), the Middle East (21 million), and developed countries. The IEA estimates that by 2030, 400 million people can be given access to electricity by extending existing national grids, while the remaining 950 million can potentially be electrified with individual household stand-alone or microgrid systems.

The population segment with no electricity access is only part of the remote energy problem since currently some remote communities (RC) have off-grid microgrids in place which solely generate electricity using fossil fuel-based generators. Moner-Girona et. al estimate that diesel engines in off-grid remote locations have a combined installed capacity of 10,000MW globally[1], and the operating conditions of these units certainly differ depending on the local settings. Some of the reasons behind diesel generators being a widely implemented alternative are their reliability, relatively simple maintenance, and mature technology which tend to overcome the associated negative effects such as high operating costs, environmental impacts, and fuel logistics. Nevertheless, these same drawbacks

[1] In addition to small off-grid 10,000+ small hydro installations and 1,000+ solar photovoltaic or wind hybrid systems worldwide.

create significant opportunities for energy supply improvements that, if properly planned and implemented, can potentially bring further development to the communities.

In Canada, approximately 200,000 people live in 280 communities across the country which, from an electrical perspective, are classified by Aboriginal Affairs and Northern Development Canada (AANDC) as off-grid communities since they are not connected to the North American electric grid. These Northern and Remote Communities (N&RCs) currently satisfy their electricity needs mainly by using diesel-based generators (Figure 1), with some important exceptions in which hydro is the primary energy source. For diesel-based generation, the electricity costs are higher than those for the rest of the country and vary significantly depending on the communities' transportation access, among other factors (Figure 2). For example, an all-year road access community can have an approximate electricity rate of C$0.45/kWh, while a mainly barge and/or air access location can scale to C$0.80/kWh, and for Arctic locations the rate can range from C$1.50/kWh to C$2.50/kWh. For hydro-based generation, the rates in N&RCs range from C$0.15/kWh to C$0.40/kWh, depending on the northern location and installed capacity. In contrast, in the rest of Canada, the average electricity rates range from C$0.07/kWh to C$0.17/kWh, depending the province given the significant difference in energy resources from province to province.

The energy-related challenges of N&RCs encompass economic, technical, social, and environmental issues that need to be collectively analyzed. From an economic perspective, the high energy rates are a direct consequence of the challenges that N&RCs currently deal with to supply electricity. Operation of the energy generation and distribution infrastructure is expensive since generally qualified technicians have to be flown in to conduct preventive and corrective maintenance. Furthermore, some N&RCs have specific rate riders on top of the base rates that fluctuate depending on the diesel-fuel cost. Road access for some N&RCs is limited to winter-roads for which serviceable life varies every year, and is subject to weight restriction depending on the ice conditions. From a technical perspective, energy generation technologies need to have a reasonably long operating life while withstanding harsh operating conditions under minimum or locally available maintenance personnel. From a social perspective, energy limitations can affect community development as the community electricity demand approaches current generation capacity limits. Finally, from an environmental perspective, diesel-based generation yields greenhouse gas emissions regardless of the location; this issue can be more significant due to the additional fuel-transportation and community heating requirements.

Figure 1. Aerial view of Makkovik Inuit RC, Labrador (photo courtesy of Oliver Johnson). A diesel generation facility operates throughout the year to provide electricity to the community.

Figure 2. Partial views of the Canadian Arctic city of Iqaluit, Nunavut (photo courtesy of Cassia Johnson and Hilary White). Community transportation access varies throughout the year based on meteorological conditions.

Northern and Remote Energy Projects

Over the last decades, there have been efforts from different stakeholders to address some of the above mentioned energy-related issues in N&RCs. Federal and provincial government agencies, utilities, non-profit institutions, companies, universities, and communities have individually and in collaboration tackled energy generation and demand challenges including energy efficiency, natural resources assessment, and renewable energy (RE) alternatives. A general view of the state-of-the-art of such efforts across Canada's provinces and territories is provided next.

Efforts from different standpoints have been made to increase the understanding of energy issues in the North, as well as the conditions required for the deployment of RE technologies. Natural Resources Canada (NRCan) has created a catalogue of the N&RCs' energy requirements and supply, which has been used as a baseline for the information presented in this article. The Pembina Institute has also conducted energy baseline assessment for several RCs in which the electrical and heating requirements are analyzed. In addition, Tim Weis and Jean-Paul Pinard have done extensive research regarding wind measurement and its potential in RCs. Chris Henderson, from Lumos Energy, has expanded on inclusive project management frameworks where he emphasizes the vital requirement of strong partnerships among the involved stakeholders at all project stages. For several years, the Canadian Wind Energy Association (CanWEA) has lobbied for the adoption of a wind turbine (WT) incentive for off-grid projects, which is yet to be implemented. In the Yukon, John Maissan has expanded the idea of a RE policy for N&RCs by analyzing the energy efficiency potential, current RE barriers, and lessons learned from failed past incentive programs.

In recent years, there have been mainly pilot projects to further understand and assess the challenges of energy projects across N&RCs in Canada:

- ✓ In British Columbia, a hydro-hydrogen-storage project was deployed in Bella Coola, proving the deployment capabilities of the technologies; the full potential seasonal savings of the project are being quantified. A 27kW$_p$ solar photovoltaic (PV)-diesel system distributed across the community has been installed in Nemiah Valley, and 25% fuel costs reduction have been reported. Recently, a smart-grid system has been installed in Hartley Bay to allow the community to explore alternatives for energy demand reduction.

- ✓ In Newfoundland and Labrador, the wind-diesel system installed in the reasonably accessible Ramea Island is an example of a system with 10-13% wind penetration (6× 65kW WTs); the system is now being tested with hydrogen storage and further wind power (162kW electrolyser, 5× 62.5kW hydrogen engines, 300kW WTs) to increase the RE penetration level with a capital investment of $9.7M. Some remote northern stations have installed PV-diesel systems to supply power to base camps in Labrador (Figure 3).
- ✓ In the Northwest Territories, there has been wind pre-feasibility studies and measurements in several RCs, as well as a slowly but continuous installation of solar PV systems across the territory, currently accounting for 180kW_p of solar PV systems. Additionally, the Diavik diamond mine recently installed a 9.2MW wind farm reducing the mine's fuel consumption by 3M litres.
- ✓ In Nunavut, significant work has been done to secure funding and assessments for the Iqaluit Hydro-Electric project, which in an initial stage will have a 10-14MW installed capacity. A few solar PV installations across the territory have been also deployed, as well as a 65kW WT in Rankin Inlet.
- ✓ In Ontario, four WTs, with a total capacity of 60kW, have been installed at Kasabonika Lake First Nation which is an initial step to understand the deployment of RE technologies in the remote communities of the province (Figure 4); the University of Waterloo has been collaborating with industry and the community to further understand the communities' energy requirements and challenges. Also, a PV-diesel system of 20kW_p solar PV and a 50kW diesel generator have been added to the microgrid system at Wawakapewin First Nation; the intention of the small diesel generator is to avoid running the larger units at low-load conditions. Additionally, Hydro One, the utility serving approximately 60% of the RCs in the province, has implemented an incentive for customers to supply electricity with RE by implementing a modified feed-in-tariff program.
- ✓ In Quebec, two stand-alone wind-diesel systems have been currently deployed to assess different technologies and RE penetration levels using flywheel systems: the Kangiqsualujjuaq project with an 800kW WT capacity and 200kW flywheel, and the Îles-de-la-Madeleine with a 3.15MW WT capacity and 5MW flywheel system. In addition, a 7.5MW run-of-the-river system has been under assessment in Innavik.

- ✓ In the Yukon, there are two WTs with an installed capacity of 810kW in Haeckel Hill, near Whitehorse, as well as a community-based wind farm project of 250kW currently developed by the Kluane First Nation and Jean-Paul Pinard.

Even though, most of the aforementioned projects refer to relatively small installed capacities compared to the respective total generation capacity, these are helping to better understand the deployment challenges of RE in the North, thus paving the way to larger deployments with higher RE contributions in the future.

Figure 3. Solar PV system installed at the remote Torngat Mountains National Park base camp, Labrador (photo courtesy of Oliver Johnson). Similar small solar PV systems have been successfully installed in Canada’s N&RCs.

Figure 4. Small WTs installed at Kasabonika Lake First Nation, Ontario. Tilt-up towers are a feasible option to install and maintain the WTs with locally available resources.

Provinces and territories have different challenges due to their available resources and energy requirements; thus, each has taken different approaches to tackle the current energy issues in their respective N&RCs. As part of an NRCan-funded project, the University of Waterloo has been involved in researching the energy challenges of such communities analyzing the typically scattered energy-related information.

The rest of this article aims to give further details about the current status of the N&RCs across Canada by classifying the communities based on their energy generation source and capacity. In this context, the energy requirements and the diesel fuel consumption required to maintain this operation are described. Also, a classification of the different types of clients and their respective rates is presented, explaining the existing subsidy framework. Finally, a summary of the most relevant issues regarding energy generation and its considerations for future RE projects is presented.

Canadian N&RCs' Grids and Microgrids

Approximately 280 N&RCs are scattered across Canada (Figure 5) and their population encompasses aboriginal and non-aboriginal groups. Aboriginal First Nation groups are mostly in Ontario, Northwest Territories, Yukon, Manitoba, Saskatchewan, and British Columbia. These groups are governed by a Band council preceded by a chief who can lead a single or multiple communities. Inuit communities are distributed across Labrador, Northwest Territories, and predominantly Nunavut. The Inuit have a self-governing body with a non-profit organization, Inuit Tapiriit Kanatami, who deals directly with the government of Canada in related matters. Non-aboriginal groups are mainly in British Columbia, Newfoundland and Labrador, and the Yukon.

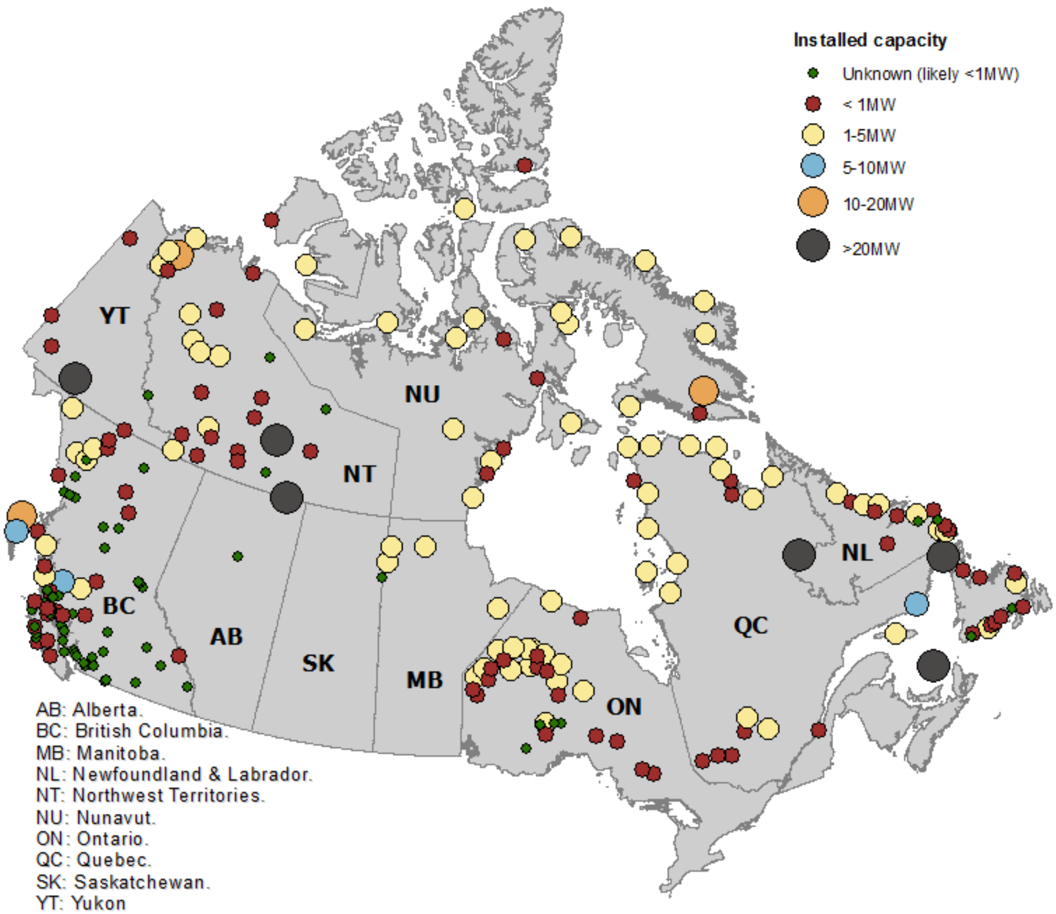

Figure 5. Classification of Canada's N&RCs based on their electrical equipment installed capacity.

From an electric perspective, these communities represent isolated microgrids and grids that range from 100kW to 150MW installed capacity. Figure 5 shows a classification for such microgrids/grids based on their installed capacity. The relatively large urban centres have an installed capacity greater than 20MW, typically supplied by hydro or fuel-oil sources; these large communities usually supply a large central load as well as nearby satellite communities; through a distribution system usually in the 4.6 to 25kV voltage range. There are 6 communities spread in the 5-20MW range (orange and blue), mostly supplied by diesel fuel for electricity generation. The rest are less than 5MW microgrids (yellow and red) with limited transportation access. Figure 5 also shows communities where data was not available (green); however, based on population density, most of these communities are likely to have an installed capacity of less than 1MW, with diesel fuel as their main source for generating electricity.

The diversity of these communities also extends to the type of utility operating the generation and distribution systems. Nearly 65% of the N&RCs are supplied by a provincial or territory-wide utility and the remaining sites are operated by community-owned utilities. Energy information for large province-wide utilities is typically easier to acquire since such organizations have a large database infrastructure. From an operational perspective, they also have sufficient technical and economic resources available to maintain systems running efficiently. In contrast, information from community-based utilities is difficult to acquire, and from the limited information available, they are likely to have limited operation and maintenance programs. These independent utilities are mostly in Ontario and British Columbia.

Electricity Generation

Most of N&RCs supply electricity via hydro and oil-based resources; however, the energy mix varies significantly by location. The total N&RCs installed capacity is estimated at 615MW, with 190MW of hydro power, 330MW of diesel generators, 67MW of heavy fuel oil generators, 7.7+MW of natural gas turbines, with the remaining capacity being relatively small wind and solar systems (Figure 6). In British Columbia, Manitoba, Newfoundland and Labrador, Nunavut and Ontario, diesel generators are the main power source for their RCs, with only a few exceptions using hydro power as a secondary electricity source. The Northwest Territories and Yukon have relatively large distribution systems with hydro power as their primary energy source; only smaller RCs use diesel fuel as the main electricity generation source. In the Northwest Territories there are two communities that have natural gas facilities, mainly due to the existence of on-site deposits, with no fuel transportation required. Quebec has three large grids running with different sources: the Lac Robertson and

Schefferville system run on hydro power, while the Îles-de-la-Madeleine system is the only off-grid plant in Canada running on heavy fuel oil, with a significantly higher efficiency than diesel; the rest of the communities are small and run on diesel generators.

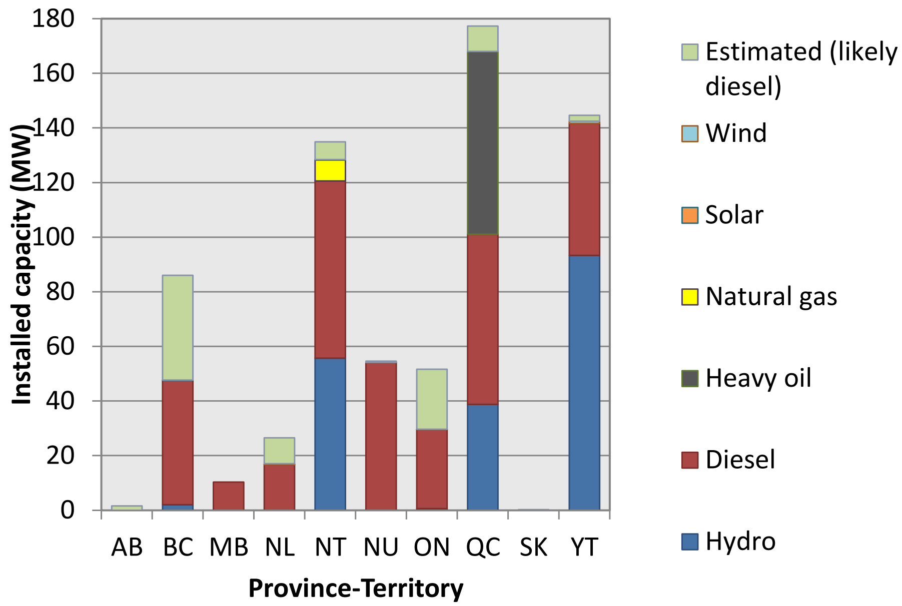

Figure 6. N&RCs electrical equipment installed capacity by province and energy source.

If large hydro power facilities are excluded, RE has yet to have a significant contribution to the energy mix in N&RCs. As previously mentioned, there are relevant past and on-going studies and projects that are slowly paving the path to overcome the technical, social, economic, and political barriers preventing a significant RE growth. Based on the existing diesel-based capacity, there is significant potential for RE to contribute to the development of N&RCs if the various issues associated with RE cost, deployment, operation and maintenance are properly addressed.

Diesel-based equipment operation is, as expected and analyzed in the next section, a key driver of the high energy costs in N&RCs. The equipment and facilities employed in N&RCs have certainly some differences; however, the following list presents the common characteristics among the various facilities and their operation that contribute to the high energy costs:

- ✓ Approximately 90% of the diesel engines in operation in RCs have a capacity in the range 100kW to 3MW. Most RCs' generation facilities have a 3-5 diesel engine unit configuration. The specific sizes depend on the operation strategy of the utility. Some utilities operate the units in parallel, where the diesel generators have similar rated capacities. Others operate mainly with a single unit strategy; in this case, the diesel generators have different rated capacities ranging from the expected minimum to maximum load of the community.

- ✓ The rated plant capacities of the diesel generation facilities are typically 40%-60% of the sum of the in-house generation equipment (total installed capacity). All utilities always have a contingency plan to keep operating in the event of a unit failing; if required, load shedding is an alternative.
- ✓ There are several factors that affect diesel engine efficiency, such as preventive maintenance, diesel fuel quality, and engine loading. In RCs, these factors likely play a major roll which creates a significant variation across facilities. The diesel fuel efficiency (to electric energy) range is 2.4-3.9kWh/litre, with a 3.5kWh/litre average. In the case of the heavy fuel oil plant in the Îles-de-la-Madeleine, the fuel efficiency is 4.6kWh/litre.
- ✓ The sources of electrical losses are difficult to determine and their variation across different utilities is significant. Based on the information provided by the utilities, the losses range from the 5% to 20%.
- ✓ Fuel supply channels vary significantly across N&RCs mainly due to access restrictions, season and fuel storage capacity. Access to these N&RCs can be a combination of road (year-round and winter-only), rail, barge, and air access. Some communities are able to store a full year supply in local tanks while others can only store for a few months of demand on-site (Figure 7 and 8).

Figure 7. Air-access is the only means of transportation available for some RCs during certain seasons of the year.

Figure 8. Fuel transportation to RCs is an expensive operation, since resources are mainly flown in (photo courtesy of Oliver Johnson).

Electricity Demand and Fuel Consumption

The electricity demand and profile differ significantly from the respective values for on-grid systems on each province. Thus, in 2010, the average electricity consumption in the country was 15.1MWh/year per capita, while the estimated range for N&RCs, where information was available, was 3.5 to 18MWh/year per capita. This wide range also applies to the electric load profile which presents significant differences across communities (Figure 9). Some of the reasons for the wide range likely include the type and quantity of electrical loads serviced, cut-off rates (see next section), daylight hours, local industry development (e.g., mining and fisheries), and seasonal services. This load variation highlights the importance of understanding the community use of electricity, and being cautious with regard to assumptions where information might not be readily available or existent.

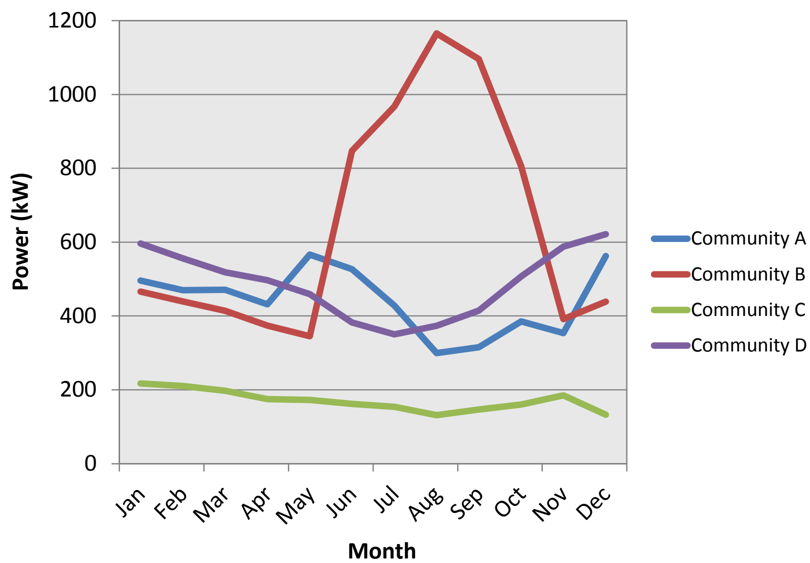

Figure 9. Annual load profile examples for selected remote communities across Canada.

Diesel and heavy oil are the energy sources used to supply electricity to more than two thirds of the N&RCs. The estimated annual fuel consumption for electricity generation in the North is 215 million litres (corresponding to approximately 600 kton CO_2eq), and its breakdown by province and territory is shown in Figure 10. Approximately 60% of the fuel is consumed by British Columbia, Nunavut, and Quebec, and with the exception of the Îles-de-la-Madeleine and Iqaluit, all serviced communities have relatively small and scattered grids (microgrids). Evidently, the rising fuel and shipping costs have a direct impact on the energy prices in the North. The next section will examine the wide range of electricity rates based on fuel source, access, intended use and type of customer.

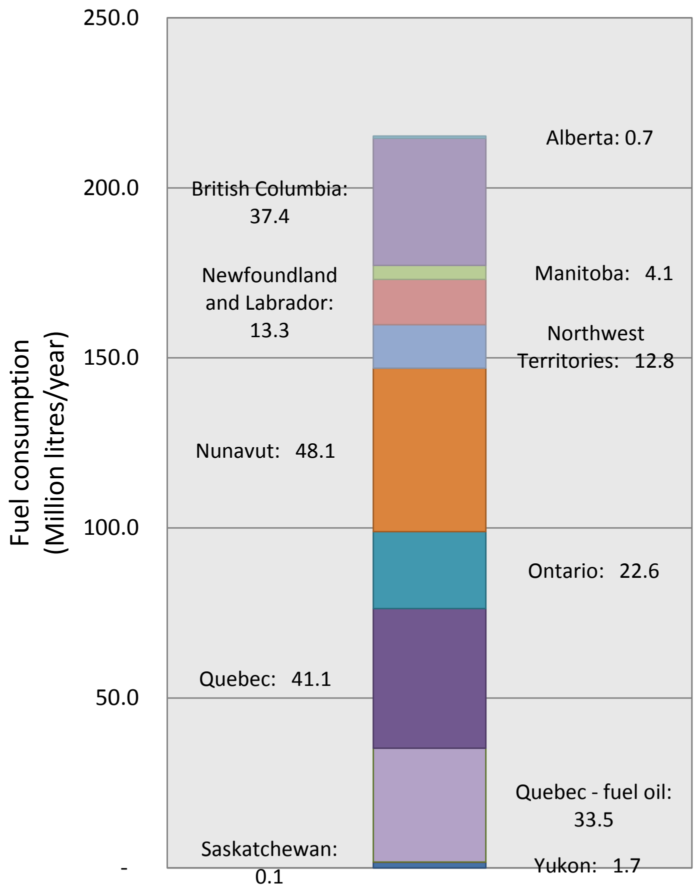

Figure 10. Fuel consumption for electricity generation per province and territory. Unless otherwise stated the reported quantity is for diesel fuel.

Electricity Rates

The cost of supplying services to the North is high, and electricity is no exception. As with regular electricity rates, the price depends on the energy sources available, but in the case of N&RCs, access, utility type, and customer classification play a significant role in determining the corresponding electricity rate. Regardless, the costs are primarily covered by the government of Canada, under different provincial and/or federal agencies and payment frameworks. The government agencies' role and detailed structure are beyond this article's scope, since it is an extensive topic; however, a general perspective regarding rates can formulated without getting into further details regarding the role of each stakeholder. The rates structure varies by province and territory, and it is challenging to make a direct comparison among them; however, a simplified classification is given below to give a general economic perspective of electricity rates in N&RCs.

The electricity rates vary among customers and are set to cover the operational costs and reflect the subsidy framework available for each rate. Figure 11 presents a simplified classification of the diverse electricity rates by customer type, government and non-government, and end-use of electricity (residential and general services). Figure 11(a) shows the non-government residential rates which are generally lower than the total operation costs, especially for diesel-based locations. In the case of provinces, these lower rates are set to match the equivalent on-grid electricity rates; for the territories, the rates are set to match the tariffs charged in their respective capitals (Yellowknife, Whitehorse and Iqaluit). Figure 11(b) shows the non-government general service rate, which in most locations is similar to the residential tariff; the differences depend on the subsidy level of commercial clients. For the previous rates, an energy cut-off scheme applies in which a tariff closer to the operational cost is charged after certain period is reached (e.g., in NT, the base rate for Sachs Harbour is C$0.26/kWh and in the winter, after 1,000kWh/month, the rate increases to C$0.54/kWh). An important objective of this scheme is to discourage the use of electricity for heating purposes. Figure 11(c) and (d) present the government rates for residential and general services use, respectively. These rates are commonly higher than the non-government parts and nearly reflect the average operation costs in the region. How the rates are set in each location depend on the utility; some calculate an average operation cost based on a specific region, while others set a distinct tariff by community.

A subsidy framework is required to bridge the gap between the operational costs and the lower non-government rates. These frameworks can involve federal and/or provincial agencies, and vary significantly by province and territory, type of utility, customer type, and diesel-fuel price. For example, British Columbia has a high subsidy for the delivered diesel fuel price, which leads to low electricity rates for all customers. In Ontario, the diesel fuel prices are the same as those in the rest of the province, which after adding transportation costs, drives operation and maintenance costs to approximately 8-10 times the on-grid residential rate. The government of Ontario has a provincial fund in place to support utility-operated communities, while AANDC supports community-operated locations. In Manitoba, the government rate is calculated to pay for the gap between the total generation costs and the non-government rates; thus, the high discrepancy between the two prices.

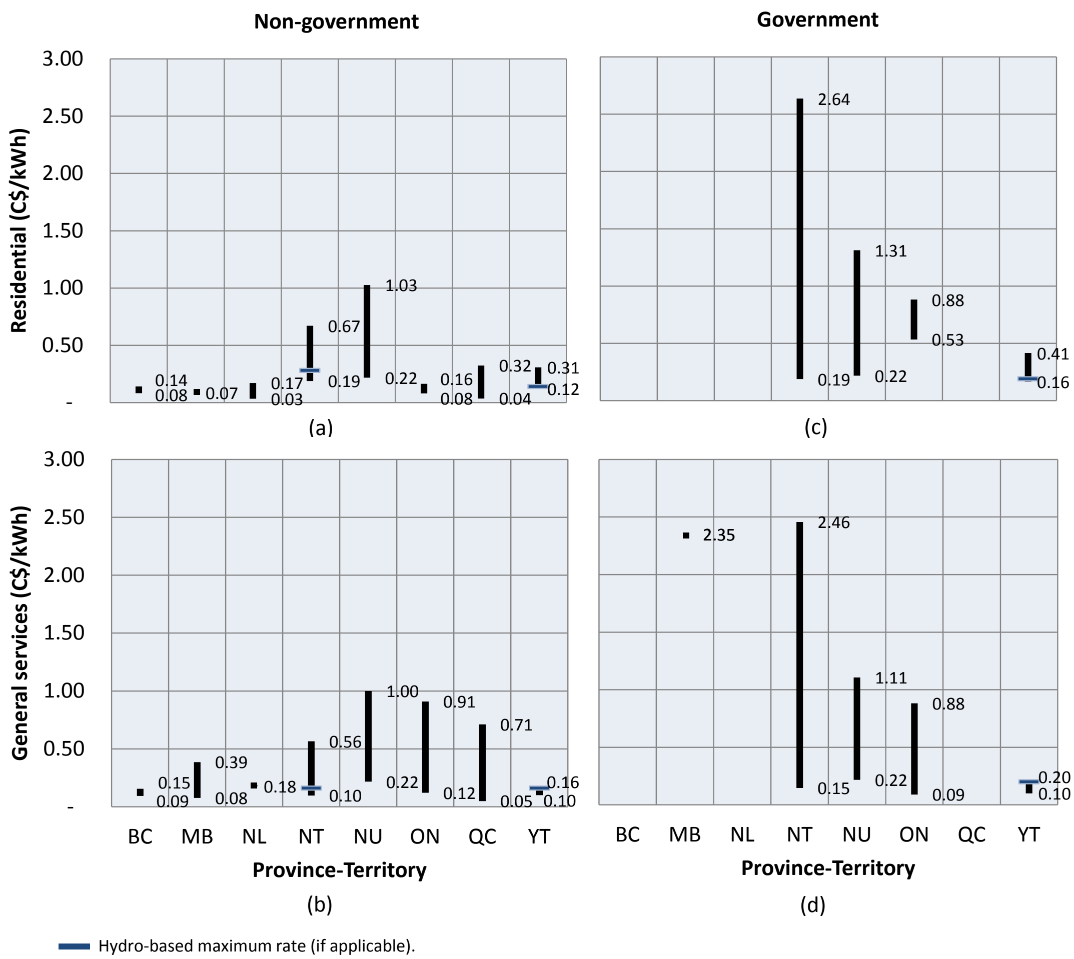

Figure 11. N&RCs' electricity rates by province and territory for: (a) non-government residential, (b) non-government general services, (c) government residential, and (d) government general services.

Energy-related Issues

From the previous discussions, it is clear that there are significant energy challenges that N&RCs currently face. The following list summarizes the main:

- ✓ **Fossil fuel dependency:** The estimated fuel consumption (215 million litres/year) only accounts for the diesel and heavy oil required to generate electricity in communities where the primary energy source is fuel-based. This consumption has an environmental footprint of approximately 4.8 tCO_2eq per capita for diesel-based communities, while the Canadian emission average for electricity generation was 2.6 tCO_2eq in 2011. The fuel dependency and related environmental impact are even greater if one considers the diesel required for fuel transportation and heating requirements.
- ✓ **Load restrictions:** Peak demands in some RCs have, or are close to, reaching rated plant capacities. This leads to communities with load restrictions, which means that no more buildings can be built and/or connected to the local grid until additional generation equipment is installed or other similar buildings are permanently disconnected from the system.
- ✓ **Deployment costs:** Limited access is one of the main drivers for high energy costs, and the same applies to equipment deployment, operation and maintenance in N&RCs, which limit the economic viability of potential projects. Installation and maintenance costs from previous and current energy projects in N&RCs are not widely documented, but based on the information provided by reliable sources, project costs can easily double those of an equivalent on-grid project.
- ✓ **Operation and avoided fuel costs:** A diesel-based community with high energy costs could make an RE project economically feasible. However, from a utility perspective, the potential savings are not defined by the full energy cost, since indirect costs are not likely to decrease; hence, only fuel-related or avoided fuel costs should be considered in this case. Depending on the community, the utility should be able to determine a calculated avoided fuel cost which could range from 50% to 60% of the total energy cost.
- ✓ **Subsidy frameworks:** Electricity rates and subsidy frameworks are relatively complex mechanisms that need to be properly considered to assess if the stakeholders would benefit

from potential energy-related projects. Without any changes to the existing subsidy framework or without proper incentives, it is challenging to conceive RE-based projects that would interest the community.

- ✓ **Unbalanced loads:** In some communities during light-load conditions, three phase distribution system can reach unbalance of 10% or higher. This situation could lead to potential premature failures in the generators from undesirable mechanical vibrations. If this situation is encountered frequently, utilities may re-distribute the load across the three lines depending on the season, which would be an expensive practice.
- ✓ **Winter roads:** Winter season variations have a significant effect on ice-roads conditions and their serviceable lifetime, resulting in variable weight restrictions for such roads depending on the weather conditions. For example, in northern Ontario in 2012, the weight limit was dropped from 80,000 to 40,000 pounds due to reduced ice-thickness; as a result, fuel trucks had to be sent to RCs with partial loads. In addition, winter-roads are maintained by different parties and thus proper coordination is required to ensure that vehicles can reach the intended destination.
- ✓ **Community-operated utilities:** Obtaining energy-related information for community-operated utilities can be a significant challenge. These utilities can also have different operating standards than their provincial and/or territorial counterparts. As a result, community-operated utilities likely deal with different issues on top of those previously mentioned.

Conclusions

This article presented a general overview of the different technical, economic, social, policy, and environmental issues that need to be considered to properly understand the electric energy situation in N&RCs. The main objective of this article is to give the reader a better understanding of the challenges and opportunities with regard to electricity generation in Canada's N&RCs. There is significant RE potential in N&RCs, yet more than half of the population in these communities still rely solely on fuel-based sources for electricity generation, mainly due to geographical locations and low population densities. Recent RE studies and projects have aimed at slowly changing the perception of diesel-fuel as being the sole alternative for such communities; however, there are still significant challenges to change the existing energy mix to include considerable contributions from RE sources.

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For further reading

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Biographies

Mariano Arriaga is a Ph.D. candidate at the University of Waterloo, Canada.

Claudio Cañizares and Mehrdad Kazerani are Professors at the University of Waterloo, Canada.