FEW-meter

An Integrative Model to Measure and Improve Urban Agriculture, Shifting it Towards Circular Urban Metabolism

FINAL REPORT

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FOOD ENERGY WATER METER

FEW-meter, an Integrative Model to Measure and Improve Urban Agriculture, Shifting it Towards Circular Urban Metabolism

Project duration

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Project partners

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CNRS-IRSTV, Nantes / FR

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LEAP-micro AD Ltd, London / UK

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Content

Executive Summary

An increasing number of urban gardeners, farmers and community groups are committing themselves to growing food in cities to improve their health, their lives and their neighbourhoods. But while urban agriculture is expanding, the evidence of its impact and potential effects remains limited. To learn more about the environmental, economic and social costs and benefits of growing food in the city we developed the FEW-meter project - an Integrative Model to Measure and Improve Urban Agriculture Shifting it towards Circular Urban Metabolism. The project aimed to study the resource efficiency of urban agriculture by measuring food produced as well as energy and water use (FEW-nexus) and social impacts.

The research team comprised five countries: France (FR), Germany (GE), Poland (PL), the UK and the US. The team invited gardeners and farmers representing various forms of urban agriculture to participate in the project. They represent community farms from New York (US), community gardens, farms and allot-ment gardens from London (UK), allotment gardens, urban farms and school gardens from Nantes and Paris (FR), allotment gardens from cities of the Ruhr Area (GE) and allotment gardens, home gardens, urban farms and a school garden from Gorzów Wielkopolski (PL).

Together with gardeners and farmers, the research team gathered qualitative and quantitative data from March to October 2019 and 2020, including on water and fuel consumption, use of fertilisers, crops harvested and transport methods. We measured materials used for growing food such as timber for raised beds and plastic membranes for poly-tunnels and quantified their impact on the environment. The research team also interviewed farmers and gardeners to identify their motivations for practising horticulture. We also analysed planning and policy reports and papers to ascertain if and how the FEW-nexus is recognised or even embedded in policy. In addition, 16 experts from the five partner countries were interviewed.

To organise and store data we developed a multi-dimensional database, crucial to achieve the project goals which were as follows:

- to measure production efficiency of the case studies
- to model the material and energy flows of urban agriculture, as the basis for scenarios for upscaling production
- to measure social benefits of gardening
- to increase knowledge about possible health risks due to soil quality

Co-production of knowledge was a key part of the project. Gardeners and farmers involved cooperated with us to develop the FEW-meter system during workshops and meetings in each partner country, before and after the first year of data collection. Their advice proved to be crucial and their knowledge as citizen practitioners (not found in the academic literature) was immensely beneficial for us and the project.

Introduction

Collaborative research

The FEW-meter project was developed by an international consortium comprising researchers, practitioners, and associations in the urban agriculture sector from five countries: France, Germany, Poland, UK, and the US. The project was funded under the Sustainable Urbanization Global Initiative (SUGI), Food-Water-Energy Nexus call, established by a Joint Programming Initiative of the Belmont Forum and Urban Europe. The consortium´s submission proposed to investigate the FEW-nexus in urban agriculture. There are studies that evaluate the quantity of crops harvested but not many investigate the resource efficiency of growing food in urban environments. SUGI recognized the innovative character of our proposal, titled: „FEW-meter, an Integrative Model to Measure and Improve Urban Agriculture, Shifting It Towards Circular Urban Metabolism".

At the core of our project is the collaboration between researchers, farmers and gardeners. We invited associations to cooperate, such as the Polish Allotment Gardeners Association, the German Landesverband Westfalen und Lippe der Kleingärtner, which represent allotments holders in the regions of these countries where some case studies are located, Jardin des Eglantiers - a local French allotment garden association, Social Farms & Gardens (the UK charity representing community gardens and city farms), and Green City Force (a US based organization training young people from low income social housing communities to farm). Their insights, experience and dedication were invaluable and enabled co-production of new knowledge. They supported the recruitment of case studies, participated in workshops and, together with farmers and gardeners from our case studies, provided constructive feedback for the development of the project's methodology and data analysis.

Context

Urban agriculture (UA)—growing edible plants and raising animals for food and other uses in and around cities and towns, and related activities such as the production and delivery of inputs and the processing and marketing of products—has received increasing attention over the last decades as being able to provide multiple benefits [1]. There is evidence that UA can be highly productive, contributing to food security [2, 3]. Others have suggested that the social and economic benefits are more significant [4]. While UA is often described as environmentally beneficial, major challenges for soil-based or open-air forms of UA include exposure to pollutants [5] that may affect the quality of produced fruits and vegetables. Researchers have described UA as an alternative to the predominant, resource-intensive agro-food system. However, its potential to contribute to a regional-scale sustainable system of food production - more viable in terms of productive capacity – is still largely unexplored from a material flow and energy use perspective. Moreover, data are not widely available to provide urban farmers guidance on how to ensure that their projects contribute to urban sustainability. We are sure that a better understanding of urban agriculture and its position in the socio-ecological system of a city will contribute to the achievement of the United Nations' Sustainable Development Goals.

The Food-Energy-Water Nexus[1] is a term that captures the relationship between food and the resources needed for its production. Studies about the nexus focus predominantly on large geographical scales. At that scale, it is perhaps easier to fully understand the consequences of inefficiencies in the management of water basins, power stations and agricultural production. Agriculture uses 70% of the global freshwater [6]. Potentially, by redistributing water globally and avoiding excessive irrigation, yields could be increased up to 30% [7]. Water is key to energy generation too, and in some cases, food competes with energy for water supply. Studies on the nexus in UA are fewer; with some suggesting that UA is not very efficient [8]. An investigation of the UA FEW-nexus can help promote higher efficiency as well as the use of abundant urban resources currently wasted (e.g., rainwater, greywater, food waste and heat from buildings) [9].

A comprehensive system

The *main aim* of this project was to develop a comprehensive system to measure existing UA practices (i.e., the FEW-meter) and to create a digital platform enabling urban farmers to understand and improve the efficiency of their practices in terms of FEW-nexus. This involves measuring production efficiency; expanding knowledge about possible health risks due to soil contamination, and opportunities for enhanced resource use (e.g., more efficient use of organic waste); and using this system to ascertain and identify approaches to advance the performance of diverse types of UA. We achieved this aim through an extensive case study analysis developed in a transdisciplinary perspective, encompassing key factors of urban food production and its supply chains.

A second aim was to utilize data gathered through case study analysis to model flows of energy, water and other resources, complemented with surveys to measure changes in behavior (e.g., shopping and eating habits) within the selected case studies. This, and the analysis of the city-wide context, led to the identification of urban conditions favoring or impeding the optimization of the FEW-nexus as well as the improvement of the resource efficiency and reuse of waste and urban byproducts of UA practices. One key characteristic of this project was the co-production of the FEW-meter with urban farmers to ensure that it reflects their expertise and meets their needs.

Project objectives were:

- to develop the FEW-meter methodology;
- to form an online community of farmers enabling the gathering of data and the exchange of knowledge;
- to gather and analyze data from case studies;
- to develop two experiments within the case studies: growing food on contaminated soil in France and use of organic waste with an innovative micro anaerobic digester (mAD) in the UK;
- and to develop scenarios of optimal use of urban resources, based on an expansion at a city scale of UA practices in the project case study cities.

[1] The title of the call that funded this project mentions the Food – Water – Energy Nexus (FWE Nexus). In our project, we modified the sequence (FEW-Nexus). In this report, we use the FEW acronym; we mention the FWE Nexus only when we refer to the proposal solicitation.

Methodology and Co-creation

Urban metabolism as a framework

The methodology of the FEW-meter was developed in stages. The initial stage was a review of studies on the FEW-nexus and tools to measure it, with the aim of applying findings from this review to the development of a UA FEW-nexus tool. In the literature some nexus studies at an urban scale use urban metabolism (the flow of inputs and outputs) as an analytical framework. We decided to use such a framework for the FEW-meter. We also decided to add a fourth element to the urban agriculture nexus: people. In agriculture, especially at small scale, farmer knowledge and behaviour can have a great impact on efficiency in terms of resource use. This is especially the case in urban agriculture, where gardens and farms tend to be small and, more importantly, the attainment of social, health-related and ecological benefits is as valuable as food production. The diagram below (Table 1) shows our conceptualisation of UA, using the urban metabolism framework. The four elements of the urban agriculture nexus (food, energy, water and people) are presented as input and output flows.

In the following stage, we identified indicators suitable for each of the four elements of the nexus. This was attained through consultation within and outside the research team. The initial list was comprehensive and ambitious, including indicators on biodiversity, soil health, horticulture techniques and access to solar resources. Social indicators (or social benefits) covered four areas: education, health, community-building and economy. We drafted the final list, with a reduced number of indicators, after consulting with farmers and gardeners via five national workshops, in which the relevance of each indicator and the viability of the overall collection system were discussed.

A co-creational approach

Co-creating the modalities for data collection and storage was the final stage of the methodology development. We agreed that farmers and gardeners would collect data on food produced and resources used (i.e., a citizen science approach to research), and the research team would survey practitioners and volunteers to record social indicators and

	FOOD	ENERGY	WATER	PEOPLE
INPUTS	fertilisers pesticides compost animal feed	electricity fuel trips to garden trips to deliver food infrastructure	water rainwater groundwater	labour capital knowledge/ experience
OUTPUTS	crops animals compost	CO_2	wastewater	health education profit / jobs social bonds

Table 1
Diagram showing the four elements of the UA nexus as resource flows.

collect any other supplementary information. We designed a diary to transcribe quantities of crops harvested and resources used, but each country agreed with practitioners how to customise the diary according to farmers and gardeners' preferences. In some countries, they opted to upload the data digitally; others compiled a paper diary with data that was entered by research staff. The agreed timeline for data collection was between March and October over a period of two years, 2019 and 2020. These data were then uploaded to a cloud-based (online) relational database. After the two years of data collections, the database included about 50,000 entries, representing an invaluable resource for future studies. One of the aims of the project was mutual learning on how to attain a higher urban agriculture resource efficiency. We organized national workshops at the end of the 2019 data collection to present an initial analysis and discuss approaches for improvements in growing practices. These workshops were successfully run but COVID-19 changed radically the programme of the project, with some of the gardens and farms closing and others having to adapt their activities to the restrictions imposed by the pandemic.

The final FEW-meter methodology combined data collection and analysis and life cycle assessment. The data collection was both quantitative and qualitative: quantitative data captured food production and resource use; qualitative data, gathered through surveys to practitioners and volunteers, captured the perceived benefits from practising food production. We developed a life cycle assessment, which quantifies the flow of materials and energy and related environmental impacts, using quantitative data as well as an additional flow measurement: materials used for food production (such as timber for raised beds and metal and glass for greenhouses). For this, the research team measured all materials supporting food production. A further step of the methodology was the extrapolation of the data to estimate at a city scale the potential for food production and its impact on resources. This is attained by identifying suitable spaces over the urban surface area and by using the dataset for the quantification (see section 4).

We applied this methodology to a sample of 74 case studies across the five partner countries. UA is practised in different organisational types, mainly (but not only) allotments, community gardens and city farms. In this project, we gave a definition to each type, based on the destination of the food produced: in allotments, the food is consumed by the gardeners or distributed to friends; in community gardens the food is distributed among gardeners, volunteers, or local groups; in city farms, the food is sold. These descriptions enabled an analysis of resource efficiency (FEW-nexus) in relationship to each type's organisational structure.

Data Collection

Indicators for measuring resource-efficiency

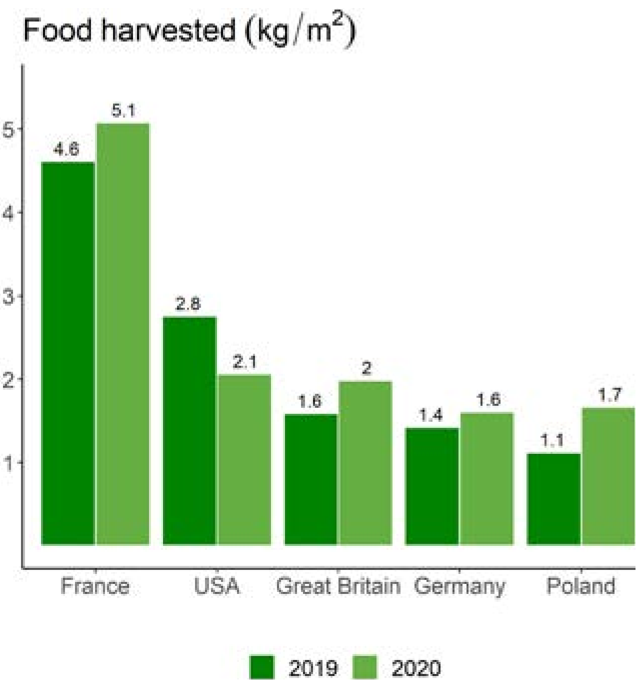
The list of indicators and the methodological approach that we developed to gather and analyse data, as outlined in the previous section, informed our measuring of the production of food, resource use (water, energy, fertilisers and any phytosanitary product, together with any material used to support food growing), trips to gardens and farms and the social impact of urban farming. These data were gathered using several methods, depending on the farmers and gardeners' preferences. The research team also collected secondary data such as climatic data and local food prices. All data were stored in a digital relational database enabling the partners to cross-check information and develop statistical analyses.

UA food production and water and energy use

74 sites were studied, presenting the following types:

- urban individual gardens such as allotment gardens and home gardens, owned or leased by individual gardeners;
- urban collective/community gardens such as community gardens, community farms and school gardens, where food produced is shared and the association is not-for-profit; and
- urban farms, where the produce is sold for profit.

Figure 1a/b compares the food productivity over two years, measured as weight/space (kg/m²) in each partner country and for each UA type. France has the highest yield, with 4.6kg/m² in 2019 and 5.1kg/m² in 2020. All other countries share a similar level of productivity, varying between 2.8kg/m² (US) and 1.1kg/m² (PL) in 2019, and between 2.1 kg/m² (US) and 1.6 kg/m² (D) in 2020. All countries except the US (with some farms affected by the COVID pandemic) show a higher yield in 2020 in spite of the effects of the pandemic on production.



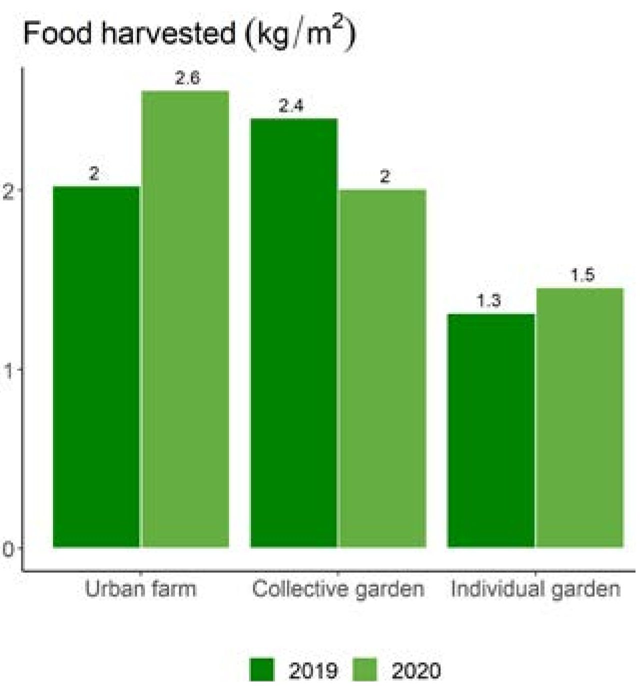


Figure 1a/b
Total food harvested per m² productive space
a) by country and b) by UA type (in 2019 and 2020)

Data collected to record water use was not always reliable. France had a very high use of water per m² compared to other countries, and the UK also has high water use when compared to the US, Germany and Poland (Figure 2a/b). The variation between the two years studied is very high in the US. Data was also compared between UA types. Commercial farms used more water per m² but had a higher food yield per m². All types show an increase in water use between 2019 and 2020. There is also a progressive increase in water use from allotment gardens to community gardens to school gardens which need to be compared to their productivity gradient. In the US and in the UK sites, water mainly comes from municipal water. Polish case study sites use a high proportion of groundwater from wells. German sites use more rainwater than the sites in the other countries (Table 2).

Figure 2a

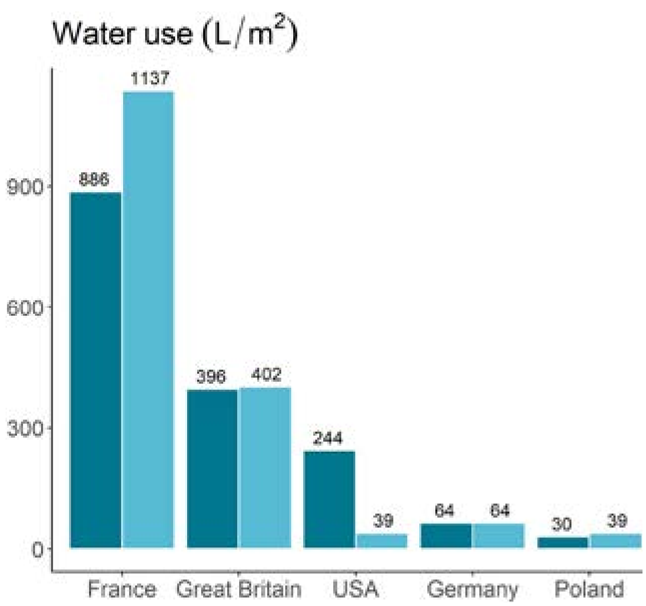


Figure 2b

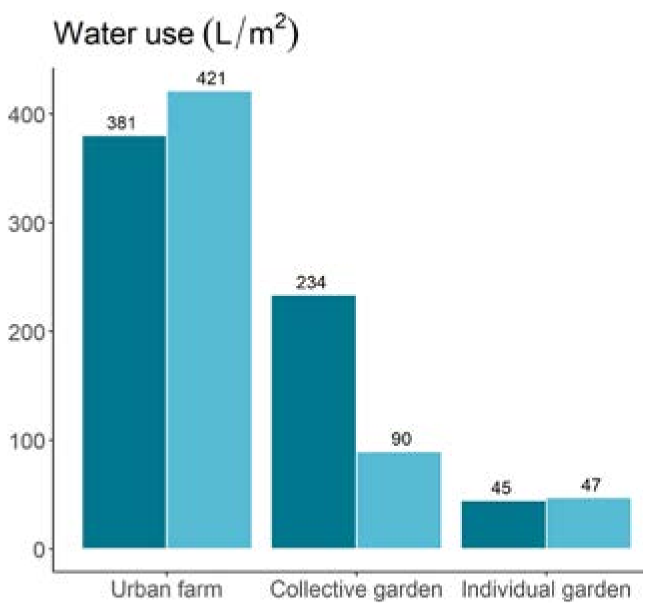


Figure 2a/b Water used a) per country and b) per garden/farm type (in 2019 and 2020).

	Municipal water (potable and non-potable)	Groundwater	Collected water (rainwater and other)
France	94,2%	-	5,8%
Germany	58,4%	24,8%	16,8%
Poland	6,8%	86,9%	6,3%
Great Britain	99,8%	-	0,2%

Table 2 Type of water used for irrigation of gardens and farms, by country.

The survey of the trips to the farms and gardens showed public transport as the most common means of transportation in the UK and the only one in the US, with the exception of a few farmers traveling by foot. Bicycle use is relatively high in Germany and France and the car is used extensively in all countries except the US (New York). Walking is more frequent in Germany (Figure 3a/b). The mean distance from home to garden or farm (coming and going) is less than 25km.

Figure 3a

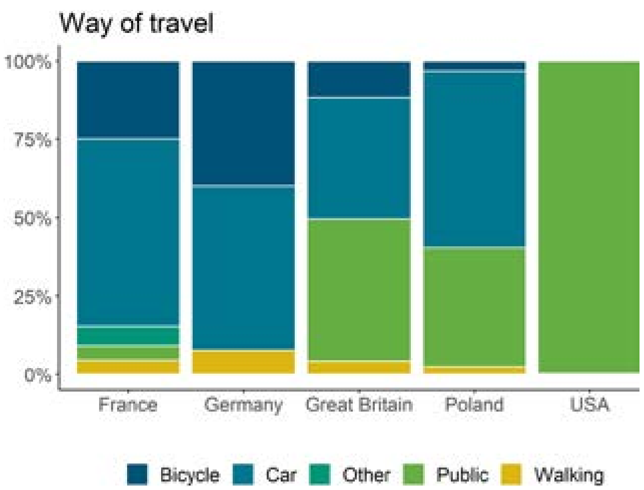


Figure 3b

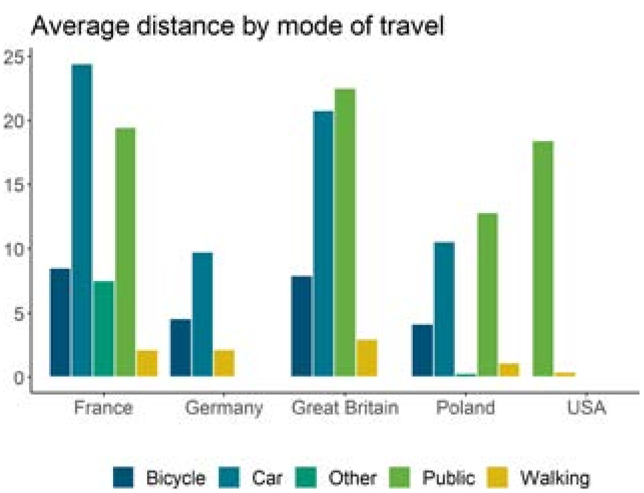
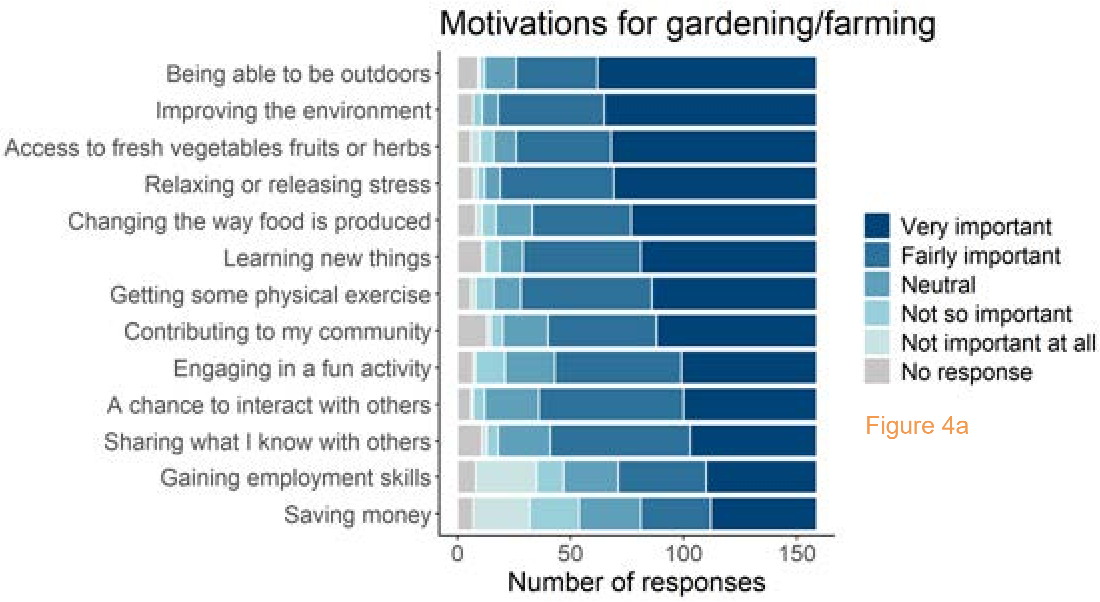


Figure 3a/b
Method and distance of travel by gardeners and farmers, by country.

Social indicators

A specific survey was conducted to quantitatively assess the relationships between UA types, farmers and gardeners' motivations, and the social impacts of urban agriculture [10]. Through factor analysis, we established valid and reliable measurements of participants' motivations and impacts. We identified four areas: general wellbeing, nutritional health, economic interests, and socialisation motivations. Through multivariate analysis of variance, we documented significant differences in motivations and reported impacts across types of urban agriculture. Finally, we conducted a multilevel multivariate analysis to explore the predictors of general wellbeing.

Results indicate that farmers and gardeners engage in UA with multiple motivations and experience largely positive impacts. There are significant differences in motivations and impacts across participants in different types of UA (Figure 4a/b). Economics and nutritional health are comparably weak drivers, while the strongest self-reported impacts related to a range of general well-being benefits. Different motivations and impacts are reported in different types of urban agriculture—socialisation motivations dominate in communally farmed spaces and economic motivations dominate for employees rather than volunteers. Stronger socialisation motivations and economic interests predict higher general wellbeing benefits. Different models of urban agriculture attract participants with different needs; it is therefore possible with careful planning and incentives to match urban agriculture types with local needs. For urban planners and garden organisations interested in urban food production, understanding the social impacts of urban agriculture, that is, the impact beyond the value of food produced, is essential to justify land access, funding and protection of these spaces.



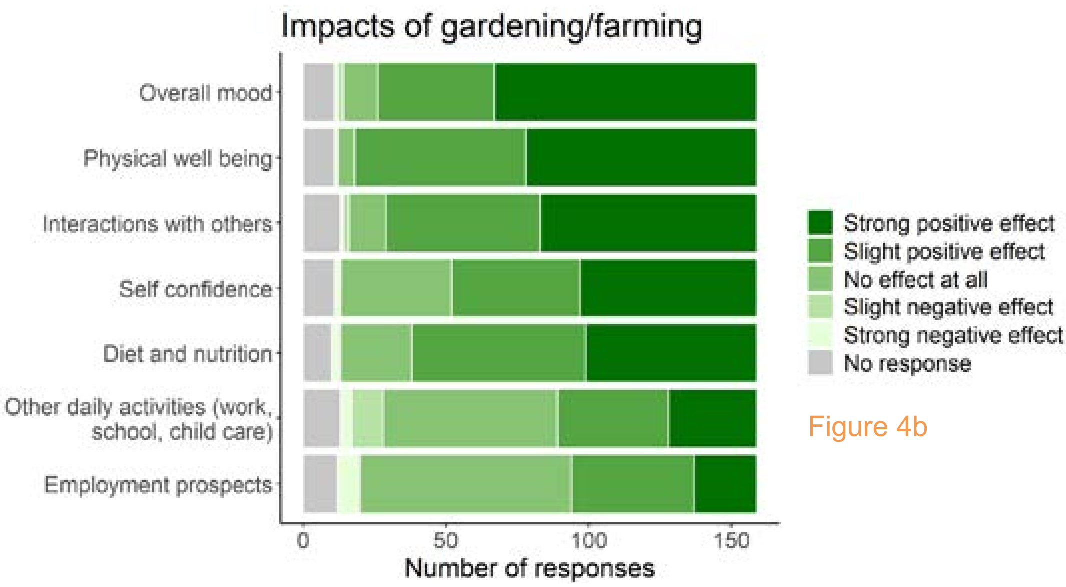


Figure 4a/b
Motivations and impact of urban agriculture on gardeners and farmers in the 74 studied sites.

Material Flow Simulation

Calculating the environment footprint

With data from the survey of all materials used for food production we developed a material flow simulation with two primary objectives:

- to estimate environmental impacts embodied in different urban food production systems (and identify key contributors to this impact and points of leverage for intervention); and;
- to conduct a material flow analysis in each city, tying these flows to larger urbanisation trends and scoping the potential role of UA in determining future urban FEW metabolisms.

Consequently, we developed a life cycle assessment (LCA) of several different forms of UA; and we analysed opportunities for "scaling up" (i.e. expanding) UA in five case study cities.

The LCA of UA at each of the case study sites will be the largest LCA of UA to-date and is being prepared for submission to Nature: Food in 2022. The life cycle inventory and impact assessment will be made publicly available as supplementary data. Due to COVID-19, results from 2020 will not be used. Results from the 2019 data indicate that, while the carbon footprint of vegetables in American, German, and French supermarkets is relatively consistent, significant variation in carbon footprint exists between UA types (Figure 5). For this material flow analysis, we adopt the same farm/garden typology as presented in the Data Collection section of this report (see page 9). To date, our analysis has only extended to carbon footprint, but future iterations will include energy intensity and synthetic nutrient inputs. We will also include comparisons with produce sold at supermarkets in the UK and Poland and include fruits alongside vegetables.

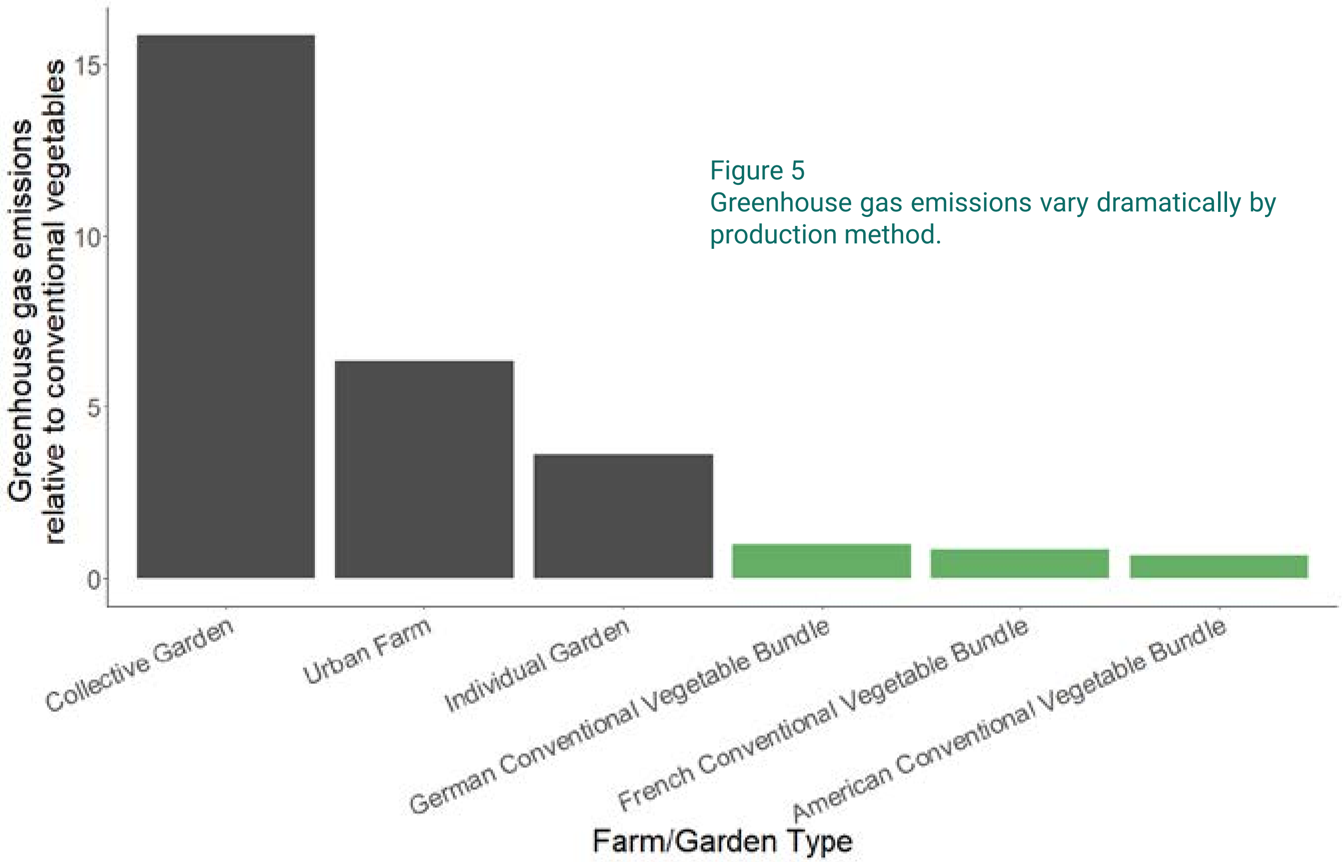


Figure 5
Greenhouse gas emissions vary dramatically by production method.

In our sample, collective gardens and individual gardens are significantly ($p < 0.05$) more impactful than conventional agriculture while crops produced by the urban farms are statistically indistinguishable from conventional vegetables due to high variation in impacts across that subsample. Urban farms and gardens in our sample grow many types of crops, making them difficult to compare to conventional agriculture monocultures. We address this difficulty in two ways. First, as shown in Figure 5, we construct "bundles" of conventional crops found on supermarket shelves. Conventional vegetable bundles are constructed based on the most-consumed crops in each country. We constructed conventional vegetable bundles by country because each country employs slightly different growing systems and imports crops from different areas of the globe. Each crop had to first be analysed individually before being bundled together to create a weighted average per kg of vegetable at a supermarket. This has led to the construction of a database of several hundred conventional LCAs, which will also be made public after the publication of the deliverable.

The second form of comparison occurs at the level of individual crop. To compare our urban agriculture results to these individual crops, we can use several forms of allocation, meaning that we assign impacts to crops based on the proportion of output from a farm. In this case, we measure output in three ways: by mass, by economic value, and by nutrient/calorie output. All three allocation schemes yield similar results, and the implications of our study do not vary by allocation strategy.

In addition to our findings related to variation across types of farms, we have also identified farm infrastructure (e.g., raised beds, greenhouses, pavement, etc.) as the primary source of UA greenhouse gas emissions (Figure 6).

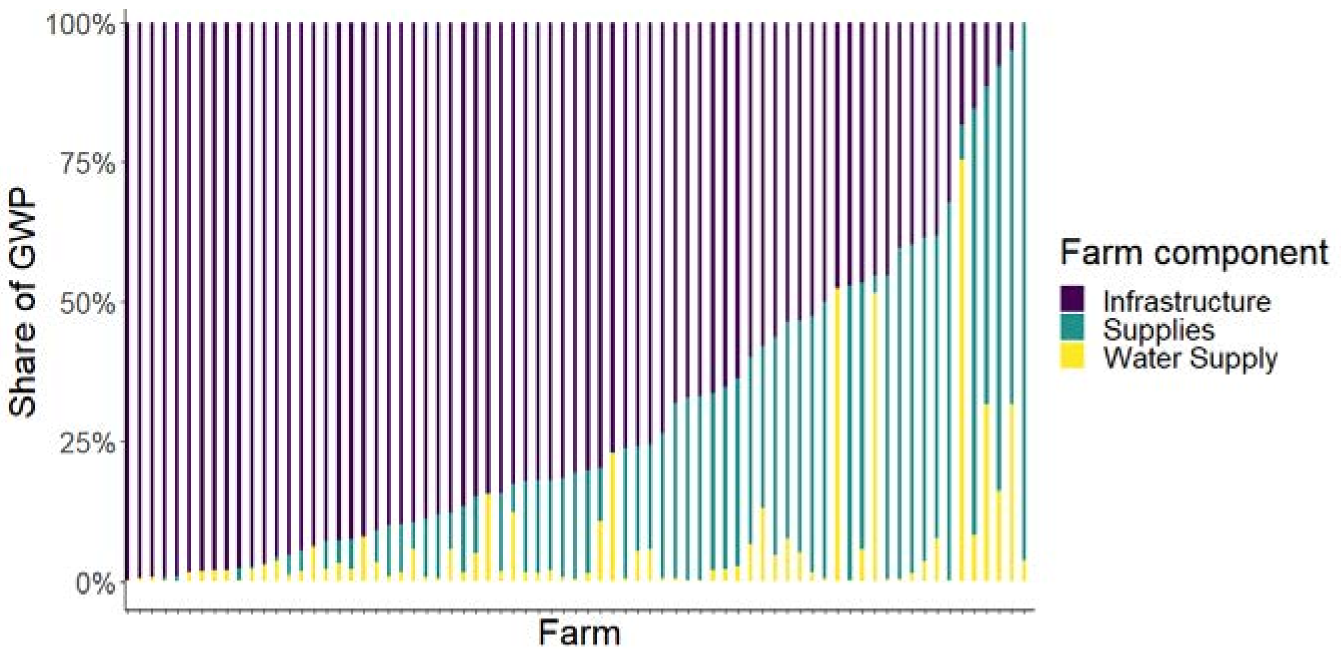


Figure 6
Infrastructure dominates the greenhouse gas emission footprint (global warming potential (GWP) in the figure) of most farms studied.

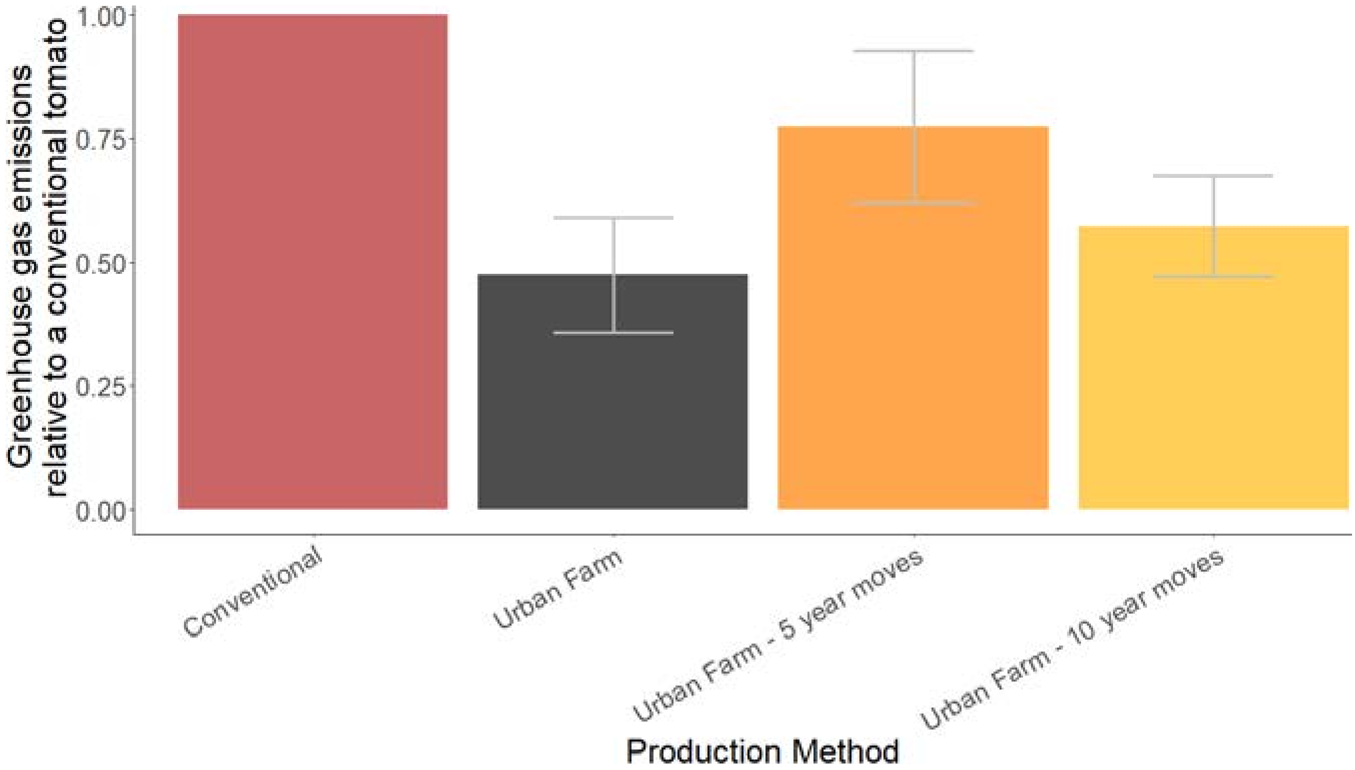


Figure 7
Greenhouse gas emissions of urban-grown tomatoes are highly sensitive to farm longevity.

The role of infrastructure

Since the infrastructure tends to be long-lived, one particularly concerning conclusion of our work is that UA impacts grow dramatically if UA is relocated frequently (Figure 7) as UA can be an interim or ephemeral land use. Due to the importance of infrastructure in the carbon footprint, moving the farm at five-year intervals (the orange bar) yields a higher ($p < 0.05$) carbon footprint than allowing a farm to stay in place for several decades (the grey bar). We are unable to detect a difference between urban farms that move at 10-year intervals and those that remain in place indefinitely. Therefore, farms must remain in place for at least 10 years to avoid significantly raising the carbon footprint of urban crops.

Scaling-up UA – the New York example

Based on this material flow analysis and the social benefits assessment presented in Section 3, we intend to assess material and social flows at the city scale. To accomplish this, we first plan to assess the potential for urban agriculture to scale-up (i.e., expand) in each city. This is being accomplished through collection and assessment of remotely sensed secondary data. We have developed an initial model of New York City (NYC) to test our data and methods (Figure 8).

A bounty of flat roofs and relatively flat land mean that nearly a third of NYC might be suitable for expansion of UA, but plentiful trees mean that crop selection may be limited in some cases. Preliminary analysis revealed land availability for more than 60,000 farms and gardens resembling those in our sample. These farms and gardens could meet up to 10% of the city's non-tropical vegetable demand, with corresponding significant increases in the city's climate and water footprints (expanding existing impact by >5% at maximum extent). Those same preliminary results indicate that energy demand impact is likely to be minimal for farms of the type seen in the New York case studies (expanding existing

demand by <1% at maximum extent).
These impacts were calculated based on the results of the LCA. Similar models are in development for the remaining FEW-meter case cities.

A recent systematic review developed by a project partner suggests that our contribution of 74 new urban farm/garden LCAs could nearly double the existing knowledge base [11]. Furthermore, the assessment of potential scaling across contexts is novel in the context of UA. As part of our broader framework of co-production, these results will be packaged for use by project partners as they work to improve garden efficiency.

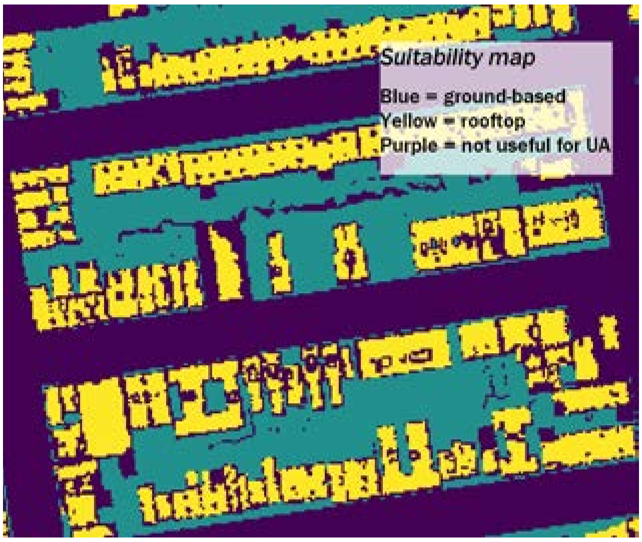


Figure 8
Side-by-side, the satellite image and suitability map of this Brooklyn neighbourhood show large areas possibly suitable for urban agriculture.

Policy and Cost-Benefit Analysis

Significant differences in policies among the five case study regions

Food, energy and water are key to three of the UN Sustainable Development Goals (2, 6 and 7 respectively) and are widely recognized as human rights. Yet, despite extensive scientific evidence on the nexus, the knowledge about policies affecting the FEW-nexus in the context of UA is very limited. Optimising the nexus between food, energy and water is expected to improve efficiency, support reimagined resource management (e.g., sewage disposal), and address social issues, from public health to economic development [12]. This part of the project focused on the cities` food, energy and water policies, including those that are indirectly relevant (second order) such as green infrastructure and climate change resilience policies.

The main goals of this research were
- to understand how governance and the policy environment in different national contexts and at different spatial scales shape the resource-efficiency of UA; and
- to explore which types of policy are most efficient in promoting resource-efficient UA.

For each country, partners collected national and local documents such as food policies, sustainability agendas, urban development plans, and strategies that potentially influence resource-efficiency in UA, resulting in 78 policies identified. These were organised along an analytical scheme developed, tested and modified by the research team. We analysed the policies´ spatial context and framework conditions, e.g., the origin of the regulation, the spatial level and the type of policy, and the effects of these policies in relation to the FEW-nexus and UA generally.

Results indicate that there are significant differences among the five case study regions in the number of policies and the integration of the FEW-nexus, with overall most policies focusing on the local level (Figure 9). This is not surprising as cities are increasingly enacting food policies, often including local food production considering land use which regularly is regulated at local level.

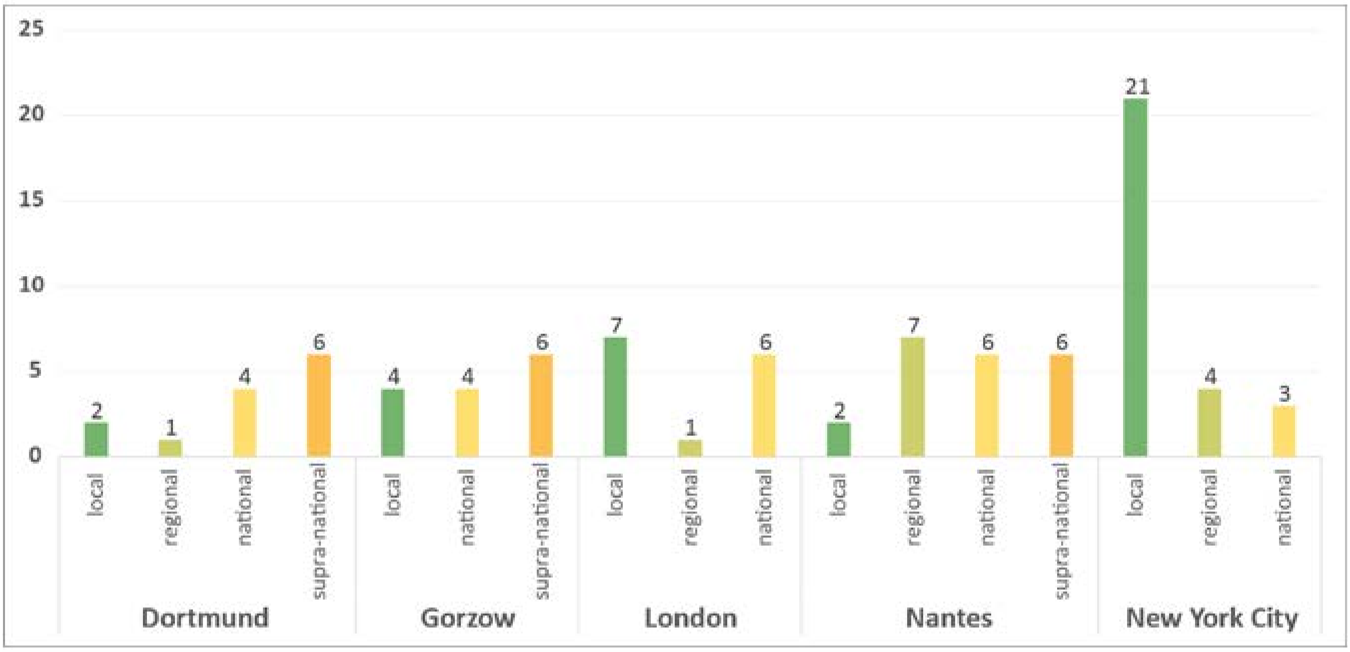


Figure 9 Level of policies in the case study regions.

We classified policies as: regulations (i.e., laws or rules), funding or incentive-based (e.g., funding schemes), and awareness-increasing (e.g., campaigns). We noticed that most of the policies that affect UA in the FEW context are regulations, followed by funding or incentive-based and then awareness-increasing policies. There are significant differences between case study regions (Figure 10), probably due to different planning cultures. For example, the majority of NYC's local policies were funding or incentive-based, based on a existing zoning permitting UA while for London we characterised a majority of policies as awareness-increasing. Most policies in Nantes, Dortmund and Gorzów case studies are regulations, influenced by the supra-national, mostly regulative, EU policies.
To answer the question: which types of policies are most promising to promote resource-efficient urban agriculture we asked 15 experts to rank policies in an online survey (Qualtrics) using the Q-Sort method.
A set of 16 policies was derived from the inventory of 78 policies, and included an equal number of policies from the regulation, awareness-increasing and incentive-based types. Respondents could select one policy as the most effective and one policy as the least effective, and select in between, to achieve a typical normal distribution. Experts ranked regulations as the most effective type. In the other types only those policies that directly addressed UA were ranked high.

Nexus-thinking in UA-related policies

A major obstacle in the development of effective nexus policies is siloed decision-making bodies that lead to compartmentalised policies that fail to address food, energy, and water simultaneously. That is why we also examined if the policies collected relate directly or indirectly to only one element of the nexus, such as food or water or if they apply a more encompassing approach by focusing on more than one nexus component.

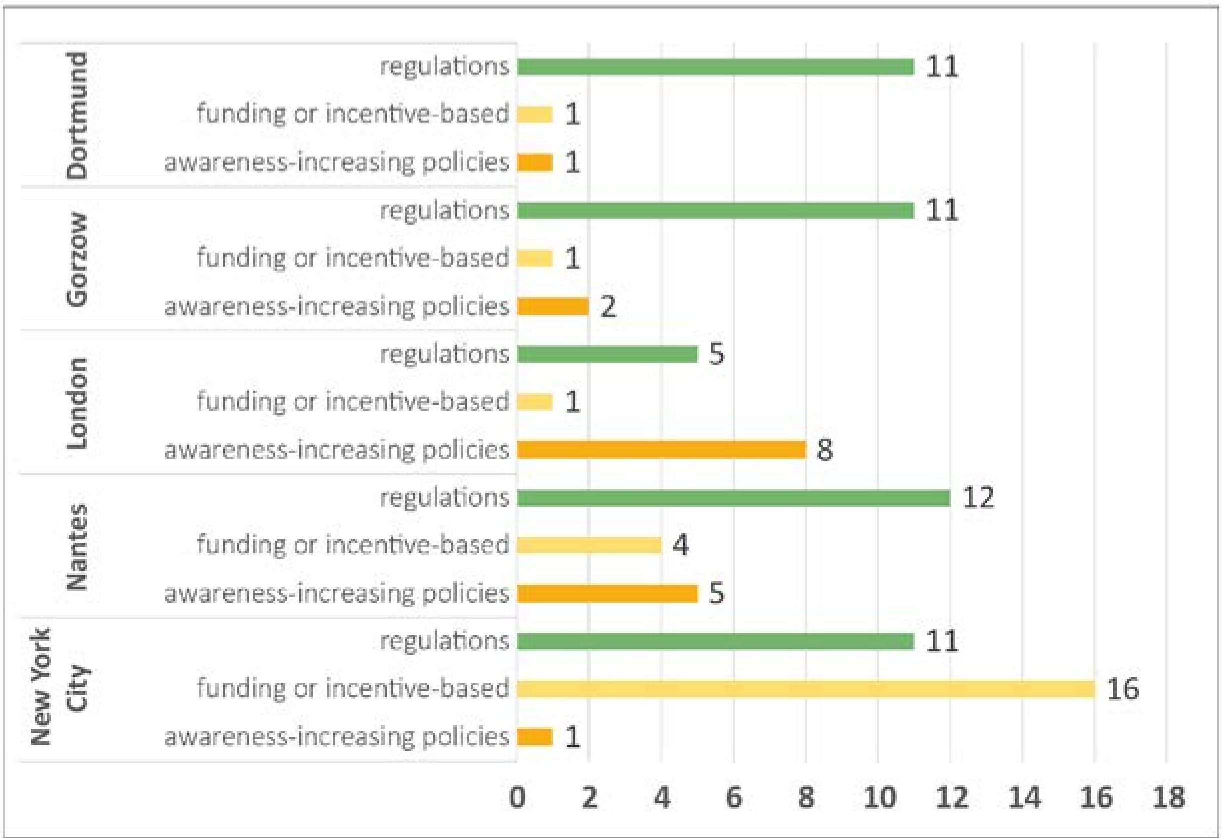


Figure 10 Number of policies along three main types in the case study regions.

In our inventory, 34 policies consider only one element of the nexus, while 25 include two and 19 include all three elements of the nexus. None of the six EU policies takes into account all three nexus elements. Overall, policies that consider all three elements of the nexus and follow a more holistic view are rare (Figure 11).

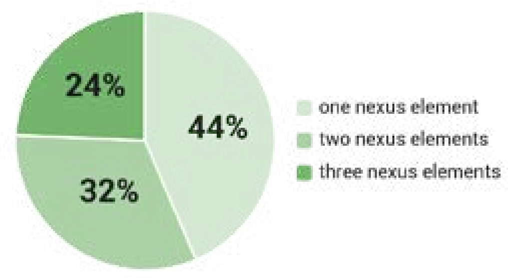


Figure 11 Number of policies considering one to three FEW-nexus elements.

To sum-up, our analysis of policies shows that policies directly or indirectly focusing on UA can have a crucial influence on the resource efficiency of UA but also point to the fact that nexus thinking is not yet established in the policy environment of UA. It can be assumed that nexus considerations will gain importance in the food system due to climate change mitigation and adaptation and concerns about food security and malnourishment. The share of nexus-related policies indirectly targeting UA implies the potential for better integrating UA in the future. The detailed results of the research conducted in this part have been summarised in a scientific paper that has been submitted for publication.

Cost-benefit analysis (CBA)

As a contribution to the debate on the monetised benefits of community gardens, the FEW-meter project also made use of a social cost-benefit methodology to value the social benefits emanating from one garden in central London and to combine this with the monetary value of fruit and vegetables produced [13]. The method is used to calculate the public value return on investment achieved by the garden and assesses the policy implications of the resultant cost-benefit ratio. The research was published in Sustainability in 2020 (https://doi.org/10.3390/su12135452).

The research uses an 'off-the-shelf' tool for calculating a public value return on investment ratio of costs to benefits of 1:3 [14]. The analysis values the physical and social output from the case study community garden and its value is in highlighting the important contribution that community gardens make to society and in its use for comparison, for the same garden over time and between gardens with similar objectives and activities. It also offers potential as a tool to aid activity and infrastructure planning within urban farms and gardens, as well as policy and urban planning in a wider sense. The analysis shows:

- Community gardens can provide social support services at times when the UK government – as well as many other European governments – curtail state intervention. The analysis shows the value of the benefits such gardens offer, which would be significant if scaled up across London.
- Community gardens have the potential to play a significant role in the three main policy areas receiving focus from the UK government: health, climate change and environment and community cohesion/

development. The analysis shows the value of social outputs as well as the fiscal savings possible from reduced hospital admissions.

- Social CBA can be used by gardens to assist with internal planning of regular groups and less frequent events and can provide the hard evidence needed for future funding applications.

The impact of the COVID-19 pandemic on UA case studies

We decided to investigate the effects of COVID-19 on our urban agriculture case studies as well as the city regions in which they are located because we expected significant changes that would alter farm productivity and social impacts of the gardens and also change a perception of the significance of UA within the cities. We took a two-way approach:

- To gain information from gardeners and farmers about their experiences during the pandemic, we developed a survey about the impacts of COVID-19 on their individual gardening activities. This survey was distributed to the participants in the FEW-meter project. The survey was adapted to community and allotment gardening and its administration was tailored to social distancing and research constraints in each of the participating countries.
- In each of the five countries, we added questions to the interview guides for policy stakeholders about the general effects of the COVID-19 pandemic on urban agriculture activities in their city region.

Results are published in Schoen et al., 2021 [15]. They show a differentiated picture.

Within allotment and community gardens efforts were made to keep the sites open for as long, and for as many volunteers and gardeners, as possible, where restrictions allowed. Just as with national governments, urban growing spaces adapted to the changing situation. Allotment gardens offered an important contribution to city resilience, especially during the lockdowns for those without gardens, when these spaces were often the only option for parents to find outdoor space for their children.

Urban community gardens at their best provided both food and, perhaps more importantly, social activities when these services were required more than ever. Community gardens grew and adapted to whatever obstacles they encountered, finding alternative means to meet their regular and newly acquired objectives.

Experiments

Two small-scale experiments were carried out within the project, opening up two perspectives for FEW-nexus: 1) considering the quality of the soil to ensure the production of healthy food and avoid health risks, and; 2) improving energy efficiency through waste recycling.

- **Experiment 1** was carried out in an allotment site (one of the project case studies) and therefore in connection with the community of gardeners who could learn from it.
- **Experiment 2** was embedded in the activities of a community garden (one of the project case studies) and directly affected both awareness and water use patterns of the community of volunteers.

Both experiments successfully trialled approaches to scientific research that directly involve civil society.

Experiment 1: Phyto-remediation

In 2019 and 2020, a phyto-remediation experiment was conducted on the "Eglantiers" allotments site (Nantes, France) to test a crop system capable of remediating a moderately lead (Pb) contaminated soil by phyto-extraction.

Chosen crops - tomato and butternut squash - were tested in "garden squares" on two different soils, both showing moderate Pb contamination levels: Eglantiers soil with geogenic (=natural) contamination and another one showing anthropic contamination.
The experiment's aim was to test the limits of phytoextraction and identify levels of Pb accumulation in fruit grown in those soils, the efficiency for phytoextraction of the crops selected, and their suitability and safety for consumption.

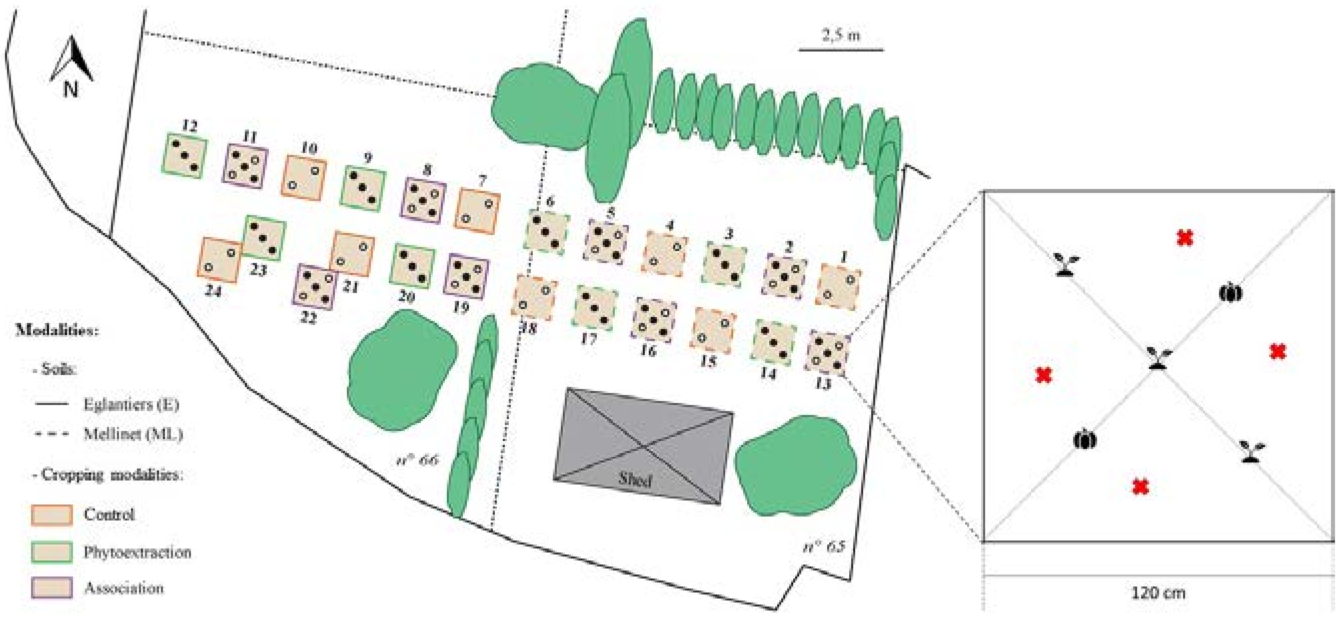


Figure 12
Experiments implemented on plots of the Eglantiers allotment gardens, comprised of 4 replicates of 3 crop treatments: Association - association of butternut and tomato, Phytoextraction - only tomato and Control - only butternut.

The crops grown were tested in three modalities (**Figure 12**):

1) Association - growing butternut and tomato at the same time;
2) Phytoextraction - growing only tomato; and
3) Control - growing only butternut.

Each treatment was repeated four times.

At the end of the experiment, vegetables were harvested to determine their lead content. The tomato plants were separated into shoots and fruits and butternut into fruits. They were all rinsed with tap water, deionized water, and, lastly, ultrapure water.

The harvested fresh masses were weighed and dried at 40°C until reaching constant mass. Moreover, one composite vegetable sample was extracted per garden square. The harvested samples were washed using the three types of water, stored at -80°C, coarsely crushed and lyophilized. They were then reduced into a fine powder for analysis.

Results

- For both fruits, the amounts of Pb were under the EC regulatory thresholds (0.1 mg/kg FM) (Figure 13). Thus, they were safe for consumption.
- Pb accumulation in the fruits was not significantly different between both soils. But there were significant differences between modalities: for tomato (between phytoextraction and association) and for butternut (between control and association). These results did not show that the Pb origin affects Pb accumulation in the fruits.
- Pb amounts were higher in tomato leaves developed on soil with anthropic Pb contamination (Figure 13), possibly because Pb in this soil is more available. The experiment shows that tomatoes can store Pb in the leaves leaving the fruit suitable for consumption.

Conclusion

These results show that, with a correct selection of crops and management, it is possible to produce safe food with low Pb amounts under the EC regulatory threshold in slightly contaminated urban soil.

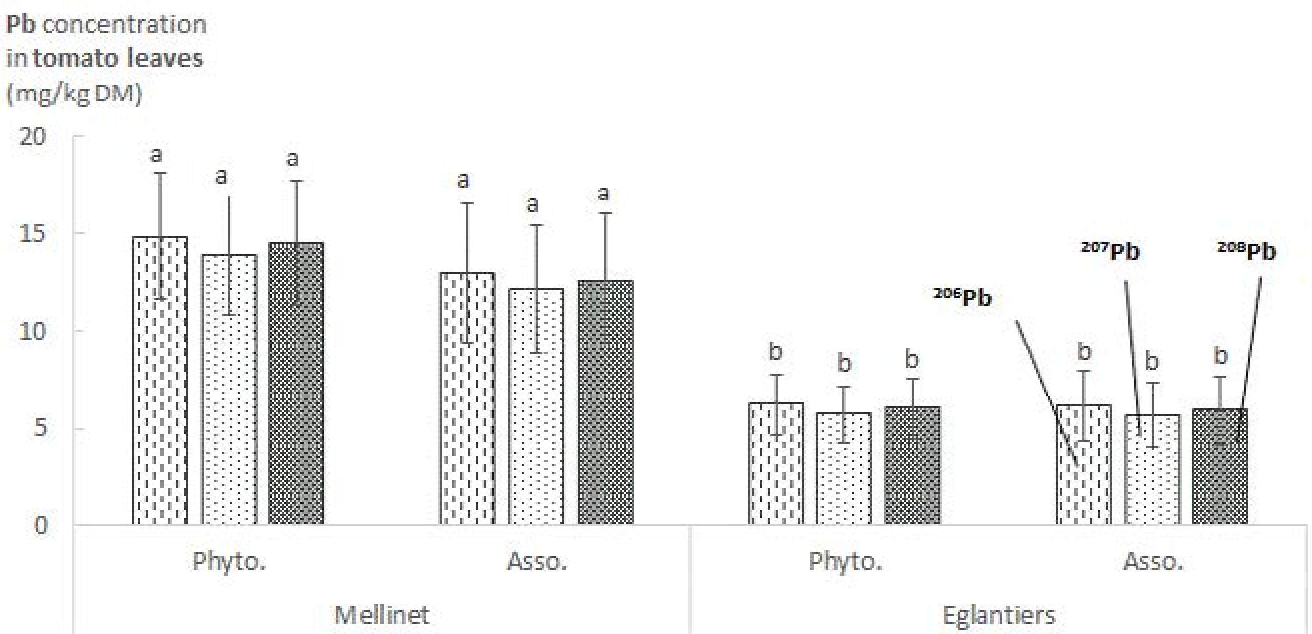


Figure 13 Pb concentration in tomatoes leaves.

Experiment 2: Anaerobic digestion

LEAP Micro AD was an industrial partner within the FEW-meter project. They experimented with anaerobic digestion (AD) as a technology with a pivotal role in supporting resource efficient urban food production, hence an optimal FEW-nexus. AD is a technology with some drawbacks, especially in urban environments with reduced land or space availability. These drawbacks are that very little waste volume reduction occurs during the AD process; and inadequate training leading to operators causing AD plant failure.

To address these drawbacks, in this experiment, LEAP developed:

- a cost-effective technology recovering water, concentrating nutrients, and reducing digestate volume. The digestate was subsequently trialled as an effective nutrient for crop production;
- training modules alongside educational workshops, low-cost control and touch screen data entry, and an online monitoring system.

A randomised control trial was executed comparing three treatments: raw digestate, filtered digestate and water only. A moisture meter was used to assess irrigation levels needed on a weekly basis. Raw digestate helped the soil retain water, thus requiring far less irrigation than crops fertilised with filtered digestate or irrigated with water only, showing the critical role of fibre and organic matter in improving soil structure and minimising water use (see Table 3).

Results of the trial show:

- The whole/raw digestate treatment helped soil retain the most water requiring 44% less irrigation than the control (water only) treatment.
- The raw digestate treatment required 15% less irrigation than the filtered digestate treatment, demonstrating the role played by the removed fibre in maintaining soil structure.

These relatively simple but valuable findings led us to re-evaluate the importance of soil health, rethink our AD design approach, and integrate AD with composting in a way that accelerates both processes.

Total use of water per irrigation method/l	
Water	148.35
Filtered digestate	98.36
Raw digestate	83.20

Table 3 Irrigation compared across three treatments.

The low-cost control and monitoring system developed for this project was trialled across three AD plants. While some low-cost components (Arduino, Raspberry Pi) were robust and reliable, other cheap electronic components were problematic. In addition, Electrical interference became an issue. In response, work began on a low-cost PCB (printed circuit board), which was developed under a future project.

Conclusions

The AD technology trialled is scalable, and market research has uncovered a very significant need for larger plants to improve their economic viability. Cost effective nutrient recovery would add another revenue stream for farmers needing to diversify, but far larger benefits would come from the reduction in volume of digestate through the recovery of greywater.

Conclusion

In this report we have summarized the results of a 3.5-year research project on the resource efficiency of UA. We believe that the outcomes of this project are valuable. In particular, we highlight the following:

- We demonstrated the importance of introducing the human element in this UA nexus study, and we coined the acronym FEWP to capture our methodological approach to data collection and analysis [12];
- We recruited and worked with 74 food gardens and farms across five countries to gather quantitative and qualitative data, trying to identify patterns across diverse types of urban agriculture (allotment, community gardens and community farms);
- In these gardens and farms, we measured all materials constituting the infrastructure that supports food production and related social benefits to assess its environmental impact;
- We analysed the policy view of the UA nexus by interviewing experts, analysing the interviews and identifying factors that are key for the promotion of resource efficiency and the scaling up of urban agriculture;
- We developed a simplified cost-benefit analysis tool and applied it to a case study;
- And finally, we worked on two experiments: growing food on low-contaminated soil and organic waste/anaerobic digestion. These two experiments are valuable because they focus on urban soil quality and food safety, which is a key concern for providing healthy food grown on urban soil; and on organic waste recycling and nutrient recovery. Waste is a component of the UA nexus that was not sufficiently studied within our FEWP-methodology and that is bound to become even more important in the effort to lower the impact of urban food production.

We believe that we have been productive, although results of our investigation are not always positive. They suggest, for example, that the environmental impact of urban agriculture can be substantial, and productivity sometimes low. But the social benefits of UA are significant. More importantly, the identification of inefficiencies and the development of nexus profiles of diverse agriculture types is an important finding that can be used to improve performance and provide evidence to practitioners, policymakers and researchers. In fact, we are aware that we only scratched the surface and we do hope that this report and the detailed documentation of our projects in open access articles will enable other researchers to further advance knowledge in this field.

This project would not have been possible without the dedication and keen interest of the farmers, gardeners and associations with which we partnered. In fact, we believe that through constant collaboration with farmers, co-creation workshops and webinars (documented in the dissemination section) not only we succeeded in co-producing new knowledge, but we also formed an international network of experts in urban farming. We are particularly proud of this last outcome.

Annex

FEW-meter project partners agreed to make results of this project available to a wide community of users such as the scientific community, the funding bodies, policy-makers at different levels, garden associations, related projects (e.g., SUGI), media and the general society (citizen interested in the topic).

The appendix contains a short list of our dissemination activities. For the complete overview visit our website www.fewmeter.org or https://www.researchgate.net/project/The-FEW-meter-an-integrative-model-to-measure-and-improve-urban-agriculture-shifting-it-towards-circular-urban-metabolism.

Publications in peer-reviewed journals

Bosiacki, M., Bednorz, L., Fedeńczak, K., Górecki, T., Mizgajski, A., Poniży, L., Spiżewski, T. (2021). Soil Quality as a Key Factor in Producing Vegetables for Home Consumption—A Case Study of Urban Allotments in Gorzów Wielkopolski (Poland). Agronomy, 11(9), 1836. https://doi.org/10.3390/agronomy11091836

Caputo, S., Schoen, V., Specht, K., Grard, B., Blythe, C., Cohen, N., Fox-Kämper, R., Hawes, J., Newell, J. & Poniży, L. (2021). Applying the food-energy-water nexus approach to urban agriculture: From FEW to FEWP (Food-Energy-Water-People). Urban Forestry & Urban Greening, 58, 126934. doi: 10.1016/j.ufug.2020.126934

Di Fiore, G., Specht, K., Zanasi, C. (2021): Assessing motivations and perceptions of stakeholders in urban agriculture: a review and analytical framework. In: International Journal of Urban Sustainable Development, Vol. 13, Issue 2, pp. 351–367. doi: 10.1080/19463138.2021.1904247.

Ilieva, R.T.; Cohen, N.; Israel, M.; Specht, K.; Fox-Kämper, R.; Fargue-Lelièvre, A.; Ponizy, L.; ˙ Schoen, V.; Caputo, S.; Kirby, C.K.; et al. The Socio-Cultural Benefits of Urban Agriculture: A Review of the Literature. Land 2022, 11, 622. https://doi.org/10.3390/ land11050622

Kirby, C. K., Specht, K., Fox-Kämper, R., Hawes, J. K., Cohen, N., Caputo, S., Ilieva, R., Lelièvre, A., Poniży, L., Schoen, V., Blythe, C. (2021). Differences in motivations and social impacts across urban agriculture types: Case studies in Europe and the US. Landscape and Urban Planning, 212, 104110. doi: 10.1016/j.landurbplan.2021.104110

Maćkiewicz, B., Szczepańska, M., Kacprzak, E., Fox-Kämper, R. (2021): Between food growing and leisure: contemporary allotment gardeners in Western Germany and Poland. In: DIE ERDE – Journal of the Geographical Society of Berlin, Vol. 152, Issue 1, pp. 33–50. doi: 10.12854/erde-2021-502.

Schoen, V., Caputo, S., & Blythe, C. (2020). Valuing physical and social output: A Rapid assessment of a London community garden. Sustainability, 12(13), doi: 10.3390/su12135452

Schoen, V., Blythe, C., Caputo, S., Fox-Kämper, R., Specht, K., Lelièvre, A., Cohen, N., Poniży, L., Fedeńczak, K. (2021). “We Have Been Part of the Response”: The Effects of COVID-19 on Community and Allotment Gardens in the Global North. Frontiers in Sustainable Food Systems, 5. doi: 10.3389/fsufs.2021.732641.

Workshops and events

Workshop for stakeholders, 28.10.2021, online

- Aim: to gain feedback on our findings based on summary of the data gathered in the course of our project and our investigation on the policy strategies that are necessary to support resource-efficient, socially-oriented urban agriculture.
- Attended by 50 persons, such as policy experts, representatives from municipalities and NGO´s as well as experienced practitioners representing ten countries (US, Germany, UK, France, Poland, Italy, Australia, Austria, Canada and Luxembourg)
- The webinar was recorded and is available through this link https://drive.google.com/drive/folders/1qe9sGZgnA1BjXtFNcgDySLNt4-nt-j67.

Webinar for gardeners and farmers, 29.03.2021, online

- Aim: Presentation and discussion of project results of the data collection in two years as overview and at national level
- Attended by 47 farmers and gardeners and other interested stakeholders
- Short videos produced by one garden or farm team in each country are available through this link http://www.fewmeter.org/en/home/

Sessions “Food Production in Cities – Efficiency & Potential” and “Ecological & Socio-Economic Benefits from Urban Agriculture” at 3rd World Conference of the Society for Urban Ecology (SURE) 2020/21, 08.07.2021 Poznan and online with contribution from the FEW-meter:

- Dorr, E.; Grard, B.*; Fox-Kämper, R.*; Specht, K.*; Caputo, S.*; Poniży, L.*; Hawes, J.*; Cohen, N.*; Goldstein, B.*; Jean-Soro, L.*; Lelièvre, A.*: How efficient is urban agriculture regarding the food-energy-water nexus?
- Caputo, S.; Dorr, E.*; Goldstein, B.*; Hawes, J.*; Specht, K.*; Blythe, C.*; Cohen, N.*; Fox-Kämper, R.*; Jean-Soro, L.*; Lelièvre, A.*; Poniży, L.*:How to measure the multiple benefits of urban agriculture: a review of multi-criteria tools for the development of a UA index
- Poniży, L., Bednorz, L.*, Bosiacki, M.*, Grard, B.*,Ilieva, R.*, Jean-Soro, L.*,Spiżewski, T.*: Is a city a good enough place for healthy food production? The soil quality of urban agriculture sites from Europe and the US
- Kirby, C.; Specht, K.*; Fox-Kämper, R.*; Hawes, J.*; Cohen, N.*; Ilieva, R.*; Caputo, S.*; Schoen, V.*; Blythe, C.*; Lelièvre, A.*; Poniży, L.*: Differences in motivations and social impacts across urban agriculture types: case studies in Europe and the US

Ilieva, R.; Cohen, N.*; Isreal, M.*; Specht, K.*; Fox-Kämper, R.*; Lelièvre, A.*; Poniży, L.*; Schoen, V.*; Caputo, S.*; Kirby, C.*; Goldstein, B.*; Blythe, C.*:The socio-cultural benefits of urban agriculture: a scan of the literature

- Dobrodolac, M.; Specht, K.*; Fox-Kämper, R.*; Poniży, L.*; Fedeńczak, K.*; Bechet, B.*; Lelièvre, A.*; Jean-Soro, L.*; Heidemann, W.*: Socio-economic and socio-ecological benefits of allotment gardens – findings from case studies in France, Poland, and Germany

Symposium "Technology and Green Spaces", 29.10.2019, London

- A one-day symposium showcasing the use of the latest technology in green spaces. Key note speaker, Mike Hardman, from University of Salford. Attended by UK university research staff, urban gardeners and urban gardening organisations and FEW-meter project staff.

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