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ScienceDirect

Procedia CIRP 69 (2018) 540 – 545

www.elsevier.com/locate/procedia

25th CIRP Life Cycle Engineering (LCE) Conference, 30 April – 2 May 2018, Copenhagen, Denmark

Environmental impacts of urban hydroponics in Europe: a case study in Lyon

Daina Romeo[a], Eldbjørg Blikra Vea[a], Marianne Thomsen[a]*

[a]*Department of Environmental Science, Aarhus University, Frederiksborgvej 399, Postboks 358, DK-4000 Roskilde, Denmark*

* Corresponding author. Tel.: +45 8715 8602; fax: +45 8715 5021. *E-mail address:* mth@envs.au.dk

Abstract

The food provisioning of European cities depends on the global food supply system. However, both economic crises, environmental pressure and climate change effects represent a risk for food chain stability. Urban agriculture (UA) increases the self-sufficiency and resiliency of cities and is able to deliver positive environmental and social benefits. However, its efficacy depends on several variables, including the type of UA and the geographical location of the city. This paper analyses ReFarmers' pilot farm, a vertical high-yield hydroponic croft located in the urban area of Lyon, France, from a life cycle perspective. The results show that the hydroponic farm performs better than cultivations in heated greenhouses, and similarly to conventional open field farms. Moreover, the source of the electricity input is a determinant factor that, if carbon neutral (e.g. wind energy) allows vertical hydroponic production to outperform the two conventional types of agriculture.

Peer-review under responsibility of the scientific committee of the 25th CIRP Life Cycle Engineering (LCE) Conference

Keywords: Life Cycle Assessment; Urban agriculture; Hydroponics

1. Introduction

The urban population in Europe has been growing at a constant rate in the last 50 years, and is expected to reach 80% of the total European population by 2050 [1]. This represents a challenge for food provisioning, since cities are not able to internally satisfy it [2]. Hence, the import of goods is necessary to meet the food demand of urban citizens, which has caused an increased dependency on the global food production and supply system. Such a reliance on external inputs represents a vulnerability when major political or economic disruptions occur, and it can often be the leading cause of such instabilities [3, 4]. The inequality in food distribution represents an additional risk, worsen by the increasing urban poverty [5, 6].

Adding on to the local challenges for food provisioning, the global food supply chain is also vulnerable to big-scale changes. In fact, climate change will put food security at risk on several levels, for example by reducing yields and land suitability, and by increasing frequency and severity of extreme weather events [7]. Satisfying the demand of fertilisers is another environmental challenge of food production, given that mineral fertilisers are a non-renewable resource that is being consumed at an increasing rate [8].

In addition to being vulnerable to disruptions, the food system is also responsible of environmental degradation [9]; considering the environmental impacts generated by the final consumptions of the European Union, the production and distribution of foodstuff accounts for 30% of the impacts on climate change, 33% of the impacts on ecotoxicity and 60% of the impacts on eutrophication [10].

Urban agriculture (UA) has been proposed as a practice to respond to the challenges presented above, and produce positive environmental, economic and social effects, such as shortening the food supply chain, reducing the emissions of greenhouse gasses, microclimate improvement, improved water management, improved diet-related health, and stress reduction[3, 11–15]. Smit and Nasr [16] pointed out that urban

Peer-review under responsibility of the scientific committee of the 25th CIRP Life Cycle Engineering (LCE) Conference
doi:10.1016/j.procir.2017.11.048

agriculture could promote the development of a circular economy by closing ecological loops using wastewater and organic solid waste as inputs. However, urban agriculture is not a homogeneous practice, and includes, among the others, small commercial farms, community-supported agriculture, community gardens, rooftop gardens or greenhouses, hydroponic and aquaponics farms and indoor agriculture [17]. Mougeot [18] proposed to categorize UA based on types of economic activity, products, location, area used, production system, production scale, and product destination. Given this variability, a case-by-case evaluation is needed to show if and in what conditions UA can deliver positive impacts and can replace conventional agriculture.

Urban agriculture has been studied from a life cycle perspective, reporting different results that show that UA is not a less impacting production system per se. For example, Kulak et al. [14] calculated that up to 34 t CO_{2eq} ha^{-1} a^{-1} could be avoided by substituting conventional agricultural products with vegetables from community gardens in the UK. On the other hand, for Goldstein et al. [19] urban agriculture in northern climates performs worse than its conventional counterpart, mainly because of its high energy requirement and/or low yields. Sanyé-Mengual et al. [20] evaluated a rooftop greenhouse production in Barcelona: their results show that the UA system had a lower impact on the environment, but that crop efficiency was determinant for the performance of the cultivation.

This case study analyses, from an environmental perspective, a vertical hydroponic urban farm called "La Petite Ferme du Grand Lyon" and based in Lyon (France), using Life Cycle Assessment. The pilot farm is run by the private company ReFarmers and produces leafy greens and herbs that are sold directly to restaurants and citizens.

2. Methods

Life Cycle Assessment (LCA) is a methodology used for the evaluation of the environmental impacts of a product or a service. Its utility in the food sector has been recognized, thanks also to the opportunity of improving the performance of a product by acting on the most burdensome processes [21].

2.1. Goal and scope definition

This work's goal is to evaluate the environmental performance of a high-yield vertical hydroponic farm, and to compare it to conventional agriculture. The analysis shows whether and to what extent this type of hydroponic is able to produce vegetables with a lower environmental impact than soil-based conventional agriculture. By showing if urban agriculture can compete with conventional vegetable production, this study highlights the strong and weak points of urban hydroponic production in temperate continental climates, and therefore supports the improvement and development of sustainable urban food supply systems.

Urban agriculture is, in this case, a supplementary source of vegetables; therefore, the capacity of urban hydroponic agriculture to fulfil the entire food requirement of European cities is outside of the scope of this study.

The modelling framework applied is attributional LCA. According to the ILCD Handbook we identified our case study as a Situation A "micro-level, product or process-related decision support study". In fact, by having a small market share, the farm's products can impact on the market solely to a limited extent, generating only small-scale consequences [22].

2.1.1 Functional unit

The selected functional unit is one kg of leafy greens delivered to the retailer. To be able to perform the comparison between hydroponic and conventional agriculture, we assumed that: lettuce and leafy greens can be considered substitutes, given their almost overlapping function; the quality of the vegetables is the same for all cultivation types. The same assumptions were made and described by Goldstein et al. [19].

2.1.2 System boundaries

We performed a cradle-to-gate analysis considering the cultivation phase and the transport of the products to the retailers. Figure 1 shows the boundaries of the system. Capital goods were included into the analysis as they are considered fundamental assets in hydroponic cultivation. The end-of-life of the capital goods was selected depending on the material: steel, aluminium and iron parts are recycled, as well as PVC and PE plastic components; the other plastic materials, which cannot be recycled due to their composition, are sent to incineration.

We had to exclude the process of pest control through insect release; the insects are not bred in the farm, and no literature data could be found about the breeding process of parasitoids and the related inputs. The fixation of CO_2 by the plants was omitted because the gas is expected to be released in the near future as a biogenic emission of carbon dioxide. Moreover, as we compare the same amount of produced lettuce, the uptake of carbon dioxide is the same for both types of cultivation. Since the fertilisers are not lost through the soil, but remain available to the plants thanks to the recirculation of the water, we assumed the fertilisers emissions to be zero.

For conventional agriculture, we considered two scenarios: the production and delivery of lettuce grown in heated greenhouses (scenario S2) and the production and delivery of open field cultivated lettuce (scenario S3); both the scenarios were derived from the Ecoinvent database [23].

In all the three scenarios, the packaging of the vegetables has not been included. This choice is justified by the fact that the impact of packaging has been showed to be relatively low [24].

2.1.3 Impact categories

The impact assessment was performed using the software Simapro 8 and the ReCiPe methodology (version 1.13) at Midpoint level. We focused on seven impact categories that, accordingly to Goldstein et al. [19], are considered representative of the main potential impacts of agriculture: climate change (CC), freshwater and marine eutrophication (respectively FE and ME), freshwater ecotoxicity (FT), agricultural land occupation (ALO), water depletion (WD) and fossil depletion (FD).