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Equity in Green Space Planning and Management

Synthesis study on data availability for the development of a Socio-Ecological Index

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Report 2025

Publisher
SLU Movium Think Tank / SLU Tankesmedjan Movium
movium.slu.se

DOI https://doi.org/10.54612/a.7h5gdnod5n
ISBN (elektronisk version): 978-91-8046-610-3

Place of publication
Swedish University of Agricultural Sciences. Department of Landscape Architecture, Planning and Management. Alnarp, Sweden.

Keywords
Green space Equity, Socio-Ecological Index, Urban Green Space (UGS), Spatial Planning, Environmental Justice.

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STAD & LAND

This report is published in SLU Movium Think Tank's book- and report series Stad & Land with number 203

Summary

As cities densify to meet environmental and economic goals, the equitable distribution of urban green spaces (UGS) becomes critical for fostering community well-being, promoting environmental justice, and enhancing climate resilience. This report presents a synthesis study conducted by the Swedish University of Agricultural Sciences (SLU) in collaboration with Nilsson Landscape, aimed at understanding the relationship between socio-economy and accessibility to UGS, to assess and enhance green equity in urban environments. The research focuses on Malmö specifically, and have involved Region Skåne as a proxy for other municipalities in southern Sweden, leveraging data on green space access, canopy cover, socio-economic indicators, and maintenance costs.

The primary objective of this study was to establish a data-driven, replicable framework that quantifies green space equity at the city district level. Specifically, the research seeks to (i) identify key indicators of green space availability and socio-economic status that can be measured consistently across Swedish municipalities; (ii) develop a composite relationship (a matrix or an index) that integrates these indicators to provide actionable insights for urban planners and policymakers, and (iii) to test the applicability of this index in Malmö, illustrating its potential to guide future investments in UGS for equitable urban development. The research integrates three complementary initiatives:

i. KSLA Project: A synthesis of socio-economic and green space factors relevant to equity in urban environments.

ii. FoMA Project: Development and testing of green space indicators, including canopy cover, urban green space per capita, and distance to the nearest green space, in relation to socio-economic metrics like income, education, and employment.

iii. Movium Partnership: Evaluation of the Green Equity Matrix, a tool that categorizes neighborhoods based on their socio-economic status (SES) and green space status (GSS), and explores policy implications and maintenance costs.

The ambition to develop a matrix or an index aligns with international models such as the Tree Equity Score and Spatial Equity NYC but adapts them to the Swedish context, where socio-economic factors and access to UGS are measured differently. Data sources include GIS-based analyses, municipal records, and socio-economic data from Statistics Sweden. All computations of UGS rely on open datasets, which are updated at varying frequencies but not always regularly. All the SES data is easily accessible and reliable, and available at DeSO level.

A Green Equity Matrix was developed, including seven indicators 'UGS per capita', 'canopy cover', 'distance to UGS' as Green Space Status (GSS) indicators, and 'age dependency', 'income', 'education level', and 'employment rate', as Socio-Economic Status (SES) indicators. Each indicator was computed and combined into two individual indexes. All indicators are combined unweighted, meaning they are treated equally when combined.

Contrary to widespread assumptions, our analysis reveals that neighbourhoods with lower SES often have higher GSS in Malmö. Lower SES neighbourhoods in Malmö were often developed around the 1960'es and early 1970'es (the Million Program), where larger parks and green spaces were prioritized. As such, we believe these areas have benefited from earlier planning efforts aimed at providing green amenities to balance socio-economic disadvantages, and that the effects of these efforts are still notable in a Swedish context like in Malmö. However, while higher GSS in lower SES areas is a positive finding, it does not necessarily reflect equitable quality or functionality of green spaces. Socio-economic disparities might still influence the usability, safety, and maintenance of these green areas, affecting their actual benefits to residents.

We calculated maintenance cost in DeSOs characterized by both low GSS and low SES. Here, costs range from 24 to 335 SEK per capita, with an average in Malmö being 448 SEK per capita. Even though we indicate a relationship between low SES and low maintenance cost, we recognise the need for better data, including a calculation based on actual use, rather than cost per capita. However, such data is not available today.

The actual quality of UGS should be further explored and considered incorporated into or related to the matrix. This will ensure that green space interventions align with the needs and preferences of residents. In line with this, local governments' capacities to develop such indices should be explored too. However, the use of accessible data in combination with relatively simple GIS-based socio-ecological analysis has been prioritised for this project. Thus, our proposed method does not require advanced GIS skills, making it accessible for all municipalities.

The suggested method ranks neighbourhoods within a municipality or urban area, meaning the GSS and SES results cannot be directly compared across different municipalities or urban areas. However, metrics such as the percentage of neighbourhoods within each quadrant or within a certain standard deviation can still be used for comparisons with other municipalities or urban areas.

Our new and nuanced understanding of the relationship between SES and GSS challenges the conventional narrative that socio-economically disadvantaged neighbourhoods lack access to green spaces. Instead, it highlights the need for context-specific urban planning and management that recognizes both the strengths and challenges of different neighbourhoods.

Keywords: Green Space Equity, Socio-Ecological Index, Urban Green Space (UGS), Spatial Planning, Environmental Justice

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1. Introduction

There are many valid arguments for the development of densified cities. EU has, since the initial discussions about a joint European urban policy (see e.g. the European Regional Development Fund, ERDF), argued for denser cities as a response to urban sprawl. Currently ERDF will enable investments to make Europe and its regions more competitive and smarter, greener, more connected, more social and closer to citizens. However, cities also produce some of the largest greenhouse gas emissions, and a large proportion of this relates to traffic (Pichler et al. 2017). To reduce traffic gas emissions, and to capitalize the limited urban land, the concept of compact cities has been proposed (Kain et al. 2022). However, densification and compact cities also comes with a cost, especially to vegetated land such as green spaces, parks and urban forests. A compact city with large areas of paved surfaces is a vulnerable city when the surface cannot absorb water from storm events, (Qiao et al. 2019), or when there is not enough space to plant trees to provide shade (Esperon-Rodriguez et al. 2022). On top of this comes negative effects on human health and well-being, as it has been widely documented that trees and green spaces are beneficial to both, particularly for socio-economically vulnerable citizens (see e.g. WHO 2020).

The challenge is to develop a city, which is both dense and green. Nordic cities should be frontrunners when it comes to urban development, which promotes both climate adaptation, human health and well-being and an equal access to green space. To meet this challenge, there is a need for farsighted policies, backed by consistent planning and management based on documented scientific and practical experience.

This report presents a pre-study carried out at the Swedish University of Agricultural Sciences (SLU), Department of Landscape Architecture, Planning and Management aiming at developing the basis for an Index for equity, based on accessibility to green spaces and trees in a Southern Swedish context. The report is based on three individual projects, developed and run in parallel during 2024 (see section 1.2).

1.1 Purpose and objective

The overall purpose is to understand the relationship between urban green spaces (UGS) and socio-economic factors, in order to describe how equal or un-equal the accessibility to green spaces in modern cities are. Based on this, the development of a quantitative tool for urban planners and decision makers is an aim. With such a tool, we envision to apply an inclusive perspective to planning and management of public green spaces. This specific project has synthesized how accessibility to UGS links to a larger socio-economic perspective defined by a number of equity dimensions such as employment rate, and residence income. The objectives of this project have been to assess:

(i) which factors can describe green equity at a city district level

(ii) which of these factors are readily available at a municipal scale

(iii) to test how the selected factors can generate a preliminary outset for an Index to be used for future green space planners and managers to prioritize what and where to invest in green spaces, for the sake of a just and equal future city development.

An important element of creating such an Index is to assess the actual capabilities, meaning organizational structures, knowledge, resources, rules and regulations related to the wider application and implementation. Such aspects are meant to be included in the next steps of this project, based on larger projects potentially to be funded by e.g. Formas. During the finalization of this project, a 6 million SEK research application has been submitted to Formas annual call 'Explore', with a decision of funding to be made during 2025.

1.2 Three initiatives that complement each other

This project was performed by a research team from SLU, Department of Landscape Architecture, Planning and Management (Thomas B. Randrup, Neil Sang and Agnes Pierre), and Dr. Kjell Nilsson from Nilsson Landscape. Strategist Ludwig Sonesson, Malmö Stad, and landscape architect Karl Magnus Adielson, Region Skåne, represented practice in advisory roles. Further Malmö and Region Skåne have acted as testbeds, and have provided data and GIS analysis in close collaboration with the research team. The three projects which have been funded and performed in parallel are:

iv. *Equity in Green Space Planning and Management – synthesis study on data availability*, funded by The Royal Swedish Academy of Agriculture and Forestry (KSLA)

v. *Development of a Greenspace Equity Index*, funded by SLU's environmental monitoring and assessment program for the built environment (Fortlöpande miljöanalys - FoMA)

vi. *Den gröna infrastrukturens roll ur ett jämlikhetsperspektiv*, funded by Movium Partnership

The KSLA project focused on synthesis of existing knowledge related to green justice and relevant equity factors, specifically aimed at socio-economic factors and green space factors. Further, this project tested which factors were readily available in practice.

The FoMA project developed the selected green space indicators and tested these against the selected socio-economic indicators on a city district level in Malmö. We called this approach the 'Green equity matrix'.

The Movium Partnership project tested the Green equity matrix, based on which DeSOs scored high/low in socio-economy, against which DeSOs scored high/low in relation to green availability/accessibility. In the Movium project, we also performed an initial policy analysis in combination with a green space maintenance cost analysis.

See Figure 1 for an illustration of the relationships between the three projects.

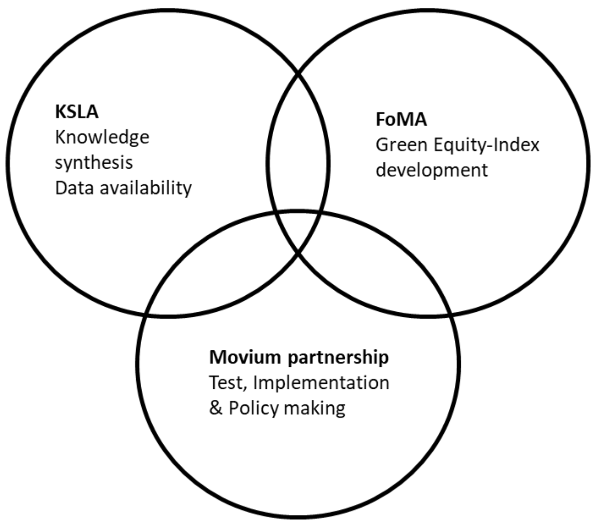


Figure 1. Indications of key focus areas in relation to each of the three projects behind this report. All three project ran in parallel and complemented each other.

2. Background

2.1 Importance of green spaces

The importance of providing urban green space (UGS) close to where people live has long been mentioned in research, city planning and policies (e.g. Region Skåne 2024; Stanners & Bourdeau 1995; WHO 2020), as a short distance to green space is associated with increased use and improved human health and well-being (Grahn & Stigsdotter 2003; Konijnendijk 2022; Nilsson & Grahn 2024; Toftager et al. 2011). While the benefits of green spaces are both manifold and well established, its relationship to social and spatial inequalities is less so (Brooks & Davoudi 2018). Several studies have documented inequalities in population exposure to UGS. E.g., poverty levels in the USA were negatively associated with distances to parks and percentages of green spaces in urban/suburban areas, and in a Norwegian context, Venter et al. (2023) found that poorer citizens were surrounded by less urban nature and were more exposed to air pollution and heat, than more well off residents.

To fulfill the many benefits of UGS, a multi-functional approach to planning and management is needed; supporting recreational purposes; preventing biodiversity loss; adapting to a changing climate; promoting human health and well-being; supporting human rights and promoting social justice and integration. Thus, planning and management of UGS can be described as a ‘wicked problem’ (Head 2022; Rittel & Webber 1973), requiring coordination of opposing interests within limited budget frames. Addressing and prioritizing the many contemporary societal challenges in local government planning and management requires strategies (Randrup & Jansson 2020), and tools for well-informed decision-making (Randrup et al. 2024).

The study of inequality in how environmental benefits and burdens are distributed, often influenced by factors like class, income and health status is denoted as environmental justice. It underscores the uneven distribution of environmental assets, such as e.g., green spaces and liabilities, such as e.g. waste sites, with marginalized communities typically facing the brunt. Environmental justice has emerged as a concept to promote increased recognition and to consider the ability of certain groups to participate and influence decision-making, and also to be recognized as legitimate actors in the process (Scott 2014).

UGS planning and management are key processes affecting the degree to which such decision-making is provided in the urban environment (Jansson et al. 2020). Recent research indicated that due to the complexity of UGS and planning's impact on different stakeholders, the complexity of the involved infrastructures, institutions, and perceptions still need to be addressed (Kronenberg et al. 2021), and while some improvements in this respect has recently been found among European city planners, Hansen et al. (2023) concluded that considerable work remains to be done.

In a European context, national and local governments are perceived to have the main responsibility for developing green space policies (Slätmo et al. 2019), while implementation of strategies for publicly accessible spaces in urban areas most often lies at the local government level (Carmona et al. 2004). This also accounts for the Nordic countries (Randrup & Persson 2009), which Davies et al., (2015) even described as belonging to their own 'planning family' representing a comprehensive integrated coordination of spatial impacts of public policies by the frame of strategic documents and plans. Regional actors can also support green space initiatives by implementing policies that align municipalities within a county toward common goals. In the context of Skåne, Region Skåne has outlined this priority in its regional development strategy (Region Skåne 2024) and regional plan (Region Skåne 2022), both emphasising the importance of green spaces and their connection to health.

To promote an equitable just green city, the 3-30-300 rule has recently been promoting the planting of minimum three trees in front of every home or work place, a minimum of 30% canopy cover on a district level, and a maximum distance of 300 meters to the nearest green space (Konijnendijk 2022). This rule has been widely applied globally, including in Sweden (https://se.thegreencities.eu/fakta-om-3-30-300/), promoting a generic planting of urban trees. However, the rule does not take the potential in-equality aspect into consideration in terms of distinguishing between city districts with more socio-economic deprivation, compared to others. This is, should be, and will be a decisive factor in local government planning and management, prioritizing among infrastructures, institutions, and perceptions.

During recent years, indexes to describe socio-economic factors in relation to various green space factors have been developed and promoted, not at least in a North American context (see e.g. https://www.treeequityscore.org/ or https://www.spatialequity.nyc/). Such tools can serve as inspiration, however in a Swedish context, specific socio-economic factors are likely to be derived and calculated differently, just as certain factors may apply more in a US context than in a Swedish well-fare context. Likewise, many Swedish urban agglomerations are indeed green (forested), but how the accessibility and relevance of these green areas can be indexed, assessed and measured in an environmental justice context is unknown.

The importance of green spaces and their impact on health has been emphasized in national and international frameworks of goals addressing urban ecosystems. These include Sweden's environmental quality objective *Good Built Environment* and the sustainable development goals *Sustainable Cities and Communities* and *Life on Land* outlined in Agenda 2030. Sweden has committed to pursuing these goals at both national and local levels. The EU has in 2024 implemented the first law focusing on the restoration of ecosystems, habitats, and species to enhance environmental resilience and health. The Nature Restoration Law includes aims to implement actions that stop the reduction, and both restore and increase previously lost UGS and trees. The law suggests, among others, that on a national level, there shall be no net loss in the total national area of UGS and urban tree canopy cover by 2030, just as there should be an increasing trend in UGS and urban tree canopy cover after 2031. This is likely to be seen as a major challenge for most municipal planning and management authorities as in Sweden there are no standardized means or methods developed to monitor UGS. Likewise, Swedish planners and managers do not have the means to assess and describe socio-economic factors in relation to UGS. Thus, to make qualified decisions when new investments are made, and in order to obtain a more just and equal distribution of UGS there is a need to assess both UGS and socio-economic factors, and to enhance the capacity of Swedish municipalities to prioritize the available investment in UGS within their planning and management processes.

2.2 Models to be inspired by

If we want to limit ourselves to a single index, it is natural to glance at the Gini coefficient. The Gini coefficient is a statistical measure of inequality, often used to represent income or wealth inequality within a population. The method was developed by the Italian statistician Corrado Gini in a paper *Variabilità e mutabilità* (English: variability and mutability) published in 1912 (Gini 1912). The Gini coefficient is derived from the Lorenz curve, which shows the distribution of a variable (e.g., income) across a population. The Gini coefficient ranges from 0 to 1, where 0 represents perfect equality, where everyone has exactly the same income or wealth. One (1) represents perfect inequality, where one individual or group has all the income or wealth, and everyone else has none.

The Gini coefficient is usually defined mathematically based on the Lorenz Curve (Figure 2), which plots the proportion of the total income of the population (y-axis) that is cumulatively earned by the bottom x of the population (see diagram). The line of equality is a diagonal line that represents perfect equality. The more the Lorenz curve deviates from this line, the higher the Gini coefficient, indicating greater inequality. The Gini coefficient is calculated as the ratio of the area between the line of equality and the Lorenz curve to the total area under the line of equality.

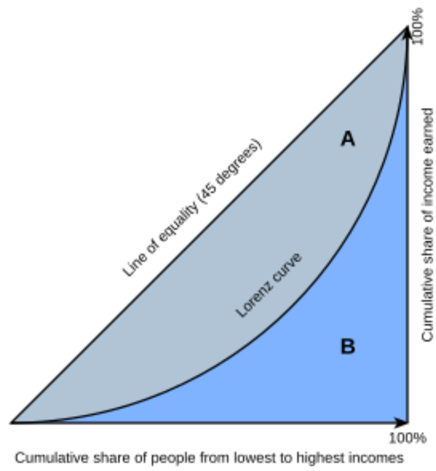


Figure 2. The Gini coefficient is equal to the area marked A divided by the total area of A and B, i.e. Gini = A / A + B.

The Gini coefficient is primarily used by economists and policymakers to assess inequality, and can help in comparing inequality levels between countries or regions. The Nordic countries still have one of the lowest Gini coefficients within the OECD, but it has increased sharply over the past 20 years. Within the Nordic Region, inequality is largest in Greenland and Sweden, while it is least in Norway and the Faroe Islands. Municipalities with a particularly high Gini coefficient are Danderyd, Lidingö, Gentofte, with values between 0.5 and 0.6, while several municipalities in Norwegian Trøndelag are at 0.2 and below (Norlén et al., 2024). For Malmö, the Gini coefficient for disposable income in 2022 was 0.33.

As a single metric, the Gini coefficient does not provide details about the nature of inequality (e.g., whether it is due to poverty or extreme wealth concentration). Therefore, the Gini coefficient is a helpful snapshot of inequality but works best when combined with other metrics and analyses. In a recent systematic review, Martin & Conway (2025) found 41 articles where Gini coefficient has been used to describe distributional justice with regards to UGS. More than half of them included case studies from Chinese cities, one fourth included US case studies while the remaining quarter included cases spread all over the world.

One may regard the Gini coefficient as a baseline inspiration for many related indexes or matrix' focusing on inequality. In the following, we present a number of studies which have developed a relationship or an Index to describe an area's socio-economic standard or has worked on showing an overall value of the residents' access to greenery. In several of the studies, the authors have worked with both socio-economic indicators and indicators related to access to UGS, while other studies have only focused on producing a socio-economic Index or a green space score.

Two of the methods are established and used in practice by various cities around the world (3-30-300, Tree Equity Score). Three are developed for American cities (Tree Equity Score, NYC, Philadelphia), the first of which covers all US cities, the second is specifically developed for New York, and the third, which refers to a research study and as such is not a practically applied tool, is developed with Philadelphia as a case study. Of the other six, one is a specific assignment for Malmö municipality on heat vulnerability, two are assignments for Region Skåne (3-30-300 and on social segregation), and one is a Swedish degree project, also on heat vulnerability. Finally, of the three Nordic projects included, one is a research project (NORDGREEN), one is a consulting assignment (Yggdrasil) and the other is a well-established method for measuring regional development (RPI).

2.2.1 The 3-30-300 rule in Skåne

Here, we present the 3-30-300 rule, as it has been applied in Sweden and specifically in the region Skåne. We emphasise the methodological approach (Region Skåne 2023) in detail as we have used the work from Region Skåne on the 3-30-300 rule as an outset in this study.

The 3-30-300 model, developed by Konijnendijk (2022), consists of the following three guidelines for urban greenery: from the home you must be able to see at least three trees and the distance to the nearest green area must not be more than 300 meters. In addition, the canopy cover rate in the neighborhood must be at least 30%.

As part of the implementation of the Regional Plan for Skåne 2022-2040, the Regional Authority has applied the 3-30-300 rule in nine urban areas in Skåne, including Malmö (Region Skåne 2023). The geographical demarcation has been made up of Statistic Sweden's urban area boundaries plus 300 metres. Within the urban areas, the demographic statistical areas (DeSO) that were established in 2018 were used. The analysis was carried out by the companies Spacescape and Geografiska Informationsbyrån.

For visible trees and degree of canopy cover, two methods were used:

i. A vegetation height grid (developed by the company Metria on behalf of the Swedish National Board of Housing, Building and Planning). Skåne was included in the study as one of the test areas and resulting data layers with vegetation heights in the following height classes have been used: 5-10 m, 10-20 m, 20-30 m and 30-45 m.

ii. For individual trees (in point form), The Swedish Geodata Agency's national program Laserdata Skog (developed by the Swedish Forest Agency) was used.

A ‘tree height map’ was made to contain vegetation taller than five meters and with a canopy diameter of over two meters. A comparison between the two models resulted in the vegetation height grid being found to be most suitable for analyses at urban and district level. The percentage of tree points that were represented in the vegetation height grid was around 90 and 85 percent in Hässleholm and Ystad, respectively. This data is freely available for all urban areas in Skåne.

3 visible trees

The starting point for "3 trees within sight" is that at least three trees must be visible at ground level from the outside of the facade around a building. The method consisted of 8 steps from selection of canopy cover data, buildings, zoning to modelling.

The regression analysis showed that, on average, about 200 square meters of canopy cover is enough to meet the goal of three visible trees. But that presupposes an optimal placement of the trees, which in reality means that for three trees to be visible from 80-90% of the buildings, it corresponds to a canopy cover of 500 square meters. The result for the nine municipalities is that, on average, half of the buildings meet the requirement that they have access to at least three visible trees with 90% certainty. For 25% of the buildings there is less than 50% security and for the remaining quarter between 50 and 90 percent. Among the municipalities, Lund is at the top with 60% and Kristianstad the lowest with just over 30%. It should be noted that newly planted trees were not counted, which means that most newly built areas are classified as areas lacking three visible trees.

An alternative analysis can be carried out, using trees and buildings in vector form.

30% canopy cover

A comparison of the degree of canopy cover gave an eight percent larger area in Hässleholm when using a vector-based model compared to a raster-based model, while for Ystad it did not make any difference.

Statistics Sweden's latest mapping of green areas is from 2015. Because much has been built and changed since then, it is partly out of date. In addition, the urban area boundaries have been updated in 2020, which means that the mapping from 2015 is not comprehensive. Further, WHO uses the Urban Atlas, which creates harmonized maps of land use in hundreds of cities and their surroundings. However, it does not cover Skåne’s urban areas comprehensively.

Statistics Sweden distinguishes between green space and green areas, where green space is defined as "All types of green areas that build up the collective green structure within the urban area boundary. These can be public parks and open grass areas as well as other areas covered with trees or grass, green areas left over during construction (impediment), residential gardens, green areas between apartment buildings or industrial buildings and also green lanes between roads, etc. Green space is further broken down into the subcategories of open land and forest." (Statistics Sweden, 2020b) while green areas are defined as "an area of contiguous green spaces that amounts to at least 0.5 hectares and is publicly accessible. Pasture is counted as green areas, but not arable land. Green areas are geographically delimited to within the urban area and within a surrounding area from the urban area boundary, and three kilometers out." Decisive is whether the land is publicly available or not. Cemeteries and schoolyards are included, but not home gardens, housing estates, allotment gardens and sports fields.

In the statistics, the green areas are grouped by size 0.5-3 hectares, 3-10 hectares and 10 hectares and larger. The minimum accounting unit is 0.5 hectares and 30 meters has been set as the minimum width to screen out grass strips along roads that lack social values.

The mapping was based on open data from the Swedish Geodata Agency, Statistics Sweden, the Swedish Board of Agriculture, the Swedish Environmental Protection Agency, the Swedish Transport Agency and the Open Street Map. It contained 12 steps, as explained by Region Skåne (2023).

The degree of canopy cover was measured within DeSOs, 50-meter grids and within 300 meters of buildings. The motive for a combination is that a forest may be close to urban areas and/or placed inside the urban area boundary. As many DeSOs extend beyond the town boundary, these must be adjusted at the town boundary. Calculation of the proportion of canopy cover within DeSOs and 50-meter grids is so-called zonal statistics in QGIS with the statistical areas as zones and the raster mask as input.

In general, the canopy cover in Skåne was found to be significantly lower than 30%. As an average value measured in 50-meter squares, Ängelholm tops with just under 15% and with Trelleborg at the bottom with just under 6%. Only one percent (4 out of 400) of the DeSOs reach a canopy cover rate of 30%.

An alternative that puts people more at the center is to measure the degree of canopy cover within a 300 meter radius from the residential buildings. Only three percent of the residential buildings have a surrounding canopy cover of at least 30%, 10% have a surrounding canopy cover of at least 20% and just under half (46%) of at least 10%. Among the municipalities, Hässleholm and Ängelholm have at least 20% canopy cover within 300 meters for respectively 27% and 25% of the number of homes, while the corresponding figures for Malmö and Trelleborg are as low as 2% and zero percent.

300 m to nearest green area

Proximity to the nearest green area has been measured as direct distance between building and the green space ('as the crow flies'). The mapped green areas are buffered by 300 meters and then the proportion of residential buildings that are within this buffer is calculated. A buffer of 200 meters was also studied.

The results show that 97% of the homes in the nine municipalities are within 300 meters of a green area. In Lund, Landskrona and Kristianstad it applies to all homes, while Malmö is the lowest with 92%. At 200 meters distance, the target fulfillment is still very high (87%), with Lund and Hässleholm at the top with 95% and Malmö clearly the lowest with 77%.

The project also analysed green assets in relation to socio-economic status and states that there are no clear relationships between green assets and socio-economics. Another common perception is that neighborhoods with many poor and low-educated people have less access to greenery.

Target fulfillment for the 3-30-300 standard varies widely. It is very difficult to achieve for 30% canopy cover, relatively low for 3 visible trees (which is also difficult to measure), while virtually all homes meet the distance requirement of 300 meters. As an alternative, the authors propose a 2-20-200 model that would mean 37% of homes meet all three criteria, 75% meet at least two, and 97% meet at least one criterion.

2.2.2 Yggdrasil – The 3-30-300 rule in the Nordic Region

The project, which is carried out on behalf of the Nordic Council of Ministers, by the Swedish consultancy company Trädkontoret (https://tradkontoret.se/yggdrasil/) is about evaluating and implementing 3-30-300 in Nordic cities (Konijnendijk et al, forthcoming). The implementation has taken place in the cities of Holbæk and Kolding in Denmark, Turku and Tampere in Finland, Reykjavik in Iceland, Bergen and Stavanger in Norway, and Malmö and Umeå in Sweden.

The GIS analysis, which has been carried out by Cobra Groeninzicht – a consulting company from the Netherlands, takes its starting point from The Overture Global Building dataset consisting of 22 million buildings throughout the Nordics.

To calculate the 3-rule, each building is surrounded by a 25 meter buffer. Next, the number of tree crown pixels (10m x 10m) is counted, where each pixel is assumed to represent a tree. The distance of 25 meters is justified by the fact that it is at that distance that the individual leaves can still be distinguished. Actually, they do not exactly measure the number of visible trees, but the number of trees that are in the vicinity of the houses.

To calculate the 30-rule, each building is surrounded by a 500 meter buffer. Within this, the number of tree crown pixels is counted, which is divided by the number of land cover pixels and multiplied by 100 to indicate the percentage of crown cover.

To calculate the 300-rule, a machine learning model is used to identify urban green space using the ESA (European Space Agency) World Cover Map and

OpenStreetMap. The distance between each building and the nearest Park Entry Point is then calculated.

An overall figure for the availability of green space is obtained by normalizing the three elements in 3-30-300 on a scale from 1 to 10, where the value 6 corresponds to the norm value, i.e. 3 visible trees, 30% crown coverage and 300 meters to the nearest green area.

Cities in the Nordic Region, with the exception of Iceland, the Faroe Islands and Greenland, generally have good access to greenery. For the 3-rule, a target fulfillment of more than 97% applies for Finland, approximately 85% for Norway and Sweden, and well over 70% for Denmark (Konijnendijk et al., forthcoming). A similar pattern applies for the 30-rule, while for the 300-rule, a target fulfillment of more than 90% applies for all the Nordic countries except Iceland (Konijnendijk et al., forthcoming).

A gap analysis shows which areas lack trees and green areas. Through this, focal areas are identified where the cities are recommended to concentrate their greening efforts. Above all, areas with large gaps and many buildings together are pointed out.

2.2.3 NORDGREEN

In the NORDGREEN project was a research project funded by NordForsk (2020-2023). Six Nordic municipalities have been studied with regard to access to green areas, health data and socio-demographic data at the municipality and district level (Aamodt et al. 2022; 2023). The six municipalities are Aarhus (DK), Stavanger (NO), Espo (FI), Täby (SE), Ii (FI) and Vilhelmina (SE). The project was carried out by researchers from Nordregio (lead partner), Swedish University of Agricultural Sciences, Norwegian University of Life Sciences and Aalto University.

Health data and socio-demographic data were obtained from the National Statistics in Denmark, Finland, Norway and Sweden, supplemented with data from citizen surveys where such were conducted. As health variables, statistics were collected on life expectancy for both women and men, the proportion of the population that is physically active or is overweight (BMI over 30), perceived health and the number of incidents of stroke and heart attack per 100,000 inhabitants. Sociodemographic information was collected on the population's age distribution, education level and household income. Four variables were chosen:

i. The proportion of the population older than 80 years

ii. The proportion of foreign-born and children with two foreign-born parents

iii. The proportion with education at least at bachelor's level

iv. Median household income

The access to UGS was mapped with the help of land use maps from e.g. the national geodata agencies. Parks, cemeteries and forests were defined as UGS. The national map material was supplemented with the EU's CORINE database and Urban Atlas. A second set of data consisted of satellite images that were analysed for their greenness in each pixel and used to calculate a Normalized Difference Vegetation Index (NDVI). It is proposed that the following variables be used to map the availability of greenery:

i. The distance from home to green area

ii. The percentage of green space according to the Urban Atlas

iii. Vegetation cover NDVI

iv. Area of green space per inhabitant

v. The percentage of green space in the neighbourhood

The greatest correlation between socio-demographic variables and access to greenery were the proportion of the elderly and the proportion with higher education. However, the results for the four cities of Espo, Täby, Stavanger and Aarhus did not give clear, but rather conflicting results. See Borges et al. (2024) for a complete project description, results and references.

2.2.4 Heat segregation

In his master thesis at Stockholm University, Pils (2023) tested four hypotheses:

i. Socio-economically vulnerable areas are warmer

ii. Socio-economically vulnerable areas have a lower proportion of tree cover

iii. Higher temperature is due to lower proportion of tree cover

iv. Socio-economically vulnerable areas are warmer due to a lower proportion of tree cover

The hypotheses have been tested on 1015 DeSOs in Stockholm, Gothenburg and Malmö. Socio-economically vulnerable areas were identified using a socio-economic Index based on three indicators: proportion of people with low economic standards, proportion of people with no more than pre-secondary education and proportion of people who have had financial assistance for at least ten months or been unemployed for longer than six months. Since this index is only available at the RegSO level, a new weighted Index was developed that combined four variables: socio-economic index at the RegSO level, proportion of people with low and high economic standards, respectively, and earned income. The variables were normalized so that all values lie between 0 and 1, where 0 corresponds to the smallest value and 1 to the highest within the respective urban area.

Data for tree coverage was taken from the Swedish National Board of Housing, Building and Planning's mapping (resolution 1x1 meter) which was adjusted for the DeSO limit and processed for identified error sources. Data on ground temperature was taken from the Swedish Civil Contingencies Agency's heat mapping service (resolution 30x30 meters).

To test the hypotheses, a regression analysis was carried out partly of all observations, partly of the 40 most exposed DeSOs. In addition, a mediation analysis was conducted for both groups for the relationship between socioeconomic index and temperature with tree cover as a mediator. The results of the study showed that socio-economically vulnerable areas have a higher average temperature and that many vulnerable areas were simultaneously characterized by insufficient tree cover, which the study demonstrated has a stabilizing and cooling effect on the temperature.

2.2.5 Heat vulnerability

Malmö Stad's (Malmö city) Environmental Department has mapped what contributes to increased vulnerability during heat waves, what abilities different groups have in handling heat and where in the city high temperatures and vulnerabilities overlap (Sonesson et al. 2024). The mapping is carried out at sub-area level, which is the designation of the city's internal geographical division.

For this purpose, a vulnerability index consisting of three categories; heat exposure, health condition and socio-economic status, has been developed. To map the heat exposure, three indicators are used: degree of crown coverage, average maximum temperature in the years 2017-2022, and the average distance between the residence and the nearest green area. The state of health is also determined using three indicators: the proportion of people under five and over 65, respectively, and the average number of sick days. The socio-economic status is measured with the help of five indicators: the proportion of people living alone without children, average disposable income, and the proportion of car owners, the number of detached houses, and the number of people per square meter of living space.

In the interwoven vulnerability index, a cluster of sub-areas in central, eastern and southern Malmö stand out as particularly vulnerable (Sonesson et al. 2024). However, the adaptation measures can vary from creating more greenery to provide coolness to social interventions that increase the standard of living and thus the population's tolerance for high temperatures.

2.2.6 Regional Potential Index

The Regional Potential Index (RPI) was introduced by Nordregio for the first time in the State of the Nordic Region report 2016 (Grunfelder et al. 2020a; 2020b). The RPI is an attempt to provide an overall quantitative picture of the development potential of all regions in the Nordic Region. Data from nine selected socio-economic indicators in demography, labour market and economy have been used to construct an Index that aims to provide an overall picture of how the well-being of a region and its citizens are.

The demographic dimension consists of four indicators which max. can give 75 points each. The first of these concerns urbanisation, namely what proportion of the population lives in urban areas with at least 5,000 inhabitants. The motive is that medium-sized and larger conurbations offer relatively good access to workplaces, healthcare, cultural offerings, public transport and other services thanks to the fact that they contain a critical size of the population. The second, net migration, highlights how attractive the region is for people to work and settle in. It helps to increase the availability of labour, tax revenues and social capital but also poses challenges in the form of burdens on administrative and social services. The age dependency ratio is about how big the dependency burden is on the part of the population that is of working age in relation to the proportion of children and young people, respectively the elderly. Finally, gender balance is considered beneficial as it indicates that there is a balanced range of work and study opportunities for both women and men.

The labour market dimension consists of three indicators that can give max. 100 points each. High employment rates indicate that residents possess the skills that are in demand in the labor market and contribute to higher tax revenues, among social cohesion and integration, and greater quality of life among citizens. The share of the working-age population with a higher education shows the availability of skilled labor and gives a hint about the potential for innovations and new entrepreneurship. A high level of education among the population also tends to coincide with more interesting jobs as well as longer life expectancy and greater satisfaction among the population. The third labor market dimension, the rate of youth unemployment, focuses on the ease of entering the labor market.

The economic dimension consists of two indicators; gross regional product per capita, which can provide max. 200 points, and R&D investments per capita, which max. can give 100 points. GRP per capita shows the total production of goods and services in the region and is a relatively safe overall measure of how the economy is doing, while the size of R&I investments is a sign of how willing one is to invest in future economic development.

The last RPI ranking was done in 2024 (Norlén et al. 2024). Unsurprisingly, it is the capital regions that top with Oslo at the top, followed by Region Stockholm and with Copenhagen (Region Hovedstaden) in third. Among other Swedish regions, Uppsala comes in sixth place, closely followed by Västra Götaland in eighth, Skåne is in 10th place.

2.2.7 Socio-economic index

As part of the work to reduce and counteract socio-economic segregation, Ramboll has produced a socio-economic Index (Region Skåne 2021) on behalf of the Regional Planning Unit in Region Skåne. The work was part of a project financed by the Delegation against segregation (Delmos). The Index is based on the national follow-up system developed by Delmos to follow the development of segregation.

The socio-economic Index is calculated on the basis of 10 indicators distributed so that two deal with household finances, four with work, three with education and one with health. As financial indicators, the percentage of households that receive financial assistance is used, and the household's disposable income, i.e. the income after tax and including transfers such as housing allowance, child allowance, pensions, unemployment and health insurance etc. The indicators in the labour market area consist of the percentage of young people who neither work nor study, the percentage of the unemployed, the employment rate and the percentage of overcrowded housing. The three indicators dealing with education are the percentage with tertiary education, the percentage eligible for upper secondary vocational programs and the percentage eligible to study at university. The only indicator in the area of health is the so-called unhealthy number, i.e. the number of days with paid sickness benefit including work injury sickness benefit, rehabilitation benefit and activity and sickness benefit from social insurance.

The Index is calculated by normalising the values for each indicator so that they go from negative to positive with zero as the mean. The indicators are weighted through a data-driven process based on covariation so that indicators that are highly correlated receive lower weight, while indicators whose values stand out are given higher weight. Weighing different indicators together with adjustment for the covariance between them reduces the risk of a so-called Type I error in the form of false positive results.

Lomma (0.71) has the highest socio-economic index among municipalities in Skåne, followed by Vellinge (0.59), Lund (0.43) and Höganäs (0.40). The lowest socio-economic index is found in Perstorp (-0.74), Östra Göinge (-0.61), Klippan (-0.45) and Landskrona (-0.41) (Region Skåne 2021). Malmö receives a socio-economic index of -0.14, which gives it a shared 18th place among the region's 33 municipalities. At the DeSO level, the city's districts are distributed so that 63 of Malmö's 193 DeSOs place themselves in the lowest quartile (0-25 percentile) and 53 in the one with the highest socioeconomic standard (75-100 percentile).

2.2.8 Tree Equity Score

The Tree Equity Score (TES) includes 10,000 "towns, cities and villages" across the United States (American Forest 2024). Thus, it covers all urban areas (according to US Census 2020) in the country and affects 80% of the population. TES is owned by American Forests, a non-profit conservation organization founded in 1875, and is used to assess and identify urban areas in special need of tree planting and also as a basis for tree donations to special need districts. TES is equal to the gap between existing and desired canopy cover times the priority. See https://treequityscore.org/methodology (Methods & Data/Detailed methods).

The canopy cover (the footprint of trees when viewed from above) is taken from Google Environmental Insights Explorer. This compares to a figure for the area recommended by the USDA Forest Service and The Nature Conservancy. Other data comes from the American Community Survey and the US Census which is updated every ten years and includes the following indicators:

i. The proportion of coloured people

ii. The proportion of children and the elderly (dependency ratio)

iii. Linguistic isolation where no one in the family speaks English

iv. Health burden index of perceived mental or physical ill health, asthma and heart disease Source: Center for Disease Control CDC PLACES 2022

v. Heat disparity, i.e. surface temperature above or below average (Source: USGS Earth Explorer – Landsat 8 Collection 2 Level 2 Surface Temperature)

vi. Poverty

vii. Unemployment

The priority appears in the form of a number on a scale of 0-100. The lower, the greater the need for trees. At 100 there are enough trees, at 90-99 the need is small, at 80-89 moderate and at 70-79 rather high. If there is a number between 0 and 69, the community has the opportunity to receive tree assistance from American Forests.

2.2.9 Spatial Equity

Originally a movement that started with a group of cyclists at the initiative of an urban planner named David Gurin gathered in Central Park for an action against automobiles. The following year, in 1973, Transportation Alternatives was formed, an NGO that, together with MIT, is behind the Spatial Equity NYC project

(Transportation Alternatives & the Massachusetts Institute of Technology n.d.). It consists of a database with three types of indicators: health, environment and mobility.

The health indicators are air pollution (measured as the level of PM2.5 in micrograms per cubic meter of air), asthma (the number of visits to the children's emergency room per 10,000 inhabitants), noise, and traffic accidents with personal injury (the number of seriously injured people per 10,000 inhabitants since 2022), and fatal outcomes (the number of deaths per 10,000 inhabitants since 2014) as a result.

The environmental indicators are extreme heat (average surface temperature during summer), flood risk (proportion of residents living in such areas), parks (proportion of residents living within walking distance to a park), permeable soil (square meters of "green streets & biosvales" at neighbourhood level), canopy cover (in percent).

Mobility is measured using the following indicators: the number of bicycle parking spaces per 10,000 inhabitants, what proportion of the street network has bus traffic, average speed of bus traffic, the proportion of inhabitants with a square within walking distance, what proportion of the street network has protected cycle lanes, the number of benches per 10,000 inhabitants, what proportion of the street space is pavement, and the traffic volume measured as the annual total mileage within one square kilometre.

The results are analysed in relation to socio-economic data based on US Census data regarding race and ethnicity, poverty (the proportion of households living below the poverty line), car ownership (the proportion of households that do not own a car), solo driving (how many of the commuters drive alone to the job) and mode of commuting (train, bus, bicycle, on foot or other).

The web page provides excellent easy-to-access presentation of data, e.g. fact sheets on how bus dependency, flood risks and access to footpaths differ between different districts.

2.2.10 Green Infrastructure Equity Index

The Philadelphia Water Department has adopted an approach that involves investing in green infrastructure to reduce runoff into the sewer system as part of its Combined Sewage Overflows strategy, the so-called Green City Clean Water program involving investments in the order of 1.6 billion dollars over 20 years. However, the investments have been criticized from an environmental justice perspective for not being deployed where there is the greatest need for additional green areas. The GI Equity Index was developed thanks to a research grant from the U.S. The Environmental Protection Agency's STAR program (Science to Achieve Results) to be a tool for cities like Philadelphia in their prioritization of investments in the green infrastructure (Heckert & Rosan 2016).

They chose to work with two types of data sets. First, socio-economic variables related to disadvantage or vulnerability, second, environmental factors related to both the risk of being exposed to risks in the environment and the access to what is environmentally pleasant. The six socio-economic indicators are 1) the proportion of minorities, 2) the proportion of low-income earners, 3) the proportion who have not completed high school, 4) the proportion of young people younger than five years, 5) the proportion of elderly people over 64, and 6) the proportion who own their residence. Data were drawn from EPA's Environmental Justice Screening and Mapping Tool with the exception of the latter indicator of home ownership which was drawn from the 2010 Census.

The environmental indicators included 1) proximity to public transport, 2) ozone content in the air, 3) content of small particles (less than 2 micrometres), 4) access to parks, 5) degree of canopy cover, 6) access to playgrounds, 7) proportion of hard surfaces, and 8) the amount of undeveloped land. Data for the first three indicators were obtained from EPA's Environmental Justice Screening and Mapping Tool, while the others were obtained from the City of Philadelphia.

A total of 1128 districts were included in Philadelphia, which is the number covered by a combined sewer system and thus affected by the Green City Clean Water strategy. The values for each indicator were normalized so that a value of 0 was given to the result that was least and 1 to that which was most unfavourable. The index value for each district was obtained simply by adding the value of the fourteen indicators, i.e. a number between 0 and 14. The fifth of the districts with the highest values was then selected and compared with the fifth of the districts that had the highest values with regard to the indicators for minorities and low-income earners which gave a coincidence of 50%, i.e. of the 20% districts most in need of investment in green infrastructure, only half are particularly vulnerable in terms of the proportion of non-whites and the poor.

2.3 Summary of methods

2.3.1 Green indicators

Tree cover is the most frequently used green indicator, present in six out of seven methods, while proximity/distance is being used in four out of the seven studies (Table 1). Surface temperature and amount of permeable ground are used in three studies, while area or amount of greenspace per inhabitant is used in two out of seven studies. Risk of flooding, and number of playgrounds are used in one study each.

Table 1. Overview of which indicators have been used to describe the areas' environmental and green space status.

	NORDGREEN	3-30-300	SCB	SEI	TES	SE NYC	GIEI Ph.
Proximity to GS (4)	X	X		X		X	
Area GS (2)	X						X
Tree cover (6)		X	X	X	X	X	X
Surface temperature (3)			X	X		X	
Risk of flooding (1)						X	
Permeable ground (3)	X					X	X
Playgrounds (1)							X

2.3.2 Socio-economic indicators

Poverty is used as an indicator in eight out of eight studies (Table 2). Health status, age dependency and education are used in five studies. Employment rate and ethnicity are used in four out of nine studies, housing type in three, car ownership in two and net migration and gender balance in one study each.

Table 2. Overview of which socio-economic indicators have been used to describe the areas' socio-economic status.

	NORDGREEN	SCB	SoNR RPI	Ramboll	SEI	TES	SE NYC	GIEI Ph.
Age dependency (5)	X		X		X	X		X
Ethnicity (4)	X					X	X	X
Education (5)	X	X	X	X				X
Poverty (8)	X	X	X	X	X	X	X	X
Unemployment (4)		X	X	X		X		
Net migration (1)			X					
Gender balance (1)			X					
Health status (5)	X			X	X	X	X	
Residence (3)				X	X			X
Car ownership (2)					X		X	

2.3.3 Combinations of green and socio-economy

The NORDGREEN study has its main value in that it makes a thorough review of the access to data in the Nordics regarding green areas as well as socio-economic and health data. Furthermore, attempts have been made to find a connection between access to greenery and socio-economic status, but without finding any clear results.

Region Skåne's report on the application of the 3-30-300 principle in nine urban areas in Skåne is valuable for its detailed method description of how to measure greenspace, e.g. crown coverage. The 3-30-300 principle is more of a policy-oriented goal (albeit justified with the support of contemporary research) than a measurement tool or an index, but one can of course use it as such by indicating the degree of goal fulfilment, which has been implemented on a Nordic scale through the Yggdrasil project.

In the SCB-supported study of heat segregation, unlike in several other studies, it has been possible to demonstrate a connection between socio-economically vulnerable areas and a lack of greenery. Even in Malmö's heat vulnerability index, a number of areas have been identified where there is both a lack of greenery and socio-economic challenges. An important detail is that Malmö chooses its own division into sub-areas that differ from the nationwide DeSO division.

Nordregio's Regional Potential Index is interesting for its access to socio-economic data and how to create a normalized ranking. Ramboll's study of socio-economic segregation also provides valuable tips on how to calculate an index using different variables that partially overlap.

The American studies naturally differ in terms of access to data compared to Nordic conditions. The strength is mainly in the application, where in Tree Equity Score they have developed a powerful instrument for prioritizing tree planting measures and in Spatial Equity NYC they have developed a pedagogic website for conveying knowledge about the connections between socio-economic conditions, health and urban environmental factors. The Philadelphia study is a desktop product that nevertheless has interest because it focuses on how investments in the green infrastructure are distributed based on an environmental justice perspective.

The degree of canopy cover is the most common indicator for measuring the availability of green spaces. It has been used in six out of seven studies where green space status has been attempted. Next comes the distance between the home and the nearest green area, which appears in four studies. However, there is no accepted standard for how to measure, so there is reason to look more closely at the methodology around these two indicators.

When choosing indicators for access to green areas, it is important to reflect on which different functions they represent. Canopy coverage, soil temperature and permeable soil are all examples of indicators that mainly reflect the importance of greenspace for the climate and the environment. Then it do not matter, for example, whether a tree or a lawn is in a private garden or in a public park. On the contrary, when it comes to the importance of green areas for play and recreation, only the publicly accessible green areas are of interest.

Poverty, either described by household disposable income or as the proportion of families living on a low income, is the criterion used in all studies to describe socio-economic status. Next comes a trio of criteria that appear in five out of eight studies: age dependency ratio, educational level and health status. Of these, health status is problematic at the DeSO level, as commonly used indicators such as life expectancy or prevalence of non-communicable diseases can only be obtained at the municipality level. We have considered to include an indicator for the health status of the population, but have for the time being opted out of it due to the difficulty of producing relevant data at the DeSO level.

Apart from the above mentioned approaches and Indexes, we have also considered including an indicator that states the proportion of foreign-born residents. The reason why we ultimately excluded this is partly that another ethnic background should not in itself be a negative factor, but that a high percentage may covary with, for example, high unemployment or a low level of education, leading to a double measurement. We will therefore follow up with data on foreign background when we discuss the results.

Ethnicity is used as an indicator in four out of eight studies. Here European and American views clearly differ. In all three American studies, the proportion of minorities (black, Spanish-speaking, etc.) is an accepted indicator of an area's socio-economic status, while in Europe and the Nordics it can be considered discriminatory to use a high proportion of foreign-born as an indicator of low socio-economic status. Thus, the residents of two vulnerable areas in Denmark have sued the state for illegal ethnic discrimination because one of the criteria for being designated as a "ghetto", or "parallel community" as it is now called, is that more than half of the population has non-Western origins. The Court of Appeal (Østre Landsret), which will rule on the case, has in turn asked the EU Court for a preliminary ruling, which is expected next year.

Unemployment and ethnic background appear as criteria in four out of eight studies. When it comes to ethnicity, we see a clear difference between the Nordics and the USA. While in the USA it is an accepted criterion of low socio-economic status that the population of an area consists of non-white, Spanish-speaking and other minorities, in the Nordic countries it is considered discriminatory to per se link a high percentage of the population with foreign or non-Western ancestry to socio-economic vulnerability. Housing, car ownership and balance between the sexes also appear as criteria for socio-economic status.

3. Selection of indicators

We have decided to work with seven indicators based on the indicators listed in the review of existing indices in section 2.2. The seven indicators are presented in Table 3 and include three green indicators and four socio economic indicators. The three green indicators include canopy cover, urban green space per capita, and distance to urban green space. The socio economic indicators include age dependency ratio, employment rate, household income, and education level. Each of the indicators will be explained in the following sections, including a reasoning behind the choice of each indicator, possible data sources, and our methodological approaches.

When selecting data for each indicator and determining how the indicator should be derived, several important factors must be considered. In general, the **data** used for all indicators **should be open or accessible to Swedish municipalities**, and **updated regularly** to allow for follow-up analyses. Additionally, the **methodology** should be **feasible and relatively simple**, enabling municipalities with **limited GIS expertise to perform the analysis**. At the same time, the data and methods should be **advanced enough to accurately capture the essence of each indicator**.

Table 3. List of indicators.

Indicator	Definition	Unit	Data source	Update frequency	Geographical coverage	Smallest spatial unit
Canopy cover	Amount of land covered by canopy per DeSO	%	The Swedish National Board of Housing, Building and Planning	Not determined	National, but currently excluding urban areas with less than 5000 inhabitants	-
Urban green space per capita	Amount of green space wider than 10 m per inhabitant	m^2 /capita	Created by combining multiple datasets	Dependent on the various datasets	National	-
Distance to urban green space	Network distance from homes to the nearest green space (larger than 100 m^2 and wider than 30 m). Mean distance calculated per DeSO.	m	Created by combining multiple datasets	Dependent on the various datasets	National	-
Age dependency ratio	The proportion of age groups 0-14 and 65+ in relation to the age group 15-64	%	Statistics Sweden	Annually	National	DeSO
Employment rate	Proportion of the age group 20-64 that is employed according to Statistics Sweden's definition	%	Statistics Sweden	Annually	National	DeSO
Household income	Households' disposable mean income after taxes and transfers	thousands of SEK	Statistics Sweden	Annually	National	DeSO
Education level	Proportion of the age group 25-64 that has post- secondary education	%	Statistics Sweden	Annually	National	DeSO

3.1 Neighbourhood level

The analysis was performed on Demographic Statistical Areas (DeSO), the smallest statistical areas provided by Statistics Sweden (Statistics Sweden 2018). This national dataset, created in 2018, divides Sweden into 5984 areas based on geographical conditions and population distribution. Each DeSO contains between 700 and 2700 inhabitants, with the division taking into account geographical boundaries such as streets, watercourses, and railways, as well as urban, municipal, and county boundaries. Each DeSO is a part of a Regional Statistical Area (RegSO), where the DeSOs can be aggregated into anywhere from 2 to 147 RegSO areas within a municipality (Statistics Sweden 2020a). Malmö municipality is divided into 192 DeSO, which are further aggregated into 91 RegSOs.

While many municipalities have their own neighbourhood divisions for municipal work, DeSO offers a standardised division across the entire country. This enables all municipalities to use it and facilitates comparison between different municipalities. Additionally, Statistics Sweden provide open data on socio-economy and statistics at both the DeSO and RegSO levels. However, the boundaries of the DeSO are limited by a population threshold, which affects their geographical size. This results in smaller DeSO in central urban zones and larger DeSO in more rural areas. For this analysis, we worked with DeSOs from Statistics Sweden (Statistics Sweden 2018), clipped with the urban boundary (Statistics Sweden 2020b) to exclude the marine part of the DeSOs.

3.2 Green space indicators

In selecting indicators for access to UGS one needs to define three things: What counts as UGS? How to measure access? And access for whom? Together, the three indicators of canopy cover, UGS per capita, and distance to UGS provide a good picture of access to the various functions of green spaces. The social functions are represented by the amount of UGS and the distance to it, while the tree cover (potentially together with the permeable soil indicator) represents the importance of greenery for the local climate and adaptation to climate change.

The following subsections include a literature review of existing research articles that explore previous methods used to analyse access to urban green space, the definition of UGS used in this project, followed by a testing of different methods for each of the three green indicators along with a presentation of the final approach for assessing green space indicators.

3.2.1 Review of existing articles relating to urban green space

A literature review was undertaken to learn how the selected UGS aspects have been defined by previous studies across various fields. Table 4 provides a summary of the results search.

Table 4. Search terms used in the literature review, search engines used and number of references retrieved.

Objective	Base Term	AND	OR	Search Engine	Hits	References Retrived
Review Articles						
Extant Dimensions of Greenness						
	"Urban Green Space"	Area, Review	Wellbeing/Health/Equity	ScienceDirect	944	48
	Urban Green Spaces, indivic	Area, Review	Wellbeing/Health/Equity	SpringerLink	105	14
	Urban Green Spaces, indivic	Area, Review	Wellbeing/Health/Equity	CORE	5	0
	Urban Green Spaces, indivic	Area, Review	Wellbeing/Health/Equity	GoogleScholar	1040	75
		.+ Spatial + GIS		GoogleScholar	360	12
Total						149

Of the 149 articles retrieved further review found 32 relevant papers, most of which were review papers, resulting in 219 examples of UGS definition and/or access metric (of these 13 referred to the same article but did not necessarily draw the same key points from them, in these cases duplicates were either removed or combined). Each was then classified according to 47 categories relating to what type of UGS was identified, methods for measuring the amount, quality and/or accessibility of UGS, demographic characteristics of the respondents if applicable, sampling methods and reporting units, key thresholds such as spatial extent of the study and whether or not the paper addressed physical or physiological health benefits of UGS. Figure 3 shows the number of papers referring to key categories.

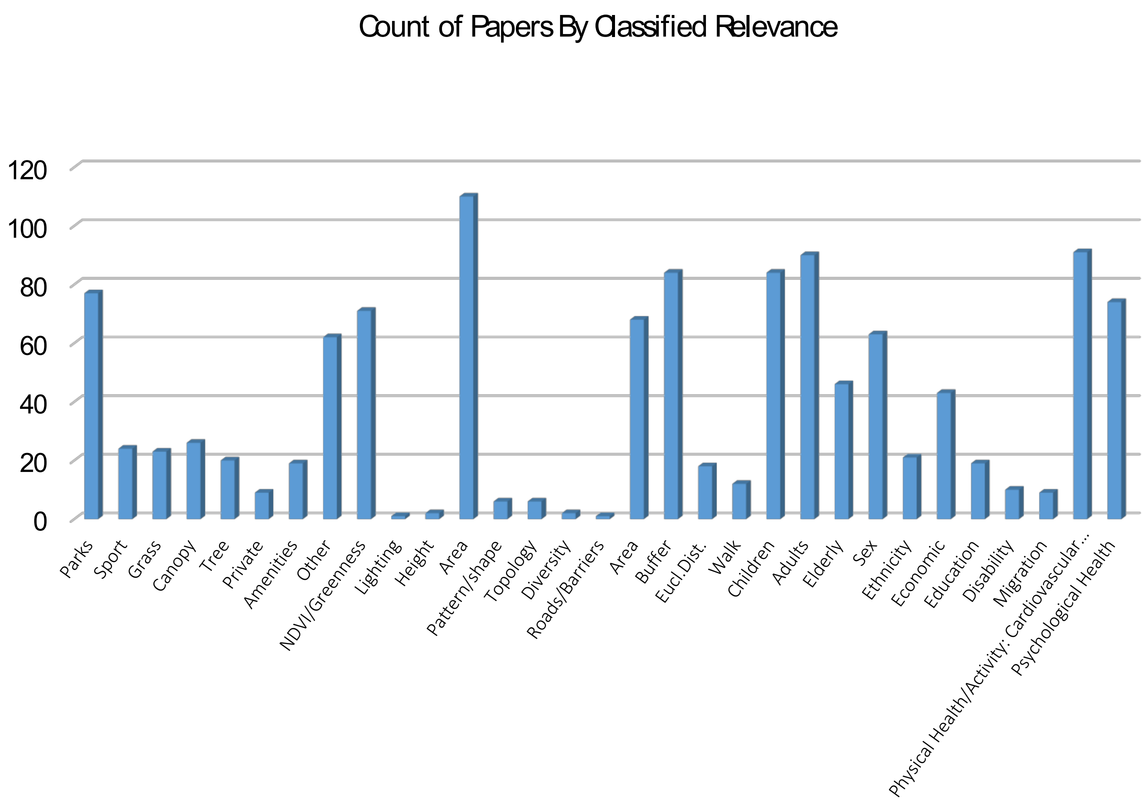


Figure 3. Count of papers classified as relating to key aspects of urban green space (UGS) equity.

In terms of the characteristics defining UGS, a minimum size threshold was common with some studies also imposing a criterion of shape in order to avoid long thin patches such as grass verges being classed as UGS. Table 5 gives some selected examples.

Table 5. Examples of definitions of urban green space (UGS).

Source	Type	Area
Amoly et al. 2014	UGS patch	50k m^2
Bixby et al. 2015	UGS patch	5k m^2
Konijnendijk 2022	zone	30%
WHO 2017	UGS Patch	5 – 10k m^2
Annerstedt van den Bosch et al. 2016	Park patch	10k m^2
Koohsari et al. 2018	Park Patch	10.5 k m^2
Schipperijn et al. 2013	Park patch	50k m^2
Peschardt et al. 2012	SPUGS (important for those without private garden)	<5k m^2

Statistics Sweden 2019	UGS Patch	5k m^2
Net World Sports n.d.	Children's football pitch U7 (36*27 m)	1k m^2
Region Skåne 2023	UGS Patch	5k m^2

To identify which methods were more commonly applied, a cluster analysis was run against these categories showing how different studies identified sufficiently close UGS for respondents (e.g. by spatial unit or distance), the way UGS is characterised and the social issues in focus:

Green typologies

- Canopy and trees were distinguished in relatively few studies, even within those using NDVI.
- Park amenities were more regularly recorded than other UGI typologies but this did not cluster with other aspects.

Distance

- Thresholds for distance are mostly in the 300-800m range.
- Distance was assessed mostly with respect to UGS area (usually mainly parks) and was most common when considering children's physical health.
- Most studies used Euclidean buffers, only a few used walking distance.
- NDVI was used to identify UGS mostly for studies of access over shorter distances, for adult's physical and psychological health.

Social focus

- Studies with stronger demographic focus tend to be less spatial and vice versa.
- Elderly people are an under-studied demographic group in the papers found.

The range of distance limits used (300-800 m) is wide considering the nature of accessibility afforded. Indeed, given 300 m is the maximum threshold referred to in the 3-30-300 guidance, this is perhaps surprising. The general lack of use of remote sensing for mapping urban canopy in particular was also notable given this is now standard practice for mapping urban green infrastructure (UGI) generally and may reflect the focus of studies relating to green equity for outcomes relating to human health. Few studies quantified the sensitivity of their results to different definitions of UGS or access.

It was decided to test the sensitivity of different measures of both UGI and accessibility for the Malmö case with the particular goal of determining how suitable national datasets might be or whether each city should be individually mapped.

3.2.2 Definition of urban green space

We adopted the definition of public UGS from Region Skåne's proposed definition in the "3-30-300 in Skåne" project. Here, public UGS is defined as "areas of contiguous green areas that are publicly accessible, according to the right of the public, the public order law or the criminal code. Parks, nature, open air areas, pastures, for example, count as green areas, but not arable land, as it is not publicly available. Cemeteries and schoolyards are included, but not allotment gardens and sports facilities." (Region Skåne 2023, p.20). The project outlines a GIS-based methodology to create a dataset of public UGS. The approach is based on open data or data currently available through Lantmäteriet's geodata collaboration (*Geodatasamverkan*), which provides municipalities, regions, and public authorities' access to a wide range of national geodata. It is expected that much of the data currently accessible through the geodata collaboration agreement will soon become open to the public, allowing free download and use. The methodology combines multiple datasets to identify public UGS by excluding areas that are neither publicly accessible nor green from the study area, specifically the municipality's urban zone. The geographical data used for mapping public UGS include:

i. Urban areas from Statistics Sweden (SCB)

ii. Topografi 10 from the National Land Survey of Sweden (Lantmäteriet)

iii. Agricultural blocks from the Swedish Board of Agriculture (Jordbruksverket)

iv. National Land Cover Data from the Swedish Environmental Protection Agency (Naturvårdsverket)

v. Railways and roads from the Swedish Transport Administration (Trafikverket)

vi. Buildings and properties from the National Land Survey of Sweden (Lantmäteriet)

vii. Parking areas from Open Street Map

The method was applied to compute public UGS without imposing thresholds on size or width. A detailed description of the methodology can be found in the project report (Region Skåne 2023).

As the literature review did not suggest a single broadly accepted definition of UGS it was decided to test alternative definitions of UGS to see how these affected the measured total area, its distribution and proximity (Table 6). The “base line” selected was any mapped green space according to Region Skåne’s method for computing public UGS, without imposing any width or size thresholds (Region Skåne 2023). Further thresholds were then applied as total area and/or minimum width, the argument being that both impact the affordance of the UGS for different activities. The minimum width was applied using an inverted buffer, which, after testing, had to retain some UGS. Notice that when applying a width threshold of 20 or 30 metres to the size threshold 100 m^2, the minimum observed area of the resulting UGS is 254 m^2, and 753 m^2, respectively (Table 6). A change of just 10 metres in width doubles the observed minimum area.

Table 6. The different definitions of public urban green space (UGS) tested. a = area; w = width

Name	Definition
Base line	Public UGS according on Region Skåne’s definition without any size or width threshold applied
a100w10	Public UGS according on Region Skåne’s definition with an area > 100 m^2 and width > 10 m
a100w20	Public UGS according on Region Skåne’s definition with an area > 100 m^2 and width > 20 m. The size thresholds results in an observed minimum area of 354 m^2
a100w30	Public UGS according on Region Skåne’s definition with an area > 100 m^2 and width > 30 m. The size thresholds results in an observed minimum area of 753 m^2
a300w10	Public UGS according on Region Skåne’s definition with an area > 300 m^2 and width > 10 m
a500	Public UGS according on Region Skåne’s definition with an area > 500 m^2
a1000	Public UGS according on Region Skåne’s definition with an area > 1000 m^2
a5000	Public UGS according on Region Skåne’s definition with an area > 5000 m^2

The total area of UGS in Malmö municipality according to the eight definitions can be observed in Figure 4. Notice that adding any width criterion excluded more potential UGS than applying a minimum threshold area of 1000 m^2. Figure 4 shows that a minimum width of 30 metres reduced total available UGS by around a quarter. It also sets a de-facto minimum area of 753 m^2 even though only 100 m^2 was required. Therefore, it is important to consider whether a shape criterion is relevant to the ecosystem service of interest given that it is likely to exclude UGS with significant patch size e.g. a long thin patch may still provide ecological benefit.

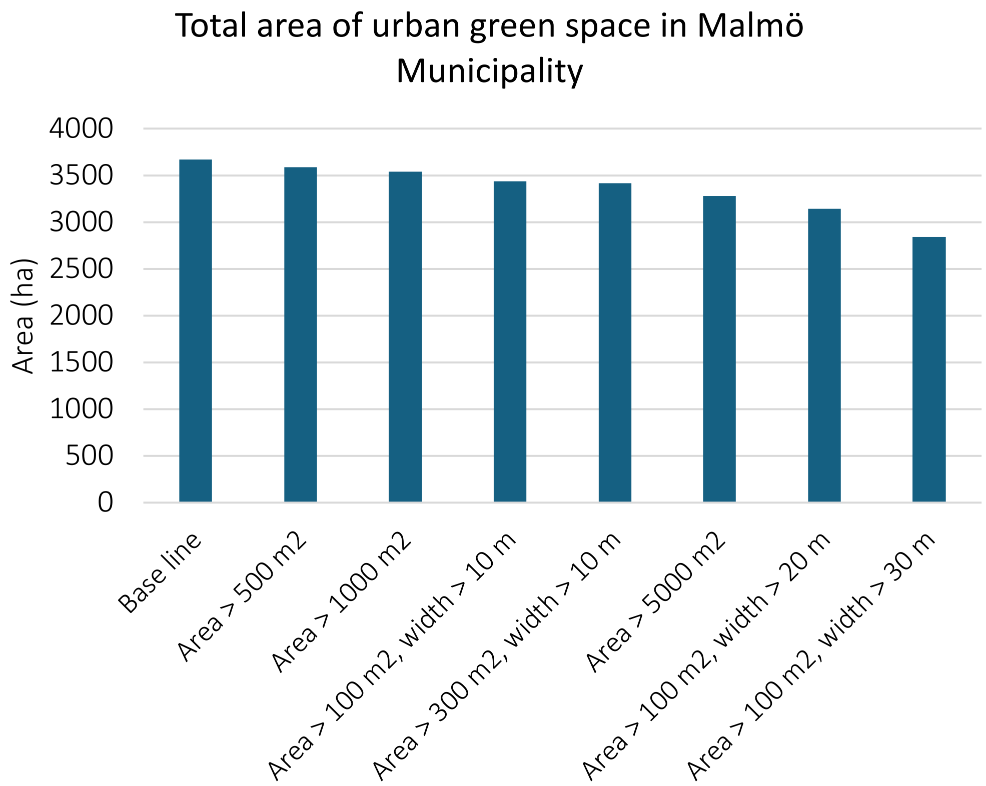


Figure 4. Total area (ha) of urban green space (UGS) in Malmö municipality with the eight definitions of UGS.

Figure 5 shows how the space affected by the area and width thresholds is often near to buildings, particularly inside court yards. While much of this space is likely to be private, it is also the very green space that is closest to people most of the time. By implementing a width threshold, both narrow UGS, and slivers created as a result of the chosen methodology, are removed. This is especially observed along roads and between buildings.

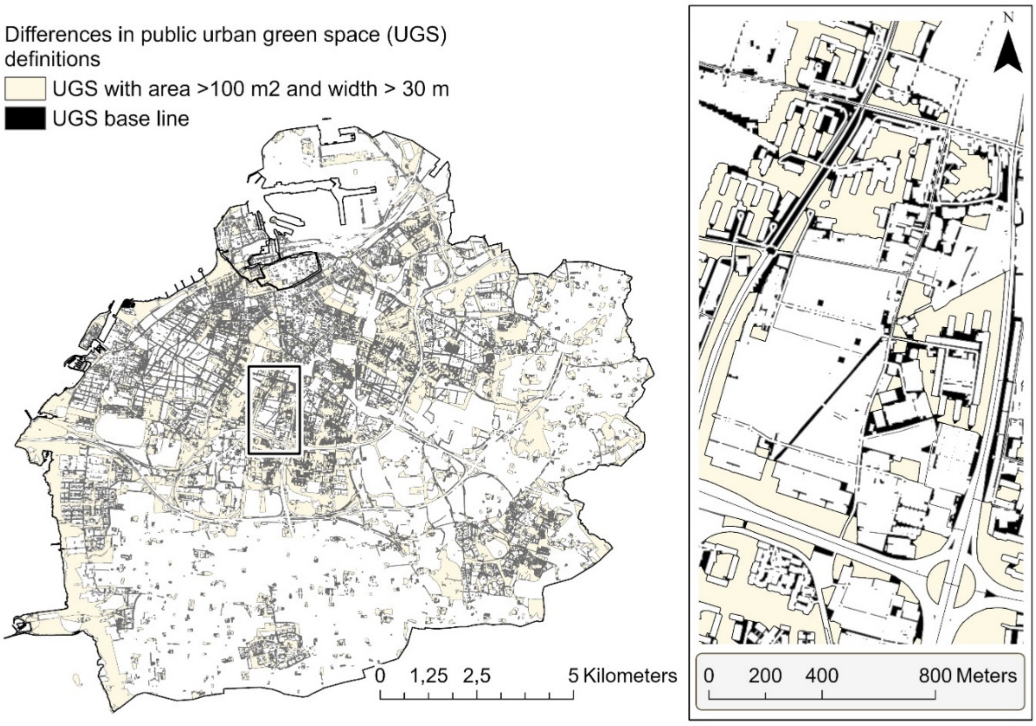


Figure 5. Difference between two definitions of computed public urban green space (UGS) in Malmö municipality. The base line UGS, where no threshold in area or width has been applied, is visualised in black. UGS with an area > 100 m2 and width > 30 m is visualised in light yellow. The spatial distribution of the two UGS definitions in Malmö municipality can be observed to the left. A close-up of an area in central Malmö municipality shows more details of how the two UGS definitions differ to the right.

3.2.3 Urban green space per capita

The indicator 'UGS per capita' shows how many square meters of green space there are per person in a district. WHO recommends a minimum of 9 m^2 per inhabitant and an ideal of 50 m^2 (Russo & Cirella 2018). According to the British charity Fields in Trust (established as the National Playing Fields Association in 1925), the average in the UK is 24 m^2 per inhabitant, while they themselves have set 30 m^2 as a minimum requirement. A recently published study by Einar Dyvik on Statista calculated the number of square meters per inhabitant in Stockholm in 2018 to be 70 m^2, of which the majority (47 m^2) is forest. According to Statistics Sweden's calculations, the urban population in Sweden has 458 m^2 per person, with the general rule that the smaller the urban area, the more square meters (Statistics Sweden 2019).

The green space indicator UGS per capita is calculated using three sets of data; UGS, population, and DeSOs. The UGS for this indicator are based on the definition from Region Skåne (see section 3.2.2) but additionally includes a width threshold of 10 meters. The minimum width was applied using an inverted buffer, which, after testing, had to retain some UGS. This approach ensures the inclusion of smaller public green areas while excluding narrow slivers, strips, or other minor features. Population data was sourced from Statistics Sweden using the table "*Folkmängden per region efter ålder och kön. År 2010 – 2023*", specifically for all genders and ages per DeSO for the year 2023 (Statistics Sweden 2023b). The method for calculating the indicator follows these steps:

i. Download the table "*Folkmängden per region efter ålder och kön. År 2010 – 2023"* from Statistics Sweden.

ii. Compute UGS using Region Skåne's methodology, applying a width threshold of 10 meters.

iii. Calculate the total area of UGS within each DeSO.

iv. Compute UGS per capita by dividing the UGS area within each DeSO by the population of that DeSO.

3.2.3.1 Urban green space per capita in Malmö

The UGS per capita in DeSOs within the urban areas of Malmö municipality ranges between 0 and 893 m^2/capita, with a mean UGS per capita of 76 m^2/capita across all areas (Figure 6). The UGS provision per person generally increases as you move further out from the centre of Malmö's urban area, as the DeSOs increase in size and thereby are able to include more UGS. The areas of low UGS provision per capita are concentrated in three zones triangulating the city centre. This suggests a significant lack of UGS in each zone that is not a statistical artefact of the units (but probably is to some degree an effect of the 30 metre threshold in width). Perhaps surprisingly the port area ranks quite highly for UGS provision but the lack of trees suggests this is not from well-established parkland. Given the effects of non-residential access to UGS (see Insert 1), and the fact that the nearest UGS may be in another DeSO, this map should be read with caution. However it does show several zones of multiple DeSO where there is relatively little provision per person and other DeSO, for example to the Eastern outer edges, where total area provision is average but is none-the-less high per capita.

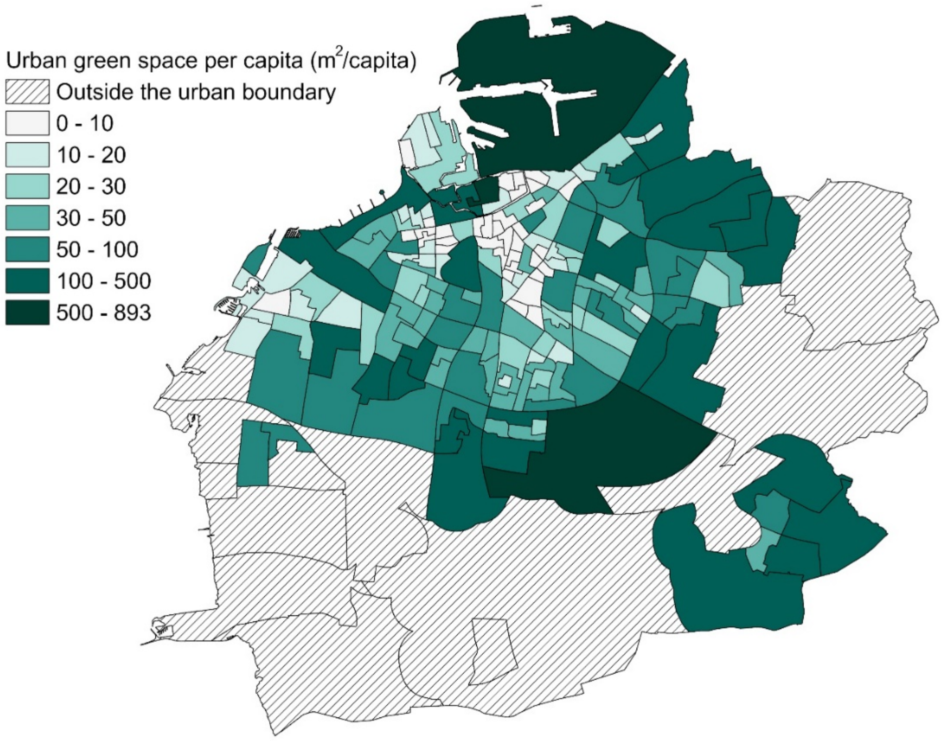


Figure 6. Urban green space per capita (m²/capita) per DeSO. Urban green spaces were defined as public green areas wider than 10 meters. The number of inhabitants per DeSO was calculated using population statistics per DeSO for the year 2023 from Statistics Sweden.

The UGS provision per person ranges between 0.2 and 1.6 m²/capita for the five DeSOs with the lowest provision (Table 7). Four of the five DeSOs are neighbouring each other, and are located in the neighbourhood belonging to RegSO Möllevången syd, väst, öst, or to the RegSO Rådmansvången. Here, the UGS provision per capita ranges between 0.2 m²/capita, the lowest value found across the study area, to 1.6 m²/capita (Table 7). This area is one of the centres within Malmö's urban area, which is densely populated and popular for recreation. The third lowest UGS provision per person of 1.5 m²/capita is observed in DeSO 1280C2800, belonging to RegSO Gamla staden öst, where also some of the highest distances to UGS were observed.

Table 7. The five DeSOs with the lowest urban green space (UGS) per capita (m^2/capita) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	UGS per capita (m^2/capita)
1280C2100	Möllevången syd	0.2
1280C2260	Möllevången väst	1.0
1280C2800	Gamla staden öst	1.5
1280C2140	Möllevången	1.6
1280C2240	Rådmansvången	1.6

The five highest UGS provisions per capita ranged between 323 and 893 m^2/capita (Table 8) and were mainly observed in the larger DeSOs (Figure 6). Three of the DeSOs are located in the south of Malmö municipality. DeSO 1280C1180, located in RegSO Fosieby-Kastanjegården, where the highest UGS per capita was observed, is located in the southern border of Malmö's urban area. Two DeSOs are located in Oxie's urban area, namely 1280C1050 and 1280C1080, where UGS per capita range between 377 and 456 m^2/capita. The DeSO 1280C2920, which is located in RegSO Hamnen-Stortorget, has the second highest UGS per capita of 516 m^2/capita, however the lowest canopy cover was previously observed in this DeSO (Table 8). The DeSO 1280C2190, which largely consists of the park Pildammsparken and was mapped having the highest canopy cover, additionally has a large UGS provision per capita.

Table 8. The five DeSOs with the highest urban green space (UGS) per capita (m^2/capita) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	UGS per capita (m^2/capita)
1280C1180	Fosieby-Kastanjegården	893
1280C2920	Hamnen-Stortorget	516
1280C1050	Oxie syd	456
1280C1080	Oxie syd	377
1280C2190	Kronborg-Pildammsparken-Teatern	323

3.2.4 Distance to urban green space

The UGS a person experiences most may not be the one closest to their home. Some of the studies reviewed did measure distance from other locations, for example schools may be used as a starting point for children to access UGS. It may also be that the point of access to a park is not the nearest edge of that park and that different groups access the park in different ways (see insert 1). However, the vast majority of studies reviewed use place of residence as the assumed point origin and any boundary sufficient for access, so for pragmatic purposes this study follows that president.

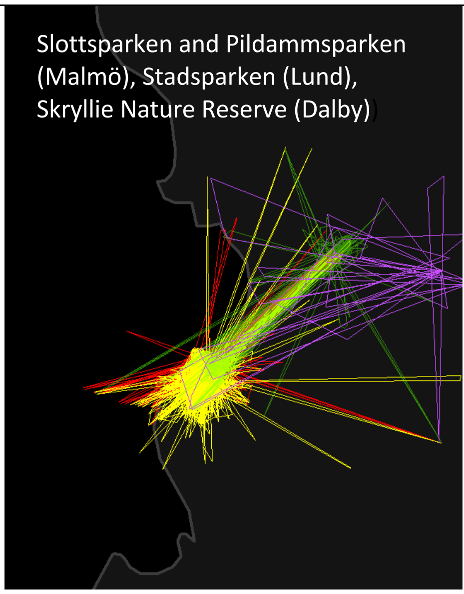
<table>
<tr><td colspan="2">Insert 1: Measuring distance to UGS, further methods and questions.</td></tr>
<tr><td>

Figure 7a. Range of locations visitors to a park have tweeted from</td><td>In this study, Twitter data was used to map the range of locations that visitors to parks also tweeted from.

This shows how the "home range" of people who use these parks extends well beyond the immediate vicinity of the park and underscores how simple per. capita measures of UGS provision may provide an incomplete picture.

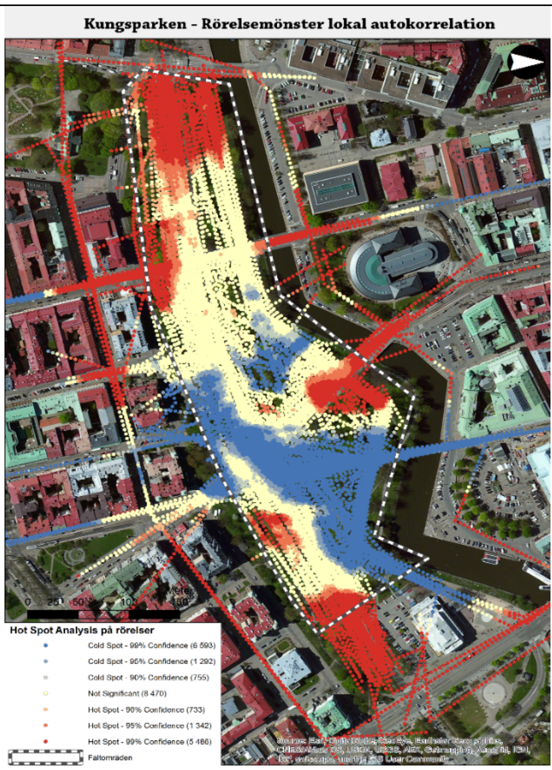
(Sang N., Hinterland Diagrams: Visualising the extended footprint of urban green space with Twitter data, Urban Forum Gothenburg, 2019)</td></tr>
<tr><td>

Figure 7b. Differences between men and women in their usage and access to a Gothenburg park</td><td>This study found clear differences between which entrances are used by men and women accessing the same park in Gothenburg, Sweden.

It demonstrates how demographic differences may compound the effect of physical barriers (such as the presence of water or defined by entrances) on simple "to the park edge" measures of accessibility.

(Ode-Sang et al. 2021)</td></tr>
</table>

3.2.4.1 Testing different methods for measuring distance

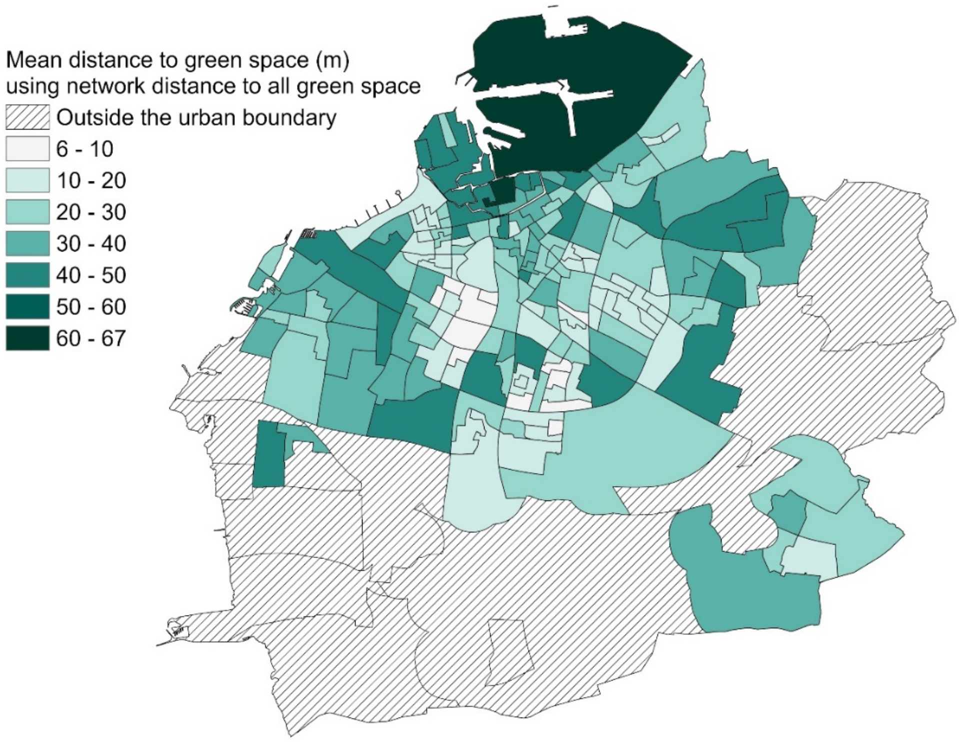
Three different approaches were used to measure access to UGS:

i. 'As the crow flies' (Euclidean). The distance between each home and the nearest green space.

ii. Network Distance. The distance between each home and the nearest greenspace as measured along a network of roads and paths.

iii. Cost distance. The time taken to walk to the nearest greenspace given a different walking speed for each land cover type, as estimated for a typical adult.

Figure 8 shows that, when aggregated to DeSO units, the general pattern of accessibility is similar between network and Euclidean measures of distance. However the relative values of individual neighbouring DeSO do change in places which may influence the apparent severity of any inequality between them.



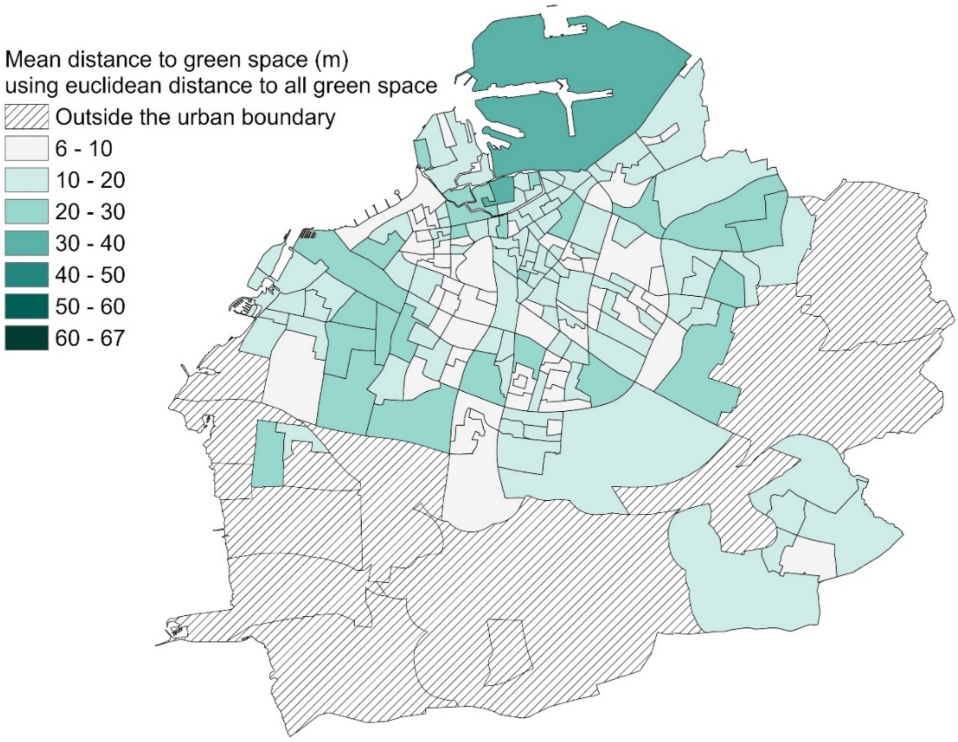


Figure 8. Mean distance to urban green space (UGS) calculated with network distance and Euclidian distance. UGS without any size or width thresholds applied.

Cost distance is a method to estimate some measure of the 'cost' - in this case time cost - of moving between two locations along the lowest-cost route. Based on a literature review of factors affecting walking speed each land cover was allotted a suitable cost, in seconds per meter walked across it (Appendix 1). Most time routing algorithms (for example Google Maps) use a network to estimate walking time.

The resulting map represents time-to-access, including waiting time to cross roads etc. (Figure 9). Areas in yellow to red are locations with more than 5 minutes walking time and thus typically more than 300 m to the nearest public UGS. Inaccessible areas, such as water or private land, are masked out in black. Therefore where red/yellow shows in lines along roads intersecting areas of black, this suggests that access to public UGS is lacking even if private UGS such as gardens may be close by.

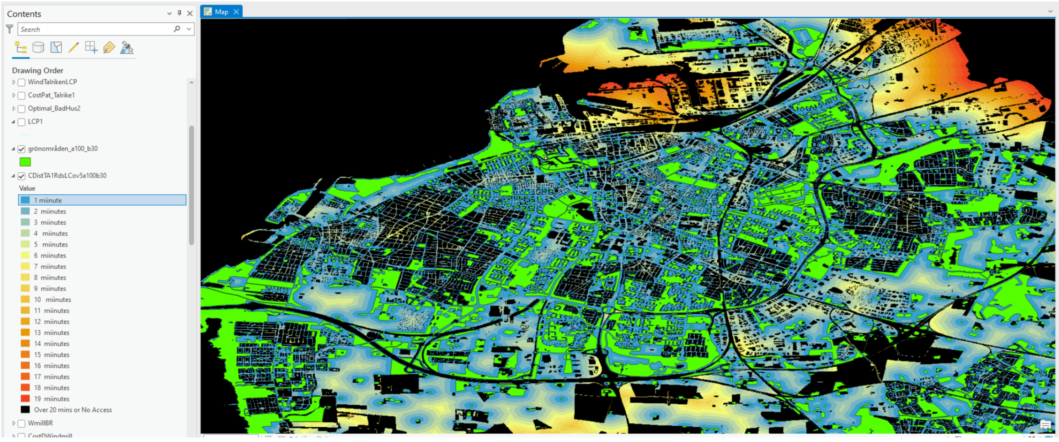


Figure 9. Walking time to greenspace (>100 m2 and 30m wide).

The main advantage of cost distance is also its main limitation – who is walking affects how the time cost should be calibrated. As a result it is possible to tailor the calculation by e.g. age, sex or infirmity but each result reflects those assumptions. Any error in the assumptions about relevant walking speeds will therefore affect the result in a complex way.

Figure 10 shows the effect of choosing different definitions of UGS calculating distance to that UGS by a Euclidean or Network distance measure. It shows the network distance is both on average further from UGS and more sensitive to the definition of that UGS. Therefore, using a network model will tend to show a greater range for inequality in UGS access but also be more sensitive to which UGS definition is used.

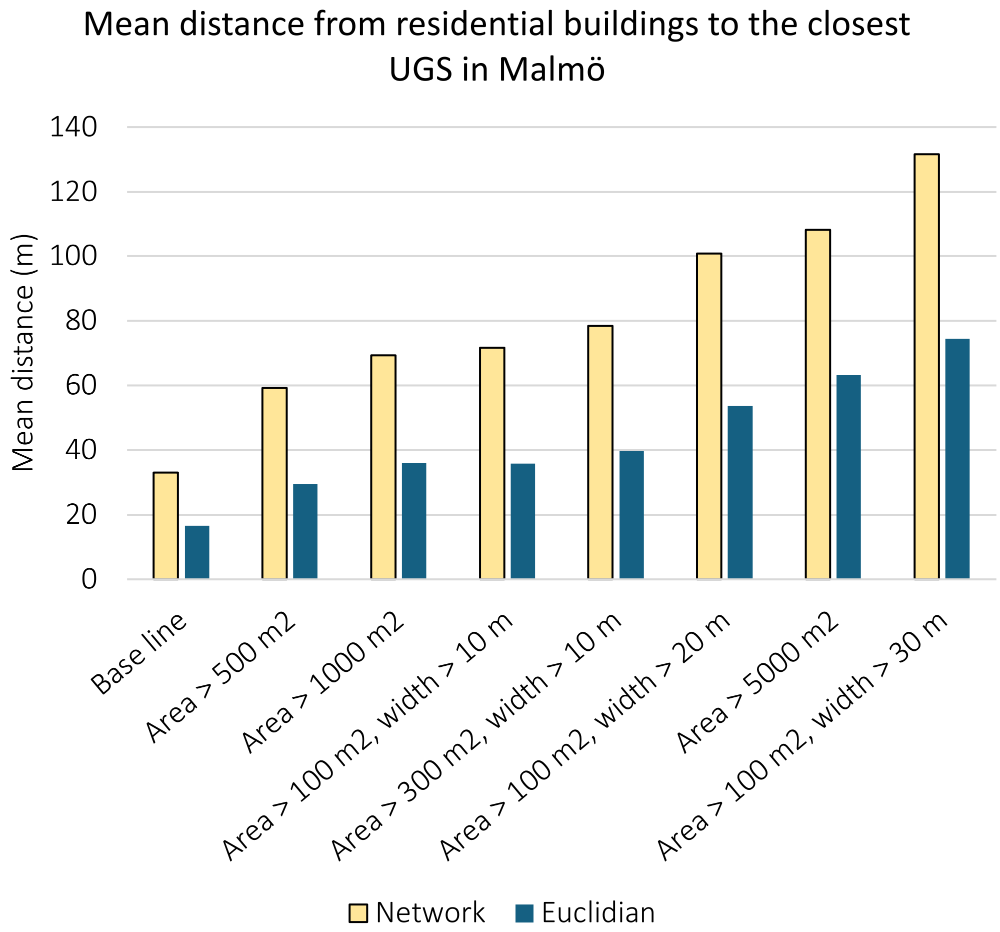


Figure 10. Mean distance from homes to the closest urban green space (UGS) by Euclidean or network distance measure for different definitions of UGS. Population points were used to define homes.

If working at DeSO level, the question remains as to whether the relative ranking of DeSO would be affected by different combinations of UGS and distance metric.

The Spearman's Rank test measures the degree to which rank order differs between a set of test data and a comparator. In Figure 11 the comparator is the "base line" UGS defined earlier i.e. without any limits as to minimum size or shape. Each bar in the graph shows the rank similarity between this and other combinations. The bars are sorted left to right by similarity to that base line.

In general the factor causing greater differentiation between the test data and the baseline is that of UGS definition. Most pairs sharing the same UGS definition are found adjacent to one another in Figure 11 with the network option being very similarly ranked to its Euclidean sibling.

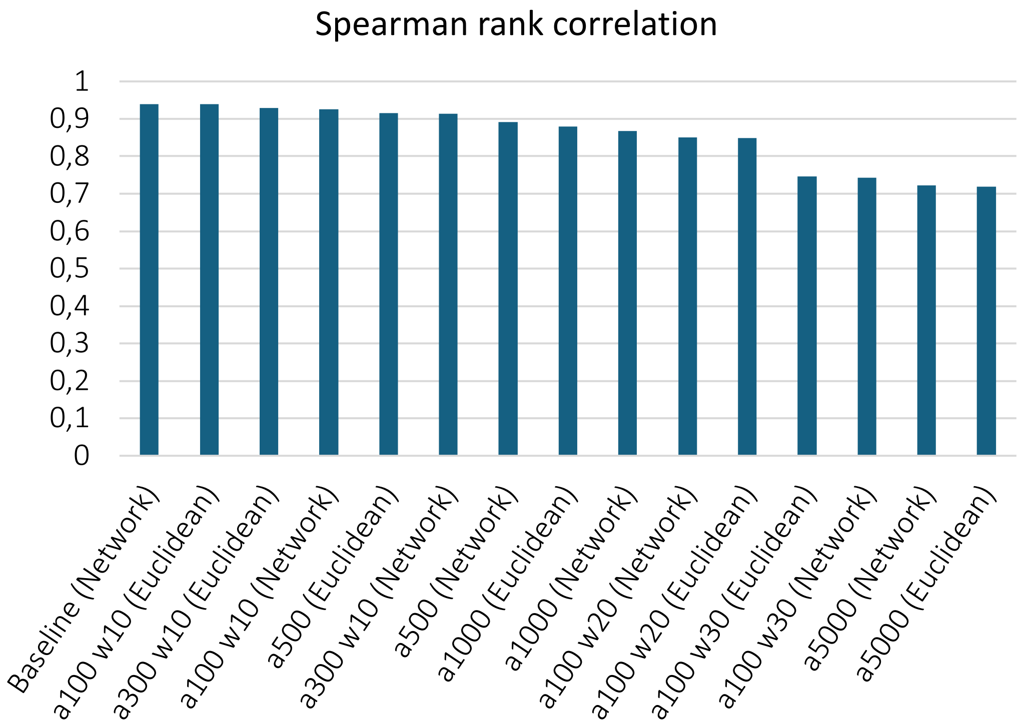


Figure 11. Results from the Spearman rank correlation, a measure of the relationship between two ranked sets of observations. The Spearman rank correlation was used to rank the computed average distance to urban green space (UGS) for each DeSO according to the different methods of calculating distance and the different definitions of UGS by comparing it with a baseline. The results from the Euclidean distance to base line UGS was used as the baseline.

Summary of conclusions:

- Definition of UGS is more important than the choice of distance metric, the criteria of width being more influential than the minimum area size (perhaps because it also imposes a higher defacto minimum area).
- Once aggregated to DeSO units, the difference in accessibility due to distance metric is up to 3%, which could lead to potentially significant differences in degree of apparent inequality between DeSO locally but does not visibly change larger scale patterns across the city.
- Comparison of the Spearman rankings between different Distance-UGS definitions shows up to 0.3 difference in rank, mainly driven by size selection. It is therefore likely that the choice of UGS definition will affect which DeSO appear most unequal in terms of UGS access, however it is also likely that this is largely the result of many DeSO swapping places with other similarly ranked DeSO rather than a few changing rank dramatically since the maps do not show such cases.

Therefore it suggests caution as to the precision with which DeSO can be placed on such a scale but does not undermine the general validity of doing so.

- The particular combination of UGS and distance definition recommended (100 m^2, 30 m, Euclidean) is significantly different from the base-line. Therefore, applying this definition is likely to affect the apparent ranking of DeSO with respect to UGS accessibility.

3.2.4.2 Method for calculating distance to urban green space

The green space indicator 'distance to UGS' was calculated using four datasets; UGS, population points, a network, and DeSOs.

The UGS for this indicator were based on the definition from Region Skåne (see section 3.2.2) and included a size threshold of 100 m^2 and a width threshold of 30 meters. The minimum width was applied using an inverted buffer, which, after testing, had to retain some UGS. Population points, which are based on the population register, were used to calculate the distance from homes to UGS.

The network used for distance calculation should include pavements, bike paths, crossings, and roads suitable for walking. In this analysis, Malmö Stad's comprehensive network of pedestrian and cycling paths, crossings, and roads was used. An alternative recommendation is to base the network on data from NVDB, which offers open data on pedestrian paths, cycling lanes, and streets. In cases where the pedestrian and cycling paths are not fully covered in the municipality, walkable roads can be included.

The method for calculating the indicator followed these steps:

i. Compute UGS using Region Skåne's methodology, applying a width threshold of 30 metres followed by a size threshold of 100 m^2.

ii. Create the network to be used in the distance analysis. The network should include pedestrian and cycling paths, crossings, and roads that are walkable.

iii. Calculate the distance from each population point to the nearest UGS using a network analysis.

iv. Aggregate the results by calculating the average distance per DeSO.

3.2.4.3 Distance to urban green space in Malmö

The mean distance to UGS in DeSOs within the urban areas of Malmö municipality ranges between 12 and 287 m with a mean distance of 117 m across all DeSOs (Figure 12). The lower distances are generally found in patches in the south part of the Malmö urban area, while higher distances generally are concentrated in the northern and western parts of Malmö's urban area.

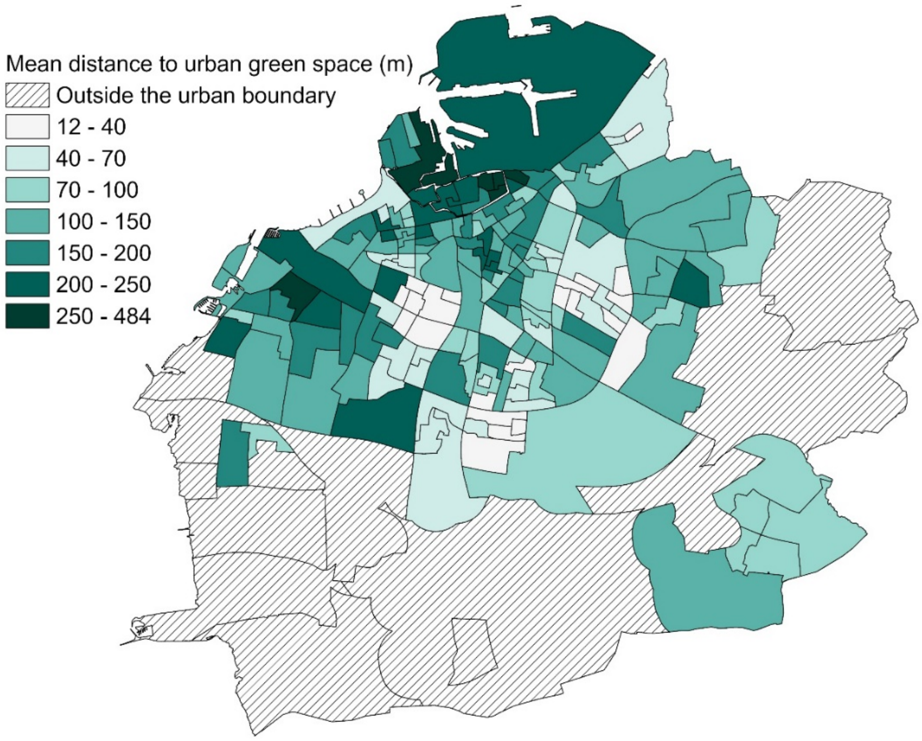


Figure 12. The mean distance to urban green spaces (m) calculated per DeSO. Distance is measured as the actual walking distance in a network from each population point to the nearest urban green space. Urban green spaces are defined as public areas larger than 100 m^2 and wider than 30 meters. The walking network includes sidewalks, bike paths, and crosswalks in a comprehensive network. The average distance from homes to the nearest green space was aggregated to DeSO level.

The five lowest mean distances range between 12 and 15 metres and four of the five DeSOs were observed in the patch of low distance DeSOs in the eastern part of Malmö, although belonging to different RegSO areas (Figure 12; Table 9). This includes DeSO 1280C2000 belonging to RegSO Emilstorp-Östra kyrkogården-Apelgården, DeSO 1280C2020 that belongs to RegSO Kryddgården, DeSO 1280C1890 that belongs to RegSO Persborg-Törnrosen, and DeSO 1280C1830 that belongs to RegSO Örtagården syd-Herrgården syd (Table 9). The third lowest distance to UGS was found in DeSO 1280C1700, located in the western patch of DeSOs with low distance, which belongs to RegSO Bellevuegården öst. Common to all these areas, along with most DeSOs visualised in the class 12-40 metres in Figure 12, is that they are dominated by apartment buildings.

Table 9. The five DeSOs with the lowest mean distances to urban green space (UGS) in metres across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	Mean distance to UGS (m)
1280C2000	Emilstorp-Östra kyrkogården-Apelgården	12
1280C2020	Kryddgården	13
1280C1700	Bellevuegården öst	14
1280C1890	Persborg-Törnrosen	14
1280C1830	Örtagården syd-Herrgården syd	15

The five highest mean distances range between 287 and 484 metres (Table 10). Four of the five DeSOs are located in one of the neighbouring RegSO areas Gamla staden öst or Slussen, and it was here that the largest mean distances were observed. For the DeSOs in Gamla Staden, distances to UGS varied between 305 to 484 metres, while the mean distance for DeSO 1280C2810 in Slussen was 358 metres. The fifth largest mean distance of 287 metres was observed in DeSO 1280C1950, located in RegSO Gamla Limhamn, in the western part of Malmö's urban area.

Table 10. The five DeSOs with the highest mean distances to urban green space (UGS) in metres across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	Mean distance to UGS (m)
1280C2800	Gamla staden öst	484
1280C2810	Slussen	358
1280C2730	Gamla staden öst	327
1280C2780	Gamla staden öst	305
1280C1950	Gamla Limhamn	287

3.2.5 Canopy cover

The green space indicator canopy cover was calculated using two datasets; a dataset of canopy cover in the municipality along with DeSOs. While some municipalities, like Malmö, have mapped their own canopy cover with detailed techniques, the Swedish National Board of Housing, Building and Planning recently released a national dataset of canopy cover in urban areas with more than 5000 inhabitants (The Swedish National Board of Housing, Building and Planning 2023). Although the dataset currently is not including all urban areas in Sweden, the Swedish National Board of Housing, Building and Planning has an ambition to continue to produce a data set that fully covers all urban areas in Sweden and that is continuously updated. The data, which is open and accessible for everyone to download, allows most municipalities do analyse canopy cover in their urban areas.

Using the data from the Swedish National Board of Housing, Building and Planning, the average canopy cover in Malmö municipality is 7.9%, the average for the nine largest towns in Skåne is 10.4%, and for the whole country, the canopy cover varies from 2.6% in Hjärup to 56.2% in Hofors, with an average value just under 30%.

3.2.5.1 Comparison of datasets

In order to understand the difference between the Swedish National Board of Housing, Building and Planning's national canopy cover data and Malmö Stad's detailed mapping of canopy in the municipality, we analysed the key characteristics between the two datasets (Table 11) and mapped the difference in canopy cover per DeSO.

The datasets are created using two different methods. While Malmö used LiDAR scanning, a costly technique which captures height with a very high accuracy, the Swedish National Board of Housing, Building and Planning's data is based on combining open and available orthophotos and digital surface models from the Swedish Mapping, Cadastral and Land Registration Authority's aerial photographs. There is however a few cons with the Swedish National Board of Housing, Building and Planning's approach that results in a higher error compared to the LiDAR approach. First, their method uses aerial photographs captured after June 1st, which could result in missing trees that have not yet undergone full leaf emergence. Second, they identify canopies as cells in the orthophotos with positive NDVI that has an elevation range within the range of 0.5-45 metres. This results in all green surfaces being captured, even green roofs, which is clear when comparing the datasets in areas like Västra Hamnen in Malmö.

The datasets also differ in their geographic coverage. The Swedish National Board of Housing, Building and Planning's canopy cover data is limited to urban areas with populations greater than 5000, which excludes smaller communities and rural areas, including some parts of Malmö municipality. On the other hand, Malmö's data encompasses the entire municipality, providing a more comprehensive view of canopy cover across various urban and suburban settings.

A significant difference lies in the definition of DeSO. The Swedish National Board of Housing, Building and Planning's calculations of canopy cover per DeSO includes both land and sea area of the DeSO in its calculations, which may lead to reductions in the reported canopy cover percentages in DeSOs adjacent to the coast compared to if only analysing the land area. Conversely, Malmö Stad excludes marine areas from its calculations, focusing solely on terrestrial land.

Table 11. Table comparing key characteristics of the canopy cover data from the Swedish National Board of Housing, Building and Planning and Malmö Stad.

	The Swedish National Board of Housing, Building and Planning	**Malmö Stad**
Data type	Raster	Geopackage
Spatial resolution	1 x 1 m	No minimum area threshold
Minimum heights in the dataset	0.5 m	0.5 m
Data source	Ortophoto and digital surface models	LiDAR
Temporal resolution	Based on images captured between 2018-2021	Scanned and created 2022
Geographical coverage	Urban areas with a population > 5000 inhabitants	Malmö municipality
DeSO definition	The calculations of canopy cover per DeSO includes sea and land	Excludes sea

Figure 13 compares Malmö Stad's canopy data with the recently released urban canopy data from The Swedish National Board of Housing, Building and Planning. The comparison is made by analysing the area covered by canopy above a height of 3 meters in both datasets. The canopy cover percentage is calculated based on the land area of the DeSO, excluding portions of the DeSO that are located in the sea. The difference in canopy cover varies between -3% to +2% per DeSO, where the difference between the datasets are attributed to the differences in method, temporal resolution, and level of detail described above.

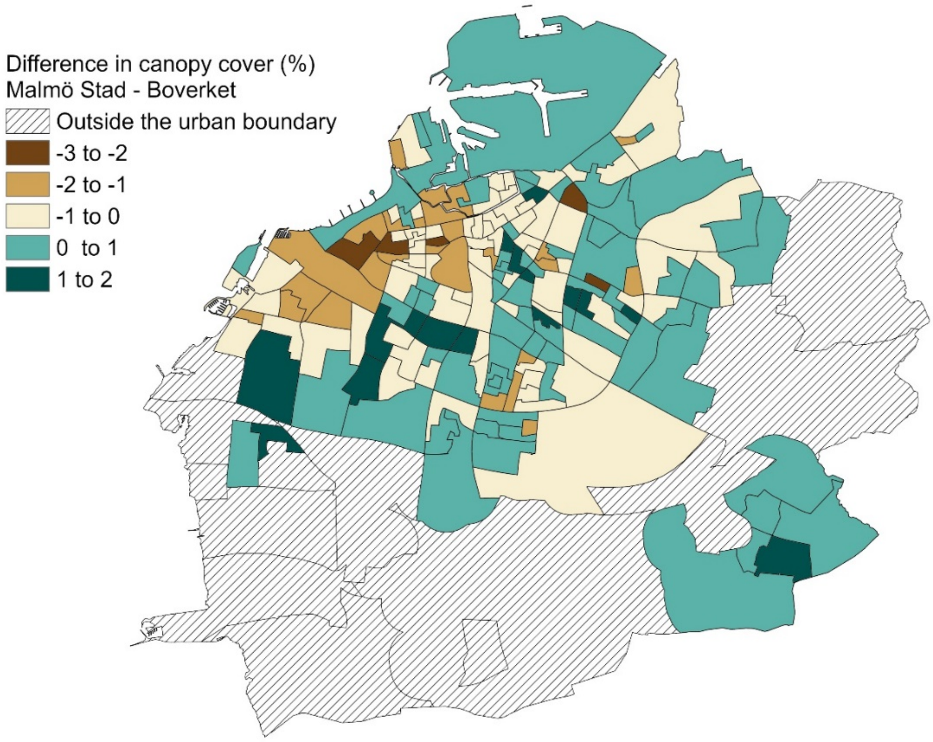


Figure 13. Difference in canopy cover per DeSO (%) between The Swedish National Board of Housing, Building and Planning's and Malmö Stad's data. Positive values indicate DeSOs where Malmö Stad's canopy cover exceeds the Swedish National Board of Housing, Building and Planning's. Negative values indicate DeSOs where the Swedish National Board of Housing, Building and Planning's canopy cover exceeds Malmö Stad's. The comparison is made by analysing the area covered by canopy above a height of 3 meters in both datasets. The canopy cover percentage is calculated based on the land area of the DeSO, excluding portions of the DeSO that are located in the sea.

Summary of conclusions:

In terms of statistics about tree canopy extent for the entire city, the choice of dataset makes little difference. However, to individual DeSO the difference may be up to 3%, meaning two adjacent DeSO may differ in their reported relative canopy area by 5-6% depending on which dataset is used. This effect, however, must be considered against the effect of the different areal unit aggregations that DeSOs impose. In respect of equity, the significant question is whether this difference can affect the relative ranking of DeSOs? In terms of regional and national comparison, the more significant strength of the Swedish National Board of Housing, Building and Planning's Canopy Cover Data is that it provides a standardised method across Sweden, but it has not been produced for urban areas with less than 5000 inhabitants. The Malmö dataset includes a little more detail and pertains to the entire municipality.

3.2.5.2 Final method

Although Malmö Stad's canopy data has a higher accuracy, we decided to work with the Swedish National Board of Housing, Building and Planning's canopy data since it is a national dataset which makes it comparable with other municipalities. The method for calculating the indicator follows these steps:

i. Clip DeSOs with the urban boundary to exclude marine areas. Calculate the area of the resulting clipped DeSOs in square meters (m^2). This step is crucial to ensure that your calculations only consider land areas.

ii. Download the Swedish National Board of Housing, Building and Planning's Canopy Cover Data (the Excel document titled "*Trädtäckning tätorter och DeSO*")

iii. Within the Excel file, navigate to the tab labelled "*DeSO_2018_v2_urval_tradtackning*". Here, you will find the column titled "*Trädtäckning area [kvm]",* which provides the area covered by trees in square meters for each DeSO.

iv. Calculate canopy cover for each DeSO using the equation below

$$Canopy\ Cover = \frac{Area\ canopy\ cover\ in\ a\ DeSO\ (m2)}{Total\ terrestrial\ area\ of\ a\ DeSO\ (m2)}$$

3.2.5.3 Canopy cover in Malmö

The canopy cover in DeSOs within the urban areas of Malmö municipality ranges between 2% and 38% with a mean canopy cover of 12% across all areas (Figure 14). The general pattern of canopy cover in Malmö is that it varies quite a lot within the urban areas of the municipality. However, patches of high canopy cover coincides with areas with large parks and patches with low canopy cover coincided with relatively newly developed areas.

Generally, there is a more equal distribution of canopy cover than UGS per capita with only one major DeSO showing very low levels of canopy cover (the port area to the North). The individual DeSOs otherwise showing low canopy cover are very small and scattered, suggesting this is likely to be largely a Modifiable Area Unit effect which might well appear differently with only slight modification of the unit boundaries. None the less, within these areas there is clearly some lack of trees.

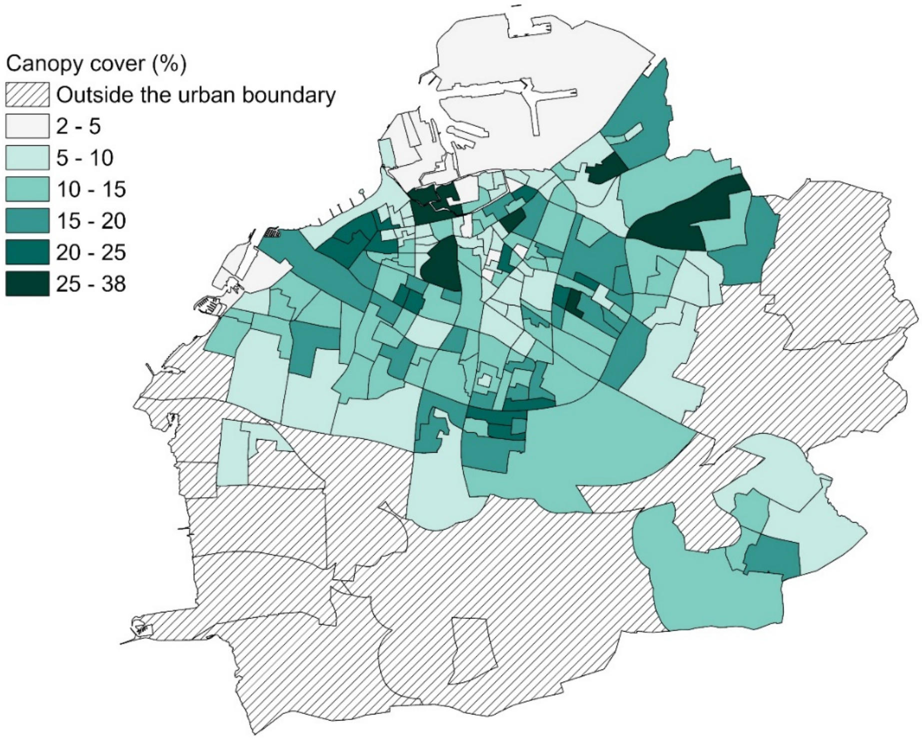


Figure 14. Canopy cover (%) per DeSO calculated using the Swedish National Board of Housing, Building and Planning's canopy cover data. The canopy cover is calculated for tree-covered areas with a height of at least 3 meters. The canopy cover percentage is calculated for DeSOs within the urban boundary, thereby only including terrestrial areas.

The five DeSOs with lowest canopy cover can be found across different RegSO areas, but are mainly located in the central urban area. The lowest canopy cover of 2% can be observed in DeSO 1280C2920, which belongs to RegSO Hamnen – Stortorget and includes the very central part of the urban area of Malmö along with the entire harbour area in Malmö (Table 12). The canopy cover in the three DeSOs 1280C2870 belonging to RegSO Västra hamnen sydöst, 1280C2770 belonging to RegSO Slussen, and 1280C2100 belonging to Möllevången syd, is about 3%. While Slussen and Möllevången are two of the smaller DeSOs in Malmö that are both residential and offer recreational activities, Västra hamnen is a larger DeSO that is relatively newly developed. DeSO 1280C2320, belonging to RegSO Ön norr, an area of similar size as Västra hamnen and also located by the sea, has the fifth lowest canopy cover.

Table 12. The five DeSOs with the lowest canopy cover (%) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	Canopy cover (%)
1280C2920	Hamnen-Stortorget	2
1280C2870	Västra hamnen sydöst	3
1280C2770	Slussen	3
1280C2100	Möllevången syd	3
1280C2320	Ön norr	3

The five DeSOs with the highest canopy cover closely coincides with the occurrence of large parks. The highest canopy cover of 38% can be observed in DeSO 1280C2190, which belongs to Kronborg-Pildammsparken-Teatern, and the DeSO basically covers the park Pildammsparken (Table 13). Similarly, DeSO 1280C2680 that is located in RegSO Malmöhus contains the large parks Slottsparken, Kungsparken, and the old cemetery, and the canopy cover there is 35%. DeSO 1280C1830, where the canopy cover is 32%, belongs to RegSO Örtagården syd-Herrgården syd. No large parks are found there, but the DeSO contains apartment buildings and a lot of open space for recreation, such as basketball courts, sports fields and playgrounds. Again, the occurrence of large parks are found for DeSO 1280C2600 located in RegSO Riseberga and DeSO 1280C2560 located in RegSO Värnhem – Västra Sorgenfri, where Risebergaparken and Sankt Pauli North cemetery are located. Here, the canopy cover is 30 and 28%, respectively.

Table 13. The five DeSOs with the highest canopy cover (%) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	Canopy cover (%)
1280C2190	Kronborg-Pildammsparken-Teatern	38
1280C2680	Malmöhus	35
1280C1830	Örtagården syd-Herrgården syd	32
1280C2600	Riseberga	30
1280C2560	Värnhem-Västra Sorgenfri	28

3.3 Socio-economic indicators

We have chosen to work with four socio-economic indicators, namely age dependency ratio, employment rate, household income and education level. These are in general the most used indicators to socio-economic mapping across the studied methods (see section **Fel! Hittar inte referenskälla.**), and the data is easily accessible and reliable data and available at DeSO level. The following subsections describe the definition of, and methods used to calculate, each indicator.

3.3.1 Age dependency ratio

The age dependency ratio explains the percentage of the population that is dependent on the livelihood of the working population, i.e. what is the proportion of the age groups 0-14 and 65+ in relation to the age group 15-64. In recent years, for the older age group, the prospective old-age dependency ratio has started to be used, which takes into account how long one has left to live, statistically speaking. The reason is that it is during the last 15 years that we are most dependent on help, but that can be considered a premium in our project.

The age dependency ratio as the average in Sweden's municipalities was 77% on 31 December 2023, of which the old-age dependency ration is 36.5%. For Malmö, the corresponding numbers are 61.6% and 24.6% respectively. Since it is positive to have a high proportion of the population of working age, it means that the lower the number the better.

The indicator 'age dependency' ratio was calculated using population data from Statistics Sweden (Statistics Sweden 2023b). The method for calculating the indicator followed these steps:

i. Download the data set "*Folkmängden per region efter ålder och kön. År 2010 – 2023"* from Statistics Sweden. Select to download data per DeSO for the year 2021, classified by age group.

ii. Calculate the proportion of people in the age groups 0-14 and 65+ relative to the age group 15-64 per DeSO with the equation below.

$$Age\ Dependency\ Ratio = \frac{Number\ of\ people\ \leq 14 + Number\ of\ people \geq 65}{Number\ of\ people\ aged\ 15 - 64}$$

3.3.1.2 Age dependency ratio in Malmö

The age dependency ratio in DeSOs within the urban areas of Malmö municipality ranges between 17 and 138, with a mean age dependency ratio of 56 indicating that a greater proportion of the population are between 15-64 years old (Figure 15). Lower age dependency ratios are generally found across the central parts of Malmö's urban area, while the age dependency tends to increase closer to the urban boundary.

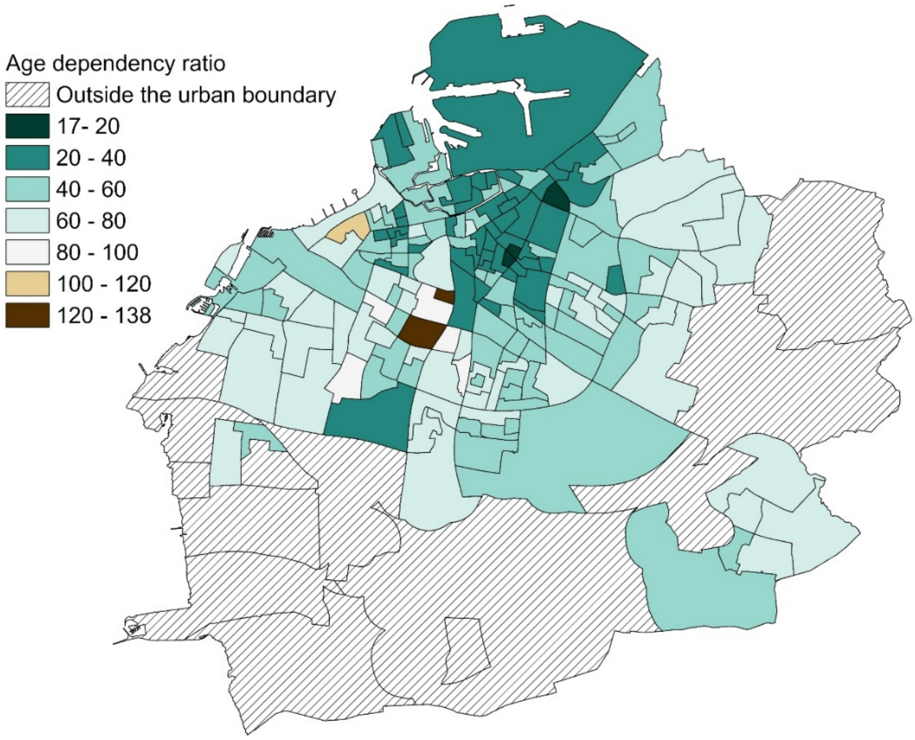


Figure 15. Age dependency ratio calculated using data from Statistics Sweden in 2021. The dependency ratio is the sum of the young population (younger than 15 years) and the elderly population (65 years and older) relative to the working-age population (aged between 15 and 64). Values above 100 indicate a population where a larger proportion is either elderly or young. The lower the value, the greater the proportion of the population is between 15 and 64 years old.

Among the five lowest age dependency ratios observed in Malmö, three have a value below 20 and two just above 20 (Table 14). Two of the DeSOs, 1280C2700 and 1280C2750, are located in RegSO Östervärn-Ellstorp. The second and third lowest age dependency ratios are found in DeSO 1280C2220 and 1280C2290, which are neighbouring each other but belong to different RegSOs.

Table 14. The five DeSOs with the lowest age dependency ratio across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	Age dependency ratio
1280C2700	Östervärn-Ellstorp	16.8
1280C2220	Möllevången öst	17.8
1280C2290	Västra Sorgenfri öst	19.9
1280C2750	Östervärn-Ellstorp	20.5
1280C1970	Södervärn-Allmänna sjukhuset-Flensburg	20.5

The age dependency ratio only exceeds values above 100 in three DeSOs, indicating that the largest proportion of the population are either elderly (>64) or young (<15). An age dependency ratio exceeding 130 can be found in DeSO 1280C1920, belonging to the RegSO Stadion-Borgmästaregården and DeSO 1280C1650 in Ärtholmen-Södertorp-Gröndal, where the observed age dependency ratio is 139 and 131, respectively (Table 15). A lower age dependency around 100 can be found in DeSO 1280C2550 in RegSO Västervång-Fridhem and DeSO 1280C1590 in RegSO Ärtholmen-Södertorp-Gröndal. It is also in RegSO Stadion-Borgmästaregården and Ärtholmen-Södertorp-Gröndal that we observe most of the DeSOs with age dependency ratios between 80 and 100, visualised in white in Figure 15.

Table 15. The five DeSOs with the highest age dependency ratio across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	Age dependency ratio
1280C1920	Stadion-Borgmästaregården	138.9
1280C1650	Ärtholmen-Södertorp-Gröndal	130.9
1280C2550	Västervång-Fridhem	100.9
1280C1590	Ärtholmen-Södertorp-Gröndal	98.9
1280C1850	Stadion-Borgmästaregården	89.7

3.3.2 Employment rate

Employment rate indicates the percentage of the population that can support itself. The indicator can either be measured as the employment rate, i.e. how many according to Statistics Sweden's definition of being employed for a sufficient number of hours, or as unemployment, i.e. how many are neither employed, studying nor participating in labour market policy measures. In both cases, the indicator is measured as a percentage of the population in the age group 15-64. To be extra considerate, one can calculate both indicators and use the average in the ranking. On December 31, 2022, the employment rate in Sweden was 81.4%, while unemployment was at 4.8%.

The indicator 'employment rate' was calculated using population data from Statistics Sweden (Statistics Sweden, 2021). The method for calculating the indicator followed these steps:

i. Download the data set "*Befolkningen 20-64 år efter region, sysselsättning och kön, ny tidsserie. År 2019 - 2021*" from Statistics Sweden. Select to download data per DeSO for the year 2021, including all genders.

ii. Calculate the proportion of employed inhabitants relative to the total number of inhabitants using the equation below.

$$Employment\ rate = \frac{Number\ of\ employed\ inhabitants}{Total\ number\ of\ inhabitants}$$

3.3.2.1 Employment rate in Malmö

The employment rate in DeSOs within the urban areas of Malmö municipality ranges between 38 % and 85 %, with a mean employment rate of 70 % (Figure 16). The employment rates vary with a similar pattern to mean annual income (Figure 16), with a higher employment rate across the western, costal area of Malmö's urban area and patches of lower employment rates in different parts of the southern urban area of Malmö. However, high employment rates are also found in the eastern part of Malmö's urban area, and in Oxie's urban area.

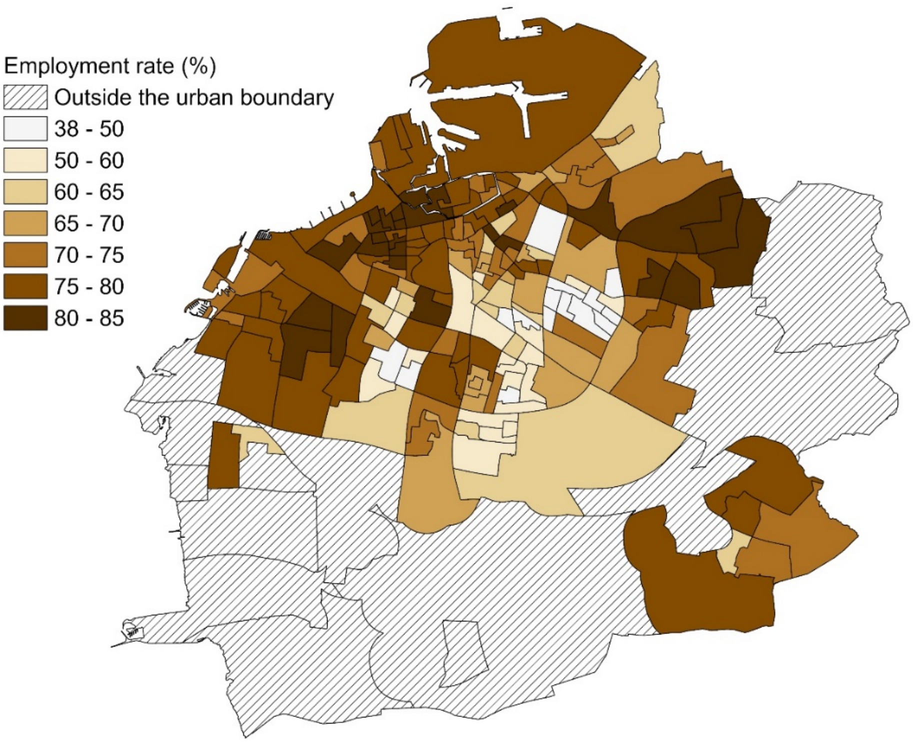


Figure 16. Employment rate calculated using data from Statistics Sweden in 2021. The employment rate is defined as the percentage (%) of the population aged 20-64 that is employed according to SCB's definition. To be considered employed, a person must have an income from employment that exceeds a calculated threshold or have declared active business operations during the relevant year.

The five DeSOs with the lowest employment rates coincide with the five DeSOs where the lowest mean incomes were observed. This includes DeSO 1280C1880, 1280C1750, and 1280C1690 belonging to RegSO Herrgården norr, DeSO 1280C2020 belonging to RegSO Kryddgården, and DeSO 1280C1980 in

Örtagården norr (Table 16). Here, employment rates vary between 38.2 % and 44.7%.

Table 16. The five DeSOs with the lowest employment rate (%) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	Employment rate (%)
1280C1880	Herrgården norr	38.2
1280C1750	Herrgården norr	43.8
1280C2020	Kryddgården	44.2
1280C1690	Herrgården norr	44.3
1280C1980	Örtagården norr	44.7

On the contrary, the five DeSOs where the highest employment rates are observed do not coincide with the five DeSOs with the highest mean annual income. There is not a large difference in employment rates for the top five DeSOs, which varies between 83 % and 85 % 8 (Table 17). The highest and third highest employment rates are found in RegSO Ribersborg, in central Malmö, in DeSO 1280C2620 and 1280C2590. The three other are spread out across the eastern part of Malmö's urban area, in RegSO Virentofta - Östra Skrävlinge – Toftanäs, Håkanstorp – Bulltofta – Valdemarsro, and Videdal.

Table 17. The five DeSOs with the highest employment rate (%) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	Employment rate (%)
1280C2620	Ribersborg	85.2
1280C2340	Virentofta-Östra Skrävlinge-Toftanäs	85.1
1280C2590	Ribersborg	84.6
1280C2640	Håkanstorp-Bulltofta-Valdemarsro	84.1
1280C2070	Videdal	83.4

3.3.3 Mean income

The indicator 'income' refers to households' disposable income after tax and transfers. The mean income in Sweden on 31 December 2022 was 557 100 SEK. The indicator 'income' was calculated using income data from Statistics Sweden (Statistics Sweden 2022). The method for calculating the indicator followed these steps:

i. Download the data set "*Andel av befolkningen per inkomstklass efter region, inkomstslag och kön. År 2011 – 2022*" from Statistics Sweden. Select to download data per DeSO for the year 2021, where type of income is mean net income.

ii. Retrieve the mean net income per DeSO from the table.

3.3.3.1 Mean income in Malmö

The mean income in DeSOs within the urban areas of Malmö municipality ranges between 173,000 and 1,048,000 SEK, with a mean income of 315,000 SEK (Figure 17). The income level varies in the urban areas of Malmö municipality, with higher household incomes generally found across the coastal area in Western Malmö and along the city centre. Lower household incomes are observed across many neighbourhoods in the southern urban area of Malmö.

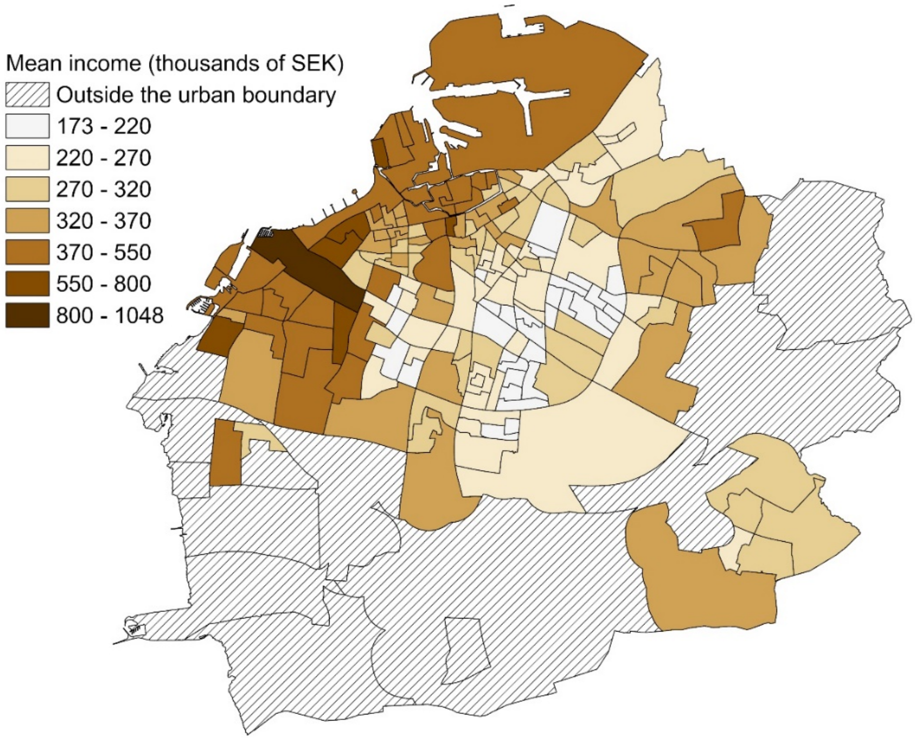


Figure 17. Mean annual income calculated using data from Statistics Sweden in 2021. The mean income is the mean of households' disposable net income after taxes and transfers, measured in thousands of Swedish kronor (SEK) per DeSO.

32 of the 192 DeSOs have a mean annual income below 220 thousand SEK a year, which corresponds to a monthly income of about 18 thousand SEK. Many of these DeSOs are observed in the same neighbourhoods in the southern urban area of Malmö (Table 18). The five DeSOs where the lowest mean annual income was observed belong to the RegSOs Kryddgården, Herrgården norr, and Örtagården

norr, which are all neighbouring each other. Here, the mean annual income ranges between 172,800 and 184,700 SEK.

Table 18. The five DeSOs with the lowest mean annual income (thousands of SEK) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	Mean income (thousands of SEK)
1280C2020	Kryddgården	172.8
1280C1880	Herrgården norr	180.2
1280C1980	Örtagården norr	181.6
1280C1750	Herrgården norr	184.4
1280C1690	Herrgården norr	184.7

The highest mean annual incomes are also found in the same neighbourhood in Malmö along the coastal area in Malmö's urban area. The five DeSOs with the highest income are neighbouring each other and are located in any of the RegSOs Bellevue-Nya Bellevue, Västervång-Fridhem, Djupadal-Rosenvång, or Sibbarp (Table 19). Here, the mean annual income varies between 1,047,600 SEK in DeSO 1280C2210 to 661,400 SEK in DeSO 1280C1640. There is a large difference in mean annual income between the top five DeSO, where the highest mean income is almost 250,000 SEK higher than the second highest.

Table 19. The five DeSOs with the highest mean income (thousands of SEK) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	Mean income (thousands of SEK)
1280C2210	Bellevue-Nya Bellevue	1047.6
1280C2330	Västervång-Fridhem	789.7
1280C2550	Västervång-Fridhem	748.4
1280C1660	Djupadal-Rosenvång	664.7
1280C1640	Sibbarp	661.4

3.3.4 Education level

The population's level of education can either be calculated as the percentage in the age group 25-65 who have longer or shorter tertiary education, which for Sweden as a whole was 45% on 31 December 2023. Or the percentage at most with pre-secondary education, which in the same age group was 7% at the same time.

The indicator education level was calculated using population data from Statistics Sweden (Statistics Sweden 2023a). The method for calculating the indicator followed these steps:

i. Download the data set ”*Befolkning 25-64 år (fr.o.m. 2023, 25–65 år) efter region och utbildningsnivå. År 2015 – 2023*” from Statistics Sweden. Select to download data per DeSO for the year 2021, classified by education level.

ii. Calculate the proportion of people with at least a post-secondary education with the equation below.

$$Education\ level = \frac{Inhabitants\ with\ at\ least\ a\ post - secondary\ education}{Total\ number\ of\ inhabitants}$$

3.3.4.1 Education level in Malmö

The post-secondary education level in DeSOs within the urban areas of Malmö municipality ranges between 15% and 81%, with a mean education level of 51% (Figure 18). The education level is measured as the percentage of the population aged 25-64 with post-secondary education. The pattern generally follows the pattern observed for mean income and employment, with the highest education level in the western and central area of Malmö’s urban area.

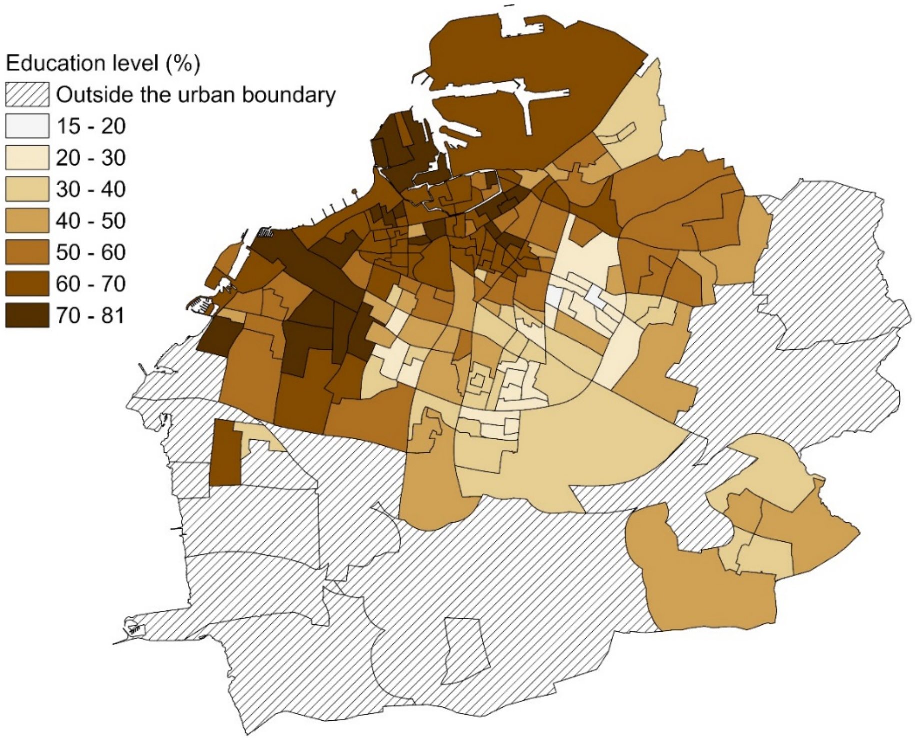


Figure 18. Education level calculated using data from Statistics Sweden in 2021. The education level is measured as the percentage (%) of the population aged 25-64 with post-secondary education.

Within the five DeSOs with the lowest education level, only 15% to 22% of the population in the DeSO have completed a post-secondary education (Table 20).

Three of these DeSOs have previously been highlighted as having some of the lowest employment rates and mean annual incomes, namely DeSO 1280C1880 and 1280C1750 in Herrgården norr and DeSO 1280C1980 in Örtagården norr. Similar education levels are observed for the two other DeSOs 1280C1890 and 1280C1830, which are located in neighbouring areas.

Table 20. The five DeSOs with the lowest education level (%) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	Education level (%)
1280C1880	Herrgården norr	15.3
1280C1890	Persborg-Törnrosen	20.0
1280C1750	Herrgården norr	20.5
1280C1830	Örtagården syd- Herrgården syd	20.6
1280C1980	Örtagården norr	21.7

The education level ranges between 79 % and 81 % within the five DeSOs with the highest education level (Table 21). The top two DeSOs with the highest proportion of the population with a post-secondary education are DeSO 1280C2380 in RegSO Västra Sorgenfri öst and DeSO 1280C2330 in RegSO Västervång-Fridhem, followed by three DeSOs belonging to RegSO Djupadal-Rosenvång.

Table 21. The five DeSOs with the highest education level (%) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to.

DeSO	Belongs to RegSO	Education level (%)
1280C2380	Västra Sorgenfri öst	81.4
1280C2330	Västervång-Fridhem	81.4
1280C1560	Djupadal-Rosenvång	80.5
1280C1660	Djupadal-Rosenvång	79.6
1280C1810	Djupadal-Rosenvång	79.3

3.4 Calculation of Greenspace Status and Socio Economic Status

Each of the seven indicators ‘UGS per capita’, ‘canopy cover’, ‘distance to UGS’ and ‘age dependency’, ‘income’, ‘education level’, and ‘employment rate’, have been computed, and combined into two individual indexes. All indicators are combined unweighted, meaning they are treated equally when combined.

The following method was applied to derive a Green Space Status (GSS) and a Socio-Economic Status (SES) when all indicators have been calculated. Note that only DeSOs that have data for all indicators are included in the calculation. The analysis in this project is conducted on 179 DeSOs since 13 DeSOs are missing from the Swedish National Board of Housing, Building and Planning's dataset on canopy cover.

In order to combine the indicators, they first had to be normalised to a value between 0 and 1. Many of the existing models reviewed in section 2.2 used this approach (American Forest 2024; Heckert & Rosan 2016; Pils 2023; Sonesson et al. 2024; Transportation Alternatives & the Massachusetts Institute of Technology n.d.). This normalisation was achieved using the equation below.

$$Normalised\ value = \frac{Xi - Xmin}{Xmax - Xmin}$$

Where X_i = the value for a specific DeSO being normalised, X_{min} = the minimum value across all DeSOs, X_{max} = the maximum value across all DeSOs.

The normalised indicators were then used to calculate a GSS and a SES. Both statuses were calculated by taking an unweighted average of the indicators. Green Space Status (GSS) was calculated by combining the indicators UGS per capita, distance to UGS, and canopy cover according to the equation below. Distance to green space was subtracted as a lower distance indicates better access, which should result in a higher GSS.

$$GSS = \frac{UGS\ per\ capita - distance\ to\ UGS + canopy\ cover}{3}$$

Socio-Economic Status (SES) was calculated by combining the socio-economic indicators age dependency ratio, employment rate, income, and education level according to the equation below. The dependency ratio was subtracted since a lower value is considered more favourable from a socio-economic perspective, which should result in a higher SES.

$$SES = \frac{-age\ dependency\ ratio + employment\ rate + cineome + education\ level}{4}$$

The resulting SES and GSS may have negative values if the indicator that is subtracted is greater than the others combined. For example, if the distance to UGS is greater than canopy cover and UGS per capita combined, the resulting GSS will become negative. They therefore needed to be normalised again. This was accomplished using the same normalization method as previously described, with the equation below. The normalised statuses were also multiplied with 100 to yield a value between 0 and 100.

$$Normalised\ status = \left(\frac{xi - xmin}{xmax - xmin}\right) \times 100$$

4. Results

4.1 Green Space Status (GSS)

Combining canopy cover, UGS per capita and distance to nearest UGS shows, depending on one's perspective, either a more balanced or a more muted picture as areas which do poorly in one aspect may be lifted by another. Only a few, small, DeSOs have very low scores and this will be likely sensitive to their exact boundaries, however it does suggest a severe need for more UGS because the GSS is particularly sensitive to changes at the lower end of the scale (Figure 19). Comparing these maps with the result for the cost distance calculation also shows some unit averaging effects. For example the area inland from Ribban appears relatively well provisioned with both canopy cover and UGS per capita. However on the cost-distance map this area is largely coloured black (private land) transacted by veins of yellow-red which are roads through the area. This suggests that while the area has private green space it lacks these larger public spaces and the larger trees they can support.

Excluding DeSOs beyond the border of the urban area has the benefit of avoiding some of the issues with very large, internally heterogeneous, DeSOs but of course also excludes the people living in those areas. Some of the remaining units still face ”edge effects” , particularly those by the coast since distance to UGS is not bounded by the DeSOs but open sea has not been accounted for, e.g. the Ribban coastal area ranks relatively low despite being a popular area for a day by the sea.

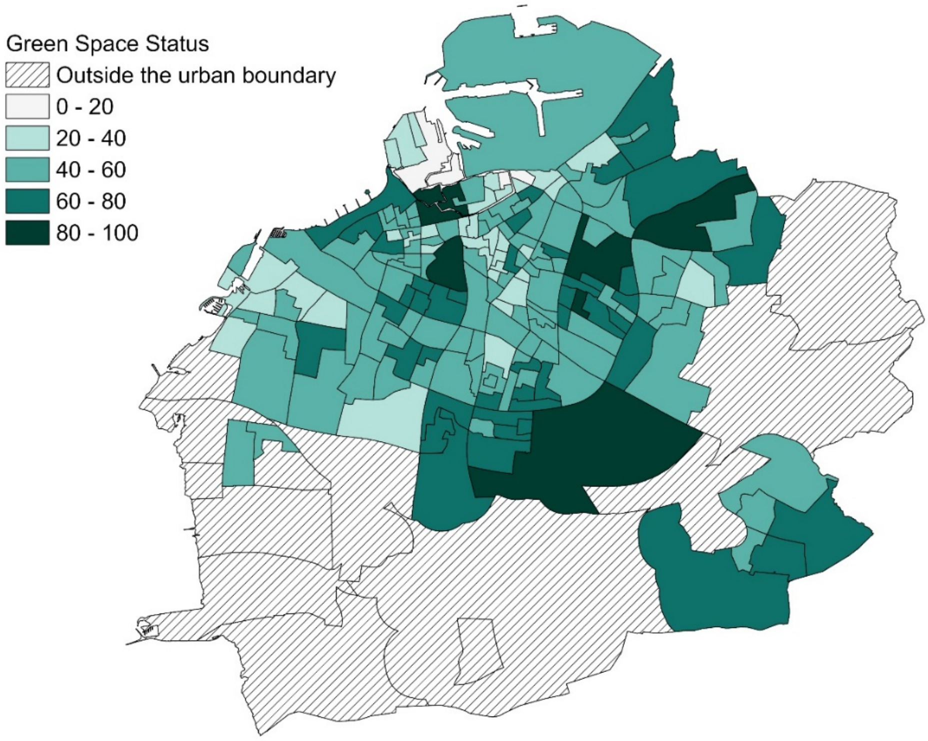


Figure 19. Green Space Status (GSS) visualised in 5 classes. GSS is calculated by combining the three unweighted green indicators; canopy cover, distance to urban green space, and urban green space per capita. GSS is normalised to a value between 0 and 100, where 0 represents the DeSO with the lowest value in the municipality, and 1 represents the DeSO with the highest value in the municipality.

Among the DeSOs with the lowest GSS, we again observed DeSOs where we previously have observed low provision and access to UGS as well as low canopy cover. The areas around Slussen, Gamla staden öst, and Västra hamnen sydöst stand out with their low GSS ranging from 0 - 21 (Table 22). When analysing each green indicator for each of these five DeSOs, we notice that these UGS per capita and canopy cover are far below the mean value, and distance to UGS is far above the mean value observed across the urban areas in Malmö municipality.

Table 22. The five DeSOs with the lowest green space status (GSS) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to. The sign within brackets indicate that the value is below (-) or above (+) the mean.

DeSO	Belongs to RegSO	GSS	UGS per capita (m^2/capita)	Canopy cover (%)	Distance to UGS (m)
1280C2800	Gamla staden öst	0	2 (-)	6 (-)	484 (-)
1280C2810	Slussen	13	5 (-)	5 (-)	358 (-)
1280C2870	Västra hamnen sydöst	18	20 (-)	3 (-)	284 (-)
1280C2780	Gamla staden öst	20	5 (-)	7 (-)	305 (-)
1280C2730	Gamla staden öst	21	2 (-)	9 (-)	327 (-)

Among the DeSOs that rank the highest of the GSS scale, we again find DeSOs that previously have been highlighted as having some of the highest green indicators. This includes the DeSOs 1280C1180, 1280C2190, 1280C2680, and 1280C2600 where the large parks Lindängelund and Kastanjegårdparken, Pildammsparken, Slotts- and Kungsparken, and Risebergaparken are located, respectively. It also includes the small DeSO 1280C1830 which consists of apartment buildings and large open areas available for recreation. None of the top five DeSOs with the highest GSS are consistently above or below the mean value for each of the green indicators (Table 23). Three of the five DeSOs have a canopy cover and UGS per capita that is much higher than the mean, but a distance to UGS that is above the mean. In the two remaining cases, either canopy cover or UGS per capita is lower than the mean.

Table 23. The five DeSOs with the highest green space status (GSS) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to. The sign within brackets indicate that the value is below (-) or above (+) the mean.

DeSO	Belongs to RegSO	GSS	UGS per capita (m^2/capita)	Canopy cover (%)	Distance to UGS (m)
1280C1180	Fosieby-Kastanjegården	100.0	892 (+)	11 (-)	77 (+)
1280C2190	Kronborg-Pildammsparken-Teatern	100	323 (+)	38 (+)	135 (-)
1280C1830	Örtagården syd-Herrgården syd	88	54 (-)	32 (+)	15 (+)
1280C2600	Riseberga	85	267 (+)	30 (+)	134 (-)
1280C2680	Malmöhus	81	224 (+)	35 (+)	215 (-)

4.2 Socio Economic Status (SES)

Combining the four socio-economic indicators ‘age dependency ratio’, ‘household income’, ‘education level’, and ‘employment rate’ emphasises the neighbourhoods that previously have been highlighted as having the lowest or highest values for each indicator (Figure 20). As similar DeSOs often were observed having consistently low values, or consistently high, across most of the socio-economic indicators, this pattern is further emphasised after combining the indicators.

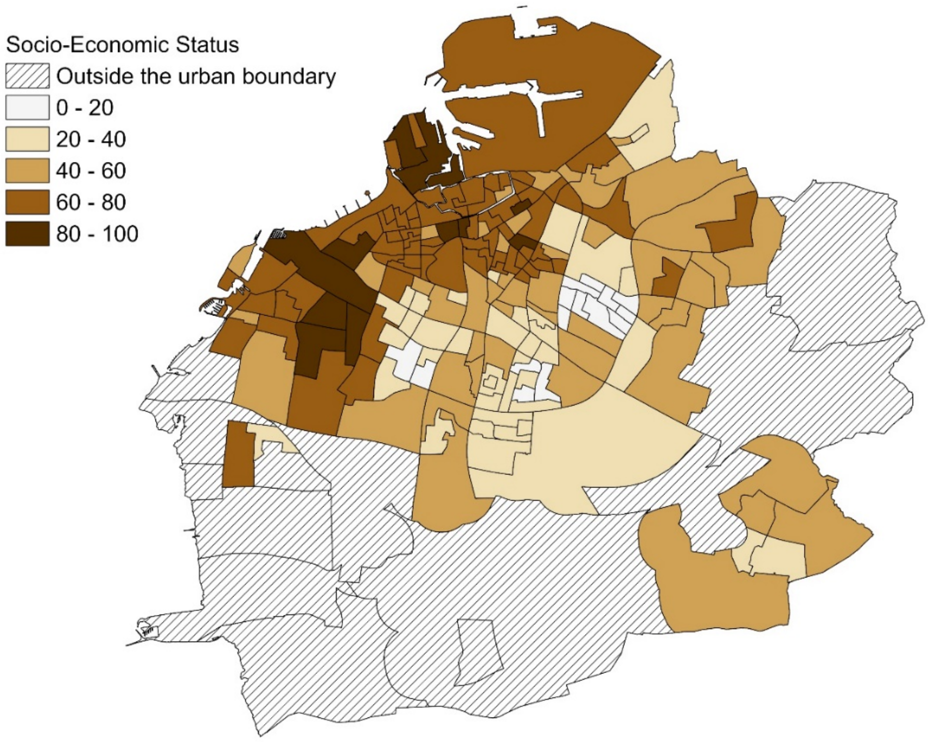


Figure 20. Socio-Economic Status (SES) visualised in 5 classes. SES is calculated by combining four unweighted socio-economic indicators; education level, employment rate, income, and age dependency ratio. SES is normalised to a value between 0 and 100, where 0 represents the DeSO with the lowest SES value, and 100 represents the DeSO with the highest SES value in the municipality.

Among the DeSOs with the lowest SES, we again observed DeSOs where we previously observed low employment rates, mean income, and education level. The neighbourhoods around Herrgården, Örtagården, Persborg, and Törnrosen stand out with their low SES ranging from 0 to 10, and they are all dominated by apartment buildings (Table 24). When analysing the socio-economic indicators for each of these five DeSOs, we notice that the age dependency is slightly higher than the mean, while education level, employment rate, and mean income are far below the mean value for urban areas in Malmö municipality (Table 24). All of these five areas are neighbouring each other and are located in a cluster of DeSOs with low SES in the southern part of Malmö's urban area. The share of foreign born in these DeSOs are greater than the mean (34%), with values ranging between 57% and 70%.

Table 24. The five DeSOs with the lowest socio-economic status (SES) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to. The sign within brackets indicate that the value is below (-) or above (+) the mean.

DeSO	Belongs to RegSO	SES	Age dependency ratio	Education level (%)	Employment rate (%)	Mean income (thousands of SEK)
1280C1880	Herrgården norr	0	60.6 (-)	15.3 (-)	38.2 (-)	180.2 (-)
1280C1760	Örtagården syd-Herrgården syd	8	70.3 (-)	22.6 (-)	46.3 (-)	190.4 (-)
1280C1750	Herrgården norr	9	56.4 (-)	20.5 (-)	43.8 (-)	184.4 (-)
1280C1890	Persborg-Törnrosen	9	61.4 (-)	20.0 (-)	45.9 (-)	187.0 (-)
1280C1980	Örtagården norr	10	57.5 (-)	21.7 (-)	44.7 (-)	181.6 (-)

Among the DeSOs that rank the highest on the SES, we again find areas that previously have been highlighted as having some of the highest values across the socio-economic indicators (Table 25). This includes the DeSOs 1280C2210, 1280C2330, and 1280C1660 which are neighbouring each other along the coast in western Malmö and which are dominated by houses with private gardens. It also includes two DeSOs in central Malmö, 1280C2660 and 1280C2380 that mainly consists of apartment buildings. Two of the top five DeSOs with the highest SES have age dependency ratios far below the mean of the urban areas in Malmö municipality, namely 1280C2660 in Rörsjöstaden and 1280C2380 in Västra Sorgenfri öst (Table 25). The low age dependency ratio indicates that a high proportion of the population in these DeSOs are aged 15-64 in comparison to elderly and children. The other three DeSOs have a higher proportion of elderly and children living in the DeSOs, which is more alike the age dependency ratios observed in the DeSOs with the lowest SES values (Table 25). The employment rates, education levels, and mean annual income across these DeSOs are above the mean for urban areas within the municipality. While employment rates are slightly higher than the mean, education levels are far above the municipal mean. The education level and employment rates do not differ much between the five DeSOs, but there is however a large difference in mean annual income. While DeSO 1280C2210, which has an SES of 100, coincides with the highest mean annual income of 1,047,600 SEK, the mean income drops to 664,700 SEK for DeSO 1280C1660, which is the DeSO with the fifth highest SES.

Table 25. The five DeSOs with the highest socio-economic status (SES) across the studied DeSOs in Malmö municipality, along with the RegSO they belong to. The sign within brackets indicate that the value is below (-) or above (+) the mean.

DeSO	Belongs to RegSO	SES	Age dependency ratio	Education level (%)	Employment rate (%)	Mean income (thousands of SEK)
1280C2210	Bellevue-Nya Bellevue	100	59.5 (-)	77.6 (+)	75.4 (+)	1047.6 (+)
1280C2330	Västervång-Fridhem	91	77.9 (-)	81.4 (+)	81.6 (+)	789.7 (+)
1280C2660	Rörsjöstaden	86	32.6 (+)	79.1 (+)	81.9 (+)	375.9 (+)
1280C1660	Djupadal-Rosenvång	86	72.1 (-)	79.6 (+)	80.8 (+)	664.7 (+)
1280C2380	Västra Sorgenfri öst	85	32.8 (+)	81.4 (+)	80.8 (+)	344.0 (+)

4.3 Green space in relation to socio economy

When GSS and SES have been computed, the statuses can be combined in different ways to analyse how equitable the access to greenspace is. This section will analyse the statistical patterns between GSS and SES, followed by our suggested approach to analyse green space in relation to socio economy. Lastly, an alternative, or supplement, to the approach will be presented and discussed.

4.3.1 The relationship between GSS and SES – The Green Equity Matrix

The calculated GSS and SES for each DeSO were plotted in a graph with GSS on the y-axis and SES on the x-axis (Figure 21). The social and green inequality statuses, SES and GSS, have a generally negative association. However the data is highly dispersed meaning there are many "exceptions to the rule". The relative position of any two points may be influenced by the caveats noted thus far:

- Definition of UGS (particularly the width threshold)
- Choice of Tree Canopy data source
- Range of difference in distance is sensitive to choice of measure
- Unit boundary definition of DeSO.

In addition to the effects of normalisation and summation of the separate variables, the distance to UGS dimension may be expected to reduce net apparent difference toward the upper end of the scale as the distance criterion becomes saturated. These caveats probably do not affect the overall trend but do suggest that the exact quadrant into which any one DeSO may fall, or the respective rank of any two DeSOs should not be used for decision making. Rather the lower and upper quartiles may be considered reliably distinct from each other. In particular where a group of points from this graph represent a contiguous spatial area on the maps below, this may be considered a representative picture of the relative status of that zone.

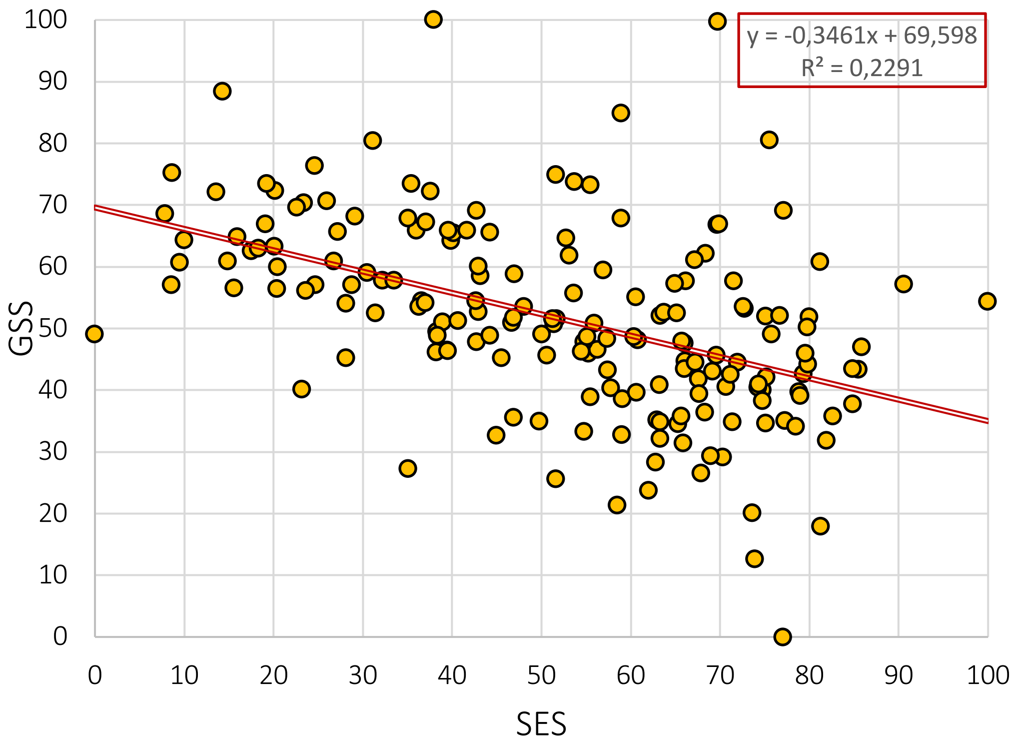


Figure 21. Linear regression analysis performed on Green Space Status (GSS) and Socio-Economic Status (SES), with GSS on the Y-axis and SES on the X-axis. Each point represents the GSS and SES values for each DeSO.

4.3.2 GSS and SES with quadrants

The results can be visualised in four quadrants that divide GSS and SES into equal intervals of 0-50 and 50-100, where each DeSO falls into one quadrant (Figure 22). As the statuses are normalised per municipality, the value 0 represents the DeSO with the lowest value within the municipality, and the value 100 represents the DeSO with the highest value within the municipality. Dividing the DeSOs into four quadrants enables the user to identify which DeSOs to further analyse in order to understand which areas that needs to be prioritised in planning and management, although considering the limitations mentioned above.

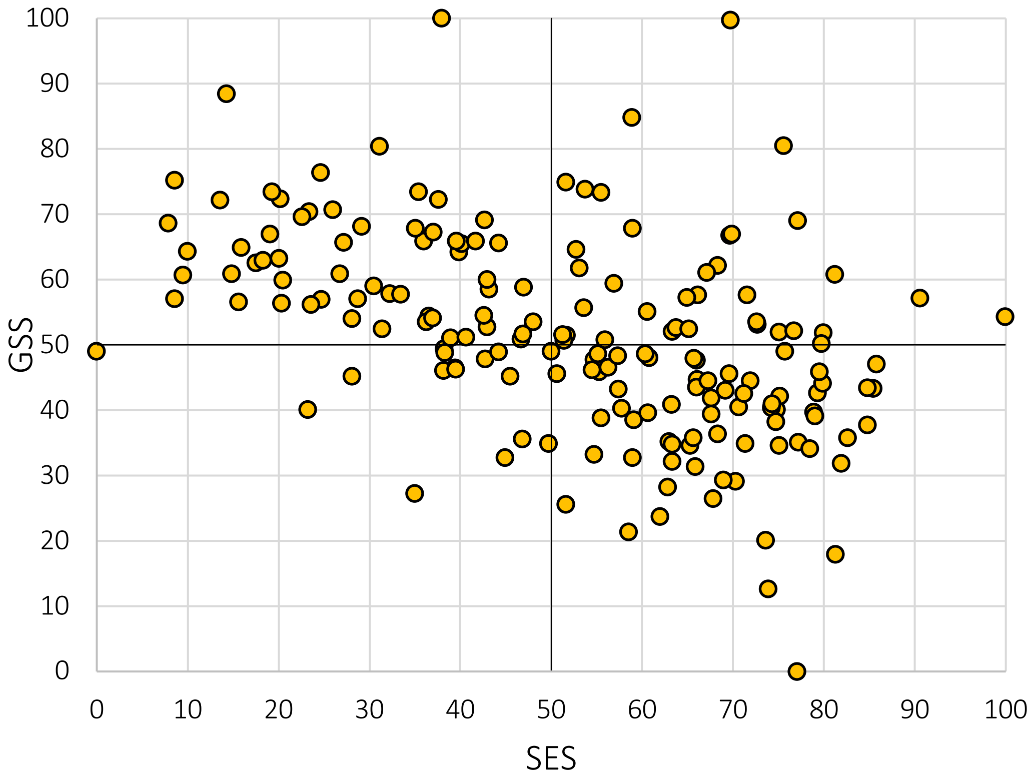


Figure 22. Green Space Status (GSS) and Socio-Economic Status (SES) for each DeSO visualised as points, with GSS on the Y-axis and SES on the X-axis. The results are visualised in four quadrants that divide GSS and SES into equal intervals of 0-50 and 50-100.

The percentage of the areas that fall within each quadrant is presented in Table 26. The highest proportion of DeSOs are found in the fourth quadrant with low GSS and high SES, namely 38.5%, The second highest proportion of DeSOs is found in the first quadrant, where 33% of the analysed DeSOs have a high GSS and low SES. This is followed by the second quadrant, where we find 20.1% of all analysed DeSOs, which both have a high GSS and high SES. In the third quadrant, which is defined as DeSOs having both a low GSS and low SES, we find 8.4% of the analysed DeSOs in Malmö municipality (Table 26).

Table 26. Percentage of DeSOs within each quadrant.

Quadrant	Definition	Percentage of DeSOs within each quadrant
1	High GSS & low SES	33.0%
2	High GSS & high SES	20.1%
3	Low GSS & low SES	8.4%
4	Low GSS & high SES	38.5%

Visualising which quadrant each DeSO is categorised into on a map can help us identify the spatial pattern (Figure 23). There is clearly a spatial influence where access to green space and socio-economic status stretch over multiple DeSOs. In general, low green space access is observed in the harbour areas, around the city centre, and around the south-western part of Malmö's urban area. On the opposite, high green space access is largely concentrated around Ribersborg/Bellevue, Oxie, along with most parts in the Southern and Western part of Malmö's urban area.

The socio-economic status also follows a strong spatial pattern, with higher socio-economic status concentrated around the northern and western part of Malmö's urban area and lower socioeconomic status mapped in the southern and western part of Malmö's urban area. There are a few exceptions of DeSOs that differ from their neighbouring areas. This includes the DeSOs with low GSS and low SES, which are located across different parts of the municipality.

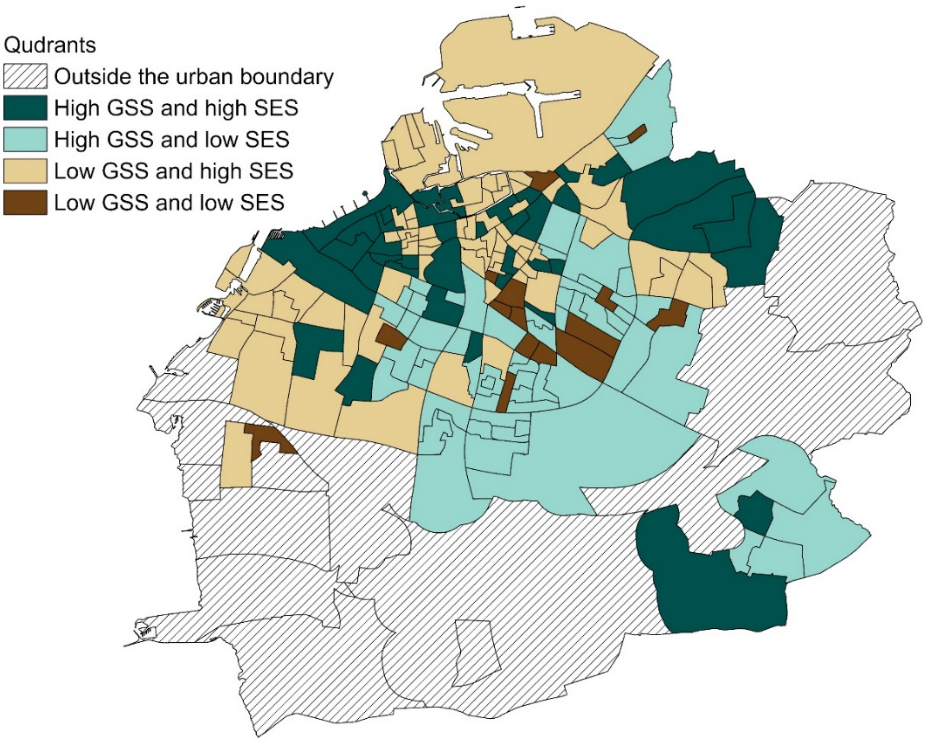


Figure 23. DeSOs categorized by which of the four quadrants they belong to.

When the DeSOs with low GSS and SES had been identified, we further analysed these areas with additional information to get a comprehensive overview of the greenspace status and socioeconomy of the population living there. The GSS, SES, housing situation and amount of inhabitants for each of the DeSOs within the third quadrants is presented in Table 27. Among the 15 DeSOs with low GSS and SES, two are located in Bunkeflostrand and Kroksbäck in south-western Malmö and two in Östervärn-Ellstorp and Sege väst in north-western Malmö (Figure 23). The remaining are concentrated around the areas Sofielund, Heleneholm, Möllevången, Hindby, Söderkulla, Västra Kattarp and Jägersro. The population in these DeSOs ranges between 935 and 2481, with the lowest population found in the DeSO in Herrgården Norr and the highest population found in the DeSO in Sofielund Norr (Table 27). The share of the population that are foreign-born is greater than the mean (34%) in all but one DeSOs. However, the listed DeSOs do not coincide with the DeSOs with the highest foreign born ratios in Malmö. Instead, 9 of the 15 DeSOs have a foreign born ratio under 46%, which is 13% above the mean.

The majority of the population in these DeSOs live in apartments, with the exception of the DeSO in Hindby and Västra Kattarp where 63% and 83% of the population live in houses (Table 27). The number of people living in houses is very low in the other DeSOs, where only five of the DeSOs have over 20% of the population living in houses. The ownership type differs more between the areas. Tenancy is the most common ownership type in 8 out of the 15 DeSOs. In five, tenant-owned housing is the most common type of ownership, which is the case in Heleneholm-Almhög, Söderkulla, Sege väst, Kroksbäck väst, and Jägersro öst – Stenkällan. In the two DeSOs in Hindby and Västra Kattarp, where the majority of the population live in houses, the most common ownership type is home ownership

Table 27. DeSOs within quadrant 3, with low green space status (GSS) and low socio-economic status (SES). The population data, building type, and ownership type was retrieved from SCB (SCB 2024a; SCB 2024b). The building type house includes detached one- and two-family houses as well as semi-detached- and terraced houses, and apartment refers to multi-family homes, including residential buildings containing three or more apartments.

DeSO	RegSO name	GSS	SES	Population (% foreign born)	Building type	Ownership type
1280C188 0	Herrgården norr	49	0	935 (63%)	0% in house 97% in apartment	0% ownership 0% tenant-owned 97% tenancy
1280C171 0	Södra Sofielund	40	23	2082 (55%)	2% in house 97% in apartment	2% ownership 12% tenant-owned 84% tenancy
1280C153 0	Heleneholm -Almhög	45	28	1853 (63%)	12% in house 87% in apartment	12% ownership 0% tenant-owned 87% tenancy
1280C158 0	Heleneholm -Almhög	46	38	2029 (60%)	10% in house 90% in apartment	10% ownership 90% tenant-owned 0% tenancy
1280C210 0	Möllevången syd	27	35	1548 (53%)	1% in house 84% in apartment	1% ownership 0% tenant-owned 98% tenancy

1280C1330	Söderkulla	49	38	1469 (45%)	18% in house 81% in apartment	12% ownership 87% tenant-owned 0% tenancy
1280C2890	Sege väst	49	38	1459 (44%)	0% in house 100% in apartment	0% ownership 65% tenant-owned 34% tenancy
1280C1200	Bunkeflostrand öst	46	40	2154 (46%)	6% in house 93% in apartment	6% ownership 14% tenant-owned 79% tenancy
1280C1620	Kroksbäck väst	46	40	1424 (43%)	25% in house 74% in apartment	25% ownership 74% tenant-owned 0% tenancy
1280C1800	Södra Sofielund	33	45	1645 (52%)	0% in house 98% in apartment	0% ownership 27% tenant-owned 71% tenancy
1280C1510	Hindby	48	43	2331 (45%)	63% in house 35% in apartment	56% ownership 31% tenant-owned 11% tenancy
1280C1610	Västra Kattarp	45	46	1782 (45%)	83% in house 15% in apartment	74% ownership 24% tenant-owned 2% tenancy
1280C2790	Östervärn-Ellstorp	35	50	1426 (45%)	0% in house 90% in apartment	0% ownership 0% tenant-owned 99% tenancy
1280C1940	Sofielund norr	36	47	2481 (39%)	32% in house 58% in apartment	25% ownership 9% tenant-owned 61% tenancy
1280C1730	Jägersro öst-Stenkällan	49	44	1714 (34%)	20% in house 79% in apartment	20% ownership 79% tenant-owned 0% tenancy

4.3.3 GSS and SES with standard deviation

The approach of identifying neighbourhoods using quadrants resulted in 15 DeSOs being classified as having low greenspace provision and low socio-economic status. However, these areas are not necessarily significantly different from others in adjacent quadrants, as some GSS and SES values are close to the threshold of 50. Incorporating an analysis of standard deviations can complement the quadrant-based approach by identifying areas that are statistically different from each other. This approach provides a more nuanced view of the quadrant results and can offer additional insights if relevant to the user's objectives.

Standard deviation measures how much individual values deviate from the mean. In this context, it indicates how a specific GSS or SES value differs from other GSS or SES values across the analysed DeSOs. Figure 24 illustrates SES and GSS values in a graph, with mean and standard deviation lines plotted along both axes. A positive/negative standard deviation indicates that the value is above/below the average, while the larger a standard deviation indicates greater deviation from the mean. By analysing the magnitude and direction of standard deviations, it becomes possible to further categorise DeSOs based on their greenspace provision (low or high) and socio-economic status (low or high).

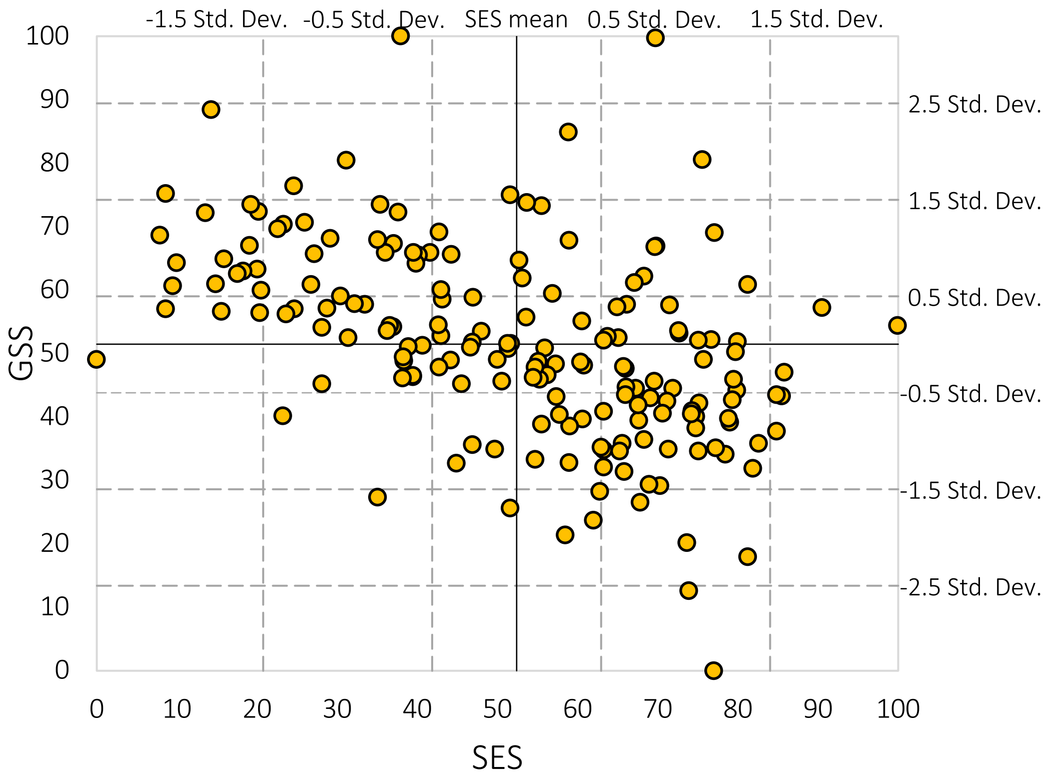


Figure 24. Green Space Status (GSS) and Socio-Economic Status (SES) for each DeSO visualised as points, with GSS on the Y-axis and SES on the X-axis. The mean GSS and SES is plotted as full lines, and the standard deviations are plotted as dotted lines. A positive standard deviation indicates that the value is above the average, and a larger standard deviation indicates that the value differs more from the mean.

Below is an example illustrating the differences low GSS and low SES as determined by the original quadrant analysis and the complementary analysis of standard deviations. A low GSS is defined as a value below 1.5 standard deviations from the mean, which corresponds to a GSS value below 28.6 (Figure 24).

According to this definition, 10 DeSOs have a low GSS. These are primarily located in central Malmö (Figure 25) and include neighbourhoods such as Gamla Staden, Slussen, Västra hamnen, Möllevången and Hästhagen. More than half of these DeSOs have a relatively high socio-economic status, with SES values above 62.9, which corresponds to 0.5 standard deviations above the mean (Figure 24; Table 28). Among the 10 DeSOs identified as having low GSS, only one aligns with the DeSOs outlined in quadrant 3 of the original quadrant analysis - namely DeSO 1280C2100 in Möllevången Syd.

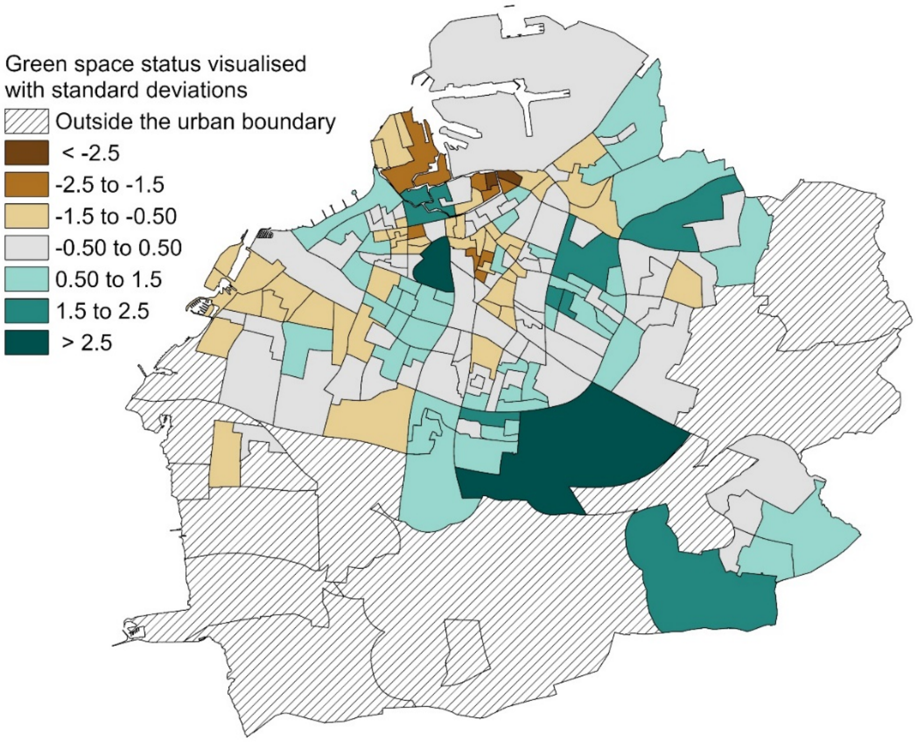


Figure 25. Green Space Status (GSS) visualised with standard deviations, a statistical measure of how much the various GSS values deviate from the mean. DeSOs visualised in light grey represent standard deviations between -0.5 and +0.5, indicating that they are close to the mean. Areas in dark green or brown represent standard deviations above +2.5 or below -2.5, where the GSS values are significantly above or below the mean.

Table 28. DeSOs where the greenspace status (GSS) is below 1.5 standard deviations from the mean.

DeSO	RegSO name	GSS	SES
1280C2730	Gamla staden öst	21	59
1280C2780	Gamla staden öst	20	74
1280C2800	Gamla staden öst	0	77
1280C2480	Hästhagen-Kronprinsen	26	52
1280C2100	Möllevången syd	27	35
1280C2260	Möllevången väst	28	63

1280C2240	Rådmansvången	27	68
1280C2770	Slussen	24	62
1280C2810	Slussen	13	74
1280C2870	Västra hamnen sydöst	18	81

A low SES is defined as a value below 1.5 standard deviations from the mean, corresponding to a SES value below 20.8 (Figure 24). According to this definition, 19 DeSOs have a low SES, primarily located in the southern part of Malmö's urban area (Figure 26). As shown in Figure 26, SES exhibits a strong spatial pattern, with higher SES in northern and western Malmö and lower SES in the southern and eastern part of Malmö. Most of these 19 DeSOs have good greenspace provision, indicated by GSS values above 0.5 standard deviations from the mean (Figure 24; Table 29). Notably, only one of these DeSOs - 1280C1880 in Herrgården – is also located in quadrant 3 in the original quadrant analysis.

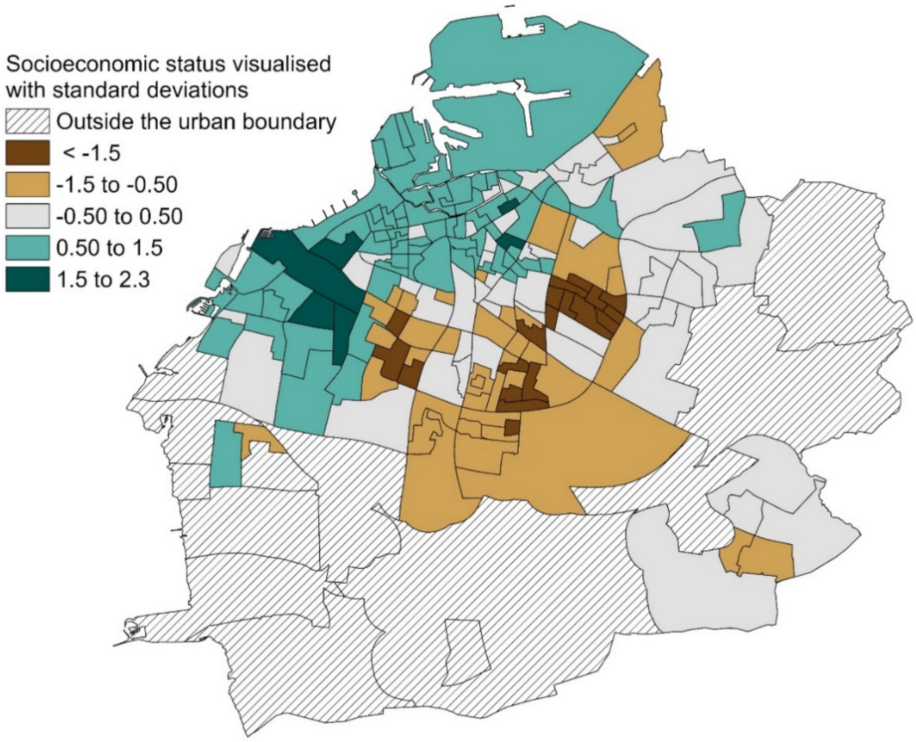


Figure 26. Socio-Economic Status (SES) visualised with standard deviations, a statistical measure of how much the various SES values deviate from the mean. DeSOs visualised in light grey represent standard deviations between -0.5 and +0.5, which are close to the mean.

Areas in darker colours represent standard deviations above +1.5 or below -1.5, indicating that the SES values are significantly above or below the mean.

Table 29. DeSOs where the socio-economic status (SES) is below 1.5 standard deviations from the mean.

DeSO	RegSO name	SES	GSS
1280C1600	Augustenborg	20	56
1280C1700	Bellevuegården öst	21	60
1280C2000	Emilstorp-Östra kyrkogården-Apelgården	19	74
1280C1290	Gullviksborg-Hermodsdal syd	20	72
1280C1350	Gullviksborg-Hermodsdal syd	18	63
1280C1320	Hermodsdal-Gullviksborg	18	63
1280C1880	Herrgården norr	0	49
1280C1690	Herrgården norr	10	64
1280C1750	Herrgården norr	9	57
1280C1430	Holma	16	57
1280C1480	Holma-Kroksbäck	14	72
1280C1840	Kryddgården	16	65
1280C1240	Lindängen	20	63
1280C1460	Nydala norr	19	67
1280C1720	Persborg-Törnrosen	15	61
1280C1890	Persborg-Törnrosen	9	75
1280C1980	Örtagården norr	10	61
1280C1830	Örtagården syd-Herrgården syd	14	88
1280C1760	Örtagården syd-Herrgården syd	8	69

The results above investigate areas with low GSS and low SES separately. However, the standard deviation lines in Figure 24 can also be used to identify areas with both low GSS and low SES. This is demonstrated in Figure 27, where DeSOs within the overlapping area of the two red rectangles are classified as having both low GSS and low SES. In this example, no DeSOs fall within this overlapping area, indicating that none of the DeSOs with low GSS also have low SES. This finding aligns with the original quadrant analysis, which suggests that areas with low greenspace provision more commonly have a higher socioeconomic status in Malmö. It also confirms that the areas highlighted in quadrant 3 of the original analysis are not necessarily significantly different from other DeSOs located near the threshold of 50.

By adjusting the threshold for what constitutes low GSS or SES to 0.5 standard deviations below the mean, we focus on the DeSOs located in the overlap of the two blue rectangles shown in Figure 27. Within this overlap, we identify two DeSOs: DeSO 1280C1710 in Södra Sofielund and DeSO 1280C2100 in Möllevången Syd. In the context of Malmö, these two DeSOs are key areas of interest when considering the combined results for GSS and SES with standard deviations.

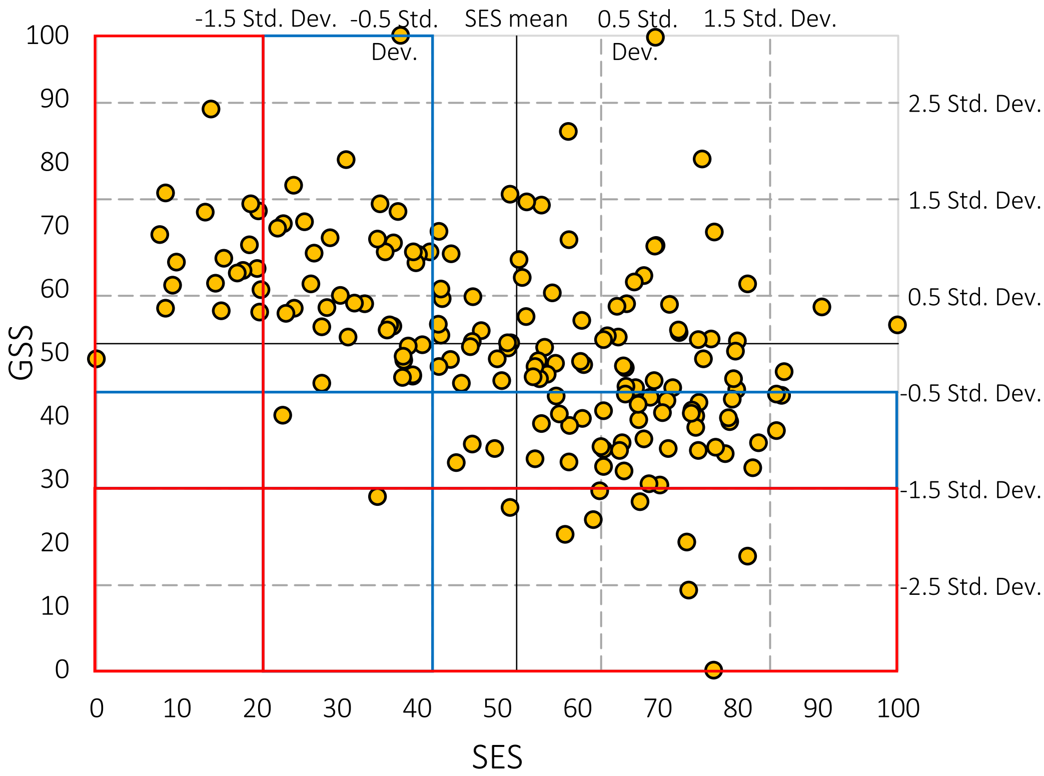


Figure 27. DeSOs with both low Green Space Status (GSS) and Socio-Economic Status (SES) highlighted with standard deviations lines. DeSOs located within the overlapping area of the red rectangles have both a low GSS and low SES (above or below 1.5 standard deviations from the mean). DeSOs located within the area where the blue rectangles overlap have a GSS and SES below 0.5 standard deviations from the mean.

To summarize, standard deviations can complement the original quadrant analysis by further identifying areas to prioritise for greenspace provision. This method can be used not only to identify areas with low GSS and low SES, but also to examine any combination of greenspace provision and socio-economy relevant for the user. Analysing GSS and SES with standard deviations separately - without combining them - is also valuable. This is particularly true for identifying areas with low greenspace provision. In Malmö's case, many areas identified as having low GSS actually exhibit higher socioeconomic status and, as a result, are not included in the original quadrant analysis. These findings underscore the importance of also considering areas with low greenspace provision and high socioeconomy when prioritising new greenspace implementations in the city.

5. Maintenance and operational costs of public spaces in Malmö

As the matrix is meant to support and supplement planners and managers, we have added a perspective of maintenance costs for public spaces in Malmö. The purpose has been to evaluate to which degree it is possible to see where the city's maintenance budget is used, compared to the above analyses of GSS and SES.

The maintenance costs were calculated using data from the Fastighets- och Gatukontoret in Malmö Stad. They have detailed information and data on the areas they maintain, clean, and manage, which includes both detailed GIS data on areas they are maintaining and price lists for operational and maintenance costs.

5.1 Maintenance data

Operational and maintenance costs were calculated per DeSO by combining GIS data of maintenance areas with detailed price lists for various types of maintenance areas. These resulting costs per DeSO were then combined with population data for each DeSO in 2023 from SCB to calculate the maintenance cost per resident for each DeSO.

The GIS data consists of a polygon layer that includes detailed areas classified into one of three main categories; park, street or beach. Each area is further categorized into a specific maintenance class, which specifies the type of surface represented in the GIS data. The dataset covers all areas maintained by Fastighet- och Gatuförvaltningen including operational, maintenance or cleaning activities. However, areas like cemeteries or certain playgrounds and recreational sites (e.g., football fields) maintained by other actors or departments in the municipality are excluded in the data. Additionally, the dataset includes areas where the department only performs cleaning, not maintenance, as well as planned areas that do not yet exist.

The price lists contain operation and maintenance costs for different maintenance classes, including price per square metre for the various maintenance classes in the GIS data. They also include fixed costs for point objects, which are not included in the GIS data, which includes objects such as water posts, culverts, decorations, wells, fences, signs, park benches, rubbish bins, dog waste bins, lifesaving equipment, oil separators, sculptures, and pergolas.

As of spring 2024, maintenance in Malmö municipality is divided into five operational zones, with varying costs across zones. This is partly a result of some zones previously being maintained by external contractors, and the fact that Malmö Stad maintain some of the more challenging (complex) areas. The price lists are thus divided into five operational zones, with the highest costs in the area Västra, which includes large parts of Malmö's urban area, followed by the area Naturvård, which consists of smaller, dispersed natural areas across the municipality.

The prices for different maintenance classes also vary based on the cleaning level required by the area (Table 30). The maintenance classes are divided into three cleaning levels; normal cleaning (RN), elevated cleaning on weekdays and weekends (RF), and elevated cleaning on weekdays and weekends during the summer season (RFS). It is mainly the central parts of Malmö urban areas, along with coastal recreational areas, that require elevated cleaning either year-round or during summer, resulting in higher price per square metre.

Table 30. Example of how maintenance costs (price per square meter) vary by operational area and cleaning level. The maintenance classes are divided into three cleaning levels; normal cleaning (RN), elevated cleaning on weekdays and weekends (RF), and elevated Cleaning on weekdays and weekends during the summer season (RFS). The table below shows examples for two maintenance classes; asphalt concrete under the street category and open shrubs under the park category. Where prices are missing, it means no areas with that combination of maintenance class and cleaning level were registered in that operational area.

Main category	Maintenance class	Cleaning level	Natur	Södra	Östra	Norra	Västra
Street	Asphalt concrete	RN	8,8	3,2	3,0	3,0	6,2
Street	Asphalt concrete	RFS	23,7	5,5	4,5	4,5	7,4
Street	Asphalt concrete	RF	84,9	7,4	7,6	6,7	9,9
Park	Open shrubs	RN	86,7	61,8	58,6	58,4	71,3
Park	Open shrubs	RFS	-	64,2	60,2	-	72,5
Park	Open shrubs	RF	8,8	66,1	62,4	62,1	75,0

5.2 Calculating maintenance- and operational costs

Maintenance and operational costs per resident in each DeSO was calculated using ArcGIS Pro and FME by combining GIS data on maintenance areas with price per square metre for various maintenance classes. The detailed steps of the methodology are described below.

i. Selection of maintenance areas

Maintenance areas under the main categories of park, beach, and street were identified in the GIS data. Areas maintained by external contractors but where Malmö Stad is responsible for cleaning were excluded due to missing per-unit prices. Areas maintained by external contractors and areas under construction that are not currently maintained were also excluded. The remaining areas were then combined with data on cleaning levels from the Real Estate and Roadwork Department (*Fastighet -och Gatukontoret*).

ii. Calculation of maintenance- and operational costs per DeSO

For each maintenance class and cleaning level in the GIS data, the total area in square meters was calculated for each operational zone. This area was then multiplied by the corresponding per-unit price to calculate the actual cost for each maintenance class and cleaning level, while considering that per unit prices differ across the operational zones. In cases where per unit prices were missing for the cleaning levels RF or RFS, the RN per unit price was used instead. Where an entire maintenance code was missing prices, the average price of that maintenance code and cleaning level from the other operational zones was calculated and applied. The individual costs for each maintenance class and cleaning level were then summed to obtain the total maintenance cost for each DeSO.

iii. Calculation of maintenance cost per resident

After the maintenance costs per DeSO were calculated, population data in 2023 from the table Folkmängden per region efter ålder och kön. År 2010 – 2023 by Statistics Sweden was used to calculate the cost per resident in each DeSO (Statistics Sweden 2023b).

iv. Limitations and delineations

Since the GIS data only includes areas, the calculated costs are lower than the actual operational and maintenance costs for parks, streets, and beaches managed by the Real Estate and Roadwork Department. This is partly attributed to point objects like water posts and culverts. Areas where Malmö Stad is responsible for cleaning, but is not carrying out the operation were also excluded, which further underestimates the actual costs. Therefore, the calculated costs per operational zone are generally lower than Malmö Stad's actual expenses for maintaining these areas, particularly in the area Västra, which includes large parts of Malmö's urban centre.

5.3 Maintenance- and operational costs per DeSO

Malmö's urban area stands out for having the highest operational and maintenance costs across several DeSOs (Figure 28). A few specific DeSOs show significantly elevated costs per capita, ranging from 2,000 to 5,560 SEK. This is primarily due to the extensive maintenance and elevated cleaning required for the large parks, beaches, and streets in the area, such as Pildammsparken, Slottsparken and Kungsparken, and Ribersborg beach. Additionally, the operational zone is characterized by high per-unit prices. At the same time, some of the lowest costs, between 22 and 100 SEK per capita, are also found within Malmö's urban area, particularly in smaller, centrally located DeSOs near these larger parks and recreational areas (Figure 28). Moving outward from the central part of Malmö, costs per DeSO begin to rise. This is due to the larger geographical size of these areas, which include more parks and streets that require maintenance.

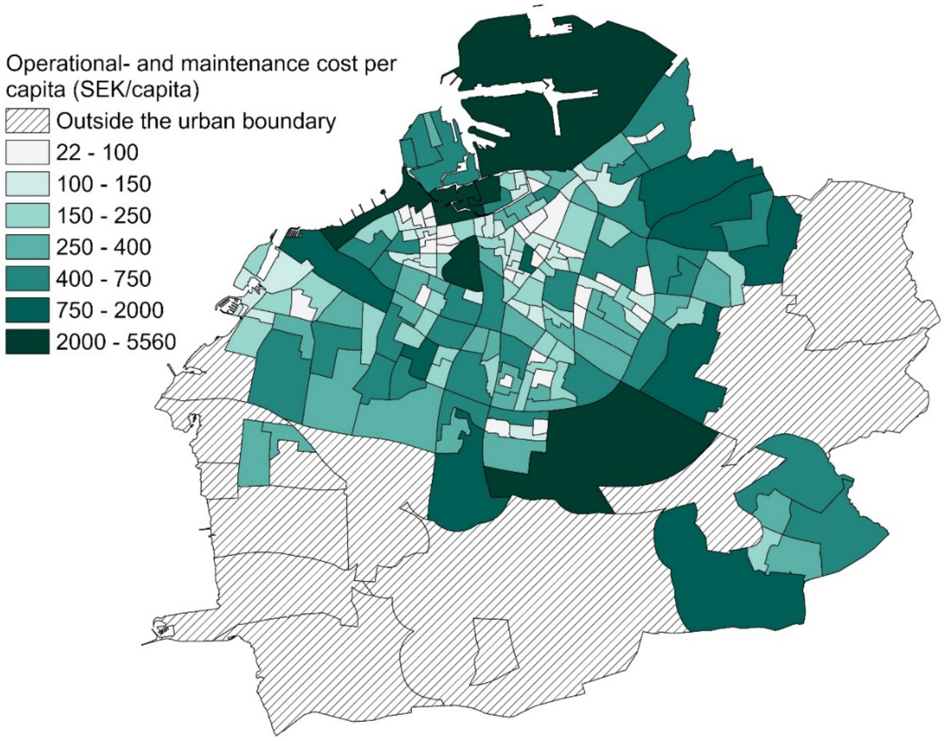


Figure 28. Maintenance cost per capita for parks, streets, and beach areas managed by Malmö Stad. This includes operational and maintenance costs. It takes into account that certain areas have increased maintenance costs during weekends in the summer or all year around. Maintenance and operational costs for public spaces in Malmö were calculated using data from the Real Estate and Roadwork Department. They have detailed information and data on the areas they maintain, clean, and manage, which includes both detailed GIS data on areas they are maintaining and price lists for operational and maintenance costs.

Figure 29 highlights the operational and maintenance costs for DeSOs within the third quadrant (Table 27), characterized by both low GSS and low SES. In these areas, costs range from 24 to 335 SEK per capita, with smaller DeSOs generally incurring lower costs, while larger DeSOs where there are more streets and parks naturally face higher expenses. Notably, the highlighted DeSOs with costs under 100 SEK per capita rank among the lowest across all DeSOs in Malmö municipality.

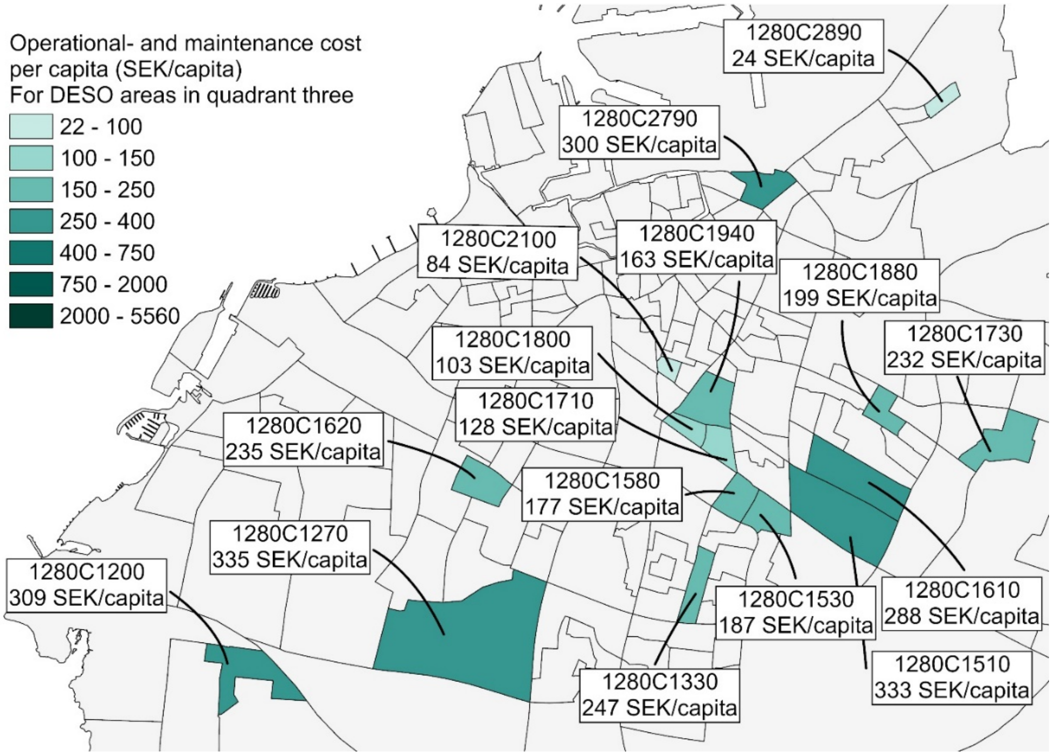


Figure 29. Operational and maintenance cost per capita for the DeSOs within quadrant three, with low SES and GSS. The analysis considers that certain areas have increased maintenance costs during weekends in the summer or all year around. Maintenance and operational costs for public spaces in Malmö were calculated using data from the Real Estate and Roadwork Department. They have detailed information and data on the areas they maintain, clean, and manage, which includes both detailed GIS data on areas they are maintaining and price lists for operational and maintenance costs.

6. Discussion

Through the synthesis of green space and socio-economic indicators, we developed a preliminary socio-ecological matrix (the Green Equity Matrix) that has the potential to serve as a foundational tool for urban planners and managers. This study's findings are timely, given the EU's 2024 Nature Restoration Law, which mandates no net loss in UGS and an increasing trend in canopy cover by 2030. The following discussion focuses on interpreting the results, examining the methodological strengths and limitations, and considering the implications for policy and future research.

Our results somewhat contradict a common trend described in the literature. As an example, the European Environment Agency (EEA 2022) recently described in a review that within cities, the degree of greening varies across neighbourhoods with less and lower quality green space typically found in communities of lower socio-economic status. They list evidence from across Europe showing that green space is less available in lower income urban neighbourhoods than in higher income ones, e.g. in Germany (Schüle et al. 2017), the Netherlands (de Vries et al. 2020), Portugal (Hoffimann et al. 2017), Poland, (Trojanek et al. 2018) and in Hungary, (Csomós et al. 2020). Also, communities with a high proportion of immigrants and ethnic minorities was found to have less access to high-quality green and blue spaces than those with lower proportions of immigrants and ethnic minorities (EEA 2022). This also includes findings from the Nordic countries, e.g. in Oslo (Suárez et al. 2020) and in Helsinki (Viinikka et al. 2018). However, in line with our findings, Region Skåne analysed green assets in relation to socio-economic status and found that there are no clear relationships between green assets and socio-economics in nine cities in Skåne (Region Skåne 2023).

In Europe, access to green and blue spaces differs, as overall, cities in the north and west of Europe have more total green space within their area than cities in southern and eastern Europe (Haase et al. 2020; EEA 2022). Green areas that are publicly accessible form a relatively low share of the total green space (EEA 2022), but the provision of publicly accessible green space is location specific and varies greatly between cities. Here, we may have an explanation to our findings in Malmö which is just one of several examples of extensive social housing policies developed in Scandinavia in the 1960'es and 1970'es. As a response to a growing need for new housing in the post-WWII era, the Swedish parliament decided that a million new dwellings should be built in the period 1965 to 1974 (Hall & Vidén, 2005). These modernist neighbourhoods are characterised by large, open green spaces as a part of the modernistic inspired urban planning ideal at the time. The Million Housing Program as it was called, has frequently been referred to as creating ‘problem areas’ which has worsened socio-economic segregation (Mack 2021). However, our findings suggest that these neighbourhoods with large, open green spaces even today makes a city like Malmö exceptional in terms of providing accessible green spaces in areas with low SES.

6.1 Factors describing green equity at a city district level

Based on previous research and practise related to socio-ecological relationships, combined with data availability, we defined three green space factors; ‘UGS per capita’, ‘canopy cover’, and ‘distance to UGS’, and four socio-economic factors; ‘age dependency’, ‘household income’, ‘education level’, and ‘employment rate’.

The green space factor ‘UGS per capita’ was calculated using two sets of data; UGS and population. The UGS are based on the definition from Region Skåne, with our addition of a width threshold of 10 meters. This approach ensures the inclusion of smaller public green areas while excluding narrow slivers, strips, or other minor features. Population data was sourced from Statistics Sweden. Three different approaches were used to measure ‘distance to UGS’: ’as the crow flies’ (Euclidean) described the distance between each home and the nearest green space. The Network Distance described the distance between each home and the nearest greenspace as measured along a network of roads and paths, and Cost distance described the time taken to walk to the nearest greenspace given a different walking speed for each land cover type, as estimated for a typical adult.

For ‘canopy cover’ we applied the Swedish National Board of Housing, Building and Planning’s national dataset of canopy cover. Although the dataset only includes urban areas with more than 5000 inhabitants, and as such is not including all urban areas in Sweden, the Swedish National Board of Housing, Building and Planning has an ambition to continue to produce a data set that fully covers all urban areas in Sweden and that is continuously updated.

For the socio-economic factors, we used the four most applied in previous studies (see section **Fel! Hittar inte referenskälla.**).

Each set of indicators were computed, and combined into two individual indexes (socio-economic, SES, and green space, GSS, respectively). As such, we suggest that the above mentioned individual factors, combined unweighted and placed in a matrix as shown in Figure 22, can be used to describe green equity at a city district (DeSO) level in Sweden.

Our suggested approach combines the factors unweighted, meaning they are equally important. There is however a possibility to apply different weights to the factors when combining them, if the municipality finds it relevant. This can be done by assigning an individual weight to each factor when combining them, where the highest weight should be assigned to the most important factor.

Further testing is required to reveal the degree of autocorrelation covariance between the indicators. Ideally, variables should be independent, i.e. have low covariance when combining multiple indicators. The risk of including multiple indicators that have high covariance, is that the combined exaggerates difference by double counting the same underlying driver twice. Or, if the relationship to the underlying driver is inverse, they will cancel each other out hiding actual differences. When combining indicators into an index, one should aim towards using fewer indicators that are independent.

The factor ’distance to UGS’ was not limited by DeSO borders as it was calculated from homes to the nearest UGS, and later aggregated to DeSO level. The other green factors ‘canopy cover’ and ‘UGS per capita’ were calculated within the DeSO borders, which can result in different results regarding provision of canopy cover or UGS when comparing it to calculations based on building level. This is especially true for areas along the borders of a DeSO, where the nearest largest areas covered by UGS and canopies could lie within the neighbouring DeSO. The choice of conducting the analysis on district level or building level depends on the objectives and level of detail of the study. District levels are suitable for providing a good estimate on different neighbourhoods in a city, while analysis on building levels are suitable for smaller clusters within and across neighbourhoods.

6.2 Which factors are readily available at a municipal scale?

The recommended method is based on datasets that are openly available and nationally accessible at the DeSO level, ensuring that all municipalities can apply the method. The socio-economic data is readily available from Statistics Sweden, which provides statistics at different geographical levels, such as DeSO, RegSO, and municipal levels, and is updated annually. Indicators related to UGS require some processing before they can be used, necessitating skills in GIS or modelling software. However, existing UGS datasets could be an alternative for municipalities that lack the necessary skills or access to GIS to compute their own UGS data, although such datasets are often not updated regularly.

All computations of UGS rely on open datasets, which are updated at varying frequencies but not always regularly. In general, the availability and consistency of green data over time remains a challenge. While the Swedish National Board of

Housing, Building and Planning has provided a valuable dataset of canopy cover, it is unknown whether this will evolve into a continuous dataset that municipalities can depend on. The lack of standardized, up-to-date national monitoring systems limits longitudinal analysis.

Some municipalities map their own green data and may therefore have highly accurate data on canopy cover and greenspaces that can be used for our proposed analysis. Such data is sufficient to assess greenspace status within one municipality, our recommendations to use open data sources ensures that all municipalities can evaluate their greenspace status.

The current analysis primarily focuses on UGS in terms of the green aspects. While the analysis examines various definitions and methods for measuring distance to greenspace, it does not address quality aspects. Understanding how these greenspaces are used, by whom, and the types of ecosystem services they provide could help in prioritizing new types of greenspace in a city. Differentiating UGS based on quality and identifying who has access to them would be a valuable addition to the analysis, which hopefully will be explored in future work.

The proposed analysis does not include any health factors, primarily due to the lack of health data available at the DeSO level. Currently, the socio-economic data at the DeSO level lacks granularity for certain health indicators, such as life expectancy or chronic disease prevalence, which could enhance the Green Equity Matrix's predictive capacity. Discussions with Region Skåne regarding health data availability revealed that most of the available health data is too sensitive to be accessible at sub-municipal levels. This aligns with data from the Public Health Agency of Sweden (Folkhälsomyndigheten), which is not accessible at sub-municipal scales**,** and BRÅ's (Brottsförebyggande rådet) national safety survey, where safety data are available at the level of police districts. Although overall health in Skåne has improved over the past two decades, health inequities remain a significant challenge as individuals with lower socioeconomic status generally experience poorer health (Region Skåne 2024). Incorporating health aspects into this analysis would provide valuable insights for further examining the Socio Economic Status.

Moreover, we deliberately opted out of including ethnicity as a socio-economic indicator due to its controversial nature in European contexts.

A strength is the integration of diverse data sources, including satellite-derived canopy cover metrics, comprehensive calculations of distances and statistics on socio-economy from Statistics Sweden. By leveraging GIS technology, we provided a spatially granular analysis at the DeSO level, enabling precise targeting for policy interventions.

A field visit to Malmö on November 6th with staff from Malmö municipality was undertaken to establish whether the statistical differences found during the study reflected perceived UGS provision ”on the ground”. While the general impression was that the two did correspond there were some relevant points to note due to details unavailable in the data used:

- The quality of UGS varied and this would have implications for relevant ES such as heat mitigation and cultural ES.
- Assumptions tend to have exceptions which will matter locally e.g. some private UGS is in fact accessible and even managed by the community.
- Some DeSO had significant internal heterogeneity in terms of the types of housing and probably level of income.
- Wider context such as proximity of roads significantly affected the experience of the UGS such as tranquility.

6.3 How can the selected factors generate a preliminary outset for an Index to be used by green space planners and managers to prioritise where to invest in green spaces for the sake of a just and equal future city development?

During the project, the possibility of combining GSS and SES into a single value to represent greenspace provision with socio-economic inequalities in a city was explored. While there are potential advantages to creating one index, several risks and challenges must be considered. A single composite value could make the relationship more comprehensible to stakeholders. However, this comes with the risk of over-generalising the detailed factors mapped in the analysis, which is one of its strengths. The more factors included into an index the harder it is to understand what is contributing to the final value. From a technical perspective the more varied the factors included (in terms of scale, unit, range and variance) the more it must be normalised or standardised to allow comparison with the risk that important details such as extreme cases become obscured.

In this context, the proposed multi-faceted approach—where SES and GSS are analysed both individually and in relation to one another—is more effective. Regarding the method of analysis, the use of standard deviations can provide valuable statistical insights into how specific neighbourhoods deviate from the mean distribution of greenspace or socio-economic factors. Stakeholders may however struggle to understand what a standard deviation represents in practical terms, particularly for non-technical audiences. The quadrant approach thereby offers a more straightforward and self-explanatory method for analysing the results.

In order to understand the potential relationship between areas with high or low SES and the municipality's cost for GSS maintenance, we calculated maintenance costs per DeSO. However, to do so we needed to make a number of assumptions. E.g. we could only include areas where Malmö Stad is carrying out the maintenance and cleaning. Therefore, the calculated costs per operational zone are generally lower than Malmö Stad's actual expenses for maintaining these areas. However, as an indicator our calculated figures can be used. The costs are closely linked to the presence of parks, with large parks and beaches in central Malmö naturally requiring higher maintenance. While large UGS and parks offer significant recreational value and entail greater costs, it is crucial to analyse who has access to these areas, as this sheds light on an important aspect of green equity.

The method is well-suited for analysing green equity in municipalities. It can be implemented by municipalities themselves, but it also holds value for regions in assisting with such analyses or providing guidance to municipalities on how to assess green equity. Regions could use the method to promote and share information about its application or even support municipalities with the analysis if their own resources are limited. This would help provide a comprehensive understanding of green equity across the region. In the context of Skåne, the method contributes to Region Skåne's planning strategy *"Strengthen the diversity of attractive and health-promoting living environments with access to recreation"* and addresses the challenge *"To reduce disparities while promoting good living environments for everyone"*, both outlined in the regional plan (Region Skåne 2022).

7. Conclusions

In conclusion, this study provides critical insights into the intersection of urban green space planning and management in relation to socio-economic equity, with Malmö as a case. Our findings highlight disparities in access to urban green spaces (UGS) across different socio-economic areas within Malmö municipality. Districts with low Green Space Status (GSS) sometimes correspond with lower Socio-economic status (SES), placing them in Quadrant 3 of the Green Equity Matrix (low SES, low GSS). However, districts with low GSS more often correspond with high SES, placing them in Quadrant 4 of the Green Equity Matrix (high SES, low GSS). We found a prima facie negative relationship between SES and GSS across the 179 DeSOs analysed in Malmö (Figure 22), meaning that city districts with lower socio-economic status in general have a higher proportion of green space accessibility than city districts with high socio-economy. This result contradicts much of the international literature and therefore a comparison with other cities or regions where the relationship between SES and GSS might be different, would highlight Malmö's context, and further test our findings.

In Figure 29, we highlight the operational and maintenance costs for DeSOs within the third quadrant (listed in Table 27), characterized by both low GSS and low SES. In these areas, costs range from 24 to 335 SEK per capita, with smaller DeSOs generally incurring lower costs, while larger DeSOs where there are more streets and parks naturally face higher expenses. The average cost per DeSO in Malmö is 448 SEK per capita, indicating that in DeSOs with low GSS and Low SES, less than the average maintenance costs are used. This may be due to the simple fact that there is less parks and streets that are maintained by Malmö Stad in these areas.

Our maintenance cost calculations are based on cost per inhabitant per DeSO. A better proxy would be to calculate costs per user which would better reflect the maintenance need and related investment in maintenance and cleaning. However, such data is not available. Our cost calculations may be seen as an early attempt to better understand the relationship between maintenance and cleaning cost and our index. However, more detailed cost calculations needs to be performed, including all costs and assessing a factor for actual use of the spaces included.

In future studies health indicators should be incorporated to better understand the relationship between green space access, use and public health. This entails more qualified consideration of the definition and characteristics of UGS (its qualities) and how it is accessed in order to ensure relevance to the specific health pathway of interest.

Also, the capabilities of engagement of local communities to participate in the planning and management of UGS should be further explored and incorporated to ensure that green space interventions align with the needs and preferences of residents. In line with this, local governments' capacities to develop such indices should be explored to utilize the socio-ecological index. Training in GIS-based socio-ecological analysis and the integration of socio-economic data into green space planning and management can empower local governments to make such data-driven decisions that promote environmental justice.

Our proposed method does not require advanced GIS skills, making it accessible for all municipalities. The analysis can provide an important baseline for urban planners to identify neighbourhoods where access to greenspace and occurrence of trees should be prioritised, and it can also be repeated to monitor changes in green equity over time. The analysis offers both an overview of the overall green space status (GSS) and the ability for municipalities to examine individual indicators to understand where greenspaces or trees are lacking in each neighbourhood. In its current form, the method is primarily designed for sub-municipal analysis. The suggested method ranks neighbourhoods within a municipality or urban area, meaning the GSS and SES results cannot be directly compared across different municipalities or urban areas. However, metrics such as the percentage of neighbourhoods within each quadrant or within a certain standard deviation can still be used for comparisons with other municipalities or urban areas.

Our new and nuanced understanding of the relationship between SES and GSS challenges the conventional narrative that socio-economically disadvantaged neighbourhoods lack access to green spaces. Instead, it highlights the need for context-specific urban planning and management that recognizes both the strengths and challenges of different neighbourhoods. Decision-makers should focus on maintaining and enhancing green space quality, while addressing socio-economic disparities through inclusive and participatory planning processes.

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Acknowledgements

This project has been conducted with input and feedback from people working at Malmö Stad and Region Skåne. Thanks to Clara Studeny for discussing and sharing data on maintenance costs in Malmö Stad. Thanks to Dennis Skoog at Malmö Stad for testing different methods of calculating distance to urban green space. Thanks to Daniel Nilsson and Fredrik Nilsson at Region Skåne, for contributing with feedback on our method and discussing the available health data at the regional level with us.

Appendix 1: Basis for assumed walking speed by land cover

Table A2 gives the time cost per meter per land cover used to calculate walking time to nearest UGS reported here. The base walking speeds is that given by Montufar et al. 2007 (Table 3) for “Younger Pedestrians” based on an adult woman walking on various surfaces. Unpaved paths have the same speed as concrete as confirmed by Wood et al. (2023). Stairs are calculated as a ratio of this as given by Bosina & Wiedmann 2017 (Table 6). The base speed is adjusted for street crossings as given by Montufar et al. 2007 (Table 3), walking within a public building is based on Bosina & Weidmann 2017 (Table 6). Grass is given the same speed as concrete based on Leicht & Crowther (2007), woodland lowers speed by 10% as found by Wood et al (2023). Private buildings, water and other barriers have a high time cost value (9999999999).

Table A2. Land cover Walking Times per m^2

RouteType	EnglishName	Source	Licence	Width	Buffer	DrawOrder	ClassCode	RouteBarrierAdult	RouteBarrierChild	RoutrBarrierW	WSAdult(F)	WSChild	WSElderly	WaitTime
BaseSpeeds	BaseSpeeds	NA	na								1.36	1.1	0.88	0
Gångväg (friliggande)	Pavement	MalmoStadRoads	MalmoStad4GE	9	4.5	1	1	0	0	0	1.36	1.1	0.88	0
Liten gata	Small Road	MalmoStadRoads	MalmoStad4GE	4	2	1	2	0	0	0	1.61	1.33	1.08	2.49
Medelstor gata	Medium Road	MalmoStadRoads	MalmoStad4GE	8	4	1	3	0	999999999	0	1.61	1.33	1.08	11.09
Stor gata	Large Road	MalmoStadRoads	MalmoStad4GE	16	8	2	4	999999999	999999999	0	1.61	1.33	1.08	11.09
Adressplats	LocalRoad	MalmoStadRoads	MalmoStad4GE	9	4.5	1	5	0	0	0	1.61	1.33	1.08	2.49
Markväg, enskild väg	Unsurfaced Road	MalmoStadRoads	MalmoStad4GE	9	4.5	3	6	0	0	999999999	1.61	0	1.08	2.49
Kvartersgata	Kvartersgata	MalmoStadRoads	MalmoStad4GE	9	4.5	1	7	0	0	0	1.61	0	1.08	2.49
Genomfartsled	Thoroughfare	MalmoStadRoads	MalmoStad4GE	9	4.5	5	8	0	0	0	1.61	1.33	1.08	11.09
Motorväg	Freeway	MalmoStadRoads	MalmoStad4GE	32	16	5	9	999999999	999999999	999999999	1.61	1.33	1.08	11.09
Av- påfartsled, ett körfält	On-ramp, one lane	MalmoStadRoads	MalmoStad4GE	4	2	5	10	999999999	999999999	999999999	1.61	1.33	1.08	11.09
Av- påfartsled, flera körfält	Off-ramp, several lanes	MalmoStadRoads	MalmoStad4GE	8	4	5	11	999999999	999999999	999999999	1.61	1.33	1.08	11.09
Other	Other	MalmoStadRoads	MalmoStad4GE	8	4	1	12	0	0	0	1.36	1.1	0.88	0
Cykelvägar	Cycle paths	main.Gångbanor	MalmoStad4GE	3	1.5	1	13	0	0	1	1.36	1.1	0.88	0
Gågatan	Pedestrian	main.Gångbanor	MalmoStad4GE	3	1.5	1	14	0	0	0	1.36	1.1	0.88	0
Gång-Cykel banor	Walking-Bike Paths	main.Gångbanor	MalmoStad4GE	3	1.5	1	15	0	0	0	1.36	1.1	0.88	0
Gångbana i grässyta	Walkway in grass area	main.Gångbanor	MalmoStad4GE	3	1.5	1	16	0	0	0	1.36	1.1	0.88	0
Gångbana inom kvarter	Walkway within blocks	main.Gångbanor	MalmoStad4GE	3	1.5	1	17	0	0	0	1.36	1.1	0.88	0
Gårdsgata	Gårdsgatan	main.Gångbanor	MalmoStad4GE	3	1.5	1	18	0	0	0	1.36	1.1	0.88	2.49
Körbana	Carriageway	main.Gångbanor	MalmoStad4GE	4	2	5	19	999999999	999999999	999999999	1.61	1.33	1.08	11.09
Pakering	Parking	main.Gångbanor	MalmoStad4GE	1	0.5	0	20	0	0	0	1.36	1.1	0.88	0
Refug	Island	main.Gångbanor	MalmoStad4GE	2	1	0	21	0	0	0	1.36	1.1	0.88	0
Skiljeremsa	Separation strip	main.Gångbanor	MalmoStad4GE	2	1	0	22	0	0	999999999	1.36	1.1	0.88	0
Särskilda Gångbana	Special walkways	main.Gångbanor	MalmoStad4GE	3	1.5	1	23	0	0	0	1.36	1.1	0.88	0
Torget	Square	main.Gångbanor	MalmoStad4GE	1	0.5	0	24	0	0	0	1.36	1.1	0.88	0
Trappa	Stairs	main.Gångbanor	MalmoStad4GE	1	0.5	3	25	0	0	999999999	0.76	0.6147059	0.4917647	0
särskilda Cykelbana	Special Bike Path	main.Gångbanor	MalmoStad4GE	4	2	1	26	0	0	0	1.36	1.1	0.88	0
Övrigt	Other	main.Gångbanor	MalmoStad4GE	3	1.5	1	27	0	0	0	1.36	1.1	0.88	0
överhångställe	Pedestrian Crossing	main.Gångbanor	MalmoStad4GE	4	2	6	28	0	0	0	1.36	1.1	0.88	2.49
Annan cykelbar förbindelse	Cyclable Route	main.Cykelvägar	MalmoStad4GE	3.4	1.7	1	29	0	0	0	1.36	1.1	0.88	0
Blandtrafik	Mixed traffic	main.Cykelvägar	MalmoStad4GE	3.4	1.7	2	30	0	999999999	1	1.61	1.33	1.08	2.49
Cykelbana/-väg	Cycle path on road	main.Cykelvägar	MalmoStad4GE	2.77	1.385	1	31	0	999999999	0	1.61	1.33	1.08	2.49
Cykelfält	Bike lanes	main.Cykelvägar	MalmoStad4GE	2.38	1.19	1	32	0	0	0	1.36	1.1	0.88	0
Cykelpassage	Bicycle passage	main.Cykelvägar	MalmoStad4GE	3.01	1.505	6	33	0	0	0	1.36	1.1	0.88	0
Cykelöverfart	Bicycle crossing	main.Cykelvägar	MalmoStad4GE	3.2	1.6	6	34	0	0	0	1.36	1.1	0.88	0
Kombinerad gång- och cykelban	Combined pedestrian and b	main.Cykelvägar	MalmoStad4GE	3.36	1.68	1	35	0	0	0	1.36	1.1	0.88	0
Planskild underfart	Underpass	main.Cykelvägar	MalmoStad4GE	3	1.5	6	36	0	0	0	1.36	1.1	0.88	0
Planskild överfart	Overpass	main.Cykelvägar	MalmoStad4GE	3	1.5	6	50	0	0	0	1.36	1.1	0.88	1
Signalreglerad överfart	Signal-controlled crossing	main.Cykelvägar	MalmoStad4GE	3.23	1.615	6	37	0	0	0	1.36	1.1	0.88	60
OtherCycle	OtherCycle	main.Cykelvägar	MalmoStad4GE	3	1.5	1	38	0	0	0	1.36	1.1	0.88	0
CrossingStreet	CrossingStreet		Calculated			6	39	0	0	0	1.61	1.33	0.88	0
Mall	Mall	Fastighetskartan	Fastighetskartan			6	40	0	0	0	1.55	1.2804348	0.847205	0
Grass	Grass	Marketack	Naturvardsverket			0	41	0	0	999999999	1.36	1.1	0.88	0
Woodland	Woodland	Marketack	Naturvardsverket			0	42	0	0	0	1.224	0.99	0.792	0
Building	Building	Fastighetskartan	Fastighetskartan			5	43	999999999	999999999	999999999	999999999	999999999	999999999	0
Vatten	Water	Marketack	Naturvardsverket			6	44	999999999	999999999	999999999	999999999	999999999	999999999	0