Green and Blue Infrastructure

Subjects: Green & Sustainable Science & Technology

Contributor: Gengyuan Liu

Green and blue infrastructure (GBI) is defined as a network of landscape components, which include green areas and water bodies. Such an infrastructure, available within an urban space, provides diverse environmental, economic, and social benefits to people and other living organisms.

Keywords: green-blue infrastructure ; food-energy-water nexus ; tradeoff ; small scale urban system

1. Introduction

Concerning the flow of key resources for human survival, food, energy, and water can be interrelated with green and blue infrastructure (GBI). This green-blue system can perform various functions, having the potential to produce multiple services, such as food, water purification, temperature regulation, and others, which are crucial for urban adaptability [1]. Several developed countries implemented their GBI to reduce the urban heat effects (Germany, Australia), improve carbon storage (South Africa), control surface runoff (Brazil, Netherland, USA), and increase local food production (Singapore) [2].

From a human perspective, in parallel to ecosystem services (ES), GBI can also produce some dis-services [3]. For example, while the cultivation of vegetables generates food to support humans, it might require a huge amount of water. For instance, 200 L of water is required to produce 1 kg of vegetables [4]. Trees in the urban environment provide regulating service, by cooling or shading effects in Summer and protection against the chilled wind in Winter [5]. Nonetheless, trees might need water in abundance [6]. On the other hand, the cultivation of fruit trees, with known edibles such as apples (Malus spp.), cherries (Prunus spp.), and pears (Pyrus spp.), is prohibited in urban streets due to the falling of their fruits on footpath and stroller injuries [7]. Green roofs (GRs) are capable of reducing the fluctuation of indoor temperatures in cold as well as warm weather conditions and minimizing the energy consumption of buildings [8]. Sometimes, the conservation of energy utilization can be induced, due to unexpected natural factors (e.g., the rainfall will reduce the requirements of extra water) [9]. Moreover, GRs reduce stormwater runoffs [10], which may include heavy metals such as Fe, Zn, Cu, and Al [11]. According to the authors' observations, large amounts of metals can be upheld (92% of Cd, 99% of Pb, 97% of Cu, and 96% of Zn), especially in summer. However, such heavy metals might contaminate the vegetables [12].

Food, energy and water (FEW) are key inter-linked resources for the survival of individuals and human communities [13]. Such a mutual relation among different resources and their dynamics is synthesized through the nexus concept and framework [14][15]. For instance, energy is necessary for food production, landfill gas, and waste from food production and consumption can be used for energy generation [16][17]. Food production and consumption also use water and generate wastewater [18][19]. Energy is needed for water treatment processes, while energy production requires water and generates wastewater [20][21].

However, FEW nexus should be further integrated with ecosystem [22]. In fact, this integration would support the achievement of sustainable development goals [23]. GBI can act as a unifying spatial and functional (referred to provide ecosystem services) framework, as well as a system within which flows of food, energy, and water exist and can be quantified. **Figure 1** illustrates the nexus structure. The food production practices drive energy use intensities and water extraction rates. At the same time, energy is essential for food and water, and water safety is the key to electricity generation and food production. Water is demanded to produce electricity, e.g., hydropower, and the harvesting of biomass can be used for biofuel production. Birol and Das [24] reported that around 15% of global water extraction was consumed for the production of energy. Energy is essential for the transport, pumping, and treatment of portable and non-portable water, i.e., wastewater, for human utilization or vegetation irrigation. On the contrary, approximately 8% of energy is used for water purposes worldly [25]. Regarding power generation integration in the water cycle, some of the GBI, e.g., constructed wetlands, can provide opportunities to mitigate energy consumption, for instance, it generates humus as well as nutrient-rich effluent water that can be utilized directly to irrigate energy crops and for short rotation vegetation through fertigation process [26][27]. Moreover, the treated water can be used for flush toilets, street vegetation, and washing the roads, and also to reduce the extra energy burden that is required for wastewater treatment. This is why a "GBI–FEW" nexus can be considered in the study of urban metabolism, with the purpose of a better management of resources, supporting the transition to more sustainable energy systems.

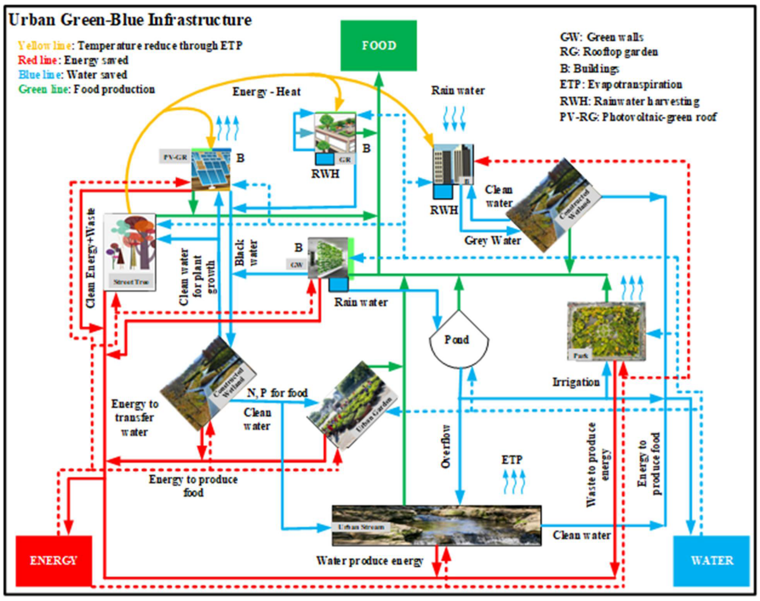

Figure 1. The sustainable "GBI-FEWN" management framework in an urban settlement.

2. Positive and Negative Impacts of GBI on FEW

We describe the most important city GBI types and the associated FEW topics that are found in studies. We observed that scientific studies on GBI–FEW nexus primarily focused on direct and indirect ES (e.g., food). Many studies on the direct positive effects of urban farming on food generation in built-up places or food-associated topics are receiving attentions in scientific literatures. Some GBI types (such as green roofs, urban gardens, urban forests, etc.) can be used for food cultivation, as shown in **Table 1**. For example, the rooftop gardens are favored in dense urban cores with limited space, and different kinds of vegetables can be produced, making people more self-reliant for local food. Nowadays, societies in developed and developing countries normally depend on urban agriculture to meet their demands for food. Orsini et al. [28] inquired about the production capability of rooftop farming in Bologna, Italy, finding that rooftop farming could provide more or about 12,000 t/year of vegetables to Bologna, satisfying 77% of the city dwellers' requirements. A Singaporean annually consumes 82.6 kg average of vegetables [29]. According to Singapore Statistics [30], the population of Singapore is 4.8 million, Singapore requires 396,480 t/y of vegetables. Both traditional farms and rooftop gardening can satisfy approximately 35.5% of Singapore's vegetable requirements [2]. Similarly, few authors observed that the urban gardens played a crucial role in food security and food supply in several historical periods, and the importance of urban gardens for food security was also stressed during political and economic crises [31]. McClintock, [32] studied in the USA and Europe, the provision of urban food production by gardens formed a part of adaptation approaches in times of battles. When Sweden was influenced by a severe food shortage during World War II, 10% of the food utilized in the whole country came from urban gardens [33]. In addition, the contribution of city gardening to the urban food supply was evaluated in Salzburg, Austria. The results indicated that out of 156 city gardeners, 76% cultivated their vegetables and fruits, the majority of gardeners providing 44% and 10% of their annual vegetables and fruits respectively [34]. Urban agriculture practices can not only satisfy the vegetables and fruits requirements of the urban dwellers but decrease the food import demands, with annual carbon emission footprint reduction as well. For instance, Lee et al. [35] demonstrated that for the greater municipal area (51 km^2) of Seoul, South Korea, the urban agriculture implementation would annually decrease carbon dioxide emissions by 11.7 million kg. This offset amount is the same value of annual carbon dioxide sequestered by 10.2 km^2 of 20-year-old oak forests and 20 km^2 of pine forests. Hence, there is a need to develop a sustainable policy to maximize the positive effects and minimize the negative effects of urban agriculture.

GBI Types	Food			Water						
	Direct ES	Indirect ES	Edis	Direct ES				Indirect ES	Edis	
	Providing Food	Providing Shrubs, Grasses and Flowers	Risk of Food Contaminated by Heavy Metal & Pollutants	Reduce Stormwater Runoff	Enhanced Water Quality	Increase Available Water Supply	Groundwater Recharge	Reduced Water Treatment Needs	Increasing Water Consumption	Water Pollu from Fertil & Chem
Green Roofs	●	●	▲	●	●	○	○	●	▲	[illegible]
Street Trees	●	○	▲	●	●	○	◒	●	▲	[illegible]
Urban Garden	●	●	▲	●	●	○	●	●	▲	[illegible]
Green Walls	○	○	△	●	●	○	○	●	△	[illegible]

GBI Types	Food			Water						
	Direct ES	Indirect ES	Edis	Direct ES				Indirect ES	Edis	
	Providing Food	Providing Shrubs, Grasses and Flowers	Risk of Food Contaminated by Heavy Metal & Pollutants	Reduce Stormwater Runoff	Enhanced Water Quality	Increase Available Water Supply	Groundwater Recharge	Reduced Water Treatment Needs	Increasing Water Consumption	Wate Pollu from Fertil & Chen
Urban forest	●	●	▲	●	●	○	●	●	▲	△
Constructed Wetland	●	○	▲	●	●	●	●	●	▲	△
Rain Garden	○	◒	△	●	◒	●	●	●	▲	△
Lakes	●	○	▲	●	●	●	●	●	△	△
Rivers	●	○	▲	●	○	●	●	○	▲	△
Streams	●	○	▲	●	○	●	●	○	△	△
Bioswales	○	◒	△	●	●	●	●	●	△	△
Permeable Pavements	○	○	△	●	●	○	◒	●	△	△
Total										

Note:

●Yes

◒Maybe

○Not ;

▲Yes

◭Maybe

△Not .

The scientific literature shows that GBI not only generates ES, but also ecosystem dis-services. However, the same urban GBI may have positive and negative effects on, e.g., food (**Table 1**). On the one hand, food cultivation in metropolitan areas ensure urban food supply especially for the poor people in developing countries. On the other hand, it also turned out that food safety is a major concern because of environmental pollutions [36][37]. For example, heavy metals pollution is becoming a main problem sourced from gaseous atmospheric deposition [38][39]. Furthermore, though wastewater reuse for agricultural irrigation improves the efficiency of urban water system, it leads to significant concerns about food safety of with pathogens moving from sewage water to food [40]. Similar to another farming system, urban agriculture itself may also contaminate water with pesticides and fertilizers [41]. Hence, unintentional negative impacts of each GBI must be taken into account, as this can offset the objectives that motivate the expansion of GBI in cities. Therefore, its existence as a green infrastructure also helps control rainwater runoff to lessen the risk of flooding. Blue infrastructure studies are also common as their green counterparts. We found that the effects of the urban rivers on reduced stormwater runoff, energy-saving, and improved water supply are the topics (24%) mostly discussed in the literature, followed by CTW (17%) and streams (15%) topics (**Table 1**). Some blue infrastructures (such as rivers, CTW, lakes, etc.) studied in the scientific literature demonstrate associations to at least one subject in each of the FEW systems.

Isolated effects of various of GBI on FEW in cities, such as the direct urban ecological service (UES), are well understood and documented in the literature. A conceptual integrated GBI-FEWN framework considering the direct and indirect effects of GBI on urban FEWN beyond the city boundaries was developed [1]. It presented the impact of main causal relationships on the urban FEWN that result from the implementation of different types of GBI in cities, highlighting potential conflicts or win-win situations. The comprehensive understanding of how GBI can affect food, water and energy systems simultaneously and interactively in urban areas could assist the decision-making process in urban planning and management, supporting the transition to more sustainable and resilient cities.

3. Conclusions

The interactive flows in the energy, water, and food system as a food–energy–water (FEW) nexus are very important for the sustainable development of cities, and they can be arbitrated via green-blue infrastructure (GBI) in the built-up area. Here, our focus is on non-built “nature in cities” infrastructure. The GBI generates multiple ecological benefits (food production, water and energy-saving, and microclimate regulation) in urban centers. The FEW flows also generate some negative effects (dis-services) within the GBI, for example, food products within the green-blue system, but over-application of pesticides and fertilizers, could generate a release of toxic substances, that might also improve water quality. If water is extracted to produce energy, it might reduce the natural water flows of rivers, impacting on the biosphere too. Well-planned urban construction can help to control the negative effects.

There is a need to make integrative and deliberate policy to link the GBI with each element in the urban FEW nexus. We also focus on nexus modeling techniques in terms of their benefits, drawbacks, and applications. Moreover, guidance is provided on the choice of an adequate modeling approach. Finally, water, energy, and food are linked physically, but tradeoffs among them often increase when their management is put into practice. We must minimize the tradeoffs and build up synergies between food, energy, and water by using a holistic approach. Therefore, the GBI-FEW nexus has become a major approach to address the relation between three important individual resource components of sustainability.

References

1. Rodrigo A. Bellezoni; Fanxin Meng; Pan He; Karen C. Seto; Understanding and conceptualizing how urban green and blue infrastructure affects the food, water, and energy nexus: A synthesis of the literature. *Journal of Cleaner Productio n* **2021**, *289*, 125825, 10.1016/j.jclepro.2021.125825.
2. Astee, L.Y.; Kishnani, N.T. Building Integrated Agriculture Utilising Rooftops for Sustainable Food Crop Cultivation in Si ngapore. J. Green Build. 2010.
3. Childers, D.L.; Bois, P.; Hartnett, H.E.; McPhearson, T.; Metson, G.S.; Sanchez, C.A. Urban Ecological Infrastructure: A n Inclusive Concept for the Non-Built Urban Environment. Elem. Sci. Anthr. 2019, 7.
4. Hoekstra, A.; Hung, P. Virtual Water Trade a Qualifcation of Virtual Water FLows between Nations in Relation to Interna tional Crop Trade; Value of Water Research Report; IHE: Delft, The Netherlands, 2002; Available online: https://www.w aterfootprint.org/media/downloads/Report11.pdf (accessed on 21 June 2021).
5. Mullaney, J.; Lucke, T.; Trueman, S.J. A Review of Benefits and Challenges in Growing Street Trees in Paved Urban En vironments. Landsc. Urban Plan. 2015, 134, 157–166.
6. Escobedo, F.J.; Kroeger, T.; Wagner, J.E. Urban Forests and Pollution Mitigation: Analyzing Ecosystem Services and Di sservices. Environ. Pollut. 2011, 159, 2078–2087.
7. City of Seattle. Street Tree Planting Procedures. Available online: http://www.seattle.gov/transportation/treeswithreserv ations.htm (accessed on 20 May 2011).
8. Castleton, H.F.; Stovin, V.; Beck, S.B.M.; Davison, J.B. Green Roofs; Building Energy Savings and the Potential for Ret rofit. Energy Build. 2010, 42, 1582–1591.
9. Ascione, F.; Bianco, N.; de’ Rossi, F.; Turni, G.; Vanoli, G.P. Green Roofs in European Climates. Are Effective Solutions for the Energy Savings in Air-Conditioning? Appl. Energy 2013.
10. Rowe, D.B. Green Roofs as a Means of Pollution Abatement. Environ. Pollut. 2011.
11. Czemiel Berndtsson, J. Green Roof Performance towards Management of Runoff Water Quantity and Quality: A Revie w. Ecol. Eng. 2010, 36, 351–360.
12. Ye, J.; Liu, C.; Zhao, Z.; Li, Y.; Yu, S. Heavy Metals in Plants and Substrate from Simulated Extensive Green Roofs. Ec ol. Eng. 2013.
13. Bieber, N.; Ker, J.H.; Wang, X.; Triantafyllidis, C.; van Dam, K.H.; Koppelaar, R.H.E.M.; Shah, N. Sustainable Planning of the Energy-Water-Food Nexus Using Decision Making Tools. Energy Policy 2018.
14. Romero-Lankao, P.; McPhearson, T.; Davidson, D.J. The Food-Energy-Water Nexus and Urban Complexity. Nat. Clim. Chang. 2017, 7, 233–235.
15. Vora, N.; Shah, A.; Bilec, M.M.; Khanna, V. Food-Energy-Water Nexus: Quantifying Embodied Energy and GHG Emissi ons from Irrigation through Virtual Water Transfers in Food Trade. ACS Sustain. Chem. Eng. 2017.
16. Xin, X.; Ma, Y.; Liu, Y. Electric Energy Production from Food Waste: Microbial Fuel Cells versus Anaerobic Digestion. Bi oresour. Technol. 2018.
17. Ali, M.; Geng, Y.; Robins, D.; Cooper, D.; Roberts, W. Impact Assessment of Energy Utilization in Agriculture for India a nd Pakistan. Sci. Total Environ. 2019.
18. Zou, Y.; Duan, X.; Xue, Z.; Mingju, E.; Sun, M.; Lu, X.; Jiang, M.; Yu, X. Water Use Conflict between Wetland and Agric ulture. J. Environ. Manag. 2018.

19. Weber, O.; Hogberg-Saunders, G. Water Management and Corporate Social Performance in the Food and Beverage In dustry. J. Clean. Prod. 2018.
20. Jin, Y.; Tang, X.; Feng, C.; Höök, M. Energy and Water Conservation Synergy in China: 2007–2012. Resour. Conserv. Recycl. 2017.
21. Feng, C.; Tang, X.; Jin, Y.; Höök, M. The Role of Energy-Water Nexus in Water Conservation at Regional Levels in Chi na. J. Clean. Prod. 2019.
22. Biggs, E.M.; Bruce, E.; Boruff, B.; Duncan, J.M.A.; Horsley, J.; Pauli, N.; McNeill, K.; Neef, A.; Van Ogtrop, F.; Curnow, J.; et al. Sustainable Development and the Water-Energy-Food Nexus: A Perspective on Livelihoods. Environ. Sci. Poli cy 2015.
23. Bidoglio, G.; Vanham, D.; Bouraoui, F.; Barchiesi, S. The Water-Energy-Food-Ecosystems (WEFE) Nexus Water in the Nexus. Encycl. Ecol. 2018, 4, 459–466.
24. Birol, E.; Das, S. Estimating the Value of Improved Wastewater Treatment: The Case of River Ganga, India. J. Environ. Manag. 2010.
25. UN. United Nation, World Urbanization Prospects; 2014; Available online: https://unu.edu/media-relations/releases/wwd 2014-un-stresses-water-energy-issues.html (accessed on 18 January 2021).
26. Barbagallo, S.; Barbera, A.C.; Cirelli, G.L.; Milani, M.; Toscano, A. Reuse of Constructed Wetland Effluents for Irrigation of Energy Crops. Water Sci. Technol. 2014.
27. La Bella, S.; Tuttolomondo, T.; Leto, C.; Bonsangue, G.; Leone, R.; Virga, G.; Licata, M. Pollutant Removal Efficiency of a Pilot-Scale Horizontal Subsurface Flow in Sicily (Italy) Planted with Cyperus Alternifolius L. and Typha Latifolia L. and Reuse of Treated Wastewater for Irrigation of Arundo Donax L. for Pellet Production—Results of Two-. Desalination Wa ter Treat. 2016.
28. Orsini, F.; Gasperi, D.; Marchetti, L.; Piovene, C.; Draghetti, S.; Ramazzotti, S.; Bazzocchi, G.; Gianquinto, G. Exploring the Production Capacity of Rooftop Gardens (RTGs) in Urban Agriculture: The Potential Impact on Food and Nutrition Security, Biodiversity and Other Ecosystem Services in the City of Bologna. Food Secur. 2014.
29. AFVAS. Agri-Food and Veterinary Authority of Singapore (AFVAS) Statistics; 2008. Available online: http://www.ava.go v.sg/AVA/Templates/AVA-GenericContentTemplate.aspx?NRMODE=Published (accessed on 20 November 2020).
30. Singapore Statistics. 2008. Available online: www.singstat.gov.sg (accessed on 10 December 2020).
31. Barthel, S.; Isendahl, C. Urban Gardens, Agriculture, And Water Management: Sources of Resilience for Long-Term Fo od Security in Cities. Ecol. Econ. 2013.
32. McClintock, N. Why Farm the City? Theorizing Urban Agriculture through a Lens of Metabolic Rift. Camb. J. Reg. Econ. Soc. 2010.
33. Barthel, S.; Folke, C.; Colding, J. Social-Ecological Memory in Urban Gardens-Retaining the Capacity for Management of Ecosystem Services. Glob. Environ. Chang. 2010.
34. Breuste, J.H.; Artmann, M. Allotment Gardens Contribute to Urban Ecosystem Service: Case Study Salzburg, Austria. J. Urban Plan. Dev. 2015.
35. Lee, G.G.; Lee, H.W.; Lee, J.H. Greenhouse Gas Emission Reduction Effect in the Transportation Sector by Urban Agri culture in Seoul, Korea. Landsc. Urban Plan. 2015.
36. Huang, B.; Shi, X.; Yu, D.; Öborn, I.; Blombäck, K.; Pagella, T.F.; Wang, H.; Sun, W.; Sinclair, F.L. Environmental Asses sment of Small-Scale Vegetable Farming Systems in Peri-Urban Areas of the Yangtze River Delta Region, China. Agri c. Ecosyst. Environ. 2006.
37. Vazquez Morales, W.; Jazcilevich, A.; Reynoso, A.G.; Caetano, E.; Gomez, G.; Bornstein, R.D. Influence of Green Roof s on Early Morning Mixing Layer Depths in Mexico City. J. Sol. Energy Eng. Trans. ASME 2016.
38. Russo, A.; Escobedo, F.J.; Cirella, G.T.; Zerbe, S. Edible Green Infrastructure: An Approach and Review of Provisioning Ecosystem Services and Disservices in Urban Environments. Agric. Ecosyst. Environ. 2017, 242, 53–66.
39. Ng, K.T.; Herrero, P.; Hatt, B.; Farrelly, M.; McCarthy, D. Biofilters for Urban Agriculture: Metal Uptake of Vegetables Irri gated with Stormwater. Ecol. Eng. 2018.
40. Miller-Robbie, L.; Ramaswami, A.; Amerasinghe, P. Wastewater Treatment and Reuse in Urban Agriculture: Exploring t he Food, Energy, Water, and Health Nexus in Hyderabad, India. Environ. Res. Lett. 2017.
41. Wielemaker, R.C.; Weijma, J.; Zeeman, G. Harvest to Harvest: Recovering Nutrients with New Sanitation Systems for Reuse in Urban Agriculture. Resour. Conserv. Recycl. 2018.
42. Rodrigo A. Bellezoni; Fanxin Meng; Pan He; Karen C. Seto; Understanding and conceptualizing how urban green and blue infrastructure affects the food, water, and energy nexus: A synthesis of the literature. *Journal of Cleaner Productio n* **2021**, *289*, 125825, 10.1016/j.jclepro.2021.125825.