Critical Pathways to Renewable Energy in Remote Communities: A Comparative Analysis of Renewable Energy Transitions in Alaska

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ABSTRACT

The global transition from fossil-fuel based power generation to renewable energy is well underway; however, this transition is highly uneven and not all regions and communities are engaging equally. The circumpolar north is one region where disparities in the uptake of community renewable energy projects (CREs) is evident. Many Northern, remote communities are not connected to national electric grid infrastructure and as a result, rely heavily on imported fuels for power generation at costs significantly above national averages. However, within this context, there are places in the US state of Alaska that have forged a leading path toward CRE projects. This paper investigates why some remote communities develop renewable energy while others do not. Using Qualitative Comparative Analysis (QCA), we compare 24 remote communities in Alaska to identify the combination of explanatory factors that can lead to CRE transitions. We first identified 37 potential conditions, from which we drew three primary explanatory factors: community capacity, electricity subsidies, and pooled resources, that were found to be particularly salient. Results show the absence of large electricity subsidies is a necessary condition to the development of CRE. It also shows that the presence of subsidies (above a state-wide program) stymies CRE transitions. We also found that particular combinations of the absence of large subsidies, community capacity for managing infrastructure and projects, and working collaboratively to pool resources across communities, were found to be key explanatory variables in the establishment of CRE. The study of Alaskan communities show that community-level factors matter, especially capacity for local agency. These findings may have implications for other communities both in the Circumpolar North and elsewhere, clarifying the conditions that support CRE.

Keywords: *renewable energy; remote communities; Alaska; qualitative comparative analysis, community capacity, microgrids*

1. INTRODUCTION

The transition toward a low-carbon future based on renewable energy appears to be firmly underway in most industrialized and many developing countries. However, when scaled down to the sub-national or community level, less uniform progress is evident. This uneven development is particularly noticeable in remote communities not connected to electrical grids. These communities often rely on imported, expensive, and high-emission diesel fuel to generate electric power locally. According to the International Energy Agency, 4000 remote communities presently rely on diesel worldwide to power microgrids ranging from 100 kilowatts (kW) to 1 Megawatt (MW)[1]. In addition, 72% (487 million) of the global population expected to gain energy access by 2030, are projected to be served by decentralized power solutions (e.g. solar energy) in off-grid and mini-grid contexts [3]. For this reason, understanding the logistics – the barriers and enablers – of transitioning from diesel-dependent energy systems to decarbonized and decentralized renewable energy offers unique incentives to geographically and culturally diverse remote communities from the circumpolar Arctic to equatorial regions as they look toward mitigating climate change.

Few studies have examined the sociopolitical factors that enables sustainable and locally successful renewable energy transitions of remote communities and island nations [see exceptions 6,7]. Discussions on energy transitions have largely focused on techno-scientific goals and transition management. The past few decades have seen a proliferation of social science research on energy transitions [8,9] and related community renewable energy (CRE) [10,11] literatures [12,13]. This growth of scholarship is based on the recognition that energy systems are sociotechnical and that public support, justice, and equity are important considerations to advance renewable energy transitions [14,15]. Yet, even within the social sciences, energy transitions scholarship has focused largely on global energy developments and mega-trends where processes are driven predominantly by disruptive technological factors [8]. This often results in the downplaying of important social, community, and place-based context [16]. Consequently, energy geographers like Walker et al. [17] have shown that energy transitions toward decentralization [see also 18], draws heavily on geographical, placed-based infrastructural, socioeconomic, ecological and political characteristics in host communities and

[1] Diesel-dependent communities are not restricted to the developing world. We can point to 280 remote, mostly Indigenous communities in Canada and most remote villages in Alaska, who rely on diesel-fired generation [1,2].

beyond. Analyzing the multi-level perspective (MLP) framework for analyzing socio-technical transitions to sustainability, Geels and other scholars [19, 20,21] offer global or national-level understanding of energy transitions – the drivers and necessary conditions for successful change – but conclude that the societal consequences especially at the local or community-scale, remains incomplete [10,22,23]. Energy transitions are fundamentally social – they are "woven into societal, geographic, and geopolitical arrangements at scales from the individual and the planet" [24; p.29]. As Parkhill et al. [25] notes, "the *where*-ness of community is integral to our understandings of how communities develop and can contribute to low-carbon energy transitions" (p. 4). Paying attention to the social and place-based context in renewable energy development is not only key to energy equity and energy justice but may also help to ensure the longevity of the policies and programs that support such development [26-28], given the push toward decentralization across a range of energy sectors [17,29]. Leaders from remote communities themselves are now recognizing the potential benefits [4], and increasing economic viability [5] of transitions.

This research compares 24 remote community transitions to viable renewable energy resources in Alaska to ask: what factors inhibit or facilitate the adoption of CRE in remote communities? Utilizing Qualitative Comparative Analysis (QCA) it systematically identifies the necessary and sufficient conditions leading to the adoption or absence of a CRE project. This analysis is situated within an underlying socio-political and economic landscape that is largely uniform across the state, and focus on community-specific enablers or barriers to renewable energy development. In the sections that follow, we first introduce the remote Alaskan context, followed by our approach to scoping the community-based attributes that influence CRE. Results of the QCA are then presented, identifying the most impactful attributes and combinations of conditions (i.e. pathways) that lead to the adoption of CRE projects. Although our analysis is based on the Alaskan context, the paper concludes with a critical analysis of the identified pathways in accomplishing renewable energy transitions in remote communities worldwide.

2. STUDY AREA AND APPROACH

All 24 communities in our dataset (Figure 1) are located in remote Alaska and relied 100% on diesel fuel for local power generation at the beginning of our timeframe for analysis (2007). The combination of imported fuel, difficult fuel delivery logistics, and minimal economies of scale result in energy costs and energy burden that are significantly higher in remote Alaska than the national average [30]. Alongside relatively high rates of local poverty, many remote Alaskan communities experience lower than state and national levels of educational attainment, household incomes, and economic opportunities. These costs lead to an untenable situation for residents, and arguably, may create a significant incentive to adopt CRE [31]. The very conditions of remote Alaskan communities serve as an instructive case study of the barriers and enablers toward CRE.

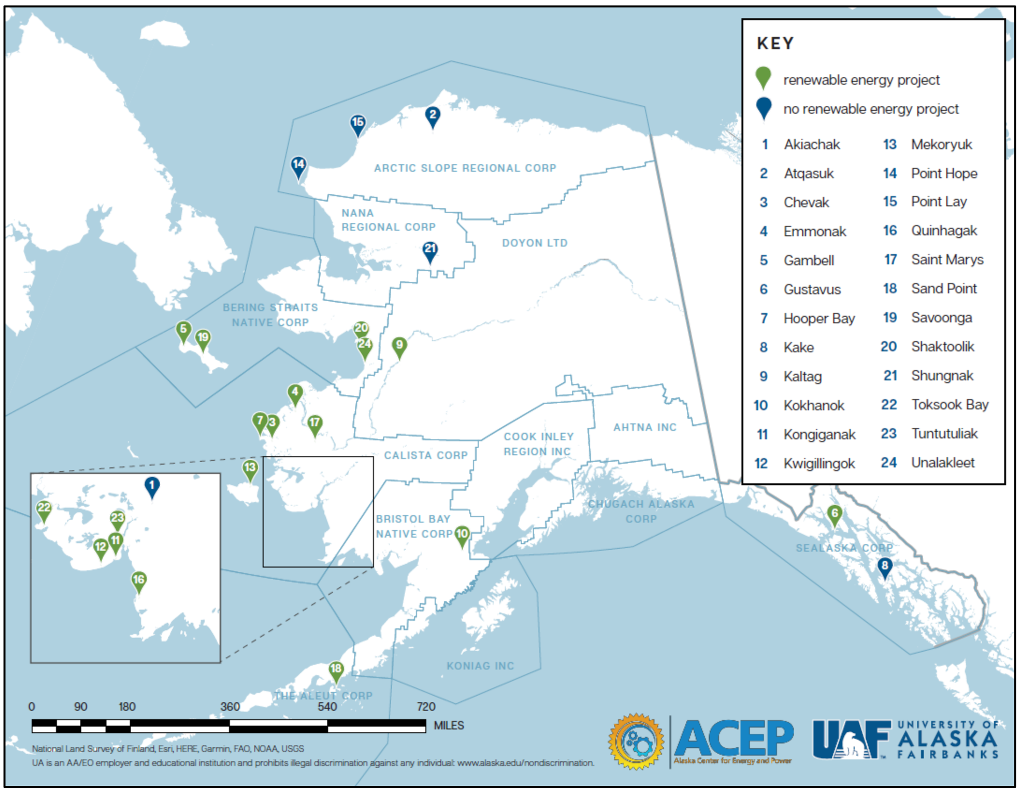

Figure 1 – Rural Alaskan case study communities, including the presence and absence of a CRE project at the end of 2017

There are more than 90 independent utilities in Alaska, serving approximately 250 remote or rural communities (with a total population of 60,000) that qualify for the state's Power Cost Equalization (PCE) program, an economic assistance program for communities with rural electric utilities where electricity costs are significantly higher compared with urban areas. The majority of these rural utilities serve a single community, while a few provide services to multiple communities. A majority are public utilities or member-owned (i.e., either a cooperative or municipally-owned) with some privately-owned and tribally-owned utilities.

Case selection for this study was based on a number of criteria. The first, was related to our

exclusive focus on diesel-reliant communities (as of 2007, see above) within Alaska. Much of the literature on CRE identifies regulatory and policy frameworks and access to financial capital as significant barriers to renewable energy development [26-28], often making comparisons across geographically disparate cases difficult. The Alaskan context on the other hand provides a valuable opportunity to investigate CRE, while controlling social, political, and economic factors. Despite the fact that some communities in our sample (6/24) regulate land use at the municipal or borough level, we find no significant cross-jurisdictional differences across communities – all are subject to the same regulatory and policy regime within the State[2]. Second, in order to focus on remote communities, none of the communities included are connected to a larger transmission and transportation network and are accessible only by plane or water most of the year. There are no parallels to the geographical remoteness of these communities in the contiguous United States, southern Canada, or Europe, where most research on community energy is focused. Third, case selection was also dependent on data availability. We chose only those communities that participate in the Power Cost Equalization (PCE) program. This allowed us: (i) access to community-level electricity data and (ii) knowledge that all communities received (at least) a baseline level of electricity subsidy. Fourth, this study limits cases to those communities that have a viable renewable resource as defined by the Alaska Energy Authority's Affordable Energy Strategy [32]. This model includes a consideration of source intermittency and ultimately identified the potential for wind, solar, hydro, and biomass-for-heat projects across Alaska. Geothermal, in-river hydrokinetic, wave, tidal, and biomass-for-electricity were not considered because they are either not available as a resource, or too immature and/or expensive to develop. Fifth, communities in Alaska with fewer than 100 residents are also excluded from the analysis, as scholars have identified 100 residents as the threshold population for which a community could reasonably expect to remain a viable independent community over time based on population demographics [33]. Lastly, remote 'hub communities' were excluded

[2] While local zoning and planning regulations could be seen as a barrier toward CRE, it does not appear to be the case within our study of remote communities in Alaska. Four of the six communities that do regulate land use developed CRE (66.7%) – nearly identical to the overall sample (17/24 or 70.8%).

because their larger labor pools and more developed economies make them fundamentally different than smaller communities. As a result, the communities included in the dataset have populations ranging from 170 residents (Kokhanok) to 1,093 residents (Hooper Bay). Table 1 thus provides a summary of the 24 communities included in our data set that meet the above six criteria.

Table 1 – Statistics of Viable Remote Alaskan Communities with CRE

Community	Post-PCE Residential Rate ($/kWh)[a]	Median Household Income[b]	2010 Population[c]	Percent Alaska Native[d]
Akiachak	0.21	$45,313	627	95%
Atqasuk	0.12	$56,500	233	92%
Chevak	0.23	$33,269	938	95%
Emmonak	0.23	$59,875	762	96%
Gambell	0.22	$26,000	681	96%
Gustavus	0.26	$59,107	442	3%
Hooper Bay	0.23	$35,938	1093	95%
Kake	0.22	$40,769	557	69%
Kaltag	0.24	$23,000	190	92%
Kokhanok	0.26	$46,250	170	80%
Kongiganak	0.20	$32,500	439	96%
Kwigillingok	0.19	$41,250	321	95%
Mekoryuk	0.23	$26,250	191	93%
Point Hope	0.12	$76,250	674	89%
Point Lay	0.12	$42,188	189	88%
Quinhagak	0.23	$31,429	669	93%
Saint Mary's	0.23	$38,162	507	92%
Sand Point	0.21	$67,000	976	39%
Savoonga	0.23	$36,250	671	94%
Shaktoolik	0.23	$26,667	251	96%
Shungnak	0.27	$47,656	262	94%
Toksook Bay	0.22	$53,125	590	92%
Tuntutuliak	0.31	$34,167	408	96%
Unalakleet	0.19	$47,500	688	77%

[a] [34]; [b] Income By Place 2007-2011 American Community Survey 5-year Estimates; [c] Alaska Department of Labor and Workforce Development (2010); [d] We use Alaska Native to describe the state's Indigenous population because it is often the preferred term and rooted in self-identification [35].

2.1 Conceptual framework: CRE barriers and enablers

A particular focus of the community energy literature, and one central to our study, has been to identify the factors – both barriers and enablers – that help explain local renewable energy transitions. Vallecha et al. [36] provide a comprehensive summary of six key categories of enablers and barriers[3] to CRE: economic, technological, social, political, environmental, and infrastructural. While certain kinds of economic conditions or policy frameworks can support renewable energy at the community scale, the 'wrong' set of conditions can create barriers to development. These barriers and enablers also exist on a spectrum, from micro and meso-level factors that can potentially be addressed at the local or community level, to more macro-level landscape factors such as policy or institutional structures and ownership, which are difficult to control at the community level.

We used Vallecha et al. [36] as a starting point to frame our analysis, as it reinforces the broader literature on the barriers and enablers of community energy. This includes, approaches from a compilation of studies including, Walker [37] and Allen et al. [38] who addressed barriers to and incentives for community energy; Brummer [11] who examined pathways toward renewable energy across the UK, USA, and Germany; and a number of CRE studies from Tanzania and Mozambique [39], Australia [40] and France [41]. These studies examine the conditions that help promote or create barriers to CRE across a range of urban, rural, and remote contexts. However, given that our study is set within remote Alaska, home to mostly Indigenous Native Alaskan peoples, it is important to also acknowledge a quickly growing energy literature focused on Indigenous communities [42-47]. Additional layers of embedded social, political, and historical challenges may amplify barriers but also create novel motivations for CRE (i.e., energy autonomy) transitions within Indigenous communities [46-47].

Adopting Vallecha et al. [36] as a guide, and drawing on local and regional[4] Alaskan energy policies, plans, programs, and contexts, we scoped 37 targeted conditions (i.e., variables) across the six categories with the potential to act as a barrier or enabler of CRE and with promising application within the context of remote Alaska (Table 2). Most of these variables (30/37) apply to at least two categories, and 15 variables apply to three or more categories, illustrating the cross-cutting nature of the conditions potentially impacting CRE. Based on the tenets of QCA, drawing on previous empirical analyses of CRE barriers and opportunities, and after multiple rounds of iterative analyses, we reduced the number of potential variables to a manageable set to

[3] Vallecha et al. [36] also include 'marketing' as an enabler, it is not a common factor seen in the wider community energy literature so we have decided not to include it here.
[4] Here and throughout the paper, we use regional (or region) to describe the eight distinct geographic regions of Alaska (Northern, Northwest, Interior, Western, Southcentral, Southwest, Gulf Cost, and Southeast).

eliminate redundancy between conditions and to eliminate conditions that were unlikely to lead to the CRE outcome [see 48,49]. Three conditions emerged to form the basis of our analysis: community capacity, subsidies, and pooling resources.

Table 2– Initial set of variables and application to Vallecha's [36] six categories. The highlighted conditions were identified as relevant to shaping outcomes for the communities in our dataset.

		Economic	Technological	Social	Political	Environmental	Infrastructural
Screening Questions	Community is eligible for PCE subsidy	●		●	●		
	Community has economically viable renewable energy resource		●			●	●
	Community is not a regional hub but has more than 100 residents	●		●	●		
Utility Ownership	Utility ownership type (community or private)			●	●		●
	Membership in the Alaska Village Electric Cooperative				●		●
	The utility shares or pools resources across multiple communities	●		●	●	●	
	Partial or total postagestamp rate[a]	●					●
Power Costs	Fuel price paid by utility for diesel ($)	●					
	Annual total fuel costs	●					
	The average fuel cost per kilowatt hour ($/kWh)	●					
	The average nonfuel cost per kWh ($)	●					
	The cost to generate 1 kWh of electricity before subsidies[b]	●					
	The residential rate for 1 kWh (of electricity) after subsidies	●					
	The commercial rate for 1 kWh after subsidies	●					
Community Power Sales	Total annual electricity sales in kWh		●				●
	The average number of kWh sold to residential customers	●	●				
	Total annual residential electricity sales in kWh		●				●
	The number of the utility's residential customers			●	●		
	Industrial anchor tenant in community is purchasing electric from the local utility			●		●	●
Subsidy	Total PCE eligible kWh sold by the utility		●				●
	The non-PCE eligible kWh sold by the utility		●				●
	Percentage of total kWh sold that are not eligible for PCE		●				●
	The community has an additional subsidy (beyond the PCE)	●		●	●		
Community Capacity	The number of residents in the community			●	●		
	The number of community facilities eligible for PCE			●	●		●
	% of qualifying facilities (i.e., >20% eligible for PCE subsidies)	●		●	●		
	The % of kWh claimed under the PCE program			●	●		
	The total number of PCE eligible kWh for a community			●	●		●
	Community capacity (as a fuzzy variable)	●		●	●		
Regional Government	The community is located in an organized borough			●	●		
	Total residents in the borough, including remote & non-remote communities			●	●		
	Total number of remote communities within borough			●	●		
	Total tax revenue collected by the borough in 2015	●		●	●		
	Median household income in area (borough)	●		●			
Poverty	Poverty levels (% of residents under the poverty line)	●		●	●		●
	Utility costs to average household income (ratio)	●		●	●		●
	Average household income in the community[c]	●		●			

[a] Whether the community has a partial or total postagestamp rate. Inside Passage Electric Cooperative (IPEC) communities have a total postage stamp rate, while AVEC communities only have a postage stamp rate for non-fuel costs. [b] The cost to generate 1 kWh of electricity before utility and end-user subsidies have been applied. [c]Based on census data [50].

The focus on these three conditions does not mean that there are no other factors that may shape CRE outcomes in remote Alaska. Indeed, the literature is clear on the importance of policy and regulatory frameworks [51], ownership structures [42], renewable energy data and information [52], financial capital [7,45,46], energy and transport infrastructure [36], sociocultural values [45,53], and income/levels of poverty [54]. However, given our exclusive focus on remote communities in Alaska, we were able to either control for many of these factors or determine them *a priori* to be relatively insignificant. For example, all communities in our sample are of similar geographic scale, operate under the same regulations and policies, have access to both quality renewable energy data [55], and had significant financial capital via the state's Renewable Energy Fund (REF) during the timeframe analyzed[5] [56]. Most remote communities in Alaska, including all in our sample, have neither a grid or transport connection beyond their community [57]. While there are important demographic, sociocultural and linguistic differences among communities [58,59], each community has demonstrated an interest in renewable energy transitions as evidenced by at least one grant application submitted to the REF related to project development thus reducing the significance of sociocultural factors in explaining different CRE outcomes. Finally, we examined several measures of income and poverty across the 24 communities in the dataset and found them all to be relatively weak factors leading to the presence or absence of CRE (Table 2). With these considerations in mind, below we briefly define the three key factors informing our study.

2.1.1. Subsidies for energy production

Linked closely to both economic and political factors are subsidies for renewable and fossil fuel-based energy sources. Diesel-powered generation in remote Alaskan communities is subsidized for residential consumers and qualifying community facilities through the PCE program[6]. Lack of subsidies for non-renewable technologies is a critical barrier to low-carbon transitions – the higher the PCE-subsidies for diesel power generation, the less competitive renewable energy technologies are because rate payers are insulated from the true cost of their electricity [61,62].

[5] The REF is a grant program meant to help communities develop renewable energy projects and was established in 2008 in part as a response to record high global oil prices that disproportionately impacted rural residents.

[6] The program is a residential subsidy program established by the State of Alaska in 1985 with the goal of equalizing the cost of residential electricity between rural and urban areas of Alaska [60]. The PCE subsidy is available to electric utilities that generate a majority of their electricity with diesel-fired generators and covers the first 500 kWh of electricity per household per month.

On average, the PCE subsidy is applied to only about 1/3 of the kilowatt hours sold in rural Alaskan communities, the rest are absorbed by the community. Commercial and Government customers, including schools, do not qualify and thus must pay the fully burdened rate. All communities in our sample participate in the PCE program at differing rates based on the amount of renewable energy produced. However, three case study communities located in an area called the relatively wealthy North Slope Borough receive an additional subsidy from their Borough government, which applies to electric power sales. Our interest is on the impact of this *additional* subsidy on CRE outcomes.

2.1.2. Capacity for managing local projects and infrastructure

Centered within three of Vallecha et al.'s six factors (economic, social, and political), a community's internal capacity is likely a powerful barrier (i.e., low capacity) or enabler (i.e., high capacity) [46,63][7] to developing a CRE project [64]. Based on consultations with community leaders, utilities, and state agencies, and after exploring several approaches to quantifying community capacity, we based *capacity* on an existing scoring system for assessing operations and maintenance capacity of rural/remote water and wastewater utilities developed by the Alaska Department of Environmental Conservation's Village Safe Water (VSW) and Remote Maintenance Worker (RMW) programs. While the system is designed to assess capacity for management of water and wastewater, based on case knowledge, it appears to also align well with local electric utility management.

2.1.3. 'Pooled' resources available across communities

Relating to both political and infrastructural factors, and based on our understanding of energy development in remote Alaska, we hypothesized that the presence of a community's utility that pools its resources across multiple communities rather than serving a single community will create an enabler for CRE. Pooling resources across communities may advance proportionate savings to achieve economies of scale relative to electric utilities [65] thereby enhancing community's capacity to seek and acquire external resources, including funding and access to

[7] When we refer to community capacity, we refer to the capacity of communities to undertake the development renewable energy projects not the capacity of communities in general. Many rural, remote, and Indigenous communities are highly functional communities rooted in deep traditional or Indigenous knowledge systems. High levels of capacity for general community life are necessary to, but not necessarily sufficient for, community capacity to initiate, develop, and maintain new energy technology systems.

project partners [52,66]. In other words, the ability and willingness to secure external resources, particularly pooled resources through a cooperative structure serving one or more community, a non-profit focused on regional CRE development, or larger parastatal institutions, is a mechanism to augment internal community capacity for CRE.

2.2 *Qualitative comparative analysis*

Qualitative comparative analysis (QCA) is a set-theoretical approach to assess complex causality in social phenomena [67] and is particularly useful for midsized datasets (i.e., between 10 to 100 cases) [48]. QCA combines case study-oriented and variable-oriented comparative methods allowing researchers to combine the qualitative analysis of case studies with systematic cross-case comparisons. QCA is used to identify specific combinations of potentially necessary and sufficient *conditions*[8] (i.e., independent variables) that together form a 'causal recipe' or pathway that lead to an *outcome* (i.e., dependent variable) [68]. Unlike statistical analyses which are probabilistic, QCA analyses are contingent; "causal relationships identified are not inferred from the (statistical) likelihood of them being found by chance, but rather from comparing sets of conditions and their relationship to outcomes" [69; p. 2]. QCA has been used across several studies of the low-carbon energy transition [70,71]. Most relevant to our study, this also includes research determining the set of conditions that led to renewable energy deployment in Asia [72,73] and Europe [74,75]. In our study, we aim to determine the necessary and sufficient conditions (from capacity, subsidy, and pooled resources) to the adoption or absence of a CRE project. A condition is *necessary* for the adoption/absence of CRE is not possible without it. A condition is *sufficient* if adoption/absence of CRE will occur if the condition is present, but other factors beyond the conditions in question may also produce the outcome [48].

2.2.1 Conditions

QCA modelling allows for two types of conditions: *crisp* and *fuzzy*. Crisp memberships are binary, where the existence of a factor is assigned a '1' and its absence is assigned '0'. Fuzzy memberships capture variability beyond a binary categorization, where it is not possible to easily simplify into presence or absence. For the variables *subsidy* and *pooled*, we used binary (crisp) memberships. If a community received an additional electricity subsidy, they were given a score of 1 (0 if they did not). Likewise, a community was given a score of 1 if they belonged to a utility that pooled resources. Given the nature of *capacity,* we created ‘fuzzy’ conditions for each community. *Capacity* was calibrated using the scores produced through the Alaska Department of Environmental Conservation's VSW and RMW programs, which annually provides a score for each community in three categories: technical capacity (maximum 45 points), financial capacity (45 points), and managerial capacity (10 points). We averaged total capacity scores for each community over five years (2015-2019) with scores ranging from a low of 31 to a high of 98. To calibrate the condition, scores of 60, 52, and 35 were used for full membership, crossover, and non-membership, respectively. All three conditions (by each community) are presented in Table 3. Except when noted above, data for conditions were based on 2007 (base year) information.

Table 3 – List of Independent variables (conditions) by community

Community	Capacity (0→1)	Subsidy (0=no; 1=yes)	Pooled (0=no; 1=yes)[a]
Akiachak	0.38	0	0
Atqasuk	0.17	1	1
Chevak	0.99	0	1
Emmonak	0.90	0	1
Gambell	0.12	0	1
Gustavus	1	0	0
Hooper Bay	0.98	0	1
Kake	0.91	0	1
Kaltag	0.13	0	1
Kokhanok	0.98	0	0
Kongiganak	0.27	0	1
Kwigillingok	0.09	0	1
Mekoryuk	0.89	0	1
Point Hope	0.43	1	1
Point Lay	0.35	1	1
Quinhagak	1	0	1
Saint Mary's	1	0	1
Sand Point	0.99	0	0
Savoonga	0.95	0	1
Shaktoolik	1	0	1
Shungnak	0.98	0	1
Toksook Bay	1	0	1
Tuntutuliak	0.90	0	1
Unalakleet	0.96	0	0

[a] Data for Pooled are from the Fiscal Year 2007 Statistical Report on the Power Cost Equalization Program [34].

2.2.2 Outcome Variable

In total, 17 of the 24 communities included in the analysis had developed a CRE project by 2017. The first outcome in the QCA analysis is the *presence* of a CRE project (noted as CRE), which is a dichotomous variable that takes a value of ‘1’ if a community has developed a successful CRE project that was installed between 2008-2017, and ‘0’ otherwise. The second outcome is the *absence* of a CRE (noted as ~CRE). ~CRE is a dichotomous variable that takes a value of ‘1’ if a community has *not* installed a community-scale renewable energy project and ‘0’ otherwise[9].

[9] The type of renewable energy project or installed capacity is not specifically taken into account and is variable based on resource availability.

Renewable energy projects represented in the dataset include wind, solar, and hydroelectric projects[10]. Data for the outcome is based on the Fiscal Year 2017 Statistical Report on the Power Cost Equalization Program or specific case knowledge.

2.2.3 Analyses

Using fsQCA 3.1b software, we first used our dataset to determine whether the presence or absence of each condition was necessary for either outcome. Consistent with Legewie [49], we used a high threshold for consistency (>.90) and coverage (>.50). We also used truth table analysis[11] to identify combinations of conditions that are sufficient for the outcome. The truth table comprises all possible combinations of independent variable values versus each of the two outcomes. Of the eight possible combinations in this analysis for communities with a CRE project, only five configurations are represented by empirical cases (see Table 4). Consistency scores range from 0 to 1 and represent the degree to which a causal combination leads to an outcome. Coverage ranges from 0 to 1 and measures the percentage of the outcome that is explained by a causal combination.

3. RESULTS

3.1 Necessary conditions

Our QCA analysis reveals that of the conditions analyzed, only ~*subsidy* (lack of subsidy) met the necessary condition of full threshold (of 100% consistency and 86% coverage) to the outcome of CRE (see Table 4). No conditions meet the consistency and coverage thresholds to be considered a necessary condition for the outcome ~CRE. This means that for our cases, lack of additional subsidy was a necessary condition to the adoption of CRE, but this condition was not by itself sufficient to explain this outcome. In other words, communities without the additional subsidy were not always successful in developing a CRE.

[10] It should also be noted RE is not indicative of the long-term sustainability of a renewable energy project. Two communities developed a system, which was no longer operational at the end of the study period.
[11] The truth table is minimized based on the Quine-McCluskey algorithm [76].

Table 4 - Analysis of Necessary Conditions

	Outcome: CRE		**Outcome: ~CRE**	
Condition	***Consistency***	***Coverage***	***Consistency***	***Coverage***
Capacity	0.79	0.81	0.54	0.19
~Capacity	0.21	0.58	0.46	0.42
Subsidy	0.00	0.00	0.50	1.00
~Subsidy	1.00	0.86	0.550	0.14
Pooled	0.78	0.74	0.83	0.26
~Pooled	0.22	0.80	0.17	0.20

3.2 Pathways to the *presence* of a CRE project

Truth tables identify the combination of conditions that are sufficient for the outcome of the presence of a CRE project (Table 5). There are two such paths described below which together have a solution coverage of .996 and a solution consistency of .882. This means that 99.6% of the outcome of a CRE project can be explained by the solution, and 88.2% of communities with these configurations of conditions have CRE projects.

Table 5 - Results of intermediate solutions for a community renewable energy project (CRE)

Causal Configuration	***Raw Coverage***	***Unique Coverage***	***Consistency***
Capacity*~Subsidy	0.786	0.218	0.861
~Subsidy *Pooled	0.777	0.210	0.875
Solution coverage: 0.996; Solution consistency: 0.882			

The first pathway to the presence of a CRE is *capacity and no subsidy* (i.e., *capacity* *~subsidy) (see Figure 2 and Table 5). This means that communities with a combination of high capacity and no additional subsidy for power generation have a CRE project. This pathway covers 16 communities (Gustavus, Toksook Bay, Saint Mary’s, Shaktoolik, Quinhagak, Sand Point, Chevak, Kokhanok, Hooper Bay, Shungnak, Unalakleet, Savoonga, Kake, Emmonak, Tuntutuiliak, and Mekoryuk) and raw coverage is .786, meaning that 78.6% of the outcome (i.e., presence of a CRE project) is explained by this pathway. The consistency of this pathway is .861, meaning that 86.1% of the cases covered by this pathway have a CRE project.

Highlighted project: Unalakleet

Unalakleet is an Iñupiat Eskimo community in northwestern Alaska with 686 residents based on the 2020 US census. Unalakleet was the first rural community in the northwest Arctic to form an electric cooperative (Unalakleet Village Electric Cooperative, or UVEC) in 1961 with the goal of providing central power electricity to all residents and businesses. Unalakleet is generally considered to be a community with high capacity, as is supported by our data. UVEC has since invested in 600 kW of wind power to augment diesel generation, and thus has been successful in developing a CRE. Thus, Unalakleet has high capacity but is served by a stand-alone independent utility.

The second pathway to a CRE project combines the conditions of no additional subsidy and service through a utility that pools resources (i.e., ~subsidy *pooled) (Figure 2 & Table 5). This pathway also captures 16 communities (Toksook Bay, Saint Mary's, Shaktoolik, Quinhagak, Chevak, Hooper Bay, Shungnak, Savoonga, Kake, Emmonak, Tuntutuiliak, Mekoryuk, Kwigillingok, Kongiganak, Gambell, and Kaltag). Based on raw coverage and consistency, 77.7% of the outcome (i.e., presence of a CRE project) is explained by this pathway, and 87.5% of the cases covered by this pathway have a CRE project.

Highlighted project: Kongignak

Kongiganak is a Yupik Eskimo community in Southwest Alaska with a population of 433 residents based on the 2020 US census. Kongiganak is one of three communities in our dataset that are part of the Chaninik Wind Group (CWG) and were successful in developing CREs. The CWG was formed as a non-profit collaboration to pool resources between communities in order to develop wind power to reduce energy costs, as well as promote self-sufficiency and economic development. Kongiganak does not have a modern water and wastewater treatment system, and most residents obtain water from a centrally located Village Safe Water (VSW) system, and use "honey buckets" that are disposed of in a local sewage lagoon in lieu of modern septic systems. Kongiganak has developed an advanced wind-diesel system that is capable of operating at greater than 100% wind penetration. In cases where the wind resource exceeds community demand, excess wind is used to power electric thermal stoves in 80 individual residences, which are metered separately and charged at a rate competitive with heating oil.

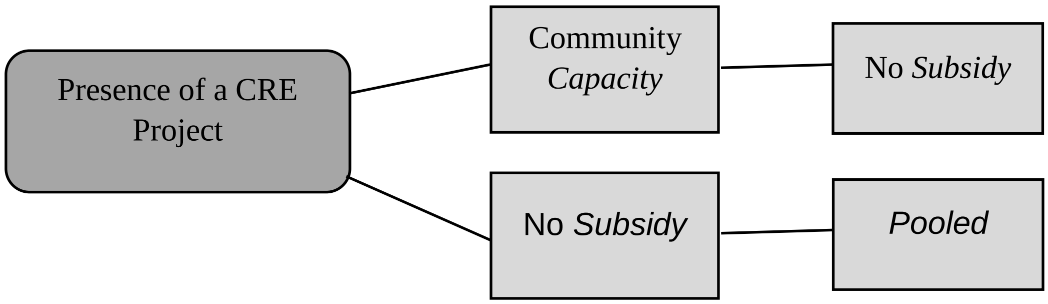

Figure 2 – Branching diagram representing the two pathways resulting in the presence of CRE.

3.3 Pathways to the *absence* of a community renewable energy project (~CRE)

The intermediate solutions for the QCA analysis with the outcome of no renewable energy project (~CRE) are reported in Table 6. Results indicate two paths to the *absence* of a CRE project. For both pathways, the solution coverage is .445 and the solution consistency is .974, which means that 44.5% of the outcome of *no CRE* project can be explained by the solution, and 97.4% of communities with these configurations of conditions do not have a CRE project.

Table 6 - Results of intermediate solutions for the absence of a community renewable energy project (~CRE)

Causal Configuration	*Raw Coverage*	*Unique Coverage*	*Consistency*
~Capacity *~Pooled	0.103	0.103	0.898
~Capacity *Subsidy	0.341	0.341	1
Solution coverage: 0.445 *Solution consistency: 0.974*			

The first pathway to the *absence* of a CRE project combines the conditions of low capacity and lack of pooled resources (~capacity*~pooled). The pathway covers only the community of Akiachuk. Just 10.3% of the outcome is explained by this pathway and 89.9% of the cases covered by this pathway do not have a CRE project. While this pathway covers only one community in our sample, preliminary evidence from other unpublished studies indicate this pathway may apply to a number of communities that are not part of our cases.

The second pathway includes communities with low capacity, and an additional electricity subsidy (~capacity *subsidy) and covers three communities: Atqasuk, Point Hope, and Point

Lay. The raw coverage of the pathway is .342, and the consistency of the pathway is 1. 34.2% of the outcome is explained by this pathway, and 100% of the cases covered by this pathway *do not* have a CRE project.

Highlighted project: Port Hope

Point Hope is an Iñupiat Eskimo community in the North Slope Borough of Alaska with a population of 715 residents based on the 2020 US Census. The Borough manages electric power services for the community, and the other 7 communities in the North Slope Borough. Hence, the communities are pooling resources through a shared service provider, although unlike AVEC the NSB Power Distribution and Utility division is a parastatal entity. In addition to the PCE subsidy, the North Slope Borough provides an additional subsidy to communities in the region, reducing the delivered cost of electric power to 15 cents/kWh. This is effectively the lowest delivered cost of power in the state of Alaska - including the City of Anchorage - as a result of this subsidy. Point Hope has not developed a CRE, despite having access to an economically viable wind energy resource.

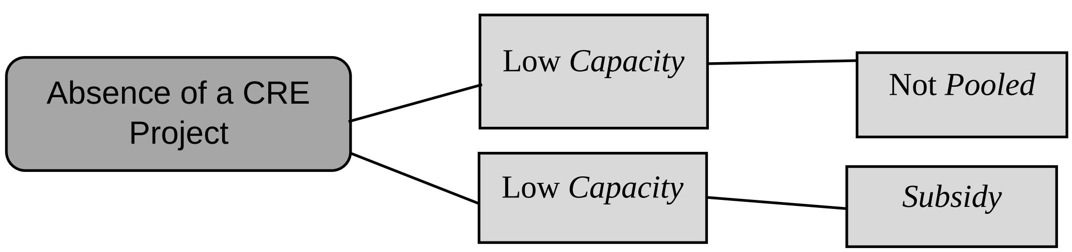

Figure 3 – Branching diagrams representing the absence of CRE related to sufficient conditions

3.4 Inaccurate but reinforcing conditions

On first glance, three of the 24 CRE outcomes appear as anomalies and inaccurately predicted based on the conditions. Two pathways to CRE 'missed' one community that did develop a CRE project. This is Kokhanok, the smallest community with 179 residents, which was not predicted to develop a CRE because it has a utility that does not pool resources, and it had only an intermediate score for capacity. However Kokhanok did go on to develop a high penetration wind project in 2010, but unfortunately the project never functioned as designed and is not currently operational[12]. Conversely, Kake and Saint Mary's were predicted to develop renewable energy projects, though they did not do so during the study period of 2007-2017. That said, Saint Mary's did install wind energy in 2019 and Kake is currently seeking funding for a hydroelectric project that is permitted and ready for construction. Therefore, the three communities whose outcomes were inaccurately predicted by the QCA analysis in fact serve to reinforce the validity of the pathways.

4. DISCUSSION

This paper examined why some remote communities in Alaska have succeeded in developing CRE projects while others have not. Our study shares similarities with a growing number of others that investigate the barriers and enablers to renewable energy [11,39,41]. However, it also differs as it uniquely compares remote communities of similar scale in a single US State (Alaska), which face many similar underlying conditions that act as enablers and barriers to CRE transitions. The paper also joins a list of other energy transition studies that have effectively used QCA, including work from Ide [70], Schmid and Bornemann [75], and Lee et al. [73]. From an historical perspective, we were able to define a 'clean' start date, namely the 2008 implementation of Alaska's Renewable Energy Fund (thus selecting 2007 as the base year for this analysis), and then assessed the development of community renewable energy projects over the following decade. Over those 10 years, 17 of the 24 communities we considered successfully developed CRE projects. This divide between the communities that 'have' and 'have-not' transitioned might implicate an element of energy (in)justice to this study – a point of emphasis in the quickly growing energy social science literature [77]. It is within this literature that socio-technical approaches generally, and MLP more specifically, often downplay the importance of place or community-based factors.

Our results showed that lack of *subsidies*, community *capacity to manage projects/infrastructure*, and whether a community *pools resources*, were important variables shaping both the presence and/or absence of CRE across remote communities in Alaska. Based on Vallecha et al. [36], these three conditions fall at different points along the macro to micro-level spectrum of CRE barriers and enablers. We observe that community capacity falls at the

[12] This project is currently in the process of being revitalized through a partnership that includes the community, the Lake and Penn Borough, and the Alaska Center for Energy and Power at the University of Alaska Fairbanks.

micro level because it is often based on factors controllable by the community. The pooling of resources and the presence of an additional subsidy are both meso-level conditions, because they are largely outside of the direct control of communities and based on decisions made at the regional level. Because of their unique effects within the QCA presented here, we discuss each condition separately.

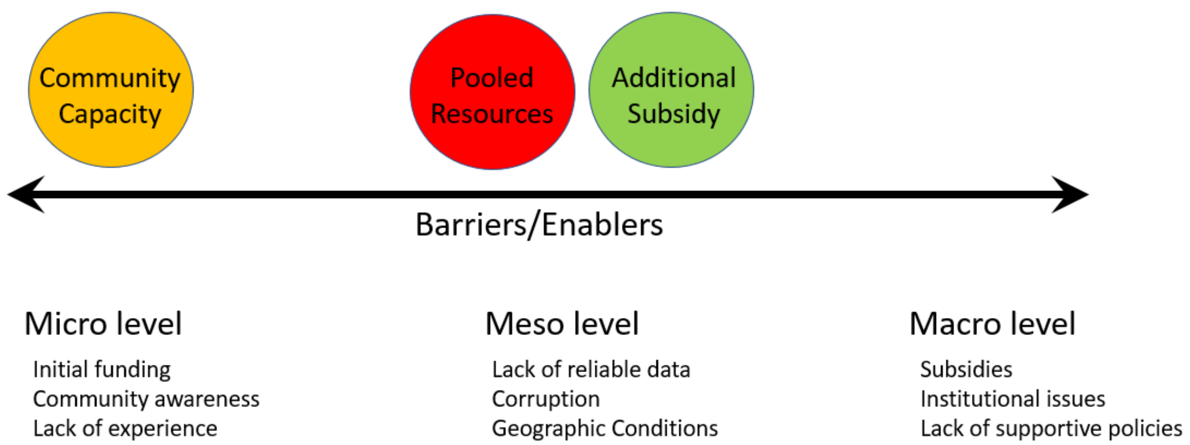

Figure 4 – Position of the three main conditions on a scale of Micro to Macro-level barriers or enablers (based on Vallecha et al.'s [36] framework)

First, our analysis revealed that the condition of *lack of subsidy* (i.e., any subsidy beyond the PCE for diesel power generation) was the only condition that met the threshold for necessity and was captured in three of the four pathways leading to the presence or absence of CRE. This aligns with prior research [61,62] that has shown that subsidies for status-quo (diesel) technologies can distort market economics and can serve as a powerful barrier to CRE. It follows that as long as these subsidies are in place, remote communities (and residents therein) will not only avoid paying the true cost of their electricity in terms of economics – but [often] in terms of socio-environmental harms as well [78]. However, this study shows that higher or additional subsidy than PCE stymies the CRE transitions in the communities studied. The absence of the additional subsidy does not mean a community necessarily goes on to develop a CRE. It appears that based on the fact that 17 communities developed CRE from 2007 to 2017, the modest subsidy provided to all remote Alaskan communities, through the PCE, may not be a powerful barrier. The impact of additional subsidies may also be seen via the fact that three remote Alaskan communities (Atqasuk, Point Hope, and Point Lay) in an area called the North Slope have not developed any CRE project to date. This is surprising considering the renewable energy resources available and overall wealth derived from oil and gas resources in the Northern region. However, all three North Slope communities do receive an additional subsidy. The story is of course more complex, as an unusual para-statial utility company provides services in all three North Slope communities included in our sample. The extent to which this is a contributing factor is difficult to assess for our dataset. Using QCA through a multi-national study could tease apart the relative influence of each of these conditions, which are more representative of utility operations and cost structure in Northern Canada or Greenland, than in other parts of Alaska. Thus, it may not be a coincidence that much of Northern Canada (such as Nunavut) has also been slow to adopt CRE projects. Under the territory's crown utility (QEC), for example, electricity rates in Nunavut are heavily subsidized and very little renewable energy can be found [79]. In these circumstances, it may be that local governments and customers do not, or cannot, exert pressure on their utility to reduce the cost of electricity.

Second, community *capacity* was also found to be an important condition influencing the presence or absence of a CRE. Unlike *lack of subsidy*, it was not shown to be a necessary condition, but it did appear within three of the four pathways identified. This indicates a certain degree of alignment with the existing literature focused on community-scale [63,64] and Indigenous-led [46] renewable energy, which indicated that a minimum baseline level of technical, financial, and managerial capacity can powerfully enable renewable energy transitions. We entered this research understanding that community capacity is difficult to quantify. To be clear, when we refer to the term, it is specifically around the capacity of communities to undertake the development of CRE projects – not the capacity of communities in general. Many rural, remote, and Indigenous communities are highly functional communities rooted in deep traditional or Indigenous knowledge systems, but this may be distinct from the type of capacity required for a community to initiate and develop new energy systems. We explored many proxy variables for community capacity, but through consultation with community members, utility managers, and program managers, ultimately settled on the methodology described in this paper. We assumed that a communities' ability to represent other utilities and utility infrastructure, namely, water and wastewater systems, would be representative of their local capacity to develop a CRE. We believe it is a reasonable proxy considering the lack of data on energy infrastructure management and technical and management capacity for transitions, which we highlight as a key problem in remote Alaska.

Third, we observe that through its inclusion in two of the four pathways, the condition of *pooling* resources matters. Consistent with the literature, we hypothesized that in remote Alaskan communities pooling resources is a relevant factor in the development of a CRE because it can allow communities to: (a) develop economies of scale [65] and (b) increase their ability to acquire external resources, including funding [52,66]. Indeed, in addition to local community capacity, many communities in Alaska build strength through pooling their resources and utilities are the primary institutional structure through which these pooling arrangements occur. Alaska has a very decentralized utility structure with the 24 communities we examined served by 15 separate utilities. These ownership models include investor-owned, cooperatives, municipally-owned, tribally-owned, and quasi-governmental and can be fluid. For example, one of the communities in our dataset, Gustavus, changed hands during the ten-year period we studied. The most obvious way communities pool resources is when the utility serves multiple communities, with the two most prominent examples being the Alaska Village Electric Cooperative (which serves 58 communities including 10 in our sample), and Alaska Power and Telephone (AP&T), a privately owned utility that serves 27 communities, including one (Gustavus) in our sample. Another interesting example of the pooling of resources in our sample is the Chaninik Wind Group, which includes the communities of Kongiganak, Kwigillingok, and Tuntutuliak. These three medium-sized remote communities each have their own tribally-owned and operated utilities, but have partnered under the non-profit umbrella, the Chaninik Wind Group, to benefit from economies of scale. At each location, 475 kW of wind capacity has been installed alongside residential ceramic-based thermal electric stoves which are capable of storing excess wind energy as heat.

Our dataset originally included 37 conditions that align with at least one, and often several of Vallecha et al.'s [36] categories of factors that act as barriers or enablers of CRE, and our 24 study communities share commonalities in terms of grid-connection status, regulation and policy regime (e.g. access to similar sources of grants, subsidies and project financing), community size, and renewable energy resource. That said, while QCA proved to be a valuable tool to determine the pathways toward CRE in this context, we recognize the need for future research using more traditional qualitative (i.e., interviews and focus groups) and quantitative (i.e., surveys) datasets – both in Alaska as well as other remote, diesel-dependent communities around the world and in the Arctic in particular. Based on our findings, further research is needed to better understand the factors, including their procedural and distributive justice elements [80] that support local energy systems such as CRE. It may also be helpful to for future work to more deeply consider the potential impact of local planning authority and opposition to specific projects. While we did not find such factors to be especially pertinent to the study of CRE in remote Alaska, doing so may allow researchers to provide a clearer picture of ‘success’ beyond whether a project was built or not. There may also be added value in research that is able to consider more precise measures of renewable resource viability and/or source intermittency.

5. CONCLUSION

The purpose of this research was to complete a systematic comparative analysis of the community-centered conditions that enable or prevent CRE transitions in remote communities. We feel that we have addressed this important gap in the literature, where most research on the barriers and enablers of CRE is set outside of the context of remote, diesel-dependent communities. Our study shows that the lack of additional subsidies for diesel power generation is a powerful, and indeed necessary condition behind CRE projects in remote Alaska. We also found that our measure of community capacity was instrumental in shaping the presence or absence of CRE. Additionally, we introduced the unique condition (variable) of an empirically measurable model of community capacity. Too often proponents, including governments, focus on short-term project development and not issues of capacity-building. Community leaders, energy champions and everyday citizens are essential to getting CRE projects off the ground and making them successful in the long term, and this idea should be recognized as such. Lastly, we also found the condition of the pooling of resources to be very important to CRE transitions in Alaska. We suggest that pooling for economies of scale across models such as cooperatives can hold great benefit for communities looking to develop their own CRE project.

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