Setting priorities for greening cities with monetary accounting values for amenity services of urban green

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Abstract

Life Satisfaction Analyses in Germany reveal a significant positive correlation between the amount of green space within 1 km of residence and well-being. The comparison of the effects of green space and income on well-being allows the derivation of a monetary demand function for green spaces close to the place of home. This demand function was used together with land-use and population data to estimate the monetary value of green space close to home for every 2 km × 2 km grid cell in Germany.

The results can be used in environmental economic accounting as a proxy for the (visual) amenity services of green spaces close to residences and provide urban planners with additional information on the strength and spatial distribution of demand for green spaces in residential areas.

The study shows that, especially in densely populated areas where more than 30 per cent of the German population lives, the (simulated) exchange value of green spaces (price per additional hectare derived from the demand function) multiplied by the number of households that would pay this price, is higher than the price per ha that can be achieved on the real estate market.

A comparison with the results of a Hedonic Price Analysis that estimates the effect of urban green space on property prices finds that the values of urban green spaces calculated with this method were 38 to 124 times smaller than the values calculated with the Life Satisfaction Analysis and far below building land prices. The reason for the relatively low impact of urban green on property prices can be explained by market imperfections in the housing market.

Keywords

economic valuation, ecosystem services, urban planning, amenity service, ecosystem accounting, life-satisfaction analysis, experienced preference analysis, hedonic pricing

Introduction

Due to the Millenium Ecosystem Assessment (2005), the international TEEB study (TEEB 2012) and its national follow ups (e.g. Naturkapital Deutschland - TEEB DE 2018) and the implementation of target 2, action 5 of the European Biodiversity Strategy to 2020 (European Commission 2011), ecosystem services and their economic valuation have increasingly received the attention of science and politics. With the 'UN System of Environmental Economic Accounting - Ecosystem Accounts', which was adopted at the beginning of 2021 (UN SEEA-EA 2021), a first international standard for the integration of ecosystem services into environmental economic accounting is now available.

In a pilot project on ecosystem accounting for the German Federal Ministry for the Environment, commissioned by the Federal Agency for Nature Conservation, Hirschfeld et al. (2020) prepared the first Germany-wide assessments for selected ecosystem services. The services should be quantified throughout Germany in a spatially specific way by physical indicators as well as monetarily.

This article presents the results of this study with regard to "visual amenity services". According to UN SEEA-EA 2021 (table 6.3), these are "the ecosystem contributions to local living conditions, in particular through the biophysical characteristics and qualities of ecosystems that provide sensory benefits, especially visual".

UN SEEA-EA 2021 (para. 6.58) recognises that, within its proposed ecosystem service reference list, there are several additional ecosystem services that are relevant to the amenity of a location. Recreation-related and noise-attenuation services are mentioned as examples. Furthermore, green urban areas can reduce air pollution (air filtration service), have a positive influence on a healthy urban climate by buffering summer heat waves, which becomes of increasing importance due to climate change (local climate regulation service) and serve as places for social contacts and interactions (Kowarik et al. 2017). Ideally, "where possible, each of these services should be measured distinctly" (UN SEEA-EA 2021, ibid.). However, in practice, only combinations of amenity-related services can be measured with the methods applied today. This is also true for the present study (see discussion).

The physical and monetary values for the amenity services of urban ecosystems (or, more generally, ecosystems close to one's home) can help to correct or provide information for national accounts for the impacts on "goods" (here: neighbourhood amenity) that are relevant to people's welfare, but are not traded or only imperfectly traded on markets (TEEB 2009, chapter 3.3; Natural Capital Germany 2017). Furthermore, they can also serve as additional information for plannning purposes.

The economic valuation technique used in our study attempts to determine the price one would pay to extend the amenity services of urban green space in one's neighbourhood. This hypothetical price is based on the idea that such services are traded on the market, that each seller posseses only a small part of the green space in a neighbourhood and that the seller can restrict the "use" of the amenity services to those people who pay the price to him. In such a case, people's willingness to pay - as a hypothetical price - for amenity services can be compared with the prices paid for other goods, for example, the price of building land. If the willingness to pay of all stakeholders for the amenity services provided by, say, one hectare of urban green space is higher than the price of one hectare of building land, then there is a chance of a social welfare gain if a larger share of urban land is used for the production of amenity services (cf. OECD 2018; for the grounding in economic theory, see Hicks 1939, Kaldor 1939, Scitovsky 1941, for discussion see below).

The following chapters first explain why the Life Satisfaction Method was used here as the basis for a nationwide estimate of the amenity values of green spaces close to housing and present some relevant details of the Life Satisfaction Study by Krekel et al. (2016) used for this purpose.

Next, the land use and population data for our nationwide assessment are presented. The extrapolation required an adjustment of the Krekel et al. (2016) evaluation function, as their analysis was based on different geographical data. Another adjustment was made to correct for sorted preferences.

The results of our extrapolation are then presented cartographically and broken down by different population densities. The social demand for green spaces close to housing is compared with corresponding values for building land. From this, it can be deduced where the demand for urban green space is highest and where the value of an additional hectare of urban green exceeds the value of an area as building land.

The article concludes with an evaluation and discussion of the results and identifies future research needs.

Methodology of economic valuation

For a German nationwide assessment of the amenity services of ecosystems in the vicinity of the place of residence, it must first be decided which valuation method should be used to determine hypothetical prices for these services. The reliability of direct surveys of willingness to pay (contingent valuation studies) and the results of choice experiments, in which the best combination of the amount of an ecosystem service and its price has to be selected between several alternatives, is considerably questioned in the economic literature (cf. McFadden and Train 2017). Rather, indirect methods are preferred (UN SEEA-EA 2021, chapter 9.3). Such methods are, for example, the "Hedonic

Pricing Analysis" in which preferences for amenity services are derived from real estate market data and the "Life Satisfaction Method" in which results of sociological studies on life satisfaction are evaluated together with spatial land-use data to derive preferences for green spaces in the residential environment (Kolbe and Wüstemann 2014, Krekel et al. 2016).

The concept of environmental economic accounting according to SEEA EA presupposes that a service is associated with a transaction (UN SEEA-EA 2021, chapter 6.3.4). In the "Hedonic Price Analysis", recommended by the SEEA EA for assessing the amenity value of urban green spaces, this transaction is the payment of a premium on the price of a property due to a more favourable green space provision in the residential environment.

In our study, the "Life Satisfaction" or "Experienced Preference" method was used instead. This method measures the effect of green spaces on a life satisfaction scale and then compares this effect with the increase in income that leads to the same increase in life satisfaction (Krekel et al. 2016). This increase in income then represents a monetary value of the additional green space which is taken as an approximation of the hypothetical price for amenity services sought.

If this method is classified in the methods proposed by UN SEEA-EA (2021) for the monetary valuation of ecosystem services, the "Life Satisfaction Method" can be best defined as a 'Simulated Exchange Value' method. In this approach, a market for an ecosystem service is theoretically constructed and the price is simulated, in which the market generates an equilibrium between supply and demand, based on the measured marginal utility function of the users or beneficiaries.

The values or prices used in our study are based on the assumption that there is a competitive market for the supply of (publicly accessible - see below) green space. This means that the price for the right to use or benefit from each unit of green space is negotiated individually between its suppliers and each buyer (beneficiary) and that those who do not want to pay the price can be excluded from the use or benefits. The actual transaction underlying the valuation is, therefore, not the payment of a possibly slightly higher real estate price as is the case with Hedonic Pricing. Instead, it is the experience of urban green with the senses, by seeing, smelling and hearing. Often, this requires no separate effort; rather, it also arises as a by-product of everyday activities, such as shopping, walking to work, a short walk in the neighbourhood etc.

Kolbe et al. (2019) compare the results of two German studies using Hedonic Price Analysis and the Life Satisfaction method, both of which used the proportion of public green space within a 1 km radius of the place of residence as an explanatory variable (Kolbe and Wüstemann 2014, Krekel et al. 2016). They find that the Hedonic Price Analysis leads to values that are only the 38th to 124th part of the value that the Life Satisfaction Method yields. Using a market simulation model in which both methods are represented, they show that market imperfections that characterise the real estate market, such as incomplete information, high transaction costs, short-term limited supply and equity preferences, can explain why it is possible that Hedonic Price Analysis only represents a fraction of the actual effect of green space on life satisfaction. The use of this method would, therefore, lead to results that could not be justified from a methodological point of view. At the same time, Kolbe et al. (2019) show that the Life Satisfaction Analysis overestimates the value of publicly accessible green spaces if the inhabitants are distributed amongst the residential locations according to their individual "green preferences" ("sorted preferences"). Based on the same market simulation, they also propose quantitative adjustments to the results of the Life Satisfaction Analysis to correct for sorted preferences (see below and Fig. 1).

In our study, we used the Life Satisfaction Analysis by Krekel et al. (2016), which comes to very similar results as the study of Bertram and Rehdanz (2015), but uses more data and covers a larger area. It is based on approx. 42,000 records from the 'Socio-Economic Panel' (SOEP) of the German Institute for Economic Research from the years 2000 to 2012 (for further information, see DIW 2022). Each dataset includes a subjective assessment of life satisfaction on a Likert scale from 0 to 10, as well as possible explanatory variables such as age, gender, marital status, health, education, income etc. In addition to these explanatory variables, the proportion of publicly accessible green spaces within a 1 km radius of the place of residence is examined in the context of a multi-criteria regression analysis to determine how it affects life satisfaction, besides the other explanatory variables. Private gardens could not be taken into account. There was insufficient geographical data available for this and, moreover, it is not possible to allocate specific garden areas to the persons surveyed in the SOEP solely on the basis of the available geographical reference data. Additionally, qualitative aspects of the green spaces and green elements like roadside trees could not be considered. Despite these shortcomings (for a discussion see below), the share of green space in 1 km radius can be at least taken as a rough indicator of the bio-physical quantity of amenity services.

The relation between the area of green space within a radius of 1 km in hectares and the price people would hypothetically pay for an additional hectare (marginal utility function), as estimated by Krekel et al. (2016), is shown in Fig. 1, grey dashed line. Kolbe et al. (2019) derive lower limits and upper limits from their market simulation model to correct the marginal utility function of Krekel et al. (2016) for "sorted preferences". In addition to these upper and lower bounds (blue and ochre line), also a "medium" variant is proposed (Fig. 1, black line). The valuation function we use here is this "medium" variant after adjusting for the spatial dataset used in our study.

Spatial data and adjustment of the valuation function

Krekel et al. (2016) use the spatial data of the European Urban Atlas for Germany for the year 2006 (Copernicus 2022) to calculate the proportion of green spaces within 1 km of the residence of each SOEP participant whose dataset they used. The green spaces taken into account are the ´Green Urban Areas´defined by the Urban Atlas.

The Urban Atlas only covers the most urbanised parts of Germany. In contrast, the aim of our study was to assess the amenity services of all green spaces close to home, regardless of wether they are located in densily or sparsely populated areas. Futhermore, the defintion of ´Green Urban Areas´ by the Urban Atlas excludes all wooded areas that are not completely surrounded by settlement areas. From an amenity service perspective, however, all wooded areas in the vicinity of one's home have to be taken into account when measuring amenity services, regardless of whether they are completely sorrounded by settlements or not. Additionally, any kind of agriculturally used grassland is excluded. However, Krekel et al. (2016) found a significant positive influence of meadows and pastures on life satisfaction, in contrast to arable land that had no influence. Utilised grassland must, therefore, also be included in the indicator green spaces within a 1 km radius used to measure the bio-physical strength of amenity services.

Instead of the Urban Atlas and the Green Urban Areas defined there, we, therefore, base our study on the the geodataset of the ATKIS Basis-DLM (BKG 2016) in the version of the IOER-Monitor (IOER-Monitor 2022). This dataset is updated more frequently and regularly than the Urban Atlas. It covers the whole area of Germany and uses, in the case of settlements, cadastral data (BKG 2016), which are often more precise than the remote sensing data (see Copernicus 2016) of the 2006 Urban Atlas. The following types of areas of the ATKIS Basis-DLM/IOER-Monitor are considered as publicly accessible green space: woody vegetation, woodland, meadow and pasture, park/publicly accessible greenspace, other sport, leisure and recreation area and cemetery.

The data basis for the distribution of the population is the data from the last population census (StBA 2011), in which all 100 m × 100 m grids with more than three persons are recorded with their respective population numbers.

Before the values of the marginal utility function of Krekel et al. (2016) - corrected on the basis of Kolbe et al. (2019), see above - could be extrapolated to the whole population in Germany, the function first had to be the adjusted to the changed spatial database and the additionally included green space types.

For this purpose, it was first adapted by linear transformation to the higher average green space supply per person resulting from the use of ATKIS Basis-DLM data and the inclusion of additional green space types, compared to the Urban Atlas and the Green Urban Areas defined there. In the second step, the function was then further calibrated so that a spatial extrapolation with Urban Atlas data and the original marginal utility function of Krekel et al. (2016), corrected according to Kolbe et al. (2019) on the one hand and the extrapolation for the same area with ATKIS Basis-DLM data, extended green space definition and adjusted marginal utility function on the other hand, yielded the same estimate for the total monetary value of the amenity service (measured as: marginal utility × green space in a 1 km radius × number of persons). This calibration was done by reducing the slope of the already linearly fitted function to such an extent that both calculations led to the desired equality of results.

Fig. 2 shows the linearly adjusted and calibrated marginal utility function (black line) and, derived from it, the utility function (violet curve) and the simulated expenditure function (red curve). The marginal utility function, as explained above, shows the willingness to pay for an additional unit of green space (simulated price); the utility function expresses the monetary value of the total green space close to home for a household (average: 1.8 persons); and the simulated expenditure function shows the total expenditure the household would make for it.

The simulated expenditure is the accounting compatible exchange value of the green space for one single household. It is caclulated according to the formula "value of total green space within a radius of 1 km = simulated price per hectare × hectare of green space ". The welfare value (utility) of the total green space is higher than the exchange value. It is calculated as the area under the marginal utillity function. (For the differences between exchange and welfare value, see also UN SEEA-EA 2021, Section D, p. 174 and ibid. chapter 12.)

An evaluation according to different population density classes in 2 km × 2 km grids shows that the calculation for the ´Green Urban Areas´ of the 2006 Urban Atlas, which shows only minor deviations from the 2012 version regarding the definition of green space, compares rather well with the caculation based on ATKIS Basis-DLM for 2012 (Fig. 3). Only in the lowest density class do the total amenity values of urban green deviate strongly from each other, which is mainly due to the fact that, in this class, the supply of ´Green Urban Areas´ is lowest due to the exclusion of forests and grassland on the edge of settlement areas. As a result of the calibration, the sum across all grids yields the same value for both calculations.

Extrapolation to Germany

To ensure that the underlying life satisfaction analysis, based on SOEP data from 2000 to 2012 and spatial data from the 2006 Urban Atlas, as well as the available population data of the 2011 census and the spatial data used in our own analysis are not too far apart in time, the 2012 version of the ATKIS Basis-DLM was used for the Germany-wide extrapolation rather than the current version of ATKIS.

The extrapolation to all households in Germany using the calibrated marginal utility function was carried out within the framework of a detailed analysis restricted to all cities with more than 50,000 inhabitants and a German-wide analysis in a 2 km × 2 km grid. The results of the detailed analysis regarding the green space supply per household are published in the IÖR-Monitor (2021).

In the detailed analysis, the sum of publicly accessible green spaces within a 1 km radius was determined for each 100 m × 100 m census grid. The exchange value of this green space area was then calculated using the calibrated marginal utility function as "marginal utility per hectare × number of hectares × number of households in the 100 m × 100 m grid". The monetary values per census grid were then added up for each municipality. No values were assigned to the individual green spaces within a settlement.

In addition, a larger-scale analysis was carried out in which, for simplicity, the total area of publicly accessible green space within each 2 km × 2 km grid in Germany was assigned to the entire population in this grid, multiplied by a factor of 0.785 (π/4), in order to take into account that the green space supply in the underlying empirical study of Krekel et al. (2016) was measured in a 1 km radius around each residential location and not in the larger area of 4 km^2 corresponding to a 2 km × 2 km grid.

The 2 km × 2 km analysis cannot assess the respective supply situation in such detail for each place of residence as is the case with the detailed 100 m × 100 m census grid analysis. This could theoretically lead to a distortion of the results in connection with the valuation function used. However, as it turned out, the value calculation on the basis of the Germany-wide mean value of green provision arrives at a figure that is very close to the aggregation of the partial values of the 2 km × 2 km grids, although these grids differ greatly with regard to green provision. It can, therefore, be assumed that the values calculated on the basis of 2 km × 2 km grids are very close to the values that would have been calculated on the more precise basis of the detailed analysis.

Since the monetary results of the detailed analysis, which had already been published as preliminary in Grunewald et al. (2021), subsequently proved to be incorrect, valid monetary results are currently only available for the 2 km × 2 km analysis.

Results, comparison with prices for building land and relevance for municipal planning

Fig. 4 shows four maps with nationwide results in a 2 km × 2 km grid. They present:

a: The extent of publicly accessible green space within a 1 km radius of residence.

b: The value of green space calculated according to the principles of environmental economic accounting: simulated price (marginal utility of an additional/the ´last´ green space unit according to Fig. 2 × area in ha × number of households.

c: The value of green space calculated according to the principles of welfare economics or cost-benefit analysis: value of all green space according to the utility curve in Fig. 2 (this corresponds to the area under the marginal utility curve) × number of households.

d: The marginal utility or simulated price of an additional/the 'last' green space unit multiplied by the number of households.

Fig. 4a presents the bio-physical indicator for amenity services used in our study. Fig. 4b and Fig. 4c show the accounting compatible exchange value (simulated market value) and the welfare value, which is under normal market conditions always higher than the exchange value. In all areas where the green space supply exceeds the saturation point, i.e. the quantity at which households are no longer willing to pay a price for an additional green space unit, the welfare value per household reaches its highest value, while the exchange value (simulated price paid for an additional unit × total quantity sold) is zero. Such areas are normally situated on the outskirts or outside urban areas. Although the individual welfare value has the highest possible level here, the social welfare value for all inhabitants is rather small compared to densely populated urban districts due to the lower number of inhabitants.

Fig. 4d presents an indicator for the social scarcity of green spaces. The scarcer the areas are, the more valuable each additional area is from the individual perspective and the higher is the individual simulated price. Multiplication by the number of inhabitants gives the individual scarcity a social significance. Multiplication follows the economic principle of aggregating individual benefits to society by adding them up (usually) without further weighting. According to this principle, the highest social benefit from one additional hectare of green space is achieved where the product of marginal utility for an average household multiplied with the number of households is highest (for discussion see below).

For government programmes that aim to increase the greening of cities, for example, to make them more resilient to climate change, as well as for municipal green space planning, the monetary scarcity indicator presented here offers - in addition to other, already existing indicators like the distance to the next green space (Grunewald et al. 2017) - further guidance for deciding where more green spaces could make the greatest contribution to public well-being.

Since the scarcity indicator presented is a value that expresses an economic benefit, it can - unlike other parameters - also be directly compared with the economic costs that are incurred if settlement areas are kept free of further development, for example, for residential or commercial use, in order to establish and maintain them as green spaces. The most important cost factor, besides construction and maintenance costs of parks (see below), is the renunciation of an alternative use as residential or commercial land. One indicator of this is the price of a building site.

In the grid squares with the highest population density, where 30% of Germany's population lives, the value per ha of green space aggregated over the residential population is, on average, 783,838 euros per ha and year (cf. Fig. 5). This corresponds to a one-off payment of 2,613 euros per m^2 ("present value" calculated with a 3% discount rate for an infinite period of time). If a lower discount rate of, for example, 1.5% is used, which can be justified for long-term environmental considerations (TEEB 2010, chapter 6), this one-off payment would even double. According to Krekel et al. (2016), the reference year for the monetary values is 2016. This means that the value of the green spaces in these grids was far above the average expenditure for land ready for construction in large cities with more than 500,000 inhabitants, which was just under €700 per m^2 in 2016 (StBA 2021), including construction and maintenance costs for particularly expensive green spaces, for which a present value of €680 per m^2 results when calculated on the basis of the information from Krekel et al. (2016).

In the grids squares with the lowest population densities, where 40% of the German population lives, the value per ha of green space is on average only just under 12 euros per m^2. In each of the density classes in this group, it is below the average sales value of building plots in municipalities with less than 2000 inhabitants (56 euros per m^2 in 2016), including the cost of particularly low-cost green spaces (78 euros per m^2). However, the green spaces in question are likely to be mainly grassland and woodland rather than parks.

The remaining 30% of the German population live in grid squares, for which a mean green space value of approx. 486 euros per m^2 results. In the respective density classes, this is partly above and partly below the sum of the price of building land in cities with between 200,000 and 500,000 inhabitants (294 euros per m^2) and the mean value of the above-mentioned cost maxima and minima of park facilities (379 euros per m^2).

The figures show that the monetary value of the amenity services of green spaces often far exceeds the sum of building land prices and the construction and maintenance costs of urban parks. Taking into account their monetary impact on citizens' well-being, the preservation and creation of green spaces is, therefore, economically worthwhile in many cases and would lead to a net increase in welfare. The 2 km × 2 km grids, for which the monetary amenity value of urban green spaces were identified throughout Germany (Fig. 4d), can serve as a guide for local decision-makers as to where there is a particularly high need for additional green space.

More precise proposals for the location of new green spaces would be possible if additional information were available on the current land use dynamics in the different neighbourhoods and more detailed knowledge on local land prices including their differentiation between different neighbourhoods and between inner city and suburban areas.

Discussion and scope for further research

On the basis of the ecosystem service "amenity values of publicly accessible green spaces in the vicinity of residential areas", it was shown that a monetary valuation of ecosystem services, as currently discussed and developed for application in environmental accounting, can support decision-making processes on the ground with socially relevant information.

Monetary values for ecosystem services have the advantage over other decision support tools that they can be compared with each other and with other monetary values. Here, it is the alternative value of land when used as building land. They thus provide an additional basis for weighing different concerns, taking into account individual preferences for green in the city and for building land, which is not available in a comparable form when using other decision criteria and methods.

In the case of urban green spaces, the monetary valuation presented can be used to describe relatively precisely in which urban areas, depending on the population density and the current green supply, additional green spaces have an effect on the welfare of the inhabitants that is greater than the economic benefit the corresponding areas would provide as residential or commercial spaces. A relatively high discount rate of 3% was used for this comparison. At lower discount rates, the relative value of green space versus building land would shift further in favour of green space.

In addition to showing the practical benefits of our results, it is also important to point out that the presented nationwide assessment of the benefits of green spaces for Germany still has weaknesses and should be further developed.

We have used an economic welfare concept for our analysis. Under this concept, the willingness to pay of the various stakeholders is usually aggregated into a societal value without taking income differences into account. This could lead to poor sections of the population being given less consideration than rich ones in the provision of public goods. Here, however, we use an average marginal utility function. Therefore, the monetary results shown in the figures are income neutral. This means that green areas are only valued according to population density and total green space provision, regardless of income differences.

However, in low-income neighbourhoods, the need for green space may be relatively higher due to a lack of private gardens or fewer resources for trips to recreation sites. This is not considered, here. Additionally, the concept of a minimum provision for everyone is not included in our analysis. The latter would alter the picture, however, only marginally. An example would be a small residential population surrounded by industrial areas. Our demand indicator also does not capture the maintenance and creation of large representative green spaces that have value for the population, for example, as a local identification factor that goes beyond normal use as green space. For more discussion about economics and social values, see, for example, Massenberg (2019).

As mentioned in the Introduction, green spaces close to home provide a bundle of different ecosystem services, some of which also have a potentially positive influence on well-being. Krekel et al. (2016) used health as an explanatory variable for well-being, alongside urban green space and other variables. The effect of health-related services, such as air filtration and local climate regulation, could therefore already be subtracted from the measured well-being effect. This would mean that possibly only recreation-related services are still included in the values presented here. The exact interaction of amenity values with other benefits should be analysed in more detail in the future. In the meantime, the present values could be considered as a lower estimate of the combined value of visual amenity and recreation-related services, which may, to some extent, also include air filtration and local climate services.

Private gardens as well as urban trees were not considered in the study, although they also have positive welfare effects. If urban trees or private gardens were fully linearly spatially correlated with green spaces, the presented benefits of green spaces would be overestimated, as the values would include both the values of green spaces and the value of trees and private gardens. If there were no correlation at all between green spaces and urban trees/private gardens, private gardens and urban trees would have an additional benefit/value for well-being. Thanks to improved spatial data, these correlations can also be analysed more precisely in future studies.

As presented, the original Life Satisfaction Analysis from Krekel et al. (2016) referred to a different spatial data base and had to be adapted to the ATKIS Basis-DLM used here. Although an attempt was made to minimise possible errors through calibration, it would be useful to conduct one or more further life satisfaction analyses directly based on ATKIS data in the future.

Such analyses should also be used to solve the other shortcomings of our approach through the following additional investigations, amongst others:

- Further investigation of the significance of 'sorted preferences'. The meancorrected preference function used lies between upper and lower limits that are (still) relatively far apart and should, therefore, be analysed empirically in more detail.
- Inclusion of other green elements, such as private gardens and city trees, for which nationwide information is now available.
- Differentiation of the appreciation of different types of green spaces and consideration of quality parameters.
- More detailed investigation of the relevance of other ecosystem services (e.g. microclimate, air filtration, recreation) in order to quantitatively assess overlaps.
- Comparison with stated-preference valuations in order to better combine advantages and avoid disadvantages of different economic methods.
- Broader and more detailed coverage of the costs for investment and maintenance of urban green spaces.

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Conflicts of interest

References

- Bertram C, Rehdanz K (2015) The role of urban green space for human well-being. Ecological Economics 120 (C): 139-152. https://doi.org/10.1016/j.ecolecon.2015.10.013

- BKG (2016) Bundesamt für Kartographie und Geodäsie: Digitales Basis-Landschaftsmodell (AAA-Modellierung). Basis-DLM (AAA). Stand der Dokumentation: 01.04.2016. Bundesamt für Kartographie und Geodäsie, Frankfurt (Main)..
- Copernicus (2016) Copernicus Land Monitoring Service: Mapping Guide v4.7 for a European Urban Atlas. https://land.copernicus.eu/user-corner/technical-library/urban-atlas-2012-mapping-guide-new/. Accessed on: 2022-3-28.
- Copernicus (2022) Copernicus Land Monitoring Service: Urban Atlas 2006. https://land.copernicus.eu/local/urban-atlas/urban-atlas-2006. Accessed on: 2022-3-20.
- DIW (2022) Deutsches Institut für Wirtschaftsforschung: Research Infrastructure Socio-Economic Panel (SOEP). https://www.diw.de/en/diw_01.c.615551.en/research_infrastructure__socio-economic_panel__soep.html. Accessed on: 2022-3-28.
- European Commission (2011) European Biodiversity Strategy to 2020. https://ec.europa.eu/environment/nature/biodiversity/strategy_2020/target2/index_en.htm. Accessed on: 2022-10-02.
- Grunewald K, Richter B, Meinel G, Herold H, Syrbe R (2017) Proposal of indicators regarding the provision and accessibility of green spaces for assessing the ecosystem service “recreation in the city” in Germany. International Journal of Biodiversity Science, Ecosystem Services & Management 13 (2): 26-39. https://doi.org/10.1080/21513732.2017.1283361
- Grunewald K, Hartje V, Meier S, Sauer A, Schweppe-Kraft B, Syrbe R-, Zieschank R, Ekinci B, Hirschfeld J (2021) National accounting of ecosystem extents and services in Germany: a pilot project. In: La Notte A, et al. (Ed.) Ecosystem and ecosystem services accounts: time for applications. Publications Office of the European Union, Luxembourg, 14 pp. [In Englisch]. URL: http://dx.doi.org/10.2760/01033
- Hicks J (1939) The foundations of welfare economics. Economic Journal 49 (196). https://doi.org/10.2307/2225023
- Hirschfeld J, Hartje V, Pekker R, Grunewald K, Meier S, Sauer A, Syrbe R-, Zieschank R, Schweppe-Kraft B (2020) Integration von Ökosystemen und Ökosystemleis-tungen in die Umweltökonomische Gesamtrechnung. Theoretische Rahmenbedingungen und methodische Grundlagen. Research report commissioned by the Federal Agency for Nature Conservation, publication planned.
- IOER-Monitor (2022) Leibniz-Institut für ökologische Raumentwicklung, Monitor der Siedlungs- und Verkehrsfläche: Flächenschema. https://www.ioer-monitor.de/methodik/#c239. Accessed on: 2022-3-28.
- IÖR-Monitor (2021) Leibniz-Institut für ökologische Raumentwicklung, Monitor der Siedlungs- und Freiraumentwicklung: Indikator. Bevölkerungsbezug. Einwohnerdichte. Städte ab 50.00 Einwohner. https://monitor.ioer.de/. Accessed on: 2022-3-28.
- Kaldor N (1939) Welfare Propositions of economics and interpersonal comparison of utility. Economic Journal 49 (195). https://doi.org/10.2307/2224835
- Kolbe J, Wüstemann H (2014) Estimating the value of urban green space: A hedonic pricing analysis of the housing market in cologne, Germany. Acta Universitatis Lodziensis. Folia Oeconomica 5 (2014): 45-61. [In English].
- Kolbe J, Krekel C, Schweppe-Kraft B (2019) Reconciling Experienced-Preference Val-uation with Hedonic Pricing: The Case of Green Spaces. Bundesamt für Naturschutz, Bonn. Research report, publication planned.
- Kowarik I, Bartz R, Brenck M, Hansjürgens B (2017) Natural Capital Germany: Ecosystem services in the city - Protecting health and enhancing quality of life. Summary

for decision-makers. Technical University of Berlin, Helmholtz Centre for Environmental Research - UFZ, Berlin, Leipzig, 75 pp. URL: https://www.ufz.de/export/data/global/190507_TEEB_De_Broschuere_KF_Bericht3_Stadt_engl_web.pdf [ISBN 978-3-944280-31-8]

- Krekel C, Kolbe J, Wüstemann H (2016) The greener, the happier? The effect of urban land use on residential well-being. Ecological Economics 121: 117-127. [In Englis]. https://doi.org/10.1016/j.ecolecon.2015.11.005
- Massenberg JR (2019) Social values and sustainability: a retrospective view on the contribution of economics. Sustainability Science 14 (5): 1233-1246. https://doi.org/10.1007/s11625-019-00693-w
- McFadden D, Train K (Eds) (2017) Contingent Valuation of Environmental Goods. A Comprehensive Critique. Edward Elgar Publishing, Cheltenham, UK; Northampton, MA,USA. https://doi.org/10.4337/9781786434692
- Millenium Ecosystem Assessment (2005) Overview of the Millenium Ecosystem Accounting. https://www.millenniumassessment.org/en/About.html. Accessed on: 2022-10-02.
- Natural Capital Germany (2017) The Value of Nature for Economy and Society. An Introduction. Ifuplan, Helmholtz Centre for Environmental Research, Federal Agency for Nature Conservation, Munich, Leipzig, Bonn. URL: https://www.ufz.de/export/data/global/190500_TEEB_DE_Einfuehrungsbericht_engl_Gesamt_%20web.pdf [ISBN 978-3-944280-02-8]
- Naturkapital Deutschland - TEEB DE (2018) Natural Capital Germany - TEEB DE. Ecosystem services: Nature´s gifts to us. https://www.ufz.de/teebde/index.php?en=43767. Accessed on: 2022-10-02.
- OECD (2018) Cost Benefit Analysis and the Environment: Further Developments ans Policy Use. OECD Publishing, Paris. https://doi.org/10.1787/9789264085169-en
- Scitovsky T (1941) A note on welfare propositions in economics. Review of Economic Studies 9 (1): 77-88. https://doi.org/10.2307/2967640
- StBA (2011) Statistisches Bundesamt: Zensusatlas 2011, zuletzt aktualisiert 2015. https://atlas.zensus2011.de/. Accessed on: 2020-11-27.
- StBA (2021) Statistisches Bundesamt: Genesis Datenbank, Tabelle 61511-0104: Kauffälle, Veräußerte Fläche, Durchschnittlicher Kaufwert für Bauland: Deutschland, Jahre, Baulandarten, Gemeindegrößenklassen. https://www-genesis.destatis.de/genesis/online. Accessed on: 2022-3-28.
- TEEB (2009) The Economics of Ecosystems and Biodiversity for National and International Policy Makers. UNEP URL: https://teebweb.org/publications/teeb-for/national-and-international-policymakers/
- TEEB (2010) The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations. Earthscan, London and Washington. URL: https://teebweb.org/publications/teeb-for/research-and-academia/
- TEEB (2012) TEEB Synthesis Report. UNEP URL: http://teebweb.org/publications/teeb-for/teeb-synthesis-report-2012/
- UN SEEA-EA (2021) System of Environmental-Economic Accounting – Ecosystem Accounting: Final Draft (2021), prepared under the guidance of the SEEA Experimental Ecosystem Ac-counting Technical Committee under the auspices of the UN Committee of Experts on Envi-ronmental-Economic Accounting (UNCEEA), version 5 February 2021. https://seea.un.org/ecosystem-accounting. Accessed on: 2022-3-28.

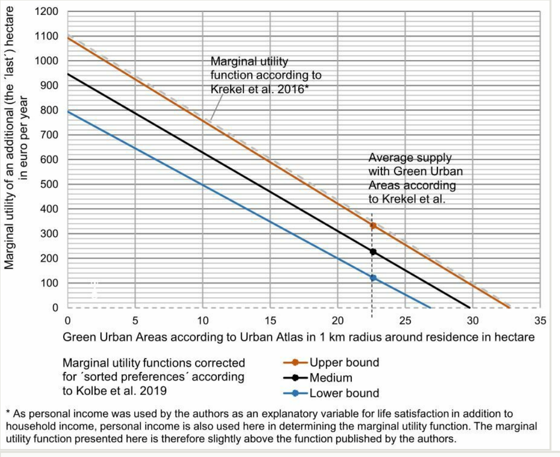

Figure 1.

Marginal utility functions for Green Urban Areas of the European Urban Atlas corrected for "sorted preferences" (source: Kolbe et al. 2019, modified).

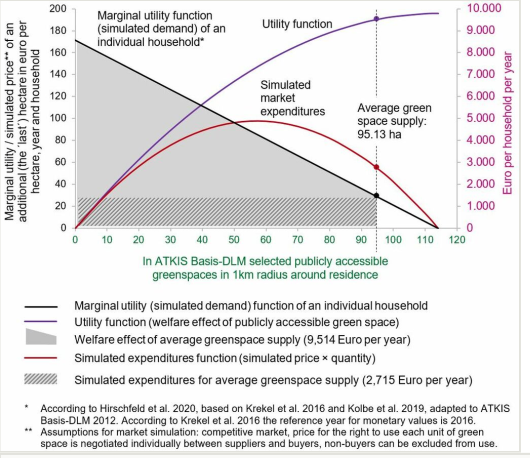

Figure 2.

Individual demand function (marginal utility function), utility function and simulated expenditure (exchange value) for publicly accessible green spaces in the vicinity of the residence (source: Hirschfeld et al. 2020, modified).

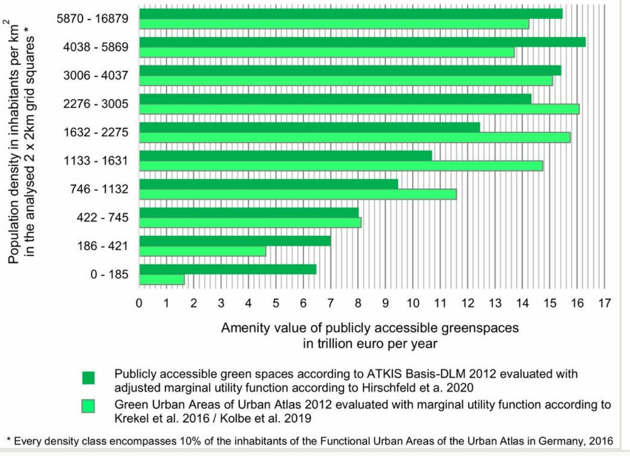

Figure 3.

Green areas selected according to ATKIS Basis-DLM, evaluated with the adjusted evaluation function compared to the value of Green Urban Areas, evaluated according to the function of Krekel et al. (2016)/Kolbe et al. (2019) (source: Hirschfeld et al. 2020).

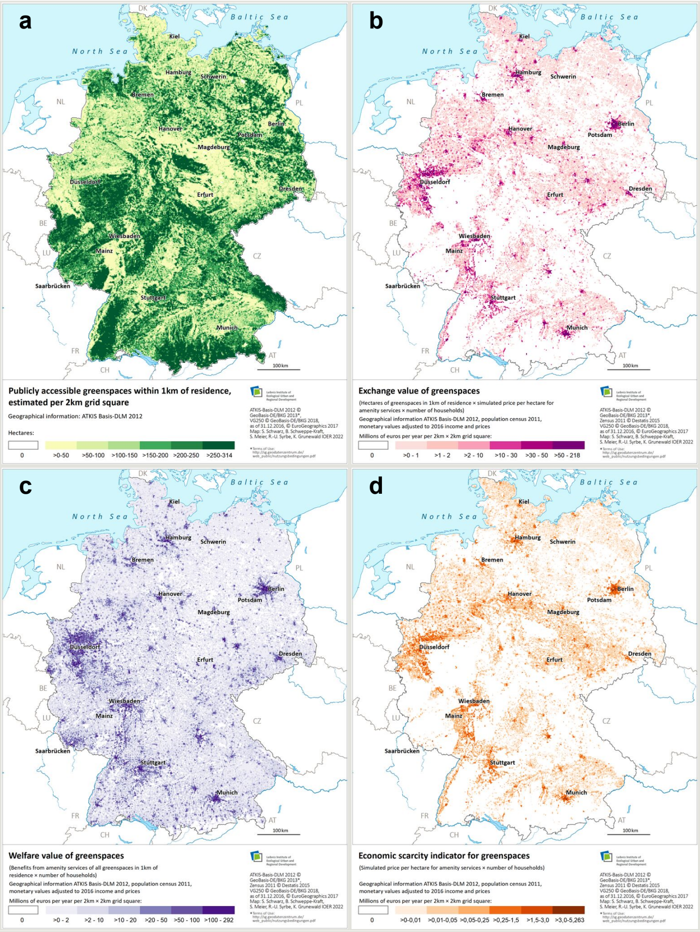

Figure 4.

Extent and monetary value of publicly accessible green spaces within a radius of 1 km from the place of residence measured per 2 km × 2 km grid square (source: Hirschfeld et al. 2020).

a: Extent of publicly accessible green space
b: Exchange value according to environmental economic accounting
c: Welfare value used in Cost Benefit Analysis
d: Scarcity indicator.

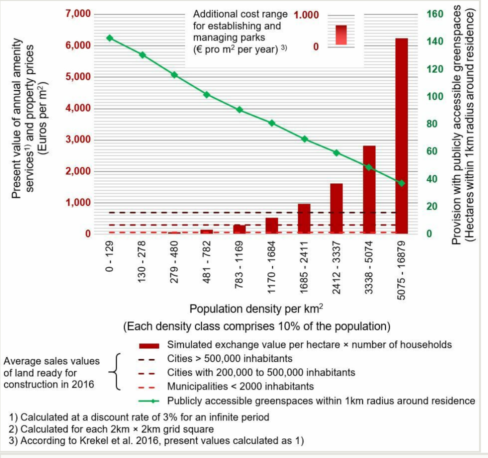

Figure 5.

Simulated exchange values of publicly accessible green spaces as a function of population density – comparison with property prices and costs for the creation and management of parks (source: own illustration).