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K. Hawes, Jason, Gounaridis, Dimitrios, Newell, Joshua P., Goldstein, Benjamin P., Caputo, Silvio, Cohen, Nevin, Fargue-Lelièvre, Agnès, Poniży, Lidia and Specht, Kathrin (2026) *Assessing the potential to scale-up urban agriculture in the Global North.* Landscape and Urban Planning, 272 . ISSN 0169-2046.

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Assessing the potential to scale up urban agriculture in the Global North

Abstract

Urban agriculture (UA) is frequently promoted as a pathway to improve urban sustainability, food security, and resilience, yet cross-city evidence on its scalable, system-wide impacts remains limited and methodologically inconsistent. We assess the theoretical scaling potential and food–energy–water (FEW) metabolism implications of expanding low-tech UA across five Global North cities—London, New York City, Paris, Dortmund, and Gorzów Wielkopolski—using a harmonized two-part framework. First, we conduct 1-m resolution spatial multi-criteria suitability modeling, supplemented with sensitivity scenarios. Second, we upscale empirically derived site-level resource–yield "metabolisms" to quantify potential contributions to vegetable provisioning, resource demand, and nutrient cycling. Across base scenarios, 12–24% of city area is suitable for UA, with individual/home gardens comprising the dominant share of expandable space in every case. Under average observed yields, scaled UA could supply 16–95% of current non-tropical vegetable demand (and substantially more under high-productivity assumptions), while requiring relatively modest shares of city electricity use but potentially meaningful shares of potable water in smaller cities. Expanded UA could also absorb more than 100% of current vegetable food-waste streams via composting, indicating strong circularity leverage. However, participation requirements emerge as a primary constraint: labor availability and willingness limits feasible realization of these theoretical maxima. Together, results provide a transferable, cross-city methodology and identify policy-relevant leverage points—especially enabling home gardening, securing land tenure, supporting new farmers or gardeners, and pairing expansion with composting and water-harvesting practices—to design context-sensitive UA scaling strategies.

Keywords

- Urban agriculture
- Scaling up
- Remote sensing
- Urban metabolism
- Food-energy-water

Highlights

- UA potential modeled across five diverse US and European case study cities.
- 12–24% of city area is suitable for scaling low-tech urban agriculture.
- Individual home gardens are a key resource for large-scale UA expansion.
- Labor availability, not land, is the primary limit to urban agriculture scaling.
- Scaled UA can absorb over 100% of urban vegetable food waste via composting.

1. Introduction

Growing food in cities through urban agriculture (UA) is rapidly expanding across the Global North (Cohen & Wijsman, 2014). This expansion is driven by both individual and institutional motivations. Participants report that they draw emotional and physical health benefits from UA (Kirby et al., 2021; Newell et al., 2022), while non-profits seek to promote community capacity-building, environmental education, and food security (Reynolds & Cohen, 2016). Although the benefits of farms and gardens on local communities and participants are well documented (Ilieva et al., 2022), the impact of scaling up UA on cities' food-energy-water (FEW) systems remains unclear (Caputo et al., 2020; Newell et al., 2019). Despite this, cities increasingly promote the practice as a strategy for shoring up food supplies in crisis (Lal, 2020; Slater & Birchall, 2022), envisioning more sustainable urban material flows (Goldstein et al., 2016), and greening the urban landscape (Limerick et al., 2023). This work explores the potential for urban agriculture to transform urban FEW metabolisms across contexts.

"Scaling up" assessments (i.e., analysis of the potential growth of UA) have largely focused on single cities (e.g., Goldstein et al., 2017; Newell et al., 2022), often limiting the scope of investigation to potential food supply impacts (Ackerman et al., 2014; Hara et al., 2018). The results of these studies vary widely, casting doubt on the generalizability of their assessments of UA's potential. Published studies estimate that production could range from about 7% of fresh vegetable demand (Hara et al., 2018; Sioen et al., 2017) to well over 100% (Grewal & Grewal, 2012; Saha & Eckelman, 2017).

A potential explanation is urban morphology (e.g., comparing Manhattan to post-industrial Cleveland), but different studies have reported widely differing results for similar cities (e.g., UA could potentially supply 31% of vegetable demand for Detroit vs. 100% for

Cleveland), suggesting that methodological differences are responsible for much of this variation. This variation can hamper the ability to draw generalizable conclusions about the effects of scaling up UA. Improving methodological consistency can illustrate trends across cities, such as the influence of urban morphology. Work has assessed the impact of an assortment of biophysical characteristics of cities on UA potential, including slope, sunlight availability, land cover, soil suitability, and building type in various combinations. This work extends this by applying the same method across five different cities.

While some work has attempted to apply the same basic scaling up methodology across two cities, these assessments have been limited, such as focusing only on public or vacant land in the urban fabric (Hara et al., 2018; Mendes et al., 2008). Scholars often focus on the differences between the cities, whether these be in their interpretation or legislation of UA or in their food-production outcomes. This limits our ability to identify generalizable policy implications which might support or guide multi-city planning efforts and pacts like the Plant-Based Treaty or the Milan Urban Food Policy Pact ("The Milan Pact," 2024; *The Plant Based Treaty*, 2024).

Methodological inconsistencies are compounded by limited data availability on yields and resource use in UA systems (Caputo et al., 2020), resulting in analyses constrained by simplifying assumptions like comparing UA yield to conventional agriculture systems (Uludere Aragon et al., 2019). For instance, the only multi-city assessment of the global potential for UA scaling up, productivity, and ecosystem services, relied on country-level yields and assumed material consumption data equivalent to conventional agriculture (Clinton et al., 2018). The material and social footprints of conventional and urban agriculture vary substantially (Dorr et al., 2023; Hawes et al., 2024), as do the material and social footprints of different forms of UA in different climes (Dorr et al., 2023; Mcdougall et al., 2020).

This variation across types and sites for UA is clouded in many existing analyses by a disproportionate focus on UA as a solution for vacant or underutilized land (Hara et al., 2018; Thapa et al., 2021), building on the long history of land reclamation by urban greening groups (Reynolds & Cohen, 2016). Such work has struggled to capture urban food-producing futures that embrace food growing at home, in common spaces, and at local businesses — well beyond the bounds of underutilized or vacant space. In contrast, work on UA in a commercial context has often focused on high-tech food production, ignoring low-tech farming, which is the most common (and socially productive) form of UA (Appolloni et al., 2021; Cameron et al., 2012). Recent work in NYC found that limiting UA to publicly-owned vacant lands severely restricted access by residents (Limerick et al., 2023).

This paper addresses these gaps, exploring the potential for scaling up low-tech UA in Europe and the United States using consistent data and methods in five diverse cities representative of a range of urban typologies (Dortmund, DE; Gorzów Wielkopolski, PL; London, UK; New York City, USA, and Paris, FR). To support this effort, we built the largest existing dataset of resource inputs and yields at urban farms, collective gardens, and individual gardens (c.f., Caputo et al., 2020 for discussion of dataset development). We couple this dataset with spatial analysis via urban metabolism modeling (i.e., tracking possible changes to material and social flows – c.f., Newell & Cousins, 2015) to explore the bounds of possible impacts from low-tech UA expansion. Specifically, we answer three questions:

- To what extent can UA expand, and what key land use or biophysical factors might limit this across contexts? (Section 3.1)
- What is the scope of expanded UA's possible effects on cities' water and energy demand, food provisioning, and nutrient cycling (i.e., urban metabolism)? (Section 3.2)

- What level of participation (i.e., labor or volunteerism) is required to support large-scale UA expansion, and how could this limit the overall impacts of UA? (Section 3.3)

To answer these questions, we model UA from an urban metabolism perspective. In a metabolism framing, we treat UA as a multi-functional land use, delineating the impacts on different sectors (e.g., food, water, economy) as additional square meters of UA are added to our case cities. While we draw on spatial multi-criteria analysis - a common form of scaling up modeling - to explore different suitability scenarios, we advance these models by harmonizing heterogeneous data landscapes across the US and Europe. This enables us to understand how different criteria (i.e., urban characteristics) influence scaling up in our case study cities.

Our results reveal that, even in large, dense cities, low-tech UA can fundamentally transform food provisioning, water demand, and waste management. Home gardens are the most important untapped UA resource in all five cities, indicating that homeowners and families may be understudied constituents for UA scaling policies. But catalyzing them will require a preciputous increase in participation rates, particularly in the smaller case study cities. In larger cities, though, large-scale UA expansion could occur with as few as 2-6% of the population cultivating food at home or collectively. In a hypothetical future where a large number of farms and gardens do sprout up, we project that there will be important changes in food availability, food waste recycling, and access to active green space in our case cities.

This paper addresses key limitations in the UA literature, including addressing the complexity of cross-city analysis, the dynamics of land use and garden management, the biophysical considerations impacting garden siting, the material metabolism impacts beyond food, and the participation rates required to enable meaningful impacts on cityscapes and material flows. We use this analysis to identify opportunities for scaling UA across contexts as well as the knowledge limitations that should be addressed to empower planners, innovators, and decision-makers to more effectively stimulate garden growth.

2. Methods

We examined the future role of UA in five temperate cities from the FEW-meter project: Dortmund, Gorzów Wielkopolski (herein “Gorzow”), London, New York City, and Paris, chosen for their diverse urban typologies and UA histories (Section 2.1). FEW-meter researchers and citizen scientists used social and material surveys, as well as daily logs, to gather data on UA inputs, outputs, and participant benefits, synthesizing this to document the material and social metabolism of urban farms, collective gardens, and individual gardens, supplemented by secondary literature data (Section 2.2). A spatial multi-criteria analysis overlaid land use, land cover, slope, and sunlight availability layers, harmonizing land use classifications across cities and using a random forest model to fill Dortmund's land cover gap. Slope and sunlight data focused on suitable areas for gardens (Section 2.3). Scenarios tested UA expansion limitations, including exploring how pollution at industrial sites, rooftop structural integrity, tree cover, and strategic land repurposing might impact land availability. In post-hoc analysis, we summarized gardens by parcel, filtered areas below size thresholds, and analyzed proximity to residences and metabolism impacts using QGIS and R (Section 2.4). Limitations include the focus on temperate cities and consistent UA forms, suggesting further work considering diverse climates and socio-demographic factors (Section 2.5).

2.1. Case study cities: selection, history, and current metabolism

We explore the future role of UA in determining urban metabolisms across five diverse case study cities. These cities were selected as part of the FEW-meter project (Caputo et al., 2020), an interdisciplinary, international assessment of the impacts of UA on individuals, cities, and the environment. To do this, the team selected a series of temperate cities across Europe and North America, aiming to leverage established connections between the research team and urban farmers and gardeners in these cities to recruit a broad cross-section of UA sites. The cities used in this study (Appendix Table 1) are a subset of the host cities for the FEW-meter farms and gardens. This subset was selected because the cities: 1. Are well-known for UA policy and practice (London, Paris, NYC); 2. Represent a useful cross-section of population, density, and built environment (skewed towards larger cities); 3. Offer relatively rich data environments for a consistent analysis (e.g., Nantes was removed because of data restrictions); and 4. Shared similar climate characteristics. This work defines UA broadly as growing food within the administrative bounds of a city. Consistent with this definition, we select the planning boundary of each city for analysis (either the city planning jurisdiction or regional planning jurisdiction).

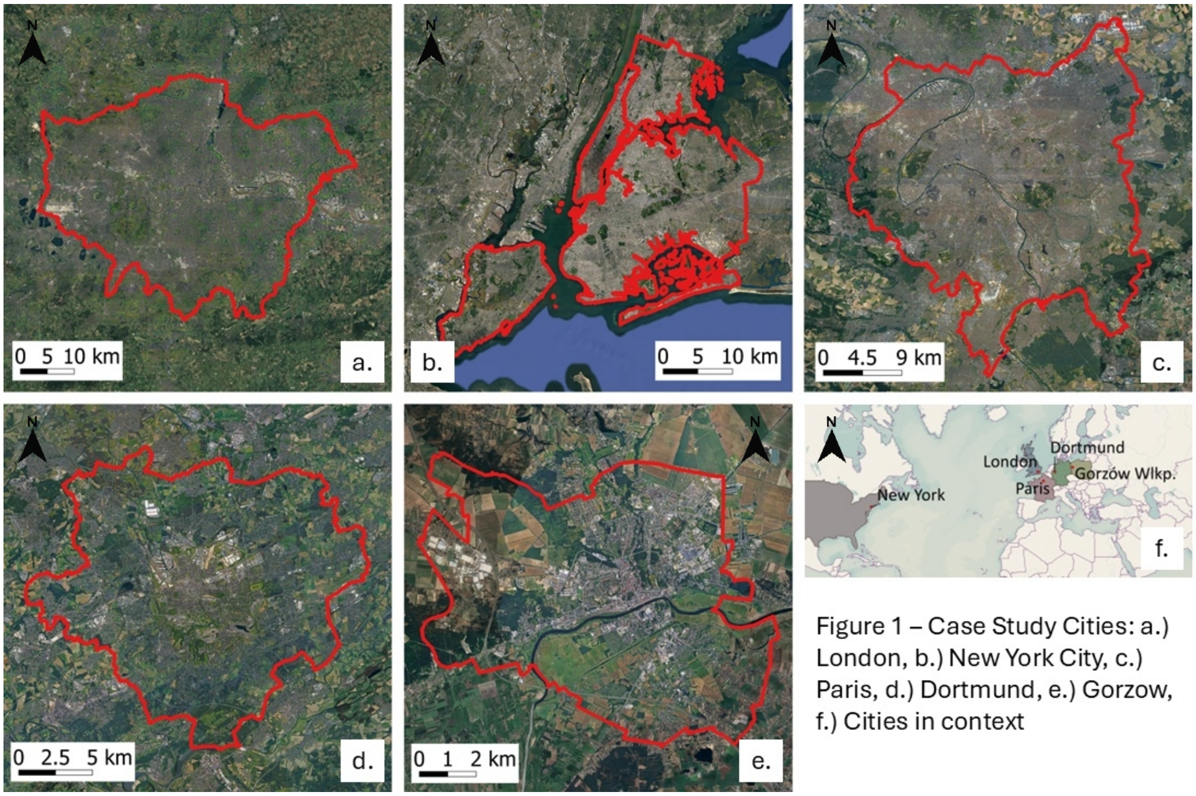

Figure 1 – Case Study Cities: a.) London, b.) New York City, c.) Paris, d.) Dortmund, e.) Gorzow, f.) Cities in context

2.2. Site-level metabolism model of urban agriculture

For this work, we employed citizen science to gather data on the inputs and outputs associated with urban farming and gardening spaces across varied built and social contexts (Caputo et al., 2020). We documented the material footprint of gardens, including the food produced and resources consumed (Dorr et al., 2023) as well as the carbon footprints associated with these resources (Hawes et al., 2024). We also explored participant motivations and perceived benefits, providing a basis for understanding the local impacts of UA on individuals and communities (Kirby et al., 2021).

These analyses have been synthesized to produce a material and social metabolism of UA spaces, documenting the impacts on cities across three common types of UA (Appendix Table 2). Specifically, the synthesis characterized: 1. Urban farms, sites focused on foodproduction that often sell to local markets; 2. Collective gardens, jointly managed plots often centered on social benefits and community investment; and 3. Individual gardens, small plots managed by an individual or family to provide food for the household and serve as a leisure activity. Individual gardens may be in a private yard or in a larger allotment complex. Urban farms may occur on commercial properties or on rooftops across the city. We assume based on our experience in the field that rooftop UA is commercial (i.e., urban farms) due to access constraints that might limit volunteer participation and community engagement on many rooftops. Since every city had a different assortment of UA types (e.g., only community gardens in NYC, a mix of allotments, gardens, and farms in Gorzow), we do not use UA data specific to each city but rather synthesize the average by type. In other words, we use an average value for individual gardens, collective gardens, and urban farms for every city. This analysis is supplemented with secondary data from literature, specifically for the number of volunteers or employees associated with each type of site (CoDyre et al., 2015; Mcdougall et al., 2020).

2.3. Spatial Multi-Criteria Analysis

As highlighted by Ridder (2017), systematic cross-case analysis can reveal key similarities and differences in UA futures. The first step in developing plausible scenarios for the expansion of UA is therefore to simplify the complex social and biophysical landscape of a city into consistent components. In spatial multi-criteria analysis, layers representing suitability criteria are systematically combined, producing a final layer that indicates spaces suitable for the growth of UA. We integrated four such layers into our models: land use, land cover, slope, and sunlight availability. All layers were rasterized and resampled to 1m resolution and reprojected to locally relevant coordinate systems defined in meters. All spatial analysis is conducted in the OSGEO environment using QGIS graphic interface and select tools from GRASS GIS.

2.3.1. Land Use

Land use refers to an urban space's primary purpose as defined by its service to society (e.g., residential spaces, commercial, industrial). Land use, in our analysis, is used to identify both the feasibility of UA and the type of farm or garden that might be most suitable to inhabit a space (Appendix Table 3). This constitutes a major simplifying assumption in our analysis; for example, commercial properties were assumed to host urban farms, while public properties and multi-unit housing were assumed to host collective gardens. These farm and garden types (urban farm, collective garden, individual garden) are consistent with the metabolism model derived from FEW-meter project data, enabling us to model metabolism changes at the city scale.

As part of the modern planning apparatus, most cities systematically catalog land use and make it available to the public. Because cities' classification schemes and thematic resolutions vary by cultural and institutional context, these data were collected and synthesized to produce a harmonized land use classification scheme across cities (Appendix A). For example, New York's Primary Land Use Tax Lot Output (PLUTO) catalogs eleven land use categories, including various forms of residential plots, industrial and commercial sites, and public buildings (Department of City Planning, 2024a, 2024b). In London, land use has historically been cataloged by Geomni as part of the UKMap program (though as of writing, this dataset has been archived pending a transition to new data products incorporating additional building-level data - Seppe Cassettari, 2022). UKMap employs a modified form of the UK's National Land Use Specification version 4.4, which provides higher thematic resolution data for most public, commercial, and industrial sites, but lacks the distinction between types of residential properties offered by PLUTO.

Such thematic mismatch across cities led to the creation of the FEW-meter land use code (Appendix Table 3, with city-specific equivalencies also recorded in Appendix), derived for each city from a combination of spatial data layers. Detailed derivation of land use specifications is available in Appendix, as part of a broader explanation of land use, land cover, slope, and sunlight derivation for each city. For example, in NYC, land use classifications at the parcel level are reprojected, rasterized at 1m resolution, and reclassified per the scheme in Appendix.

2.3.2. Land Cover

Land cover classification seeks to distinguish between different built or natural features occupying physical space. Like land use, a series of publicly available layers are used to derive land cover classification. In most cities, these data are made available at high thematic resolution, often including ecological characteristics of land cover or distinguishing, for example, bare land from concrete. For the purposes of our analysis, land cover is simplified to distinguish between buildings, other artificial structures (e.g., monuments), impervious and pervious ground, and trees (Appendix Table 4).

Land cover layers underwent the same pre-processing as land use, including rescaling to 1m resolution and reprojection to a suitable coordinate system - a process that is described in detail in Appendix A. Dortmund is the only city in our study without publicly available land cover data. However, Germany has published aerial ortho-imagery and other high resolution remote sensing data, which we used to train a random forest model to classify land cover, creating an original dataset. Model training is described in detail in the Appendix.

2.3.3. Slope

Recent assessments of urban agriculture report that, while it is possible to build raised beds into a slope, most ground-based gardens appear in areas with less than a 15% slope (Saha & Eckelman, 2017) and rooftop gardens should be situated on less than 5% slope for safety (Berlioz et al., 2020; Saha & Eckelman, 2017). Using digital elevation models and digital surface models of each city, we derive the ground slope and roof slope for each location (Appendix).

2.3.4. Sunlight availability

Finally, while high-tech farms often rely on artificial light to support plant growth, our work specifically assesses relatively low-input, low-tech UA spaces, meaning that sufficient sunlight must be available naturally. Again, using the digital surface models available in each city, we calculate the average hours of sunlight available across the growing season. Due to computational constraints, this is not assessed as a constant measure of sunlight availability, but rather as an integrated average between three months in the growing season - early season (April), peak sunlight (June), and late season (October). Sunlight maps for each of these points were derived via the r.sun package in GRASS GIS (Appendix). We assess shading from buildings, trees, and variation in ground height. Shading assessment *below* trees is not possible using the methods described, but this is explored in the land cover sensitivity assessment described above. We focus only on the minimum sunlight required for crop growth, deriving a binary suitability indicator for spaces receiving at least partial sun (defined as 4 hours on average through the growing season).

2.3.5. Scenario assessment

These midpoint layers (Land use, Land cover, Slope, and Sunlight) are then used to define the bounds of the sensitivity scenarios explored in this article (Appendix Table 5). Scenario maps are produced from the midpoint layers via spatial multi-criteria analysis, operationalized as spatial overlay via raster algebra. In the base scenario, we explore the limitations of UA scaling under typical assumptions as derived from the literature. We develop sensitivity scenarios which test the impact of ignoring slope, ignoring sunlight, or treating trees as completely obstructing garden space. In all scenarios, rooftop UA is restricted to buildings less than 30 m high (ten stories) due to concerns over safety and wind speed (Berger, 2013; Saha & Eckelman, 2017).

2.4. Post-hoc analysis

Gardens are summarized at the parcel level where parcel data are available. In Dortmund and London, alternative polygons similar to parcels are used. In all cases, we assumed that individual gardens must be larger than 10 m^2 to be considered, while collective gardens and urban farms must be larger than 100 m^2. Although there are exceptions to these thresholds in real UA, these rules of thumb help to avoid overestimation in what is otherwise a top-down UA exploration (c.f., Goldstein et al., 2017 for more discussion). Using zonal statistics, we summarize the total area per polygon and use the field calculator to generate a new attribute which filters out areas less than the prescribed threshold.

Using this filtered layer, the total space available for UA is summarized in R, according to the R Markdown file available in Appendix A. Garden physical distance to residential units was calculated in QGIS using proximity analysis tools. Final summarization of proximity was conducted in R. Metabolism analysis of material flows was also conducted according to the R Markdown file available in Appendix A. Matrix algebra was used to calculate the scale of metabolism impacts on the city, including comparisons to existing material flows.

2.5. Limitations

Several features of the methodology limit the generalizability of applications of the findings. First, the case study cities selected for this work were in temperate, northern climates, building on the availability of primary metabolism data from those and similar cities. Further work should expand this analysis to cities in semi-arid and arid areas (e.g., Uludere Aragon et al., 2019) as well as warmer and Mediterranean climates (Pueyo-Ros et al., 2024; Pulighe & Lupia, 2016). The typology of urban farms and gardens proposed in this work is also not relevant to all settings (c.f., discussion of the conceptualization of UA in Osaka, Japan - Hara et al., 2018), and the consistency of forms across the case study cities was one of the most important commonalities that made the FEW-meter project possible. On the other hand, the sample of different types of UA was not consistent across cities, and inter-city variation within the typology is beyond the scope of our data. Future work could explore a broader sample of these forms of UA in particular climates, which should enable more detailed analysis of future impacts of scaling up for particular locations. Finally, this work does not explore willingness to transform large swaths of land in cities to food production – instead, we treat this as a maximum possible expansion exercise, which assumes both willingness and financial support for UA development (c.f., Fox-Kämper et al., 2023 for discussion of UA in the policy landscape).

3. Results

Our results reveal that urban agriculture (UA) has significant but variable potential for scaling across Global North cities. Individual gardens represent the largest share of available space in most cities, particularly in London (78%), though this varies based on urban form and land use patterns. Ground slope is rarely a limiting factor, but sunlight availability and tree cover can meaningfully constrain suitable growing space.

Industrial contamination poses a greater challenge in smaller, post-industrial cities like Dortmund and Gorzow than in larger metropolises. Rooftop agriculture remains a modest share of potential space in most cities, with NYC being a partial exception due to its abundance of flat roofs.

In terms of food production potential, smaller cities like Dortmund and Gorzow could theoretically supply nearly all their vegetable needs, while London, Paris, and NYC could meet between one-sixth and two-thirds of demand under highly productive scenarios. Energy demands from UA would remain negligible, but water requirements could be substantial in smaller cities.

Labor availability emerges as a critical constraint. At average work rates, several cities lack sufficient volunteers to manage all available space. Nevertheless, aggressive scaling could bring 95–99% of residents within a 15-minute walk of a UA site, broadening access to its social and health benefits.

3.1. Opportunities for and limits to scaling up

While cities' unique physical and cultural environments have often been cited as limiting factors in developing generalizable principles for expanding urban food-growing, our results indicate that some features of UA scaling up are consistent across our case cities. For example, individual gardens hold the most promise for large-scale expansion of UA across all Global North cities we studied (Table 1).

Table 1 – Summary of available space for UA across case study cities in base scenario

						Percent of total UA area…			
City	**Total area of city (km^2)**	**City area suitable for UA (km^2)**	**Ground area suitable (km^2)**	**Roof area suitable (km^2)**	**Percent of city suitable for UA**	**On roofs**	**Individual gardens**	**Collective gardens**	**Urban farms**
London	1575	389	376	13.4	24%	3%	78%	9%	12%
NYC	789	121	106	14.7	15%	12%	66%	24%	8%
Paris	815	159	149	10.1	19%	6%	60%	30%	9%
Dortmund	280	55	51	3.9	19%	7%	58%	9%	31%
Gorzow	85	10	9	0.97	12%	9%	42%	24%	32%

The city with the lowest proportion of individual gardens is Gorzow, a relatively small, open city with large swaths of unbuilt land held in common or on industrial sites within city limits. On the other end of the spectrum, almost 80% of London's available space is attributed to individual gardens. While this is consistent with the character of London's largely residential outer boroughs, the degree of difference between London and the other large cities is likely exaggerated by limitations in land use data, which did not differentiate between multi-family and single-family housing in the UK's capital.

Sensitivity analysis reveals that ground slope is unlikely to be a key limiting factor in the scaling up of UA across most cities. Acceptable area for UA on the ground expands by between 8 and 18% when slope is ignored (Appendix Table 6), indicating that, after many centuries of building, most urban spaces that might be considered for farms or gardens are relatively level. This is, of course, likely to vary more in particularly hilly cities or those built in sharp river valleys (e.g., Pittsburgh, USA). Ignoring sunlight availability produces more dramatic results, with a ground-based UA expansion of between 15 and 29% (Appendix Table 7). This indicates that certain low-light crops (e.g., mint, baby lettuce, certain carrots) have a much wider range in our case study cities. This indicates that artificial lighting (while energy intensive – c.f., Goldstein et al., 2017) could also expand outdoor UA area substantially, even ignoring the potential for controlled-environment agriculture indoors, which we do not explore here.

We also find that obstruction from trees could restrict suitable UA spaces in some cities by almost 35% even with only existing trees (Appendix Table 8). This highlights the importance of coordination of urban greening strategies across city divisions, where urban trees may be planned by parks or transportation departments, while urban farming and gardening is increasingly handed over to offices of UA and food policy councils. In our base scenario, we assume that trees do not obstruct gardens, since existing evidence from NYC has indicated that many community gardens coexist with substantial tree cover (Limerick et al., 2023). However, denser tree cover or alternative species composition could shift this pattern.

3.1.1. Cities vary in the importance of industrial and rooftop sites

Although this work assumes that many gardens will use raised beds to avoid potentially contaminated soil, there are some parts of cities that are simply unsuitable for growing food or even public use in general (e.g., brownfields, some industrial sites). If we assume that some proportion of the identified industrial sites would fall into this category, we can begin to explore what level of barrier contaminated sites might pose for UA scaling in different cities (Table 2). Industrial contamination proves to be a central concern in Dortmund and Gorzow, both small to medium sized cities with strong industrial legacies. Of course, the relatively low percent of potential UA space currently listed as industrial in NYC, Paris, and London is not evidence that soils are essentially safe in other parts of cities. For any large-scale UA expansion, broadly available soil testing will still be very important because of non-point sources of contamination, including internal combustion engines and runoff.

Table 2 – Evaluating the importance of industrial sites for scaling up UA*

City	**Total area of potential UA on industrial sites (km^2)**	**% total UA area on industrial sites**	**% ground UA area on industrial sites**	**% roof UA area on industrial sites**
London	13.5	3%	3%	4%
NYC	6.2	4%	2%	21%
Paris	11.5	6%	5%	22%
Dortmund	17.6	31%	28%	70%
Gorzow	2.8	25%	24%	39%

*Default scenarios assume that industrial space can be used through raised beds or remediation. This sensitivity analysis is intended to explore the impacts of policies or plans that exclude industrial spaces due to higher risk of contamination. These policies are intended to protect public health, an important part of UA framing. Therefore, it is important to note that this sensitivity analysis does not question the importance of such policies but rather makes explicit the tradeoffs implicit in them regarding space availability.

The loss of industrial sites had a larger impact on rooftop agriculture than ground-based UA, likely due to the modern growth of warehouse-style industrial facilities with large, flat roofs. Of course, we do not have to worry about contamination of existing soil on rooftops. Instead, this hypothetical connects us to another important question of suitability - the structural integrity of buildings for rooftop UA. Many modern industrial buildings (e.g., large, skeletal warehouses) are not built to support meaningful weight on the roof, although in northern climates, preparation for snow load might render more of these buildings usable (e.g., NYC). In most of our case study cities, rooftop agriculture comprises less than 10% of available space - though in NYC, the prevalence of flat roofs in private residences and commercial buildings pushes it to 12% of available space. Some percentage of this space will be structurally unsuitable for rooftop agriculture, though this is impossible to determine with remote sensing alone (Goldstein et al., 2017). Appendix Table 9 explores the space availability and metabolism implications of rooftop structural suitability.

3.1.2. The role of parks and parking lots in UA scaling up

Base scenarios in this assessment focused on space without a clear alternative use. Other literature has proposed reserving some portion of public green space for food-growing (Clark & Nicholas, 2013) or reclaiming urban outdoor parking lots as city transport patterns shift away from owner-operated cars (Cervero & Sullivan, 2011; Limerick et al., 2023). Our modeling reveals that the role of parks and parking in future scaling up is particularly variable across cities (Figure 1). For example, NYC could increase potential UA space by 50% through conversion of parks (~3/4 of gained space) and parking (~1/4), but Gorzow is unlikely to expand its total area available by more than about 13%. Similar analyses for Dortmund were prevented by a lack of suitable publicly available parcel maps.

Ecosystem functions and social services vary considerably by type of urban green space (Czembrowski & Kronenberg, 2016; Graça et al., 2018; Grafius et al., 2018), and parking lots are necessary for accessible mobility, so even in this aggressive exploration of UA expansion, we do not explore the metabolism impacts of complete park and parking transformation to urban farms and gardens. Instead, we consider the impacts of shifting about half of the identified park and parking space to UA. This has the most significant effect in NYC, where widespread parks and parking areas could add as much as 8,700 hectares as compared to the base scenarios alone. Results are less substantial in London and Paris, where the parks and parking lots identified could add about 30% of the previous total.

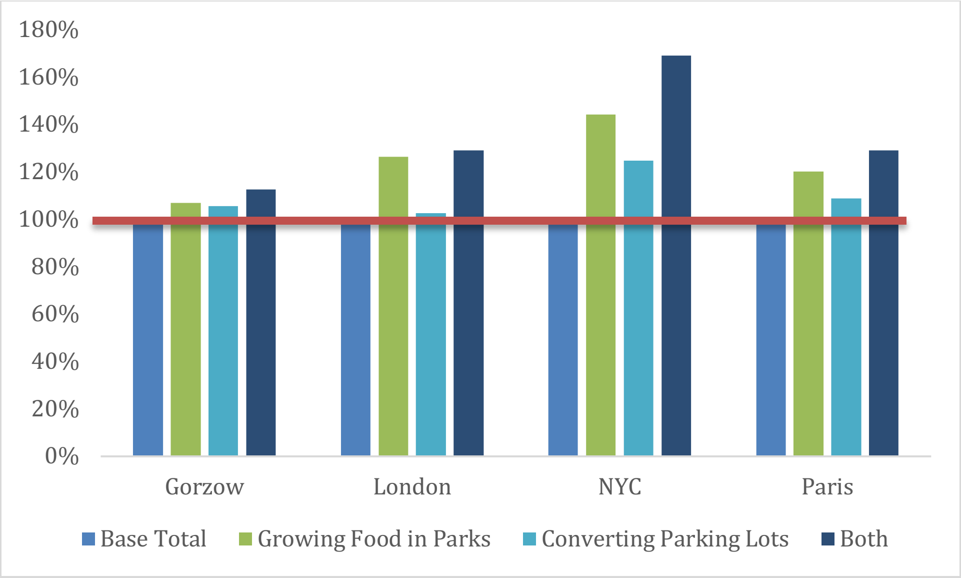

Figure 2 –Space available if parks and parking lots are used as UA sites, as compared to base case

3.2. Metabolism impacts of scaled-up UA

Although the metabolism results vary by city more than space availability, some generalizable conclusions still emerge. For example, while water and food supply impacts may be substantial if cities invest heavily in scaling up urban food production, total UA energy demand and GDP contribution are likely to remain meagre when investment is focused on low-tech food production of the kind studied here (Table 3). A large-scale investment in UA also opens unique opportunities across cities for large-scale food waste recycling - even in NYC, more than two times the current vegetable waste of urbanites could be recycled back into feasible UA sites. UA can also absorb all rainfall on-site in each city studied, reducing water demand by between 5 and 20%.

Table 3 - Metabolism implications of large-scale expansion of UA

City	**Total area of city (km^2)**	**City area suitable for UA (km^2)**	**Percent of vegetable supply from UA**	**Percent of vegetable supply from UA (highly productive)**	**Percent of potable water supply needed for UA**	**Percent of electricity use needed for UA**	**Percent of vegetable waste which could be absorbed as compost**	**Percent of GDP produced at UA sites**

London	1575	389	59%	204%	2.8%	0.3%	507%	0.1%
NYC	789	121	16%	52%	0.4%	0.02%	224%	0.03%
Paris	815	159	23%	69%	2.6%	0.1%	292%	0.1%
Dortmund	280	55	90%	311%	13.5%	0.3%	572%	0.6%
Gorzow	85	10	95%	304%	14.2%	0.4%	932%	1.8%

Food production on UA sites varies by practice, by crop choice, and by gardener expertise (Dorr et al., 2023). Assuming yields typical of the sites we studied, Dortmund and Gorzow could supply nearly all their own non-tropical vegetables (e.g., carrots, lettuce, etc.). If all UA sites in the case study cities were highly productive (as measured by the most productive sites of each type), it would be possible for Dortmund, Gorzow, and London to produce more vegetables than currently consumed by citizens, while NYC and Paris could produce between one-half and two-thirds of their current vegetable demand. Because of seasonal variation in yield, production on this scale would require historically unnecessary approaches to harvest scheduling, storage, and marketing of urban crops. This would also require more elaborate and accessible methods of provisioning urban food, including potential integration into conventional food marketing systems, institutional acquisition, and expanded sharing programs (Bloom & Hinrichs, 2011; Mittal et al., 2018; Schreiber et al., 2023)

Perhaps the most dramatic metabolism impact documented is the opportunity to recycle more than 100% of the vegetable waste generated in each city with urban food growing. Not only does this reduce nutrient loss to landfills, but this transition to organic nutrient feedstocks could also result in a net reduction of synthetic nutrient input of thousands of tons across the five cities (Appendix Table 9). The dependence of UA on organic sources of nutrients may help cities do their part in addressing a pressing planetary boundary, synthetic nutrient mineral depletion and environmental pollution (Steffen et al., 2015). Of course, this potential must be balanced with careful best practice adoption; compost application rates and leaching potential vary widely across soils and soil histories (Metson et al., 2025).

3.3. Participation in scaled-up UA

These impacts on the city rely not only on land availability and material inputs for expanded UA sites, but also extensive volunteer and employee hours dedicated to food growing. Existing estimates of time spent per square meter of garden or farm per growing season vary dramatically - from 0.16 hours per square meter for a fast-working gardener in Guelph, Canada (CoDyre et al., 2015) all the way up to 22 hours per square meter at the least efficient site studied in Sydney, Australia (Mcdougall et al., 2020). Efficiency varies by person and site – depending on payment structure and experience, among other things (Dorr et al., 2023; McDougall et al., 2019). So if, on average, the number of hours spent per m^2 of garden falls in between these extremes, to what degree would labor willingness and availability limit this massive expansion of UA?

To test this, we assume that volunteer labor (4 hours per volunteer) is required for scaling up individual and community gardens, while full-time paid labor can support urban farms. This is a simplifying assumption, since many community gardens have one or two paid staff, and allotment complexes often have paid managers, while urban farms may have volunteer days or a collection of regular volunteers. Our results indicate that if farmers and gardeners are extremely efficient (~0.16 hours per square meter), managing all scaled up UA space would require between 2% (NYC) and 17% (Gorzow) of the population of our case study cities. If farmers and gardeners took 22 hours per square meter of new UA space, none of our cities would have enough participants to manage the farms and gardens. Averages reported across multi-site case studies often fall between 3 and 6 hours per m^2 of farm or garden. In this case, it is unlikely that

Dortmund, Gorzow, or London could fully take advantage of their available space, since they simply would not have enough volunteers or potential employees. Paris and NYC, meanwhile, may have enough people to care for the proposed UA spaces at those work-rates, but participation rates would have to grow precipitously, approaching 50, 75 or even 100%.

Estimation of willingness to participate in urban agriculture needs more research, as well as the feasibility of substantial portions of the population participating in gardening or farming. However, one predictor of willingness to participate is often ease of access, and under the aggressive scaling scenarios explored here, 99% of residential properties lie within a 15-minute walk of a garden or farm in Gorzow, NYC, and Paris (Appendix Table 10). In London, about 95% of residences are within walking distance of a new UA site. Limitations in the high-resolution land use data in Dortmund prevented its inclusion in this analysis. As evidence continues to mount for the social and health benefits of UA (Ilieva et al., 2022), expanding access within walking distance of home is an important indicator of expanding access to the health and wellness services offered by UA (Limerick et al., 2023). Our results indicate that near-universal access is possible, even without the level of expansion we model, with strategic siting on land we document as available (c.f. ibid for further discussion of planning for walking access to gardens).

Of course, the benefits associated with full-time employment at a garden are different than those associated with volunteer gardening (Kirby et al., 2021). If we separate out employees at urban farms from volunteers, we again see differentiation between small/medium and large cities (Appendix Table 11) as reported in analysis of industrial sites. In Gorzow and Dortmund, about half as many employees are required as gardeners (for at least the growing season), and even with a conservative estimate of 0.16 hrs spent per m^2, about 5% of the population work full time on urban farms – a clearly impractical number, even if the seasonal nature of the work may make this marginally more plausible. On the other hand, if we assume that employed farmers in our larger case study cities are highly efficient, the full extent of possible urban farms would employ less than one-tenth of 1% of the population of London, Paris, and NYC. If we assume less efficient employees, employment estimates far exceed the available workforce in Gorzow, Dortmund, and London. Yet, in NYC the number of jobs created if we assume relatively inefficient labor (~210,000) nearly matches the current (December 2025) number of jobseekers in the city (New York State Dept of Labor, 2024). This is, of course, a theoretical maximum that would both require high willingness to participate and extensive job training support. This in no way suggests that a large portion of unemployed New Yorkers could (should) become farmers – given this, and the limits on volunteer availability, we argue that labor may ultimately be the most important limitation to scaling up UA.

4. Discussion

Our results indicate that scaled up UA could have profound impacts on the material and social metabolism of cities in the Global North . While it remains unlikely that UA would feed the city, particularly in an era of unprecedented year-round dietary diversity, exploring the bounds of UA impacts offers insights into dynamics of scaling that can inform policy design. UA remains widely popular, and adoption rates are high in areas where additional space is being made available, while waitlists are long in places where space is restricted (Edmondson, 2024). Work continues to document the expansive benefits of UA for participants, including healthier diets (Gulyas & Edmondson, 2024), emotional and physical health benefits (Ilieva et al., 2022), and local sustainability enhancements (Pueyo-Ros et al., 2024). In this work, we have complemented those case studies by identifying overarching trends for scaling up UA across Global North cities, including three key trends which we explore further here.

4.1. Home gardens - an underexplored UA opportunity

Our analysis confirms the work of others who have indicated that the long-term food production potential of many Global North cities is intimately linked to the propagation of gardens on private, single-family residential property (Gulyas & Edmondson, 2024; Mcdougall et al., 2020). Despite this, little work has been done on policy mechanisms for scaling up home gardening (Edmondson et al., 2020). Among the most promising findings from the limited research that has been done in the US, Hunter and Brown found that spatial contagion plays an important role in determining the spread of home gardens (2012). This indicates that, at least for frontyard gardens, cities may be able to target early adopter groups and trigger domino-like spread of gardens in neighborhoods.

Other work has shown, though, that backyards tend to be less similar than frontyards (Larsen & Harlan, 2006), meaning that adoption of backyard gardens is likely to require additional incentivization or attitude change. In the Global North, widespread home garden adoption has tended to follow in the wake of crises, from the famous Victory Gardens of WWII to more recent pandemic gardens during the peak of the COVID-19 pandemic (Lal, 2020; Schoen et al., 2021). Although not as prevalent, similar tendencies for home gardening to follow involvement in local food movements or pro-environmental organizations may indicate that perceived food or climate system crises motivate some current home gardeners (Schupp & Sharp, 2012). And perhaps most well-known, gardening in both the Global North and South has long been associated with responses to economic hardship (Schupp & Sharp, 2012; Taylor & Lovell, 2014).

In general, gardens on residential property may partially address one of the most vexing challenges to UA management: land tenure (Newell et al., 2022). Assuming, of course, that housing is relatively stable (acknowledging challenges of gentrification and densification, among others – c.f., Hawes et al., 2022), development pressures and city plans are less likely to disrupt private gardens than those on vacant land. The challenge for policymakers, then, is to identify strategies for incentivizing or promoting urban home gardens that do not rely only on perceived crises, instead encouraging more lasting gardening practices that could make long-term interventions in urban food systems.

For example, France's zero net artificialization efforts is testing the balance of increasing density while retaining important green infrastructure (Delaville & Nolorgues, 2020). Into this context, UA can offer highly productive, active green spaces that can enhance services for a denser population within a similar green footprint (Li et al., 2024). Recent work has shown that current gardeners profess a variety of motivations for their work, including environmental sustainability, mental and physical health, and time spent outdoors, among others (Kirby et al., 2021). Programs that engage with a wider array of these motivations can tap into the substantial potential of gardens on individual residential properties (Fox-Kämper et al., 2023). Alternatively, small-scale exploration of shared management of gardens at private residences has demonstrated the feasibility of professionally managed garden space at homes (Newman, 2008). Less is known, though, about the impact of hired garden spaces on homeowners' behaviors, including their relationships to local food systems, their investment in garden continuation, or their participation in FEW system circularity efforts, all of which are crucial to sustainability in gardening (Hawes et al., 2024).

Despite this potential, the prominence of home gardens in our modeling does not change the importance of securing long-term land tenure for community gardens, allotment gardens, and other social gardening spaces. Private gardens cannot replace many of the community-building opportunities and other unique benefits offered by these spaces (Kirby et al., 2021). Furthermore, home-ownership in most of the Global North is racially and socio-economically stratified. This means that policies focusing *exclusively* on home owners or even renters in single-family homes are likely to exclude populations who most benefit from gardening through cultural food provision or food security enhancement.

4.2. Recruiting and training of new gardeners essential for planning

The individual and community impacts of UA are most marked when community members develop, maintain, and steward the farms and gardens (Hawes et al., 2022; Reynolds & Cohen, 2016). This means that planning, design, and implementation will likely continue to be decentralized, with the role of municipalities to facilitate UA expansion via incentive programs, land tenure rules, and educational efforts (Fox-Kämper et al., 2023; Lovell, 2010). Building on past work, which highlighted the massive labor requirements of scaled-up UA (Mcdougall et al., 2020), we find that one of the biggest hurdles for extensive expansion of UA is likely to be recruiting farmers and gardeners, both paid and volunteer. In other words, our results suggest that it is perhaps not space, but labor, that will limit adoption of UA at scale in cities. Recruitments efforts will have to be varied (Kirby et al., 2021) and targeted (Tiraieyari et al., 2019) with diverse engagements of motivations and participant identities.

The most successful recruitment will also likely include some level of education related to environmental stewardship, food system planning, and local food, building on the strong emotional attachment felt by current gardeners to their gardens and local food movements more broadly (Petrovic et al., 2019). These training efforts recruiting may prove central to the overall performance of UA in cities. For example, recent work on the carbon footprint of UA has shown that farm and garden design must account for climate impact up-front and throughout the life cycle of the sites (Hawes et al., 2024). While this requires city-level efforts to make long-lasting sites and reused materials available to new farmers and gardeners, it also will rely on educational efforts highlighting the importance of these best practices and behavior changes.

Gardeners are also, on average, less carnivorous than non-gardeners and more likely to seek out organic, local produce (Gulyas & Edmondson, 2024) - but it is unclear whether food system-minded folks seek out gardens, or if gardens create food system-minded citizens. In any case, a shift towards vegetable-heavy diets is not only critical for healthier city-dwellers (Edmondson, 2024), it is critical for climate-friendly food systems (Poore & Nemecek, 2018). The relatively limited evidence is mixed, with UA sometimes showing strong educational effects (Mitchell et al., 2019) and other times a mixed effect (Petrovic et al., 2019). Further exploration of the impacts of gardens and gardener training on behavior could prove vital for understanding the systemic effects of UA scaling cities and ecosystems, especially around climate change.

Likewise, the level of self-sufficiency achieved in the three large cities we studied depends largely on farmers' and gardeners' abilities to outperform yields achieved at many current UA sites. Recent work by Dorr et al. (2023) found that the most consistent predictor of enhanced yields was either the grower's experience or formal training. With this in mind, we argue that cities can take advantage of the required recruiting efforts to train new growers, which can both reduce the carbon footprint of new UA sites and enhance their productivity.

4.3. Expanded UA could foster food and water circularity in cities

Finally, we provide quantitative evidence for the potential role of scaled-up UA in creating more circular cities. Circularity has often been cited as one of the most important possible benefits from a turn to UA (Goldstein et al., 2016), but existing evidence suggests that uptake of circularity remains mixed (Dorr et al., 2023). For example, composting is popular in nearly every study done on current gardeners (Dorr et al., 2023; Gulyas & Edmondson, 2024), but rainwater harvesting and use remains uncommon. Our modeling efforts highlight circularity as one of the most consistent opportunities for sustainability and resilience enhancements because of scaling up, and other recent work highlights the role of garden access in promoting circular economy behaviors (Di Fiore et al., 2024).

In an ideal world, expanded UA use of compost could absorb far more food waste than the current vegetable scrap production in our case study cities. This upscaling faces numerous challenges, including adequate supply of green waste to accompany food waste, best practice for compost production and distribution, and judicious application to reduce runoff (Keng et al., 2020; Martínez-Blanco et al., 2010; Metson & Bennett, 2015; Vandecasteele et al., 2016). UA can also absorb all rainfall on-site in each city studied, reducing water demand by between 5 and 20%. Where possible, rainwater capture on neighboring sites could provide additional water and reduce overall water demand even further. This is particularly relevant to home gardens, where organic and liquid waste could be re-used right on site. From a policy perspective, this implies that resource-efficient UA must be planned for, and policies which encourage material reuse, composting, and rainwater harvesting (e.g., REUT in France - Mendret, 2022) should accompany land use and grant programs designed to expand UA (Fox-Kämper et al., 2023; Wissmann et al., 2022).

5. Conclusions

Urban agriculture is a promising intervention in urban food systems and ecosystems, offering a combination of material, social, and environmental benefits that continue to capture the interest of planners and policymakers globally. Despite this, little work has previously analyzed how scaling up UA might impact a variety of cities. This work addresses this and other shortcomings of the existing UA scaling literature, employing a combination of case studies to assess the metabolism impacts of UA in five cities in the US and Europe. This generalizable approach is not without limitations. Future work should emphasize how these trends interact with more complete characterizations of urban morphology and policy landscapes. For example, this work assumes broad land use reform that allows UA across many areas of the city, while this may prove unacceptable in some cultures or contexts. It also explores challenging or unrealistic scenarios in the interest of understanding a theoretical maximum for UA, including scenarios which require more than 100% of a city to volunteer for food growing or scenarios which might involve many private property owners renovating much of their lawn.

Nonetheless, this theoretical framing provides useful insights into the opportunities and limitations of UA in future cities. We find that UA could have a substantial impact on food supplies across contexts, although the impacts may be limited by the labor requirements of UA and the existing morphology of some particularly dense cities (e.g., NYC). By bridging the gap between narrow case studies and generalizable principles, this work lays the foundation for a broader understanding of the generalizable policy and planning characteristics of UA scaling up. For example, individual gardens are likely to play an important role in UA growth across contexts, challenging traditional narratives which foreground communal or commercial food production as the most important subject of policy and planning. We also find that traditional concerns like slope and sunlight availability differ in their importance. In older cities, slope has been leveled over the course of centuries and is unlikely to be an important limiting factor, while light availability may play a more important role in UA suitability (or at least in restricting crop choice). This work also reinvigorates labor availability as a critical field of study for UA scholars. This should consider both volunteer interest and availability of funds to pay employees in a future where local food becomes cheaper as UA scales up.

By building on the generalizable principles for scaling identified here, future work can extend both a generalizable theory of UA scaling and a more nuanced understanding of key land use, built environment, political, and cultural dynamics in particular cities. By demonstrating how different data environments can be synchronized to produce a cross-city investigation, this work also establishes a proof of concept for more global assessment of UA potential for integration into the food system. As humanity strives to reign in resource use and waste generation, the principles of scaling practice described here can guide advocates, planners, and policymakers as they seek to unlock UA's potential and limit its unintended consequences.

Generative AI acknowledgement: During the preparation of this work the authors used a proprietary GPT at the University of Michigan to improve the readability and succinctness of the abstract. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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7. Appendix: Scaling up methods and supplemental tables

Appendix contents (each section starts on a new page):

- Appendix summary
- Overview of methods
- Guide to online supplemental materials
- Supplemental tables

Appendix summary

This appendix summarizes the methods used in this manuscript. Most of the documentation provided here is offered as short descriptions of the files available for permanent download in DeepBlue Data (a permanent online repository through the University of Michigan). The version available online during Peer Review also contains methods for a second chapter of the corresponding dissertation, but they are organized such that reviewers can just ignore anything labelled “Chapter 2.” After peer review, the supplemental material for only this manuscript will be made available in a new repository, but since repositories cannot be edited after depositing, we are taking advantage of the version made public with a previous dissertation. These methods documents offer a much more detailed, often step-by-step, look at how the scaling up process worked in this manuscript, and they are not replicated in this print copy out of concern for space. If you are reading a print version of this document, you can find the full repository of all relevant methods documents by following this QR code:

Overview of methods

The basic workflow for the scaling task is:

1. Collect data from each city. The data sources (and an assortment of backup data sources) are described in the "Master Database" spreadsheet.
2. Derive simplified land use, land cover, slope and sunlight availability raster layers (also called midpoint layers in this dissertation) at 1m resolution. This is detailed independently for each city in the "Midpoint derivation" folder.
    a. Although it is linked in each of the Midpoint derivation document, since the Land Use Equivalencies spreadsheet is mentioned in text, I want to highlight that it is also available in the Appendix online SI. The spreadsheet shares the land use derivation scheme for each city.
3. Create a map of potential gardens, then analyze scenarios – "Potential garden derivation and post-hoc analysis":
    a. Combine midpoint layers to generate suitability rasters for each scenario.
    b. Aggregate gardens into parcels or parcel-like polygons.
    c. Post-hoc analysis of scenarios, both based on these polygons:
        i. Metabolism analysis: Based on matrix algebra in R (Markdown html available in DeepBlue)
        ii. Proximity analysis: Conducted mostly in QGIS, summary in R

Guide to online supplementary materials

Below, the file directory and file summaries are complemented by a systematic overview of the scaling methodology employed. This is organized in accordance with the supplementary file directory to make the relationships between files and methods more apparent.

- ⇒ Appendix A SI:

  Top-level folder, including folders for Chapters 2 and 5 (ignore Chapter 2), as well as the master secondary data source list.

  - ⇒ Master Database

    The first step in spatial analysis was the collection of many secondary data layers, some combination of which could be synthesized into land use, land cover, slope, and sunlight availability for each city.

  - ⇒ Chapter 5 – Cross-city analysis methods

    This folder provides an in-depth guide to the methods used in scaling up across cities. Part of the innovation of this chapter is the cross-sectional case study, applying a standardized concept for scaling to multiple cities. To do this, the methods had to be standardized across diverse data environments. The overall methods described above were customized for each city, and the guide to this process is included in this folder.

    - ⇒ Midpoint derivation

      The first step in conducting analysis across cities is to derive what I call the midpoint files – Land use, Land cover, Slope, and Sunlight availability. This includes careful identification of high resolution data sources in each city, as well as the derivation itself. In this folder, these are coupled in walkthroughs of the procedure in QGIS for each city.

- ⇒ Garden derivation and post-hoc analysis – Word document

  From these midpoint rasters, we proceed to derive suitability maps in each city, aggregate these to parcels or parcel-like areas, and conduct post-hoc analysis for the outcomes of each suitability scenario. This document walks through that process, highlighting data sources when relevant but otherwise focusing on providing documentation for replication in QGIS. The document begins by outlining the exact derivation of the suitability scenarios (the same across cities), before describing the specific processes and data sources for aggregating these results to parcel or parcel-like polygons. Once the farm and garden areas are available in a polygon layer, two stages of post-hoc analysis yield the results tables shown in the manuscript. First, proximity analysis reveals what percentage of residential households in each city are within walking distance of feasible farm or garden sites (sorted by UA type). Second, linear algebra allows us to convert the site-level metabolism to city-level impacts, simply by multiplying the metabolism impacts by the total areas converted in each scenario.

- ⇒ Land Use Equivalencies – Excel spreadsheet

  As discussed in-text and above, the midpoint derivation relies on the systematization of diverse land use codes across countries. This Excel spreadsheet serves as a codebook for the equivalencies adopted by this project.

- ⇒ Scenario-Polygons-Data-Cleaning-and-Analysis.html – R-markdown

This R-markdown document provides a guide to the code used to conduct post-hoc analysis of the scenarios. As with most Markdown products, it includes displays of the code alongside plain-language discussion of the goals of each code block. It takes two sets of inputs – first, the raw parcel-type polygon data that includes area of UA sites, and second the polygon data that includes the results of the proximity/access analysis. In both cases, it walks through the analysis process from import to the production of tables used.

Supplemental tables

Appendix Table 1 - Case study cities: characteristics and urban metabolism (2021-2023)*

City **Country**	**Dortmund** **Germany (DE)**	**Gorzow Wlkp** **Poland (PL)**	**London** **United Kingdom (UK)**	**New York City** **United States (US)**	**Paris** **France (FR)**
Population	593,317	118,011	8,799,800	8,622,467	6,962,961
Population density (persons/km^2)	2,114	1,377	5,585	10,922	8,542
Administrative area used in this study	Dortmund, borders of the *Kreis* (district) and *Gemeinden* (municipality) coincident	*Powiat* Gorzów Wielkopolski, *powiat* (county) and *gmina* (city) coincident - 'City-County'	Greater London (32 boroughs + City of London)	NYC administrative boundary (five boroughs)	Métropole du Grand Paris: All communes in Departments 75, 92, 93, 94 + plus seven communes in outer suburbs
Study area (km^2)	280.68	85.72	1575.72	789.43	815.1
Built density (% built area)	9.6%	5.1%	15.8%	21.3%	19.7%
GDP per capita (Intl $, PPP)	$60,346	$28,097	$88,077	$95,334	$90,653
Vegetable consumption per capita (g/day)	193.22	178.69	117.43	128.60	155.43
Finished water use per capita (L/day)	145.2	147.1	187.9	454.2	120.0
Electricity consumption per capita (kWh / day)	16.272	10.956	11.280	48.344	12.996
Food waste per capita (rate)	0.236	0.236	0.177	0.196	0.236

* While selected primarily as a means to assess a wide range of UA types (Fox-Kämper et al., 2023), this set of cities also offers a variety of urban typologies, including small, medium, and large cities, dispersed and dense areas, and old and new built environments. The cities also have unique histories of UA. In Dortmund and Gorzow, the history of UA is dominated by allotment gardens (Fox-Kämper et al., 2023), while in NYC, London, and Paris, associations like Social Farms & Gardens and city agencies like GreenThumb have helped shape a legacy of community-focused collective gardens alongside a growing number of urban farms (Reynolds & Cohen, 2016). However, none of the cities currently grow a significant portion of their own food, nor does UA constitute a major land use.

Appendix Table 2 - Site-level metabolism of low-tech urban agriculture (reproduced from Chapter 1)

Urban agriculture type	**Urban farm (n = 7)**	**Collective garden (n = 9)**	**Individual garden (n = 55)**
Percent of UA site for food growing (Dorr et al., 2023)	37.4%	32.0%	31.1%
Food production (kg / m2 - Dorr et al., 2023)*	1.03	0.562	0.501
Irrigation water use (L / m2 - Dorr et al., 2023)*	179.18	75.67	17.50
Energy use (kWh / m2 - Dorr et al., 2023)*	0.076	0.033	0.283
Synthetic N use (g / serving food - Hawes et al., 2024)	0.18	0	0.05
Synthetic P use (g / serving food - Hawes et al., 2024)	0.14	0	0.03
Synthetic K use (g / serving food - Hawes et al., 2024)	0.23	0	0.04
Compost use (kg compost / m2 - Dorr et al., 2023)*	0.824	3.672	0.347

Economic value ($ / m2 - Dorr et al., 2022)*	5.19	3.66	1.12

*All measures per m^2 are per m^2 total farm or garden area. This assumes internal site design is similar to existing sites, including the widespread use of raised beds, creation of recreational areas, and extensive walking paths.

Appendix Table 3 – Land Use Equivalencies

Name	Number	Description	UA Type
General Residential	10	Residential which cannot be classified without further information	Individual
Residential - Single-family	11	Single-family homes	Individual
Residential - Multi family	12	Multi-family buildings	Community
Residential - Children or senior	13	Children's or senior community housing	Community
Hotels and Temporary residences	14	Hotels, campgrounds, or other temporary residence	--
Mixed Residential and Commercial Buildings	21	Mixed use area (e.g., Apartments over a business)	Community
Commercial	22	Commercial property	Farm
Industrial and Manufacturing	23	Industrial or manufacturing property	Farm
Churches	24	Church property	Community
Mines or other extraction	25		--
Sports venues	26	Professional and amateur sports venues	--
Misc. private structures	29	Uncategorized structures that don't seem to be in the public domain (39)	--
Parks and Playground	31	Public parks or playgrounds	--
Other public open space, used	32	Cemeteries, botanical gardens, etc.	--
Other public open space, unused	33	Open woodlands, grasslands, etc.	Community
Hospitals and medical centers	34	All medical facilities	Community
Schools	35	Schools, trade schools, colleges	Community
Detention facilities	36	Jails, prisons, juvenile detention	--
Scientific facilities or historic sites	37	Laboratories, archaeological sites, historic homes, etc.	--
Museums, art galleries, cultural sites	38		--
Other public facilities and institutions	39	Public buildings which cannot be classified otherwise	--
Parking	41	Parking	Community
Transportation and Utility	42	Non-through-way transportation facilities, electricity generation, water supply - all municipal and national utility infrastructure	--
Waste disposal	43	Any type of waste disposal facility - landfill, slag heap, etc.	--
Vacant land	70	Vacant or unused land - often previously developed, ok if there are buildings (contrary to other definitions of vacancy)	Community
Insufficient information - probably vacant	71	Insufficient information to code as anything.	--

Roads	80	Roads	--
Walking and recreation paths	81	Pedestrian paths	--
Railway	82	Rail, tram, surface subway lines	--
Waterways	83	Water	--
Existing Agriculture	90	Existing agricultural spaces - farms or animal rearing	--
Existing community food production	91	Allotments, community gardens, community-driven peri-urban agriculture	--
Ignore	0	Don't use this category	--
Polyline - ignore	0	Difficult to use polylines unless they come with a width parameter	--
Points - ignore	0	Difficult to use points unless they come with shape parameters	--
Land cover - ignore	0	Not helpful for characterizing land use	--

Appendix Table 4 – Land cover classification across cities

Name	**LC #**	**Description**
Unusable	0	Statues, awnings, and other structures without standard roof area for rooftop garden consideration
Impervious ground cover	1	Concrete
Low vegetation	2	Grass, dirt, and vegetation below 2m in height
Buildings	3	All buildings
High vegetation	4	Trees and other vegetation above 2m in height

Appendix Table 5 – Sensitivity scenarios

Scenario	**Description**	**Slope**	**Sunlight**	**Land Use**	**Land Cover**
Base	Explores the maximum possible extent of UA under standard assumptions	Ground less than 15% slope, rooftops less than 5% slope	Greater than 4 hours sunlight per day on average	Individual gardens: Single-family (LU = 11) and unclassified residential (LU = 10) Collective gardens: Multi-family (LU = 12) and communal residential (13), Mixed-use (21), Churches (24), Medical facilities (34), Schools (35), and Vacant land (70) Urban farms: Commercial (LU = 22) and industrial	Ground gardens: Impervious (LC = 1), Low vegetation (LC = 2), Under trees (LC = 4) Roof gardens: LC class 3
Ignore slope	Test the degree to which slopes limit UA scaling	No cutoff	Greater than 4 hours sunlight per day on average		
Ignore sunlight	Test the degree to which sunlight availability limits UA scaling	Ground less than 15% slope, rooftops less than 5% slope	No cutoff		
Tree obstruct-ion	Test the degree to which denser urban canopy cover could limit	Ground less than 15% slope, rooftops less	Greater than 4 hours sunlight per day on average		Ground gardens: Impervious (LC = 1), Low vegetation (LC = 2)

	UA scaling	than 5% slope		(23) sites	Roof gardens: LC class 3

Appendix Table 6 – Ignoring slope unlocks large swaths of new area, but mostly on rooftops. While this is likely to signal relatively widespread applicability for rooftop solar, rooftop gardens cannot compensate for slope without risk to participants. Instead, we focus on the more modest gains in ground area, which indicates that slope is not an important limiting factor in ground-based UA.

City	**Total area of city (km2)**	**Base Scenario**		**Ignore slope scenario**		**Percent change**	
		City area suitable for UA (km2)	***Ground area suitable for UA (km2)***	***City area suitable for UA (km2)***	***Ground area suitable for UA (km2)***	***City area suitable for UA***	***Ground area suitable for UA***
Dortmund	280.68	55.74	51.82	83.56	60.91	49.91%	17.53%
Gorzow	85.72	10.61	9.64	15.35	11.09	44.60%	15.04%
London	1575.72	389.43	376.02	632.68	408.78	62.46%	8.71%
NYC	789.43	121.33	106.63	211.95	117.45	74.69%	10.14%
Paris	815.10	159.60	149.46	326.12	170.44	104.34%	14.04%

Appendix Table 7 – Ignoring sunlight offers more meaningful insights into the limitations on ground-based UA than slope. It is likely that sunlight availability will be a meaningful determinant of crop choice if not overall suitability in somewhere between 15 and 29% of otherwise suitable space. These impacts are, unsurprisingly, much more important in NYC, the site of one of the densest and most iconic skyscraper skylines in the world.

City	**Total area of city (km2)**	**Base Scenario**		**Ignore sunlight scenario**		**Percent change**	
		City area suitable for UA (km2)	***Ground area suitable for UA (km2)***	***City area suitable for UA (km2)***	***Ground area suitable for UA (km2)***	***City area suitable for UA***	***Ground area suitable for UA***
Dortmund	280.68	55.74	51.82	75.81	59.75	36.00%	15.30%
Gorzow	85.72	10.61	9.64	15.66	11.41	47.55%	18.36%
London	1575.72	389.43	376.02	468.67	455.22	20.35%	21.06%
NYC	789.43	121.33	106.63	155.45	137.78	28.11%	29.21%
Paris	815.10	159.60	149.46	183.93	173.73	15.25%	16.24%

Appendix Table 8 – Assuming that trees obstruct UA allows us to model the potential impacts of diverse urban greening strategies on one another. For example, if tree cover expands to address climate change and urban heat island, it could be an important obstacle for UA even at relatively low levels of canopy cover. This highlights the importance of coordinated greening strategies to address multiple ecosystem services.

City	**Total area of city (km2)**	**Base Scenario**		**Trees as obstacles scenario**		**Percent change**	
		City area suitable for UA (km2)	***Ground area suitable for UA (km2)***	***City area suitable for UA (km2)***	***Ground area suitable for UA (km2)***	***City area suitable for UA***	***Ground area suitable for UA***
Dortmund	280.68	55.74	51.82	40.00	36.08	-28.23%	-30.37%
Gorzow	85.72	10.61	9.64	13.23	9.39	24.65%	-2.63%
London	1575.72	389.43	376.02	363.20	349.78	-6.74%	-6.98%
NYC	789.43	121.33	106.63	91.07	77.69	-24.95%	-27.14%
Paris	815.10	159.60	149.46	106.96	97.04	-32.98%	-35.07%

Appendix Table 9 – Impact of roof suitability on space available and food production in cities.

City	Total area on roofs (km2)	Proportion of available garden area on roofs	Total area if no rooftops are suitable (km2)	Proportion of veg supply on rooftops - Avg	Proportion of veg supply on rooftops – Max	Min % of veg supply lost if 25% of rooftops are unsuitable
Dortmund	3.921	7.03%	51.821	8.30%	28.68%	2.07%
Gorzow	0.977	8.97%	9.907	9.99%	32.24%	2.50%
London	13.416	3.34%	388.182	2.59%	8.67%	0.65%
NYC	15.188	12.05%	110.819	2.66%	8.35%	0.67%
Paris	10.396	5.92%	165.306	1.83%	5.00%	0.46%

Appendix Table 10 – Synthetic nutrient savings by city

	Tonnes synthetic nutrient input saved annually in maximum scaling scenario		
City	Nitrogen	Phosphorus	Potassium
Dortmund	234.68	403.59	261.06
Gorzow	48.58	82.97	53.96
London	1334.70	2242.60	1504.53
NYC	435.75	720.99	491.77
Paris	599.18	990.02	675.17

Appendix Table 11 – Proximity to gardens as a function of the types of farms or gardens sought

City	Average residential distance to a collective garden (m)	Average residential distance to an urban farm (m)	Percent of residential parcels with quarter-mile access to a collective garden	Percent of residential parcels with room for a garden on-site	Percent of residential parcels with access to any UA site*
Gorzow	354.21	167.24	79%	51%	99%
London	543.92	529.14	85%	76%	95%
NYC	71.18	255.11	100%	74%	100%
Paris	80.97	414.50	99%	68%	100%

* Access is defined as Euclidean distance (as the crow flies) from a collective garden or urban farm less than 440m, or an individual garden on-site.

Appendix Table 12 - Rates of participation if gardener/farmer efficiency varies (i.e., if rates of participation vary with need for workers)

City	Dortmund	Gorzow	London	NYC	Paris
Area of individual gardens per capita (m2)	55.46	38.36	34.55	9.4	13.76

Area of collective gardens per capita (m2)	9.4	21.91	4.09	3.47	7.01
Area of urban farms per capita (m2)	29.99	29.65	5.62	1.2	2.16
Percent of population needed as volunteers at gardens - minimum	10.57%	9.83%	6.30%	2.10%	3.38%
Percent of population needed as volunteers at gardens – maximum	1426.91%	1326.14%	850.05%	283.22%	456.82%
Percent of population needed as employees at farms - minimum	0.49%	0.48%	0.09%	0.02%	0.04%
Percent of population needed as employees at farms - maximum	65.97%	65.23%	12.36%	2.64%	4.74%
Conservative estimate of combined participation	11.06%	10.31%	6.39%	2.12%	3.42%