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RESEARCH ARTICLE

A local perspective on renewable energy development in the Russian Arctic

Daria Gritsenko and Hilma Salonen

Many Arctic communities are exposed to energy security risks. Remote settlements rely largely on diesel for energy production, which results in higher consumer prices, negative impacts on the environment and public health. In the past few years, pilot projects for switching remote villages from diesel-generated to wind- and solar-diesel hybrid power plants were realized across the Arctic. Renewable energy projects have a major potential to alleviate energy security risks, promote public health and better environment. Yet, renewable energy does not take hold easily in the Arctic region. Especially in Russia, significant subsidies for fossil fuel present a major disincentive, as well as perpetuate vested interests of national oil companies. Despite the Russian Arctic being a 'hard case' for renewables development, there has been both interest in and progress towards the uptake of renewable energy across the Russian Arctic regions. This article contributes to the 'local turn' in sustainable energy policy studies by exploring two intertwined questions: which factors contribute to renewable energy development in the Russian Arctic and how do these factors characterise differences between individual Arctic communities? Using a combination of exploratory factor analysis and correspondence analysis in application to the local level (municipal) data, we update the existing models of the factors contributing to renewable energy uptake and put forward four distinct community-level models that describe renewables uptake. We conclude by emphasizing the importance of the local perspective on sustainable energy as a key to explaining differences in observed policy outcomes.

Keywords: Arctic; Renewable energy; Russia; Community; Exploratory analysis

Introduction

Sustainable energy transition refers to an all-encompassing transformation of the ways how societies produce, use, and value energy (Verbong and Geels, 2007). One of its key elements is the uptake of renewable energy (RE) sources – such as solar, wind, hydro, geothermal, and ocean – in particular as an answer to local energy challenges (Kuzemko, 2019). Coupled with increased energy efficiency, RE can reduce the demand for and supply of energy generated from fossil fuels (e.g., natural gas, oil, and coal-fired power plants), while opening pathways for an energy system that provides a sustainable alternative to fossil fuels. Globally, in 2018, 28% of electricity was generated from renewable sources, mostly hydropower, wind, and solar, and the share of RE in global electricity generation is expected to increase to 49% by 2050 (EIA, 2019). Yet, the development of RE remains largely uneven across world's regions.

Despite the availability of RE sources in the Arctic, RE projects do not take hold easily in this region (Boute, 2016), mainly associated with ongoing and future potential for fossil fuel extraction (Nuttall, 2010; Gritsenko, 2017b). While the hydrocarbon riches drive global expectations with regard to Arctic development, many Arctic communities are not connected to the energy grid and use diesel generators to generate energy. Reliance on imported diesel for energy production results in high consumer prices and negative impacts on the environment and public health. Energy vulnerability in these remote communities compromises human wellbeing and disadvantages their economic development (McCauley et al., 2016). During the past decade, a number of RE projects ranging from small scale (such as a few solar panels or a single wind generator) to sizeable facilities (such as a 1mW solar power station in Batagai (Yakutia, Russia) and a 0.5mW solar farm south of Fairbanks (Alaska, USA)), have been realized across the Arctic. What factors contribute to, and impede, the development of these new RE projects are debated in the sustainable energy literature (Boute, 2016; Poelzer et al., 2016; Mortensen et al., 2017).

Much of the existing scholarship focuses on the highest political level and international politics to explore global implications of Arctic oil and gas development projects and their legal intricacies (Johnston, 2010; Aalto and Jaakkola, 2015). Yet, some scholars have started to re-think the role of the local governments in sustainable

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energy policy-making, emphasizing their agency, interests, and ideas as crucial for RE development (Kuzemko, 2019). Local perspectives have proven useful in examining the subnational tendencies in Arctic energy governance, in particular, indigenous perspectives on energy development and problems of local sustainability (Stammler and Wilson, 2006; MacDonald and Pearce, 2013; Poelzer et al., 2016). These studies shift focus away from national and international governance, prompting investigation of mechanisms that allow aligning local needs, resources, and opportunities to attain sustainable energy (Gritsenko, 2017a). As case-studies demonstrate, RE in the Arctic is a feasible way of enhancing energy security (Rud et al., 2018). In addition, reduction in black carbon emissions contributes to both local air quality (respiratory disease) and climate change mitigation (Kholod et al., 2016).

This article contributes to the 'local turn' in sustainable energy policy studies by exploring two intertwined questions: which factors contribute to renewable energy development in the Russian Arctic and how do these factors characterise differences between individual Arctic communities? The Russian Arctic can be seen as a 'hard case' for RE development. The existence of an energy subsidy regime coupled with the lack of funding instruments to support the renewables (Boute, 2016) and growing climate change scepticism (Tynkkynen and Tynkkynen, 2018) create an environment that lacks incentives for RE development. Yet, there has been both interest in and progress towards the uptake of renewables across the Russian Arctic regions (**Figure 1**). Our central hypothesis is that while the national political and institutional factors as well as technological developments have a similar framing effect on all the regions, there is no universal model for how renewables come about in the Russian Arctic. Without an adequate understanding of the different models for renewable energy development, we can neither explain the differences in sustainable energy policy outcomes nor devise practical knowledge how to support locally contingent energy mixes to reduce energy vulnerability and allow local economies to thrive.

This empirical study operates at the municipal level to explore how RE projects in the Russian Arctic are grounded locally. Methodologically, we combine exploratory factor analysis (EFA) and correspondence analysis to address our research questions. First, on the basis of initial literature review, we operationalise the mechanisms that are considered central to RE development in the Arctic and test the viability of the existing model through an exploratory factor analysis. Second, we use the obtained factors to devise community-specific models for renewables uptake. Our results are two-fold. First, we propose a revised model that suggests five factors of RE development for the Russian Arctic based on local-level indicators. Second, we put forward four distinct community-level models that describe renewables uptake. We conclude by emphasizing the importance of the local perspective on sustainable energy as a key to explaining differences in observed policy outcomes.

The article proceeds as follows. Section 2 provide review of literature on local determinants in RE uptake, specifically building upon the Arctic cases. Section 3 elaborates on the methodology of the study. Section 4 presents the

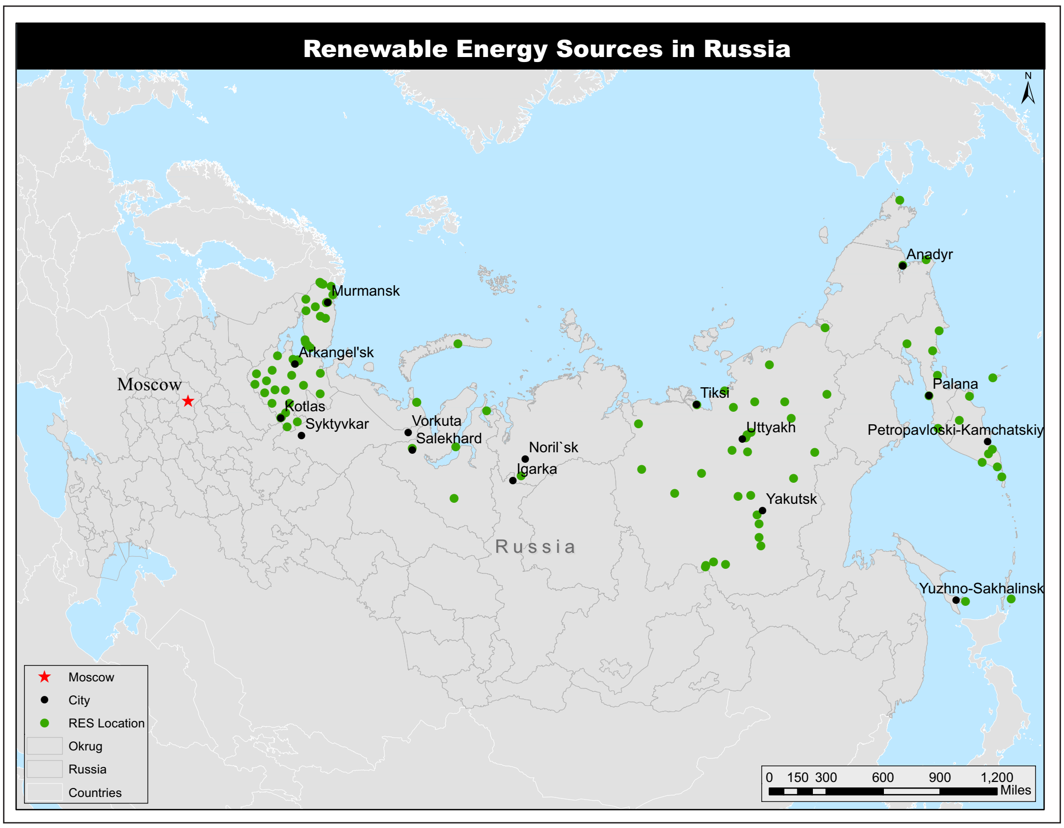

Figure 1: Renewable energy in the Russian Arctic (as of 01. 01. 2019). Source: Authors. This figure maps renewable energy facilities in the Russian Arctic. DOI: https://doi.org/10.1525/elementa.441.f1

results of the empirical investigation. Section 5 discusses the results and concludes.

Renewable energy in the Arctic

Many Arctic communities are exposed to energy security risks. The International Energy Agency defines energy security as "the uninterrupted availability of energy sources at an affordable price" (IEA, n.d.). In the remote Arctic settlements that rely largely on diesel generators for energy production, both availability and affordability of energy sources is compromised by complex logistics. In the absence of permanent year-round connections, diesel can be delivered only during the navigation season for those communities situated along the inland waterways or at the coast, and only by winter roads for the inland communities. In some cases, the delivery process takes up to two years, which results in high consumer prices. For instance, in some remote villages of the Arctic Russia the cost of electricity for private consumers can top 600 rubles for kW/h compared to three rubles for kW/h for the country average. These prices are so high for consumers that energy is subsidized all across the Arctic by the government, which is straining for the local and regional budgets. The high price is a strong motivation to find ways to reduce energy cost. McDowall (2018) argues that "the cost of diesel generation has prompted Arctic communities to embrace renewable energy resources such as wind and solar power" (p. 28). In addition to high price, remote communities usually find themselves in a situation of monopoly – they rely completely on one energy provider and lack any kind of back up (McDonald and Pearce, 2012).

Diesel generators also have a negative impact on the environment and public health (Schmale et al., 2018). Burning diesel fuel contributes to local atmospheric pollution, including particle matter, sulphur, and nitrogen, all contributing to respiratory disease and dangerous lung conditions (Ristovski et al., 2012). This atmospheric pollution has adverse impact for the environment, in particular, due to black carbon release (Kholod et al., 2016). Unlike CO2, which remains in the atmosphere for a long time, black carbon remains in the atmosphere for only a short time (days or weeks) and does not travel far, setting on the ground in form of soot. In the Arctic, melting of ice and snow has been accelerated by deposition of wind-blown soot particles, among others coming from diesel generators. In addition, diesel generators are noisy, which can be equally disturbing for humans and the animals (McDonald and Pearce, 2013).

Given the high energy cost, the negative environmental and health effects, and the increased availability of technology that can be used in the severe Arctic weather conditions, RE seems like an attractive energy option for the remote settlements in the Arctic. In the past decade, pilot projects for switching remote villages from diesel-generated to wind- and solar-diesel hybrid power were realized in Canada, Russia, Greenland and the US (arcticrenewableenergy.org). Yet, we still observe significant disparities in uptake motivation, scale and speed between localities. Some recent literature on the topic sought to better understand the existing variation.

The first group of studies we review are qualitative case-studies. McDonald and Pearce (2012) in their research in Nunavut identified the barriers to renewable energy uptake stemming from high cost, lack of federal and territorial government support, lack of suitable technologies, lack of knowledge within the communities and absent capacity to maintain the installations. They concluded that community-government-industry alliance is crucial for developing successful RE projects in Nunavut. Strand (2018), who studied NWT and Alaska, also suggested that economic rather than environmental considerations are driving a shift to renewables, and identified that barriers to and drivers for RE uptake lay within four interrelated spheres: technical, financial, organizational, and community. The study highlighted the role of interdependencies between these four factors in making the decision on RE project implementation.

The second group of studies are qualitative comparisons. Cherniak et al. (2015) conducted a study of sustainable energy projects spread across five Canada's northern jurisdictions (Yukon, Northwest Territories, Nunavut, Nunavik and Nunatsiavut). The study demonstrated that "while there are many commonalities in the drivers and policies behind the projects, the challenges faced and the factors contributing to their success, there are many more influencing factors that are unique to each project, technology, location or jurisdiction" (p. 137). The differences within Canada are explained by the differences at the local level. Within the supportive local policy environment, a few key individual proponents or energy NGOs have been crucial to overcome the inertia of the established energy system and to drive the deployment of renewables. The study underscores the interplay between community, government and industry.

Mortensen et al. (2017) conducted a cross-national comparison and identified three crucial factors that influence the RE uptake in the Arctic: financial mechanisms (feed-in tariffs, auctions, direct subsidies and tax credits), infrastructure (transport routes and logistics), and technology. and technology (availability of domestic and/or imported components for RE production). They also emphasized the current lack of knowledge-sharing between communities and the importance of capacity-building. The inclusion of community as a key factor is aligned with the other research that shows the importance of the local level of analysis to RE development in the Arctic. In sum, the study confirmed Cherniak et al.'s (2015) findings that differences exist among the regions of the same country, while also demonstrating the significant differences in the type and level of implementation or RE projects between countries.

Cherniak et al. (2015) also identified subsidies as an important factor that hinders the adoption of RE. They pinpoint that currently a consistent and transparent definition and measurement of the marginal cost of diesel generation is lacking. They advocate a need for a comprehensive calculation of all the saved costs (including local GHG) to estimate the real economic value of RE uptake. Mortensen et al. (2017) similarly highlighted that significant fossil fuel subsidies, especially in Canada, Russia, and Greenland, can create disincentives to RE projects.

All the factors that may affect RE uptake in the Arctic explored in the above-mentioned studies can be divided into two groups. First, the 'internal' factors include challenges that communities face due to their dependence of imported fossil fuels (high transportation and commodity prices, lack of transportation infrastructure, high environmental and human health risks). The second group of factors can be called 'external' as they stem from the global context in which these communities find themselves (global climate change mitigation agenda, renewable energy targets adopted by nation states, RE technology development, inter alia for the Arctic use). While there is an interplay between the two groups of factors, Cherniak et al. (2015) study highlighted that in Canada, internal factors have more relevance. A series of interviews and workshops with local and territorial stakeholders revealed, that while reliability, and hence local energy security, is perceived as a minimal requirement, affordability and cost minimization is a top criterion for decisions on energy supply and governance, while environmental impact reduction and local economic benefits are seen as secondary.

The Russian case has a number of specificities. First, financial mechanisms for RE support exists only for the capacity market (since 2013) and in retail (since 2015). There is currently no mechanism supporting microgeneration and individuals cannot sell to and buy from the grid. Boute (2016) argued that the lack of appropriate support mechanisms is a major barrier for RE uptake in Russia. Second, Russia has a highly centralized governance system: regional laws cannot deviate from or contradict the federal provisions while local self-government does not have a law-making authority. As a result, territorial governments differ only with regard to their reaction to the federal policies, for example, how motivated they are to implement by-laws that translate federal instruments into concrete regional and local actions. Third, Russia is highly technologically dependent when it comes to RE: domestic technologies either do not exist or are inferior to their foreign counterparts. In addition, during the 2014 Ukrainian crisis, international sanctions were imposed against Russia, leading to both direct (certain equipment no longer available) and indirect (currency devaluation) effects. In particular the latter made imported RE technologies expensive to an extent where payback time has excessively increased and made RE investments largely unattractive.

The above-mentioned factors are valid for all the observed regions: financial incentives, fossil fuel subsidies, and legal initiative are structured in a similar manner across the Russian regions, and the level of technology available to different regions only differs with regard to their natural characteristics regarding the availability of renewable energy sources. As a result, these incentives and disincentives can be assumed to have a comparable effect and therefore cannot be used to explain the local variation. On the contrary, local-level factors pertaining to infrastructure, characteristics of the local community and self-government can be regarded as both varying and unique. In what follows, we deploy multivariate exploratory methods to clarify how RE projects in the Russian Arctic are grounded locally.

Methodology

Data collection and preparation

The study is based on several data sources and largely relies on open statistical data. First, based on Berdin et al. (2017) complemented by extensive Internet search, we compiled a list of renewable energy projects deployed in the Russian Arctic regions and in Kamchatka, which is a remote region with a significant amount of off-grid settlements, making it comparable to the Arctic communities. Our list included specific information on each of the projects, such as energy source (biomass, hydro, solar, wind, geothermal or waste), capacity, year of installation, and municipality where the facility is located with geographic coordinates (N = 98). Second, this list has been amended by demographic, economic, financial, and budget data at the municipal level, derived from the Russian official Database of Municipal Indicators (Baza dannyx pokazateley municipal'nyx obrazovaniy, https://www.gks.ru/free_doc/new_site/bd_munst/munst.htm) for the period 2006–2018. The data availability for the period varies greatly from one municipality to another, with larger cities and municipalities displaying a tendency to provide more complete datasets, whereas smaller municipalities may only include a few data points. In a few cases (less than 10), the Database did not include population numbers, and those were added from third sources (e.g., Wikipedia) using Internet search. Third, we added municipal voter turnout statistics derived from the website of the Russian Electoral Commission (http://www.cikrf.ru/). To avoid the distorting effect of federal elections held together with local ones, included statistics are of years when there were no presidential or parlamentary elections in Russia, that is 2013–2015 and 2017. In cases when municipal elections data was not available for the aforementioned years, data from other close periods was used. Finally, each renewable energy facility has been assigned a winter accessibility score, calculated on the basis of the data derived from various online open data sources (see Supplementary material).

The resulting database (N = 98) had a number of missing values. If we were to exclude all observations that had at least one value missing, our dataset would shrink by 20%. Hence, we made an assessment of the missing values by observations and for those cases that had less than 3%, we calculated missing values based on linear regression. Our imputation protocol was based on Expectation-Maximization (EM), an iterative procedure that uses other variables to impute a value (Expectation), as well as selects the value most likely (Maximization). We opted for EM imputation rather than a mean imputation because it preserves the relationship with other variables. While EM imputations still underestimate standard error, since our data is further used for exploratory factor analysis, which is a dimension reduction rather than a causal predictive technique, and the amount of missing values did not exceed 3%, we consider our final dataset valid for the analysis. Software used for imputation is SPSS. Our final dataset contains 92 observations.

Methods of statistical analysis

The study relies on two methods of multivariate analysis: Exploratory Factor Analysis (EFA) and Correspondence Analysis (CA) (Vehkalahti and Everitt, 2019). EFA is a dimensionality reduction technique performed on a set of independent variables based on the assumption that a smaller set of latent variables – factors – can explain the variance observed in the data. CA, in its turn, is a non-probabilistic technique for measuring the relative relationships between categorical variables using a geometric (distances) approach. All calculations were conducted using R (R Core Team, 2017), specifically the psych and ca packages for EFA and CA respectively.

EFA: Variables description and operationalisation

We rely on the previous studies to determine the variables that potentially contribute to the deployment of RE facilities in remote Arctic conditions and operationalise them using the indicators that could be created from the available data (**Table 1**). First, we consider local accessibility as a factor contributing to high fossil energy cost and energy insecurity that may vary significantly at the local level. Poor accessibility makes fuel logistics expensive and complicated as it has to be delivered from afar by marine and inland water ways, ice (winter) roads and sometimes even by airways, with a constant risk that delivery will not be completed on time (Mortensen et al., 2017). Combining Atkinson et al.'s (2005) methodology with the Arctic Transport Accessibility Model (ATAM) developed by Stephenson et al. (2011), we calculate the least-cost path between each RE facility and their nearest fuel logistics node (refinery or port). Since many remote communities are accessible only during a limited time period throughout the year (maybe even just a few weeks a year), we approximate the distance through travel time and assign each locality a winter accessibility score, defined as a number of round trips that can be conducted within three winter months. For a detailed description of the data and methods used to calculate winter accessibility, see Supplementary material.

Second, previous studies demonstrated that a local administration can provide technical and legal knowledge, participate in the preparation of a proposal, lobby the regional government, and in various ways support and promote the renewables (Kammermann, 2017). Cherniak et al. (2015) argued that by-laws that translate political strategies into concrete measures and community energy strategies developed by municipal governments have been paramount to support both alternative energy and energy efficiency initiatives in the Canadian North. Hence, municipal capacity can define the ability of a given municipality to engage with local energy projects. We used four indicators to operationalize municipal capacity. First, we calculated the budget spending on local self-administration as a share of total municipal income as a proxy of administrative capacity. Second, we inferred the share of directly transferred income from the state to the total municipal expenditures to capture the local fiscal capacity. By directly transferred income, we refer to various federal subsidies that are often vitally important to municipalities so that they may manage their tasks with very low municipal budgets. Third, we control for the local budget balance by dividing total expenditure by total income. Finally, we consider the rate of private investments into a municipality as a proxy of local government's capacity to attract capital and promote local economic development.

Third, the literature acknowledges that the current energy provision model can have an impact on RE uptake. For instance, in Nunavut's remote off-grid communities there is usually only one energy provider, and even if community members do not want diesel generated electricity, there are no feasible alternatives (McDonald and Pearce, 2013). In Alaska, the recent trend has been the raise of native corporations in the RE sector (Strand, 2018). Research also suggests that the aging fossil fuel energy infrastructure and the high cost of acquiring diesel constitute powerful drivers for remote communities to establish small-scale wind, solar or hybrid (wind–diesel, solar–diesel) utilities to supplement diesel generators (Mortensen et al., 2017). In Russia, municipalities are legally obligated to take responsibility for the local energy and utilities, yet, the local realities vary due to different infrastructure (Salonen, 2019). In order to reflect this fact, we introduce utility spending as an indicator measuring the share of housing and utilities spending from the total municipal income.

Finally, we build on the literature that underlines the importance of demography and civic engagement for community future outlook. Arctic communities often experience boom and bust cycles (Orttung, 2016). In some communities, population dynamics is negative as people are gradually leaving, while in others population may be stable or even growing through work-related migration promoted by new industrial development or tourism projects (Heleniak et al., 2013). Future outlook and motivation to invest in new technology, such as RE facilities, are connected. We use population and migration data to establish the community outlook measure. First, we calculate compound annual population growth, using this formula: (last year of observation/first year of observation)^(1/N of Years) −1, which provides us with comparable indicator for all communities and allows to minimize the effects of data disparities. Second, we calculate the share of working age migration of total migration. We complement the two demographic indicators by a civic outlook indicator of community civic engagement. We operationalize it through the participation rates in the last municipal elections. In Russia, municipal self-governance plays a marginal role in public administration. In general, turn out in municipal elections is much lower than in the regional and federal elections. Hence, we consider that voter turnout in the recent municipal elections that did not coincide with federal or regional elections, calculated as the number of votes divided by total amount of eligible voters, may indicate the higher level of civic interest (although other interpretations are also possible) and engagement in the

Table 1: Summary of variables. Source: Authors. This table provides the basic statistical indicators for each of the variables, as well as indicates their strict definition and identifies the data source.[1] DOI: https://doi.org/10.1525/elementa.441.t1

Factors and Indicators	Variable name	N	Minimum	Maximum	Mean	Std. Deviation	Description	Data Source
Accessibility								
Local Accessibility	*winter_access*	92	−1180,19	10647,27	501,1123	1355,71612	Number of round trips that can be conducted within three winter months between the locality and its closest fuel hub.	Multiple*
Municipal capacity								
Investment capacity	*investment*	92	−62,97	660,84	37,4296	98,91417	The rate of private investments in a municipality	DMI
Fiscal capacity	*subsidy*	92	,11	,97	,7836	,16095	The share of directly transferred income in total municipal expenditures	DMI
Budget capacity	*budget*	92	,76	1,09	,9959	,03730	Budget balance expressed as total expenditure divided by total income	DMI
Administrative capacity	*admin_cost*	92	,02	,29	,0887	,05926	Budget spending on local self-administration as a share of total municipal income	DMI
Utility model								
Utility spending	*utility_cost*	92	,04	,77	,2537	,17277	The share of housing and utilities spending from the total municipal income	DMI
Community future outlook								
Compound population growth	*pop_growth*	92	–,08	,02	–,0184	,01557	Compound of annual population growth	DMI
Work-age migration	*work_migr*	92	−3,51	1,87	,5398	,69603	Share of working age migrants in total migration	DMI
Civic engagement	*voter_turnout*	92	,16	1,00	,4617	,19993	Number of votes divided by total amount of eligible voters in recent municipal elections	REC

NB: Since there is a significant variance in completeness of statistics, all the indicators are calculated using the average of all available data points.

community life, that is, a future orientation of the community members.

CA: Variables description and operationalization

As stated above, CA is a dimension reduction technique that allows analysing the 'proximity' between different categories. In our case, the goal was to explore whether there are stable patterns accompanying different types of RE projects in different regions. First, we assigned the categories of "region" (Republic of Sakha (Yakutia), Yamalo-Nenets Autonomous Region (YNAO), Nenets Autonomous Region (NAO), Chukotskiy Autonomous Region (ChAO), Kamchatskiy Krai (Kamchatka), Arkhangelsk region, Murmansk region[2]), "energy source" (solar, wind, biomass, hydro, waste, mix of solar and wind), and "project size" (nano-, micro-, and small projects) to each of the projects. In order to operationalize "project size", we calculated the installed RE capacity per capita. For this, all values (giga calories per hour and megawatt) were converted to kilowatt, which then was divided by total population of a municipality where this project has been realized, cited from the latest available year (in most cases 2018). A few larger cities, such as Arkhangelsk, have multiple RE facilities in place, all of which were summed up to calculate the total installed capacity. Non-renewable capacity (diesel) was excluded from the calculations. The resulting values of installed capacity per capita were continuous and needed to be re-coded into a categorical variable. For this, we plotted all the projects on a histogram (**Figure 2**) and inspected the distribution of all projects with regard to RE capacity installed per capita. The first category – what we call 'nano-projects' – are those with <0.5, covering slightly over the third of all cases. The second category includes projects with >2 kW installed pc capacity, which could be considered 'small' projects, while all the projects in-between these two fall within the third – micro-project category.

Second, we wanted to explore whether the factors of RE uptake that resulted from exploratory factor analysis group together and form distinct community profiles. In order to do this, we obtained factor scores for each case using regression method and categorized all factor variables according to the following protocol: each continuous factor variable is re-coded into three categories that respond to the two groups of 'extreme cases' (lowest and highest quartile), and the broad middle (two middle quartiles). Since the total number of observations is 92, one quartile includes 23 cases.

Results

Exploring the factors of renewable energy development

Exploratory Factor Analysis was performed using maximum likelihood method and varimax rotation (**Table 2**),

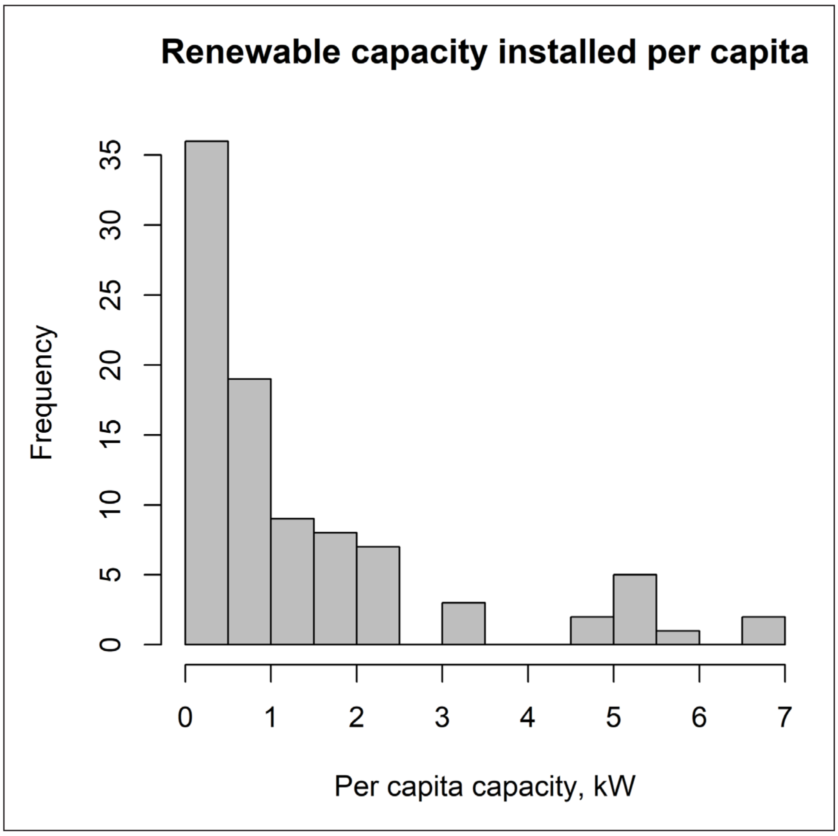

Figure 2: Facility distribution by pc installed capacity. Source: Authors. This figure illustrates the distribution of all RE projects with regard to RE capacity installed per capita. DOI: https://doi.org/10.1525/elementa.441.f2

Table 2: Model summary. Source: Authors. This table presents the model with five factors and shows factor loadings, correlation coefficients between observed variables and latent common factors, as well as cumulative variance (observations explained by the model) and proportion (contribution of each factor to the model's explanatory power). DOI: https://doi.org/10.1525/elementa.441.t2

	Factor 1	Factor 4	Factor 5	Factor 3	Factor 2
SS loadings	1.40	1.17	1.16	1.06	1.01
Cumulative Variance	0.16	0.28	0.41	0.53	0.64
Cumulative Proportion	0.24	0.44	0.64	0.83	1.00

assuming uncorrelated factors. We have selected a model with five factors based on SS loadings (>1) and parallel analysis scree plot. The model explains 64% of the cumulative variance in our data. Model fit has been assessed as acceptable (RMSEA<0.05; TLI>0.9; Chi Square – insignificant). For all items except for 'voter turnout', cross-loadings are less than 0.3, and correlations between factors are low, justifying the validity of the model. As demonstrated in **Table 3**, individual variables that contribute most to the model (h2) are subsidy, voter turnout, population growth, utility spending, and work-age migration.

The resulting factor model is presented graphically in **Figure 3**. The resulting factors partially diverge from those that we had in our initial model created on the basis of the literature review, yet, substantive factor interpretation presented below explains how the local factors of renewable energy development are influenced by the specificity of the Russian Arctic.

We call the first factor "The New Russian Arctic". This factor illustrates an interesting relation between the share of subsidies in total municipal income and low access at wintertime. This relation is in discord with our initial assumption that remoteness and poor transport connections would be an important factor motivating new renewable energy investments — instead, it clearly appears that high subsidies and better winter access go together. However, this goes well together with what is known of the current Russian priorities in its spatial development of the Arctic areas. Contrary to the Soviet times, when Arctic development initiatives were characteristically extensive, recent development strategies on transport infrastructure, for example, are centralized on specific large-scale projects and core zones linked to them (Müller, 2011; Kinossian, 2017). These core zones receive targeted funding from the federal government under the assumption that they will become hubs of future socioeconomic development in the long run, for example as the traffic along the Northern Sea Route increases (Dmitrieva and Buryy, 2019). Against this background, it is not surprising that higher subsidies and better winter access link together.

The second factor consists of only one variable – work-age migration – but has a high loading and adds explanatory power to the model. As we expected, the share of people of working age in total migration is an important indicator depicting the future outlook of local communities (Helenius et al., 2013). According to the literature, communities with more future prospects are more likely to see the need of and invest in renewable energy infrastructure (Denis and Parker, 2009).

The third factor – which we term "Burden of maintenance" – mainly relies on the variable utility spending,

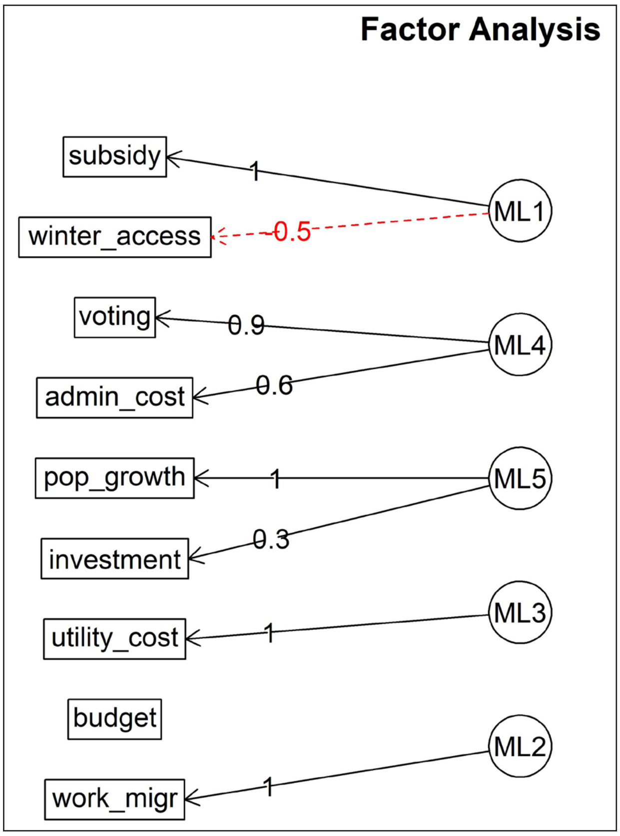

Figure 3: Local factors of renewable energy development in the Russian Arctic. Source: Authors**.** This figure presents the model with five factors and observed variables contributing to these factors.[3] DOI: https://doi.org/10.1525/elementa.441.f3

Table 3: Standardized loadings (pattern matrix) based upon correlation matrix. Source: Authors. This table demonstrates how the observed variables correlate to the latent common factors. DOI: https://doi.org/10.1525/elementa.441.t3

	Item	Factor 1	Factor 4	Factor 5	Factor 3	Factor 2	h2	com
subsidy	2	**0.97**	0.01	–0.23	0.05	–0.02	0.995	1.1
winter_access	9	**–0.45**	–0.11	0.10	–0.14	0.00	0.247	1.4
voter_turnout	8	0.40	**0.89**	0.13	0.00	0.15	0.995	1.5
admin_cost	4	–0.08	**0.59**	–0.10	0.00	–0.08	0.366	1.1
pop_growth	6	–0.10	0.00	**0.96**	0.03	–0.10	0.939	1.0
investment	1	–0.22	–0.04	**0.33**	0.06	–0.08	0.167	2.0
utility_cost	5	0.07	0.08	0.01	**0.99**	–0.01	0.995	1.0
budget	3	0.17	0.08	0.08	**0.22**	0.08	0.093	2.8
work_migr	7	–0.01	0.00	0.18	0.06	**0.98**	0.995	1.1

which describes the share of utility cost in the total budget. The burden of maintaining the population increases the bigger share utilities take up in the total budget, so it stands to reason that these two variables correlate with each other, even though the loading of the budget balance is low.

The fourth factor – "Local activity and input" – consists of two strongly loading variables. It signals the assumed commitment that both the residents and the local government have toward their municipality, operationalized as civic engagement (voter turnout in the last municipal election) and the administrative capacity (amount of money spent by municipalities on public administration). In short, we assume that when both indicators are high, the community is more able to actively engage with its surroundings, and thus also to influence the energy projects built there.

Finally, the fifth factor can be termed "Influx of resources" as it comprises of population growth (compound annual growth) and the relative amount of private and public investments. The inflow of both resources is elementary for the development of new initiatives in Russian Arctic localities, and especially the increase of population may be a factor separating one region from others as mass emigration from the region increases.

Profiling the renewable energy projects

Correspondence analysis (CA) is a simple yet powerful statistical tool to detect the relationship between variables. The visual displays generated by CA – called bi-plots – are interpreted in a relational manner, meaning that points father away from the origin indicate more influential categories, and points on opposite sides of the plot stand for contrasting categories. The dimensions are usually not given substantive interpretation, in particular in multiple correspondence analysis (MCA) that models variable categories in a multidimensional Euclidean space, but represents them as points in a low-dimensional space. We start our analysis by exploring the relationship between key project characteristics: size and type, vis-à-vis their location (**Figure 4a–b**, dot size stands for 'mass' of the category in the dataset). **Figure 4a** shows the relationship between project size and location. It clearly identifies a relationship between larger projects and Kamchatka region, as well as shows that 'nano'-projects are more likely to be located in Murmansk region and YNAO. **Figure 4b** allows inspecting the relationship between project type and location. Two clear associations can be observed: biomass projects are all located in Arkhangelsk region, and solar projects in Yakutia. We conclude that there is certain variation in project type and size depending on location – different regions develop different types of energy, based on source availability, and the scale of facilities also vary, potentially also in relation to the sources used. This insight confirms our initial intuition that there are geographic differences between the projects, hence, investigation of the local factors can better reveal the patterns in RE uptake.

Since winter access is the only variable that loads negatively on our model, and given that poor transport infrastructure can be both a motivation and a barrier to RE development (Mortensen et al., 2017), we inspect it in more detail (**Figure 5**). With regard to project size, one could expect that communities with poor accessibility would be more likely to invest into larger facilities, since

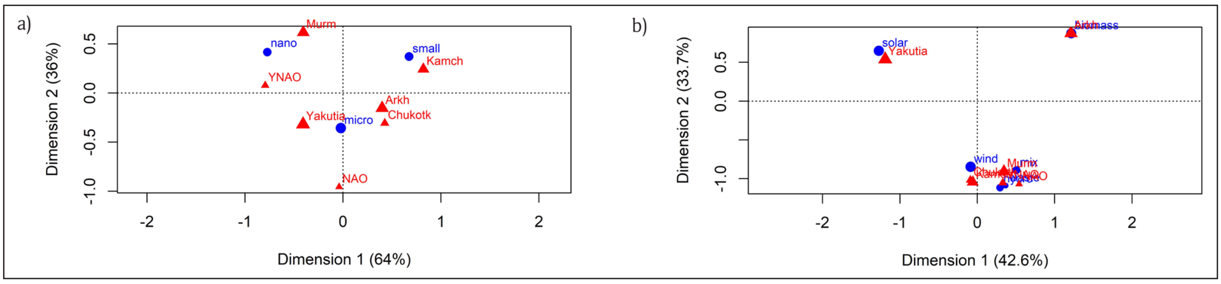

Figure 4: Project type and size by region. Source: Authors. This figure presents the results of CA, showing how different regions are associated with different types of renewables and with the size of RE capacity installed. DOI: https://doi.org/10.1525/elementa.441.f4

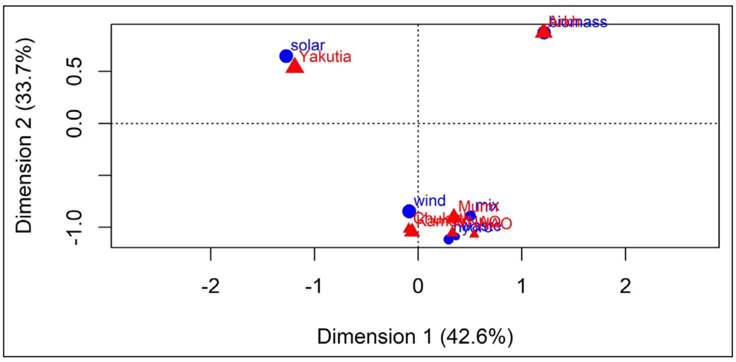

Figure 5: Community winter accessibility and the project size. Source: Authors. This figure presents the results of CA, showing the association between communities' winter accessibility and the size of RE capacity installed. DOI: https://doi.org/10.1525/elementa.441.f5

for them RE is a chance to significantly improve energy security and capital cost will pay off quickly due to exacerbated prices. In addition, one would not expect nano-projects in poorly accessible communities as the cost of transportation of equipment would be disproportionate to the potential benefit from the installation. Yet, what we eventually discovered is the reversed relationship of accessibility and project size. The rule of thumb is that the better the access, the larger the RE capacity installed. The smallest 'nano-size' projects do not specifically correspond to a community's accessibility. Other facilities can be found in both poorly and fairly accessible communities.

To address our second research question and explore the potential differences between the remote communities that have renewables installed, we use multiple correspondence analysis to "uncover" groupings of factor categories. In other words, we look at how RE projects across the Russian Arctic group together depending on the community factor scores (high, medium, and low, see Section 3.4) along the five factors established in our analysis. The analysis has been performed in the R package ca developed by Nenadic and Greenacre (2007). The advantage of this tool is that instead of the analysis based on a simple CA of the indicator matrix, which is known to lead to significant misrepresentations (Greenacre, 1991), it allows to perform the analysis based on the Burt matrix with an adjustment of inertias (variation contained in the data), meaning that the fit and the graphic representation are improved (Nenadic and Greenacre, 2007).

Figure 6 depicts four distinct groupings that can be interpreted as 'profiles' for communities that are discriminated along the two dimensions. Together, these groups account for 43,9% of the principal inertias. The remaining profiles are grouped around the origin, which means that they are of smaller influence and distinctiveness. As the four groupings are prominently separated along both dimensions, which stands for contrasting categories, we suggest that they can be substantively interpreted as community-level models for renewable energy development.

In the right upper corner there is a distinct profile for communities that communities are most prominently characterized by scoring high on Factor 1, "The New Russian Arctic", suggesting attention and perhaps even development interventions from the federal state. We call this profile "The New Arctic community". These communities are more likely than others to feature in national strategies and target programs depicting the Russian national priorities of its Arctic politics and socioeconomic development. They are usually better connected through transport infrastructure and benefit from that by being regarded as a "hub" of development where it may be profitable to build new energy infrastructure.

In the right down corner is a profile that we call "Proactive community". Proactive communities represent the classic case of why renewable energy should be supported in the Russian Arctic. They have some resources, both financial and human, and use a large share of their municipal budget on maintaining utilities, meaning that practical benefits from renewables are considerable. What is even more important is that these communities score high on civic engagement and administrative capacity, which makes them more likely to actively engage with local affairs, among other things, and to motivate and take up new energy projects.

The third grouping is located in the upper left corner and can be called "Recipient community". Unlike the previous two profiles, recipient communities lack the inflow of investments, new workforce and active engagement. As a result, they can have only a passive role regarding their energy infrastructure development. Nevertheless, renewable energy may still be built in these communities if it serves the interests of the federal or regional government, for example in relation to other infrastructure projects or strategic priorities.

Finally, in the down left corner there is a grouping that we call "Opportunity-driven community". These communities may take up the chance to test renewable energy as a part of their energy palette even when the share of utility maintenance does not take up a large share of their budget just because the resources are readily available. In some cases, experiments may be conducted by individual houses or companies in "nano"-scale.

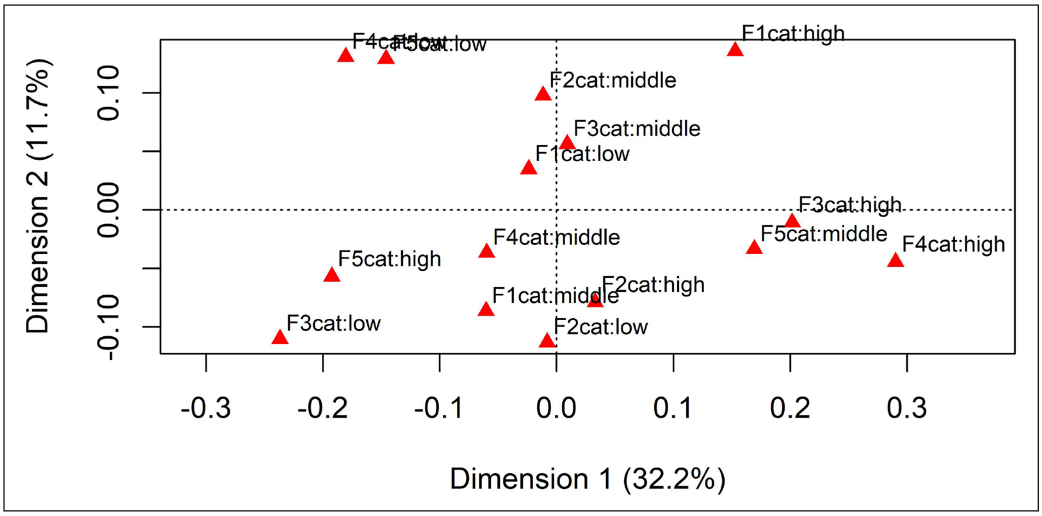

Figure 6: Models for renewables uptake in the Russian Arctic communities. Source: Authors. This figure presents the results of CA, identifying five models for RE uptake. DOI: https://doi.org/10.1525/elementa.441.f6

Conclusion

The goal of this article was to explore the local dimension of renewable energy development in the Russian Arctic. We used a combined approach of EFA and (M)CA to conduct a cross-sectional analysis in order to, upon identifying the main factors of RE uptake, explore relationships between these factors within communities that have RE facilities in place. The combination of the two methodologies is beneficial: EFA allowed grouping variables identified in the previous research into factors, and establishing scores (which were further categorized) for each community, while MCA allowed exploring how different scores may be related, thereby suggesting that some of the communities have distinct 'profiles' regarding the RE projects.

The main findings of our research can be summarised as follows. First, we demonstrate that local factors matter in explaining the renewable energy development in the Russian Arctic. By looking at local (municipal), rather than regional or national indicators, we provide an empirical illustration to the recent literature that advocate re-scaling the investigation of sustainable energy policies to the local level (Kuzemko, 2019). While the variables inferred from literature presented themselves as meaningful for the purpose of multivariate analysis, the factors explored through EFA are different from what we have expected on the basis of the literature review.

Second, our approach confirms the earlier findings by Cherniak et al. (2015) and Mortensen et al. (2017) that noticeable differences in adoption and integration of renewable energy in remote communities exist. At the same time, we suggest that some common characteristics can be found – even though not all projects can be categorised within one of the four models identified in our analysis.

Third, we show that the same factor can be meaningful in different ways. For instance, poor transport accessibility can be a barrier to renewables development, while better connectivity can correspond to larger scale RE installations. By the same token, one could expect that higher share of utility spending would correspond to a stronger incentive to install renewables. Yet, we observe the communities with low burden of maintenance would still be driving RE projects – in case they have influx of financial and human resources. Finally, while municipalities with higher engagement from both local administration and population could be expected to have superior quality of administration, better knowledge and ability to govern, and hence, have better capabilities to engage with the local energy matters, also communities with low municipal capacity can become a target of RE projects initiated 'externally', presumably, to improve the local situation.

In sum, renewable energy development in the Russian Arctic does not follow a single narrative that could be easily traced back to the official discourses on improving energy security or decreasing subsidy costs (Salonen, 2018). Instead, there exists significant local variation: the four models identified in our research differ from and even contradict to each other, suggesting that the logics of renewable energy development in the Russian Arctic does not follow an easily predictable path of top-down policies. Despite the weakness of Russian municipalities that often lack their own resources, have a very narrow tax base and no legislative initiative, there are local discrepancies in their agency, motivations, and capacity. The variation across space is so extensive that it is difficult to determine beforehand which factor — be it the amount of resources, the community outlook, or the need for alternatives — will be decisive for future prospects of renewables in the area, and if any of those could be sufficient on its own. In practice, this means that transition to sustainable energy in the Russian Arctic is locally contingent. To strengthen the development of renewable energy in the Arctic, capacity-building, education, and promotion activities at the community level is advisable.

Data Accessibility Statement

The following datasets were generated:

Database of Russian Arctic communities with renewable energy installations (to be uploaded to https://qvain.fairdata.fi/datasets).
R scripts: uploaded as online supporting information to https://github.com/dgritsen/Journal_scripts.

Notes

1. DMI — the Russian official Database of Municipal Indicators (Baza dannyx pokazateley municipal'nyx obrazovaniy, https://www.gks.ru/free_doc/new_site/bd_munst/munst.htm); REC – Russian Electoral Commission (http://www.cikrf.ru/); *winter accessibility scores were calculated on the basis of the data derived from various online open data sources (see Supplementary material).
2. The two municipalities of the Krasnoyarsky Krai belonging to the Arctic zone were not included as there was no relevant cases. While Kamchatka is not officially part of the Arctic, characteristics such as high potential of regional renewable energy resources, large amount of localities that are difficult to access, and inclusion in the Rushydro renewable energy programs made it an interesting addition to the mix.
3. NB: There is a negative loading (indicated with a 'minus' sign) on the winter_access variable, suggesting a negative linear association between the latent variable (factor) and the observed variable (winter_access). In other words, better rather than poorer connectivity is associated with RE development.

Supplemental file

The supplemental file for this article can be found as follows:

- **Text S1.** Winter Accessibility of RES in the Russian Arctic. DOI: https://doi.org/10.1525/elementa.441.s1

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Competing interests

The authors have no competing interests to declare.

Author contributions

- Contributed to conception and design: DG
- Contributed to acquisition of data: DG, HS
- Contributed to analysis and interpretation of data: DG, HS
- Drafted and/or revised the article: DG
- Approved the submitted version for publication: DG, HS

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