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Urban Agriculture and its Sustainability Implications on the Food-Water-Energy Nexus[1]

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Introduction

Global population is projected to increase more than 2 billion by 2050, resulting in a total population of 9.7 billion (UNPD 2017). In addition, more than 55% of the world's population currently resides in urban areas, which is expected to increase to 68% by 2050. The process of modern urbanization and associated urban demands for resources are reshaping our biosphere and leading to unprecedented challenges in human history. Consequences of urbanization are further exacerbated by other global changes such as shifting land use, altered climate, resource governance, and impacts from economic fluctuations (Muller 2007). Hence, it is crucial to improve resource efficiency in urban areas and explore pathways to sustainable urbanization. Given increasing urban populations, achieving urban sustainability (defined as an urban environment that meets people's needs while avoiding unacceptable social and environmental impacts; Hamilton et al. 2002) is pivotal for humanity, because global sustainability cannot possibly be achieved without urban regions becoming sustainable.

Urban agriculture, defined as growing crops and grazing livestock in urban, suburban, and peri-urban areas, has been proposed as a viable option to achieve urban sustainability (Lovell 2010). At local scales, urban agriculture could contribute to food security, water reuse, energy saving, ecosystem health, and other social-economic benefits (e.g., community interaction, social cohesion, employment opportunity, etc.) (Lovell 2010; Daigger et al. 2015; Goldstein et al. 2017). At regional scales, urban agriculture could reduce environmental impacts related to food import and transportation into urban areas (Lapola et al. 2010). While not a panacea and may have significant barriers (e.g., land scarcity, insufficient value-based marketing, and limited local food distribution network) and potential social-environmental risks (e.g., contamination, pollution, pest and disease), when combining with effective policy, planning, and collaborative stakeholder engagement, urban agriculture has potential to efficiently meet the needs of diverse actors in urban areas and help achieve Sustainable Development Goals (SDGs).

The food, energy, and water (FEW) nexus is an emerging concept in environmental sustainability that accounts for interdependences and interconnections among FEW resources. Urban agriculture, with its unique role involving all FEW sectors, has the potential to become an important piece of the puzzle in achieving urban sustainability (Hoff 2011; Daigger et al. 2015). However, integration of urban agriculture with existing and emerging technologies related to the FEW nexus has not yet been fully explored and well understood. Hence, in this publication, we aim to: (1) illustrate the concept of the FEW nexus in the urban context; and (2) elaborate on the role of urban agriculture and its sustainability implications on the FEW resource

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nexus, using specific examples in Florida. Insights from this publication are relevant for urban and regional planning and environmental decision-making related to urban agriculture. The publication will be helpful to the building design industry for conservation-minded development, and to Extension agents, who can communicate and educate about sustainability benefits of urban agriculture on FEW resources. This information may also contribute to public discussion and policy discourse regarding future development of urban agriculture and implications for urban landscapes and green infrastructures.

The Concept of the FEW Nexus in the Urban Context

The nexus approach has been identified as a priority for environmental sustainability in the United States and worldwide, and is a promising concept in multiple ways (National Research Council 2013; Allouche et al. 2014). This approach recognizes complex relationships between different resource systems (e.g., food, water, and energy), and closes material and resource loops (defined as processes to eliminate waste and reclaim and recycle materials through natural or technological methods) to maximize resource use (Figure 1) (Hoff 2011; Bazilian et al. 2011; Hussey and Pittock 2012; Ringler et al. 2013). At the global level, for example, considering all human activity, food production consumes the most fresh water, accounting for 70% of total water withdrawals globally (i.e., *water for food*). Food production and supply chains (e.g., processing, storage, and transport of food) also consumed ~30% of global energy supplies (i.e., *energy for food*). In addition, energy production accounts for 10% of total global water resources (i.e., *water for energy*) (Chang et al. 2020). The nexus approach offers a lens through which an interrelated set of goals and outcomes can be defined and coordinated efforts can be leveraged through management and policy efforts (Bazilian et al. 2011; Romero-Lankao et al. 2017). With the nexus approach, interventions (e.g., policy, planning, and management) could explicitly consider the synergies from integration across FEW resource sectors.

Specifically, in the urban context, optimal integration of FEW resources can help conserve water and energy resources, facilitate food production, mitigate carbon emissions, and shrink the overall environmental footprint. Due to the emergence of new technologies and synergistic operations, the best available technological solutions depend upon the limiting resources from each unique FEW nexus (Chang et al. 2020). For example, urban agriculture and food production, such as rooftop agriculture and vertical farming, can be irrigated by surface water or groundwater, as well as powered by renewable energy harvested locally (e.g., solar, or tidal energy). When these technologies are adopted and coordinated in the agricultural sector at a small scale, they can be referred to as decentralized technologies, which can often be driven by individual adoptions or grassroots movement. However, different regional and urban farming technologies for food production can also be integrated at a much larger scale through centralized processes to create synergistic effects, in which government and policymakers will play a dominant role. Regardless of decentralized or centralized integrations, the mobilization and closed-loop (re)utilization of FEW resources across multiple sectors is key to contemporary sustainable urban development.

Sustainability Implications of Urban Agriculture on the FEW Nexus

In specific urban systems, urban agriculture can affect the interdependencies and interconnections associated with myriad FEW flows both within and across urban boundaries (Ramaswami et al. 2017) (Figure 1). One of the most direct consequences of urban agriculture for the **food** sector is to provide food to urban residents. At present, up to 15% of food originates within metropolitan regions; however, in certain cities (e.g., Cleveland, Ohio), 100% of produce, 94% of poultry and eggs, and 100% of honey needs could potentially be met if 80% of vacant lots and 9% of residential lots could be used for urban agriculture (Grewal and Grewal 2012). Such production potentials are crucial for ensuring food security by providing access to healthy, fresh, and nutritious food, especially during economic recessions and for those living in areas classified as "food deserts" (defined as areas with limited access to affordable and healthy food) and marginal communities (defined as communities excluded from mainstream education and social, economic, and/or cultural life) (Armar-Klemesu 2000).

Urban agriculture also has important implications for the **energy** sector (Figure 1) (Canning 2010). In developed economies, greater than 75% of energy consumption in food systems occurs after production (FAO 2013); urban agriculture could substantially reduce post-production energy consumption. Urban agriculture can mitigate energy consumption associated with the processing, distribution, consumption, and disposal of food (i.e., *energy for food*) (Mohareb et al. 2017), enhance resource-use efficiency, recycle wastes (Despommier 2013; Zhang et al. 2013), and reduce energy imports through biomass production and food waste digestion for producing biogas and energy locally (i.e., *food for energy*). Moreover, mitigation of urban heat island effects (i.e., cooling benefits) from urban agriculture (e.g., in rooftop farming and green buildings) could lower the energy demand for cooling. Energy benefits from urban agriculture could also extend to water savings, since water is often required for cooling power plants (i.e., *water for energy*). In addition, urban agriculture may improve stormwater management (as compared to impervious surface) and nutrient reuse (uptake of nutrients from runoff and wastes), thus reducing energy costs for irrigation and fertilization (i.e., *energy for water and nutrients*).

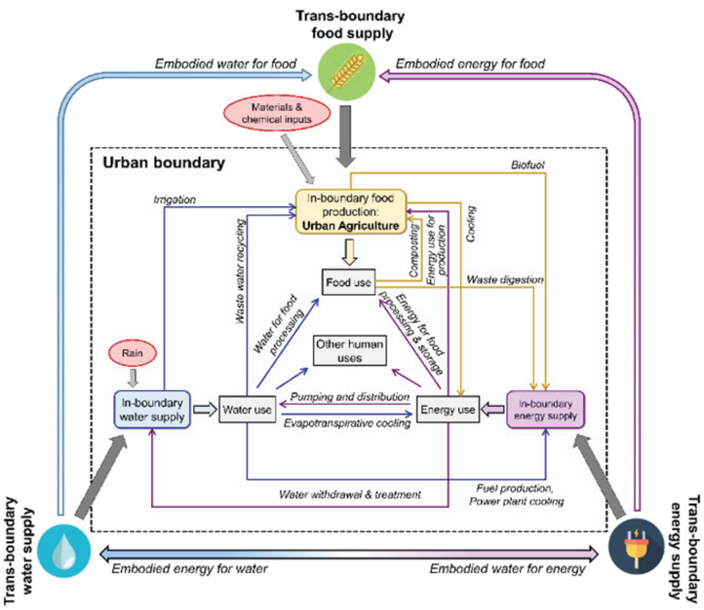

Figure 1. Conceptual framework delineating major interactions related to urban agriculture and its implications on the food, water, and energy (FEW) nexus within and across the urban boundary. "In-boundary supply" indicates resource supply occurring within the urban boundary, whereas "trans-boundary supply" means external resource supply across the urban boundary through resource supply chains. "Embodied" indicates FEW resources that are not manifested as their original forms but instead embedded in the products or services.
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Urban agriculture also provides benefits to the **water** sector (Figure 1) by enhancing rainwater harvesting and reclamation of stormwater and treated wastewater (i.e., *water for food*). These sources of water are substantial in some locations (e.g., in dry and arid regions) and can supplement irrigational water use. Urban agriculture can also reduce irrigation needs (e.g., via targeted irrigation or smart irrigation) as compared to conventional agricultural production (e.g., irrigated cropping systems) (Daigger et al. 2015). In addition, large-scale practices of urban agriculture can reduce imports of virtual water (defined as water embedded in the products or services; e.g., water used for producing food) related to external food supplies, enhance infiltration and recharge (the process through which water enters the soil and flows into the aquifers), reduce runoff generation, and, in the long run, replenish groundwater aquifers (i.e., *food for water*). Further, urban agriculture provides other vital benefits to **ecosystem services** at local to global scales, including improving microclimate, sequestering carbon, regulating surface runoff, and supporting biological diversity (Deelstra and Girardet 2000; Lovell and Taylor 2013; Gondhalekar and Ramsauer 2016).

Real-world examples of current and potential integration of urban agriculture in the FEW nexus in south Florida are illustrated at two scales: an entire community, and a single building or structure (Figure 2), both of which are feasible technologically and can reduce overall resource consumption and emissions. It is important to note that there are many ways of designing optimal integration of the FEW nexus with urban agriculture (e.g., depending upon resource availability, community acceptance, economic viability, technological innovations, etc.), which can be evaluated from the perspective of cost-benefit-risk and social-environmental tradeoffs. Indicators for evaluations include, but are not limited to: resource use, food production and demand, environmental footprint, carbon emissions, ecosystem services, social equity, and environmental justice.

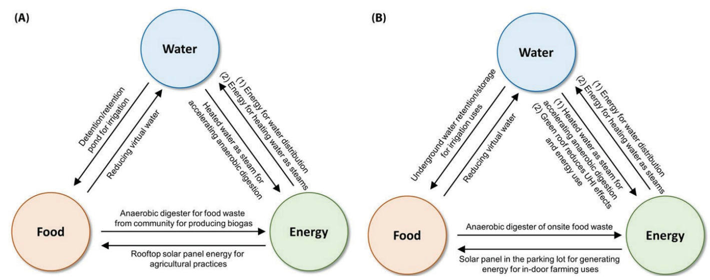

Figure 2. Examples of two urban agriculture sites in south Florida and their current and potential integration in the food, energy, water (FEW) nexus at the scale of community (A) and the scale of an individual building or urban structure (B).
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Conclusion

This publication addresses the role of the nexus approach in improving the sustainability of urban agriculture. A nexus approach seeks to close resource loops by integrating across all FEW resource sectors. It provides a unique interdisciplinary lens to understand the importance of urban agriculture in sustainable development and urbanization agendas. Urban agriculture can affect multiple sectors beyond food. This publication is relevant for urban and regional planning and policymaking related to the future development of urban agriculture, as well as for Extension agents to communicate and educate about the sustainability implications of urban agriculture on FEW resources.

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