Urban Forestry & Urban Greening 58 (2021) 126934

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Applying the food-energy-water nexus approach to urban agriculture: From FEW to FEWP (Food-Energy-Water-People)

Silvio Caputo[a,*], Victoria Schoen[a], Kathrin Specht[b], Baptiste Grard[c], Chris Blythe[d], Nevin Cohen[e], Runrid Fox-Kämper[b], Jason Hawes[f], Joshua Newell[f], Lidia Poniży[g]

[a] University of Kent, School of Architecture and Planning, UK
[b] ILS, Research Institute for Regional and Urban Development, Germany
[c] Université Paris-Saclay, INRAE, AgroParisTech, UMR ECOSYS, 78 850, Thiverval-Grignon, France
[d] Social Farms & Gardens, Bristol, UK
[e] CUNY Graduate School of Public Health and Health Policy, United States
[f] School for Environment and Sustainability, University of Michigan, United States
[g] Adam Mickiewicz University in Poznan, Poland

ARTICLE INFO

Handling Editor: T Timothy Van Renterghem

Keywords:
Food/Energy/Water nexus
Life cycle assessment
Social benefits
Urban agriculture
Urban metabolism
Urban Resource flow

ABSTRACT

Many studies examine the correlation between the use of resources such as water, energy and land, and the production of food. These nexus studies focus predominantly on large scale systems, often considering the social dimensions only in terms of access to resources and participation in the decision-making process, rather than individual attitudes and behaviours with respect to resource use. Such a concept of the nexus is relevant to urban agriculture (UA), but it requires customisation to the particular characteristics of growing food in cities, which is practiced mainly at a small scale and produces not only food but also considerable social, economic, and environmental co-benefits. To this end, this paper proposes a new conceptual basis for a UA Nexus, together with an assessment methodology that explicitly includes social dimensions in addition to food, energy and water. The conceptual basis introduces People, together with Food, Energy and Water, as a fundamental factor of the UA Nexus. On this basis, a methodology is developed measuring not only resource efficiency and food production but also motivations and health benefits. It comprises a combination of methods such as diaries of everyday UA practices, a database of UA activities, life cycle assessment (LCA), and material flow analysis to connect investigations developed at a garden scale to the city scale. A case study shows an application of the methodology.

1. Introduction

Demographic growth projections suggest that global population will reach 9 billion by 2050 (United Nations, 2004), with increase food demand of approximately 60 % (FAO (Food and Agriculture Organization), 2011). Agriculture is resource intensive, using 70 % of the total global freshwater withdrawn (FAO (Food and Agriculture Organization), 2011). Mueller et al. (2012) show that there are imbalances in fertiliser and water use, with dramatic overuse in China and underuse in Eastern Europe. A proper redistribution of resources would reduce waste and increase yields up to 30 % (Pfister et al., 2011) if water use is intensified in regions with insufficient irrigation. Water is also key to energy generation, which in some cases must compete with food production. Yet, in policy and industry, water and energy infrastructure are rarely integrated and rationalised. Similarly, food production is rarely examined in connection with infrastructure such as hydroelectric plants. Optimising the nexus between food, water and energy can therefore lead to significant savings while increasing production (FAO (Food and Agriculture Organization), 2014). A growing number of researchers are studying these links, broadly termed the “Food-Energy-Water Nexus” (FEW nexus).

Urban Agriculture (UA) is a form of food production on urban and peri-urban land at different scales, involving diverse production techniques, economic models and actors. Types of UA include allotments

---

* Corresponding author.
E-mail addresses: S.Caputo@kent.ac.uk (S. Caputo), V.Schoen@kent.ac.uk (V. Schoen), Kathrin.Specht@ils-forschung.de (K. Specht), baptistegrard@gmail.com (B. Grard), chris@farmgarden.org.uk (C. Blythe), nevin.cohen@sph.cuny.edu (N. Cohen), runrid.fox-kaemper@ils-forschung.de (R. Fox-Kämper), jkhawes@umich.edu (J. Hawes), jpnewell@umich.edu (J. Newell), lidkap@amu.edu.pl (L. Poniży).

https://doi.org/10.1016/j.ufug.2020.126934
Received 18 June 2020; Received in revised form 31 October 2020; Accepted 1 December 2020

cultivated by individuals, community gardens managed by local groups and social enterprises, and cooperatives or commercial farms selling their produce. Benefits generated by UA can include food security, enhanced biodiversity, job provision and opportunities to intensify social interaction (Borysiak et al., 2017; Warren et al., 2015; Cohen et al., 2012; Hampwaye, 2013; Travaline and Hunold, 2010; Holland, 2004). Potential threats include produce contamination, mainly linked to soil pollution (Wortman and Lovell, 2013; Romic and Romic, 2003). Like conventional agriculture, resource access is vital (Cohen and Reynolds, 2015). UA can tap into and use urban wastes such as rainwater, greywater, food waste and heat from buildings as resources (Weidner and Yang, 2020) and substantially lower its environmental impact. Conversely, if urban wastes are not used, UA can generate an equivalent or even greater environmental impact than conventional agriculture (Goldstein et al., 2016a, 2016b).

FAO recognises urban farming's importance in its recent framework for the Urban Food Agenda (FAO, 2019), mainly its potential to alleviate food poverty, although it can also be a nature-based solution to complex urban challenges such as climate change, food security, biodiversity and ecosystem services, public health and resource efficiency (Artmann and Sartison, 2018; Roberts and Shackleton, 2018). Gardens help overcome loneliness and exclusion, and aid development of horticultural skills, feelings of happiness and self-worth (Mourão et al., 2019; Van Tuijl et al., 2018; Armstrong, 2000). They provide spaces and activities to address race, class, and gender inequities (Reynolds and Cohen, 2016). In short, urban food production becomes the catalyst for social activities that otherwise struggle to find space to thrive (Caputo et al., 2020). In this respect, we hypothesise that understanding the FEW nexus in UA must include resource use, social interactions, and other immaterial benefits connected with urban food growing.

Researchers have developed frameworks or tools to identify productivity, although not from a nexus perspective and rarely together with social and ecological benefits. Frameworks for assessing and/or implementing the nexuscould be useful to assess UA, but they focus on large-scale intervention, with fewconsidering the urban scale (Zhang, 2013). A tool for measuring the nexus in UA practices is needed. To address this need, the FEW-meter project (www.fewmeter.org) has developed a framework combining qualitative and quantitative indicators of many dimensions of UA. To develop this framework, the following questions were investigated:

- Is the concept of the nexus, which was developed for large scale food systems, appropriate for UA practices significantly different from industrial food production in scale, quantities produced and purpose?
- What can be learned from existing nexus concepts and how can this be tailored effectively to UA practices?
- How can existing and novel indicators and methods capture associations between resource use, production and social benefits?

To answer these questions, Section 2 explains the nexus concept and reviews several nexus frameworks developed to assess UA. Based on this review, in Section 3, we outline the idea and methodology for a UA nexus assessment framework. In Section 4, we present the preliminary results of a case study employing this framework, and conclude in Section 5 by discussing their implications for future UA research and policy.

2. Literature review: Nexus conceptualizations and methods

2.1. The food-energy-Water Nexus

The conceptualisation of a nexus between food, energy and water appeared in the early 1980s, initially in programmes developed by the United Nations University (Al-Saidi and Elagib, 2017). In 2008 this concept was debated at a policy and industry level when the World Economic Forum introduced the nexus as a way to investigate the threats of resource scarcity and climate change for global food security. The nexus was further discussed and promoted in the World Economic Forum 2011 and in two dedicated conferences in Bonn (2011 and 2014) that discussed the challenges of implementing nexus policies through effective decision-making processes (Daher and Mohtar, 2015).

The nexus is present at many levels in our lives and is embodied in diverse goods and processes, which adds challenges to identifying correct optimisation approaches. At a national level, it is easy to view the nexus simplistically as, for example, irrigation for agriculture, water producing energy and energy deployed for food production, processing and distribution. However, more subtly, the nexus affects elements like the demand for biofuels (energy and food), deforestation and carbon sinks (FAO (Food and Agriculture Organization), 2008). It can also impact the distances between food production and consumption, resulting in larger food miles and energy intensive produce (Edwards-Jones et al., 2008), or the demand for and cultivation of water-intensive crops (Allouche et al., 2014). Within the policy realm, some countries provide energy subsidies to agriculture, reducing the cost of pumping for irrigation, thus exacerbating groundwater depletion (Bhaduri et al., 2015). Policies rarely take an integrated approach to all elements of the nexus (Gain et al., 2015).

Current nexus research demonstrates that there is no unified concept but rather several interpretations of the nexus (Dai et al., 2018; Galaitsi et al., 2018). Appendix 1 shows a summary of some nexus studies and tools, indicating their analytical scope and methodological approaches. The table includes papers reviewed because they are important to developing the UA Nexus framework. For further reference, Newell et al. (2019) completed a literature review of nexus frameworks in general and at the urban scale, classifying studies based on the conceptual framing and modelling, finding that quantitative rather than qualitative approaches predominate. Not surprisingly, issues of institutional structure, governance, equity, resource access, and behaviour were underdeveloped. The framing of the nexus often privileges managerial and specialised perspectives (Cairns and Krzywoszynska, 2016), misrepresenting its socio-technical nature and relegating the nexus debate to the scientific and technology sphere (Williams et al., 2014) rather than its political dimension, such as governance (Artioli et al., 2017) and fair resource distribution.

Broadly, the term nexus defines a system within which elements (e.g. food, energy and water) interact through feedback loops. This requires analysing the elements together to understand their interaction. Each conceptualisation is shaped by the system's boundaries of the nexus. For example, the EU-funded W4EF project (W4EF, 2015) focuses on water availability and how water is used for energy production, similar to the one developed by Rodríguez et al. (2013). In these assessments, the nexus is conceptualised as a water-energy system in which water for energy production and energy for water extraction, processing and distribution affect their optimal usage. Another conceptualisation focuses on the interaction of Climate, Land, Energy and Water (CLEW), applied to a modelling framework that maps flows of resources and particular connections between them, within the production of particular crops (IAEA (International Atomic Energy Agency), 2009). More conventionally, WEF Nexus Tool 2.0 (Al-Saidi and Elagib, 2017) considers water, energy and food.

Defining system boundaries is complex and often contentious because it excludes some elements to make the analysis manageable. Wichelns (2017), for example, contends that a food/energy/water nexus should also include elements fundamental to agricultural production such as land availability and management and crop selection, which influence water and energy consumption. In their review of macro-level nexus assessment tools, Dai et al. (2018) find that, of 35 tools examined, seven elements are used in different combinations that attempt to capture the dynamics of interaction between resource use and ecosystems: *water, energy, food, land use, climate, economy and ecosystems*. The number of elements included in each tool varies with five combinations identified: water-energy (WEN); water-energy-environment (WEEN), water-energy-food (WEFN), water-energy-food-ecosystem (WEFEN), and water-energy-land-climate (WELCN).

This issue of analytical scale cuts across boundaries and methods. In their review of nexus papers, Newell et al. (2019) concluded that although spatial scale was generally recognised, the operationalisation of multi-scalar interactions was limited. Shannak et al. (2018) identify three scales as interconnected (i.e. national, regional, watershed). Zhang et al. (2018) refine this structure of nested scales from transboundary, to national, to regional to city level. In a study reviewing 469 papers, Zhang et al. (2019) find that urban scale nexus studies are growing yet remain scarce. Only some studies offer an assessment framework (see Appendix 1). The urban nexus is mainly analysed using national aggregated resource use data, with a few analyses based on household level data. For example, Cheng (2002) examines the water-energy nexus of households in Taiwan in terms of energy required to use water. Spiegelberg et al. (2017) survey 176 households in the Laguna Lake area, Manila, to identify synergies between fishers and farmers. Only one study focuses on UA (Miller-Robbie et al., 2017) utilising a 12m^2 case study area in Hyderabad to identify GHG emissions reductions when treated wastewater is used for UA irrigation.

Water and energy resources are best examined at a regional, national or international level (Biggs et al., 2015), but cities are particularly important because, as population centres, they determine the intensity of global resource flows. Cities are also the places where the socio-technical implications of resource use are more evident and where the nexus debate can shift from the sociotechnical to the socio-political and technical (Artioli et al., 2017). Issues of access, ownership, management and interaction with technology become more evident in dense urban environments. Zhang et al. (2019) characterise the urban context of the nexus as one with *resource interdependency* (i.e. all sectors are linked and higher usage in one affects the others); *resource provision* (all sectors are based on materials flowing from outside the urban context); and *system integration* (following the above, the identification of the system of flows in which the nexus is located and from which its functioning is affected).

Although the role of humans and social processes in the nexus has not been clearly addressed, researchers have made various attempts to include behaviours and social processes in nexus analyses. For example, a tool developed for FAO treats society as an element of the system and therefore includes social variables. MuSiasem (Giampietro et al., 2013) is an assessment tool promoted by FAO employing a fund-flow framework for socio-ecological system assessment. Funds, including labour, capital and land, are elements which act in system regulation by converting factors.

Despite interest in incorporating social dimensions in nexus models, MuSiasem and other assessment tools that consider the livelihood of communities (Biggs et al., 2015) are exceptions; most nexus tools encompass physical rather than social variables. This narrow bounding of the nexus is a significant limitation because human factors play an important role in resource consumption. For example, farmers use 92 % of the water consumed in the food supply chain (Allan et al., 2015). A global estimate suggests that 'at least 90 % of the world's more than 570 million small farms (less than 2 ha) are held by an individual, small group of individuals, or household' (Lowder et al., 2016). 84 % of these farms are small (less than 2 ha). Because the farming techniques, and therefore use of resources, in these small and family farms are likely to be influenced by ecological awareness, culture, local practices, as well as economic and technological variables, social factors are important to include in any assessment. Understanding the interaction between people and their day-to-day attitudes towards food production and resource exploitation is fundamental to a systemic understanding of the nexus.

Methods for nexus analysis have been borrowed from other research areas such as LCA or Value Chain Analysis (Dai et al., 2018). Zhang et al. (2019) identified eight methods commonly used in combination to model the nexus: 1) Investigations and mathematical statistics; 2) Computable general equilibrium modelling; 3) Econometric analysis; 4) Ecological network analysis; 5) LCA; 6) System dynamics modelling; 7) Agent-based modelling; and 8) Integrated index. For example, Karabulut et al. (2018) combine a matrix with indicators, an LCA to complete the initial assessment and a final experts' consultation to evaluate qualitatively the results of the assessment. Dai et al. (2018) lament that most tools are concerned with quantitative assessments but few consider policy and/or governance pathways enabling effective nexus policy implementation. Some frameworks to embed the nexus in policy include one developed by Gain et al. (2015), which uses the phase of the policy cycle (i.e. agenda setting, policy formulation, decision-making, implementation and evaluation) to identify local priorities and effective policies. Halbe et al. (2015) propose tools for systems thinking such as Causal Loop Diagrams developed through stakeholder engagement. These diagrams map diverse factors and their negative or positive interactions.

In cities, the nexus can also be represented in terms of urban metabolism, whereby flows of materials 'enter, undergo transformations, and then exit the city.' (Walker et al., 2014). Nexus tools and urban metabolism studies share some analytical methods. For example, Wang et al. (2017) use input-output analysis to model the water-energy nexus. Each tool varies in terms of assessment methods, often combining more than one. It is therefore worth identifying an overarching structure to which tools can conform. FAO Nexus 1.0 (McNamara et al., 2014) offers one composed of three steps: (1) context analysis (qualitative analysis); (2) quantitative assessment (quantitative analysis, application of input/output tools; assessment of interventions; comparison of interventions); and (3) response options (strategic visions; policies). This overall structure maps well against the one used for urban metabolism, formulated by Zhang (2013), which includes four steps: (1) process analysis; (2) accounting and assessment; (3) modelling structure and function; and (4) optimisation and regulation. There is conceptual and methodological overlap between these two fields, and urban metabolism shares the city as the spatial focus of investigation with the UA nexus. In fact, the most prominent urban nexus approach to date has been urban metabolism modelling, largely in the field of industrial ecology. But this modelling has been rather static, looking at the flows in isolation, while social and economic aspects have been largely absent. The following section will briefly review existing UA assessment tools to subsequently build on the review of nexus tools and propose one that is specific for food growing in cities.

2.2. Urban agriculture: tools of assessment

Although official figures are unavailable, UA is expanding, increasingly recognised in urban policies as green infrastructure (Cohen and Wijsman, 2014) and an important part of larger urban food systems. A growing literature on UA describes its potential to produce significant amounts of food, although with mixed results. Studies from Detroit to Barcelona indicate that cities could produce between 18 % and 100 % of their vegetable demand, with estimates varying widely based on city morphology, climate, research methods used, and estimates of farm productivity (see, for example, Colasanti et al., 2012; Garnett, 1999; Nadal et al., 2017; Saha and Eckelman, 2017).

To effectively estimate the potential for city-wide production, researchers must effectively account for the production scale at individual sites, which can be difficult. UA projects are often small (smaller than small farms defined above), are generally not managed professionally, but rather with volunteers, making the collection and aggregation of reliable data difficult. Whereas nexus studies are often based on secondary data from national statistics agencies, UA studies must rely on farmers and volunteers to gather primary data. A few studies have tested data gathering based on citizen science, which, although aimed at collecting basic data have the merit of being replicable, easily implemented and therefore likely to be used by other farmers. For example, CoDyre et al. (2015) studied 50 farmers in Guelph, Ontario, to evaluate the productivity of the land, labour and capital used by urban gardens. Farmers compiled diaries to track food production and inputs, coupled with a random telephone survey to determine how many people in the city had a food garden to enable scaling up the data. Pourias et al. (2015) interviewed 23 farmers at the start of the growing season and 14 farmers at the season's end, in a sample of community gardens in Paris and Montreal. Like the previous study, farmers were asked to keep diaries over the growing season to record crops and harvests, including crop use and its final destination. McDougall et al. (2019) developed their study from data collected over one year by 13 gardeners in the Sydney area. This study is particularly interesting for its nexus approach to UA; it attempts to measure production effectiveness in terms of energy use and labour, considering correlations between food, energy and people. Water was excluded from this study 'as accurate measurement of this was judged to be too onerous for most gardeners' (McDougal et al., 2019 - Supplementary Information, p. 3). Another study measured the nexus potential of UA in Munich, verifying the resource efficiency of rainwater harvesting for irrigation and energy production through biogas (Gondhalekar and Ramsauer, 2017).

Selected studies and tools for measuring UA productivity are shown in Table 1. Farming Concrete, Harvest-ometer and MYHarvest are all online tools. Farming Concrete has the widest scope of analysis, taking into account variables such as: the types of crops planted and harvested; waste management and the quantity of compost produced; numbers of volunteers; the time worked and the number of attendees at events; perceived improvements in mental and physical health from visiting or working in the garden; and economic data on produce sales and food donations. It was designed as a citizen science project to enable gardeners to build political support by demonstrating the gardens' value as sources of healthy food (Gittleman et al., 2012). Harvest-ometer measures the amount of food produced per garden and its monetary value. MYHarvest is a newer project with no findings to date, but it plans to collect data on areas planted and volumes harvested of the 40 most popular UK fruits and vegetables to estimate the current levels of UK own-grown production, and the extent to which it could be increased if more urban land was available for cultivation. Additional tools for measuring the health and wellbeing generated by UA initiatives have been catalogued by the organisation Social Farms & Gardens (Turner et al., 2016).

Other studies have attempted to measure difficult to quantify benefits of UA such as the 'ecological viability' of community garden practices (Guitart et al., 2015) or city scale ecological, economic and social functions (Horst et al., 2017) using an index system (Peng et al., 2015). Goldstein et al., 2016a, 2016b use LCA and material flow analyses to measure the environmental impacts of UA (see also Sanyé-Mengual et al., 2018; Goldstein et al., 2017). Together with the tools mentioned above, these and other studies (Weidner et al., 2019) attempt to generate a systemic view of UA. Some similarities can be drawn from nexus studies, specifically attempts to elicit the multidimensional aspects of UA and trace flows of resources. There are also differences, in that people are central in UA studies and assessment frameworks, in terms of practices, ecological awareness, knowledge creation and their involvement in data gathering. The following section synthesises a methodological approach to measure a UA nexus.

3. The FEWP nexus: a framework for assessing urban agriculture

Based on this existing literature conceptualizing and operationalizing the FEW nexus, we conclude that for an effective assessment of UA, FEW must become FEWP (Food-Energy-Water-People) and that the assessment framework methodology must connect the small scale of UA project with the urban scale. Drawing on existing methods highlighted in the second section of literature review, we propose the FEWP Nexus framework for assessing UA, a novel combination of analytical methods that document complex relationships in a nexus perspective.

3.1. *Conceptualisation of the FEWP nexus*

The conceptualisation of the transition from FEW-nexus to FEWP nexus was mainly based on: (i) including the human factor in the analysis; (ii) identifying and quantifying social factors related to material and energy flows; and (iii) the approach to FEWP-nexus in various spatial scales from the site to the city. A framework for assessing the UA nexus must include human behaviour because, as noted above, within

Table 1
A selection of the existing tools to measure UA outputs.

Category	Name/reference	Data collection	Category of indicators	Subcategories of indicators/metrics
Existing tools	Farming Concrete (https://farmingconcrete.org/toolkit/) see also (Gittleman et al., 2012)	Data recorded in a diary Citizen Science	Food production	Crop count Harvest count
			Environmental data	Landfill waste diversion Compost production Rainwater harvesting
			Social data	Number of volunteers Number of participant hours per task Number of person hours per project (e.g. building a fence) Skills and knowledge sharing Reach of programmes
			Health data	Changes in attitude to fruit and vegetables Good moods in the garden Healthy eating Mood of the community about the garden
			Economic data	Market sales Food donations
	Harvest-ometer (https://www.capitalgrowth.org/the_harvestometer/)	Online tool	Food production	Weight for each crop Value for each crop
	MyHarvest (https://myharvest.org.uk/)	Online tool	Food production	Weight for each vegetable or fruit Growing area for each vegetable or fruit
Participative study	Harvest Notebook (Pourias et al., 2015)	Data recorded in a diary	Food production	Weight for each crop Frequency of harvest Type of preparation (food processing) Destination of food Annotation on practice

an urban context composed of small parcels used to grow food, and farmers who may not prioritise production and rarely have professional training, resource use and crop yields are largely influenced by highly variable behaviours, individual knowledge and social attitudes, in contrast to conventional farmers who often operate with planned organised deployment of inputs and practices, many defined by contractual arrangements with buyers or technological requirements. Hence, a conceptualisation of the UA nexus must include people, intended as individual behaviours and practices, social objectives driving individual UA projects, and the involvement of communities within a human-driven system of food growing. As Covarrubias (2019) argues, material-focused methodologies need to be complemented with a social flows analysis that pays attention to the daily practices, policies, ideologies, networks and socio-cultural meanings that influence resource use. Likewise, in a study of Sydney, Newman (1999) included social factors enabling liveability, such as local leisure opportunities and educational attainment under the assumption that cities are social organisms.

Identifying and quantifying social activities and related benefits can explain how their attainment can influence production and resource consumption. For example, in a community garden, volunteers carrying out gardening activities and acquiring horticultural skills will also learn about healthy diets and may change their eating habits accordingly. Once quantified, these social resources and “products” (i.e. social goods) can be assessed in parallel with biophysical resource flows via traditional nexus and metabolism methods. In addition to energy and water inputs, capital costs and labour can be considered. Likewise, in addition to produce and waste as outputs, social benefits and harms can be included. This enables explicit integration of material and social flows and allows researchers to highlight trade-offs between resource usage, production and wider benefits to society.

Another important point for the conceptualisation is consideration of the scales within which UA operates. UA projects vary greatly in physical dimensions, goals and objectives, and scope of activities. The goals may range from spaces for leisure, to providing social benefits, to commercial-scale food production. Patterns of utilisation of resources can change, depending on the particular agenda of each UA project and the way practices are organised (e.g. in allotments, city farms or community gardens). The UA nexus must therefore take into account these diverse production and consumption patterns within a network of small projects/farms that can have an influence over the entire system of urban flows. The analysis of the UA nexus at a single farm level can also lead to an understanding of the nexus at a city scale. While the aim of a nexus framework is to determine the best options to influence decision-making processes and policy, the UA nexus framework is concerned with both the urban policies determining resource use and measuring the level of agronomic knowledge and ecological awareness of urban farmers to affect their behaviour.

3.2. Design of a new assessment framework for UA

The FEWP assessment framework aims at measuring farmers’ practices and actions, which are at the core of some UA assessment tools reviewed here, as well as understanding the interconnectedness of resources and food. It is based on indicators, a system of data collection and the elaboration of the data collected with urban metabolism methods. As an initial step of the FEW-meter project, a nested scale analytical approach was identified as appropriate: from farm-to-city level. This entails working with farmers to gather data from individual UA sites, analysing data collected from a pool of case studies, and using this analysis to perform material flow analysis at a city scale. The resulting assessment tool is structured around the four steps of the urban metabolism assessment as follows (Fig. 1).

3.2.1. Process analysis

Identification of the indicators representing the four elements of the FEWP nexus and methodological approaches.

Differences in configuration, labour structure, and location for each UA type affect material and social inputs and outputs. Data collection must be developed using indicators that are meaningful to growers with manageable methods that may differ depending on the UA type. To this end, the list of indicators must be co-created, and the research questions developed via those indicators must be relevant to the specific cases under analysis. Gardeners in individual allotments may be, for example, less interested in maximising food production than farmers in city farms. The diagram below (Fig. 2) shows how indicator categories characterised as inputs and outputs of a process are distributed across the four elements of the UA nexus, including four categories of social benefits: health; education; community-building; and economics (Artmann and Sartison, 2018; Cohen et al., 2012; Gittleman et al., 2012; Lovell, 2010; Holland, 2004). A list of relevant indicators was co-produced by researchers on the FEW-meter team and participant growers (Appendix 2). Temporality and indicator scale varied across and within the nexus elements, and multiple tools were developed and deployed to collect these data.

3.2.2. Accounting and assessment (data collection and analysis)

As outlined previously, many of the most successful methods of measuring UA productivity have relied on participatory citizen science, emphasizing collaboration and equal partnership between researchers and growers. FEW-meter builds on this tradition by expanding the range of data types collected to include: food productivity, resource consumption, farm and farm infrastructure, and social dynamics at the farm. UA food productivity, resource consumption, and farm infrastructure have been studied extensively, but rarely in combination and almost never through participatory means. Farm social dynamics have very rarely been considered by these few “integrated” assessments.

Methods for data collection need to be flexible and adapt to local capacities; within FEW-meter, variation between farms within and across cities meant that data were collected in different formats with varying frequency. Data collection tools included: digital and paper “diaries” of resource use and food production; in-person surveys of farm infrastructure and farm biophysical make-up; survey questionnaires of growers and grower organizations; secondary data collection (e.g. spatial data); soil quality surveys; and interviews with local UA experts and policy-makers. Each country engaged in a similar process of consultation, resulting in some data collection conducted by urban growers (e.g. resources consumed and food produced) and some collected by the research team during visits to case study sites (e.g. material and equipment used, trips to garden, soil quality and social

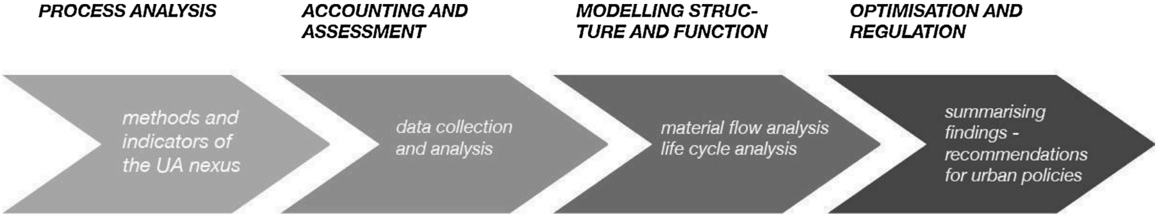
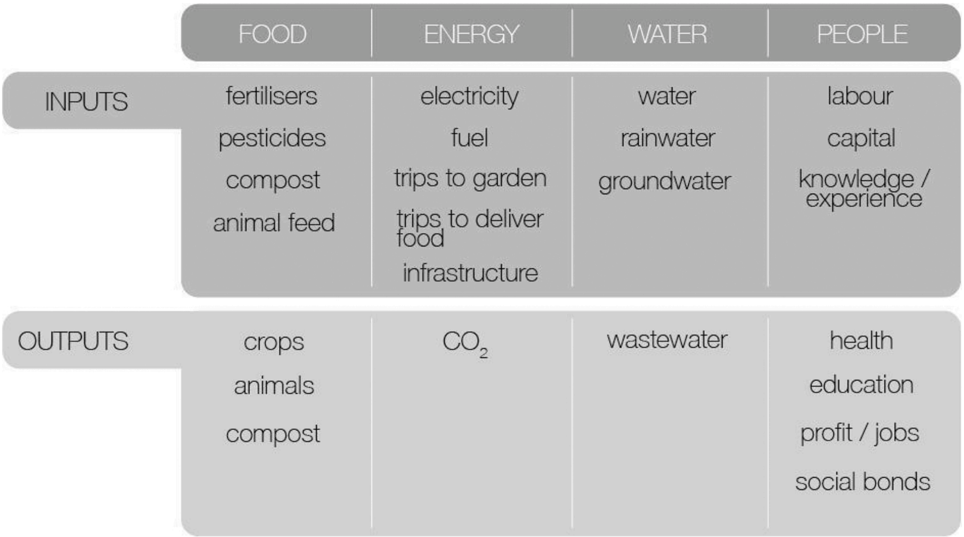


Fig. 1. Structure of the UA nexus assessment process.



	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

Fig. 2. Main categories of indicators for a UA nexus framework of assessment.

indicators through questionnaires distributed to volunteers).

Digital database integration is key for continued assessment of these varied data. An initial descriptive analysis can quantify productivity, resource intensity, the profile and motivations of growers, economic and land use patterns, and soil makeup, among other things. Later stages of assessment integrate these characteristics to develop a more holistic picture of a UA nexus. In FEW-meter, for example, life cycle assessment (LCA) is being used to identify the global environmental impact based on an inventory of the materials used to construct raised beds, poly-tunnels and other structures and material inputs used to organise food production and productivity and local crop market data. As social flows are also considered part of the outputs, negative environmental effects can also be weighed against social benefits. Various farm-scale integrated assessments are possible, but these insights reach their fullest policy relevance when modelled at the city scale.

3.2.3. Modelling structure and function

FEW nexus assessment at the urban scale has been scarce to-date. This is particularly true in the context of UA, where calls to integrate material and social inputs and outputs at the city scale have largely gone unanswered, and discourse around UA remains centred on food production. Existing evidence indicates that food from UA is at best comparable in impact-intensity to conventional agriculture and is often outperformed by conventional agriculture, especially in northern climates (Goldstein et al., 2016a, 2016b; Shiina et al., 2011). In this framework, we integrate qualitative data from interviews with local experts and policy-makers with spatial land use data to assess the potential for the expansion of urban agriculture and urban symbiosis. Through this, we “scale up” flows of material and social goods to city scale through spatialized scenario analysis.

3.2.4. Optimisation and regulation (optimising the process and producing policy recommendations)

Data analysis will be presented to growers in final workshops in each case study city, designed to validate findings and discuss improvements in efficiency of practices, and impacts and motivations of growers and volunteers. The workshop participants will also discuss modelling of the city-wide flows of materials and social goods, enabling a focus on policy opportunities and barriers. These workshops will lead to a city-based roadmap for practitioners and policy recommendations.

4. Application of the FEWP framework: Case study of a London community garden

This section shows how the FEWP nexus methodology can be applied by describing the phases of co-creation, data collection and analysis of a specific case study, the 2019 growing season of a London community garden. This case study is one of 89 gardens analysed in the overall project. The FEW-meter project is in its second year of data collection, culminating in city scale aggregation of the two years of data that will be used in a city-scale material flow analysis modelling inputs-outputs of urban agriculture. This case study therefore includes only on two already completed steps in the process outlined in section 3.

The community garden for this case study is located in the centre of London and was established to improve ‘the physical and emotional well-being of those who live, work or study in the surrounding areas’. The garden organises multiple activities, including sport and community activities for local groups, a horticultural training programme for people with learning disabilities and mental health issues, supervised activities for children aged 0–14 and their families, and a permanent experiment of a closed-loop food growing process, including consumption in the garden’s café and an anaerobic digester producing biogas and fertiliser. The community garden occupies 350 m^2 within a larger area that includes a community hub and a shed for the anaerobic digester.

4.1. Step 1 - process analysis

An initial list of indicators and methods for data collection was discussed in a workshop with community garden managers in London, January 2019. Although UA types vary by country, in the UK, community gardens are organised and run by a group of urban growers, engaging with local communities. The food produced is generally shared amongst the growers or sold to fund activities. London members of Social Farms & Gardens (SF&G), the national association representing community gardens and city farms, were identified as the population from which sample farms could be drawn. Through SF&G, a call was launched to all community gardens in London, and those that responded were visited. Out of 30 projects visited, 10 agreed to collect data, with one withdrawing two months after data collection started (March 2019). In the workshop, the participants discussed the reluctance of urban growers to engage in research projects. Community gardens often work beyond capacity in terms of people and resources and although research is valued, gardens must prioritise their activities. There was agreement on the value of measuring the indicators we proposed since they included several important dimensions of UA, but participants remarked that such comprehensive data collection required time and effort beyond their capacity. Some community gardens lacked meters to record water consumption or equipment to collect other data. Garden activities often rely on volunteers, making it difficult to assign repetitive measurements to one person, making data collection less consistent and reliable.

4.2. *Step 2 - Accounting and assessment*

4.2.1. *Data collection*

The urban growers of this case study decided that the most practical method of self-recording was to use a hand-written diary. Other UK community gardens chose to share an excel spreadsheet with the research team or to send weekly photos of harvest and resource consumption hand-recorded on a whiteboard. Data in the community garden was collected from March through October 2019. Fig. 3 includes charts with some examples of the data collected through the diaries and gardener surveys.

The garden produced 1.3 kg of 22 different crops per m2 cultivated area. Energy consumption was estimated for the facilities in the garden's community hub during the hours spent gardening. Travel to the garden by the two chief gardeners and 5 volunteers who regularly helped during the months of data recording amounted to almost 6000 km, mostly by subway. This high figure for travel is partly due to the scale of the city and the significant outreach of the project, which attracts volunteers from neighbouring areas.

Two charts in fig.3 illustrate motivations to work at the farm reported by 14 volunteers, as well as the perceived social impacts of participating. The main motivations include contributing to community building, working outdoors, interacting with others and engaging in a fun activity. The most positive impacts include enhanced self-confidence and improved interaction with others. In the questionnaire, motivations included benefits such as learning new skills and impacts such as saving money and gaining employment skills. These were not recognised as very important by the respondents. Their responses may be related to their socio-economic status or the agenda of community gardens, which prioritise community building activities. The agenda of this garden might also explain its relatively modest food production. However, as noted, the value of social impacts is high and can be considered a tangible output of the resources the garden consumes to produce food. Other indicators for social benefits were collected, including the number of social and educational events, which can indicate the broader impact of each UA project on the surrounding community. Between March and October 2019, this community garden organised 59 events: 5 educational and 54 aimed at community-building.

4.2.2. *Life cycle assessment (LCA)*

LCA is a four-stage, iterative process, conducted as participatory research in this case. First, researchers and gardeners defined the goal of the process, including the system product of interest (food), the functional unit (e.g. one kilogram or 100 Calories of crop), and the study outputs (publication, as well as hotspot analysis to identify key areas of crop production resource intensity. Next, the scope of work was defined as the 2019 growing season. Researchers and gardeners worked together to inventory all garden inputs and outputs. Researchers measured and catalogued all infrastructure, including raised beds, hoop houses, and compost bins. Growers recorded harvest, water use, supply use, and farm activities. We used this inventory to assess the "impact" of garden output as global warming potential per unit harvested. In the process, infrastructure and supply inputs were converted to generalized materials with associated embodied impacts. Materials in this garden varied from glass to reclaimed wood to compost, each with its own environmental footprint derived from the EcoInvent database (Wernet et al., 2016). Through various allocations, these impacts can be "assigned" to crop outputs. This is expected to be accomplished through allocation by nutritional value, by economic value, and by mass. Preliminary results suggest that impact per kg may be comparable to conventional crop production. These results will be used to inform Steps 3 and 4 in the FEWP nexus framework.

5. Discussion

The case study documents a partial application of the FEWP assessment framework, which, to be effective, must include additional case studies. The research project testing the assessment compares samples of 89 case studies of three different types of UA, allotments, community gardens and social farms, to identify patterns of productivity and resource use across case studies, cities and countries, and to include organisational and social factors that may affect such patterns. While the case study presented does not include the LCA of inputs, this is part of the assessment framework, in addition to analyses of yields, water and energy, indicating the real impacts of the materials required to support urban food growing.

The case study illustrates the value and limitations of the FEWP framework. For example, we estimated that the project used 122 L of water and 3kwh of electricity per kg. of produce harvested, an

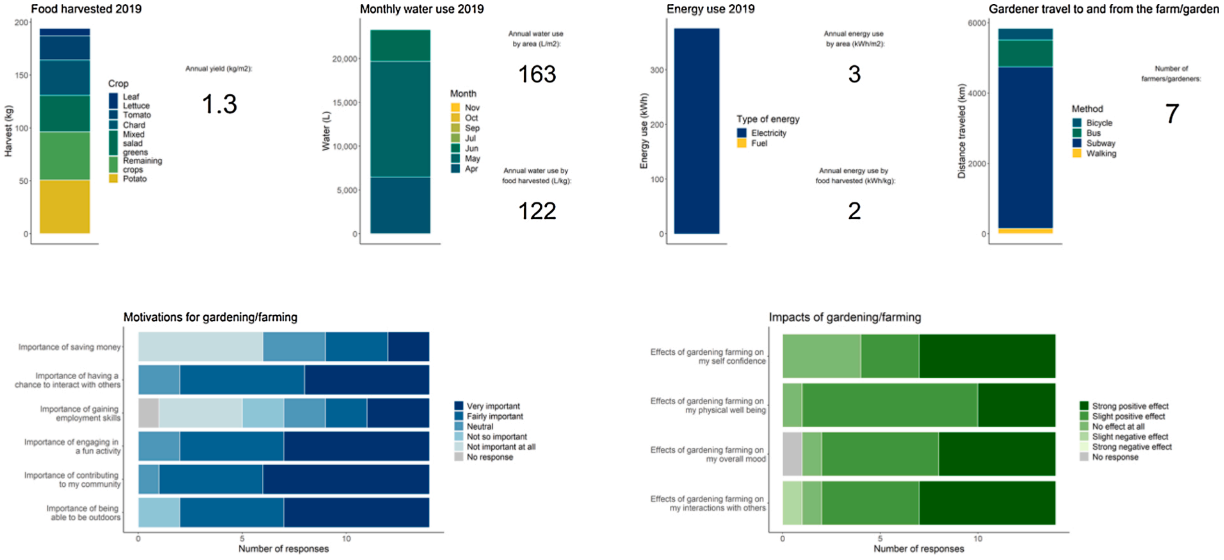


Fig. 3. Charts visualising harvest, resource consumption, motivations for gardening and positive impacts of this activity on the gardeners.

admittedly rough measurement since the farm is a polyculture and cannot record irrigation by crop, a known challenge in urban agriculture, where polycultures are ubiquitous. The researchers considered collecting energy and water consumption data per crop but decided after consulting growers that this was unfeasible. Further, observations and conversations with growers enabled us to record data idiosyncrasies in all projects, to ensure reliable analysis of the results. For example, in the London community gardens, gardeners/managers coordinate tasks such as watering, weeding and harvesting, but the work is done by volunteers, some of whom have limited gardening experience. Excessive watering and misreading the metre occurs, reducing reliability of water measurements. Irrigation varies greatly by crop, weather conditions, local climate and soil composition, making it difficult to establish a baseline to assess irrigation efficiency for the case studies. In this case study, 22 different crops were harvested, including potatoes, tomatoes and lettuce. In a LCA study on the vegetables sold (not necessarily produced) in the UK, Frankowska et al. (2019) report water use of 95 L/kg of tomatoes, 47 L/kg of potatoes and 46 L/kg of lettuce, thus suggesting high water consumption by the case study garden. The case study garden used no energy for the growing process, but we accounted for energy indirectly connected to food production from the community hub (e.g. for laptops, office lighting and kitchen equipment).

The farm produced 1.34 kg of food per m2 productive area. This is comparable to the yield from 20 allotment sites and community gardens in Paris and Montreal, which varied from 0.46 kg/m^2 to 1.96 kg/m^2 (Pourias et al. 2014). However, it is lower than a sample of 13 gardens in Sydney, Australia that ranged from 1.99 to 15.53 kg/m^2 (McDougall et al. 2018). Our yield estimate is only an approximation of productivity because it aggregates the *total* harvest per m^2 total cultivated area rather than the yield of *each crop* per m^2 of area cultivated with that crop, recognising that yields in kg. can vary by the type of crop (e.g. potatoes vs. lettuce). Finally, trips to the garden were measured. In the case study, travel impacts were particularly high compared to other case studies, in part a consequence of the garden's popularity, which attracts many volunteers travelling to the site by public transport. Preliminary LCA results indicate that global warming potential from trips to this garden may be considerably higher than global warming potential from the garden's infrastructure and supplies. Since worker travel is often excluded from LCAs of conventional agriculture, this warrants continued attention as comparative assessments seek to identify environmentally-friendly food growing strategies.

Although the case study data suggest that resource use does not yield much produce, the FEWP nexus perspective considers social benefits such as the effects of gardening on volunteers' overall mood and improved interaction with others, two significant impacts claimed by the respondents to our questionnaire measuring social benefits. Between March and October 2019, the community garden organised 59 events: 5 educational and 54 aimed at community-building. A simplified cost-benefit analysis of the social impacts of this community garden found that the economic benefits of improved wellbeing of the volunteers were substantial compared to garden costs (Schoen et al., 2020). The FEWP nexus incorporates these benefits in the final evaluation and as an output of resource use. Another important factor is the sharing of data analysis with urban growers, which may help them reflect on their practices. In early 2020, a workshop in each country discussed 2019 data assessment and key findings. From a FEWP nexus perspective, it is fundamental to co-create solutions to improve environmental efficiency and social benefits.

There are limitations in the framework's effectiveness. Data reliability must be monitored and validated, as data recorded by volunteers may be inaccurate. Researchers can mitigate risks by reviewing data, question incongruencies and compare data over two or more years to increase reliability.

The FEWP framework presented here is not comprehensive. For example, the valuation of ecosystem services is not included. In other contexts, ecosystem services are an important unifying metric by which various dimensions of project success may be monitored (Tallis et al., 2008). Analytical frameworks initially designed to elicit links between ecosystems and the cultural services they can provide (cascade model), have been used to study connections between UA and social cohesion (Petit-Boix and Apul, 2018). For some parameters, the FEW-meter overlaps with categories of the ES valuation system (e.g. measuring the provision of food, or socio-cultural services such as physical or mental health) and thereby it contains some elements of the TEEB framework (Kumar, 2011). However, the FEWP framework was not designed to assess ES and has not adopted valuation of ecosystem services as a universal single-metric system. This is also due to the difficulty of valuation across space and time, a well-known challenge in payment for ecosystem services programs (Atkinson et al., 2012). However, such an effort is likely to be useful locally as a compelling demonstration of the value of allocating desirable urban land for UA.

Tools for combining physical and social outputs of urban agriculture are rare and incomplete. It is often difficult to assess the wide diversity of actors and elements of UA projects, partly because there is still incomplete recognition that some UA settings produce greater social benefits than benefits of food production. This differs according to the (human) values and (physical) nature of the space. Therefore, UA diversity is one of its major challenges to evaluation and assessment, especially when trying to apply the FEWP model to diverse UA settings as part of FEW-meter.

The FEWP enables better integration of physical parameters and social elements which could support advocacy of the value of these spaces to policy makers. There still exists a 'double edged' challenge of research conduct and dissemination in settings where both projects and stakeholders are so diverse. First, researchers must make such an approach accessible to practitioners who value the resulting data especially with local interpretation and reflection. Second making the outputs accessible and understandable to urban policy decision-makers is challenging. The FEWP Nexus can provide a process by which the broad value of UA can be demonstrated.

6. Conclusions

This paper aimed to investigate the structure of a framework to assess UA from a nexus perspective by investigating three key questions: (1) is the conventional concept of the nexus appropriate for UA?; (2) what can be learned from the nexus concept?; and (3) which indicators and analytical methodologies can effectively identify links between resources used, food production and social benefits in UA? Our research has demonstrated the importance of addressing the social dimensions and the need for a UA nexus to be a Food-Energy-Water-People (FEWP) nexus. In UA, the social dimension refers to behaviours and policies driving resource use and production as well as to a range of outcomes made possible by using food production as a catalyst for social benefit. Generating social benefits through food production may require UA sites to operate less productively or efficiently than conventional farms that seek profitability, demonstrating the inextricable nature of social and material flows in UA. The UA nexus needs to capture 'micro-factors' related to the agronomic knowledge, ecological awareness and behaviour of urban farmers and the social benefits derived from urban food growing, to understand the potential and implications of this practice at a city-scale. The methodology enabling a UA nexus analysis must therefore focus on a nested scale of investigation: (1) looking at single projects to best identify indicators connected with material flows, social benefits indirectly generated by these flows and the level of ecological awareness of farmers; (2) subsequently analysing a sample of food growing spaces within a city; and (3) using data to model urban social and material flows. Data collected by farmers through diaries, complemented by an LCA of the materials employed by each food growing space, together with a city-scale material flow analysis, are the appropriate methods and analytical tools for this nexus framework. We expect that as case studies are developed within the FEW-meter project, the links between social benefits and resource usage will become clearer, thus providing an evidence base on the impact of UA that can support the formulation of resource-efficient and humane UA policies in the Global North.

Funding

This paper is based on FEW-meter project, funded by ESRC, UK, grant number ES/S002170/2; by BMBF, Germany, grant number 01LF1801A; by ANR, France, grant number ANR-17-SUGI-0001-01; by NSF, USA, Belmont Forum 18929627; Poland, grant no 2017/25/Z/HS4/03048; and by European Union's Horizon 2020 research and innovation programme (GA No 730254) under the JPI Urban Europe's call "SUGI – FWE Nexus".

CRediT authorship contribution statement

Silvio Caputo: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition. **Victoria Schoen:** Investigation, Writing - review & editing. **Kathrin Specht:** Conceptualization, Methodology, Investigation, Writing - review & editing. **Baptiste Grard:** Conceptualization, Methodology, Investigation, Writing - review & editing. **Chris Blythe:** Investigation, Writing - review & editing. **Nevin Cohen:** Conceptualization, Writing - review & editing, Funding acquisition. **Runrid Fox-Kämper:** Writing - review & editing, Funding acquisition. **Jason Hawes:** Formal analysis, Writing - original draft, Writing - review & editing. **Joshua Newell:** Conceptualization, Writing - review & editing, Project administration, Funding acquisition. **Lidia Poniży:** Conceptualisation, Methodology, Writing - review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix 1 Review of nexus frameworks relevant to UA

Authors	Objective	Nexus	Methodology
Al-Ansari et al., 2015	Assessment for food production, seen as a series of subsystems	Water – Energy - Food	Life Cycle Assessment
Al-Saidi and Elagib, 2017	Evaluation of the nexus frameworks in terms of effective integration into policy	Water-Energy Food	Qualitative analysis – policy and governance for effective implementation of the nexus
Biggs et al., 2015	Connection between resources and the livelihood of local communities	Water – Energy - Food (Nexus Livelihood)	Quantitative analysis - matrix including indicators related to food, energy and water and the impact of their exploitation on the livelihood of local communities.
Daher and Mohtar, 2015	Determining the impact on local resources and land use under different scenarios of food production	Water – Energy - Food (Tool 2.0)	Quantitative analysis / comparative analysis - indicators mirroring the particular energy and water usage and processing necessary for cultivation under 5 different scenarios
Gain et al., 2015	The organisation of a structured process within which the nexus can be examined in policy	Water – Energy - Food	Qualitative analysis – policy and governance for effective implementation of the nexus
Garcia and You, 2018	Framework to assess the production of bioenergy	Food-Water-Energy-Waste	Mathematical model for a bioenergy production from agricultural and organic wastes
Gondhalekar and Ramsauer, 2017	Assessment of urban agricultural production	Water - Energy - Food – Climate	Quantitative analysis - Simulation of wastewater recycling and energy available, resulting in food produced in a district in a district in Munich.
Halbe et al., 2015	Identify optimal nexus strategies using systems thinking tools	Water – Energy - Food	Causal Loop Diagram - data are elaborated and their interconnectedness discussed in a stakeholder engagement workshop
Hang et al., 2016	Assessment of local production systems to plan new towns	Water – Energy - Food	Qualitative analysis – Mathematical model allowing quantification of resource use in all possible interactions between subsystems and types of resource
IAEA (International Atomic Energy Agency), 2009	Nexus determining land availability for particular production and the impact on resources, including land and emissions	Climate – Land – Energy – Water (CLEW)	Material Flow Analysis
Karabulut et al., 2018	Food and energy security against the availability of limited and vulnerable resources such as water, land and ecosystems	Ecosystem-water-food-land-energy	Quantitative and qualitative analysis – matrix of indicators in which LCA is integrated. Expert judgement to evaluate results
Lin et al., 2018	The nexus seen through advantages that anaerobic digestion can yield	Water – Energy – Food - Waste	Comparative analysis of AD and composting technologies, evaluated from a FEW nexus perspective
Martinez-Hernandez et al., 2017	Tool modelling the impact of food production and resource exploitation on the ecosystem	Water – Energy - Food – Ecosystem (NexSym)	Quantitative analysis – dynamic modelling of flows
Mayor et al., 2015	Develop guidelines for the implementation of the nexus	Water - Energy - Food	Qualitative analysis – policy and governance for effective implementation of the nexus.
Nie et al., 2019	Framework identifying trade-off in land use for food production	Water – Energy - Food - Land	Qualitative analysis – Framework for FEW nexus modelling in relationship to land allocation scenarios.
Vanham et al., 2016	Study on the impact of diets in Dutch city on water usage levels	Water - Food	Qualitative analysis – Study on typical diets in Dutch cities and their impact on water availability
W4EF, 2015	Identify levels of resource usage between two factors of the nexus	Water - Energy (W4EF)	Qualitative analysis – Framework enabling the quantification of the impact of energy production sites on local water environments.
Nexus assessment frameworks at an urban scale			
Chen and Chen, 2016	Beijing is used as a case study in which energy consumed directly and for water infrastructure, as well as water consumed directly and for energy production are identified.	Water - Energy	Network model with quantitative analysis

(*continued on next page*)

(*continued*)

Authors	Objective	Nexus	Methodology
Fang and Chen, 2017	Beijing as a case study in which the nexus identified by analysing the impact in different sectors of water-energy consumption at a territorial scale.	Water - Energy	Linkage analysis – quantitative analysis
Miller-Robbie et al., 2017	UA case study in Hyderabad, looking at the GHG emissions in relationship to wastewater treatment for water used for irrigation, compared to those generated by the use of water from the grid	Water-Energy-Food-Health	LCA
Ramaswami et al., 2017	New Dehli is used as a case study to analyse external and internal aggregated flows of water – energy - food	Water-Energy-Food	Quantitative analysis of aggregated data at a city level
Walker et al., 2014	London as a case study to examine flows of materials and their best employment in order to reduce their carbon footprint. Urine as a fertiliser is considered.	Water-Energy-Food	Multi-Sectoral Systems Analysis (material flow analysis and sensitivity analysis)

Appendix 2 List of indicators used for the FEW-meter assessment framework

	Category	Indicator	Unit	Collected by
Water	Irrigation	Water (mains)	L	Farmer
		Water (groundwater)	L	Farmer
		Water (rainwater harvest)	L	Farmer
Energy	energy	Electricity	kWh	Farmer
		Renewable energy production	kWh	Farmer
		Fuel	L and type	Farmer
		Trips to garden	km/week and mode of transport	Research team
		Trips to deliver food	km/week; mode of transport and fuel	Research team
Food	crops	Harvest per crop	kg	Farmer
		Destination per crop	(e.g. farmer, friend, sold, uneaten…)	Farmer
		Cost per crop	Local currency	Farmer
	supplies	Fertiliser	kg and type	Farmer
		Herbicide	kg and type	Farmer
		Pest control / Insecticide	kg and type	Farmer
		Compost produced locally	kg	Farmer
		Animal feed	kg and type	Farmer
		Surface area of the project	m^2	Research team
		Surface area for cultivation	m^2	Research team
	Machinery	Inventory of tools/machinery	Number	Research team
		Inventory of timber, metal, plastic, glass used for fencing, raised beds, poly-tunnels, irrigation, greenhouses and sheds	Volume x each material	Research team
	Soil Health	Soil toxicity	Soil analysis	Research team
		Soil composition	Soil analysis	Research team
People	Social	Educational activities	Type and N of events and participants divided by age group (under 12 / 12–18 / 19–64/above 64)	Research team
		Community activities	Type and N of events and participants divided by age group (under 12 / 12–18 / 19–64/above 64)	Research team
		Socio-demographic profile of farmers and volunteers	Age, employment, salary, education etc.	Research team
		Physical and mental health	Hours spent gardening, motivations for gardening, Moods	Research team
		Diets	Increase in fruit and veg consumption; increase in number meals prepared at home etc	Research team
	Economy	Average salary (local currency/year) of FTE paid employees	Local currency	Research team
		Staff	N and FTE of farmers, people and volunteers	Research team

References

Al-Ansari, T., Korre, A., Nie, Z., Shah, N., 2015. Development of a life cycle assessment tool for the assessment of food production systems within the energy, water and food nexus. Sustain. Prod. Consum. 2, 52–66.

Allan, T., Keulertz, M., Woertz, E., 2015. The water–food–energy nexus: an introduction to nexus concepts and some conceptual and operational problems. Int. J. Water Resour. Dev. 31 (3), 301–311.

Allouche, J., Middleton, C., Gyawal, D., 2014. Nexus Nirvana or Nexus nullity? A Dynamic Approach to Security and Sustainability in the Water-energy-food Nexus. STEPS Centre, Brighton. STEPS Working Paper 63.

Al-Saidi, M., Elagib, N.A., 2017. Towards understanding the integrative approach of the water, energy and food nexus. Sci. Total Environ. 574, 1131–1139.

Armstrong, D., 2000. A survey of community gardens in upstate New York: implications for health promotion and community development. Health Place 6 (4), 319–327.

Artioli, F., Acuto, M., McArthur, J., 2017. The water-energy-food nexus: an integration agenda and implications for urban governance. Polit. Geogr. 61, 215–223.

Artmann, M., Sartison, K., 2018. The role of urban agriculture as a nature-based solution: a review for developing a systemic assessment framework. Sustainability 10 (6), 1937.

Atkinson, Giles, Bateman, Ian, Mourato, Susana, 2012. Recent advances in the valuation of ecosystem services and biodiversity. Oxford Rev. Econ. Policy 28 (1), 22–47.

Bhaduri, A., Ringler, C., Dombrowski, I., Mohtar, R., Scheumann, W., 2015. Sustainability in the water–energy–food nexus. Water Int. 40 (5–6), 723–732.

Biggs, E.M., Bruce, E., Boruff, B., Duncan, J.M., Horsley, J., Pauli, N., McNeill, K., Neef, A., Van Ogtrop, F., Curnow, J., Haworth, B., 2015. Sustainable development and the water–energy–food nexus: a perspective on livelihoods. Environ. Sci. Policy 54, 389–397.

Borysiak, J., Mizgajski, A., Speak, A., 2017. Floral biodiversity of allotment gardens and its contribution to urban green infrastructure. Urban Ecosyst. 20 (2), 323–335.

Cairns, R., Krzywoszynska, A., 2016. Anatomy of a buzzword: the emergence of 'the water-energy-food nexus' in UK natural resource debates. Environ. Sci. Policy 64, 164–170.

Caputo, S., Rumble, H., Schaefer, M., 2020. "I like to get my hands stuck in the soil": A pilot study in the acceptance of soil-less methods of cultivation in community gardens. J. Clean. Prod. 258, 120585.

Chen, S., Chen, B., 2016. Urban energy–water nexus: a network perspective. Appl. Energy 184, 905–914.

Cheng, C.L., 2002. Study of the inter-relationship between water use and energy conservation for a building. Energy Build. 34 (3), 261–266.

CoDyre, M., Fraser, E.D.G., Landman, K., 2015. How does your garden grow? An empirical evaluation of the costs and potential of urban gardening. Urban For. Urban Green. 14 (1), 72–79.

Cohen, N., Reynolds, K., 2015. Resource needs for a socially just and sustainable urban agriculture system: lessons from New York City. Renew. Agric. Food Syst. 30 (1), 103–114.

Cohen, N., Wijsman, K., 2014. Urban agriculture as green infrastructure: the case of New York City. Urban Agricult. Magazine 27, 16–19.

Cohen, N., Reynolds, K., Sanghvi, R., 2012. Five borough farm: seeding the future of urban agriculture in New York City. Design Trust for Public Space.

Colasanti, K.J.A., Hamm, M.W., Litjens, C., 2012. The City as an Agricultural Powerhouse"? Perspectives on Expanding Urban Agriculture from Detroit, Michigan. Urban Geogr. 33, 348–369.

Covarrubias, M., 2019. The Nexus between water, energy and food in cities: towards conceptualizing socio-material interconnections. Sustain. Sci. 14 (2), 277–287.

Daher, B.T., Mohtar, R.H., 2015. Water–energy–food (WEF) Nexus tool 2.0: guiding integrative resource planning and decision-making. Water Int. 40 (5–6), 748–771.

Dai, J., Wu, S., Han, G., Weinberg, J., Xie, X., Wu, X., Song, X., Jia, B., Xue, W., Yang, Q., 2018. Water-energy nexus: a review of methods and tools for macro-assessment. Appl. Energy 210, 393–408.

Edwards-Jones, G., i Canals, L.M., Hounsome, N., Truninger, M., Koerber, G., Hounsome, B., Cross, P., York, E.H., Hospido, A., Plassmann, K., Harris, I.M., 2008. Testing the assertion that 'local food is best': the challenges of an evidence-based approach. Trends Food Sci. Technol. 19 (5), 265–274.

Fang, D.L., Chen, B., 2017. Linkage analysis for the water-energy nexus of city. Appl. Energy 189, 770–779.

FAO, 2019. FAO Framework for the Urban Food Agenda Leveraging Sub-national and Local Government Action to Ensure Sustainable Food Systems and Improved Nutrition.

FAO (Food and Agriculture Organization), 2008. The State of Food and Agriculture 2008: Biofuels: Prospects, Risks and Opportunities. Food and Agriculture Organisation.

FAO (Food and Agriculture Organization), 2011. The State of the World's Land and Water Resources for Food and Agriculture (SOLAW) – Managing Systems at Risk. Food and Agriculture Organization of the United Nations and London, Earthscan, Rome.

FAO (Food and Agriculture Organization), 2014. The Water-Energy-Food Nexus: A New Approach in Support of Food Security and Sustainable Agriculture.

Frankowska, A., Jeswani, H.K., Azapagic, A., 2019. Environmental impacts of vegetables consumption in the UK. Sci. Total Environ. 682, 80–105.

Gain, A.K., Giupponi, C., Benson, D., 2015. The water–energy–food (WEF) security nexus: the policy perspective of Bangladesh. Water Int. 40 (5–6), 895–910.

Galaitsi, S., Veysey, J., Huber-Lee, A., 2018. Where is the added value? A review of the water-energy-food nexus literature. SEI Working Paper. Environment Institute Stockholm.

Garcia, D.J., You, F., 2018. Including agricultural and organic waste in food-Water-energy-waste nexus modelling and decision-making. In: Computer Aided Chemical Engineering, 43. Elsevier, pp. 1475–1480.

Garnett, T., 1999. CityHarvest: The Feasibility of Growing More Food in London. Sustain, London.

Giampietro, M., Aspinall, R.J., Bukkens, S.G.F., Cadillo Benalcazar, J., Flammini, A., Gomiero, T., Kovacic, Z., Madrid, C., Ramos Martín, J., Serrano Tovar, T., 2013. An Innovative Accounting Framework for the Food-energy-water Nexus: Application of the MuSIASEM Approach to Three Case Studies. FAO, Roma (Italia).

Gittleman, M., Jordan, K., Brelsford, E., 2012. Using citizen science to quantify community garden crop yields. Cities and the Environment (CATE) 5 (1), 4.

Goldstein, B., Hauschild, M., Fernandez, J., Birkved, M., 2016a. Testing the environmental performance of urban agriculture as a food supply in northern climates. J. Clean. Prod. 135, 984–994.

Goldstein, B., Hauschild, M., Fernandez, J., Birkved, M., 2016b. Urban versus conventional agriculture, taxonomy of resource profiles: a review. Agron. Sustain. Dev. 36 (1), 9.

Goldstein, B.P., Hauschild, M.Z., Fernandez, J.E., Birkved, M., 2017. Contributions of local farming to urban sustainability in the Northeast United States. Environ. Sci. Technol. 51 (13), 7340–7349.

Gondhalekar, D., Ramsauer, T., 2017. Nexus city: operationalizing the urban water-energy-food nexus for climate change adaptation in Munich, Germany. Urban Clim. 19, 28–40.

Guitart, D.A., Byrne, J.A., Pickering, C.M., 2015. Greener growing: assessing the influence of gardening practices on the ecological viability of community gardens in South East Queensland, Australia. J. Environ. Plan. Manag. 58 (2), 89–212.

Halbe, J., Pahl-Wostl, C.A., Lange, M., Velonis, C., 2015. Governance of transitions towards sustainable development–the water–energy–food nexus in Cyprus. Water Int. 40 (5–6), 877–894.

Hampwaye, G., 2013. Benefits of urban agriculture: Reality or illusion? Geoforum 49, R7–R8.

Hang, M.Y.L.P., Martinez-Hernandez, E., Leach, M., Yang, A., 2016. Designing integrated local production systems: a study on the food-energy-water nexus. J. Clean. Prod. 135, 1065–1084.

Holland, L., 2004. Diversity and connections in community gardens: a contribution to local sustainability. Local Environ. 9 (3), 285–305.

Horst, M., McClintock, N., Hoey, L., 2017. The intersection of planning, urban agriculture, and food justice: a review of the literature. J. Am. Plan. Assoc. 83 (3), 277–295.

IAEA (International Atomic Energy Agency), 2009. Annex VI: seeking sustainable climate land energy and water (CLEW) strategies. Nucl. Technol. Rev.

Karabulut, A.A., Crenna, E., Sala, S., Udias, A., 2018. A proposal for integration of the ecosystem-water-food-land-energy (EWFLE) nexus concept into life cycle assessment: a synthesis matrix system for food security. J. Clean. Prod. 172, 3874–3889.

Kumar, P. (Ed.), 2011. TEEB The Economics of Ecosystems and Biodiversity (TEEB): Ecological and Economic Foundations. Routledge, London.

Lin, L., Xu, F., Ge, X., Li, Y., 2018. Improving the sustainability of organic waste management practices in the food-energy-water nexus: a comparative review of anaerobic digestion and composting. Renew. Sustain. Energy Rev. 89, 151–167.

Lovell, S.T., 2010. Multifunctional urban agriculture for sustainable land use planning in the United States. Sustainability 2 (8), 2499–2522.

Lowder, S.K., Skoet, J., Raney, T., 2016. The number, size, and distribution of farms, smallholder farms, and family farms worldwide. World Dev. 87, 16–29.

Martinez-Hernandez, E., Leach, M., Yang, A., 2017. Understanding water-energy-food and ecosystem interactions using the nexus simulation tool NexSym. Appl. Energy 206, 1009–1021.

Mayor, B., López-Gunn, E., Villarroya, F.I., Montero, E., 2015. Application of a water–energy–food nexus framework for the Duero river basin in Spain. Water Int. 40 (5–6), 791–808.

McDougall, R., Kristiansen, P., Rader, R., 2019. Small-scale urban agriculture results in high yields but requires judicious management of inputs to achieve sustainability. Proc. Natl. Acad. Sci. U.S.A. 116 (1), 129–134.

McNamara, I., Nauditt, A., Penedo, S., Ribbe, L., 2014. NEXUS Water-Energy-Food Dialogues Training Material - Training Unit 01: Introduction to the Water-energy-Food Security (WEF) NEXUS. Nexus Regional Dialogue Programme. Available athttps://www.water-energy-food.org/fileadmin/user_upload/files/documents/giz/nexus-mainstreaming/Handbook_Module_1_compressed_file.pdfAccessed 12.12.2019.

Miller-Robbie, L., Ramaswami, A., Amerasinghe, P., 2017. Wastewater treatment and reuse in urban agriculture: exploring the food, energy, water, and health nexus in Hyderabad, India. Environ. Res. Lett. 12 (7), 075005.

Mourão, I., Moreira, M.C., Almeida, T.C., Brito, L.M., 2019. Perceived changes in well-being and happiness with gardening in urban organic allotments in Portugal. Int. J. Sustain. Dev. World Ecol. 26 (1), 79–89.

Mueller, N.D., Gerber, J.S., Johnston, M., Ray, D.K., Ramankutty, N., Foley, J.A., 2012. Closing yield gaps through nutrient and water management. Nature 490 (7419), 254.

Nadal, A., Alamús, R., Pipia, L., Ruiz, A., Corbera, J., Cuerva, E., Rieradevall, J., Josa, A., 2017. Urban planning and agriculture. Methodology for assessing rooftop greenhouse potential of non-residential areas using airborne sensors. Sci. Total Environ. 601, 493–507.

Newell, J.P., Goldstein, B., Foster, A., 2019. A 40-year review of food–energy–water nexus literature and its application to the urban scale. Environ. Res. Lett., 073003

Newman, P.W., 1999. Sustainability and cities: extending the metabolism model. Landsc. Urban Plan. 44 (4), 219–226.

Nie, Y., Avraamidou, S., Xiao, X., Pistikopoulos, E.N., Li, J., Zeng, Y., Song, F., Yu, J., Zhu, M., 2019. A Food-Energy-Water Nexus approach for land use optimization. Sci. Total Environ. 659, 7–19.

Peng, J., Liu, Z., Liu, Y., Hu, X., Wang, A., 2015. Multifunctionality assessment of urban agriculture in Beijing City, China. Sci. Total Environ. 537, 343–351.

Petit-Boix, A., Apul, D., 2018. From Cascade to Bottom-Up Ecosystem Services Model: How Does Social Cohesion Emerge from Urban Agriculture? Sustainability 10 (4), 998.

Pfister, S., Bayer, P., Koehler, A., Hellweg, S., 2011. Projected water consumption in future global agriculture: scenarios and related impacts. Sci. Total Environ. 409 (20), 4206–4216.

Pourias, J., Duchemin, E., Aubry, C., 2015. Products from urban collective gardens: food for thought or for consumption? Insights from Paris and Montreal. J. Agric. Food Syst. Community Dev. 5 (2), 175–199.

Ramaswami, A., Boyer, D., Nagpure, A.S., Fang, A., Bogra, S., Bakshi, B., Cohen, E., Rao-Ghorpade, A., 2017. An urban systems framework to assess the trans-boundary food-energy-water nexus: implementation in Delhi, India. Environ. Res. Lett. 12 (2) p.025008.

Reynolds, K., Cohen, N., 2016. Beyond the Kale: Urban Agriculture and Social Justice Activism in New York City. University of Georgia Press.

Roberts, S., Shackleton, C., 2018. Temporal dynamics and motivations for urban community food gardens in medium-sized towns of the Eastern Cape, South Africa. Land 7 (4), 146.

Rodríguez, D.J., Delgado, A., DeLaquil, P., Sohns, A., 2013. Thirsty Energy. World Bank, Washington, DC.

Romic, M., Romic, D., 2003. Heavy metals distribution in agricultural topsoils in urban area. Environ. Geol. 43 (7), 795–805.

Saha, M., Eckelman, M.J., 2017. Growing fresh fruits and vegetables in an urban landscape: A geospatial assessment of ground level and rooftop urban agriculture potential in Boston, USA. Landsc. Urban Plan. 165, 130–141.

Sanyé-Mengual, E., Gasperi, D., Michelon, N., Orsini, F., Ponchia, G., Gianquinto, G., 2018. Eco-efficiency assessment and food security potential of home gardening: A case study in Padua. Italy. Sustain 10 (7), 2124.

Schoen, V., Caputo, S., Blythe, C., 2020. Valuing physical and social output: a rapid assessment of a London Community Garden. Sustainability 12, 5452.

Shannak, S., Mabrey, D., Vittorio, M., 2018. Moving from theory to practice in the water–energy–food nexus: an evaluation of existing models and frameworks. Water-energy Nexus 1, 17–25.

Shiina, T., Hosokawa, D., Roy, P., Nakamura, N., Thammawong, M., Orikasa, T., 2011. Life cycle inventory analysis of leafy vegetables grown in two types of plant factories. Acta Hortic. 919, 115–122.

Spiegelberg, M., Baltazar, D.E., Sarigumba, M.P.E., Orencio, P.M., Hoshino, S., Hashimoto, S., Taniguchi, M., Endo, A., 2017. Unfolding livelihood aspects of the water-energy-food nexus in the Dampalit watershed, Philippines. J. Hydrol. Reg. Stud. 11, 53–68.

Tallis, H., Kareiva, P., Marvier, M., Chang, A., 2008. An ecosystem services framework to support both practical conservation and economic development. Proc. Nat. Acad. Sci. U.S.A. 105 (28), 9457–9464.

Travaline, K., Hunold, C., 2010. Urban agriculture and ecological citizenship in Philadelphia. Local Environ. 15 (6), 581–590.

Turner, M.L., Williams, S., Schmutz, U., 2016. Which Tool to Use? A Guide for Evaluating Health and Wellbeing Outcomes for Community Growing Programmes. Available at. https://www.farmgarden.org.uk/system/files/whichtooltouse.pdf.

United Nations, 2004. World Population to 2300. New York: Department of Economic and Social Affairs, United Nations.

Van Tuijl, E., Hospers, G.J., Van Den Berg, L., 2018. Opportunities and challenges of urban agriculture for sustainable city development. Eur. Spat. Res. Policy 25 (2), 5–22.

Vanham, D., Mak, T.N., Gawlik, B.M., 2016. Urban food consumption and associated water resources: the example of Dutch cities. Sci. Total Environ. 565, 232–239.

W4EF, 2015. Water for Energy Framework - Evaluation of the Local Interactions Between Energy Sites and Water. Available at https://www.eip-water.eu/sites/default/files/W4EF%20-%20Vol%201%20-%20General%20report%20-%20October%202015_0.pdf. Accessed 12.12.2019.

Walker, R.V., Beck, M.B., Hall, J.W., Dawson, R.J., Heidrich, O., 2014. The energy-water-food nexus: strategic analysis of technologies for transforming the urban metabolism. J. Environ. Manage. 141, 104–115.

Wang, S., Cao, T., Chen, B., 2017. Urban energy–water nexus based on modified input–output analysis. Appl. Energy 196, 208–217.

Warren, E., Hawkesworth, S., Knai, C., 2015. Investigating the association between urban agriculture and food security, dietary diversity, and nutritional status: a systematic literature review. Food Policy 53, 54–66.

Weidner, T., Yang, A., 2020. The potential of urban agriculture in combination with organic waste valorization: assessment of resource flows and emissions for two european cities. J. Clean. Prod. 244, 118490.

Weidner, T., Yang, A., Hamm, M.W., 2019. Consolidating the current knowledge on urban agriculture in productive urban food systems: learnings, gaps and outlook. J. Clean. Prod. 209, 1637–1655.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. Int. J. Life Cycle Assess. 21 (9), 1218–1230.

Wichelns, D., 2017. The water-energy-food nexus: Is the increasing attention warranted, from either a research or policy perspective? Environ. Sci. Policy 69, 113–123.

Williams, J., Bouzarovski, S., Swyngedouw, E., 2014. Politicising the nexus: nexus technologies, urban circulation, and the coproduction of water-energy. Nexus Network Think Piece Series. Paper, 1.

Wortman, S.E., Lovell, S.T., 2013. Environmental challenges threatening the growth of urban agriculture in the United States. J. Environ. Qual. 42 (5), 1283–1294.

Zhang, Y., 2013. Urban metabolism: a review of research methodologies. Environ. Pollut. 178, 463–473.

Zhang, J., Campana, P.E., Yao, T., Zhang, Y., Lundblad, A., Melton, F., Yan, J., 2018. The water-food-energy nexus optimization approach to combat agricultural drought: a case study in the United States. Appl. Energy 227, 449–464.

Zhang, P., Zhang, L., Chang, Y., Xu, M., Hao, Y., Liang, S., Liu, G., Yang, Z., Wang, C., 2019. Food-energy-water (FEW) nexus for urban sustainability: a comprehensive review. Resour. Conserv. Recycl. 142, 215–224.