Urban planning sustainability metrics for Arctic cities

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Keywords: Arctic, comparative analysis, GIS, ISO, remote sensing, urban planning, urban sustainable development

Abstract
Changing conditions in the Arctic are prompting increased interest in measuring the performance of Arctic cities to assess challenges of urban sustainability and inform policy makers. This paper presents methods, analysis, and preliminary results from a cross-comparative study of urban planning sustainability indicators using metrics defined by the International Organization for Standardization’s ISO 37120 Sustainable Cities and Communities for 46 Arctic and near-Arctic cities. The framework for evaluating urban planning indicators described in this paper establishes a multi-method approach that defines the area of the city using local statistical units and utilizes a combination of remote sensing, geospatial analysis, and statistical data collection to calculate sustainability metrics. The results of this paper reveal several city- and regional-level characteristics of the Arctic cities in this study in terms of livability, efficiency, socio-economics and sustainability.

1. Introduction
Numerically based indicators are increasingly being developed to provide policy makers and others useful metrics from which to evaluate and communicate environmental conditions across disciplines and with non-experts, and this is particularly germane to the effects of climate change on cities. Such metrics are also being standardized and aggregated to provide a much larger method for evaluating sustainability within cities and across regions (Shen et al. 2011). Although a wide range of indicators have been developed (Davidson 1996, Briassoulis 2001, Petrov et al. 2016), increasingly the International Organization for Standardization’s ISO 37120 Sustainable Cities and Communities: Indicators for City Services and Quality of Life are being adopted by U.S. federal funding agencies, such as the National Science Foundation (NSF), to coordinate sustainability studies from different researchers.

As one of the first standardized indicators set that allows city leaders to measure their performance and progress in city development and compare it with other cities (McCarney 2015), ISO 37120 provides a city-focused framework for sustainability assessment that is comprehensive in terms of topic areas covered—of which generally apply to northern cities in the same way as cities in other regions of the world (Berman and Orttung 2020). As part of a multi-year study on urban sustainability (NSF PIRE #1545913) in 46 Arctic and near-Arctic cities (table 1), this paper evaluates sustainability metrics for the set of ISO 37120 Urban Planning indicators; these include: green area, number of trees, population density, built-up density, jobs-housing ratio, basic service proximity, and areal size of informal settlements (table 2). Although only one of these indicators—‘green area’—is specified in ISO 37120 as a required core indicator (the others being recommended), all seven were employed for the cities in this study in order to understand how they can be evaluated and applied in-practice across a diverse set of Arctic cities.

The wide range of topics under ISO 37120, which includes 128 indicators across 19 themes, call for many different types of data, ranging from socioeconomic statistical data, detailed cadastral surveys and data on the built environment, and large-area land-use and environmental information. One of the challenges this presents is the frequent lack of available data, its 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). For example, developing a
Table 1. Overview of the Arctic and near-Arctic cities studied.

| Region       | Country                  | No. | City          | Latitude | Population | City area (sq. km) |
|--------------|--------------------------|-----|---------------|----------|------------|-------------------|
| North America| United States            | 1   | Anchorage     | 61.21753 | 245,407    | 257.08            |
|              |                          | 2   | Fairbanks     | 64.84525 | 31,535     | 82.08             |
|              |                          | 3   | Juneau        | 58.29973 | 29,435     | 61.94             |
|              | Canada                   | 4   | Fort St. John | 56.25254 | 20,155     | 23.11             |
|              |                          | 5   | Whitehorse    | 60.72085 | 21,732     | 38.19             |
|              |                          | 6   | Yellowknife   | 62.45447 | 18,435     | 12.46             |
| Europe       | Denmark                  | 7   | Tórshavn     | 62.00973 | 13,116     | 7.84              |
|              | Finland                  | 8   | Oulu         | 65.01035 | 152,489    | 189.11            |
|              |                          | 9   | Rovaniemi     | 66.50392 | 52,426     | 73.68             |
|              | Greenland                | 10  | Nuuk         | 64.18347 | 17,984     | 30.36             |
|              | Iceland                  | 11  | Akureyri      | 65.65999 | 18,787     | 31.08             |
|              |                          | 12  | Reykjavik     | 64.13548 | 126,864    | 95.29             |
|              |                          | 13  | Ælvsund       | 62.47151 | 13,135     | 6.13              |
|              |                          | 14  | Alta          | 69.96841 | 15,856     | 47.57             |
|              |                          | 15  | Bodo          | 67.28598 | 43,056     | 70.03             |
|              |                          | 16  | Harstad       | 68.79731 | 21,040     | 62.22             |
|              | Norway                   | 17  | Mo i Rana     | 66.31059 | 19,210     | 97.73             |
|              |                          | 18  | Molde         | 62.73972 | 21,528     | 69.84             |
|              |                          | 19  | Narvik        | 68.43949 | 15,108     | 39.69             |
|              |                          | 20  | Tromsø        | 69.65102 | 38,459     | 22.92             |
|              |                          | 21  | Bodø          | 65.82489 | 16,992     | 31.07             |
|              |                          | 22  | Kiruna        | 67.85552 | 17,988     | 23.67             |
|              | Sweden                   | 23  | Luleå         | 65.58387 | 44,564     | 42.87             |
|              |                          | 24  | Skellefteå    | 64.74945 | 36,316     | 55.09             |
|              |                          | 25  | Umeå          | 63.82529 | 88,961     | 77.62             |
|              |                          | 26  | Anadyr        | 64.73588 | 15,468     | 19.59             |
|              |                          | 27  | Apatity       | 67.58260 | 56,358     | 32.07             |
|              |                          | 28  | Archangelsk   | 64.53843 | 358,594    | 257.42            |
|              |                          | 29  | Dudinka       | 69.40963 | 23,086     | 13.95             |
|              |                          | 30  | Kandalaksha   | 67.15225 | 34,120     | 21.13             |
|              |                          | 31  | Kirovsk       | 67.61580 | 28,863     | 21.23             |
|              |                          | 32  | Labytnangi    | 66.66455 | 26,281     | 33.89             |
|              |                          | 33  | Magadan       | 59.56522 | 99,626     | 299.31            |
|              |                          | 34  | Monchegorsk   | 67.93802 | 45,955     | 31.78             |
|              |                          | 35  | Murmansk      | 68.97237 | 298,096    | 146.92            |
|              | Russia                   | 36  | Nadymsky      | 65.53309 | 68,327     | 16.31             |
|              |                          | 37  | Naryan Mar    | 67.63780 | 24,654     | 37.65             |
|              |                          | 38  | Nikol         | 69.40753 | 12,055     | 3.86              |
|              |                          | 39  | Norilsk       | 69.34575 | 178,654    | 18.73             |
|              |                          | 40  | Novy Urengoy  | 66.08717 | 113,254    | 237.76            |
|              |                          | 41  | Noyabrsk      | 63.19791 | 106,879    | 154.96            |
|              |                          | 42  | Onega         | 63.90607 | 19,206     | 72.30             |
|              |                          | 43  | Salekhard     | 66.53049 | 48,794     | 63.35             |
|              |                          | 44  | Severodvinsk  | 64.56191 | 185,042    | 80.50             |
|              |                          | 45  | Vorkuta       | 67.50474 | 80,061     | 80.50             |
|              |                          | 46  | Yakutsk       | 61.97651 | 324,651    | 126.65            |

A consistent framework for evaluation of data among different cities is challenged by a lack of consistent basic definitions, such as city and municipal boundaries or local statistical units (United Nations Statistics Division (UN Stats) 2020). Because of these challenges for obtaining accurate and consistent data between indicators for each city, we developed holistic and integrated approach; this included the use of multiple data sources from local, municipal, and regional-level agencies which provided various city-planning maps and documents, statistical information, and vector geospatial data, in combination with open geodata sources, such as OpenStreetMap (OSM). Gaps in the available data and frequent inconsistencies in definitions and classifications of data gathered from different sources, such as the administrative boundary of a city, required the use of an additional set of analysis techniques that included the use of remote sensing (RS) and Normalized Difference Vegetation Index (NDVI) image analysis, geographic information system (GIS) techniques, and empirical approximations. In this paper we present methods, techniques, and preliminary results from a comprehensive evaluation of ISO 37120 Urban Planning indicators for Arctic cities, providing a case study and reference for the future use and implementation...
of ISO 37120 for determining urban planning sustainability metrics.

2. Defining city boundaries

Across large geographic and geopolitical regions, such as in this study, definitions of a city can vary greatly, impacting the ability to meaningfully compare data and sustainability indicators between cities. In most countries, cities are defined using criteria such as population, population density, economic function, or urban built-up area, and are usually subordinate to an administrative and jurisdictional subdivision. However, the definitions of the administrative units identifying legal boundaries for cities in this study vary significantly across countries. Although ISO 37120 defines cities as ‘urban communities falling under a specific administrative boundary,’ in practice, the urban built-up area of a city often has little relationship to the lowest-level administrative boundary although, in some cases, the two may coincide (figure 1). Large rural and non-urban built-up areas can be included within this territory, often designated as a municipality, in addition to multiple population centers outside the central city (e.g. Angel et al. 2005, Bhatta 2010, United Nations Statistics Division (UN Stats) 2017).

For example, in the United States, the municipality of Anchorage covers a total land area of 4415 sq. km and includes other population centers. However, with a population of 245 407, the urban built-up area of Anchorage comprises only 257 sq. km. In Norway, the town of Mo i Rana, which has a population 19 210 and occupies only 12 sq. km., serves as the administrative center for the much larger municipality (and lowest-level administrative unit) of Rana, which covers 4588 sq. km and includes 15 other population centers. For larger, continuous metropolitan areas, such as Oulu (FI), Archangelsk (RU), and Reykjavik (IS), the urban-built up area of the city is much larger than the administrative boundary. In Russia, the relationship between the city and the administrative boundary is even more complex: each federal region is responsible for its own administrative-territorial structures, resulting in significant variation in the organization, degree of autonomy, and types of designations used to define the city (Federal State Statistics Service (GKS) 2014). Further, statistical boundaries can be defined in such a way that they do not coincide with the administrative boundaries, and such differences can create biases by misrepresenting statistics across aggregated regions and between countries (e.g. Openshaw 1977). Administrative boundaries are therefore not precise measures of the properties of the urban built-up area of a city. Indicators that are highly dependent on metrics derived from these boundaries, such as population or land area, would reflect administrative decisions, and not the actual characteristics of the urbanized area (Angel et al. 2005).

Several studies have documented methods for extracting the urban extents of a city that do not rely on administrative boundaries, instead considering functional linkages, commuting zones, or economic agglomerations (e.g. Dijkstra et al. 2019). However, in order to provide a meaningful comparison for cities in this country, it was important to maintain relationships to boundaries to which statistical data is disseminated so that multiple sources of data can be integrated and analyzed for each city and across regions (United Nations Statistics Division (UN Stats) 2020). We developed a consistent methodology for defining the urban extents of the city, rather than relying on boundaries based on political units, by using demographic statistical area districts (DeSo) (i.e. census blocks, population districts, or circuit boundaries) that provide the spatial framework for metrics of ISO 37120 urban planning indicators.

Table 2. Overview of the seven ISO urban planning indicators, data types and method of analysis.

| No. | Type | Indicator | Data types | Method |
|-----|------|-----------|-------------|---------|
| 1   | CI   | Green area (hectares) per 100 000 population | Total green area; city population | RS, GIS |
| 2   | SI   | Areal size of informal settlements (per total city area) | Total land area; areal size of informal settlements | SD, RS |
| 3   | SI   | Jobs–housing ratio | Number of jobs; number of dwelling units | SD |
| 4   | SI   | Basic service proximity (%) | Georeferenced service locations; population districts | GIS |
| 5   | PI   | Population density (per sq. km.) | Total land area; city population | SD, GIS |
| 6   | PI   | Number of trees per 100 000 population | Total number of living trees; city population | RS, GIS |
| 7   | PI   | Built-up density | Total built-up area; total floor area for all buildings | SD, GIS, RS |

CI = Core indicator; SI = Supporting indicator; PI = Indicator; RS = Remote sensing; GIS = Spatial data analysis; SD = Statistical data analysis
ESRI shapefiles containing DeSo districts, in addition to administrative boundaries, were acquired for each city from local-level, municipal, or regional authorities, or national and open-source geospatial databases. These were compared to available city-planning documents for alignment and shape and edited where needed to improve their alignment to current legal boundaries and natural features (e.g. coastlines, rivers). ESRI shapefiles were also used to identify urban area boundaries, such as localities, urban-type settlements, or population centers, which are geographic descriptions of urban areas defined independent of the administrative boundary.

At the onset, the set of DeSo districts containing the urban built-up area of the city were unknown. A spatial selection was performed between the urban area boundary and the DeSo districts contained within the administrative boundary. In some cases, the selected districts aggregated to the administrative boundary. If spatial selection resulted in a lesser or greater spatial extent, we grouped and merged the districts to create a new shapefile from the aggregate set of district boundaries containing the urban built-up area of the city, which we will refer to as ‘city boundary’ from now on. For certain cities in Denmark, Greenland, Iceland, and Russia, DeSo districts were unavailable. To proceed with our analysis, the lowest-level administrative boundary city for which statistical data is disseminated and fully contained the urban built-up area of each city was used, including areas that do not have corporate status or jurisdictional authority (i.e. urban area boundary). This method allowed us to consistently define the boundaries for the cities in this study independent of the cities in this study using digital boundaries of DeSo districts and urban areas. Comparison between the administrative boundary and urban area boundary, and the merged set of DeSo district boundaries determined with this technique are shown in figure 2.
3. Urban planning indicators

3.1. Core indicators

3.1.1. Green area (ISO 21.1)

As the only core urban planning indicator in ISO 37120, ‘green area’ refers to the amount of vegetated and/or natural surface cover in the city, including green roofs, public, and private spaces. While information on green area was available for some of the cities in this study from municipal recreation and parks departments, planning departments, census, or land cover maps (physical or geospatial), the majority did not have this information. Additionally, most of the available data referred to size and location of public green spaces and not the significant proportion of private green space that exists within a city. In order to overcome these challenges, we adopted a remote sensing image analysis technique to delineate vegetated areas within the functional city boundaries using NDVI analysis, which has been shown to be an effective method for providing data on total land area, green area (pervious surface), and urban built-up area (impervious surface) (Weng 2016, Lehner et al 2018). We used 10 m spatial resolution spectral bands from the Copernicus Sentinel-2 mission (560 nm [3—green], 665 nm [4—red] and 842 nm [8—near-infra-red]), which at the scale of each city provides full tile coverage to calculate urban green areas. Imagery was selected from mid-summer dates with total cloud cover less than 5% to maximize the detection of vegetated (green) areas.

An 8-4-3 multiband composite raster was created and clipped to the city boundary, determined with the DeSo methods described in the previous section. The NDVI ratio for each city, which is the normalized difference between the near-infra-red (NIR) and red bands, was calculated using the standard relationship (Pettorelli 2013):

$$\text{NDVI} = \frac{(\text{NIR}_8 - \text{Red}_4)}{(\text{NIR}_8 + \text{Red}_4)}$$

The results were displayed by grouping values into classes using Jenks natural breaks optimization, a data clustering method that minimizes within-class deviations (figure 3; Jenks 1967). Wide variations in surface reflectance, urban/ground conditions, ecological features (e.g. glaciers, bedrock, persistent snow cover), and industrial activity restricted our ability to apply a set of standard NDVI ratio thresholds for land cover classification across all cities. Thresholds were identified using local NDVI ratio values for smaller subareas of the raster, which were then applied to the whole raster for a given city (table 3). Raster calculations were performed using a map algebra expression based on the thresholds to identify three land cover classes: water, urban built-up area, and green area (figure 4). The green area per 100 000 residents for each city was calculated from:

$$\text{Green area} = \left(\frac{A_t - A_1}{P}\right) - A_2$$

where $A_t =$ total zonal area, $A_1 =$ total water area, $A_2 =$ total built-up area, and $P =$ city population. Results of the total green area for each city are given in table a1 and figure 9.

3.2. Supporting indicators

3.2.1. Areal size of informal settlements (ISO 21.2)

Defined as areas where groups of housing units have been constructed on land that the occupants have no formal legal claim to, or are non-compliant with current planning or building regulations, informal settlements do not exist in the same way in the Arctic as in the Global South, where they constitute a major part of the urban housing stock (Patel and Baptist 2012, Kuffer et al 2016). However, in Arctic cities—much as in other temperate latitude cities—temporary seasonal encampments are created by the relatively small homeless populations as well as occasion instances of unregulated construction. Although the number of homeless is covered in ISO 37120 12.3 Housing, we chose to use this as a proxy for the areal size of informal settlements, even though there are several significant caveats which will be later discussed. In addition, this category prompted our research to explore the potentials of analyzing the order and structure of urban fabric using analysis techniques based on informal settlements, which can be useful in developing ideas of the characteristics of city planning for a given Arctic city. Even though, in some countries, over half of homeless populations live in long-term housing arrangements (Alexandrova et al 2004, Knutagard et al 2019), we posited that an upper bound on the areal size of ‘informal settlements’ could be approximated from the total homeless population in each city, which is derived from (1) the number of individuals or families whose primary nighttime residences are in public or private places not meant for human habitation, and (2) populations living in temporary residences or long-term housing provided by social services (Edgar et al 2007). The Federal Emergency Management Agency (FEMA, USA) sets out 40–60 sq. ft. per shelter resident, which may increase to 100 sq. ft. per person when general space, access and sanitation are considered (FEMA (Federal Emergency Management Agency) 2017). For each city, we collected data on the size of homeless populations using city-level point-in-time (PIT) homeless counts and other ancillary data sources that often report city-level data, and estimated their functional areal size using the following function:

Areal size of homeless populations (as % of city area)$$= \frac{\left(\frac{P \times A_t}{A_2}\right)}{A_2}$$
Figure 3. Histogram of NDVI ratios for Murmansk, RU.

| Table 3. NDVI ratio thresholds for land cover classification. |
|-----------------|-------------|
| Class No.       | Break Value |
| 0               | −1.0        |
| 1               | −0.32       |
| 2               | −0.21       |
| 3               | −0.07       |
| 4               | 0.09        |
| 5               | 0.29        |
| 6               | 0.44        |
| 7               | 0.53        |
| 8               | 0.62        |
| 9               | 0.69        |
| 10              | 1.0         |

Mean: 0.42  
S.D.: 0.35

where \( A_1 = \text{areal size per person} \), \( A_2 = \text{total city area} \), \( P = \text{number of homeless} \). Cities with the largest homeless populations are generally located in North America (see table a1 and figure 9).

3.2.2. Jobs-housing ratio (ISO 21.3)

As a measure of the ability of employed residents to find housing within a city, the jobs-housing ratio can provide a measure of commuting time (proximity of housing to location of employment), as well as potential service costs anticipated for future urban expansion. For this indicator, data was compiled from various national statistics agencies both on the number of jobs and on the number of dwelling units (table 4). In cases where city-level data was not available (Russia: Dudinka, Kandalaksha, Nadym, Nikel, Onega), data was compiled from the next lowest-level administrative unit with the understanding that this data is likely to include both urban and rural information, and may include other population centers outside of the main urban built-up area of the city. The jobs-housing ratio was calculated from:

\[
\text{Jobs housing ratio} = \frac{J}{D}
\]

where \( J = \text{total number of jobs (full- and part-time), and } D = \text{total number of dwelling units (available for habitation). Results are given in table a1 and figure 9.}

3.2.3. Basic services proximity (ISO 21.4)

The proximity of residents (and their places of dwelling) to basic services within a city directly impacts livability and quality of life, and can help define urban characteristics such as density, transportation and mobility, job health, energy use, and resilience. Two sets of geospatial data were necessary to evaluate this indicator: (1) the location of basic services (table 5), and (2) the distribution of population. A standard method for compiling the locations of basic services is to create a point layer in GIS by georeferencing their locations to an address-based municipal street guide (ISO 37120 2018). However, this type of data is often difficult to obtain in remote contexts and for small- to medium-sized cities. Therefore, it was necessary to compile basic service locations from multiple sources, including Google Maps ‘MyMaps’, OSM data, Arc GIS World Geocoding Service (WGS), and municipal- or national-level open geodata portals. The percentage of residents living in proximity to these services was then calculated using one of several methods, depending on available population distribution data (figure 5). For those cities with population data disseminated in DeSo districts, the population was assumed uniformly distributed within each district. Higher resolution population grid data was used for two cities (Oulu, Rovaniemi, FI). For cities without DeSo districts (such as Torshavn, he u DE; Nuuk, GR; Akureyri, IS; and all the Russian cities), we chose to uniformly distribute the city population throughout urban built-up area. If land use or zoning information was available, such as from a municipal planning document, we were able to provide a further level of refinement to the distribution of population data by assigned a portion of the total city population to each land use feature contained within the urban area boundary as a ratio.
Remote sensing technique using NDVI ratios to derive green and built-up areas.

Table 4. Countries, authorities, and definitions of dwellings, employment data for jobs-housing ratio indicator.

| Country     | National statistics office (NSO) or authority | Metric used                                                                 |
|-------------|-----------------------------------------------|-----------------------------------------------------------------------------|
| Canada      | Census Profile (StatCan)                       | Work activity during reference year                                         |
|             |                                                | Total private dwellings                                                      |
| Denmark     | Statistics Faroe Islands (Hagstova)            | Population by place of work, industry, age and sex                          |
|             |                                                | Dwellings by type and place of residence                                    |
| Finland     | Statistics Finland (Tilastokeskus)             | Employed labour force in area by area                                       |
|             |                                                | Work activity during reference year                                         |
| Greenland   | Statistics Greenland                           | Main employment and employment rate for permanent residents                 |
|             |                                                | Dwellings by time, district and area                                        |
| Iceland     | Statistics Iceland (Hagstofa)                  | Employed persons by output areas, industry and sex                         |
|             |                                                | Dwelling units by municipalities, occupancy status                          |
|             |                                                | Employees and employments, by region, sector, contents and quarter          |
| Norway      | Statistics Norway (SSB)                        | Dwellings, by region, type of building, contents and year                   |
| Russia      | Federal State Statistics Service (GKS)         | Average number of employees of organizations                               |
|             |                                                | Number of residential apartments per 1000 population                       |
| Sweden      | Statistics Sweden (SCB)                        | Gainfully employed by region of work, by region                            |
|             |                                                | Number of dwellings by region                                               |
| United States| American Community Survey (ACS)                | Employment status                                                          |
|             |                                                | Housing units                                                               |

of the area of each feature to the sum zonal area of all features.

Proximity buffers were then generated at defined distances for each service location (table 5) using a GIS buffer geoprocess and projected for accurate area analysis. We performed a spatial intersection between the proximity buffers and the DeSo district boundaries or other processed geospatial population data (boundary layer) (figure 6). The percentage of population that lives in proximity to basic services was then calculated using the intersected area of each proximity buffer and the boundary layer, as follows:

$$\text{Basic service proximity (\%) } \quad = \frac{\sum_{i=0}^{n} P_i \times \left( \frac{A_2}{A_1} \right)}{P_t} \times 100$$

where $P_i =$ boundary feature population, $P_t =$ total population, $A_1 =$ boundary feature area, $A_2 =$ intersected feature area, and $n =$ total number of intersected features. Results are presented in table A1 and figure 9.

3.3. Profile indicators

3.3.1. Population density (ISO 21.5.1)
As a fundamental measure of the proximity between residents, goods, and services, population density can be a measure of the efficacy of the design of a city. For a consistent measure and for comparison between cities, city boundaries should reflect the urbanized area of a city and should be characterized by built-up land including the central city and its immediate suburbs (Knox 1994, Weber 2001, Herold et al 2003, Bhatta 2010). While population density itself is a common method for defining a city (U.S. Census Bureau, Department of Commerce 2011), a subset of those included in our study are below the minimum threshold to be defined primarily on this
basis. The spatial selection method using DeSo districts (described earlier) provides a consistent depiction of the urban built-up area of the city and its population, while also minimizing the influence of non-urban (rural) populations and land area on population density. Population density was calculated per square kilometer of land area (see 3.1.1. Green Area). Results are given in table a1 and figure 9.

3.3.2. Number of trees (ISO 21.5.2)

The number of trees in a city is often cited as an important feature and a useful measure of a city’s commitment to urban and environmental sustainability, although, in the Arctic, the presence of trees can be highly variable due to the high latitudes and presence of permafrost. When available, sources for statistical data on tree counts include forestry...
departments, municipal estimations, or other environmental city departments. However, most urban inventories are limited to public spaces and rights of way, and do not estimate the number for an entire city, including trees on both public and private land.

In rural areas and wilderness, remote sensing in combination with in-situ ground surveys, high-resolution photogrammetry, and LiDAR, has been used to effectively measure the number of trees and provide information on species, size, and canopy density. However, these techniques are best employed for areas with uniform patterns and distinctive tree canopies (Alonzo et al., 2014, Wulder et al., 2000, Wang et al., 2004, Gougeon and Leckie, 2006, Lee et al., 2016).

Given the diversity of forest types for cities located in the circumpolar Arctic taiga-tundra, some of which are above the latitudinal treeline, as well as a lack of statistical data or ancillary remotely sensed data, we developed a density sampling methodology to estimate the number of living trees by identifying zonal highly-vegetated areas using NDVI analysis (see 3.1.1. Green Area). After calculating NDVI ratios for each city, we grouped values into classes to identify vegetation gradients (figure 7). We compared the results with orthophotos to include other vegetated areas that may appear less ‘green’ due to differences in surface reflectance, resulting from species diversity, density, and proximity to urban structures, and calibrate local NDVI thresholds (mean: 0.59; median: 0.62). We extracted the zonal highly vegetated region from the NDVI raster using a map algebra expression and calculated the zonal area. Within the highly vegetated region, we performed tree counts for multiple sample cells to determine an average tree density for each city (figure 8). We then estimated the number of living trees per 100 000 population using the following function:

$$\text{Number of trees (per 100,000 pop.)} = \frac{(A_1 \times D)}{P}$$

where $A_1 =$ zonal vegetated area, $D =$ tree density, and $P =$ city population. Results are presented in table a1 and figure 9.

3.3.3. Built-up density (ISO 21.5.3)

As a ratio of the total building floor area to the urban built-up area, this indicator requires detailed data on the properties of buildings, which is sometimes available either at the city level or from regional or national authorities in cadastral registries. But most cities in our study only reported partial data, if any, and typically only data on total ground floor area. Several studies have explored the use of RS techniques to calculate building footprints and heights, but these methods present challenges in urban areas composed of densely organized buildings (Kim et al., 2007, Brunner et al., 2010, Saadi and Bensaibi, 2014, Wang et al., 2015, Wu et al., 2019). For this study,
we adopted four approaches: (1) we evaluated built-up density using city-level statistical data; (2) where available, we obtained building footprints and building heights from GIS shapefiles to estimate total floor area. These data were then combined with total urban built-up area (calculated earlier using RS techniques, see 3.1.1. Green Area), with the following equation:

\[
BUD = \frac{A_f}{A}
\]

Where \( A \) = total urban built-up area, and \( A_f \) = total floor area for all buildings. Results are presented in table A1 and figure 9.

(3) We utilized OSM building footprints, however, as an open geodata product, footprints that also contained height fields were inconsistent and unreliable; (4) we adopted a weighted approach using a building level factor (to approximate the median number of floors based on empirical observations) and a percent-area factor (the proportion of built-up area assumed to be occupied by buildings) using the following function:

\[
BUD_w = \frac{\frac{1}{2} \left( F_1 (A) \times F_2 \right)}{A}
\]

where \( F_1 \) = percent area factor, \( F_2 \) = building level factor, and \( A \) = total urban built-up area.

4. Results

The seven indicators calculated for the 46 Arctic cities in this study are listed in table A1. As a means for comparison, we plotted the z-scores, with the results grouped according to North America, Europe, and Russia and listed in order of increasing population for each region from left to right, with the population shown along the bottom (figure 9; table A2). For each city, the z-scores are plotted as bar graphs which are overlaid on each other. The maximum (or minimum) extent of each color segment corresponds to the number of standard deviations from the mean value of the indicator. It is important to make note that not all cities in this study had DeSo districts available or disseminated data to local statistical units, namely cities in Russia and smaller cities in Denmark, Greenland, and Iceland. In these cases, it was not possible to accurately determine the distribution of population within the city, and so a uniform population distribution was assumed. It is likely that these approximations results in certain indicators being underestimated, such as proximity to basic services. Overall, it is evident that there is significant heterogeneity among the urban planning indicators for the cities in this study. This result is in many ways expected since the Arctic is a diverse and large geographic region, with distinct differences in climate, geography, political, economic, and cultural histories. However, the results in figure 9 reveal several important characteristics.

The first is that in Russia—where some of the largest and densest population centers in the Arctic are located—have the largest deviations in indicator values compared to the other Arctic cities in this study. With positive and negative z-scores ranging from \(-2.1\) to \(+5.6\), the highest and lowest indicator signatures of these cities are observed for population density, total green area, jobs-housing ratio, and basic service proximity. The data shows that high population densities in Russian Arctic cities do not correspond to an increased benefit to residents, given lower indicator values for basic service proximity and jobshousing ratio. For example, Magadan, one of the least dense Russian Arctic cities, has the largest proportion of green area per 100,000 residents and a high result for the number of trees, but also ranks below average in terms of key ISO 37120 urban planning indicators intended to measure quality of life, well-being, and sustainable urban development. Overall, these results show that Russian Arctic cities underperform compared to their European and North American counterparts across multiple urban planning indicators. Specifically, more people live farther away from basic services in 57% of the Russian cities (e.g. Magadan, Novy Urengoy, Archangelsk, and Omsk). Below-average scores extend to indicators such as jobs-housing ratio for a similar grouping of Russian cities (e.g. Omsk, Kandalaksha, Monchegorsk, Apatity, and Vorkuta). In these areas, Russian Arctic cities represent the lowest z-scores of all 46 Arctic cities analyzed in this study. In many cases, low scores for basic service proximity correlate with lower population and built-up densities, meaning that residents are more dispersed across larger urban areas, while low jobs-housing ratios result from economic hardships in these mono-industrial cities. Noteworthy, however, is that even the most densely populated city in this study—Norilsk (RU)—exhibits average or below-average scores for basic service proximity and jobs-housing ratio, despite the fact that Norilsk is one of the most compact and densest cities in the Arctic, and structured by some of the most rigorous planning and development guidelines.

A second key result is that the total amount of green area per 100,000 residents is below average for nearly all of the large cities in the Arctic (\(-0.1\) to \(-1.2\)). Furthermore, Russian Arctic cities in general exhibit lower proportions of green area, coupled with higher population densities, compared to their European and North America counterparts. This differentiation is consistent with their more compact and denser city planning systems beginning during the Soviet period, in addition to the economic focus of Russian Arctic cities as industrial centers.

A third key result is that small to mid-size European Arctic cities support more favorable living conditions (better livability) than in North America or Russia. This includes higher proximity to services (+1.9), lower population densities (-0.8), an
Table A1. Results of ISO urban planning sustainability indicators.

| Region       | Country | City          | 21.1 Green area (hec. per 100 000 pop.) | 21.2 Areal size of homeless pop. (% city area) | 21.3 Jobs–housing ratio | 21.4 Basic service proximity (%) | 21.5.1 Population density (per sq. km.) | 21.5.2 Number of trees (per 100 000 pop.) | 21.5.3 Built-up density |
|--------------|---------|---------------|-----------------------------------------|-----------------------------------------------|-------------------------|-----------------------------------|------------------------------------------|------------------------------------------|----------------------------|
| North America| US      | Anchorage     | 6237                                    | 0.59%                                         | 1.34                    | 41.7%                             | 95%                                      | 86 22 843                               | 0.42                       |
|              |         | Fairbanks     | 13 199                                  | 0.33%                                         | 1.18                    | 65.2%                             | 384                                      | 52 57 558                               | —                          |
|              |         | Juneau        | 15 860                                  | 0.47%                                         | 1.21                    | 62.2%                             | 475                                      | 23 37 440                               | —                          |
|              | CA      | Fort St. John | 5035                                    | 0.37%                                         | 1.36                    | 88.1%                             | 872                                      | 10 65 749                               | —                          |
|              |         | Whitehorse    | 11 446                                  | 0.71%                                         | 1.49                    | 54.2%                             | 569                                      | 49 69 208                               | —                          |
|              |         | Yellowknife   | 2976                                    | 3.78%                                         | 1.73                    | 90.3%                             | 1480                                     | 16 42 419                               | —                          |
| Europe       | DE      | Tórshavn      | 3023                                    | 0.43%                                         | 1.51                    | 85.7%                             | 1672                                     | 275 544                                 | —                          |
|              | FI      | Oulu          | 9032                                    | 0.07%                                         | 0.89                    | 73.0%                             | 806                                      | 35 66 465                               | —                          |
|              |         | Rovaniemi     | 9927                                    | 1.26%                                         | 0.83                    | 79.9%                             | 711                                      | 25 83 333                               | —                          |
|              | GR      | Nuuk          | 6442                                    | 1.26%                                         | 1.30                    | 87.4%                             | 592                                      | —                                        | —                          |
|              | IS      | Akureyri      | 12 974                                  | 1.07%                                         | 1.24                    | 83.9%                             | 604                                      | 26 55 544                               | —                          |
|              | NO      | Ålesund       | 2452                                    | 0.14%                                         | 1.33                    | 89.4%                             | 2143                                     | 966 349                                 | —                          |
|              | SE      | Boden         | 14 174                                  | 0.41%                                         | 0.81                    | 63.4%                             | 547                                      | 57 14 375                               | 0.17                       |
|              |         | Kiruna        | 8269                                    | —                                             | —                       | 60.5%                             | 760                                      | 41 49 084                               | 0.13                       |
|              |         | Luleå         | 5625                                    | 0.66%                                         | 1.19                    | 79.3%                             | 1039                                     | 19 80 154                               | 0.19                       |
|              |         | Skellefteå    | 11 777                                  | 0.27%                                         | 1.02                    | 70.5%                             | 659                                      | 42 53 847                               | 0.20                       |
|              |         | Umeå          | 6165                                    | 0.70%                                         | 1.14                    | 80.7%                             | 1146                                     | 22 68 825                               | 0.23                       |
| Russia       | RU      | Anadyr        | 10 096                                  | 0.01%                                         | —                       | 77.5%                             | 789                                      | —                                        | 0.21                       |
|              |         | Apatity       | 4135                                    | 0.14%                                         | 0.51                    | 78.6%                             | 1757                                     | 16 06 773                               | 0.42                       |
|              |         | Archangelsk   | 6344                                    | 0.16%                                         | 0.70                    | 38.8%                             | 1393                                     | 35 23 383                               | 0.53                       |
|              |         | Dudinka       | 2703                                    | 0.11%                                         | 0.95                    | 72.9%                             | 1654                                     | 41 49 084                               | 0.13                       |
|              |         | Kandalaksha   | 4305                                    | 0.13%                                         | 0.52                    | 52.3%                             | 1615                                     | 26 26 590                               | 0.13                       |
|              |         | Kirovsk       | 5755                                    | 0.11%                                         | 1.03                    | 52.7%                             | 1359                                     | 25 26 485                               | 0.53                       |
|              |         | Labytnangi    | 8160                                    | 0.05%                                         | 0.89                    | 45.7%                             | 776                                      | 24 33 018                               | 0.07                       |
|              |         | Magadan       | 26 845                                  | 0.05%                                         | —                       | 39.4%                             | 333                                      | 141 09 801                              | 0.15                       |
|              |         | Monchegorsk   | 2215                                    | 0.12%                                         | 0.60                    | 78.1%                             | 1446                                     | 377 861                                 | 0.14                       |
|              |         | Murmansk      | 3881                                    | 0.17%                                         | 0.71                    | 51.5%                             | 2029                                     | 27 34 430                               | 0.41                       |
|              |         | Nadym         | 1047                                    | 0.27%                                         | 1.89                    | 53.7%                             | 4190                                     | 172 373                                 | 0.27                       |
|              |         | Naryan Mar    | 10 091                                  | 0.04%                                         | 1.52                    | 61.7%                             | 655                                      | —                                        | 0.07                       |
|              |         | Nikola        | 1199                                    | 0.26%                                         | 0.63                    | 76.2%                             | 3124                                     | 19 22 572                               | 0.46                       |
|              |         | Norilsk       | 284                                    | 0.65%                                         | 1.04                    | 75.4%                             | 9538                                     | 9830                                    | 0.57                       |
|              |         | Novy          | 13 213                                  | 0.03%                                         | 1.85                    | 45.3%                             | 476                                      | 42 71 247                               | 0.07                       |
|              |         | Urengoy       | 13 213                                  | 0.03%                                         | 1.85                    | 45.3%                             | 476                                      | 42 71 247                               | 0.07                       |
|              |         | Novy          | 13 213                                  | 0.03%                                         | 1.85                    | 45.3%                             | 476                                      | 42 71 247                               | 0.07                       |

abundance of green area (+4.0), and balanced jobs-housing ratios (+1.2), suggesting that European cities have diverse urban areas with enough housing to support workers in the urban center and sufficient jobs and services throughout residential areas. Compared to European Arctic cities, lower proximity to services (−1.7) and higher jobs-housing ratios (+1.8) in North American cities show an apparent deficiency of housing, given the availability of jobs, with the assumption that more workers would need to commute from outside the city to their place of work. Only Russian Arctic cities exhibit jobs-housing ratios that suggest an apparent overabundance of housing and lower employment (min. −2.1; mean: 0.9). This may be a result of the efficient, compact, and dense residential housing blocks constructed in Russia, in combination with depopulation from emigration, high mortality rates, and socioeconomic challenges.
Table A2. Z-Scores of ISO urban planning sustainability indicators.

| Region  | City       | 21.1 Green area per 100 000 pop. | 21.2 Areal size of homeless pop. | 21.3 Jobs–housing ratio | 21.4 Basic service proximity | 21.5.1 Population density (per sq. km.) | 21.5.2 Number of trees per 100 000 pop. | 21.5.3 Built-up density |
|---------|------------|----------------------------------|----------------------------------|------------------------|-------------------------------|------------------------------------------|------------------------------------------|------------------------|
| North America | Anchorage | -0.42 | 0.43 | 0.68 | -1.65 | -0.24 | 1.32 | 1.09 |
|          | Fairbanks  | 0.45 | -0.01 | 0.23 | -0.21 | -0.63 | 0.39 | — |
|          | Juneau     | 0.79 | 0.23 | 0.32 | -0.39 | -0.57 | -0.42 | — |
|          | Fort St. John | -0.57 | 0.05 | 0.74 | 1.20 | -0.30 | -0.77 | — |
|          | Whitehorse | 0.23 | 0.63 | 1.12 | -0.88 | -0.50 | 0.31 | — |
|          | Yellowknife | -0.83 | 5.82 | 1.80 | 1.34 | 0.11 | -0.61 | — |
| Europe  | Tórshavn   | -0.82 | 0.15 | 1.17 | 1.06 | 0.24 | -0.99 | — |
|          | Oulu       | -0.07 | -0.46 | -0.60 | 0.28 | -0.34 | -0.08 | — |
|          | Rovaniemi  | 0.04 | -0.53 | -0.79 | 0.70 | -0.41 | -0.35 | — |
|          | Nuuk       | -0.39 | 1.56 | 0.57 | 1.16 | -0.49 | — | — |
|          | Akureyri   | 0.43 | 1.24 | 0.41 | 0.95 | -0.48 | -0.33 | — |
|          | Reykjavik  | -0.63 | 0.32 | 0.51 | 1.87 | 0.01 | -0.78 | — |
|          | Ålesund    | -0.90 | -0.33 | 0.65 | 1.28 | 0.56 | -0.80 | — |
|          | Alta       | 1.33 | -0.53 | 0.64 | -0.64 | -0.66 | -0.11 | — |
|          | Bodø       | 0.34 | -0.45 | 0.42 | 1.37 | -0.47 | 0.62 | — |
|          | Harstad    | 1.35 | -0.53 | -0.10 | -0.60 | -0.66 | 2.25 | — |
|          | Mo i Rana  | 4.00 | -0.55 | 0.19 | 0.15 | -0.76 | 2.97 | — |
|          | Molde      | 2.30 | -0.54 | 0.82 | 0.79 | -0.68 | 0.64 | — |
|          | Narvik     | 1.18 | -0.53 | -0.19 | 0.09 | -0.63 | 0.94 | — |
|          | Tromsø     | -0.75 | -0.38 | 0.59 | 1.75 | 0.25 | -0.66 | — |
|          | Boden      | 0.58 | 0.12 | -0.83 | -0.32 | -0.52 | 0.52 | -0.52 |
|          | Kiruna     | -0.16 | — | 0.08 | -0.50 | -0.38 | 0.08 | -0.83 |
|          | Luleå      | -0.50 | 0.54 | 0.27 | 0.66 | -0.19 | -0.52 | -0.42 |
|          | Skellefteå | 0.28 | -0.12 | 0.22 | 0.12 | -0.44 | 0.11 | -0.36 |
|          | Umeå       | 0.43 | 0.60 | 0.13 | 0.75 | -0.11 | -0.44 | -0.14 |
| Russia  | Anadyr     | 0.07 | -0.56 | — | 0.55 | -0.35 | — | -0.30 |
|          | Apatity    | -0.68 | -0.33 | -1.70 | 0.62 | 0.30 | -0.62 | 1.04 |
|          | Archangelsk | -0.41 | -0.30 | -1.14 | -1.83 | 0.05 | -0.09 | 1.74 |
|          | Dudinka    | -0.86 | -0.38 | -0.44 | 0.27 | 0.23 | — | -1.00 |
|          | Kandalaksha | -0.66 | -0.35 | -1.68 | -1.00 | 0.20 | -0.34 | -0.81 |
|          | Kirovsk    | -0.48 | -0.38 | 0.20 | -0.97 | 0.03 | -0.36 | 1.74 |
|          | Labytnangi | -0.18 | -0.49 | -0.59 | -1.41 | -0.36 | -0.39 | -1.19 |
|          | Magadan    | 2.17 | -0.49 | — | -1.79 | 0.06 | 2.84 | -0.67 |
|          | Monchegorsk | -0.92 | -0.37 | -1.43 | 0.59 | 0.09 | -0.96 | -0.76 |
|          | Murmansk   | -0.72 | -0.29 | -1.13 | -1.05 | 0.49 | -0.31 | 0.99 |
|          | Nadyrn    | -1.07 | -0.11 | 2.26 | -0.92 | 1.95 | -1.02 | 0.11 |
|          | Naryn Mar | 0.06 | -0.51 | 1.19 | -0.42 | -0.45 | — | -1.16 |
|          | Nikel      | -1.05 | -0.14 | -1.33 | 0.47 | 1.23 | -0.53 | 1.34 |
|          | Norilsk    | -1.17 | 0.52 | -0.16 | 0.42 | 5.58 | -1.06 | 2.04 |
|          | Novy      | 0.46 | -0.52 | 2.16 | -1.43 | -0.57 | 0.12 | -1.21 |
|          | Urengoy    | — | — | — | — | — | — | — |

|               | Nojabshk | 0.29 | -0.50 | -0.72 | -0.30 | -0.42 | 2.01 | -0.57 |
|               | Omena    | 0.01 | -0.41 | -2.10 | -1.51 | -0.33 | -0.02 | -0.68 |
|               | Salekhard | 0.34 | -0.50 | 0.91 | 0.15 | -0.43 | -0.93 | -0.71 |
|               | Severodvinsk | -0.89 | 0.00 | -0.71 | -0.48 | 1.09 | -0.74 | 1.35 |
|               | Vorkuta  | -0.15 | -0.49 | -1.40 | 1.16 | -0.22 | — | 0.34 |
|               | Yakutsk  | -0.97 | -0.10 | -0.43 | -1.47 | 0.85 | -0.94 | -0.45 |

Mean value 9577 0.0032 1.10 0.68 1313 38.44 1323 1475 36 16 616 0.16

that many Russian cities face with transitioning from mono-industrial to ‘diversified local economies’ following the dissolution of the Soviet Union (Dushkova and Krasovskaya 2019). Unexpected, however, is the relatively poor performance of Russian cities for service proximity, since many of these cities were built with strict planning guidelines (microrayons) that emphasized minimizing service radii and enhanced urban social and infrastructural cohesion (Jull 2017).
5. Discussion

This paper presents methods, analysis, and preliminary results from a comparative study of urban planning indicators for Arctic cities with populations greater than 12,000 following the ISO 37120 Sustainable Cities and Communities guidelines. Despite focusing on only a subset of indicators within the entire ISO 37120 sustainability framework, the data shows several important features. Within a relatively heterogeneous array of data across 46 Arctic cities, certain regional- and city-specific indicator signatures are evident. These reflect not only the large range of settlement types, but also the unique historical and socio-economic conditions in the North American, European, and Russian Arctic. The results for some of the better known cities are consistent with general background knowledge (e.g. Anchorage, Norilsk: relative population density, building typology, green space), while others reveal unexpected signatures (e.g. larger than normal indicator signatures, service radii variability), providing an opportunity for further study of the factors that are driving these characteristics. Importantly, however, is that during the course of studying such a large number of cities distributed over very large geographic regions and across multiple national boundaries, it became evident that a critical evaluation of data collection and analysis techniques was necessary. The methods that were developed not only allow for the relatively low-cost and efficient collection of data, but also the incorporation of a framework that will facilitate meaningful comparisons of large-scale urban planning indicators.

One of the principal criteria for evaluating urban planning data is establishing common geographies for the definition of a city. Wide variations in such definitions are further complicated by the designation of administrative boundaries. On the one hand, cities can be understood intuitively in terms of population or the presence of built structures (buildings, roads, and infrastructure), while on the other, they are legally defined by administrative jurisdictions for the purposes of governance. That such definitions vary across national boundaries is perhaps not unexpected. But when the proportion of the urban built-up area of the city is smaller by orders of magnitude than non-urban, rural, or natural land areas within the city boundary, then it becomes meaningless to compare indicators using these definitions. Ideally all cities for which the ISO indicators are evaluated should share a common set of definitions that describe the central urban built-up area of the city and its edges, and also determine for which populations and geographic areas indicators are calculated so that a global database could ultimately be compiled. These indicators should also be based on an intuitive, consistent, and repeatable strategy to be most meaningful for analysis and for policy makers and others to understand and evaluate large sets of data pertaining to cities. Given the complexity and variability of city definitions, the use of DeSo...
districts, urban built-up areas, and cross-comparison with local planning documents as described in this paper, provides a robust method for delineating city boundaries that can avoid large aberrations in metrics when using municipal or other administrative boundaries.

Although ISO 37120 indicators were developed with the ambition of making ‘reporting as simple and inexpensive as possible’, a comparative analysis of urban planning metrics for multiple cities across large geographic regions using a standard methodology is difficult, in particular when this relies on high-resolution data about the built environment. For the cities in this study, data was often either lacking, reporting definitions were inconsistent, or there was limited availability of open geospatial (GIS) data. ISO-recommended low-cost methods for data collection from either municipal departments or land use/land cover maps were limited due to availability or low resolutions, making it difficult to calculate accurate metrics. To compensate for these problems, remote sensing and GIS became integral techniques for data collection and analysis in this study. In tandem with the use of local statistical units, these methods allowed us to develop an integrative approach, which provided many advantages, including the ability to calculate core metrics for each city (e.g. green area, built-up area, land area), remove bias that can be present in self-reported statistics, and address varying time frames for data released at different rates or for specific years (e.g. census reporting). However, despite these benefits, the extended application of remote sensing at the scale of the city for detailed urban analysis is intensive, complex, and multi-staged, in particular for automatically processing remotely sensed data for large numbers of buildings (as is necessary for indicators such as built-up density).

One of the shortfalls of ISO 37120 is a lack of relevance to any specific regional context (Sköld et al. 2018). This is a direct result of ISO 37120 being formulated to remain ‘applicable to any city, municipality or local government…irrespective of size and location,’ (ISO 37120 2018) providing an opportunity for a global comparison of cities. As a standardized and well-known sustainability framework, ISO 37120 is useful for measuring broad urban sustainability characteristics but can miss important details related to sustainable urban planning and development at more local or regional scales. For example, in the Arctic, with its unique environmental, geographic, cultural, and economic factors, indicator frameworks exclude altogether fundamental metrics such as: the impacts of climate change on permafrost and sea ice extent, coastal erosion, food security, and indigenous culture and practices (Berman and Ortung 2020); and important indicators for sustainable urban planning in the Arctic, such as natural hazard adaptation and resiliency, proximity to transportation infrastructure (i.e. road, rail, or port connections), or availability and cost of building and construction materials (Dinapoli et al. 2020). As with any indicator, care must be taken when applying ISO 37120 to cities across a broad geographic spectrum. For example, while the number of trees (21.5.2) in a city can contribute to a better quality of life and improve human health (ISO 37120 2018), such metrics could be misinterpreted in Arctic cities located above the latitudinal treeline. In other cases, it is difficult to understand the positive or negative effects of an indicator’s performance. While green area (21.1) measures all natural (vegetated) surface cover in the city (including green roofs), it does not fully describe the natural-built relationship of an Arctic city—for example, high values in Anchorage reflect the presence of interior parks and extensive forested land surrounding the city, whereas low values in Nuuk result from large areas of bedrock and impermeable soil—neither result provides any further understanding of the quality, status (i.e. protected, wilderness), or impacts of green area on the city or its residents (i.e. increased recreational access or eco-tourism). Additionally, without analyzing the results of other indicators across other sustainability themes, such as greenhouse gas (GHG) emissions or total end-use energy, it is difficult to assess the benefits of the outcomes of certain indicators (Mcmanus 2012). For example, higher built-up density may reduce GHG emissions by centralizing building heating systems but may increase building thermal transfer to permafrost, and ultimately increasing the risk of building damage.

Over the course of this study, it became apparent that there are many other simpler metrics that might also be adopted. These include, for example: ‘Is there a planning office in the city?’, ‘Is there a vision plan for the future development of the city that is publicly available?’, or ‘Are architects, urban designers, and landscape architects involved in future planning decisions?’. Such indicators, although potentially binary in nature, are fundamental for many cities with highly developed sustainability plans and can serve to provide metrics on the capacity and potential of a city for achieving more sustainable approaches to urban development.

6. Conclusions

This study presents the results of a compressive survey of the ISO 37120 urban planning indicators for 46 Arctic cities that was undertaken to understand how this subset of indicators could provide useful metrics for evaluating sustainable urban development. The results show that while there is significant heterogeneity among urban planning indicators for the cities in this study, several city- and regional-specific characteristics are observable. Russian Arctic cities underperform in comparison to European and North American Arctic cities across multiple service sectors. Small- to mid-size European Arctic cities exhibit
higher livability, efficiency, and sustainability. For the cities in this study, there also does not appear to be a strong correlation between density and size of the city, and the provision of city services or availability of jobs and housing. These results also reveal that important historical, geographic, and socioeconomic factors influence the outcome of urban planning sustainability indicators, such as urban development policy, type of settlement, and economic function.

During the course of this study, it became necessary to critically assess techniques used for data collection both in terms of metrics defined by ISO 37120 and the wide variation in reporting definitions of data in order to allow the compilation of a self-consistent and complete dataset that would allow for meaningful comparison of the indicators across the cities in this study. The framework for evaluating urban planning indicators described in this paper establishes a multi-method approach that defines—indeed of administrative decisions—the area of the city using local statistical units and computes urban planning metrics by utilizing a combination of remote sensing, geospatial analysis, and statistical data collection. While remote sensing can be applied across many sectors, for the purposes of this study it was effectively used to calculate core metrics for each city, such as urban-built up area and green area, which were fundamental in evaluating all seven urban planning indicators.

Standardized sustainability indicators, such as those defined by ISO 37120 and used in this study, provide a useful starting framework for developing a consistent database of sustainability metrics by different research for cities across the globe. However, in practice, further refinement of data collection techniques is needed, as well as of the definitions for indicators themselves, in order to provide consistency in the results and make the interpretation and analysis of data across cities more accurate and informative.

Acknowledgments

This work was funded by the National Science Foundation (NSF) Partnerships for International Research and Education (PIRE) Promoting Urban Sustainability in the Arctic (#1545913) in collaboration with the Arctic Design Group (Matthew Jull, Leena Cho) at the University of Virginia. The authors would like to thank Jane Lee and Leena Cho for their contributions and input. The authors would also like to thank the three anonymous reviewers who provided invaluable comments that contributed to improving the manuscript.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary information files).

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