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Scale up urban agriculture to leverage transformative food systems change, advance social–ecological resilience and improve sustainability

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Scaling up urban agriculture could leverage transformative change, to build and maintain resilient and sustainable urban systems. Current understanding of drivers, processes and pathways for scaling up urban agriculture, however, remains fragmentary and largely siloed in disparate disciplines and sectors. Here we draw on multiple disciplinary domains to present an integrated conceptual framework of urban agriculture and synthesize literature to reveal its social–ecological effects across scales. We demonstrate plausible multi-phase developmental pathways, including dynamics, accelerators and feedback associated with scaling up urban agriculture. Finally, we discuss key considerations for scaling up urban agriculture, including diversity, heterogeneity, connectivity, spatial synergies and trade-offs, nonlinearity, scale and polycentricity. Our framework provides a transdisciplinary roadmap for policy, planning and collaborative engagement to scale up urban agriculture and catalyse transformative change towards more robust urban resilience and sustainability.

Urbanization is a fundamental driver accelerating human pressures in the Anthropocene[1]. Currently, 57% of the global population reside in urban areas, with a projected 68% by 2050 (ref. 2) (that is, an addition of 2.5 billion new city residents). Urban populations rely primarily on imported goods and services and shape resource consumptions and emissions worldwide[3]. Accelerated urbanization and resource demands in cities are strained by a changing climate, shifting land use, rising inequalities and altered disturbances[4]. These stressors may compromise urban resilience[5]—the capacity of urban social–ecological systems to tolerate, adapt to or transform with changes to retain essential functions

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and feedback, risking exceeding planetary boundaries for humanity[6]. Hence, there is an urgent need to explore sustainable urban pathways that enhance resource security, bolster ecosystem services and improve urban resilience.

Given the magnitude of anthropogenic changes, adaptive measures may be insufficient to confer system resilience and achieve sustainable development[7,8]. Many researchers argue that transformative change—a fundamental reorganization of system structures and processes that profoundly departs from the status quo—could shift unsustainable trajectories towards a 'good Anthropocene'[9], in which normative and equitable goals for sustainability are achieved. In particular, transformative change is urged for bolstering resilience in urban systems, given their increasing social–ecological–technological complexities, risks of cascading system failures and the scale of global needs for urban development to achieve planetary sustainability[3,10].

Urban food systems, due to their intertwined links to diverse domains including social, environmental, energy, health, political and economic systems, present a promising lever to induce such transformative change towards urban resilience and sustainability[11]. In vulnerable urban and peri-urban regions, for example, disruptions to current food systems may require fundamental reorganization in food provisioning[12]. Addressing inequalities within urban systems may also necessitate transformation, as adaptive responses could perpetuate or exacerbate unequal access to wealth, food, health and ecosystem services, thus failing to meet needs of resilient urban food systems[13]. In situations where social, economic or ecological conditions have become unsustainable or unjust, or long-term 'desired' resilience has been eroded or locked into an 'undesirable' state (for example, chronic poverty, power concentration, food insecurity), transformation may be the most auspicious path forward[14].

We posit that transformative change in urban food systems may entail a shift towards urban agriculture—growing, processing and distributing food products (including agroforestry) in urban regions[15,16]. Given the scarcity of and conflicts over urban land uses, urban regions[17] (from urban cores to peri-urban and surrounding landscapes; Extended Data Fig. 1) offer pivotal spatial scales at which urban agriculture should be studied and practiced and can meaningfully contribute to urban sustainability. Recent scholarship indeed highlights capacities of urban agriculture to sustain ecosystem services and promote urban resilience, thus advancing global sustainability[15,18]. There is emerging evidence that urban agriculture contributes to food and nutritional security in urban populations[19]. While urban food insecurity is also associated with structural factors such as poverty and wealth inequality, urban agriculture could still play a vital role in improving food availability and access, especially in low-income and marginalized communities[20,21]. Furthermore, by reducing reliance on long-distance transport and global supply chains, urban food production could be more resilient than conventional agriculture[22] to disasters, food price shocks, global pandemics and social–political disruptions.

Urban agriculture is not a panacea and, besides potential issues of its economic viability, may pose social–environmental risks, including soil contamination, water pollution, pest/disease incidents and public health risks. Scholars have also criticized possible consequences of urban agriculture for aggravating social exclusion, gentrification, injustice and inequality in access to public assets and the urban commons[23–25]. In addition, urban agriculture is impeded by obstacles such as land scarcity, lack of secure land tenure, self-exploitation, insufficient investment and marketing, and limited infrastructure/technologies[20,26,27]. Urban agriculture is also fundamentally challenged by issues related to land competition driven by urban economies and speculative land markets, undervaluation of local food products and sustainable diet and consumption, and disrupted human–nature relations under capitalism and modernization[28–31].

Although urban agriculture research and practices have proliferated, current knowledge is mostly discipline specific and sector confined. Hence, there is a need to adopt a social–ecological lens and systems approach to better understand dynamics, feedback and cross-boundary interactions of urban agriculture. Despite the benefits of urban agriculture, its impacts have been constrained due to small-scale implementation. Nonetheless, arguments that 'scaling up urban agriculture'—defined as increasing the number and diversity and boosting size, productivity and capacities of urban agriculture operations—can act as transformative change towards urban resilience and sustainability[15,16] have been gaining traction, with nascent real-world examples (Extended Data Fig. 2). Yet the processes and pathways through which scaling up urban agriculture occurs and what enabling factors could catalyse upscaling remain elusive. Such knowledge is critical for informing collective action and policy interventions that aim to integrate and scale up urban agriculture to achieve resilient and sustainable urban futures.

In this Article, we address these knowledge gaps by developing a conceptual framework of urban agriculture in integrated urban socio-environmental systems and summarizing evidence of its social–ecological implications across scales with results from a systematic literature review. Within this framework, we then present theoretical foundations underlying the scaling up of urban agriculture in urban regions as transformative change that considers individual- and institutional-level factors representing 'bottom-up' and 'top-down' influences. Furthermore, we propose multi-phase developmental pathways to demonstrate dynamics, processes, factors (or 'accelerators') and feedback in driving transformational scaling up of urban agriculture. Finally, we conclude with key considerations for future research, policymaking and implementation relevant to upscaling urban agriculture.

Conceptual framework of urban agriculture

Urban agriculture in integrated urban socio-environmental systems

Urban agriculture takes a multitude of forms from urban/peri-urban farms, community gardens and edible landscaping, to vertical towers[32] (Extended Data Fig. 3), each with different niches and potentials for upscaling. Urban agriculture can exert cascading social–ecological effects across scales (Fig. 1). At local scales, urban agriculture can provide an array of ecosystem services[33–35], including food production, heat mitigation, carbon storage, water/nutrient flow regulation, air quality regulation, pollination, biocontrol, habitat support, landscape aesthetics and ecotourism. Our review (Methods) also provided empirical evidence for three provisioning, nine regulating/supporting and eight cultural services from urban agriculture (Fig. 2). It is noteworthy that specific ecosystem services (kind, amount and composition) are dependent upon urban agriculture types, along with context-specific factors such as climate, soil, management, infrastructure and human use. For example, capital-intensive and agrochemical-rich urban agriculture is less prone to deliver the same level or portfolio of ecosystem services than agroecological, soil-based and human-centred practices.

At regional scales, effects of urban agriculture, through decentralizing urban food supply and enhancing ecosystem services, can cascade along food and resource supply chains to reduce environmental externalities and shrink transboundary environmental footprints[36,37] (Fig. 1). Such cross-scale effects can be manifested in food–water–energy nexus[38]. First, urban agriculture can affect the food sector by supplementing food supply and feeding urban residents. A global meta-analysis[22] showed that urban agriculture yields are on par with or greater than conventional agricultural yields, with some crops (for example, cucumber) ~4 times higher. Even for staple crops such as wheat, urban vertical farming has potential to produce several hundred times higher than field farming, although still cost and energy intensive with current technology[39]. Such production capacity is crucial to reduce external food reliance, to increase food self-sufficiency in urban regions and to create premises for reconsidering functional

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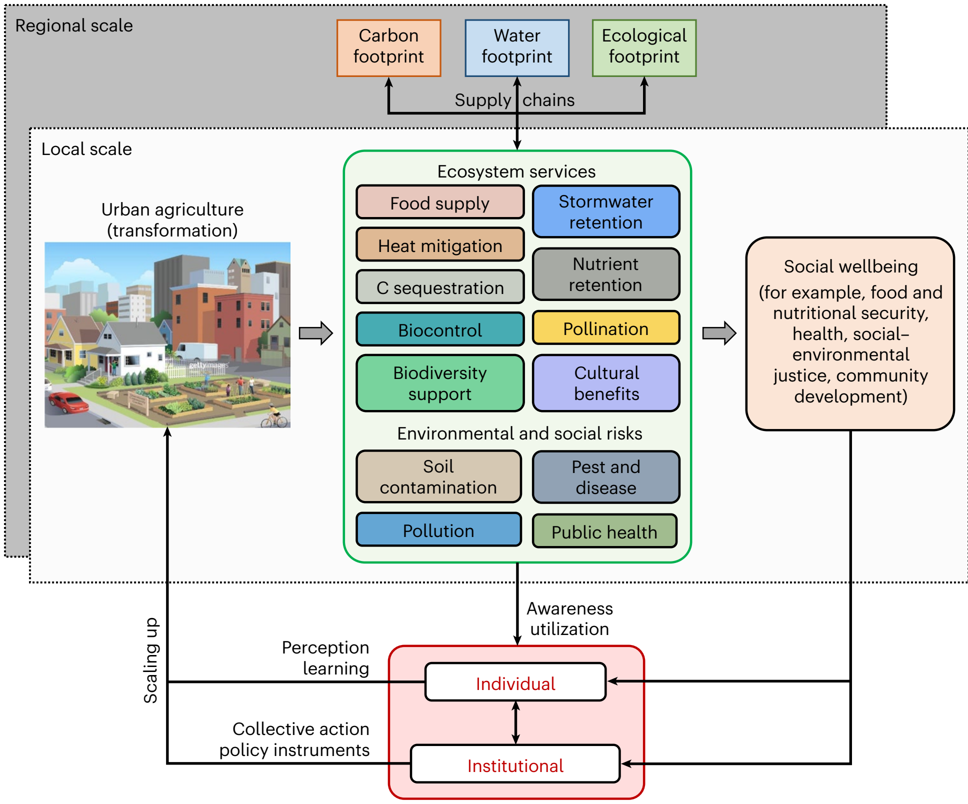

Fig. 1 | Conceptual framework of urban agriculture across scales. Urban agriculture in integrated urban socio-environmental systems, their components, dynamics and feedback across scales.

organization of urban space, people's consumption behaviour and dependency on current food regimes[23]. Second, urban agriculture can affect the water sector through fostering rainwater harvest and water reclamation that, in turn, lowers water footprints. Urban agriculture may reduce virtual water imports, enhance infiltration, mitigate runoff (thus flooding risk) and help replenish aquifers in the long run. Furthermore, urban agriculture could promote water savings[40], especially when converting irrigation-intensive lawns to vegetables. Third, urban agriculture can affect the energy sector by potentially decreasing carbon footprints through enhanced resource-use efficiency (production side)[41] and through dietary shifts and food waste recycling (consumption side)[29,42] and by mitigating transboundary environmental footprints through reducing resource uses embedded in long-distance food transportation[37,42]. Moreover, heat mitigation from urban agriculture (for example, food forestry) could lower cooling energy needs. A recent meta-analysis indeed showed importance of urban agriculture in climate change adaptation and mitigation[43]. Our systematic review of urban agriculture literature using life-cycle assessment (Methods) also empirically revealed cross-scale effects of urban agriculture, such as climate change, water quality and quantity, and resource efficiency (Fig. 2), yet specific cross-scale effects are likely heterogenous and context dependent[44].

Social–environmental risks associated with urban agriculture can negatively impact the functioning and health of urban regions[45] (Fig. 1). Examples include increasing disease/pest incidents, exposure to soil contamination, environmental pollution from chemical spill-over into surrounding habitats, and public health risks[24,46]. At the same time, ecosystem service benefits from urban agriculture can be unevenly distributed (for example, disproportionately benefiting wealthier communities), and negative changes in the system may worsen externalities for vulnerable communities (for example, concentrating pollution and contamination in certain neighbourhoods).

Biophysical effects of urban agriculture may result in feedback affecting social systems, triggering changes at individual, policy and governance domains (Fig. 1). Specifically, urban agriculture adoption could be enhanced by increased socio-economic wellbeing such as food and nutritional security, job opportunities and community development[34], providing justification for institutional changes in favour of greater public investments in urban agriculture (infrastructure, subsidy, land use planning and zoning). Utilization of ecosystem services and awareness of risks associated with urban agriculture may lead to changes in individuals' perceptions, preferences and behaviours towards engaging in urban agriculture practices, which can be amplified through social learning and changes in social norms. Positive changes at institutional and individual levels could reinforce each other, leading to transformational scaling up of urban agriculture[47].

Theoretical foundations for 'scaling up' urban agriculture

Despite resilience and sustainability effects of urban agriculture, its current adoption remains fragmented and has yet to fully realize its potential. In synthesizing literature, we argue that both institutional- and individual-level factors are indispensable for scaling up urban agriculture[48]. Specifically, current scholarship[20] highlights the importance of institutions for legal status and economic viability of urban agriculture and its ability to meet food and nutritional security goals. Examples of supportive institutions include incentive zones, urban agriculture subsidies and food policies, and infrastructure support (for example, storage and distribution network for urban agriculture products). Institutions can also affect individuals' risk, self-efficacy, capacity, and mobilization of collective action to increase system capacities for scaling up urban agriculture[49] (Fig. 3).

At individual levels, research on individuals' ability to engage in transformative change has initially focused on the importance of their objective capacities, including access to resources, technology

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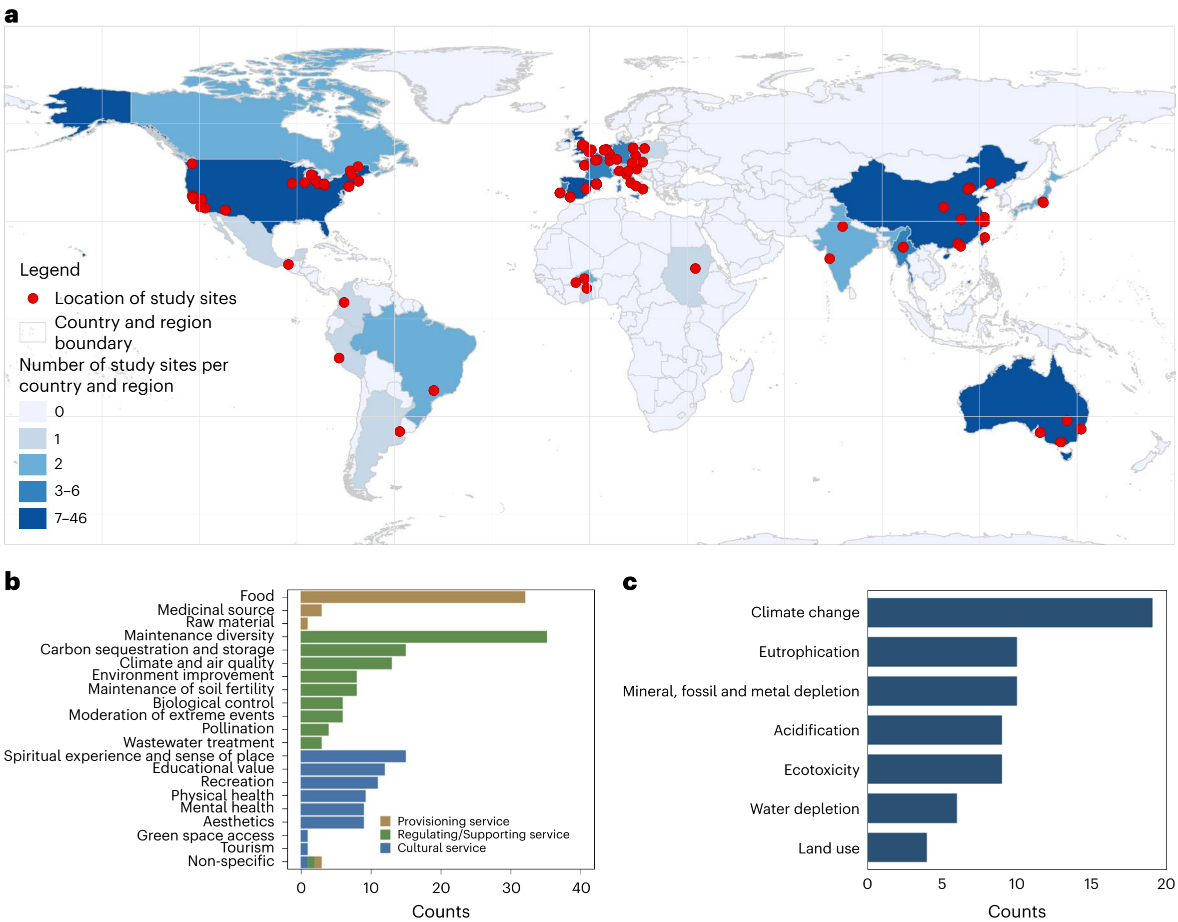

Fig. 2 | Results of literature review of urban agriculture studies. a, Global map of locations of urban agriculture studies included in the analysis; **b**, frequency of studies quantifying ecosystem services provided by urban agriculture; and **c**, frequency of life-cycle assessment studies documenting cross-scale effects of urban agriculture.

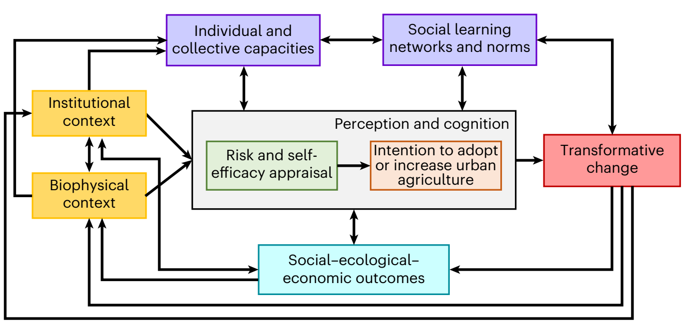

Fig. 3 | Theoretical foundations of scaling up urban agriculture as transformative change. Institutional- and individual-level factors are both indispensable for scaling up urban agriculture. These theoretical foundations of scaling up urban agriculture generically apply to both commercial and non-commercial urban agriculture types, where relative importance of dominant factors, processes and feedback may vary across urban agriculture types and socio-environmental contexts.

and land tenure[50,51]. Increasingly, scholars are highlighting influences of perception and cognition on intention/willingness to transform, including perceived risk, self-efficacy and knowledge (Fig. 3)[52,53]. Furthermore, individual decisions are affected by learning through social and informational networks[54] and/or evolution of social norms[55]. Commercial and non-commercial urban agriculture (Extended Data Fig. 3) are expected to have different sets of individual-level capacities and cognitive processes whose adaptations and transformation may occur in parallel.

Finally, as with any systemic changes, transformation has social–ecological feedback that could affect institutional- and individual-level capacities to implement and expand urban agriculture practices (Fig. 3). These feedback may be socially, ecologically or economically desirable (for example, positive changes in ecosystem services, community development, employment opportunities and market expansion) and reinforce scaling up of urban agriculture. Feedback can also be maladaptive and economically infeasible, leading to social–environmental risks and injustices[25,56] (for example, producing inequality, exclusion, oppression for vulnerable communities and economic losses) that can undermine social–ecological functions of urban agriculture and hinder upscaling. Recent research has revealed multiple 'signposts' of transformation[16] in urban agriculture that underpin upscaling, including creation of spatial synergies, connected flows of resources, individual feelings of self-efficacy and increased ecological resilience.

Developmental pathways in scaling up urban agriculture

Based on our conceptual framework and inspired by real-world socio-technical transition (for example, energy, mobility, green economy)[57] and Rostow's theory of economic growth stages[58], we propose multi-phase developmental pathways for upscaling urban agriculture, illustrated as triple 'S' growth curves indicating three dominant phases (or 'domains') with respective barriers and accelerators. We posit that upscaling process results from an interplay of a variety of dominant

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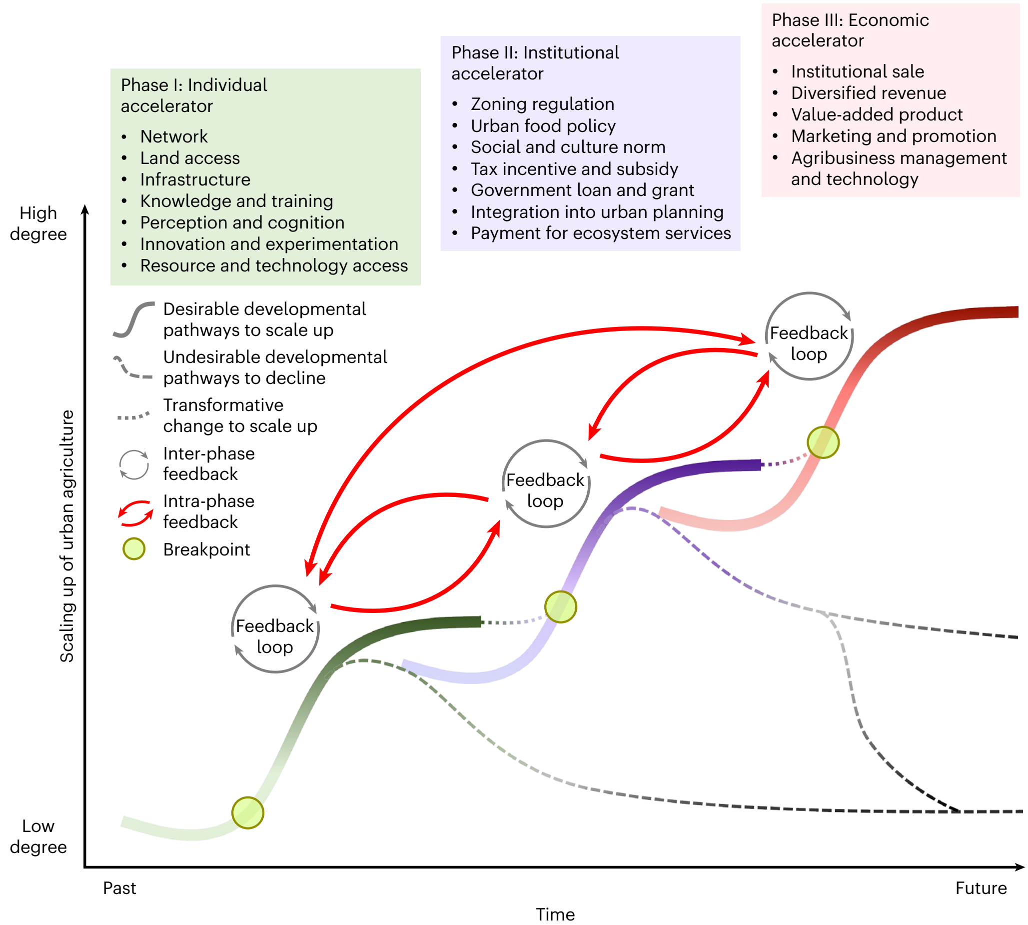

Fig. 4 | Developmental pathways for scaling up urban agriculture over time. Scaling up urban agriculture may follow a triple 'S' growth curve indicative of three dominant phases or domains, each of which has its respective barriers and accelerators. Within each phase, there are different stages of growth—predevelopment, take-off, acceleration and stabilization. In predevelopment, urban agriculture may initially struggle to grow, then move towards a 'breakpoint' that triggers accelerated and substantial growth after removal of major barriers, and eventually asymptotes. Towards the end of stabilization, transformative change needs to occur so that continuous growth can extend into the next developmental phase and be further boosted by additional accelerators inherent in latter phases. Otherwise, it could progress towards 'undesirable' pathways that lead to stagnations and gradual declines of urban agriculture practices. It is important to note that accelerator(s) from the previous phase will persist over time and be carried over into latter phases. Positive or negative social–ecological feedback loops can occur both within and across phases that, in turn, affect the process and outcomes of transformational upscaling.

changes in different domains (that is, individual, institutional and economic) that interact and reinforce each other to ultimately produce radical transformation in urban food systems (Fig. 4).

Grounded in historical development and the inherent nature of social–ecological dynamics of urban agriculture, we argue that phase I is likely driven by individual-level factors and processes. Across examples in the Global North and South (Supplementary 'Exemplary policies and cases')[34,59], urban agriculture is often stemmed or initiated from individual practices and grassroot movements, such as urban vegetable and community gardens for meeting household food needs, reducing food expenses and improving livelihoods. Accelerators in this phase include, but are not limited to, land access, infrastructure, technology and resource access, network, innovation and experimentation, knowledge and training, and perception and cognition, all of which can empower individual and community capacities and promote bottom-up approaches to initiate, develop and expand food production in urban systems (Fig. 4).

Phase II is driven primarily by institutional-level factors and processes. With sufficient stakeholder engagement and community support, urban planners and policymakers across sectors and levels of governance have become increasingly cognizant of benefits from urban agriculture (if properly developed), including social, health and environmental ones. Hence, proactive interventions begin to develop to guide and navigate urban food production, integrate urban food systems into land-use planning and urban polices and regulations, enhance social–economic benefits and reduce risks of urban agriculture[45,60]. Possible accelerators in this phase include zoning regulations (for example, designated urban lands for local food production), urban food policies, social and cultural norm shifts, tax incentives, government loans and grants, subsidies or payments for ecosystem services (that is, bridging the gap between urban agriculture profits and values of alternative land uses). All these accelerators are in favour of supporting greater public investments in urban agriculture, potentially making its upscaling possible and profitable. For instance, forward-looking zoning could allocate lands for urban agriculture to avoid prohibitive costs of converting built-up areas, while subsidies or other forms of payments could bring urban agriculture beyond the profitability tipping point, thus boosting adoption. See examples of urban agriculture-relevant policies and cases in the Global North and South in Supplementary Information.

Phase III is mainly driven by market-based economic factors and processes. With support and engagement from individual- and institutional-level actors in place, profitability is the next predominant factor upscaling urban agriculture. Current economic models for urban agriculture are fragile and concentrate solely on agricultural products. Whether and at what scales urban agriculture

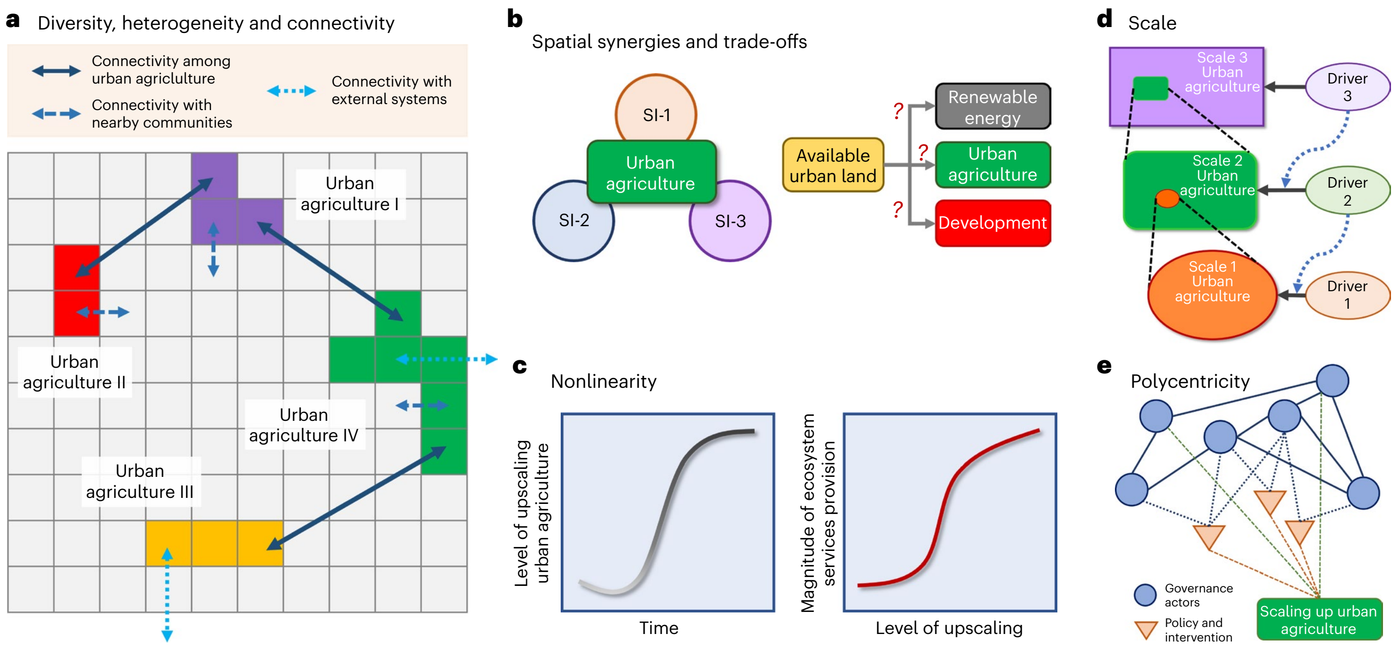

Fig. 5 | Schematic diagram of key considerations relevant to research and practices of scaling up urban agriculture. a, Diversity, heterogeneity and connectivity. **b**, Spatial synergies and trade-offs; SI, supportive infrastructure. **c**, Nonlinearity. **d**, Scale. **e**, Polycentricity. Detailed descriptions of each consideration can be found in Table 1 and the Supplementary Information.

is profitable remain questionable[61]. Typical factors influencing profitability of urban agriculture operations include market orientation and access, operation size, crop/animal choice, input cost and technology adoption[61,62]. Yet urban agriculture can provide social–environmental benefits (for example, contribution to family nutrition and health, climate mitigation, resource recycling), which, if marketable, together with institutional support in phase II, can substantially improve economic viability of urban agriculture. Hence, accelerators in this phase include marketing and promotion (for example, capitalized on increasing public awareness of sustainability benefits of urban agriculture and willingness of consumers to pay price premiums for locally grown food products), institutional sales, diversified revenues (for example, ecotourism, space rental and marketable permit of environmental footprints), value-added products and agribusiness management and technology (for example, urban agriculture-specific sale/distribution platform, automation technologies to reduce input and labour cost associated with production, management and distribution).

It should be noted that (1) the proposed pathways are one plausible 'desirable' scenario to scale up urban agriculture, which can differ from what has or will occur (for example, more 'noise' around curves in Fig. 4); (2) while each phase has its own predominant accelerators and processes, overlaps and interactions across phases exist in a coevolutionary way. One example is that economic factors could persist in all phases: for example, the cost–benefit for food production in phase I; subsides or payments for ecosystem services in phase II; (3) feedback loops can occur within and across phases (Fig. 4), leading to socially and environmentally desirable outcomes that reinforce upscaling (for example, perceived/realized improvements in ecosystem services from urban agriculture lead to increased individual adoptions and favourable public investments and policy supports); (4) feedback can be negative at multiple levels, as critical scholarship has pointed out[23,24,63], exacerbating social exclusion, gentrification and capitalist accumulation, which derail intentions of upscaling urban agriculture; and (5) developmental pathways are likely nonlinear, context dependent and path dependent. Thus, specific configuration (order, type and presence) of phases in upscaling might vary across sociopolitical, cultural and economic contexts (for example, Global North versus South) and evolve dynamically through experimentation, optimization and innovation.

Key considerations for scaling up urban agriculture

While our focus is on productivity, resilience and environmental sustainability, another concern across all developmental phases of scaling up urban agriculture is food sovereignty and justice. Literature often assumes that expanding urban food production will benefit everyone, yet this stance fails to acknowledge social–political realities. Scholars have developed multiple threads of critical research on urban agriculture. For instance, agroecology scholars have sought to better understand experiential agroecological knowledge for developing more sustainable agriculture[64]. While traditionally focused on rural agrarianism, this literature is increasingly interested in marginalized urban people and lands with practitioners seeking to empower communities to regain food production rights in urban areas[65]. Other scholars, notably ethicists, theorize food as a commons, whose commodification disrupts access to an essential human right[66]. Work on food sovereignty builds on La Vía Campesina movement, which prioritizes indigenous knowledge and diversity in production methods, promotes social equity and challenges capitalist and industrial practices in agriculture[67]. Certain urban agriculture types promise extensive and commercialized production; however, upscaling these practices may be at odds with equity and diversity goals. Hence, focusing on use value of urban agriculture (for example, as a public good) rather than simply its exchange value—can be key to scale up urban agriculture.

Furthermore, while we describe potential pathways to resilience, we acknowledge that the term has been problematized. The concept of resilience is taken from ecology and, when applied to social relations, can prioritize stability of existing, often unequal, power structures[68]. Thus, recommendations coming out of resilience literature can problematically call for action at local scales where there is no political jurisdiction[68,69]. Resourcefulness, aimed at developing locally driven political and cultural systems that privilege local and indigenous

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Table 1 | Key considerations relevant to research and practices of scaling up urban agriculture

Consideration	Description	Exemplar research questions	Possible relevant actors
Diversity	Different urban agriculture types have their own benefits, functions, risks and niches for upscaling, and responses to environmental changes. It is crucial to implement diverse urban agriculture in upscaling to achieve complementarity in their social–ecological impacts and serve a broad range of communities.	What are the relationships and balances between diversity, resilience and system-level social–ecological outcomes from scaling up urban agriculture?	Urban agriculture practitioner Scientist Non-profit Resident
Heterogeneity	Different locales have varying degrees of biophysical (for example, lot size, structure, soil) and social suitability (for example, local food demands, access to market and beneficiary groups, heterogeneity in social demographics) for implementing urban agriculture.	How does social heterogeneity and its interaction with environmental heterogeneity affect optimal siting and functional fit of specific urban agriculture across the urban regions?	Urban agriculture practitioner Scientist Policymaker Non-profit Resident Retailer
Connectivity	Connectivity can be manifested through flow of food and ecosystem services; exchange of material, information and knowledge among urban agriculture practitioners; interactions of urban agriculture with connectivity of social networks in communities; and collaborations among different social groups.	How do and what are the types, strengths and structures (for example, modularity, nestedness) of connectivity through which urban agriculture can bolster its social–ecological effects and resilience?	Urban agriculture practitioner Scientist Policymaker Non-profit Resident Retailer
Spatial synergies and trade-offs	Spatial synergies can occur when spatially aligning locations of urban agriculture practices with supportive infrastructure to facilitate its development. Spatial trade-offs can arise due to competing land uses with urban agriculture from different sectors and overall urban land scarcity.	How to take advantage of spatial synergistic effects and avoid trade-offs on both bolstering the developmental processes and positive outcomes from urban agriculture?	Urban agriculture practitioner Scientist Policymaker Non-profit Retailer
Nonlinearity	Many ecological and social processes are nonlinear and show thresholds at which small changes in drivers produce large and sometimes irreversible consequences for people and nature. Nonlinearity could occur in developmental processes of, as well as impacts from, scaling up urban agriculture.	How to identify nonlinearities to inform where, when and how interventions and shifts in values and social norms can trigger scaling up of urban agriculture and maximize social–ecological outcomes from limited resources?	Urban agriculture practitioner Scientist Policymaker Non-profit Resident
Scale	Scale (including spatial, temporal and organizational scales) could affect urban agriculture development. Research has revealed that social–ecological phenomena are scale dependent. Hence, the developmental processes and social–ecological effects of scaling up urban agriculture are contingent on the scale at which they operate (for example, a town, city, metropolis and megacity).	In which spatial, temporal and organizational scales does the upscaling of urban agriculture occur, what are the dominant factors operating at each scale, and what are the cross-scale responses of urban agriculture to changes and disturbances?	Scientist Policymaker Non-profit
Polycentricity	Polycentricity refers to a governance system with multiple governing authorities at differing scales. Polycentric governance can provide opportunities for enhanced learning and experimentation, and broader levels of participation. In the context of scaling up urban agriculture, it is key to embrace polycentricity in the implementation, management and governance.	How to design and build polycentricity while scaling up urban agriculture, and what are the structures and mechanisms through which polycentricity can improve social–ecological effects and resilience of urban agriculture?	Scientist Policymaker Non-profit Retailer

Detailed descriptions can be found in the Supplementary Information.

knowledge, evolves as an alternative to resilience that can be fundamental to understand upscaling of urban agriculture.

Reflecting on these concerns and based on landscape sustainability science, we highlight seven key considerations (Fig. 5 and Table 1) in reference to the developmental pathways that are relevant to research and practices of scaling up urban agriculture—diversity, heterogeneity, connectivity, spatial synergies and trade-offs, nonlinearity, scale and polycentricity (details in Supplementary 'Key considerations for scaling up urban agriculture'). Nonetheless, the specific roles of these considerations in promoting or hindering upscaling processes warrant more future investigations (exemplary research questions are provided in Table 1).

Conclusions

Fostering resilient and sustainable urban futures is pivotal to transitioning towards global sustainability. We argue that properly scaling up urban agriculture has the potential to induce transformative change towards sustainability through decentralizing urban food supplies, bolstering ecosystem services, mitigating transboundary environmental footprints and advancing urban resilience. To this end, we present an integrated conceptual framework for a holistic perspective of urban agriculture and devise plausible multi-phase developmental pathways to demonstrate dynamics, processes, accelerators and feedback in scaling up urban agriculture. These pathways should be perceived as working hypotheses, considering both divergent radical and neoliberal processes that operate in a co-productive manner and at different scales in shaping the outcomes of scaling up urban agriculture[63]. More interdisciplinary research and transdisciplinary process is needed to use and refine our framework and typology to analyse and cluster real-world urban agriculture development cases and their references to our pathways. Further investigation is also needed to empirically test, examine and validate processes and theories underlying scaling up of urban agriculture using innovative approaches—for example, retrofitting historical data, integrated scenarios, agent-based social–environmental modelling, participatory modelling, and latitudinal and comparative studies to analyse and contextualize real-world examples experiencing such large-scale transformation.

Current social–ecological research on urban agriculture is still in its infancy. Yet scaling up urban agriculture can be a critical window of opportunities for engagement and empowerment[23,25] to (1) question underlying logics and values that govern urbanization, land marketing, current food regimes and urban planning systems;

(2) enhance self-reflexivity and foster urban food movements and radical transformation of food systems to reconnect land access, food production, sovereignty, ethics and consumption; and (3) challenge neoliberal urbanism and advocate alternative urban economies and living recentred around food. It is necessary to have concerted actions for transformative change that take elements of resilience and resourcefulness thinking and transdisciplinary approach to help unite a range of actors[70,71] to experiment with and operationalize processes and pathways to scale up urban agriculture (for example, designing 'agri-urban systems' or 'agri-metro', transitioning towards agroecological urbanisms[72]) and forge more socially just and environmentally sustainable urban systems.

Methods

Literature search and screening

We conducted a systematic literature review to identify and synthesize published studies on ecosystem services and environmental impacts of urban agriculture. During the first round of literature search, we conducted a topic search in the Web of Science based on the terms related to 'urban agriculture' ((urban OR peri-urban) AND (agri* OR agro* OR farm* OR 'community garden*' OR greenhouse)) and 'ecosystem service' ((ecosystem OR ecological OR natur* OR environment*) AND (service* OR good* OR capital*), (biocontrol OR 'biological control') AND (pest* OR prey OR insect* OR herbivore*), (crop* OR fish* OR biofuel OR wood OR fiber OR fodder) AND (yield OR production OR productivity), (crop* OR fish* OR biofuel OR wood OR fiber OR fodder) AND (yield OR production OR productivity) AND (stability OR variability OR resistance OR resilience), (biocontrol OR 'biological control') AND (exotic OR invasive) AND (plant OR algae OR producer), (biocontrol OR 'biological control') AND (disease OR pathogen* OR infect* OR illness OR epidemic), (carbon OR C) AND (storage OR sequestration), photosynthesis OR 'oxygen production' OR 'O_2 production', flood* AND (control OR regulation), soil AND (fertility OR nutrient OR moisture) AND (remineralization OR cycling), soil AND (moisture OR humidity OR 'water retention' OR 'water consumption' OR drought OR organic), water AND (decontamination OR nutrient OR purification OR quality OR 'nutrient retention' OR 'nutrient loss' OR 'nutrient loading'), (pollination* OR pollinator*), erosion, 'greenhouse gas')). The data collection only contained peer-reviewed articles in the Web of Science databases and published in English, and the end date for the search was June 2021. The first round of literature search resulted in a total of 8,607 articles.

During the second round of literature screening, we filtered and selected articles based on identified criteria defining 'urban agriculture', 'ecosystem services' (or nature's contributions to people) and environmental impacts. These specific criteria include: (1) research on agriculture and food production, excluding other types of urban green space managed not for food purposes; (2) research sites were in urban and peri-urban areas, excluding research in the rural contexts (for example, those focused on conventional rural agriculture or row-cropping systems); (3) research of effects on ecosystem services (or nature's contributions to people), both within and across the urban boundaries; (4) research explicitly focused on environmental effects of urban agriculture across scales, excluding research using the urban agriculture setting as the background to explore other techniques' influences, efficacy or applicability (for example, those focused on testing a growing media, fertilizer or irrigation techniques); and (5) research with primary and quantitative data, excluding qualitative research and review. In the second round of screening and filtering, we read through the titles, abstracts and main texts of all papers with consistent implementation of these criteria as well as quality assurance/quality control procedures to ensure the inclusion of all possible relevant studies. As a result, a total of 105 papers met all of our criteria, and these articles were subsequently subjected to manual data extraction and analyses.

Data extraction and analyses

In data extraction, for each paper, we collected the location of the study area (country, city, coordinates), research method, scale of the study, type of urban agriculture, focal plant and animal species, management practice, proxy measured for every ecosystem service indicator and metric used in the life-cycle assessment. For studies with biophysical or environmental measurements (using either field observation or experiments), we extracted the proxy measured in the paper, including values (means, standard error/deviation if provided) and sample size or number of replications. For survey results (that is, mostly relevant for cultural ecosystem services), we extracted data including the respondents' type, response, sample size and social demographics. After data extraction, we matched the proxy to each category of ecosystem service and environmental impact. Based on our extracted database, we tallied and summarized the frequency of studies for each category, resulting in Fig. 2, which was created in R statistics software 4.1. Our purpose is to illustrate and synthesize the type and diversity of ecosystem services and environmental impacts associated with urban agriculture as documented in the literature.

Methodological considerations

In our literature review, we have strived to be transparent, comprehensive and inclusive in the search and screening process. However, it is worth noting that for a given qualitative literature review, the pool of selected papers for analysis might vary if different topical terms or filtering criteria are implemented, thus possibly leading to a slightly different set of knowledge being synthesized and consolidated. In particular, given the focus of our literature review and authors' background, the 'transdisciplinarity' has not been an explicit selection criteria in filtering and identifying papers. In addition, due to data quality and inconsistency of life-cycle assessment studies, future investigations are needed for more robust evidence of cross-scale effects from urban agriculture[73], which may be heterogenous and contingent upon local contexts such as climate, crop choice, management, production system and degree of technological integration[44].

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

All data used in this manuscript are made publicly available and deposited into Figshare at https://doi.org/10.6084/m9.figshare.24449713.

Code availability

All code used in this manuscript is made publicly available and deposited into Figshare at https://doi.org/10.6084/m9.figshare.24449713.

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Author contributions
J.Q. led the initial conceptualization of this work, and all authors contributed to the development of ideas. J.Q. designed the analyses, developed the visualizations and led the writing of the original draft. H.Z. conducted the literature search and screening of relevant empirical urban agriculture studies. All co-authors contributed to editing and revision of the manuscript.

Competing interests
The authors declare no competing interests.

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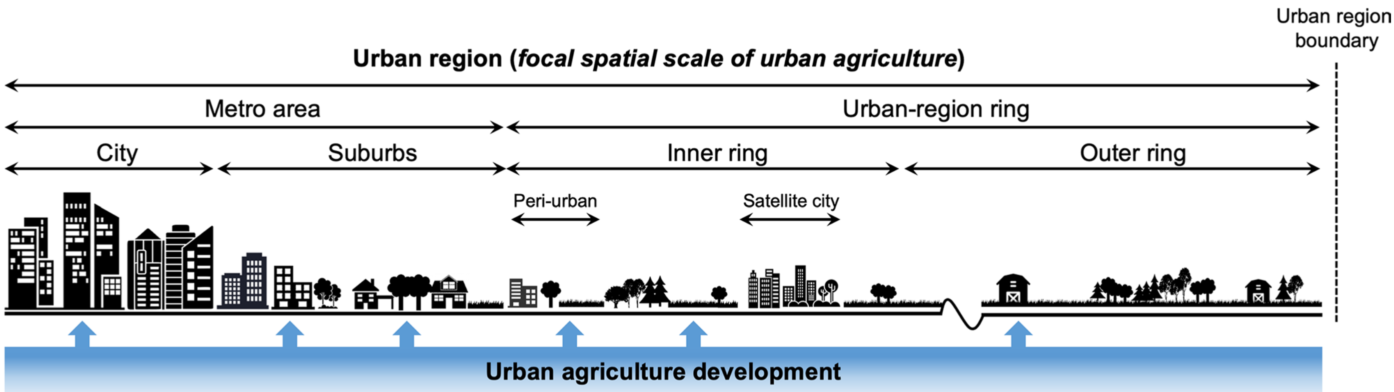

Extended Data Fig. 1 | Schematic diagram to illustrate the concept and spatial scale of the 'urban regions', at which urban agriculture is defined. Urban regions are essentially a large regional landscape encompassing a major central population center, a network of urban centers, and a mosaic of surrounding natural, rural, and production lands with internal heterogeneity and contrasting patterns. Different forms of urban agriculture practices can occur in locales (for example, as shown in arrows) along the spatial gradient of the urban regions.

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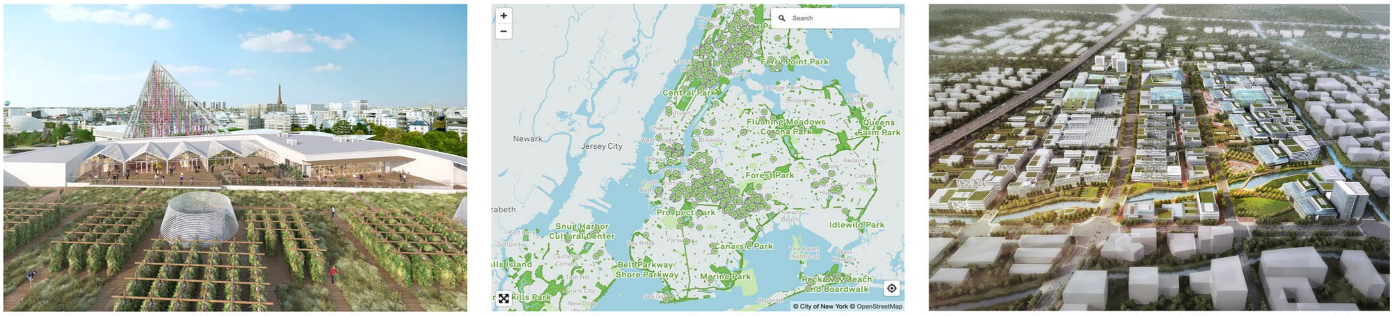

(A) Rooftop urban farm (14,000 m^2) in Paris, France (Courtesy of Valode and Pistre architects)

(B) Community garden network in New York City, USA (>550 gardens) (Courtesy of NYC Parks GreenThumb)

(C) Sunqiao Urban Agriculture District (100 hectares) in Shanghai, China (Courtesy of Sasaki)

Extended Data Fig. 2 | Nascent real-world examples of scaling up urban agriculture across the globe. Paris, France (A) has opened one of the world's largest operating urban rooftop farms to feed its residents and foster climate resilience; New York City, United States (B) boasts the most extensive network of community gardens (>550) to improve food access and life quality of residents and local communities; and Shanghai, China (C) has implemented the masterplans (construction began in 2017) to develop Sunqiao Urban Agriculture District (~100 hectare) with numerous large-scale vertical farming systems for feeding burgeoning urban populations and reducing external food dependency.

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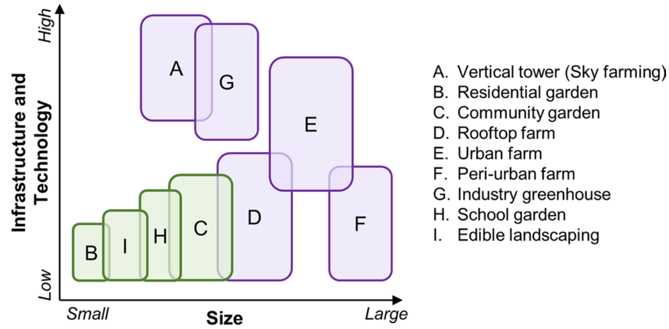

Extended Data Fig. 3 | Dominant urban agriculture types along the infrastructure and technology, and size gradients, with typical commercial (purple colored) and non-commercial (green colored) types. Size of the boxes is in relative terms, and approximates the common and representative range of each urban agriculture type along these two axes. The location of urban agriculture types along these gradients is determined based on qualitative notions of the authors after the comprehensive review of the contemporary literature, which may evolve over time.

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Data collection	R code used in this study was deposited into publicly available Figshare with DOI included in the manuscript.
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Study description	In this manuscript, we provide an interdisciplinary, systems, and social-ecological perspective to review the topic of urban agriculture by specifically focusing on the importance, cross-scale dynamics, pathways, and considerations of 'scaling up' urban agriculture.
Research sample	NA
Sampling strategy	NA
Data collection	We conducted a literature search on relevant papers published on the topic of urban agriculture in the Web of Science.
Timing and spatial scale	NA
Data exclusions	NA
Reproducibility	NA
Randomization	NA
Blinding	NA

Did the study involve field work? ☐ Yes ☒ No

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Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
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