Measuring the sustainability of Russia's Arctic cities

Robert W. Orttung, Oleg Anisimov, Svetlana Badina, Charlene Burns, Leena Cho, Benjamin DiNapoli, Matthew Jull, Melissa Shaiman, et al.

ONLINE FIRST

Ambio
A Journal of the Human Environment

ISSN 0044-7447

Ambio
DOI 10.1007/s13280-020-01395-9

Ambio
https://doi.org/10.1007/s13280-020-01395-9

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

SIBERIAN ENVIRONMENTAL CHANGE

Measuring the sustainability of Russia's Arctic cities

Robert W. Orttung, Oleg Anisimov, Svetlana Badina, Charlene Burns, Leena Cho, Benjamin DiNapoli, Matthew Jull, Melissa Shaiman, Ksenia Shapovalova, Leah Silinsky, Emily Zhang, Yelena Zhiltcova

Received: 8 June 2020 / Revised: 11 June 2020 / Accepted: 3 September 2020

Abstract How sustainable are Russia's Arctic cities? Russia's far north metropolises are distinctive from other Arctic cities in terms of their large size, efforts to conquer nature, and big business' impact on the urban landscape. The Russian Arctic cities' Soviet-era design gave them compact and dense population structures. Such features led to many benefits for achieving sustainability, including more efficient energy use, a larger number of hospital beds, more numerous cultural amenities, and greater access to public transportation. However, Arctic cities outside of Russia have made progress in their own pursuit of sustainability through on-going investments, business development, educational resources, and solid waste management. By teasing out these distinctions, this article highlights urban features that make it possible for the cities to adapt to changes in the global environment and economy. In doing so, it provides the first multidisciplinary, comparative analysis of 46 Arctic cities employing historical, remote sensing, and quantitative methods. It demonstrates the strengths and weaknesses of the world's Arctic cities in their quest for sustainability and points to where they can learn from each other in adopting best practices.

Keywords Arctic cities · Russia · Sustainability

INTRODUCTION

Fast-paced environmental and economic changes are challenging Russia's Arctic cities, while simultaneously providing new opportunities. Rising temperatures are thawing permafrost and undermining the urban infrastructure it supports (Streletskiy et al. 2019). The headlong development of fossil fuels is undermining the local environment (Josephson 2016). At the same time, opening up new waterways to cruise ships and freighters makes possible more tourism and trade, potentially providing a boon for Arctic residents (Stephenson et al. 2011).

The challenges facing Russia's Arctic cities require its most ambitious citizens to be creative in adapting to these changes (Nazarova and Poluektov 1974; Bond 1985; Jull 2017; Zamiatina and Piliasov 2018). The sustainability of urban areas in the far north will determine the trajectory of Russia's development. This article seeks to describe the drivers for sustainability in Russia's Siberian and Arctic cities and place them in comparative perspective with similar northern cities in Europe and North America. The central research question is: How sustainable are Russia's Arctic cities? To answer this question, we examine the distinct features of the cities and how they influence local levels of sustainability.

Russia's Arctic cities differ from those in other parts of the circumpolar north in their large size and design, approach to nature, and the influence of big business. These differences are more of degree than kind, but they are nonetheless important in how they shape the way that the cities respond to the northern conditions that define life for all Arctic cities: remoteness, extreme cold, dark winters and light summers, shallow resource-based economies, and a rapidly changing climate. The differences between the Russian and non-Russian cities shapes the strategies that city leaders and planners can pursue in sustaining their ability to house future generations. The Russian urban areas' compact and dense design give them advantages over their more sprawling Western peers. By comparing

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s13280-020-01395-9) contains supplementary material, which is available to authorized users.

Published online: 14 October 2020

the Russian cities with their Western counterparts, however, it becomes clear that the Russian cities do not take full advantage of their innovative design features. This work provides the first comprehensive and systematic multi-method effort to evaluate these differences by providing a comparative analysis across 46 Arctic cities.

The article takes a holistic and multidisciplinary approach to explaining how Russian and non-Russian cities differ from each other. It shows how the initial planning for the cities shaped their form and design and then lays out how this design affects the cities' sustainability potential as measured by the international standard for urban sustainability. First, after a brief literature review on Arctic development and description of the data and methodologies employed here, the article explores the origins of Arctic cities, the reasons for their founding, and the design features that guided their historic trajectories. Second, it examines the form of the cities and the planning processes that shaped them. Finally, it employs a large dataset based on the 128 indicators defined in the international standard for urban sustainability to examine the main differences between the Russian and non-Russian cities. The concluding section lays out the sustainability implications as the cities adapt to the challenges and opportunities they face and provides a springboard for future, more detailed studies. This paper contributes to a series of studies on Siberian environmental change (Callaghan et al. 2021).

MATERIALS AND METHODS

The Arctic has fired the imaginations of many scientists. Writing about the Arctic has frequently focused on the extreme and changing climate of the region (Serreze 2018), the Indigenous people who first inhabited the north (McGhee 2005), the heroic nature of the European and Russian Arctic explorers (Schultheiss 2009), the Soviet model of developing the region (Armstrong 1965; Bond 1983; Josephson 2016), and more recently efforts to understand the human-natural interactions that shape the north (Demuth 2019).

Studies examining urban life in the region have been more limited. Excellent work has been done on individual cities, such as Vorkuta (Barenberg 2014; Shiklomanov et al. 2019), Norilsk (Humphreys 2011; Jull and Cho 2013; Parente 2014; Laruelle and Hohmann 2017; Shiklomanov and Laruelle 2017), Fairbanks (Cole 2003), and Whitehorse (Dobrowolsky and Johnson 2013; Powell 2020). Other work has emphasized specific design approaches, materials and methodologies at architectural and urban landscape scales, as well as focused within countries and small regions (Sheppard and White 2017; Larsen and Hemmersam 2018; Cho and Jull 2019; Cho 2020). Little comparative work has been done on Russian cities in Russian because many authors assumed that "cities and urban development was the least specific theme in studying polar territories because here there are more commonalities than differences with other parts of the world" (Pilyasov 2011).

What is missing both in and outside of Russia are comparative, multi-method studies that place Arctic urban development and the human processes shaping this built environment in the broader context of its natural surroundings. Another gap in knowledge is the lack of synthetic studies pulling together large amounts of data from a comprehensive body of sustainability indicators. Threats to sustainability come from the changing climate, consumption of resources, and systems of governance that fail to provide for long-term planning. This study starts to fill in that gap and continue the discussion of sustainability in Arctic cities.

This article analyzes 46 Arctic and near-Arctic cities: 21 in Russia and 25 outside of Russia (Fig. 1) (Schaffner 2020). The cities all have more than 12 000 residents and all but three meet the AMAP and Arctic Human Development Report (AHDR) criteria for inclusion in their definitions of the Arctic. We included the three exceptions—Yakutsk, Magadan, Fort St. John—because Yakutsk and Magadan, while outside the boundaries of AMAP and AHDR, are two important Siberian cities in the permafrost zone which experience climatic extremes. Fort St. John is situated along the Alaska Highway, positioning it as an important center for connections to the broader Arctic region in British Columbia, Yukon, and Alaska. All of these cities are included in a 5-year study sponsored by the National Science Foundation's Partnerships for International Research and Education (PIRE).

This article uses a variety of data sources and methods for analyzing them. To identify the year of founding for the 46 cities, we referred to the city websites and secondary sources. While many of the sites have long been occupied by Indigenous groups or settlers, we defined the founding date as when the agglomerations officially became cities in their respective countries. These same sources provided information on the original purpose of the cities.

To study the form and design of the cities, we used Sentinel-2 multispectral satellite imagery. More details about this approach are provided below. Such imagery is a useful tool in explaining a city's relationship to its geography, surrounding environment, and society (Lehner et al. 2018; Seto and Reba 2018).

We analyze the similarities and differences among the cities by using a new dataset based on the metrics listed in the International Organization for Standardization's *ISO 37120 Sustainable Cities and Communities—Indicators for City Services and Quality of Life*. Originally published in

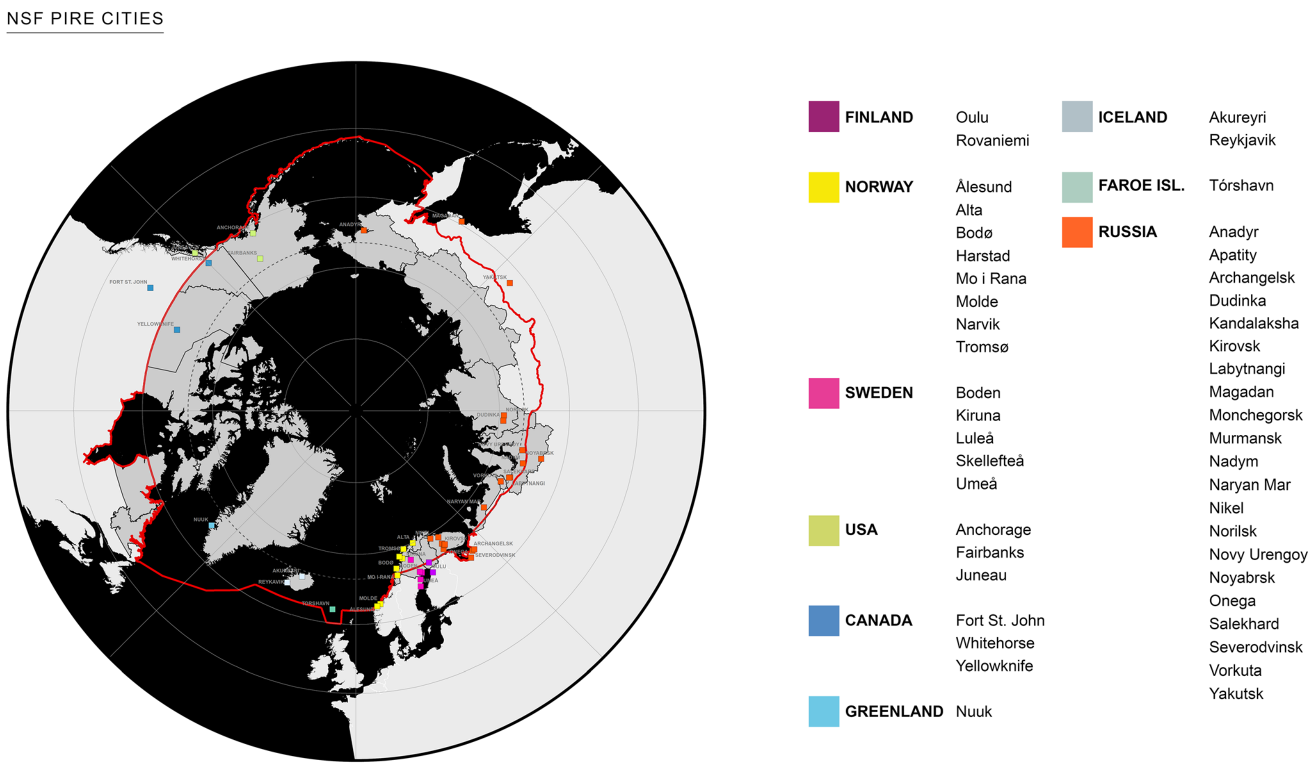

Fig. 1 The 46 Arctic cities examined in this article. *Source* Benjamin DiNapoli

2014 and revised in 2018, ISO 37120 defines 128 indicators across 19 domains of sustainability that measure everything from economic performance to wastewater management (ISO 37120 2018). While ISO 37120 is designed to be applied to all cities on the planet, it should be applied in the Arctic with caution since it lacks specific indicators for Arctic conditions, such as permafrost, remoteness, and rapid climate change (Berman and Orttung 2020).

The data characterizing the cities according to the ISO 37120 metrics have numerous flaws that must be kept in mind. One of the challenges for applying urban sustainability indicators is the frequent lack of data, their low quality when available, and, in cases where a city has high quality data, difficulties comparing this data to the data provided by other cities (Borgman 2015). In each case, we sought to collect city-level data from authoritative sources, such as the mayor's office, municipal publications, or reputable local think tanks. City officials in Russia and elsewhere answered some of our requests for information by email or on the phone. Yet, even where we were able to collect city data from primary sources, there are many reasons for the data to be inaccurate as they are primarily self-reported. To the extent possible, we tested this data against other sources and tried to identify bias. City leaders in all countries naturally want to present the best face in comparison with other cities; they may not want to report the true situation to regional, national, or international bodies. Where city-supplied data was not available, we used information from national statistical agencies which often reported city-specific data.

Where we could not find the city-level data, we used regional, state, or national data as a proxy. Naturally, this solution is unsatisfactory because such higher-level data is likely to mix urban and rural information and does not reflect the specific features of the city. Another challenge deals with the varying time frames of the data we collected. While our goal was to use the most recent data, this has different implications city-to-city as some cities are quicker to make public the most recent figures. In a few cases where we were missing some data points, we were able to impute this information (Curley et al. 2019).

We employed a variety of quantitative methodologies for this analysis. We first performed a cluster analysis of the data using only the indicators where we had city-level data. The first attempt showed that all the demographic data were in one cluster and 8 additional clusters that had no clear pattern. Since this first effort did not produce useful results, we then performed a hierarchical cluster analysis in which each city is considered its own cluster and the clusters are joined together in a step-by-step process until there are only two clusters. We used the squared Euclidean distance to perform a between-group linkage and within-group linkage analysis. One Russian and four non-Russian cities were dropped from the analysis due to missing data. The optimal result for both efforts was two clusters—one with the Russian cities (20 cities) and one with the non-Russian cities (21 cities).

RESULTS AND DISCUSSION

Arctic cities: common origins, different trajectories

Most urban settlements in the Russian and European Arctic began in the sixteenth century. Intensive construction in Russia began after the industrial revolution and the establishment of the Soviet Union in the early twentieth century (Josephson 2016). In North America, small settlements began to appear at the end of the nineteenth century and the beginning of the 20th, with the majority of development and expansion occurring in the mid- to late-twentieth century. The purposes for founding Arctic cities both inside and outside of Russia were similar—fur, mining, trade, energy development, and military bases. The bases sought to assert national sovereignty and occupy the land to prevent foreigners from capturing it.

Despite these similar origins, the Russian cities followed a different trajectory than their non-Russian counterparts. First, Russia's cities are bigger, with major population centers in Arkhangelsk, Murmansk, Severodvinsk, Norilsk, Novyi Urengoy, and Noyabrsk. The state planning of the Soviet period spurred this growth because it was not constrained by capitalism's demand for economic efficiency. Russia's Arkhangelsk is the largest Arctic city with about 350 000 inhabitants, while Yakutsk and Murmansk are nearly as large. Outside of Russia, only Anchorage, Alaska, is of similar size with a population of approximately 300 000, but it lies significantly below the Arctic Circle and has a more moderate climate than its Russian counterparts. The median population for the Russian cities in our sample was approximately 49 000 compared to the non-Russian median of 28 000, making the median Russian city nearly twice as large as the non-Russian cities.

A second difference is that the philosophy of conquering nature guided the development of the Russian cities (McCannon 1995; Bassin 2003; Bolotova 2012). Similar efforts to subdue nature through industrialization and militarization occurred in the North American Arctic, though on a smaller scale (Farish 2013; Stuhl 2016). Thus, the Soviet motivation for development was not unique among the world's countries, where similar processes were underway, but simply at the far edge of the scale and implemented by centralized planning and development efforts. Consequently, a large majority of Russia's Arctic cities are the result of a vast urbanization and industrialization program that was initiated with the formation of the Soviet Union in the early twentieth century (Hill and Gaddy 2003; Heleniak 2009, 2010). Led by bureaucrats and planners based in Moscow, hundreds of new cities were developed and built across the Russian countryside using a highly coordinated and specific set of design principles that favored high density residential complexes built in close proximity to agricultural or industrial centers.

Finally, in the post-Soviet period, Russia's major resource development companies shaped the evolution of its Arctic cities. In places like Norilsk, the nickel factory and its managers are the key leaders in the city (Laruelle 2020). Similarly, the corporate social responsibility programs of the major energy companies, like GazpromNeft, often shape the development of amenities that are provided to citizens (Hitztaler and Tynkkynen 2020). In the following sections, we show how these different trajectories shaped the evolution of Russia's northern cities in the context of the circumpolar north.

Form of Arctic Cities

A key aspect of urbanization in the Russian Arctic cities was the creation of a centralized planning and construction Ministry (Gosplan) that developed strict planning and design guidelines (Bond 1983). Based largely on a set of principles that emerged from the Moscow General Plan in the 1930s, planning and design in Russia centered on the microrayon, which formed cohesive semi-autonomous urban neighborhoods. Each microrayon, centered around high-density apartment complexes, provided amenities and services for residents according to a set of spatial rules based on service radii. In addition to a well-defined urban design framework, these cities were built throughout the country and maintained a nearly uniform set of building practices that involved precast panel block apartment complexes which allowed for rapid construction. Initially these were built as five-story buildings, but later, the introduction of elevators allowed for nine- and twelve-story complexes. In northern Russia, the design and construction of cities and buildings had to be modified to take into account the difficulties of building on permafrost and in extreme climates, resulting in adaptations to the planning and design strategies (Bond 1983), some of which were influenced by (and influenced) town planning in northern regions of Europe and North America (Jull 2017). Despite these challenges, even in the most remote and extreme Arctic conditions, these design principles and construction systems were largely adhered to, resulting in the most densely populated and "urban" cities in the Arctic, with centralized heating and power generation, public transportation, and advanced infrastructure buried in the permafrost.

We selected five cities each from Russia, Europe, and North America from the 46 PIRE study cities based on similarities in population and compared their urban forms at scale in Fig. 2. The images use combinations of three spectral bands (560 nm [3—Green], 665 nm (4—Red) and 842 nm (8—NIR) at 10-m spatial resolution to more clearly reveal urban built-up areas (DiNapoli and Jull 2020). It is evident from this comparison that the urban built-up areas of Russian cities are often smaller than comparable European or North American cities with similar populations. For example, Arkhangelsk (RU; pop. 358 594) has a built-up area of 30 sq. km, while Anchorage (USA; pop. 291 538) has a built-up area of 104 sq. km. Despite the smaller population of Anchorage, the built-up area is larger by a factor of about 3.5, resulting in a population density of 1 393 people per sq. km in Arkhangelsk, and 955 people per sq. km in Anchorage. In Europe, Oulu (FI; pop. 152 489) has a built-up area of 51 sq. km, leading to a population density more similar to Anchorage (806 people per sq. km). The differences between Russian and non-Russian cities extends to even the smallest cities in this study—the ratio of land area to urban built-up area of Anadyr (RU; pop. 15 468) is less than half that of Alesund (NO; pop. 13 135) and Yellowknife (CA; 18 435). The Russian cities appear denser and more compact in a given area for similar or larger populations—in fact, the median Russian city contains 35% to 42% less green area per 100 000 population, 49% to 63% less urban built-up area per 100 000 population, and is twice as dense as median non-Russian cities (1393 to 659 people per sq. km), though there is considerable variation among Russian and non-Russian cities. The sources for these data are provided in the Electronic Supplementary Material.

Figure 3 shows comparisons between the largest cities in this study: Arkhangelsk and Anchorage, and two of the smallest cities: Anadyr and Yellowknife. At larger image scales, we can see further detail that characterizes the differences between Russian Arctic cities and their European and North American counterparts. Most importantly, the organization (design) of the cities is different. Anchorage has a regular and uniform street grid with zones of residential, commercial, and public buildings separated into different neighborhoods, with large swaths of open space between each block and a more even distribution of detached buildings. Arkhangelsk has a distinct series of clustered large-scale residential buildings organized in neighborhood units (microrayons) with radial avenues connecting to the center of the city. Similarly, although both smaller cities (Anadyr, Yellowknife) show a much less discernible organizational structure, there are clear differences in density due to different building types. Anadyr is more compact in terms of overall layout, with a higher built density organized in microrayon clusters, while Yellowknife appears to be laid out according to local topographic and geographic considerations with predominantly low-rise buildings. Both Anadyr and Yellowknife share similar functional roles in their respective regions as administrative hubs for mining, and yet they have very different overall forms.

One of the specifications used in urban planning to regulate urban density is the floor area ratio (FAR), which for a given building is calculated as the ratio of the total building floor area to the areal size of the land parcel on which it is built. Typically combined with zoning regulations on building height and program (type), the FAR provides a means by which the density and compactness of a city can be regulated. The typical FAR for residential areas in Russian cities prior to about 1917 ranged from 1.3 to 1.8. With the introduction of cheap and rapid industrial (panel block) housing in the 1950s, the allowable FAR increased past 10 (Koncheva and Zalesskiy 2016). Compared to North American or European Arctic cities, where typical FAR ranges from 1 to 2, the allowable FAR in Russian cities is significantly greater and explains the difference in compactness and consolidation of their urban form as seen in the earlier satellite images.

Metrics of sustainability

Figure 4 provides a dendrogram showing the results of our hierarchical cluster analysis. There are two main groupings, with the Russian and non-Russian cities each in their own cluster. As this result shows, the Russian and non-Russian cities tend to be more like each other than cities from the other group, with no hybrid grouping. However, both within Russia and outside of it, there is considerable variation among the cities. Given this variability, it would be possible to create some smaller clusters, but none of those would bring together Russian and non-Russian cities, so it makes more sense to focus attention on the Russia/not-Russia divide. The key points of difference between the Russian and non-Russian cities are: demographics, future-oriented spending, cultural investments, energy usage, business development, education, levels of inequality, and solid waste management. The analysis below draws out these distinctions.

Figure 5 summarizes the differences between the Russian and non-Russian cities. Z-score values were calculated for each indicator for each city to standardize the wide-ranging dataset (Westfall 2018). The first summary chart plots the average z-score values for each indicator and groups them by Russian cities (red) and non-Russian cities (black), highlighting a general point of comparison between the two groups. The following key shows corresponding indicators for the numbers lining the circumference of the chart's circles in a counter-clockwise direction:

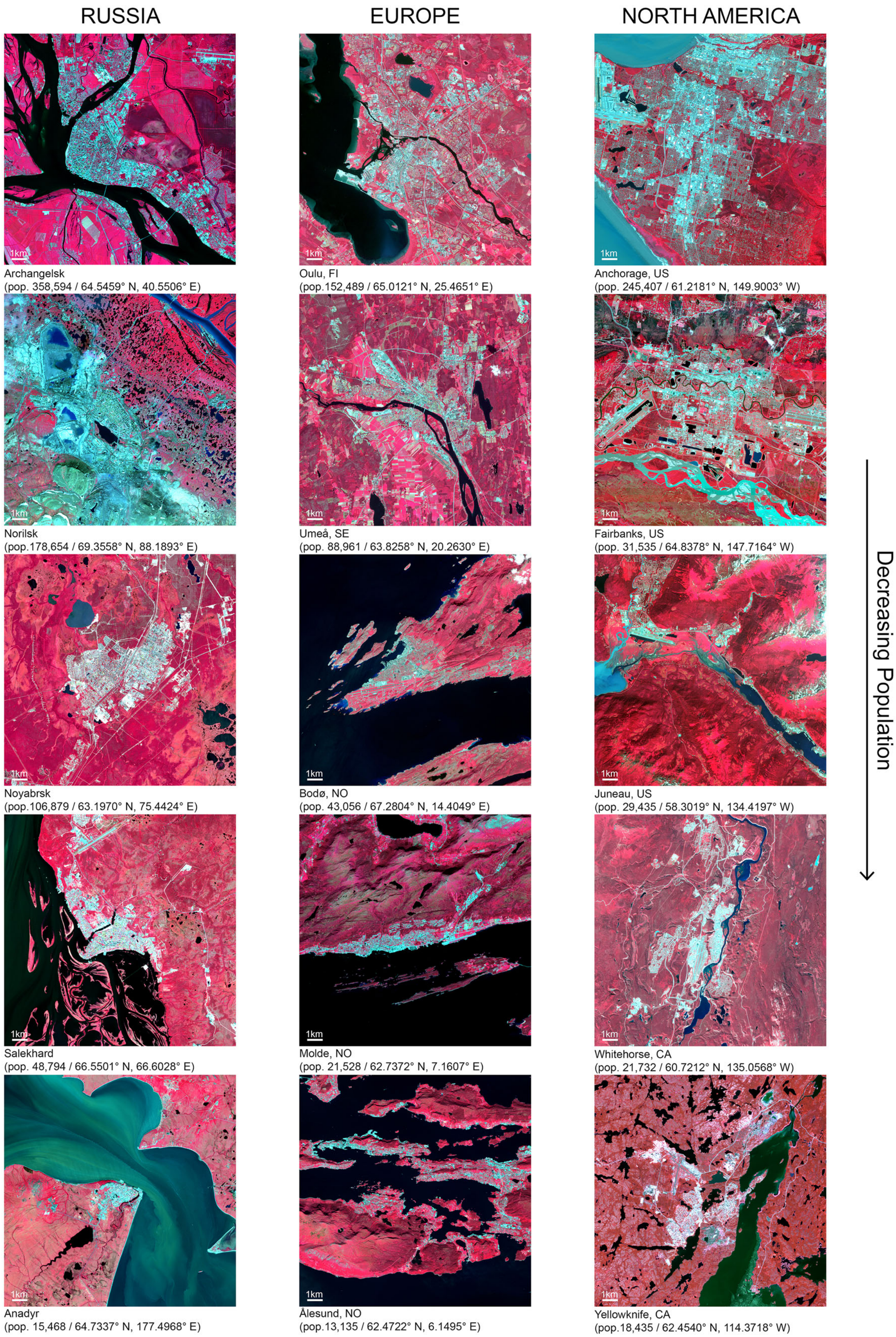

Fig. 2 Comparison of city forms at scale across Russia, Europe, and North America. *Note* urban areas are depicted in blue

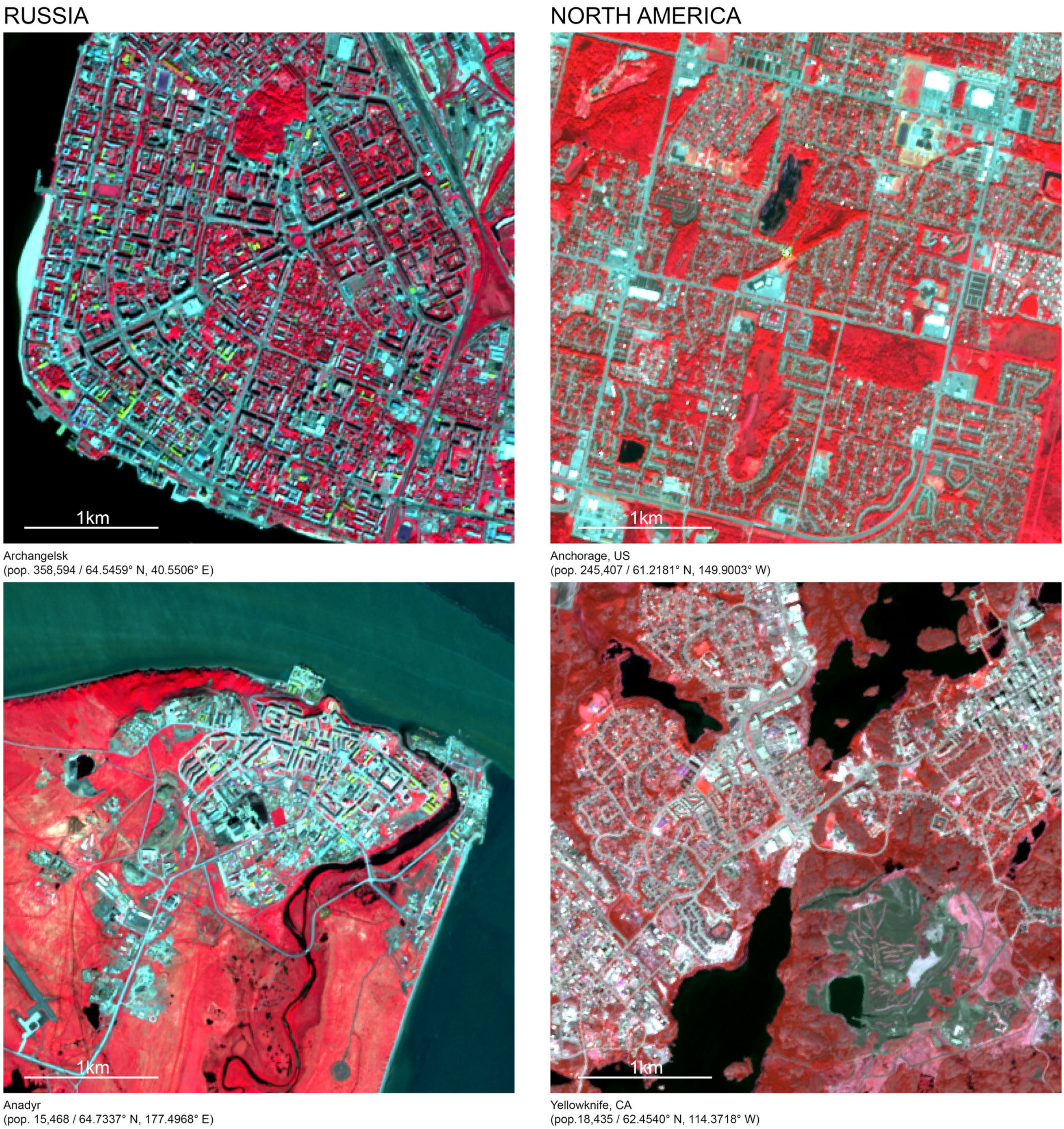

Fig. 3 Detailed comparison of urban forms in Russia and North American Arctic cities

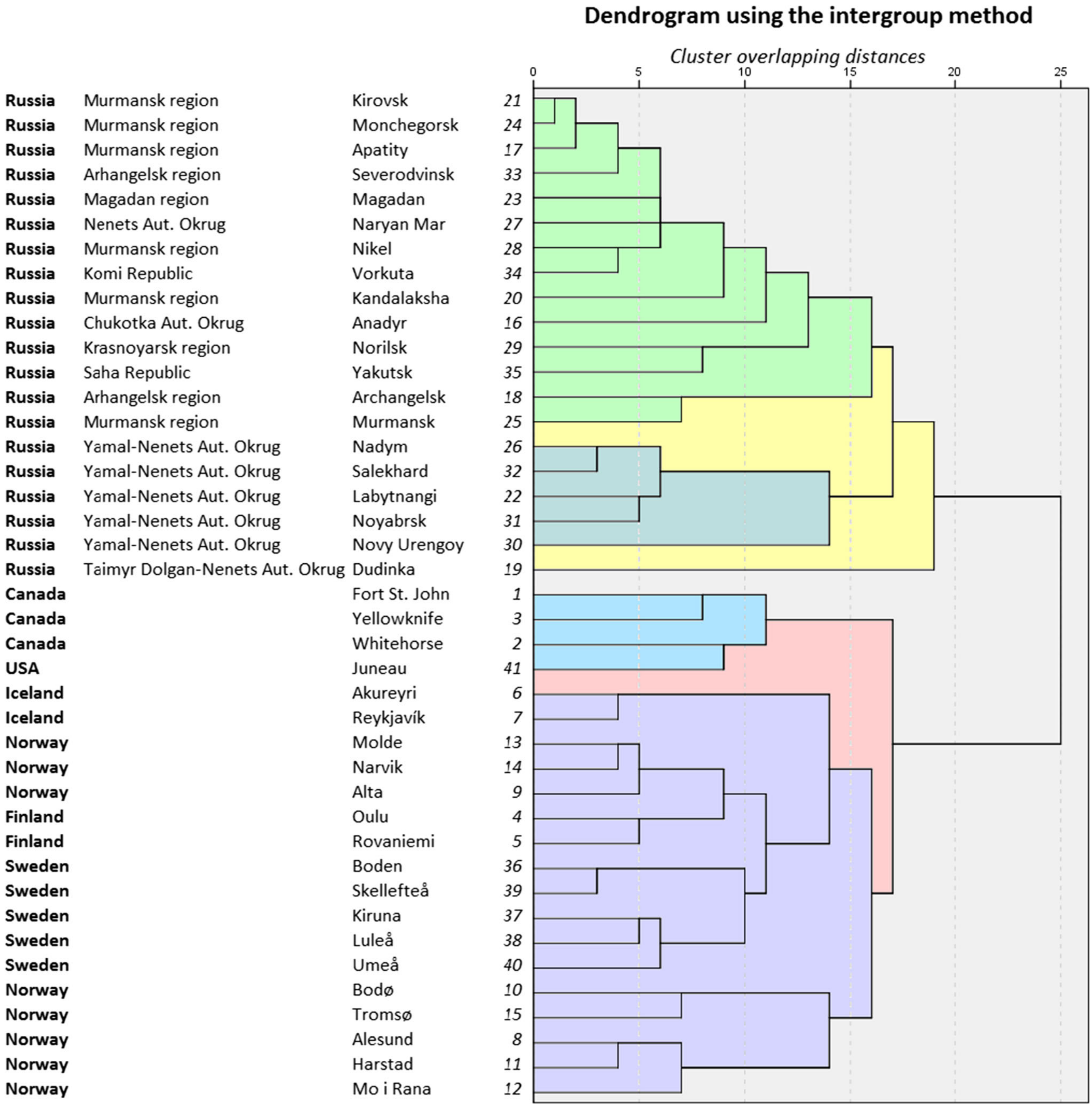

Fig. 4 Hierarchical cluster analysis of Arctic cities showing two clusters—Russian and Non-Russian Cities. *Note* The dataset used to perform this hierarchical cluster analysis is available in the Supplementary material

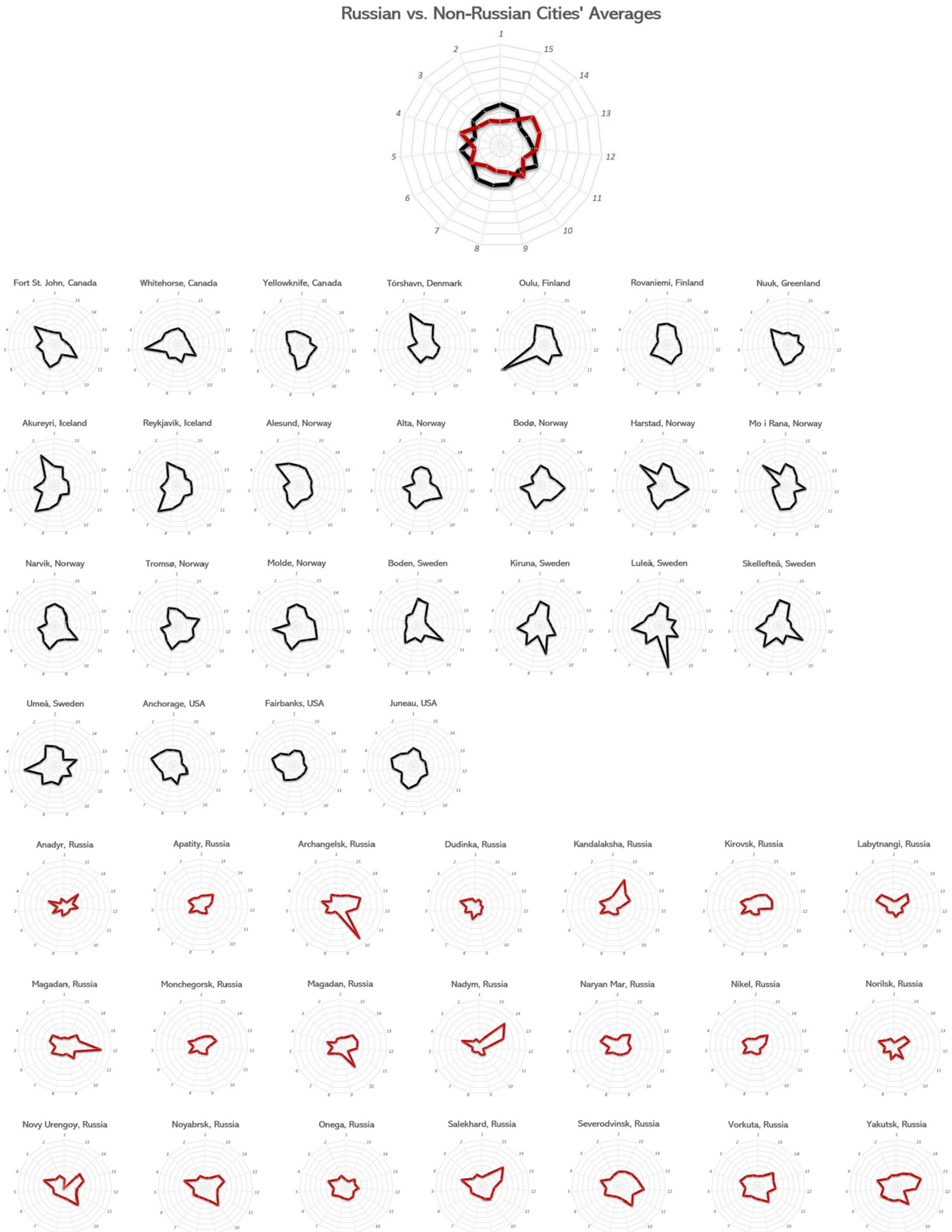

Fig. 5 Comparison of Russian and Non-Russian cities across sustainability indicators (Russian cities in red; non-Russian cities in black)

1. Percentage of population who are males aged 65+
2. Percentage of waste recycled
3. Waste production per capita
4. Gini coefficient (measurement of inequality within the population)
5. Number of university students per 100 000 population
6. Number of internet connections per 100 000 population
7. Number of businesses per 100 000 population
8. Percentage of energy derived from renewable sources
9. Energy consumption per capita (in gigajoules)
10. Number of cultural institutions and sporting facilities per 100 000 population
11. Capital spending as a percentage of total expenditures
12. Debt service ratio
13. Number of doctors per 100 000 population
14. Number of hospital beds per 100 000 population
15. Population dependency ratio (the number of children 14 and under combined with senior citizens 65 and older divided by the working age population 15–64 years old). The data (Appendix S1) and sources (Appendix S2) for these calculations can be found in the supplementary material.

These points of difference are important because they have implications for the level of sustainability in each city and the abilities of the cities to adapt to change. The threats to sustainability come from both the natural systems surrounding the cities and the social systems in which they exist. The changing climate results in thawing permafrost that undermines infrastructure in many places. Humanity's overconsumption of resources degrades the Arctic environment and places stressors on cities that rely heavily on these resources for their livelihoods. Systems of governance that fail to provide for long-term planning and investment threaten to drive current residents out of their cities if they can no longer find jobs where they currently live. By contrast, opportunities in tourism or mining could open new doors.

Demographics and health indicators

In the demographic category, the most striking difference was the finding that there are only one-third as many men over the age of 65 in Russian Arctic cities as there are in the non-Russian Arctic cities. Men over 65 years of age comprise 7.2% of non-Russian Arctic cities' population, but only 2.5% of Russian cities'. This figure ranges from 0.026% in Salekhard to over 4% in Severodvinsk; 3.07% in Yellowknife, Canada to 11.5% in Boden, Sweden. A recent study found that "one quarter of the decline in the male sex ratio in the Russian North can be attributed to higher male outmigration and that three quarters are the result of significantly higher and widening gaps between females and males in life expectancy (Heleniak 2019)."

Despite these poor health outcomes, Russia's Arctic cities have higher levels of access to healthcare facilities than their non-Russian counterparts. Russian Arctic cities have nearly four times as many hospital beds per 100 000 population as the non-Russian Arctic cities: 1683 to 412. Similarly, Russia has nearly 2.5 times as many doctors per 100 000 population as the non-Russian cities: 785 to 320. A deeper analysis would have to examine the quality of the facilities and the training that the doctors received (Twigg 2020).

Debt servicing and capital spending

There are big apparent differences between the Russian and non-Russian cities in terms of the amounts that they spend on debt servicing and capital expenditures. Russia's cities seem to do better in terms of debt service expenditure as a percentage of the city's own-source revenue as they only spend 10% of their income on loans, whereas the non-Russian cities spend 20%. This figure ranges from 0 debt service expenditure in Norilsk to 465% in Magadan; from 0 in Lulea, Sweden to 255% in Harstad, Norway. However, the Russian cities only spend about 4.8% on capital expenses as a percent of total expenditure; in contrast the non-Russian cities spend just over 18%. These numbers are hard to evaluate directly because of the different financial systems in Russia and the West and because the numbers alone do not tell us if these are financially weak cities trying to stay afloat or relatively well-off cities seeking to make investments for the future. Much more research is needed to answer these questions, but the data suggests that Western cities are using the resources that they have available to them in a more future-oriented manner that could make them more sustainable in the long term if they are in fact making investments that will keep them going in the years to come.

Sporting and cultural facilities

Cultural activities contribute to employment, income generation, and international trade in economic terms, and spur innovation, creativity and quality of life improvements in intangible terms (Kabanda 2018). Russian Arctic cities have more sporting and cultural facilities than the other northern cities. The median Russian city has 144 facilities per 100,000 population, 40% more than the median Arctic city outside of Russia which has 83, with figures ranging from 30 in Anadyr to 1055 in Arkhangelsk; 15 in Anchorage, US to 274 in Bodo, Mo i Rana, and Narvik, Norway. This difference likely reflects the strong Soviet investment in constructing cultural institutions and the continuing focus on such building in the post-Soviet era by Russia's major resource companies such as Gazprom, which invest in the construction of cultural and sporting facilities as part of their corporate social responsibility programs (Hitztaler and Tynkkynen 2020). The larger size of the Russian cities also facilitates the provision of such amenities. However, more research related to accessibility of these larger sports facilities is needed to gauge their impacts on a city's economic, social, and cultural landscape. A large number of facilities alone does not provide sufficient evidence that a city is more sustainable.

Energy usage per person

Russians living in Arctic cities use less energy per person than do Arctic residents elsewhere: in terms of total end-use energy consumption per capita (GJ/year), Russians use 36 gigajoules per year, whereas residents of other Arctic cities use 191, more than 5 times as much. Usage ranges from 21.48 gigajoules in Arkhangelsk to 99.49 in Labytnangi; from 0.23 in Torshavn, Faroe Islands to 960 in Lulea, Sweden, a city that includes a steelworks within its borders. This difference likely results from the greater population density of Russian Arctic cities, the presence of more multi-story buildings, and centralized heating and hot water supply systems. The smaller amount of living space per person translates into substantial energy savings. Russia also benefits from 25% more public transportation than cities outside of Russia and only half as many automobiles per capita.

The higher energy consumption of non-Russian cities is partially offset by the use of renewable sources of energy. Iceland benefits from a strong reliance on hydro and geothermal sources with these renewable sources providing nearly 100% of electricity consumption. On average, non-Russian cities use about 64% renewable energy to generate electricity while the figure for Russian Arctic cities is 13%. Cities such as Arkhangelsk and Severodvinsk use no renewable energy whereas Norilsk uses renewable sources for 52% of its energy; outside Russia, the figures range from 0.92% in Kiruna Sweden to 100% in Iceland's cities.

Business and entrepreneurship

Non-Russian cities have nearly three times as many enterprises as their Russian counterparts: 9363 to 3364 per 100 000 population. This figure ranges from 1050 in Anadyr to 6130 in Magadan; from 4335 Yellowknife, Canada to 21 745 in Reykjavik and Akureyri, Iceland. The reason for this disparity is multi-faceted and outside the scope of this study alone. However, the larger number of higher education institutions in non-Russian cities (particularly Sweden's) could be a potential factor. Additionally, business incentives from municipal governments vary greatly between the two groups, with non-Russian city governments like Akureyri's providing more lucrative incentives for business creation. On the other hand, Russian cities benefit from 1.5 times as many internet connections and cell phone links, suggesting potential for development in the future.

Education

One strong measure of sustainability is how many resources a community dedicates to educating future generations. In this category, the median Western city performs much better with 6583 university students per 100 000 population. The median Russian city hosts only 1290. Russia boasts two large federal universities in Arkhangelsk and Yakutsk and is investing in these. There is also an oil and gas university in Tyumen, a location outside the Arctic, but a place where many Arctic students go to study.

Following the collapse of the Soviet Union, Russia closed many universities in northern cities because they were not economically viable. This same problem is hitting non-Russian cities now. Alaska, facing a drop in oil income and the election of a radical right-wing governor, is in the process of slashing state funding for the University of Alaska system for the next few years. The university is already losing many faculty members and the future shape of the institution remains in question.

Socioeconomic inequality

The Gini Index is a broad measure of inequality that takes into account income distribution. A measure of 0 indicates "perfect" equality and a measure of 1 indicates "perfect" inequality. The Russian Arctic cities are relatively unequal in comparison to their counterparts with a Gini Coefficient of 0.384. The non-Russian cities are more equal with a median of 0.278. However, the situation varies dramatically among the non-Russian countries on this measure. The three Alaskan cities (0.436), Canadian (0.331) and Nuuk, Greenland (0.339) are relatively unequal, while the European cities are 0.3 or less, giving them higher levels of equality.

Solid waste management

As an aggregate, Russian Arctic cities produce less waste than the other Arctic cities. Russian cities average around 0.527 tons/capita every year whereas non-Russian Arctic cities average 0.924 tons/capita. In Russia, waste production can be as low as 0.14 tons/capita in Anadyr to 2.2 tons/capita in Labytnangi; outside Russia from 0.369 in

Alta, Norway to 2.21 in Alesund, Norway. The International Finance Corporation found that as much as 30% of solid waste in Russian Arctic cities is disposed of in either unsanitary landfills or open dumps, whereas other Arctic cities redirect all waste to sanitary landfills or some form of waste recovery (IFC Advisory Services in Eastern Europe and Central Asia 2012). Only a few Russian cities have access to recycling (Salekhard is an outlier with 100% recycling), while most other Arctic cities are able to support some levels of waste recovery.

CONCLUSION

The analysis provided here rejects the intuitive hypothesis that Western Arctic cities are more sustainable than their Russian counterparts. In fact, the story is much more complex, with cities in both the Russian and non-Russian parts of the Arctic demonstrating both strengths and weaknesses in terms of sustainability.

The compact and dense nature of Russia's Arctic cities gives them significant advantages in pursuing sustainability goals. Their residents use less energy per capita than counterparts in Europe and North America and they have access to more services, such as public transportation and cultural amenities. They also have more hospital beds and doctors and generate less waste per capita.

However, our analysis shows that these cities do not always fully utilize their advantages. The cities tend to rely on big businesses to shape their strategic direction and this future relies heavily on oil and gas extraction. Cities outside Russia are investing more heavily in their development, have many more businesses suggesting greater economic diversity, invest more in local education, and pay greater attention to core issues such as solid waste management. Given the extensive differences between Russian and non-Russian Arctic cities as well as within these two groups, mayors and other urban leaders can benefit from studying the experiences of neighboring Arctic cities to exchange and adopt best practices.

The data presented in summary fashion here identifies a wide range of areas where more research could provide strong benefits in better understanding what drives the sustainability of Arctic cities and their ability to adapt to changing conditions. In depth work on healthcare as a component of urban sustainability will clarify which elements of the medical system are most useful for promoting communities where individuals live longer and more productive lives. A better understanding of how Russian and non-Russian cities borrow and invest capital funds would give a sense of which kind of investments provide the most effective payoffs in terms of promoting a combination of environment, economy, and equity. Similarly, a deeper investigation of how to stimulate small business in Arctic conditions would shed light on building a sustainable economy that helps northern residents avoid the consequences of the boom-bust economic cycle. And, finally, more research on the social impact of cultural amenities such as sporting facilities would help us understand the real mechanisms of how they improve the lives of the communities where they are located.

The data presented here, and hopefully future research ahead, helps us understand how Arctic cities can adapt to address the challenges posed by environmental and economic changes. Effective adaptation requires, first of all, human capital—vibrant populations and healthcare systems that promote well-being. Strong social capital will come from cultural amenities that encourage both job creation and intellectual development and efforts to reduce inequality. Cities will need to use financial capital to invest wisely in better education and new industries that take advantage of global changes. Incentivizing entrepreneurs to find ways to increase energy efficiency will help. Finally, each city's physical capital can promote adaptation through a conscious effort to improve overall urban design and layout as well as paying attention to such mundane issues as solid waste management and recycling.

Acknowledgements This material is based upon work supported by the National Science Foundation under Grant No. 1545913, Partnerships for International Research and Education: Promoting Urban Sustainability in the Arctic.

REFERENCES

Armstrong, T. 1965. *Russian settlement in the north*. Cambridge: Cambridge University Press.

Barenberg, A. 2014. *Gulag town, company town: Forced labor and its legacy in Vorkuta*. New Haven: Yale University Press.

Bassin, M. 2003. Greening Utopia. In *Architectures of Russian identity: 1500 to the present*, ed. J. Cracraft and D. Rowland, 150–171. Ithaca: Cornell University Press.

Berman, M., and R.W. Orttung. 2020. Measuring progress toward urban sustainability: Do global measures work for Arctic cities? *Sustainability* 12: 3708.

Bolotova, A. 2012. Loving and conquering nature: Shifting perceptions of the environment in the industrialised Russian North. *Europe-Asia Studies* 64: 645–671.

Bond, A.R. 1983. Residential construction in northern USSR. *Cities* 1: 120–131.

Bond, A.R. 1985. Northern settlement family-style: Labor planning and population policy in Norilsk. *Soviet Geography* 26: 26–47.

Borgman, C.L. 2015. *Big data, little data, no data: Scholarship in the networked world*. Cambridge, MA: MIT Press.

Callaghan, T.V., O.M. Shaduyko, and S.N. Kirpotin. 2021. Siberian environmental change. Special issue. *Ambio* 50.

Cho, L. 2020. The perennial solidity of water. *Journal of Architectural Education* 74: 120–122.

Cho, L., and M. Jull. 2019. *Mediating environments*. Novato: Applied Research and Design.

Cole, D. 2003. *Fairbanks: A gold rush town that beat the odds*. Fairbanks: Epicenter Press.
Curley, C., R.M. Krause, R. Feiock, and C.V. Hawkins. 2019. Dealing with missing data: A comparative exploration of approaches using the integrated city sustainability database. *Urban Affairs Review* 55: 591–615.
Demuth, B. 2019. *Floating coast*. New York: W. W. Norton and Co.
DiNapoli, B., and M. Jull. 2020. Urban planning sustainability metrics for Arctic cities. Manuscript submitted for publication.
Dobrowolsky, H., and L. Johnson. 2013. *Whitehorse: An illustrated history*. Vancouver: Figure 1 Publishing.
Farish, M. 2013. The lab and the land: Overcoming the Arctic in cold war Alaska. *Isis* 104: 1–29.
Heleniak, T. 2009. Growth Poles and Ghost Towns in the Russian Far North. In *Russia and the north*, ed. E.W. Rowe, 129–163. Ottawa: University of Ottawa Press.
Heleniak, T. 2010. Population change in the periphery: Changing migration patterns in the Russian North. *Sibirica* 9: 9–40.
Heleniak, T. 2019. Where did all the men go? The changing sex composition of the Russian North in the post-Soviet period, 1989–2010. *Polar Record*.
Hill, F., and C.G. Gaddy. 2003. *The siberian curse: How communist planners left Russia out in the cold*. Washington, DC: Brookings Institution Press.
Hitztaler, S., and V.-P. Tynkkynen. 2020. What do ISO indicators tell us about corporate social responsibility and sustainability in cities of the Yamal-Nenets Autonomous Okrug, Russia? In *Urban sustainability in the Arctic measuring progress in circumpolar cities*, ed. R.W. Orttung, 176–201. New York: Berghahn.
Humphreys, D. 2011. Challenges of transformation: The case of Norilsk Nickel. *Resources Policy* 36: 142–148.
IFC Advisory Services in Eastern Europe and Central Asia. 2012. *Municipal solid waste management: Opportunities for Russia summary of key findings*. Washington DC: International Finance Corporation.
ISO 37120. 2018. Sustainable cities and communities—Indicators for city services and quality of life.
Josephson, P.R. 2016. *The Conquest of the Russian Arctic*. Cambridge, MA: Harvard University Press.
Jull, M. 2017. The improbable city: Adaptations of an Arctic metropolis. *Polar Geography* 40: 291–305.
Jull, M. G., and L. S. Cho. 2013. Architecture and urbanism of Arctic cities: Case study of Resolute Bay and Norilsk.
Kabanda, P. 2018. *The creative wealth of nations: Can the arts advance development?*. Cambridge: Cambridge University Press.
Koncheva, E., and N. Zalesskiy. 2016. Spatial Development of the largest Russian cities during the post-soviet period: Orienting towards transit or maintaining soviet trends. Higher School of Economics Research Paper No. WP BRP 04/URB/2016.
Larsen, J.K., and P. Hemmersam. 2018. *Future north: The changing Arctic landscapes*. Abingdon: Routledge.
Laruelle, M. 2020. Norilsk: Measuring Sustainability in Population Size, and Well-Being. In *Urban sustainability in the Arctic: Measuring progress in circumpolar cities*, ed. R.W. Orttung, 74–100. New York: Berghahn.
Laruelle, M., and S. Hohmann. 2017. Biography of a polar city: Population flows and urban identity in Norilsk. *Polar Geography* 40: 306–323.
Lehner, A., C. Erlacher, M. Schlögl, J. Wegerer, T. Blaschke, and K. Steinnocher. 2018. Can ISO-defined urban sustainability indicators be derived from remote sensing: An expert weighting approach. *Sustainability* 10: 1268.
McCannon, J. 1995. To storm the Arctic: Soviet polar exploration and public visions of nature in the USSR 1932–1939. *Ecumene* 2: 15–31.
McGhee, R. 2005. *The last imaginary place: A human history of the Arctic world*. Chicago: University of Chicago Press.
Nazarova, L.G., and V.E. Poluektov. 1974. Design and construction experience in cities in the extreme North (Using Norilsk as an Example) no. CRREL-TL- 440. Cold Regions Research and Engineering Lab, Hanover, NH.
Parente, G. 2014. Limiting migration in the Russian Arctic: The City of Norilsk.
Pilyasov, A.N. 2011. Goroda rossiiskoi Arktiki: Sravnenie po ekonomichesim indikaatoram [Cities of the Russian Arctic: comparison by economic indicators]. Vestnik Mokovskogo universiteta, Seriia 5 Geografiia no. 4.
Powell, J. 2020. Sustaining sustainability in Whitehorse, Yukon, Canada. In *Urban sustainability in the Arctic: Measuring progress in circumpolar cities*, ed. R.W. Orttung, 247–277. New York: Berghahn.
Schaffner, C. 2020. Arctic Cities. In *Urban sustainability in the Arctic: Measuring progress in circumpolar cities*, ed. R.W. Orttung, 22–48. New York: Berghahn.
Schultheiss, K. 2009. The ends of the earth and the "Heroic Age" of polar exploration: A review essay. *Historically Speaking* 10: 14–17.
Serreze, M.C. 2018. *Brave new Arctic: the untold story of the melting north*. Princeton: Princeton University Press.
Seto, K.C., and M. Reba. 2018. *City unseen: New visions of an urban planet*. New Haven: Yale University Press.
Sheppard, L., and M. White. 2017. *Many norths: Spatial practice in a polar territory*. New York: Actar Publishers.
Shiklomanov, N., D. Streletskiy, L. Suter, N. Zamyatina, and R. Orttung. 2019. *Dealing with the Bust in Vorkuta*. Land Use Planning: Russia.
Shiklomanov, N.I., and M. Laruelle. 2017. A truly Arctic city: An introduction to the special issue on the city of Norilsk, Russia. *Polar Geography* 40: 251–256.
Stephenson, S.R., L.C. Smith, and J.A. Agnew. 2011. Divergent long-term trajectories of human access to the Arctic. *Nature Climate Change* 1: 156–160.
Streletskiy, D.A., L.J. Suter, N.I. Shiklomanov, B.N. Porfiriev, and D.O. Eliseev. 2019. Assessment of climate change impacts on buildings, structures and infrastructure in the Russian regions on permafrost. *Environmental Research Letters* 14.
Stuhl, A. 2016. *Unfreezing the Arctic: Science, colonialism, and the transformation of inuit lands*. Chicago: University of Chicago Press.
Twigg, J. 2020. Russia's health care system and the Covid-19 pandemic. *Russian Analytical Digest* 251: 2–5.
Westfall, D. 2018. Z Scores. In *The SAGE Encyclopedia of educational research, measurement, and evaluation*, ed. B.B. Frey, 1835–1837. Thousand Oaks: Sage Publications.
Zamiatina, N.I., and A.N. Piliasov. 2018. *Rossiiskaia Arktika: K novomu ponimaniiu protsessov osvoeniia [The Russian Arctic: Toward a new understanding of processes of mastering]*. Moscow: Lenand.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

AUTHOR BIOGRAPHIES

Robert W. Orttung (✉) is Research Professor of International Affairs at the George Washington University Elliott School of International Affairs and Research Director for Sustainable GW. He is the principal investigator for the National Science Foundation Partnerships for International Research and Education (PIRE) Promoting Urban Sustainability in the Arctic (#1545913). His research interests include urbanization, adaptation, sustainability, and measurement of things that are hard to measure.
Address: IERES, 1957 E St NW Suite 412, Washington, DC 20052, USA.
e-mail: rorttung@gwu.edu

Oleg Anisimov is a Professor of Physical Geography at the Hydrological Institute of Roshydromet in St. Petersburg, Russia. He served as the coordinating lead author of the Polar regions chapters in the Third, Fourth and Fifth IPCC reports, and the lead author of the international scientific assessments focused on the Arctic (ACIA, SWIPA). His research interests include environmental and socio-economic impacts of changing climate in the northern lands.
Address: State Hydrological Institute, 23 Second Line V.O., St.Petersburg, Russia 199053.
e-mail: oleg@oa7661.spb.edu

Svetlana Badina is a Senior Researcher at the Institute of Economic Forecasting of the Russian Academy of Sciences (IEF RAS) and the Plekhanov Russian University of Economics; Senior Lecturer of the Peoples' Friendship University of Russia in Moscow, Russia. Her research interests include forecasting socio-economic development of Russian Regions, impacts of climate change in northern lands and natural hazards and their impacts on society and economy.
Address: Moscow, Russia 117418.

Charlene Burns is a recent graduate from the George Washington University Elliott School of International Affairs with a B.A. in International Affairs. She is a research assistant for the NSF PIRE Promoting Urban Sustainability in the Arctic (#1545913). Her research interests include solid waste management, environmental governance, and U.S.-China relations.
Address: IERES, 1957 E St NW Suite 412, Washington, DC 20052, USA.
e-mail: burnsc@gwu.edu

Leena Cho is Assistant Professor of Landscape Architecture and Co-Director of Arctic Design Group at the University of Virginia School of Architecture. Her research examines the ideas and instrumentations of climate in the design of Arctic landscapes and cities, including the impacts of climate change on the socioecological roles of built landscapes. She is an author and editor of *Mediating Environments* (2019), and a Founding Principal of award-winning design office Kutonotuk.
Address: UVA School of Architecture, 110 Bayly Drive, Charlottesville, VA 22903, USA.
e-mail: lcho@virginia.edu

Benjamin DiNapoli is a third-year graduate student in Architecture at the Harvard University Graduate School of Design and a Research Fellow with Arctic Design Group at the University of Virginia School of Architecture. His research interests include building technology, architecture, urbanism, and contemporary life in the built environment. Prior to joining Arctic Design Group, he was a designer at Bjarke Ingels Group (NY) and Skidmore, Owings & Merrill (D.C.).
Address: Cambridge, MA 02138, USA.
e-mail: dinapoli@gsd.harvard.edu

Matthew Jull PhD, is an Associate Professor of Architecture at the University of Virginia School of Architecture, Co-Director of the Arctic Design Group, and Founder and Principal of the design firm Kutonotuk. With a dual background in geophysics and architecture, his research investigates the design of cities, buildings, and infrastructure in extreme environments, particularly in the Russian and North American Arctic.
Address: UVA School of Architecture, 110 Bayly Drive, Charlottesville, VA 22903, USA.
e-mail: mjull@virginia.edu

Melissa Shaiman is an undergraduate student at George Washington University studying International Affairs, Geography, and GIS. She is a Research Assistant for the National Science Foundation Partnerships for International Research and Education (PIRE) Promoting Urban Sustainability in the Arctic (#1,545,913). She is interested in urban sustainability, especially regarding access to resources and climate adaptability.
Address: IERES, 1957 E St NW Suite 412, Washington, DC 20052, USA.
e-mail: melishaiman@gwu.edu

Ksenia Shapovalova is a researcher at the Hydrological Institute of Roshydromet in St. Petersburg, Russia. Her research interests include climate change, public perception and adaptation policy in Arctic regions of Russia.
Address: State Hydrological Institute, 23 Second Line V.O., St.Petersburg, Russia 199053.

Leah Silinsky is a second-year graduate student at the George Washington University Elliot School of International Affairs, studying European and Eurasian studies. She is a research assistant for the NSF PIRE Promoting Urban Sustainability in the Arctic (#1,545,913). Her research interests include Central Asian insurgency groups, disinformation campaigns, and narrative formation among violent state and non-state actors.
Address: IERES, 1957 E St NW Suite 412, Washington, DC 20052, USA.
e-mail: leahsilinsky@gwmail.gwu.edu

Emily Zhang is a graduate student at the George Washington University Department of Geography. She is a research assistant for the NSF PIRE Promoting Urban Sustainability in the Arctic (#1,545,913). She is interested in urban geography, green buildings, and the knowledge production process behind indicators and metrics.
Address: IERES, 1957 E St NW Suite 412, Washington, DC 20052, USA.
e-mail: ezhang@gwu.edu

Yelena Zhiltcova is a researcher at the Hydrological Institute of Roshydromet in St. Petersburg, Russia. Her research interests include climate change, modeling of vegetation in permafrost regions of Russia, and statistical analysis.
Address: State Hydrological Institute, 23 Second Line V.O., St.Petersburg, Russia 199053.