Developing Metrics to Guide Sustainable Development of Arctic Cities: Progress & Challenges

Luis Suter, Carrie Schaffner, Carlson Giddings, Robert Orttung & Dmitry Streletskiy

This article describes the preliminary results of an effort to produce an Arctic Urban Sustainability Index that will have applications for researchers and policymakers. The project aims to help policymakers define and implement sustainability policies by measuring progress towards sustainability, compare across cities, and trace development over time. Existing studies within the region provide little analysis specifically addressing urban development. This study, under the auspices of the National Science Foundation's Partnerships for International Research and Education (PIRE) project, aims to fill this gap in Arctic research by promoting urban sustainability, with a focus on optimal city planning and management to ensure the interests of future generations. Collecting the data to prepare the Index has proven challenging across a number of dimensions and efforts to address those challenges are discussed. While the Index described here remains a work in progress, we believe the process of thinking through issues related to measuring sustainability systematically will ultimately deliver useful results for researchers and policymakers.

The Arctic region has seen urban growth in resource-rich areas even as the populations in other parts of the region shrink (Howe, 2009; Dybbroe et al., 2010; Heleniak, 2010; Heleniak, 2013). A majority of the Arctic population resides in urban environments. Expanding cities provide housing, jobs, and education for human populations (Wu et al., 2011; Day & Ellis, 2013), but also impart negative effects such as pollution, encroachment on open land, and contributions to impacts on the surrounding natural environment far beyond the settlement limits (McKinney, 2008). Typically, research in the Arctic has focused on a range of specific and discrete issues, including modeling Arctic climate and weather conditions (Johannessen et al, 2004); permafrost (Shiklomanov et al, 2010); marine and shipping issues (Arctic Council, 2009); oil and gas development (Gautier et al, 2009); foreign policy and geopolitical concerns (Heininen & Nicol, 2007; Exner-Pirot, 2013); and "decolonized" research with Indigenous peoples (Smith, 2013). Focusing on cities is crucial because they represent a space where these issues intersect.

Cities, including those in the Arctic, act as a focus where intense human-environment interactions take place (Dybbroe, 2008; Rasmussen, 2011; Streletskiy & Shiklomanov, 2016). The continual growth of the global urban population has invigorated efforts to define and measure urban

---

Luis Suter and Dmitry Streletskiy are in the Department of Geography, Carrie Schaffner and Carlson Giddings are at the Elliott School of International Affairs, and Robert Orttung is at the GW Sustainability Collaborative, at The George Washington University, USA.

sustainability (Science for Environment Policy, 2015). On the global scale, there have been several important projects undertaken to quantify and track levels of sustainability in urban areas, including most recently the UN Sustainable Development Goals (UN CSD, 2007; Todorov & Marinova, 2009; Li et al., 2014; WCCD, 2017; UN, 2015). Unfortunately, Arctic cities have been vastly underrepresented in these broader research efforts. Meanwhile, the Arctic region has been undergoing accelerated and significant changes – climatically, socially, economically, and politically (Anisimov et al., 2010; Heleniak, 2013; Jakobsson et al., 2014; Underdal, 2013; Young, 2009). Observed changes have spurred interest in research tracking the evolution of Arctic cities within these individual thematic components (AMAP 2017; Larsen et al., 2015; Longergan et al., 1993; Shiklomanov et al., 2017). The Arctic Urban Sustainability Index seeks to contribute to building the knowledge base on these issues by improving our understanding of the complex linkages among them.

This article lays out a research framework for measuring urban sustainability in the Arctic region, addresses the challenges in quantifying sustainability within an easy-to-use index, and shows best practices for making this data and analysis accessible to policymakers and the public. The goal is to create a synergetic tool measuring Arctic urban sustainability across economic, social, environmental, governance, and planning dimensions. The central research question for the project is: How can Arctic urban sustainability be measured and how can the likelihood of progress on sustainability challenges be assessed? Our central hypothesis posits that a comprehensive tool for measuring sustainability efforts across the full range of scales and mechanisms, as well as the research process of creating such a tool, will trigger efforts to improve urban sustainability planning.

In order to start the conversation around measuring Arctic urban sustainability, researchers created a preliminary Index using a small set of indicators, which were most universally accessible for a limited sample of Arctic cities. The selection of indicators was informed through a series of consultations, meetings and workshops with researchers, local politicians, and other Arctic urban community members. The preliminary dataset was used to synthesize data visualization samples and was presented at several conferences and workshops to generate feedback and interaction from the wider Arctic research community. Challenges related to data quality and accessibility, combined with the limited scope of this preliminary analysis in terms of indicators and cities, suggest that the preliminary results are far from being an accurate measure of urban sustainability in the Arctic. However, by undertaking this initial phase, researchers identified several priorities and best practices for improving the project. The presentations and discussions of the research have initiated valuable exchanges within the broader scientific and policy community, generating feedback and engagement with the research team which will help drive forward the project (Arctic PIRE Workshop, 2017; Streletskiy, 2017; Schaffner et al., 2017; Suter, 2017). The reactions and support this preliminary Index has garnered indicate that the continued improvement of metrics to track sustainability will likely encourage improved urban planning models and benefit Arctic cities.

Defining Sustainability

As with intangible concepts like democracy, justice, and innovation, the substance of sustainability can be hard to define and measure. We start from the assumption that there is a concrete core to sustainability and work to quantify its key components. The conceptual roots of sustainability date back to the late seventeenth century and have evolved over time (Caradonna, 2014: 6).

Contemporary definitions for sustainable cities focus on using resources in a way that does not impinge on future generations (World Commission on Environment and Development, 1987). In looking specifically at Arctic urban sustainability, we apply the U.S. National Academies of Sciences three pillars of sustainability: economy, environment, and society (Schaffer & Vollmer, 2010) in an effort to fill existing knowledge gaps (Petrov et al., 2017: 64). Sustainability science seeks to view the world in big picture terms and understand how the various components "depend on one another, interact, and co-evolve" (Matson, Clark & Andersson, 2016). We implement these ideas by seeking to integrate concern for the environment with a broader understanding that communities need a thriving economy and jobs, as well as measures of social justice, in order to thrive.

In a review of the literature, Portney argues that the existing indices tend to mix policy measures with outcome measures (Portney, 2013: 41). He calls for creating an Index of Taking Sustainability Seriously, with the caveat that there still is not enough empirical data to state with confidence how much specific actions, policies or programs influence objective measures of sustainability. Nevertheless, cities that "take sustainability seriously" are presumably making progress toward greater sustainability. In order to avoid mixing outcome and policy measures, we define sustainability along five dimensions: the first three measure sustainability outcomes – economic, social, and environmental – while the last two focus on efforts by cities to achieve these outcomes – governance and planning.

Defining an Arctic City

The idea of a city being defined by something other than population and economics is hardly new. In 1937, urban historian Lewis Mumford wrote a philosophical piece called "What is a city?" in which he argues that "the city, in its complete sense, then, is a geographic plexus, an economic organization, an institutional process, a theater of social action, and an aesthetic symbol of collective unity" (Mumford, 1937: 8). In a 1947 *Science* article, J. Q. Stewart introduced social physics and used allometric parameters to define physical urban forms as a result of a long series of events, technological developments, and social preferences (Stewart, 1947). More contemporary theorists agree that cities are not merely defined as a dense agglomeration of people, but a place that serves a specific social function. This approach defined the city as a space containing a "contact system, [where] a set of interactions and flows define the kinds of the network that enable creativity and innovation to thrive and grow" (Batty & Ferguson, 2011: 755). Likewise, William Frey and Zachary Zimmer were not satisfied with the limitations of the definition of a city as merely an agglomeration of people, proposing instead that we view cities as 'Functional Community Areas'" (Frey & Zimmer, 2011). These theories informed our decisions in refining our research scope to communities that met a given population threshold, but also were significant in serving a defined set of regional functions.

In considering urban settlements in the Arctic, it quickly becomes apparent that they do not closely resemble cities elsewhere in the world, and cannot be defined by conventional parameters. The U.S. Census Bureau defines an urban area as any agglomeration of more than 50,000 people and classifies areas between 2,500 and 50,000 as urban clusters (Bureau of the Census, 2010). A common definition for Arctic urban areas during the Soviet era was a settlement of over 12,000 residents, where 85% of the population was engaged in the non-agricultural sectors (Heleniak, 2013: 3), but this definition has also evolved over time. In Iceland, localities of 200 or more population are classified as urban (UN Demographic Yearbook, 2015). In the Arctic we often find small urban communities filling the same functional niches as bigger "urban areas" at lower latitudes. Cities of smaller population and low population density can still serve vital administrative functions for government, sites for manufacturing and industry, and centers for social institutions. Other agglomeration services are also in play within these cities: opportunities for learning, information spillover (the rapid transition of ideas), persistent lower costs of moving people and goods, and the allure of higher wages for employees and higher productivity levels for employers (Brunn, 2016).

The Arctic is not a strictly defined region, with circumpolar countries and international organizations delineating this border varyingly. While the Arctic Circle defines the physical area approximately above 66°30' N, the region is generally considered more broadly. In Sweden, the county of Västerbotten is classified as Arctic, though a majority of the territory lies below the Arctic Circle (Husebekk et al., 2015). The US Arctic Research and Policy Act uses a strict definition of the Arctic Circle, except in Alaska where significantly more territory is added (US Arctic Research Commission, 2009). Previous research, such as the Arctic Human Development Report (AHDR), considers these variations and generally accepts a wider region to be Arctic. However other prominent organizations including the Arctic Council Emergency Prevention, Preparedness, and Response (EPPR) working group, the Arctic Monitoring and Assessment Programme (AMAP), and the Conservation of Arctic Flora and Fauna (CAFF) draw the border differently as well. This project defines the Arctic region as the largest possible area encompassed by this agglomeration of Arctic research organization borders (Figure 1).

These varying demographic, geographical, and functional classifications of Arctic urban areas forced the team to create a circumpolar definition of Arctic cities, rooted in the practicality of undertaking the research project. These considerations informed our decision-making process in classifying an Arctic city as settlement of over 12,000 population located within the Arctic region as defined in defined above. However, cities outside this region have been added based on expert opinion. For example, Yakutsk, which is outside the Arctic borders is underlined by permafrost and widely considered as a major Arctic city. The demographic and geographical definition resulted in an initial list of 50 cities (Appendix A). This list is not definitive, as more cities could be added during the project, based on advice from experts and community feedback. Because of practical considerations, the preliminary index focused on cities where the research team had experience and contacts with local stakeholders. This process identified a list of 12 cities, which are featured in analysis below. Table 1 features these cities and their most recently available (2016/2017) population statistics, sourced from countries' national statistical databases.

Table 1. 12 of 50 possible Arctic cities were selected for the pilot index

City	Population
Anchorage, US	298,192
Fairbanks, US	32,751
Whitehorse, CA	28,225
Yellowknife, CA	19,569
Nuuk, DK	17,036
Tromsø, NO	34,283
Boden, SE	28,024
Kiruna, SE	23,167
Luleå, SE	76,770
Arkhangelsk, RU	351,488
Norilsk, RU	178,654
Salekhard, RU	48,794

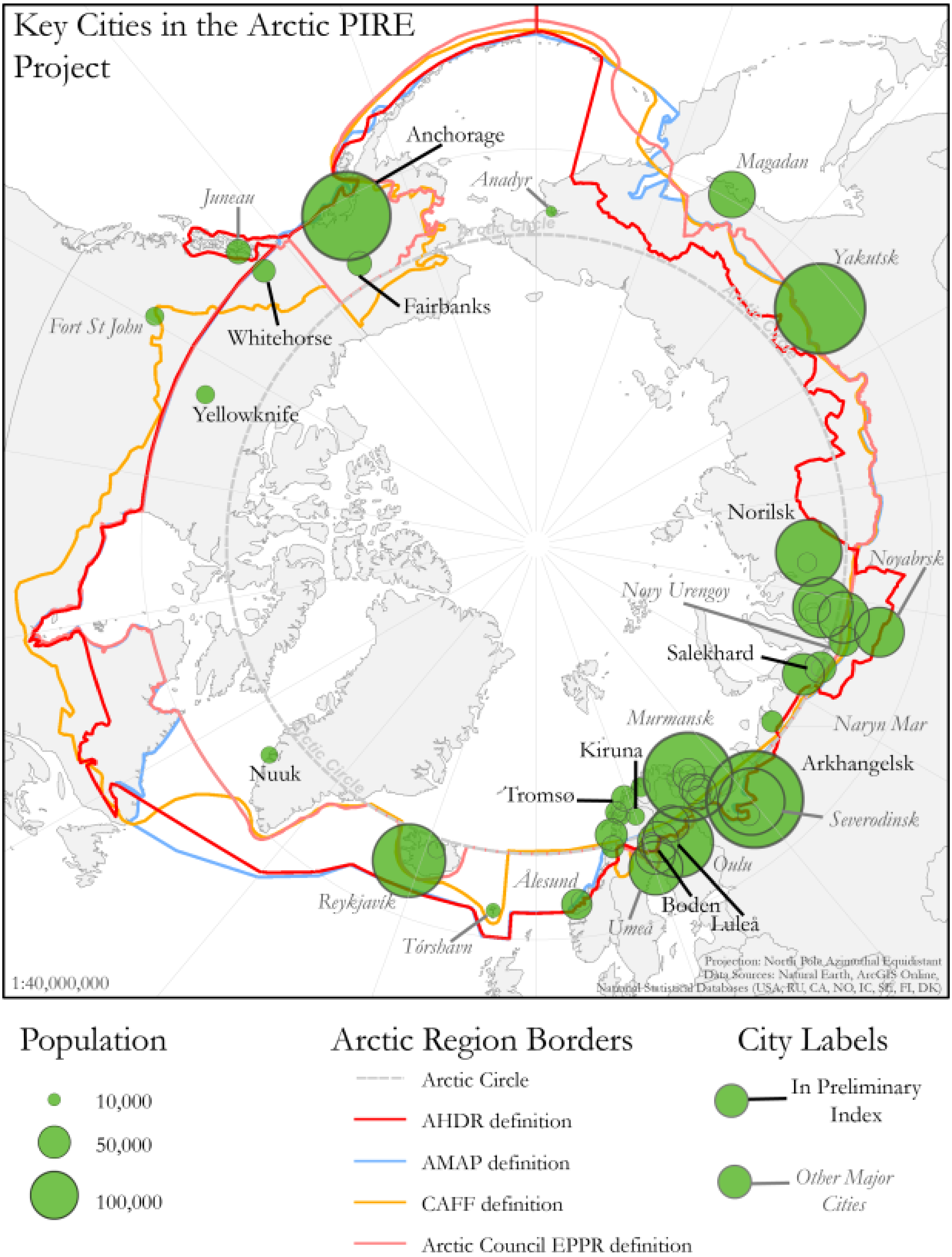


Figure 1. *A map of the cities being featured in the pilot Arctic Urban Sustainability Index, and all Arctic cities that meet the spatial and demographic criteria of this research project*

Map Author: Luis Suter

Global Challenges in Quantifying Urban Sustainability

Designing a set of measures to assess urban sustainability across these areas remains a challenge; even among the 12 cities selected for the pilot index there is diversity in their microenvironments, politics, and socioeconomic organization. Attempts to quantify complex subjects such as sustainability into indexes and ranking systems have sometimes been criticized as being "incoherently defined, anchored in confused and untested theories, measured idiosyncratically, and subject to manipulation by both the raters and the rated, leading to unintended, unwanted consequences" (Snyder & Cooley, 2015: 79). These concerns reflect the challenge of measuring and communicating the complexity of sustainability and the interactions between sustainability categories such as economics, society, politics, and environment. This criticism has stimulated universities and funding organizations to support increased multidisciplinary analysis, and encouraged the National Academy of Sciences to study ways to promote interdisciplinary team science (Cooke & Hilton, 2015).

In 2009, a group of researchers at the University of Quebec analyzed the use of sustainable development indicators in seventeen urban settings, finding 118 different indicators being tracked across these cities (Tanguay et al., 2009: 24). This diversity was attributed to the broad definitions of sustainability (and equally broad interpretations) being used within the different communities. The research showed that there was a strong correlation between the number of indicators in an index and the type of actors driving the creation of the index, where studies endorsed by municipal leaders tended to favor a "structure comprising fewer indicators, intended to achieve simple and quantifiable objectives, [while] scientists prefer[red] a minimum of aggregation and, if possible, simplification, in order to be faithful to the concepts" (Tanguay et al., 2009: 14).

The complexity and variety of sustainability definitions and sustainability metrics increase the difficulty of translating science into effective policy. The difficulties in building this particular bridge between science and policy are well documented (McCool & Stankey, 2004; Weigold, 2001), and highlight the need for more bilateral understanding between scientists and policymakers. Preparing indicators that are scientifically sound and policy relevant demonstrates the importance of knowledge production among researchers, political leadership, and other local stakeholders. Dutch researchers Niemeijer and De Groot found that the best way to find a compromise between a desire to standardize for comparative purposes and retain local relevance is the inclusion of "consensus" indicators which are universally collectible, complemented by locally specific indicators to address the unique concerns of individual communities (Niemeijer & De Groot, 2008). The fine balance between scientific robustness and political accessibility is a special consideration in constructing such metrics.

Quantifying Urban Sustainability in the Arctic Context

The Arctic PIRE project has developed a structural framework where sustainability advances are seen in the social, economic, and environmental sphere and where the main drivers are seen in the policymaking and planning spheres. The quantification of the complex interactions between the five pillars of sustainability is further complicated in the Arctic region by the breadth of microenvironments, and diversity of political and socioeconomic systems in the region. The environmental impacts to physical systems, such as effects of climate change and permafrost have been shown to be comparable across the Arctic (AMAP, 2017; Grebenets et al., 2012; Streletskiy et al., 2012; Shiklomanov et al., 2017), but the social and political systems controlling the cities vary starkly (Laruelle, 2014; Huskey & Howe, 2010). Countries have different definitions of what constitutes an urban area (Rasmussen, 2011), contributing to challenges of assessing these communities at a constant geographic scale. Perhaps the biggest challenge will be choosing a standard set of "consensus" indicators to universally assess all these unique cities (DeGroot, 2008). Cooperation with local stakeholders to assist in data collection and discussion of appropriate indicators will be vital to ensure the metrics remain accessible and useful to local actors.

Table 2. *Arctic Urban Sustainability Index Framework with five sustainability categories, related components, and related indicators to measure them*

ECONOMIC	Income	Employment Rate; Seasonality of Employment; Poverty Rate; Unemployment Rate; Median Family Income; Per Capita Income
	Remoteness/Transportation	Cost of round-trip air travel to major non-Arctic urban center; Months of River/Port navigability; Public Transit Ridership
	Public Finance	Total Local Budget Expenditure Per Capita; Annual Per Capita Expenditure of Regional/Federal Government to the City; Number of Banks / Credit Unions
	Energy	GhG Emissions; MW capacity of local grid; % of Energy Locally Generated; Renewable energy installed capacity; % Energy Generated from Renewables; Annual # poweroutages
	Housing	Habitable dwellings per capita; Local property values; Homelessness
	Food	Per capita harvest of local foods; Per capita local greenhouse area (or cultivated space); Child Obesity Rate
SOCIAL	Demographics and Migration	Median Age; Ethnic Makeup; Net migration (arrivals - departures)
	Education	Graduation Rates; Cost of post-secondary education; % adults with post-secondary education
	Health	Life expectancy; Death Rate; Infant Mortality Rate (IMR); Smoking Rate; Alcohol abuse rate; Suicide rate
	Well Being	Access to Internet; Crimes per Capita
	Social Inclusion	Gender Parity; Level of Mobility; Ethnic Segregation
ENVIRONMENTAL	Climatic Change	Temperature, Preciptation, Heating Degree Days, Snow Accumulation, Duration and Magnitude of Hot/Cold Waves, Air Quality
	Vegetation	Degree of Greeness; # of Wildfires
	Hydrological	Precipitation; Flood severity and frequency; Water potability
	Permafrost	Temperature; Active Layer Thickness; Ground Ice Content; Bearing Capacity
GOVERNANCE	Representation	% Voter Turnout; Civic organizations per capita; Representation in regional government, Youth engagement; Dependance on Military
	Fiscal Mangament	Local Revenue Raising Capacity; Local Control of Budget; Dependance on Single Industry; Inclusion of sustainability issues in budget
	Institutions	Number of Government Employees; Levels of Consesus; Stability of Institutions; Precense of Sustainability focused employees
	State-Society Relations	Discussion of Political Issues within community; local perception of government sustainability plans; political will to carry out sustainability programs
	Adaptability	Levels of adaptability among business, governmnt, society
PLANNING	Ability to Plan for Sustainability	Precense of sustainabiliy planning office; Precense of NGO or community organization in sustainability planning
	Community Input	Community input in planning; Cooperation with regional, national, or international planning organizations; Plans based off scientific and cultural assessments
	Implementation of Plans	Publication of sustainability planning report

The major focus of the Arctic PIRE project going forward is the identification or creation of metrics to quantify these indicators. Having such measurements is necessary to pinpoint areas for improvement, track changes, demonstrate advances, and examine opportunity costs of devoting resources to one area at the expense of another. In the Arctic and other places, the Index will provide a framework (Table 2) for measuring the contributions of the different actors – various levels of government, corporations, and civil society groups. These measures will work at various scales, from individual households to federal governments, and across mechanisms, from urban design to personnel decisions by private industry. Having such diverse measures will make it possible to identify best practices and transfer them to other cities. Preparing the Arctic Urban Sustainability Index will require more intensive research focused on three main tasks:

1. Defining metrics of sustainability in the Arctic;
2. Collecting data that are comparable across cities to measure progress along the indicators; and
3. Balancing the complexity of the index to provide accurate measurements with the need to present findings in a clear and concise manner so that policymakers can implement recommendations informed by the research.

The Index must communicate information effectively to policymakers. In recent years, there has been explosive growth in the number of indicators created within tools aimed at altering or supporting "the forms, the exercise, and perhaps even the distributions of power in certain spheres of global governance" (Davis et al., 2012: 4). When translating science to policy, researchers have found that "indicators of sustainability will only be effective if they support social learning by providing users with the information they need in a form they can understand and relate to" (Shields et al., 2002: 1). It has been found that indicator sets with broad political support, which actively involve those who will create policies and those who will be affected, improve the success of an index (Steward & Kuska, 2011). One scholar working on the development of indicators in the developing world argues for designing them "from the bottom up" since they will have greater legitimacy (Stone, 2012: 283). The integration of feedback and input on the design of the index and the validation would be a useful method in educating policymakers on the data and science, while ensuring that scientists are including factors relevant to policymakers and their constituents.

Preliminary Data Collection and Analysis

The index framework identifies 80 indicators that can be used to measure urban sustainability in the Arctic. These potential indicators were identified at the first meeting of the PIRE team in October 2016. As of June 2017, about 200 data points have been collected throughout the index; however, the diversity in sources and measurement standards means that these data are not easily comparable. The experience among Arctic researchers has shown that collating and collecting data regarding the region can be difficult (Forbes, 2011; Paul & Andreassen, 2009; Larsen et al., 2015), especially at the urban scale. Therefore, the identification of gaps within the easily accessible metrics alone would be a beneficial addition to the knowledge base of sustainability in Arctic urban centers. Our continued work to create a central repository of data on Arctic cities will benefit the public and cities themselves by increasing the visibility and accessibility of Arctic science. Analysis of these data could be used to identify best practice policies among localities within the circumpolar community. As a proof-of-concept, the research team identified 10 indicators that were measurable across 12 cities in the Arctic (Appendix B). Data were collected from the countries' national statistical databases and reports from NGOs, universities, and other research groups.

The 12 initial cities were selected based on their geographic distribution and the relatively "universal" availability of data within these cities and indicators. The indicators were selected from the social and economic categories because these measures were the most easily measurable, and were common in more established urban sustainability indexes (Tanguay et al 2009). The environmental, governance, and planning categories require further data collection and indicator development before they can be included. These 10 indicators within the economic and social spheres do not represent the most effective sustainability-specific indicators within the index framework, however the more complex indicators require more data collection, and potentially the production and administration of survey instruments and field-based data collection (Arctic PIRE Workshop 2017).

Table 3. A sample of Arctic Urban Sustainability Index including some identified data gaps

City Name	ECONOMIC			SOCIAL		
	Well Being	Remoteness/ Transportation	Energy	Demographics and Migration	Education	Leisure
	Per Capita Income	Cost of round-trip air travel to major urban center	Greenhouse gas emissions (tons per capita)	Median Age	Graduation rates	Access to internet
Yellowknife	$57,765.04	1.0387%	10.32	32.6	81%	90.90%
Whitehorse	$42,510.57	1.6466%	16.10	38.1	69%	78.00%
Nuuk	$39,568.97	2.5272%	11.15	33.8	48.30%	64.90%
Tromsø	$35,850.03	0.4184%	4.66	38.7	82%	77.50%
Salekhard	$41,541.71	0.9629%	0.05	N/A	N/A	70.00%
Norilsk	$36,459.09	1.3714%	18.23	N/A	N/A	67.30%
Arkhangelsk	$20,174.46	0.4957%	0.08	N/A	N/A	65.90%
Kiruna	$37,533.63	0.6661%	1.20	42.2	82%	93%
Boden	$37,802.69	0.2645%	1.20	43.9	82%	93%
Luleå	$37,264.57	0.2684%	50.70	41.8	82%	93%
Fairbanks	$33,553.00	0.8941%	38.60	27.2	93.10%	93.80%
Anchorage	$36,733.00	0.5445%	28.91	32.2	92.50%	94.70%
Mean	*$38,063.06*	*0.9249%*	*15.10*	*36.72*	*79.10%*	*81.83%*

Monetary Values in US Dollars, based on PPP adjusted Conversion Rates from OECD; Cost of Air Travel Calculated as % of per capita income.

Data Sources: Northwest Territory Bureau of Statistics, Yukon Bureau of Statistics, Statistics Canada, Statistics Greenland, StatBank Norway, Federal State Statistics Service Municipale Data Passport (Russia), Statistics Sweden, US Census Bureau, City of Fairbanks, University of Alaska, OECD, Knoema.

Even with this limited set of indicators, the research team faced significant challenges finding data, especially at the resolution adequate for urban scale analysis (Figure 3). Moreover, the normalization of data between countries proved to be difficult, with the indicators being measured differently among them. For example, in Russia, the greenhouse gas emissions report only listed pollution from stationary sources (Rosstat Municipal Data Passport, 2015), whereas in Fairbanks the University of Alaska had recently undertaken an extensive audit of all GHG emissions for the borough (Holdmann & Murphy, 2008). While some researchers have been able to quantify stationary versus non-stationary emission sources in Russian cities (Bityukova & Kasimov, 2012), these data were not easily accessible and indicate the need to engage more regional and topical experts in developing the database. These sorts of data issues resulted in the need to utilize data from the regional (or closest available) scale or to insert "Not Available" fillers where applicable (Figure 3).

Monetary values were normalized using year-appropriate OECD Purchasing Power Parity (PPP) conversion rates (OECD, 2017). Other values were normalized to a per-capita or percent measure wherever possible. Some indicators also required creative normalization techniques in order to account for differences between the research areas. The cost of air travel, for example, was calculated to the nearest major non-Arctic airport (usually national capitals), but then required normalization to account for the purchasing power of local residents. A measurement of the cost relative to the PPP normalized per-capita income was generated, which demonstrates the complexity and amount of consideration that is needed for creating every single metric.

Results and Challenges

The analysis ranked the 12 cities within each indicator and generated a ranking of performance across all 10 indicators (Figure 2). There are some general trends apparent, such as the strong performance of Swedish cities in these metrics. Another interesting finding is the vast difference between Salekhard and the other two Russian cities. The rankings are an example highlighting the tradeoffs of accessibility and accuracy (Tanguay et al., 2009), since they provide a broad overview and the trends are easily understandable. However, they do not show nuances in the data such as the distribution of scores, or city performance relative to peers and the circumpolar average.

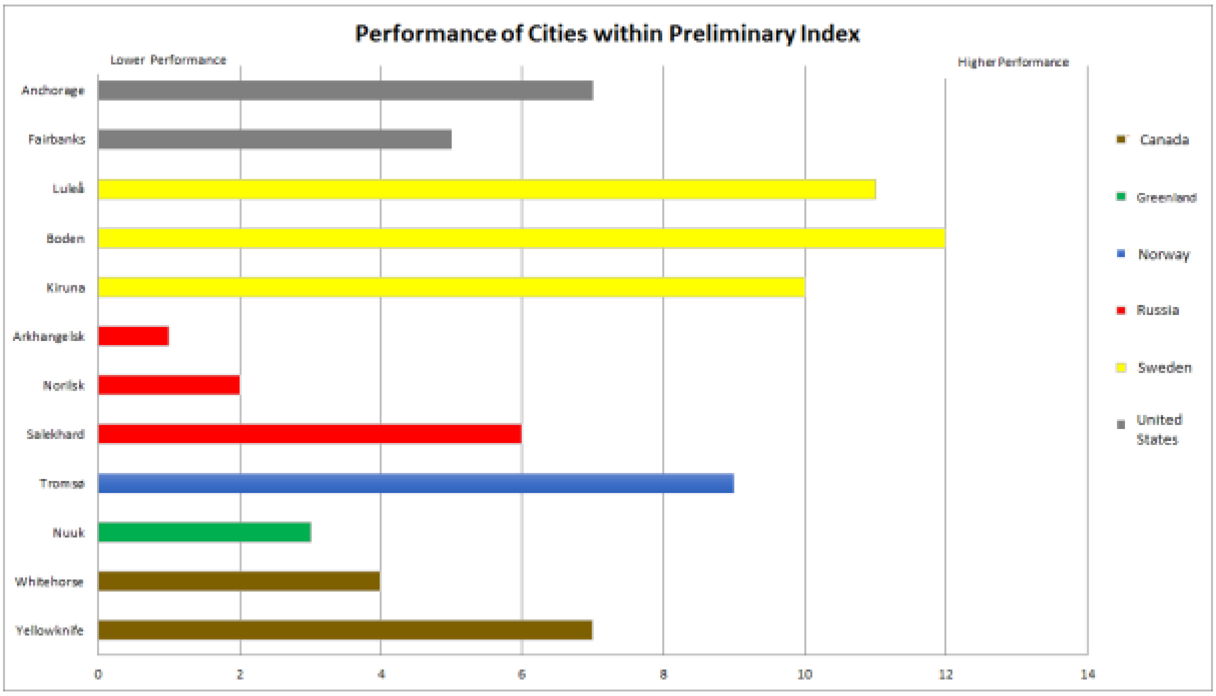
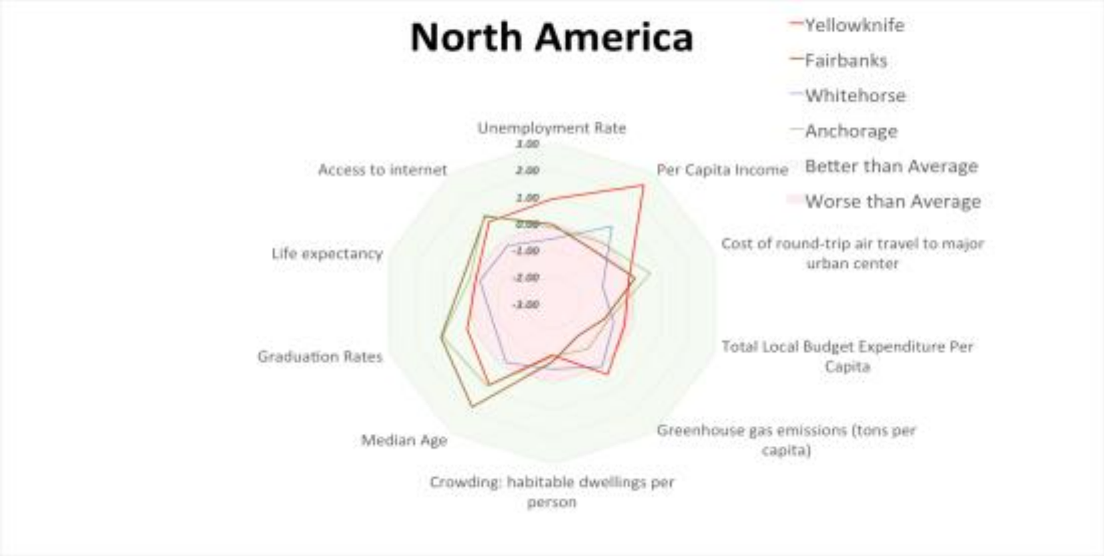
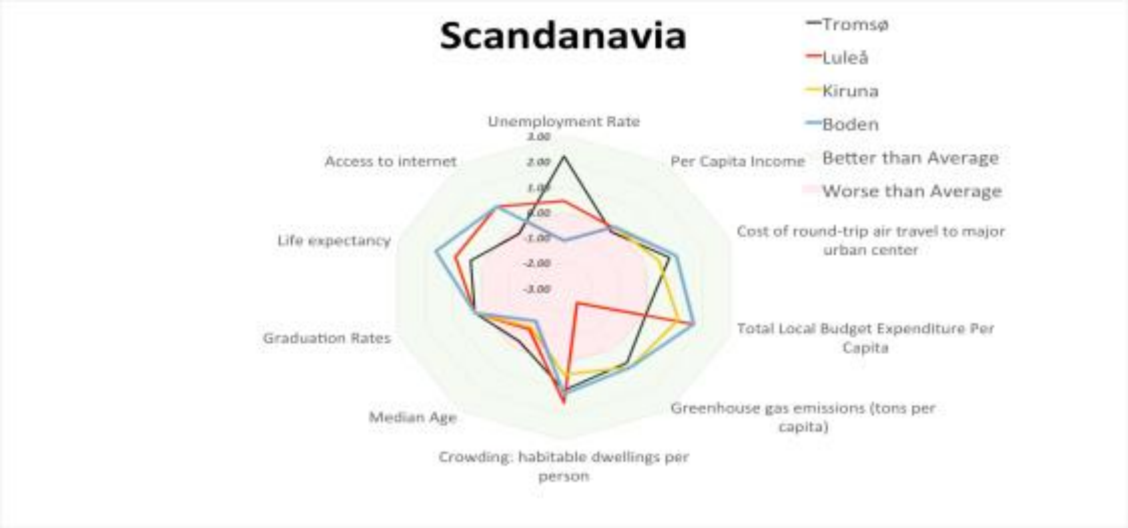


Figure 2: *Relative Ranking of 12 cities across 10 indicators in preliminary analysis*

The analysis also calculated the circumpolar mean within each indicator and calculated each city's distance from that mean in standard deviations. The visualization of these standard-deviation scores facilitates comparison among cities, while also allowing individual cities to assess how they are performing compared to the circumpolar average (Figure 3). This analysis is preliminary and inherits underlying issues in data quality and normalization; these issues will be addressed by the project in the years going forward.


North America
Yellowknife
Fairbanks
Whitehorse
Anchorage
Better than Average
Worse than Average
Unemployment Rate
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
Per Capita Income
Cost of round-trip air travel to major urban center
Total Local Budget Expenditure Per Capita
Greenhouse gas emissions (tons per capita)
Crowding: habitable dwellings per person
Median Age
Graduation Rates
Life expectancy
Access to internet


Scandanavia
Tromsø
Luleå
Kiruna
Boden
Better than Average
Worse than Average
Unemployment Rate
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
Per Capita Income
Cost of round-trip air travel to major urban center
Total Local Budget Expenditure Per Capita
Greenhouse gas emissions (tons per capita)
Crowding: habitable dwellings per person
Median Age
Graduation Rates
Life expectancy
Access to internet

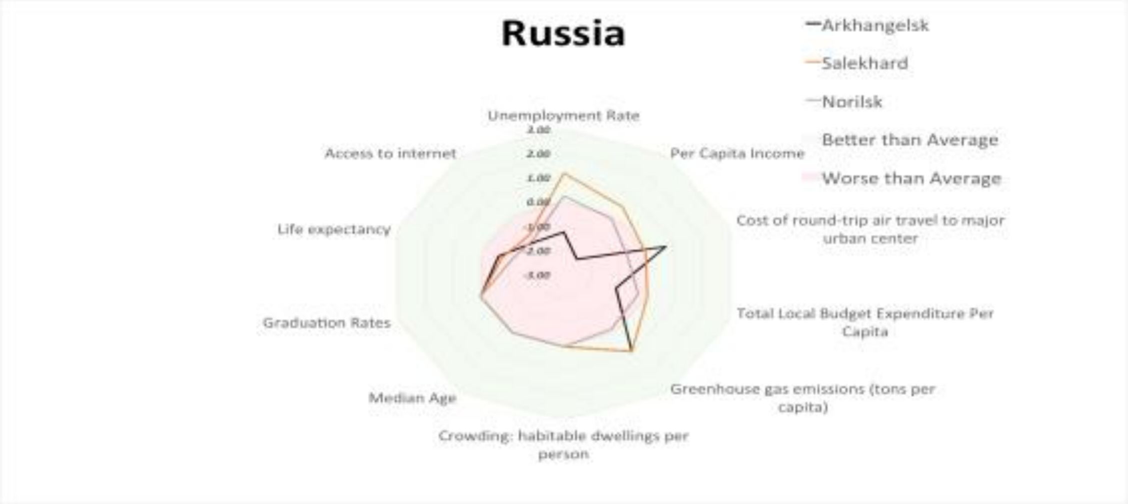

Russia
Arkhangelsk
Salekhard
Norilsk
Better than Average
Worse than Average
Unemployment Rate
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
Per Capita Income
Cost of round-trip air travel to major urban center
Total Local Budget Expenditure Per Capita
Greenhouse gas emissions (tons per capita)
Crowding: habitable dwellings per person
Median Age
Graduation Rates
Life expectancy
Access to internet

***Figure 3**. Spider diagrams for the selected Arctic cities showing relative performance of cities across several sustainability indicators. Each indicator is estimated in standard deviations relative to the circumpolar average. The below average values are outlined in the light-red circle and the above average values are located within the green circle.*

The analysis of the standard scores of cities in Figure 3 displays their performance within each of the indicator categories, relative to the circumpolar mean. These diagrams make it easy to see how cities are performing compared to the circumpolar average and to each other. It is easy to see Yellowknife has very high per-capita income than compared to the circumpolar average, but has below average local budget expenditure. In Russia, it is easy to see that Arkhangelsk is underperforming the other cities in terms of their unemployment rate. Over time, as cities implement policies to improve their performance within indicators, their 'score-lines' would move towards the outer edge of the spider-plots, representing improved performance. Moreover, if cities improve performance within one indicator at the expense of another – for example, lower unemployment at the expense of increased greenhouse gas emissions – their 'score-lines' would shift. This visualization aims to clearly show the complex interactions between different components of sustainability and how sustainability policies can have varying effects on these components.

The preliminary results were based off data from a limited selection of 12 cities, and are not informed by an analysis of all the Arctic cities which will be included within the full scope of this project (Appendix A). Thus, these rankings and patterns must be interpreted as truly preliminary, and not yet significant or appropriate for policy direction. Instead, these results grant an opportunity to present the ongoing work of this project and familiarize a broader community with the end goals and framework of the Arctic PIRE project. The results provided an opportunity to validate framework design and data presentation concepts, while a discussion of the research process encouraged engagement with the wider Arctic science and policy community. These opportunities to incorporate feedback from regional and topical experts are vital to improving the research and success of such a trans-disciplinary project.

Moving Forward

During the first Arctic PIRE conference held in October 2016, the team identified 80 indicators to be measured across the 50 cities identified. These 4,000 data points represent a massive research undertaking because of the variability in data accessibility and availability at the adequate geographical and temporal scale. Leading up to the annual Arctic PIRE conference in November 2017, the teams will be identifying one or two "core indicators" within each component of sustainability. While selecting these indicators, the Arctic PIRE teams will be working in consultation with topical and regional experts, as well as encouraging feedback from international research organizations, regional and national governments, and the Arctic communities. These interactions are vital for creating a product that is transformable and could be used to inform actionable policy (Rowe, 2013; Shields et al., 2008; Tanguay et al., 2009). By including more relevant local actors in the research process, through cooperative data collection efforts, the organization of workshops, and the promotion of science-policy interactions, all involved parties will be better informed on how and why these indicators were selected, and how they were measured.

Some data, especially those of a more qualitative nature, are simply not available on the city-scale within the circumpolar region. For the purpose of quantifying this data, the Arctic PIRE team is planning to construct a survey that can be administered across the circumpolar region. For such a survey to be successful and economical, it is critically important to establish strong relationships with city officials across the region of study to ensure proper access to subjects and to ensure the work is undertaken with the correct permissions and authorizations. Research on Arctic urban sustainability can be coordinated with other efforts on sustainability issues at different levels of government in the Arctic.

The presentation of these initial results has already generated significant interest and interaction with the project, supporting the initial hypothesis that the research process, not only the final product, will generate significant progress in promoting urban sustainability in the Arctic. The ongoing incorporation of feedback from academic peers and policymakers is important for developing a "living framework," which remains open to change and adaptation as new insights and data become available. The various side-projects the Arctic PIRE team is undertaking are aimed at further encouraging greater collaboration among all Arctic urban stakeholders, and engaging them in advancing the research. These affiliated projects include data collection initiatives in cooperation with local Arctic universities, geographic information system (GIS) models to analyze the dynamics between climate change and urban infrastructure, and remote-sensing projects to track urban growth patterns.

Just as important are efforts to engage a new generation of Arctic researchers through an exciting educational outreach project entitled #60Above60, and through yearly university level field courses which will bring together students from across the Arctic countries to experience and learn about the issues and challenges facing Arctic urban centers first-hand (Figure 4). While much work remains on improving the Arctic Urban Sustainability Index and the database that supports it, the enthusiastic engagement generated so far is indicative of great possibilities.

Figure 4. *American, Russian, German, Swiss, Dutch, and Spanish university students pose during an annual Arctic field-course on permafrost and sustainability in northern regions, led by The George Washington University in partnership with Moscow State University.*

Photo Credit: Anna Summi

Acknowledgments

Funding for this project came from the National Science Foundation's Arctic PIRE (Award # 1545913).

We would like to acknowledge all of the Arctic PIRE research institutions and team members, as well as our local community partners, who have been invaluable in continuously strengthening and driving this project forward.

References

AMAP. (2017). Snow, Water, Ice and Permafrost. Summary for Policymakers. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Anisimov, O. A., Belolutskaya, M. A., Grigoriev, M. N., Instanes, A., Kokorev, V. A., Oberman, N. G., Shiklomanov, N. I. (2010). Major Natural and Social-Economic Consequences of Climate Change in the Permafrost Region: Predictions based on Observations and Modeling. Moscow: Greenpeace.

Arctic Council. (2009). Arctic Marine Shipping Assessment 2009.

Arctic PIRE Workshop. (2017). Conference Proceedings. Anchorage, AK: May 14-17, 2017.

Bityukova, V. R., & Kasimov, N. S. (2012). Atmospheric pollution of Russia's cities: assessment of emissions and immissions based on statistical data. *Geofizika*, *29*(1), 53-67.

Batty, M., Ferguson P. (2011). "Defining City Size." *Environment and Planning B: Planning and Design*

38(5). SAGE PublicationsSage UK: London, England: 753-56.

Brunn, S. D., Williams, J., & Zeigler, D. J. (2003). *Cities of the world: world regional urban development*. Rowman & Littlefield.

Bureau of the Census. (2010). "Proposed Urban Area Criteria for the 2010 Census." Federal Register Vol. 75, No. 163. US Department of Commerce.

Caradonna, J. L. (2014). *Sustainability: A History*. New York: Oxford University Press.

Cooke, N. J., & Hilton, M. L. (Eds.). (2015). Enhancing the Effectiveness of Team Science. Washington: National Academies Press.

Davis, K. E., Kingsbury, B., & Merry, S. E. (2012). Introduction: Global Governance by Indicators. In K. E. Davis, A. Fisher, B. Kingsbury, & S. E. Merry (Eds.), *Governance by Indicators: Global Power through Quantification and Rankings*. Oxford: Oxford University Press.

Day, J., & Ellis, P. (2013). Urbanization for everyone: Benefits of urbanization in Indonesia's rural regions. *Journal of Urban Planning and Development*, *140*(3), 04014006.

Dybbroe, S., Dahl, J., & Müller-Wille, L. (2010). Dynamics of Arctic urbanization. *Acta Borealia*, *27*(2), 120-124.

Dybbroe, S. (2008). Is the Arctic really urbanising? *Études/Inuit/Studies*. 32(1): p. 13-32.

Exner-Pirot, H. (2013). What is the Arctic a case of? The Arctic as a regional environmental security complex and the implications for policy. *The Polar Journal*, 3(1), 120-135.

Forbes, D. L. (2011). *State of the Arctic coast 2010: scientific review and outlook*. Land-Ocean Interactions in the Coastal Zone, Institute of Coastal Research.

Frey, William H, and Zachary Zimmer. (1974). "Defining the City." In *Handbook of Urban Studies*, edited by Ronan Paddison, 14-35. London: SAGE Publications.

Gaylord, A. (2009). Map: *Arctic Boundary as defined by the Arctic Research and Policy Act (ARPA)*. Nuna Technologies. Retrieved from, https://www.arctic.gov/maps.html.

Gautier, D. L., Bird, K. J., Charpentier, R. R., Grantz, A., Houseknecht, D. W., Klett, T. R., ... & Sørensen, K. (2009). Assessment of undiscovered oil and gas in the Arctic. *Science*, 324(5931), 1175-1179.

Grebenets, V., Streletskiy, D., & Shiklomanov, N. (2012). Geotechnical Safety Issues in the Cities of Polar Regions. Geography, Environment, Sustainability Journal, 5(3), 104-119.

Heidbach, U., S. Bowden, and Rachold V. (2013). International Arctic Science Committee Bulletin 2013. Potsdam: International Arctic Science Committee.

Heininen, L., & Nicol, H. N. (2007). The importance of northern dimension foreign policies in the geopolitics of the circumpolar north. *Geopolitics*, 12(1), 133-165.

Heleniak, T. (2010) Population Change in the Periphery: Changing Migration Patterns in the Russian North. *Sibirica*, 2010. 9(3): p. 9-40.

Heleniak, T. (2013). Boom and Bust: Population Change in Russia's Arctic Cities. *Arctic, 2*.

Heleniak, T. (2013). Population, Health, and Migration, in *Understanding Contemporary Russia*, 2nd edition, M. Bressler, Editor. Boulder: Lynne Rienner Publishers.

Holdmann, G., & Murphy, J. (2008). Fairbanks North Star Borough baseline greenhouse gas emission inventory: base year 2007. *Alaska Center for Energy and Power, University of Alaska Fairbanks*.

Howe, E. L. (2009). Patterns of migration in Arctic Alaska. *Polar Geography*, 32(1-2), 69-89.

Husbekk, A. R., Andersson, M., Penttilä, R. E. (2015). Growth from the North. How can Norway, Sweden and Finland achieve sustainable growth in the Scandinavian Arctic? *Prime Minister's Office Publications 04/2015.* Helsinki, Finland.

Huskey, L. and L. Howe. (2010). "The Complex Geography of Alaska Native Migration in the Arctic." in *Migration in the Circumpolar North: Lessons Learned, Questions Remaining*, C. Southcott and L. Huskey, Editors. Canadian Circumpolar Institute Press: Alberta.

Jakobsson, M., Ingólfsson, Ó., Long, A. J., & Spielhagen, R. F. (2014). The dynamic Arctic. *Quaternary Science Reviews*, 92, 1-8.

Johannessen, O. M., Bengtsson, L., Miles, M. W., Kuzmina, S. I., Semenov, V. A., Alekseev, G. V., ... & Hasselmann, K. (2004). Arctic climate change: Observed and modelled temperature and sea-ice variability. *Tellus A*, 56(4), 328-341.

Larsen, J. N., Schweitzer, P., & Petrov, A. (Eds.). (2015). *Arctic Social Indicators: ASI II: Implementation*. Nordic Council of Ministers.

Laruelle, M. (2014). Resource, state reassertion and international recognition: locating the drivers of Russia's Arctic policy. *The Polar Journal*, 4(2), 253-270.

Li, X., Li, X., Woetzel, J., Zhang, G., & Zhang, Y. (2014). The China Urban Sustainability Index 2013: McKinsey Global Institute and the Urban China Initiative.

Lonergan, S., Difrancesco, R., & Woo, M. K. (1993). Climate change and transportation in Northern Canada: an integrated impact assessment. *Climatic Change*, 24, 331-351.

Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice.* Princeton: Princeton University Press.

McCool, S. F., & Stankey, G. H. (2004). Indicators of sustainability: challenges and opportunities at the interface of science and policy. *Environmental management*, 33(3), 294-305.

McKinney, M. L. (2008). Effects of urbanization on species richness: a review of plants and animals. *Urban ecosystems*, *11*(2), 161-176.

Mumford, Lewis. (1937). "What Is a City?" *Architectural Record.*

Niemeijer, D., & de Groot, R. S. (2008). A Conceptual Framework for Selecting Environmental Indicator Sets. Ecological Indicators, 8(1), 14-25.

OECD. (2017). "Prices and purchasing power parities (PPP)." Retrieved from: http://www.oecd.org/std/prices-ppp/

Paul, F., & Andreassen, L. M. (2009). A new glacier inventory for the Svartisen region, Norway, from Landsat ETM+ data: challenges and change assessment. *Journal of Glaciology*, *55*(192), 607-618.

Petrov, A. N., BurnSilver, S., Chapin III, F. S., Fondahl, G., Graybill, J. K., Keil, K., Nilsson, A. E., Riedlsperger, R., and Schweitzer, P. (2017). *Arctic Sustainability Research: Past, Present and Future*. London: Routledge.

Portney, K. E. (2013). *Taking Sustainable Cities Seriously: Economic Development, the Environment, and Quality of Life in American Cities*. Cambridge: The MIT Press.

Rasmussen, R.O. (2011). Megatrends. Copenhagen: *Danish Ministry of Foreign Affairs in collaboration with the Nordic Council of Ministers.*

Rosenberg, P., Kano, M., Ludford, I., Prasad, A., & Thomson, H. (2016). *Global report on urban health: Equitable, healthier cities for sustainable development*. World Health Organization.

Rowe, E. W. (2013). *Russian climate politics: When science meets policy.* New York: Springer.

Schaffer, D., & Vollmer, D. (2010). *Pathways to Urban Sustainability: Research and Development on Urban Systems*. Washington: The National Academies Press.

Schaffner, C., Suter, L., Giddings, C. (2017). "Arctic PIRE: Promoting Urban Sustainability in the Arctic." Presented at AMAP 2017: Reston, VA.

Science for Environment Policy. (2015). Indicators for sustainable cities. In-depth Report 12. Produced for the European Commission DG Environment by the Science Communication Unit, UWE, Bristol.

Shields, D. J., Šolar, S. V., & Martin, W. E. (2002). The Role of Values and Objectives in Communicating Indicators of Sustainability. *Ecological Indicators*, 2(1), 149-160.

Shiklomanov, N. I., Streletskiy, D. A., Nelson, F. E., Hollister, R. D., Romanovsky, V. E., Tweedie, C. E., ... & Brown, J. (2010). Decadal variations of active-layer thickness in moisture-controlled landscapes, Barrow, Alaska. *Journal of Geophysical Research: Biogeosciences*, *115*(G4).

Shiklomanov, N. I., Streletskiy, D. A., Swales, T. B., & Kokorev, V. A. (2017). Climate Change and Stability of Urban Infrastructure in Russian Permafrost Regions: Prognostic Assessment based on GCM Climate Projections. *Geographical Review*, 107(1), 125-142.

Smith, L. T. (2013). *Decolonizing methodologies: Research and indigenous peoples*. Zed Books Ltd.

Snyder, J., & Cooley, A. (2015). Conclusion: Rating the Ratings Craze: From Consumer Choice to Public Policy Outcomes. In A. Cooley & J. Snyder (Eds.), *Ranking the World: Grading States as a Tool of Global Governance* (pp. 178-193). New York: Cambridge University Press.

Steward, W. C., & Kuska, S. B. (2011). Sustainometrics: Measuring Sustainability. Norcross, GA: Ostberg Library of Design Management.

Stewart, J. Q. (1947). Suggested Principles of "Social Physics." *Science* (New York, NY), 106(2748), 179-180.

Stone, C. (2012). Problems of Power in the Design of Indicators of Safety and Justice in the Global South. In K. E. Davis, A. Fisher, B. Kingsbury, & S. E. Merry (Eds.), *Governance by Indicators: Global Power through Quantification and Rankings*. Oxford: Oxford University Press.

Streletskiy, D. A., Shiklomanov, N. I., & Nelson, F. E. (2012). Permafrost, Infrastructure and Climate Change: A GIS-based Landscape Approach. *Arctic, Antarctic and Alpine Research*, 44(3), 368-380.

Streletskiy, D.A., Shiklomanov, N.I. (2016). Arctic Cities through the Prism of Permafrost. In Orttung R. (Ed.). *Sustaining Russia's Arctic Cities: Resource Politics, Migration, and Climate Change*. Berghahn Press, 201-220.

Streletskiy, D. A. (2017). "Towards an Arctic Urban Sustainability Index." Presented at Arctic Science Summit Week 2017: Prague, CZ.

Suter, L. (2017). "Towards an Arctic Urban Sustainability Index." Presented at AAG 2017: Boston, MA.

Tanguay, G. A., Rajaonson, J., Lefebvre, J.-F., & Lanoie, P. (2009). Measuring the Sustainability of Cities: A Survey-Based Analysis of the Use of Local Indicators. Montreal: Cirano.

Todorov, V., & Marinova, D. (2009). Sustainometrics: measuring sustainability. In *MODSIM 2009 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand, Cairns, Australia* (pp. 1223-1229).

Underdal, A. (2013). Meeting common environmental challenges: the co-evolution of policies and practices. *International Environmental Agreements: Politics, Law and Economics*, *13*(1), 15-30.

United Nations Commission on Sustainable Development (UN CSD). (2007). Indicators of Sustainable Development: Guidelines and Methodologies, Third Edition. New York: United Nations.

United Nations Demographic Yearbook. (2015). *Table 6 Notes: Total and urban population by sex: 2006-2015*. New York: United Nations.

United Nations Sustainable Development Goals. (2015). Retrieved from, https://unstats.un.org/sdgs/indicators/indicators-list/.

Weigold, M. F. (2001). Communicating science: A review of the literature. *Science communication*, *23*(2), 164-193.

William H. Frey & Zachary Zimmer. Defining the City. In R. Paddison (Ed.). *Handbook of Urban Studies* (pp.14-25). London: Sage. Retrieved from, http://www.frey-demographer.org/reports/R-2001-1_DefiningCity.pdf

World Commission on Environment and Development. (1987). Our Common Future (Brundtland Report). http://www.un-documents.net/our-common-future.pdf

World Council on City Data (WCCD). (2014). Retrieved from: http://www.dataforcities.org/wccd/

Wu, J., Tu, J., Yan, X., & Zhou, Y. (2011). Study on the Coupling Mechanism between Urban Land Use Benefits and Urbanization in China [J]. *Urban Studies*, 8, 010.

Young, O. R. (2009). The Arctic in play: Governance in a time of rapid change. *The International Journal of Marine and Coastal Law*, 24(2), 423-442.

NAME	COUNTRY	Population	COMMENT
Akureyri	Iceland	18,342	
Ålesund	Norway	47,336	
Alta	Norway	20,521	
Anadyr*	Russia	8,288	Deemed Significant by Expert Opinion (Low Population)
Anchorage	United States	298,192	
Apatity	Russia	56,732	
Archangelsk	Russia	351,488	
Boden	Sweden	28,024	
Bodø	Norway	51,110	
Dudinka	Russia	21,513	
Fairbanks	United States	32,751	
Fort St. John	Canada	20,155	
Harstad	Norway	24,853	
Juneau	United States	32,468	
Kandalaksha	Russia	32,034	
Kirovsk	Russia	28,863	
Kiruna	Sweden	23,167	
Labytnangi	Russia	26,500	
Luleå	Sweden	76,770	
Magadan*	Russia	98,930	Deemed Significant by Expert Opinion (Outside Regional Border)
Mo i Rana	Norway	26,186	
Molde	Norway	20,892	
Monchegorsk	Russia	46,205	
Murmansk	Russia	298,096	
Nadym	Russia	44,660	
Nakhodka	Russia	152,294	
Narvik	Norway	18,721	
Naryan Mar	Russia	24,654	
Nikel	Russia	12,055	
Norilsk	Russia	178,654	
Novy Urengoy	Russia	113,254	
Noyabrsk	Russia	106,879	
Nuuk	Greenland	17,036	
Onega	Russia	26,070	
Oulu*	Finland	200,637	Deemed Significant by Expert Opinion (Outside Regional Border)
Polyarny	Russia	16,956	
Reykjavík	Iceland	212,385	
Rovaniemi	Finland	62,234	
Salekhard	Russia	48,794	
Severodvinsk	Russia	185,042	
Severomorsk	Russia	50,905	
Skellefteå	Sweden	72,266	
Tórshavn	Faroe Islands	12,713	
Tromsø	Norway	34,283	
Umeå	Sweden	122,892	
Vorkuta	Russia	80,061	
Whitehorse	Canada	28,225	
Yakutsk*	Russia	307,911	Deemed Significant by Expert Opinion (Outside Regional Border)
Yamburg	Russia	47,711	
Yellowknife	Canada	19,569	

Appendix B

City Name	ECONOMIC						SOCIAL			
	Well Being		Remoteness/ Transportation	Public Finance	Energy	Housing	Demographics and Migration	Education	Health	Leisure
	Unemployment Rate	Per Capita Income	Cost of round-trip air travel to major urban center	Total Local Budget Expenditure Per Capita	Greenhouse gas emissions (tons per capita)	Habitable Dwellings per Capita	Median Age	Graduation rates	Life expectancy	Access to internet
Yellowknife	4.00%	$57,765.04	1.0387%	$3,925.76	10.32	0.365	32.6	81%	77.9	90.90%
Whitehorse	6.20%	$42,510.57	1.6466%	$2,447.71	16.10	0.456956522	38.1	69%	77.4	78.00%
Nuuk	6.09%	$39,568.97	2.5272%	N/A	11.15	0.392305822	33.8	48.30%	72.4	64.90%
Tromsø	2.10%	$35,850.03	0.4184%	$5,144.82	4.66	0.739959549	38.7	82%	79.8	77.50%
Salekhard	3.60%	$41,541.71	0.9629%	$5,223.71	0.05	N/A	N/A	N/A	75.9	70.00%
Norilsk	5.00%	$36,459.09	1.3714%	$3,953.66	18.23	N/A	N/A	N/A	74.8	67.30%
Arkhangelsk	7.20%	$20,174.46	0.4957%	$945.59	0.08	N/A	N/A	N/A	76.3	65.90%
Kiruna	7.00%	$37,533.63	0.6661%	$9,411.79	1.20	0.629668393	42.2	82%	83.92	93%
Boden	7.00%	$37,802.69	0.2645%	$11,535.46	1.20	0.767558887	43.9	82%	83.92	93%
Luleå	4.70%	$37,264.57	0.2684%	$11,548.68	50.70	0.828205072	41.8	82%	81.56	93%
Fairbanks	5.40%	$33,553.00	0.8941%	$1,067.60	38.60	0.410501978	27.2	93.10%	79.4	93.80%
Anchorage	5.60%	$36,733.00	0.5445%	$1,574.75	28.91	0.374751669	32.2	92.50%	78.64	94.70%
Mean	*5.32%*	*$38,063.06*	*0.9249%*	*$5,162*	*15.10*	*0.552*	*36.72*	*79.10%*	*78.50*	*81.83%*

Data Sources: Northwest Territory Bureau of Statistics, Yukon Bureau of Statistics, Statistics Canada, Census Canada, Statistics Greenland, StatBank Norway, Federal State Statistics Service Municipal Data Passport (Russia), Statistics Sweden, US Census Bureau, City of Fairbanks, University of Alaska, OECD, Knoema