**Briefing Note**

# Frozen Frontlines: Global Security Threats and the Battle for Arctic Energy Security

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## 1. Introduction

Arctic energy security is not consistent across the eight Arctic states, however their historic under-investment in infrastructure, and climate change, along with ongoing geopolitical instability, impacts all Arctic nations and their Arctic regions equally. Broadly, the Arctic hosts military installations and critical dual-use infrastructures that support both civilian and defense operations. This is in part due to the "frenemy" nature of Arctic security (Wilson Rowe, 2020), a friendship and distrust that is tied to energy dependencies. Energy security is layered, and interdependent on many factors. This paper outlines five layers of energy security in the circumpolar Arctic, and explores factors that impact each of those layers.

This work has adopted a multi-layer framework to examine energy security across the circumpolar regions. This research has identified five interrelated layers; *physical supply security, geopolitical exposure, local exposure, system flexibility,* and *transition and future risks*. The framework is applied to three sub-regions, the North American Arctic, the Scandinavian Arctic, and the Russian Arctic. The subregions differ in infrastructure, governance, geography, and political context. Together, the farmwork helps to better understand both immediate vulnerabilities and long-term structural changes.

The analysis indicates that energy security increasingly depends on resilience rather than on resource abundance alone. Moreover, energy infrastructure is evolving beyond the traditional dual-use trajectory. Energy security can become a strategic asset for remote communities to generate excess energy. The broader perspective can provide the foundation for simultaneously strengthening national security, strengthening economic development, and enhancing local resilience, which is crucial in an era of accelerating geopolitical and environmental changes.

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# 1. Methodology

## 2. Research Design and Methods

This research uses a multi-layer geopolitical energy security framework to analyze the interaction of Arctic energy and geopolitics regarding security. Therefore, the analysis divides the Arctic into three sub-regions that share operational or infrastructural similarities, often driven by geography or geopolitics. Off-grid communities and regional grids, and several linkages in terms of security, dominate the North American Arctic. The Scandinavian Arctic has significant road and energy infrastructure. The Russian Arctic has off-grid communities and large industrial hubs. These sub-regions; North American Arctic, Scandinavian Arctic, and Russian Arctic, exhibit energy security in different ways.

In our approach, we have identified five layers: physical supply security, geopolitical exposure, local exposure, system flexibility, and transition & future risks. Across the layers, different key components have been identified, as shown in Figure 1.

| Layer (Dimension) | Key Components | Description |
|---|---|---|
| **Layer 1: Physical Supply Security** *(Hard Constraints)* | • Supply Concentration<br>• Transit & Chokepoint Exposure<br>• Infrastructure Redundancy | Assesses the ability of the energy system to maintain reliable physical access to energy supplies and infrastructure under normal and disrupted conditions. |
| **Layer 2: Geopolitical Exposure** *(External Pressure)* | • Supplier Regime Risk<br>• Energy Weaponization Potential<br>• Alliance Protection Factor | Evaluates the extent to which a country's energy security is vulnerable to external political pressures, conflicts, or strategic actions by foreign actors. |
| **Layer 3: Local Exposure** *(Internal Pressure)* | • Import Dependency<br>• Energy Infrastructure Vulnerability<br>• Affordability & Social Stability | Measures the domestic economic, social, and infrastructure vulnerabilities that determine how severely energy disruptions affect a country. |
| **Layer 4: System Flexibility** *(Ability to Absorb Shocks)* | • Fuel Substitutability<br>• Demand Elasticity & Response<br>• Storage & Buffer Capacity | Assesses the capacity of the energy system to absorb, adapt to, and recover from supply shocks through substitution, demand response, and reserves. |
| **Layer 5: Transition & Future Risk** *(Structural Evolution)* | • Critical Mineral Dependence<br>• Technology Supply Chain Exposure<br>• Policy Transition Stability | Evaluates emerging energy security risks associated with the clean energy transition, technological dependencies, and long-term policy and market changes. |

**Figure 1.** The five layers used in the study. The overview highlights the key components and gives a brief description of each layer.

The information needed for this research was acquired through a snowballing literature review. The starting points for the literature review were selected based on the different geographical locations and technologies, as identified in the authors' previous research in that field.

# 3. Regional Analysis

The regional analysis section looks holistically on energy security, therefor the Arctic was divided into three geographical regions which share significant similarities in terms of infrastructure available, policy and to some extent resources. The main reasons for the following categorization have been the remoteness with often no road and grid connection of the North American Arctic. Grid and road connected communities in the Scandinavian Arctic. Large infrastructure development from the soviet era in the Russian Arctic.

### 3.1. North American Arctic

***Layer 1: Physical Supply Security (Hard Constraints)***

The North American Arctic can be characterized as energy-rich, with significant natural energy reserves stretching from hydrocarbons to geothermal and hydropower. Large oil and gas reserves in Alaska's North Slope and Canada's Arctic basins have been a driving force for development over the past decades (Zhang et al., 2024). Mainly oriented towards markets located in distant, temperate areas. The utilization of local resources is often problematic due to the sparse population, large distances between population areas and resources, and the limited infrastructure in terms of refineries, roads and grids available given harsh Arctic conditions and tyranny of distance (Coates & Poelzer, 2014; EIA, 2025a). The remoteness has led to isolated electricity islands, which are not connected to a regional or continental electricity grid (de Witt et al., 2021). Such off-grid communities have to operate their electricity grid independently and are self-reliant, which has traditionally led to diesel-based energy systems to ensure reliability (de Witt et al., 2020). This paradigm was challenged in recent decades with the take-off of the integration of local energy sources such as wind, PV, and small-scale hydro power (Alaska Energy Authority, 2019).

***Layer 2: Geopolitical Exposure (External Pressure)***

The reliance on diesel to ensure energy security in Arctic communities has created a strong dependency, even though the Arctic is an important place for hydrocarbon extraction; most of the refining happens in distant places (EIA, 2026). This leads to the situation that a significant amount of the diesel, heating fuel, and gasoline used in the Arctic is 're-imported', which has created strong interest in the energy market. The intertie with the energy market makes North American Arctic communities vulnerable to shocks in global fuel markets, as seen in 2026, resulting from the conflict in the Middle East (Alaska Wilderness League, 2026). Furthermore, the oil industry is exposed to fluctuations in global demand for oil and gas (Agboola et al., 2024). This can be aligned with sensitivity to shifts in international climate and environmental regulations, which can impact extraction or the demand side (EIA, 2025b). The growing demand for transpolar shopping can open new opportunities to connect or create new industries (Protection of the Marine Environment, 2025), however is a long way from achieving volume or scale. In general, large infrastructure projects, such as mining and oil and gas extraction, have been dependent on external, often international, investments (Alaska Business Magazine, 2021).

***Layer 3: Local Exposure (Internal Pressure)***

The communities across the region are scattered with a small, sparse population, with a combined 4.31 million people living in the Arctic worldwide (Sustainable Development Working Group, 2020). The islanded off-grid energy systems and the remoteness, paired with fossil fuel dependency and a complex transportation infrastructure, result in high energy costs (Bhattarai & Thompson, 2016; Chade et al., 2014). The workforce in remote communities can be a critical bottleneck. For complex technical solutions, a skilled workforce can be a limiting factor, but on the other hand, limited job opportunities can foster outmigration of skilled workers from remote communities (McMaster et al., 2024). This is a problem in other Arctic areas as well. All the aforementioned points lead to high costs for public services provided. The local economy in remote communities is often dependent on a single industry (Goldsmith, 2008). Furthermore, communities are facing

increasing natural hazards in recent years, including coastal erosion, flooding, and thawing permafrost (Creel et al., 2024).

***Layer 4: System Flexibility (Ability to Absorb Shocks)***

Over the past decades, investment in renewables to decentralize electricity systems has made it possible to become a bit more independent of diesel (de Witt et al., 2021), however even in microgrids with the highest penetration of renewables diesel systems are still used for redundancy. Since diesel generators remain essential for ensuring reliability during periods of low renewable energy generation or extreme weather events (Allen et al., 2016). Battery storage systems and advanced microgrid controls ensure flexibility by balancing various electricity sources and maintaining grid stability (Hunt et al., 2020). However, long-term energy storage is the missing link for operating microgrids with only local non-dispatchable energy sources.

***Layer 5: Transition & Future Risk (Structural Evolution)***

The impact of climate change has led to a growing emphasis on decarbonization, which has been somewhat stronger in Canada than in the US Arctic in recent years (Durand et al., 2025). The US has shown a strong interest in increasing the utilization of North Slope oil and gas, reflecting the current geopolitical landscape (Graham, 2026). Furthermore, the extraction of critical minerals is becoming a focus for the future to deliver the raw materials for the green transition and increased demand for data processing and artificial intelligence (J.P. Morgan, 2026).These developments often raise discussion about how to balance economic development with long-term sustainability and environmental stewardship (de Witt et al., 2020). This goes along with climate adaptation and mitigation actions. The global green transition can lead to reduced demand for fossil fuels in the future, which will have significant economic impacts on Alaska's revenues (Kim et al., 2025; Muhire et al., 2024). For remote communities, diversifying local energy sources and increasing energy efficiency for electricity, heating, and transportation is needed.

### 3.2. Scandinavian Arctic

***Layer 1: Physical Supply Security (Hard Constraints)***

In the Scandinavian Arctic nations, whose grids are weakly connected to the continental grid, leading to end-of-line insecurity, some large-scale renewable energy projects are well connected to the south and provide affordable electricity (Tenggren et al., 2016). Crisis often have a disproportionately larger impact on remote areas, including the war in Ukraine and tensions in the Middle East, which are resulting in supply chain implications, highlighting the high levels of inter-dependence on global supply chains for fossil fuels (Liu & Lee, 2025; Rahman et al., 2026).

***Layer 2: Geopolitical Exposure (External Pressure)***

At the same time, the extraction and generation of fossil fuels and electricity resources in northern regions to supply southern populations and industrial centers has become a central feature of many national energy systems (Tenggren et al., 2016). Northern areas often possess significant renewable energy potential, including hydropower and wind resources, while the highest energy demand is typically concentrated in the south (Sanchez Nieminen & Laitinen, 2025). This geographical divide creates opportunities for renewable energy development but also places increasing pressure on transmission infrastructure and raises questions regarding environmental impacts, regional development, and equitable distribution of benefits.

***Layer 3: Local Exposure (Internal Pressure)***

The dual energy crises have strengthened interest in improving energy security, particularly in terms of energy independence and the resilience of energy systems in remote and sparsely populated regions (Sanchez Nieminen & Laitinen, 2025). Recent geopolitical tensions and disruptions in energy markets have exposed the vulnerabilities associated with dependence on imported energy and centralized supply systems. Consequently, governments and energy planners are increasingly prioritizing diversified energy sources, local production, and more robust infrastructure to ensure reliable and secure access to energy (Sanchez Nieminen & Laitinen, 2025).

***Layer 4: System Flexibility (Ability to Absorb Shocks)***

In this context, strong electricity grids along border regions are becoming increasingly important, particularly between Finland/Norway and Russia. Enhanced cross-border transmission capacity can improve regional energy security, increase flexibility in balancing supply and demand, and facilitate greater integration of renewable energy sources (Atabaki et al., 2026; Bergaentzlé et al., 2020). Norway's extensive hydropower resources can complement Finland's growing wind energy production and electricity demand, creating synergies that strengthen the stability and efficiency of the Nordic power system. Robust interconnections also enhance resilience during supply disruptions, peak demand periods, and extreme weather events, underscoring the strategic importance of cross-border energy cooperation (Nordic Energy Research, 2026).

***Layer 5: Transition & Future Risk (Structural Evolution)***

Remote sensing technologies can significantly improve understanding of the current state of grid infrastructure and inform future upgrades. Satellite observations, airborne sensing, and geospatial analysis provide valuable information on transmission corridors, vegetation growth, land-use changes, snow and ice conditions, and infrastructure stability in remote northern environments (Sharma et al., 2024). These technologies support the identification of vulnerable sections of the grid, help assess environmental and climate-related risks, and assist in planning optimal routes for new transmission lines. Through continuous, large-scale monitoring, remote sensing enables more effective maintenance, planning, and modernization of electricity networks, thereby contributing to stronger, more resilient energy systems (Matikainen et al., 2016; Silveira et al., 2025).

### 3.3. Russian Arctic

***Layer 1: Physical Supply Security (Hard Constraints)***

The Russian Arctic holds vast oil and gas reserves (McGee, 2020). The extraction from these reserves is heavily dependent on a few mega-scale projects such as Yamal 1 and 2, and Gydan (Jun, 2025). Furthermore, there are industrial and mining centers in the Russian Arctic. The long-lasting industrial activities have led to extensive development during the Soviet era, with infrastructure such as pipelines, roads, and railroads connecting cities and industrial areas (Bruno & Kalemeneva, 2023). As elsewhere in the Arctic, permafrost degradation and the harsh climate impact infrastructure and supply chains. Maritime transportation has an increasing importance due to extended ice-free periods (Boylan, 2021).

***Layer 2: Geopolitical Exposure (External Pressure)***

Western sanctions and restrictions on markets and technology have led to a refocus on new markets. The main market for oil and gas has changed from Europe towards Asia, particularly

China and India (Pye et al., 2025). Furthermore, the sanctions have partly decoupled the oil and gas prices from the global market and added a discount on Russian oil and gas (Brooks, 2025). The search for new markets to export oil and gas leads to an increased interest of Russia to increase Arctic shipping, with increased port infrastructure along the Northeast Passage (Boylan, 2021; Pye et al., 2025).

***Layer 3: Local Exposure (Internal Pressure)***

As in other Arctic regions, the Russian Arctic experiences population decline, resulting in a limited skilled workforce (Myakshin, 2024). Furthermore, it can be problematic to attract an external workforce, which might be related to the high cost of living and the high cost of maintaining infrastructure (Chanysheva et al., 2021). Since most of the infrastructure dates back to Soviet times, maintenance pressure is high (Bruno & Kalemeneva, 2023). Remote communities are often dependent on diesel and energy subsidies, since fuel is expensive due to complex supply chains (Suslov, 2012).

***Layer 4: System Flexibility (Ability to Absorb Shocks)***

The sanctions from Western countries have demonstrated the ability to substitute for foreign-restricted technologies (Huynh et al., 2025). Moreover, it leads to diversification of markets, increased exports to Asia, and the implementation of new routes. Therefore, new pipelines to China are under construction, as is the increased use of the Northeast Passage (Boylan, 2021; Pye et al., 2025). This is underscored by the extension of the ice-class tanker fleet (Reuter, 2026). The focus on fewer large-scale projects results in limited diversification of the economy.

***Layer 5: Transition & Future Risk (Structural Evolution)***

Global decarbonization and competitive, lower-cost energy generation technologies might reduce demand for fossil fuels, thereby scrutinizing the fossil-fuel-based economy (Papadis & Tsatsaronis, 2020). The economic dependence on hydrocarbons may constrain future economic diversification. Arctic warming can create both opportunities and threats. Impacts on land-based infrastructure due to permafrost thaw can create opportunities for maritime shipping (Boylan, 2021; Hjort et al., 2022). The use of renewable energy can potentially further expand across rural settlements.

# 4. Discussion

Across the different regions, it can be observed that energy security is primarily constrained by infrastructure availability and accessibility rather than resource scarcity. Even in energy-rich regions of the Arctic, energy insecurity can be driven simultaneously by the remoteness. This highlights that energy abundance does not automatically translate into energy security. The North American and Scandinavian Arctic regions remain heavily dependent on imported fuels, often delivered via long, vulnerable supply chains, with the exception of Iceland. Iceland has made impressive use of its geothermal resources for heating. Iceland is self-sufficient in terms of electricity and heat but reliant on imported fuels for transportation (de Witt & Stefánsson, 2026). The Russian Arctic's energy security remains closely linked to hydrocarbon extraction, exports, and geopolitical developments.

For remote locations with weak electricity grids and limited energy infrastructure, strengthening energy resilience by developing local, diversified energy sources is a key strategy to reduce dependence on external supply chains and global markets. In particular, integrating locally available

regenerating energy resources may improve both energy security and sustainability for Arctic infrastructure. But integrating renewables into hybrid grids poses challenges for grid resiliency and reliability. Different Arctic regions require tailored policy approaches rather than a single Arctic-wide strategy.

### 4.1. Energy Security and Geopolitics

Overall, it can be seen that energy security and national security are becoming increasingly interconnected (Mara et al., 2022). This is founded on the increased importance of energy as the backbone of modern critical defense infrastructure, as well as modern life; which makes energy a critical infrastructure. In the current geopolitical context of global tensions, sanctions, market disruptions, and tariffs Arctic energy systems are increasingly exposed to all the aforementioned issues. In particular, the war in Ukraine and the conflicts in the Middle East have highlighted the Arctic's exposure to global energy shocks. For example, Fairbanks, Alaska, has experienced gasoline price increases from $3.80 per gallon in July 2025 up to $4,46 a year later with a peak above $5,20 per gallon(AAA, 2026; Fernandez, 2026). This case is of particular interest since the Alaskan market is not directly linked to the conflict areas through supply chains. This dependency has led to a common objective across Arctic states to become more energy independent.

#### *Arctic as a Global Energy Provider*

As mentioned in the sub-regional elaborations, the Arctic contains globally significant fossil fuel and renewable energy resources. Arctic regions may play an important role in future energy and critical mineral supply chains. This can lead to export-oriented energy development that either conflicts with local energy needs or supports local energy security. For off-grid communities, energy export can be an opportunity to create local demand and establish large-scale energy projects (Cook & de Witt, 2025). In grid-connected areas, energy exports could lead to conflicts, depending on whether local regions gain benefits from the projects (Sanchez Nieminen & Laitinen, 2025). Overall, Arctic resources may contribute to both energy security and energy transition goals by providing reliable, affordable energy to local communities and critical infrastructure. Moreover, in a situation of globally growing mistrust, it may reduce the willingness to rely on imported energy. This might impact the export potential in the global market. In several countries, energy exports from Arctic regions to non-Arctic regions are a very likely future scenario.

#### *Beyond Dual-Use: Toward a Triple-Use Perspective*

In the Arctic context, energy infrastructure is increasingly shaped by dual use, serving both defense and civilian interests (Stasik, 2026). However, the Nordic context in the civilian domain can be divided into local civilian and national economic interests, suggesting that a triple-use perspective may be more appropriate. Under this framework, energy infrastructure simultaneously supports defense and security objectives, national economic and strategic interests, and the needs of local communities.

Currently, much of the discussion in the Nordic countries reflects a dual-use logic in which infrastructure projects are justified through their contribution to national resilience and defense capabilities (Middleton, 2025). Energy systems, ports, transmission lines, and related infrastructure are increasingly recognized as strategic assets that strengthen energy security and support military preparedness (Samaras et al., 2019). This reflects changing geopolitical conditions and a renewed emphasis on protecting and enhancing the resilience of critical infrastructure.

At the same time, this dual-use approach often creates uneven outcomes. While defense institutions and national governments may benefit from strengthened infrastructure and enhanced strategic capacity, local communities frequently bear a disproportionate share of the social, environmental, and economic costs (Middleton, 2025; RANE, 2025). These may include land-use pressures, environmental impacts, disruption to traditional livelihoods, or limited local influence over project development. In this sense, local societies may be expected to accommodate infrastructure that primarily serves broader national or security priorities without receiving equivalent benefits in return. This kind of "green colonialism" leads to protests against new infrastructure projects and reduces local acceptance of such projects (Mósesdóttir, 2024).

A triple-use perspective offers a possible way forward. Rather than viewing local impacts as secondary or unavoidable trade-offs, it emphasizes integrating local value creation as a core objective of infrastructure planning. Energy projects could be designed to generate tangible benefits for host communities alongside their defense and national functions, through improved local energy access, lower energy costs, employment opportunities, enhanced resilience, or shared ownership and governance arrangements.

Such an approach may also have an important political and social dimension. If local communities experience clear and meaningful benefits from energy infrastructure, this could help foster greater understanding, legitimacy, and public support for projects increasingly framed in terms of national security and strategic necessity but that have lost their local connection. In the Arctic, where questions of sovereignty, resource governance, and community rights are particularly sensitive, recognizing this triple-use dimension may be essential for ensuring that infrastructure development is not only strategically effective but also socially sustainable. The cases of the Norwegian wind farms Roan and Storheia on the Fossen peninsula has shown that the absence of local connection and the resulting acceptance can lead to severe impacts (Potthoff & Cashmore, 2026). In this case, the Supreme Court ruled that the government should not have permitted the wind farms. The local communities had to cope with the project's negative impacts, while the benefits went to communities far to the south of the country.

## 4.2. Challenges of the Energy Transition

The integration of distributed energy resources (DER), in particular renewables, can help increase energy independence and reduce supply chain risks. However, the transition from a centralized to a decentralized energy grid can add complexity, creating new challenges for grid stability and reliability.

### *Renewable Energy and Decentralization*

An underlying driver of the energy transition is the electrification of sectors such as transportation, heating, and industrial processes (Diesing et al., 2025; Renewable Energy Agency, 2019). The shift from multiple energy carriers to one energy carrier can create a new form of dependency (Wetzel et al., 2023). Furthermore, the energy carrier electricity is bound to an inflexible, static means of transportation, 'the grid' , which might add some risk. This raises the question, from a defense point of view, whether it is better to defend a widely spread-out infrastructure system or a few central points? Despite the view on energy security from a defense perspective, the decentralization and integration of local, distributed energy sources can help achieve independence from imported fuels (Švažas, 2026; Żuk, 2026). In addition, the system can help improve the resilience of the

energy system in remote communities, since energy generation is based on multiple energy resources and locations (Nkambule et al., 2025). Local energy generation can strengthen communities' energy sovereignty, as such projects can be community-owned or involve the community in ways that give them more control over their energy supply (Schelly et al., 2020). Furthermore, it detaches them from the volatility of the global energy and fuel market (Švažas, 2026).

In a global perspective, the Arctic has opportunities to economically benefit from the energy transition by providing critical minerals necessary for manufacturing new energy technologies (Arctic Economic Council, 2024). Global climate policies may have a significant impact on Arctic communities and the economy. On the one hand, it can create new opportunities, as mentioned above, in energy and critical mineral exports. On the other hand, this can add more complexity or the need for exemptions; for example, remote Alaskan communities are exempt from using tier 4 diesel generators; they can still use tier 2/3 diesel generators due to reliability and maintenance requirements (Congress of Alaska, 2019).

***Energy Digitalization & Workforce***

The move to integrate renewables into Arctic energy systems can increase the risk of attacks from the cyber domain; and energy systems writ large are becoming more susceptible to cyberattack. Inverter-based generation systems such as wind, and solar require inverters and power electronics to regulate and control generation (Department of Energy, 2022), which increase a hybrid microgrid's surface area for cyber attacks, and jeopardize energy security (Musleh et al., 2026). As a result, cybersecurity is emerging as a critical component of Arctic energy security, requiring dedicated strategies to protect increasingly complex and integrated energy systems.

From a triple use perspective, cyber attacks impact economic, societal, and defense objectives. Cyber attacks are increasingly a component of conflict, and near-conflict activities such as grey zone or hybrid threats. In active conflict, energy and informational assets have become some of the most strategic targets, and the Arctic is not spared from these. In recent years, the U.S. Arctic, and Scandinavian Arctic have been subject to attacks on both energy and telecommunications infrastructure such as sub-sea cables (Berge & Bergmann, 2024; Kamper, 2025; Parlow, 2026). The large scale of cyber attack in the Arctic upon energy infrastructure has not been fully realized, such as attacks that gain control of generation or other parts of the energy system to destabilize or damage the grid, or coordinated attacks across energy systems to exploit similar vulnerabilities in either software, network, or hardware configuration. These types of larger scale attacks are made possible by well-funded cyber teams that perform extensive research and waiting; information collection while undetected in preparation for a larger event. With that in mind, early defense, deterrence, and detection of cyber incursions is an important factor of energy security.

These technologies also create another infrastructural requirement where the Arctic has historically lagged behind, and that is in telecommunications and broadband investments; as well as a need for a cyber-aware energy workforce (Cunningham, 2022). Advanced systems require specialized technical knowledge, different maintenance and operational training, and strong cyber-safety cultures to ensure reliable and secure performance. This raises an important question: can small and remote communities manage these technologies in accordance with local energy security needs? While new technologies may offer solutions to reduce reliance on costly imported diesel,

their successful implementation depends heavily on a different set of skills to be available as local capacity, institutional support, and in skilled personnel.

***Emerging Sensitive Technologies***

These concerns become particularly significant in the case of sensitive technologies such as Advanced Small Modular Reactors (SMRs). The Arctic already has conventional nuclear power plants and ships, however the circumstances for utilizing Advanced SMRs in remote communities are different (Lysenko et al., 2022). Although Advanced SMRs are often promoted as suitable for remote regions due to their smaller size and lower energy output, their deployment raises important practical and ethical questions. Remote communities may face limitations in skilled labor, technical training, emergency preparedness, and maintenance capabilities. In situations where external expertise is located far away and transportation or weather conditions can delay assistance, operational and safety challenges may become more difficult to manage.

Furthermore, introducing relatively immature technologies with a technology redness level ranging from 3 to 7 shows that the technology is currently in its prototyping phase depending on the technology and model (Shepherd et al., 2015; Chmielewska-Śmietanko et al., 2025). Deploying such a technology into high-stakes environments carries additional uncertainty. While Advanced SMRs show technological promise, many designs still have limited operational experience compared to conventional energy systems. Testing or deploying such technologies in isolated locations may expose communities to risks associated with technical failures, regulatory gaps, or insufficient support infrastructure. Therefore, decisions regarding Advanced SMR deployment in remote communities should not focus solely on technical feasibility or economic benefits but must also carefully evaluate workforce readiness, emergency response capacity, governance structures, and long-term community resilience.

This debate ultimately highlights a broader issue: technological innovation alone does not guarantee successful energy transitions. Equal attention must be given to human capacity, institutional preparedness, and the specific social and geographic conditions of the communities expected to host these technologies.

### 4.3. Climate Change

Energy systems are planned 20 to 50 years in advance, but Arctic conditions for terrestrial infrastructure challenged by permafrost thawing and frost heaves, changes in snow and precipitation patterns, increased storm severity that impacts both land, ice-bound, and sub-sea infrastructure, and impacts on renewable resource availability such as wind and solar irradiance, will change over time. The Arctic Leadership Initiative-funded "Future Load & Uncertainty Experiment" brings together global weather and environmental forecasters from the University of Alaska Fairbanks' International Arctic Research Center's (IARC) Scenarios Network Analysis and Planning (SNAP) team, and Alaska Center for Energy and Power (ACEP), to use future forecast conditions from 2045 - 2055 into energy modelling processes for Arctic remote microgrids. This is a marked deviation from energy modelling norms that use historical environmental and load conditions to identify critical infrastructure sizing. This type of research will be necessary as future conditions diverge more from past conditions.

## 5. Conclusion

Beyond energy supply considerations, the Arctic also offers strategic opportunities for digital infrastructure development, particularly in the role of data centers. While data centers are often derided for requiring huge amounts of energy, water, and land, and produce heat and may impede on grid infrastructure that counters community desires, in remote Arctic locations that may have low populations, data centers may act as a load that can use (and pay for) excess generation from renewables, and in turn lower rates for ratepayers. And in the North American and Russian Arctic, where the coldest temperatures are experienced, data center byproducts of heat or hot water may benefit when coupled with district heating systems. As they say, in the Arctic, there is no such thing as 'waste' heat. While the U.S. Arctic has not yet leveraged the potential benefits of data centers, several ongoing studies, bills, and conversations are exploring the role data centers may play in advancing community needs. It remains to be seen whether U.S. Arctic ratepayers grant the social license and whether the region's communications challenges will prevent any talk of data centers before they begin.

Future research can help to map critical energy infrastructure vulnerabilities. The integration of remote sensing data into energy security can help to assess vulnerabilities and opportunities in particular in a context of end of grid and remote infrastructure. Remote sensing would give the advantage that several preliminary studies can be executed from distant places, which reduces the need for field campaigns in remote and rough terrain. Adjusting energy resilience indicators to the needs of remote communities and including particularly cyber security. The research has shown that it seems like the acceptance of energy projects is highly dependent on benefits. This would make it of interest to study in depth the relationship between ownership or participation in energy projects and local acceptance and knowledge about energy. That knowledge would be beneficial to successfully structure future energy projects in Arctic communities. On a more regional level it would be of interest to study the balance between local energy security and energy export-oriented development. Such a research would help local decision makers to take future steps.

Arctic energy security is evolving from a question of energy supply toward a broader challenge of resilience, infrastructure, governance, geopolitics, and community participation.

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