



Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

Measuring the 3-30-300 rule to help cities meet nature access thresholds



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<https://doi.org/10.1016/j.scitotenv.2023.167739>

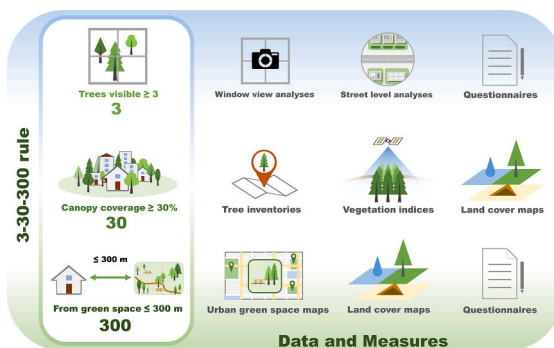
Available online 11 October 2023

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HIGHLIGHTS

- The 3-30-300 rule provides objective, universal benchmarks for green space access.
- Expert-based consensus found 7 data and processes to measure 3-30-300.
- Questionnaires and window-view analyses were recommended for the 3 component.
- High-resolution land cover maps were recommended for the 30 component.
- Green space maps with network analyses were recommended for the 300 component.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Elena Paoletti

Keywords:

- 3-30-300
- Urban green space
- Geographic information system (GIS)
- Environmental equity
- Urban planning

ABSTRACT

The 3-30-300 rule offers benchmarks for cities to promote equitable nature access. It dictates that individuals should see three trees from their dwelling, have 30 % tree canopy in their neighborhood, and live within 300 m of a high-quality green space. Implementing this demands thorough measurement, monitoring, and evaluation methods, yet little guidance is currently available to pursue these actions. To overcome this gap, we employed an expert-based consensus approach to review the available ways to measure 3-30-300 as well as each measure’s strengths and weaknesses. We described seven relevant data and processes: vegetation indices, street level analyses, tree inventories, questionnaires, window view analyses, land cover maps, and green space maps. Based on the reviewed strengths and weaknesses of each measure, we presented a suitability matrix to link recommended measures with each component of the rule. These recommendations included surveys and window-view analyses for the ‘3 component’, high-resolution land cover maps for the ‘30 component’, and green space maps with network analyses for the ‘300 component’. These methods, responsive to local situations and resources, not only implement the 3-30-300 rule but foster broader dialogue on local desires and requirements. Consequently, these

3	 Trees visible ≥ 3	 Trees visible < 3
30	 Canopy coverage ≥ 30%	 Canopy coverage < 30%
300	 From green space ≤ 300 m	 From green space > 300 m
	Met	Not met

Fig. 1. 3-30-300 recommends that everyone should be able to see at least 3 trees from their residence, workplace, or place of learning; have at least 30 % tree canopy cover in their neighborhood; and live within 300-m of a high-quality public green space (at least 0.5 ha in size) (Konijnendijk, 2021).

techniques can guide strategic investments in urban greening for health, equity, biodiversity, and climate adaptation.

1. Introduction

The health and well-being benefits of high-quality green space are increasingly recognized (Zhang et al., 2020). These benefits are prominent in the UN Sustainable Development Goal 11 Target 7, which states, “by 2030, providing universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities.” Specifically, scholars and practitioners have increasingly focused on urban greening, which involves planting, conserving, and maintaining outdoor vegetation in cities and other urban areas (Eisenman et al., 2019), where increasing numbers of the world’s population live. Relatedly, in 2021, Cecil Konijnendijk introduced a new standard for creating healthy, green, equitable cities: the 3-30-300 rule (Konijnendijk, 2021). 3-30-300 is a set of objective benchmarks for cities seeking to provide their residents with adequate access to nature and the benefits of exposure to natural settings. This approach leverages a vast and growing literature demonstrating the importance of trees and public green spaces, especially close to where people live, work, and play, for mental health, physical health, and climate adaptation (Nieuwenhuijsen, 2020; United Nations, n.d.; Yang et al., 2021).

3-30-300 incorporates three components of nature or “green”: visual green, residential green, and access to green for outdoor recreation. The goal states that everyone should be able to see at least 3 well-established trees from their home, workplace, or place of learning; have at least 30 % tree canopy cover in their neighborhood; and live within 300-m of a high-quality public green space (at least 0.5 ha in size) (Konijnendijk, 2022) (Fig. 1). This new heuristic for urban nature and green space provision combines different metrics for proximity, quantity, and access.

The evidence and policy guidelines underpinning the rule are now being fully characterized (Konijnendijk, 2023). In brief, the 30 and 300 components are supported by a significant body of past research findings (van den Bosch et al., 2023; Nieuwenhuijsen, 2020; United Nations, n.d.). Studies of Australian adults have found that living in areas with ≥ 30 % canopy cover is associated with reduced risk of Dementia (Astell-Burt et al., 2020); diabetes, hypertension, and cardiovascular disease (Astell-Burt and Feng, 2020); poor general health (Astell-Burt and Feng, 2019a); and short sleep duration (Astell-Burt and Feng, 2019b). Quantitative health impact assessments have estimated that increasing canopy cover to 30 % could have prevented 2644 premature deaths across 93 European cities in summer 2015 (Iungman et al., 2023) and 403 annually in Philadelphia, PA U.S. (Kondo et al., 2020). Meanwhile, living within 300-m of urban green space has been associated with fewer childhood mental and behavioral disorders in Spain (Pérez-del-Pulgar et al., 2021), hyperactivity/inattention problems in Munich, Germany (Markevych et al., 2014), poor mental health among women in Sweden (Annerstedt and Östergren, 2012), physical inactivity in the Netherlands (Klompaker et al., 2018), breast cancer risk in Spain (O’Callaghan-Gordo et al., 2018), and cardiovascular disease in Kaunas, Lithuania (Tamosiunas et al., 2014). The 300 component also aligns with existing recommendations by the European Office of the World Health Organization (World Health Organization Regional Office for Europe, 2017). There is less evidence yet to support the 3 component, a practical aspiration that “alliterates” with 30 and 300, but numerous studies have identified tangible benefits of visual access to greenery for mental health, psychological restoration, and wellbeing (Benfield et al., 2015; Browning et al., 2020; Labib et al., 2022; Patwary et al., 2022; Ulrich, 1984). For instance, three visible trees from home have been associated with fewer medications and psychiatrist/psychologist visits in Spain (Nieuwenhuijsen et al., 2022), and larger numbers of mature street trees in a virtual reality simulation have improved recovery after acute

stressors in the U.S. (Jiang et al., 2016). More broadly, access to greenery is associated with reduced risk of all-cause mortality, heart disease, obesity, mental disorders, low birth weight, physical inactivity, and sleep disorders, among dozens of other diseases, illnesses, and conditions (Bratman et al., 2019; Hartig et al., 2014; Markevych et al., 2017; Twohig-Bennett and Jones, 2018; Yang et al., 2021).

Since its launch, 3-30-300 has attracted considerable attention from urban foresters and allied environmental professionals—but also from urban planners and architects, politicians, and journalists. Many cities worldwide, including Malmö, Sweden; Zurich, Switzerland; St. Petersburg, Florida; Haarlem, The Netherlands; Saanich, British Columbia; and Viladecans, Spain have already adopted 3-30-300, either formally or informally, as part of their urban forestry or greening programs. International organizations such as the United Nations Economic Commission for Europe (United Nations Economic Commission for Europe, 2021) and the Nordic Council of Ministers (Nordic Council of Ministers, 2022) have recommended implementing 3-30-300. The region of Scania in Southern Sweden has asked consultants to develop an initial assessment method (Development Scania, n.d.). The NGO Future Woodlands Scotland started an urban forestry program with 3-30-300 as the key target (Future Woodlands Scotland, 2022). Another NGO, Nature Canada, recommends 3-30-300 as part of a strategy to reduce urban forest inequity (Nature Canada, 2022).

Epidemiologists have also embraced 3-30-300 as a set of “exposures” worth investigating for potential health and equity benefits. A recent city-wide 3-30-300 study in Barcelona, Spain, reported fewer per capita psychiatrist or psychologist visits in neighborhoods where all three rule components were met (Nieuwenhuijsen et al., 2022). Other outcomes were not associated with meeting all three components of 3-30-300, including self-reported mental health and the use of tranquilizers, sedatives, or antidepressants. A survey of 1716 adults living in Florida, U.S., found 37.3 % met all three components of 3-30-300 and that the most commonly reported benefits of trees by residents were shade, aesthetic value, nature access, and air filtration (Koeser et al., 2023).

Despite the excitement around the launch and early implementation of 3-30-300, much remains to be clarified about the rule. Various public and private organizations have embarked on developing assessment and monitoring methods to implement the rule (Development Scania, n.d.; Future Woodlands Scotland, 2022; Nature Canada, 2022; Nordic Council of Ministers, 2022; United Nations Economic Commission for Europe, 2021). It may be difficult for city administrators and urban planners to know which options are available and recommended when measuring 3-30-300 across urban landscapes. Currently, there is no expert-based guidance on how to measure, monitor, or evaluate the rule, leaving its measurement up to the perspectives and knowledge base of the analysts available at each city or institution.

Therefore, this review aims to overcome the current gap in understanding how best to calculate the 3-30-300 rule by providing an expert-led and accessible overview of ways to measure each component of the rule. We summarize each metric relevant to 3-30-300, and describe each metric’s strengths and weaknesses, ultimately arriving at a suitability matrix for each component of the rule and the corresponding measures. We discuss considerations for measuring and adopting 3-30-300 according to geographical and contextual factors that may limit the relevance of the rule as a proxy for equitable nature access. Ultimately, we hope this review promotes robust monitoring and evaluation techniques for cities’ ongoing investments in improvements and expansions to urban canopy and green space.

2. Methods

2.1. Overview

Relevant research and methodological approaches to measuring urban greenspace/forestry span tens of thousands of studies from diverse disciplines (Zhang et al., 2020). We followed a former review's approach to retrieve relevant information from this large body of literature using expert-based consensus rather than the systematic collection of literature (Markevych et al., 2017). The former approach might be suitable for effectively collecting, classifying, and synthesizing this topic, as suggested by the scientific community's adoption of the former review: 1400+ citations according to Google Scholar in the five years since its publication (October 2017). In the current review, we convened a series of asynchronous and synchronous virtual discussions from October 2022 to July 2023. Prior to the first discussion, an initial description of the relevant measures and their strengths and weaknesses were proposed by four authors (M.B., D.L., S.L., R.Y.). These descriptions were critiqued, revised, and expanded by the remaining authors. The presented measures and their strengths and weaknesses were subject to multiple iterations. Ultimately, consensus was reached among all authors.

2.2. Definitions of terms

The multidisciplinary nature of this review's relevant fields of study warranted clear definitions of terms. These included "tree", "viewshed", "canopy cover", "neighborhood", and "urban green space." We define these terms in the following ways.

2.2.1. Tree

Although there is no standard botanical or taxonomic definition of 'tree' and varied ways of defining 'tree' in urban forestry (van Doorn et al., 2020), in practical terms, trees are generally considered woody perennial plants whose trunks thicken over time, with some distinctions of tree vs. shrub and other woody herbaceous plants suggesting that trees are taller than 3 m (Götmark et al., 2016; Richardson and Rejmánek, 2011). Decisions about what qualifies as a tree are often made locally or regionally, for instance, in tropical climates where palms function as trees but do not display the growth patterns of botanically-recognized trees (van Doorn et al., 2020). In this review, we generally do not differentiate between tree types; however, 3-30-300 does recommend mature, well-established, larger trees (Konijnendijk, 2023). This recommendation has been supported by Belgian research finding wider crowns (the upper part of the tree) are associated with fewer mood disorders and cardiovascular medications, while higher densities of stems are associated with more of these medications (Chi et al., 2022). Further evidence is available from a study in Oregon, U.S., documenting older and presumably larger trees showed greater protective associations with lower non-accidental mortality rates than younger trees (Donovan et al., 2022). However, there are still numerous benefits associated with small-stature trees, including resident preferences for flowering and fruiting trees (Nguyen et al., 2017), and cultural affinity for palms 'trees' in some regions (Blair et al., 2019).

2.2.2. Viewshed

Determining whether a person can view three trees from a window in a building requires an understanding of that person's viewshed. For this review, we define viewshed as the landscape visible from a vantage point without obstructions (i.e., buildings or sloped terrain) (Cimburova and Blumentrath, 2022). 3-30-300 focuses on viewsheds from any window in homes, offices, and schools. It does not limit viewsheds by location (i.e., bedroom or home office windows).

2.2.3. Canopy cover

We define urban tree canopy cover as the proportion of an area (e.g.,

neighborhood) covered by leaves, branches, and stems of trees when viewed from above. Canopy cover is usually expressed as a percentage, with 0 % representing an area with no canopy, and 100 % representing an area completely covered by canopy. 3-30-300 does not specify whether 30 % canopy cover pertains to summer-time high estimates when deciduous trees are fully leafed out. Much research on greenery and human health has utilized single-day estimates, such as maximum values during the summer (Markevych et al., 2017). City-wide tree canopy cover goals are also common (Locke et al., 2017; Nguyen et al., 2017).

2.2.4. Neighborhood

We define neighborhoods within cities, towns and suburbs as geographically-bound areas of limited size, with relative homogeneity in housing and population, as well as some level of social interaction and symbolic significance to residents (Chaskin, 1997; Weiss et al., 2007). Two types of neighborhood definitions are commonly used in the research on greenery and human health: *allocentric* units based on administrative zones (e.g., census tracts) and *egocentric* units based on areas around an individual's location (e.g., their home) (Chaix et al., 2009; Labib et al., 2020a). Subjective boundaries can also represent individuals' perceptions of their neighborhood (Christensen et al., 2022; Yang et al., 2020).

2.2.5. Urban green space

We rely on previous definitions to describe urban green space as city areas with greenery that support biodiversity, ecosystem services, or passive and/or active outdoor recreation (Grabowski et al., 2022; Jennings et al., 2019; Li et al., 2023; Matsler et al., 2021; Morpurgo et al., 2023; Taylor and Hochuli, 2017). These areas can take on many forms, such as parks, athletic fields, forests, cemeteries, private open spaces, gardens and agricultural areas, green stormwater infrastructure (i.e., rain gardens, bioswales, detention/infiltration basins), and green roofs/walls, among other forms (Grabowski et al., 2022; Jennings et al., 2019; Li et al., 2023; Matsler et al., 2021; Morpurgo et al., 2023; Taylor and Hochuli, 2017). 3-30-300 prioritizes definitions that include quality assessments as well as amenities and tangible abilities to positively affect residents' health and well-being. Identification of a high-quality urban green space may depend on place-specific features such as the total canopy and leaf area for heat reduction, recreational facilities such as sport fields and trails for physical activity, and infrastructure such as playgrounds and picnic shelters for social cohesion (Markevych et al., 2017).

3. Results

3.1. Measures and their strengths and weaknesses

Our expert-based consensus found that most data related to measuring 3-30-300 can be organized into seven main categories: vegetation indices, street-level analyses, tree inventories, questionnaires, window view analyses, land cover maps, and urban green space property maps (Fig. 2). However, the methods of processing these data can overlap. For example, semantic segmentation - a computer vision technique used to classify and separate objects or regions of an image - can be applied to photographs from windows and street-view images to derive tree visibility. Additionally, some data sources can produce other datasets, such as airborne light detecting and ranging (LiDAR) and high-resolution imagery, which are used to derive high resolution ($\leq 1 \text{ m}^2$), high classification accuracy ($\geq 95 \%$) tree canopy maps. Therefore, we caution that these seven categories are discussion points rather than a complete and mutually exclusive set of data sources and processing techniques. The uneven material in these seven categories reflects, in part, the stage of development in urban greenery measurement and degree of applicability to 3-30-300.



Fig. 2. Categories of data and processing techniques for 3–30–300.

3.1.1. Vegetation indices

Numerous satellite-based products are available to measure vegetation cover. However, they do not measure tree canopy cover directly. For instance, vegetation continuous field (VCF) values indicate the percentage of vegetative cover ≥ 5 -m in height (Hansen et al., 2003). Moderate Resolution Imaging Spectroradiometer (MODIS) derived VCF data are available annually (2000–present) and globally at a resolution of 250-m². Annual and global VCF data are available from Landsat 5 and 7 imagery at 30-m² resolution at 5-year intervals (2000, 2005, 2010, 2015) (Sexton et al., 2013). In the U.S., the Multi-Resolution Land Characteristics Consortium provides National Land Cover Database (NLCD) and tree canopy cover estimates at 30-m² resolution (Coulston et al., 2012; Nowak and Greenfield, 2010). Recently, Lang et al. (2019, 2022) used Sentinel 2 and Global Ecosystem Dynamics Investigation (GEDI) space-borne LiDAR data to generate 2017-present 10-m² estimates of canopy height, which could be used to calculate canopy cover. Normalized difference vegetation index (NDVI) values that measure healthy green vegetation can be calculated from many of these datasets as well as other satellite, drone, or aerial imagery such as the National Agriculture Inventory Program (NAIP).

3.1.2. Street level analyses

Georeferenced street view images (SVI) can be used to calculate several metrics related to 3–30–300 (Biljecki and Ito, 2021). Imagery is available from Google (2007–present), Baidu (2012–present), and Mapillary geotagged photos (2013–present), among other sources. For all three data sources, individual locations have 360-degree views from images in the four cardinal directions along streets. Images can be used to extract the percentage of visible greenery along the selected streets with data. For instance, Harvard University researchers developed a 100-m street network grid for U.S. metropolitan statistical areas by utilizing a Google application programming interface (API) to find the nearest SVI at each point along a street each year. Computer vision was used to calculate visible greenery (e.g., trees, shrubs, grass, plants, and flowers) through a pyramid scene parsing network (PSPNet) (Zhou et al., 2017) deep learning model with the ADE20K pre-trained dataset (Zhou et al., 2017). Helbich et al. (2021) used SVI in Amsterdam to create a high-resolution greenness visibility surface, and MIT's Treepedia has performed a similar function for select cities globally (Cai et al., 2018).

These datasets and image pixel analysis models often cannot count the number of visible trees but instead can create estimates (i.e., SVI with 10 % tree cover may represent three visible trees). Other deep learning object detection models like You Only Look Once (YOLO) can also be used to detect and count individual trees in SVIs (Branson et al., 2018; Liu et al., 2023; Redmon and Farhadi, 2018). Pre-trained deep learning models, such as SegFormer and Mask2Former on CityScapes, are available through open APIs on the Hugging Face platform for tree visibility modeling using SVIs without requiring extensive programming skills. Other image segmentation approaches for SVIs include manual selection in Adobe Photoshop histograms (Adobe, San Jose, CA) and the Brown Dog Green Index (Suppakittpaisarn et al., 2022). Manual estimates of each tree location, species, and diameter at breast height (dbh) can also be performed on SVIs (Berland and Lange, 2017). By design, SVIs focus on streetscapes, so while they may capture street trees (with omission and commission errors), they miss trees in backyards and other spaces entirely (Labib et al., 2020b; Ossola et al., 2019; Yeager et al., 2023).

Street-level analyses can also be performed with LiDAR products to conduct viewshed analyses that model tree visibility. LiDAR uses laser pulses to measure distances between a sensor and a surface (i.e., the Earth's surface), where the laser beam is sent toward the ground, and the time it takes for the light to bounce back is measured to determine the distance. Sensors are often located on low-flying aircraft but can be located on unmanned aerial vehicles (UAV) or handheld devices (Tang et al., 2023; Xia et al., 2023). The resulting high-resolution point cloud data can generate digital surface models (DSMs), three-dimensional representations of the Earth's surface, including natural and anthropogenic features such as trees, buildings, and terrain (Labib et al., 2020a; Vosselman and Maas, 2010; Yu et al., 2016). LiDAR can, therefore, “see through” shadows in urban areas. Several viewshed analysis tools have been developed and applied to model eye-level vegetation visibility, for instance, the GVI-R/Python packages (Brinkmann and Labib, 2022; Labib et al., 2020a). The open-source GRASS GIS AddOn *v.viewshed_impact* tool can also be applied to model individual tree visibility (Cimburowa et al., 2023). By integrating these tools with building and window location information, precise representations of tree visibility can be estimated (Cimburowa and Blumentrath, 2022).

3.1.3. Tree inventories

Tree inventories are systematic and comprehensive surveys of trees on public lands within a defined area, such as a city. Tree species, size, health, and geolocation are usually available in inventory datasets. Research teams and organizations like [OpenTrees.org](https://opentrees.org) have compiled datasets across numerous municipalities, notably, the Global Urban Tree Inventory (Ossola et al., 2020). Some countries have national-scale inventories as well, specifically the UK National Tree Map™. In addition to surveys, photogrammetry can be applied to mobile phone images to create tree inventories (Arboreal, 2018; Marzulli et al., 2020; Roberts et al., 2019; Texas A&M Forest Service, n.d.; The Globe Program, n.d.; Vastaranta et al., 2015). Related to 3-30-300, tree inventories can generate maps that can be compared with residence locations for visibility assessments. Tree inventories are often limited to publicly managed trees (e.g., street trees, public parks) and therefore do not capture private lands, representing a considerable portion of the urban forest in many neighborhoods. Municipal tree inventories may also be outdated, inconsistently updated, or contain imprecise location data for individual trees.

3.1.4. Questionnaires

Questionnaires can be administered to residents through the mail, internet, door-to-door interviews, phone calls, text messages, and other methods (Dillman et al., 2014) to collect data on several aspects of 3–30–300. For example, the Urban National Landowner Survey was developed by the U.S. Forest Service and asked respondents about the number of trees on their properties (United States Forest Service, 2021). Nieuwenhuijsen et al. (2022) assessed window views in Barcelona, Spain, by

asking residents whether they could see green elements from their homes. These data were cross-referenced with geolocated tree census data. In addition, data on urban green space proximity has been collected by asking residents whether parks are within walking distance or not (Giles-Corti and Donovan, 2002), as well as the distance to the closest green space (Helbich et al., 2020).

3.1.5. Window-view analyses

Evaluating tree visibility for 3–30–300 requires self-reported or researcher-assisted data, or geospatial and image analysis methods. In addition to questionnaires, image segmentation or object detection can be applied to residents' photographs (Lin et al., 2022) or trees can be manually counted in these images. Another approach is drawing buffers around building footprints and counting trees in a city census (Battisti et al., 2023). A more precise visibility approach using geospatial (e.g., viewshed) and image analysis methods requires three datasets: (1) window location including cardinal direction and exact geolocation, (2) window height including meters above ground level, and (3) terrain information from a digital elevation model or digital surface model, including buildings, trees, and other above-ground features. Zhang et al. (2023) proposed a green window-view index by extracting the green elements of photos taken by respondents from their most viewed windows with the best viewing angle in the daytime. The best viewing angle is relevant since wider fields of view may capture more trees than views farther away (Ko et al., 2023). Additionally, using the GVI model and *v.viewshed.impact* tool with window location and height information, window-view analyses can be performed using a viewshed approach.

3.1.6. Land cover maps

Land cover classification is the physical characteristics of the land into categories, such as tree canopy cover, soil, water, or rock. Summarizing a tree canopy class within neighborhood polygons directly can create the 30 component of 3-30-300. Recent developments in deep learning models and the availability of Sentinel imagery have allowed the creation of global land cover datasets at 10-m² spatial resolution (Table 1). The European Space Agency's WorldCover map, Esri's Sentinel-2 Land Cover Explorer, and Dynamic World (Brown et al., 2022) provide near real-time data (every 2–5 days) to classify areas with trees or assess green space locations. The Environmental Protection Agency (EPA) also provides 1-m² resolution land cover data for select cities currently covering the places where about 70,000,000 people live.

In Europe, the Coordination of Information on the Environment (CORINE) Land Cover (CLC) covers all European Economic Area (EEA) countries (1990–present) (European Environment Agency, 2021). The resolution is limited to a Minimum Mapping Unit (MMU) of 25-ha for areal features and minimum width of 100-m for linear features, making it less suitable for intra-city studies. Another Europe-wide land cover map is the Urban Atlas, available for all EEA cities of >100,000 inhabitants (2006) or 50,000 inhabitants (2012, 2018) (European Commission, 2020), providing an MMU of 0.25-ha for urban classes and 1-ha for rural classes. The Urban Atlas in Europe has included an extra layer for contiguous rows or patches of trees of 500-m² or more and a MMU of 10-m since 2012 (European Commission, 2020) (Table 1). Additionally, some European countries have higher-resolution LULC datasets, including green space class, such as the Dutch land use model LGN 2020 and UK land use data LCM2015 (Table 1).

DSMs from LiDAR, in conjunction with high-resolution imagery such

Table 1
Selected datasets to measure 3-30-300.

Measure	Name	Coverage	Further information
Tree locations	OpenTree.org's database of municipal street and park trees	Street trees in selected Cities	https://opentrees.org/
	Global Urban Tree Inventory	Street trees in selected Cities	https://figshare.com/articles/dataset/Global_Urban_Tree_Inventory_GUTI_vers_1_0_12062634/1
	MIT Senseable City Lab's Treepedia	Street trees in selected Cities	https://senseable.mit.edu/treepedia
Canopy cover	Bluesky International's National Tree Map	United Kingdom	https://bluesky-world.com/ntm/
	ETH Zurich-Barry Callebaut's global canopy height from GEDI LIDAR	Global	https://prs.igp.ethz.ch/research/current_projects/automated_large-scale_high_carbon_stock.html
	Google's Environmental Insights Explorer	Selected Cities	https://insights.sustainability.google/?hl=en-US
	Multi-Resolution Land Characteristics Consortium's NLCD tree canopy cover	United States	https://www.mrlc.gov/data/type/tree-canopy
Urban green space	Local sources	Varies	For example, Chesapeake Conservancy, United States (https://www.chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/lulc-data-project-2022/)
	Multi-Resolution Land Characteristics Consortium's National Land Cover Database	United States	https://www.mrlc.gov/
	GlobaLand30	China	In Chinese: https://www.webmap.cn/commres.do?method=globeIndex
	Commission for Environmental Cooperation's North American Environmental Atlas	North America	http://www.cec.org/north-american-environmental-atlas/
	European Environment Agency's coordination of information on the environment (CORINE) Land Cover (CLC) inventory	Europe	https://land.copernicus.eu/pan-european/corine-land-cover
	Ordnance Survey (OS) MasterMap Greenspace Layer	United Kingdom	https://beta.ordnancesurvey.co.uk/products/os-mastermap-greenspace-layer
	Land Use Database of the Netherlands (LGN)	The Netherlands	https://www.wur.nl/en/research-results/research-institutes/environmental-research/facilities-tools/kaarten-en-gis-bestanden/land-use-database-of-the-netherlands/different-versions-of-databases/ign2018-ign2019-and-ign2020.htm
	Land Cover Map 2015 (LCM 2015)	UK	https://catalogue.ceh.ac.uk/documents/0255c014-1630-4c2f-bc05-48a6400dd045
	U.S. Environmental Protection Agency (EPA)	United States	https://www.epa.gov/enviroatlas/
	European Environment Agency's Urban Atlas	Selected European Cities	https://land.copernicus.eu/local/urban-atlas
Esri's Land Cover	Global	https://livingatlas.arcgis.com/landcover/	
PAD-US-AR	United States	https://www.nature.com/articles/s41597-022-01857-7	
Google and The World Resources Institute's Dynamic World	Global	https://dynamicworld.app/	
Latin American cities urban green space map	Selected Latin American cities	https://www.nature.com/articles/s41597-022-01701-y	

as airborne NAIP or very high resolution satellite images (Sicard et al., 2023), can then be used to create high-resolution ($\leq 1\text{-m}^2$), high-accuracy ($\geq 95\%$) land cover maps for measuring green space locations and canopy cover estimates (Cardinali et al., 2023; Kimball et al., 2014). For example, the University of Vermont Spatial Analysis Lab has completed approximately 90 land cover and tree canopy change mapping projects (MacFaden et al., 2012; O’Neil-Dunne et al., 2012, 2014a, 2014b; University of Vermont Spatial Analysis Lab, n.d.). The combination of LiDAR and high-resolution imagery may be considered the gold standard for urban land cover mapping and in service of the 30% canopy cover measure. Other countries have national LiDAR data coverage, such as the AHN in the Netherlands (Actueel Hoogtebestand Nederland, n.d.) and Digimap (Digimap, n.d.) in the UK. Mobile apps can also leverage some smartphones’ LiDAR sensors to create 3D scans of objects and landscapes. Notable examples are KIRI Innovations (2023) and ForestScanner (Tatsumi et al., 2022). When scaled, these apps may allow communities to create high-resolution 3D maps of trees and vegetation at a lower cost than traditional approaches (i.e., flyovers from low-flying aircraft) (Pace et al., 2022).

3.1.7. Urban green space property boundaries

Several national and regional urban green space GIS data are available to identify the locations of urban green spaces such as parks and other open spaces. These GIS datasets are usually stored in a vector data format (e.g., polygons) that are different from the grid-based land cover (vs. land use) data discussed in the previous section. Browning et al. (2022) recently curated the Parks and Protected Areas Database United States (PAD-US) (U.S. Geological Survey, 2020) to create a PAD-US-AR (PAD-US-[A]ccessible[R]ecreational), specifying parks for public access and outdoor recreation for the U.S. Esri’s USA Parks contains parks across the U.S. (Environmental Systems Research Institute, 2022), and the Trust for Public Land’s ParkServe contains park locations for nearly 14,000 U.S. cities, towns, and communities (Trust for Public Land, 2022). The Urban Atlas in Europe includes a class for urban green spaces at least 500-m² in size and a 10-m MMU (European Commission, 2020). The OS MasterMap Greenspace layer in the United Kingdom provides very high resolution green space data, including multiple green space types (e.g., parks, gardens, amenity space) (Table 1). Outside of Europe

and the U.S., Ju et al. (2022) created a map of urban green space in major Latin American cities. We are unaware of similar data for other low to middle-income countries (LMICs) and nations. However, some LMIC cities have their public park data set locally through city authorities, often created as part of the urban master or strategic plans. For example, the city management authorities have detailed green space data in Dhaka (Labib and Harris, 2018) and Johannesburg (Khanyile and Fatti, 2022).

Globally, urban green space polygons are available from open street map (OSM), which requires a series of user-entered keys (topic/category) and values (features) to map parks and similar areas (i.e., dog parks, playgrounds). The accuracy and consistency of tags vary geographically and are often imprecise, making identifying green spaces difficult (Ludwig et al., 2021). Small, informal open spaces like vacant lots turned gardens are often missed. Nonetheless, Boeing et al. (2022) demonstrated that OSM-based urban green space data could be used in green space accessibility assessments at diverse geographic locations with acceptable accuracy.

Spatial proximity analysis can be used with urban green space data to determine the distances to the urban green space maps for 3-30-300. Distances are operationalized based on “as the crow flies” (i.e., Euclidean) or with more sophisticated analyses taking into account transportation networks (e.g., such as streets) and access points (e.g., centroids or entry points for the urban green space) (Cardinali et al., 2023; Labib et al., 2020a; Wang et al., 2021) (Fig. 3). Calculating Euclidean distances is simple and fast but can be inappropriate when physical barriers exist, such as roads without pedestrian crossings. Euclidean distances often evaluate whether a green space boundary or access point intersects with the 300-m circular buffer around the home. Necessary data for spatial proximity analysis include home location, green space boundary or access point locations, and road networks (Labib, 2021; Wang et al., 2021). Urban green space maps often represent polygonal areas (Wang et al., 2021), but for network analysis, the destination must be a point, ideally related to an access location to a green space (e.g., gate). While the polygon’s center (centroid, Fig. 3) can be used as this destination, this approach might lead to overestimated or otherwise inaccurate distances for larger or irregularly-shaped green spaces (Labib, 2021). Some locations have geolocated access points

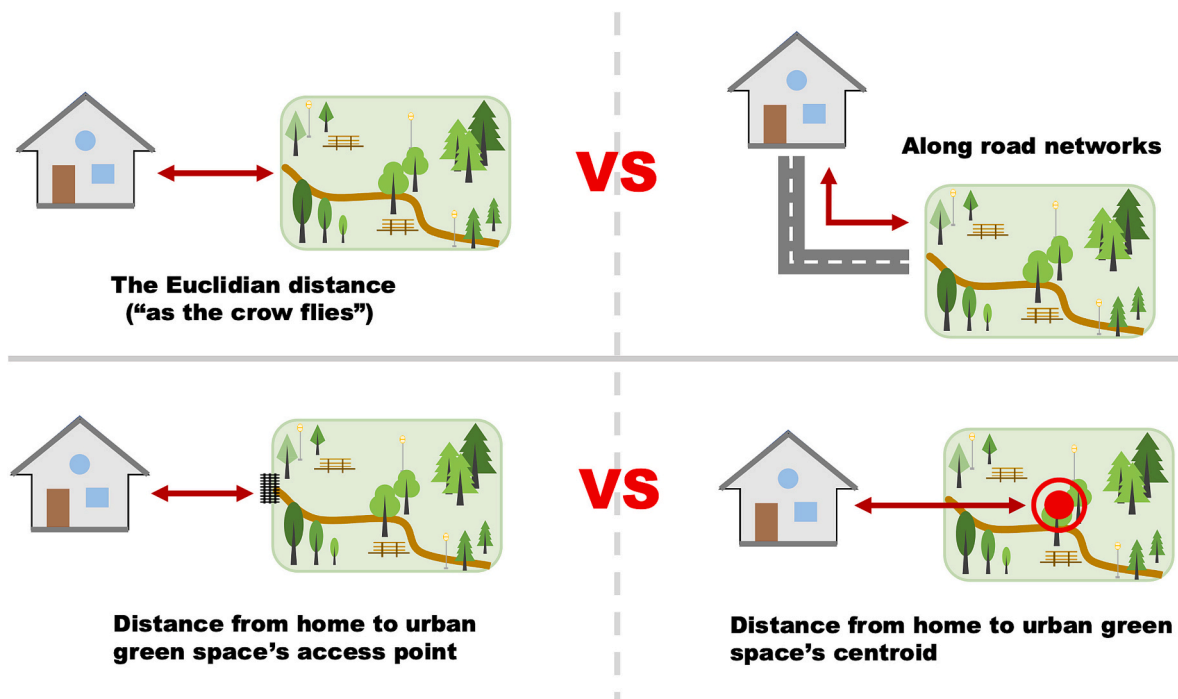


Fig. 3. Calculating distance to urban green space is based on transportation mode (Euclidean vs. network) and access point (formal entry vs. centroid distance).

(Fig. 3), such as the UK Ordnance Survey, and other locations might rely on pseudo-access points created by intersecting the polygon boundary with the road network (Labib et al., 2020a; Wang et al., 2021). Network distances sum the lengths of the street links connecting the origin (home) to the green space. Numerous geospatial software tools such as ArcGIS Pro Network Analyst (esri, n.d.) and QGIS QNEAT3 (Raffler, 2018) as well as programming packages - igraph in C (igraph core team, 2023); NetworkX (NetworkX Developers, 2023) and OSMnx (Boeing, 2017) in Python; and sfnetwork (van der Meer et al., n.d.) and r5R (Pereira et al., 2021) in R - can run shortest path algorithms (e.g., Dijkstra's or A*) (Doran and Michie, 1966). These tools can connect with road network data and routing engines (e.g., MapBox (Walker, 2020) and OSRM (Luxen and Vetter, 2011)) through APIs, and can adopt different cost functions (e.g., distance, time, and composite cost) to find the shortest distances between origins and the nearest green space. The function of the road network (e.g., for driving, walking, biking, or all three) is relevant in these analyses (Boeing, 2017). If walking and biking are the preferred travel modes to green space, highways and other high-traffic roads should be excluded. See Talen (2001) and Cardinali et al. (2023) for additional guidance on measuring walking access to urban green space.

3.2. Suitability of each measure

Evaluating 3-30-300 can require substantial financial and technical resources. From LiDAR-derived canopy cover to professional assessments of urban green spaces, the necessary resources for highly accurate assessments may be out of reach for some municipalities (Hummel et al., 2011). Secondary datasets might be behind paywalls or difficult to process without advanced computing. Such issues are particularly relevant for cities in LMICs and medium-sized and small municipalities elsewhere. Larger cities in more developed countries, with more staff in planning and park management, might have the capacity and know-how to measure the 3-30-300 rule with the "best" metrics (Lowe et al., 2016; Rigolon and Christensen, 2023). The relative imbalance of the subsections describing the state of the technologies and measures used to operationalize 3-30-300 is itself a finding. Some measures are harder to describe than others. Not all aspects of 3-30-300 are well-developed, while others, like high-resolution tree canopy mapping, are well-established industry standards (Kimball et al., 2014).

Table 2 provides an overview of such metrics as well as our expert-based consensus on the suitability of each metric (i.e., best, fair, poor, or unknown). We present the heterogeneity in the quality and availability of data to measure and evaluate 3-30-300. Researchers and practitioners may still be well-served by selecting less-than-ideal metrics than none at all. If data and computational resources are available, questionnaires and window-view analyses are best for assessing the visibility of 3 trees, high-resolution land cover maps are best for measuring tree canopy cover, and urban green space property maps with network analyses are best for the 300 component.

Table 2
Suitability of measures for each component of the 3-30-300 rule.

	Suitability		
	3 trees	30 % canopy	300-m distance
Vegetation indices	Poor	Fair	Poor
Street-level analyses	Fair	Poor	Poor
Tree inventories	Fair	Fair	Poor
Questionnaires	Best	Unknown	Fair
Window-view analyses	Best	Poor	Poor
Land cover maps	Fair	Best	Poor
Urban green space property maps	Poor	Poor	Best

4. Discussion

4.1. Overview on measuring 3-30-300

Implementing the 3-30-300 rule requires thorough measurement, monitoring, and evaluation methods, yet little guidance is currently available to pursue these actions. To overcome this gap, we employed an expert-based consensus approach to identify ways to measure the 3-30-300 rule of equitable green space access and availability. We also evaluated each measure's strengths and weaknesses and created a suitability matrix for which measure could be used for which component of the rule. Through virtual discussions from October 2022 to July 2023, we presented seven relevant data and processes for this goal: vegetation indices, street level analyses, tree inventories, questionnaires, window view analyses, land cover maps, and urban green space maps. Furthermore, based on the available data and techniques available through July 2023, we identified the following measures as the best option for each component of the rule: questionnaires and window-view analyses for the 3 component of the rule, high resolution land cover maps for the 30 component, and urban green space property maps with network analyses for the 300 component.

4.2. Considerations on measuring and adopting 3-30-300

Regardless of how the 3-30-300 rule is measured, each component might have varying degrees of applicability in specific geographic, economic, social, political, and cultural contexts. For example, old European cities, sprawling North American metropolises, new cities in China, and megacities in Latin America and Africa with informal settlements have different building densities, planning policies, transportation infrastructures, zoning requirements, and governance systems. Select components of the rule may not always be reasonable or warranted, given that increasing nature access has some opportunity costs (Rigolon et al., 2018; de Souza and Torres, 2021; Torres et al., 2022). McDonald et al. (2022) provided evidence that urbanization and greenery have competing trade-offs, both with benefits for sustainability and human health. Still, numerous greening interventions have been successful at allowing neighborhoods to be both dense and green in diverse settings. For instance, new urban models during the COVID-19 pandemic enabled city streets to serve some of the same functions as urban green spaces, such as superblocks (Barcelona, Spain) and car-free neighborhoods (Freiburg, Germany) (Nieuwenhuijsen, 2021). Therefore, seeking to meet the components of 3-30-300 may need to be approached with care and creativity. In the section below, we discuss the difficulties and opportunities across geographic contexts for applying and measuring 3-30-300.

4.2.1. 3 and 30 components

Regarding the 3 and 30 components, many high-density neighborhoods may lack sufficient plantable space. Examples of such places, common to many European cities, eastern U.S. and Canadian cities, and Asian megacities, often have dense apartment buildings, no yard space, and little room for trees outside of public streets or small parks (Schwab, 2009). In such neighborhoods, achieving a smaller threshold of canopy cover (e.g., 15 %) could constitute a significant achievement in nature access (Pataki et al., 2021).

Climate and climate change might also limit the degree to which the 30 component could be achieved. This threshold might be an unrealistic and unattainable goal in climates with water restrictions (Begert, 2022; Pincetl et al., 2013; Schwab, 2009), such as dry cities in the Middle East, North Africa, the U.S. Southwest, northeastern China, and Australia. For example, the city of Las Vegas (Nevada, U.S.) aims to achieve a 20 % canopy cover by 2025, an ambitious goal that would double its most recent estimate of 10 % cover (City of Las Vegas, n.d.). In cities facing water scarcity outside of forested biomes, concentrating on 30 % vegetation cover (rather than tree canopy) may be more appropriate, as well

as focusing on native or drought-tolerant plants. Alternative measures to those suggested for 3-30-300 may be appropriate in these regions, including a modified soil-adjusted vegetation index (MSAVI) (Qi et al., 1994) and fractional vegetation cover (FVC; percent vertical projection of branch, stem and leaves in an area) (Gitelson et al., 2002; Purevdorj et al., 1998).

Acceptance of new trees might also vary across populations, further hindering a city's capacity to achieve the 3 and 30 components. Some racial/ethnic minority populations in the U.S. have rejected tree planting programs because there was not enough community engagement before planting, and due to legacies of municipal disinvestment, insufficient mature tree maintenance, and associated burdens (Carmichael and McDonough, 2018, 2019; Riedman et al., 2022). Similar barriers have been seen in European cities (Henley, 2023). Also, in the U.S., tree planting is often performed by cities or counties, but watering and upkeep are delegated to residents, with some exceptions (Carmichael and McDonough, 2018, 2019; Riedman et al., 2022), creating additional barriers to tree planting and maintenance. In these cases, municipalities may maintain newly planted trees on private lands, facilitate programs for individuals, organizations, or companies to maintain trees along a road segment, or compensate residents for planting and maintaining new trees. In the recently released urban forest plan for Philadelphia (Pennsylvania, U.S.), investing in the maintenance of existing trees (including proactive inspection cycles and removal as appropriate) was framed as crucial to building trust and interest in new plantings (Philadelphia Parks and Recreation, 2023).

Finally, the 3 and 30 components do not mention quality assessments of the trees (i.e., biodiversity, tree health), nor do they assess management and long-term likelihood of survival of trees that are being planted (Hilbert et al., 2019). Cities implementing 3-30-300 may also improve genus and species diversity by focusing on native species that are climate-change tolerant for particular areas (Which Plant Where, 2023). For instance, cities could combine 3-30-300 greening efforts with other heuristics such as the 10/20/30 benchmark (Santamour, 1990) suggesting municipal forests diversify with no more than 10 % of any one particular species, 20 % of any one genus or 30 % of any single family. Other measures are also relevant, like the Shannon Diversity Index (a species diversity calculation) (Kendal et al., 2014), Pest Vulnerability Matrix (an urban forest vulnerability calculation), and aesthetic evaluations of canopy distributions and shapes (Hu et al., 2022).

4.2.2. 300 component

The feasibility of the 300 component may be dependent on population densities, financing systems for green spaces, and political will to fund urban green space. Low-density cities where the primary transportation mode is the automobile might be unlikely to achieve this threshold. Despite the U.S. goal of everyone living within 10-min walk (800-m) of a park (Trust for Public Land, 2023), very few cities (San Francisco, CA being the notable exception) have met this goal (Land, 2019). Estimates of how many U.S. residents live within a 10-min walk of a park vary between 33 % and 75 % (National Recreation and Park Association, 2022; Trust for Public Land, 2023). Because of relatively low population densities and low tax bases in U.S. cities, it might be unattainable to have a park within 300-m of every resident. The same limitation in achieving the 300 component might apply to car-dominated, low-density cities in Canada, Oceania, Europe, and Asia.

The 300 component also does not specify visitation, green space use, or quality. Residents might choose to travel farther from their homes to reach a larger green space or that has the amenities they are looking for (e.g., a sports field) rather than visiting a green space that is within 300-m of their homes. Some studies have shown that park amenities, not proximity, are associated with park visitation (Kaczynski et al., 2014). Many people in North America choose to drive to parks instead of walking (Loukaitou-Sideris and Sideris, 2009; National Recreation and Park Association, 2018). Green space visits are associated with better mental and physical health; they may be a better indicator of health

benefits than accessibility indicators (Triguero-Mas et al., 2017b). To this extent, the increasing use of self-report and GPS tracking green space visitation data may need to be cross-referenced with green space accessibility for meaningful measures of the 300 component (Triguero-Mas et al., 2017a). Additionally, cities can use participatory processes to define future green space to increase the likelihood of acceptance and use by residents (Loukaitou-Sideris and Mukhija, 2023; Mattijssen et al., 2018a, 2018b; Mell, 2020; Rigolon, 2018). Since green space visitation may be influenced by pressure and crowding (Westover and Collins, 1987), green space cover per capita can be considered a factor in use and subsequent benefits (Larson et al., 2022). Relatedly, green space quality may factor into visitation and observed benefits, so professional on-site assessments and delineations through instruments like the 90-item RECITAL survey can refine the extent to delineate the "high-quality" green spaces qualifying for meeting the 300 component (Knobel et al., 2019, 2020).

4.3. Limitations of review

Due to the expert-based consensus approach, the reported measures, their strengths and weaknesses, and the suitability matrix may not provide a comprehensive listing of the recommended options for measuring 3-30-300. Many of the reviewed measures have also not been tested against each other. Future research should incorporate multiple measures within the proposed "fair," "best," and "unknown" cells of the suitability matrix (Table 2) to determine their reliability and validity across geographic and sociopolitical contexts. Data and processes for measuring environmental exposures are also developing rapidly. Readers should continue to follow relevant bodies of literature for emerging ways to measure 3-30-300. At the same time, newer approaches should be vetted as we've done here (expert-based consensus) or through validation studies with established approaches, such as the "fair" and "best" measures in our suitability matrix, to refine the recommendations presented.

5. Conclusion

The UN Sustainable Development Goal 11 Target 7 recommends universal access to safe, inclusive and accessible green and public spaces. The 3-30-300 rule provides a set of objective, universal benchmarks for cities to determine how they fare on urban green space proximity, tree canopy coverage, and access, as well as where to target investments for the future. Seven well-defined categories of data and processes to measure 3-30-300 are available, including vegetation indices, street level analyses, tree inventories, questionnaires, window view analyses, land cover maps, and urban green space maps. Based on available data and current techniques, our expert-based consensus suggests questionnaires and window-view analyses for the 3 component, high resolution land cover maps for the 30 component, and urban green space property maps with network analyses for the 300 component. These data and processes can inform targeted investments in urban greening for health, equity, biodiversity, climate adaptation, and aesthetics. Decisions should be responsive to local conditions and available resources, with 3-30-300 representing a starting point for broader discussions about local needs and wants. 3-30-300 can serve as a powerful catalyst for action to address disparities in nature access and improve the health, equity, and well-being of our communities and cities.

CRediT authorship contribution statement

M.B. and D.L. conceptualized the study. All authors contributed to the methodology, investigation, data curation, and writing of the original draft as well as review and editing. H.L. and S.M.L. created the visualizations for the study.

Declaration of competing interest

C.K. developed the 3-30-300 rule but holds no financial stake or conflicts of interest in how it way is measured. No other authors report conflicts of interest.

Data availability

No data was used for the research described in the article.

Acknowledgments

The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA, U.S. Environmental Protection Agency, or U.S. Government determination or policy. Any mention of trade names, products, or services does not imply an endorsement by the U.S. Government. The authors also extend thanks to the anonymous reviewers who assisted in improving an earlier draft of this manuscript.

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