How to compare basic CO2e emissions in vertical farming and open-field farming

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Abstract

This paper compares the carbon dioxide equivalent emissions (kgCO2e) produced per kilogram (kg) of lettuce grown using vertical farming versus open-field farming. It demonstrates how the carbon intensity of energy consumption (kgCO2e/kWh) and transportation (kgCO2e/km) affects the carbon intensity of the product (kgCO2e/kg).

Introduction

Vertical farming is the process of growing food in vertically stacked layers, typically using hydroponic or aeroponic methods; it uses less water, less fertilizer, and no pesticides compared to open-field farming, producing food year-round independent of extreme weather events or seasonal changes.[1]

Vertical farms can be built anywhere, as they do not require solar light or soil, and their productivity is over 100 times that of traditional field production.[2] However, a significant drawback of vertical farming is its high electricity consumption.

This paper is organized as follows: the first section explains how to quantify CO2e emissions for a vertical farm based on its electricity consumption; the second section discusses how to quantify CO2e emissions for an open-field farm, focusing on the use of synthetic fertilizers and the transportation of food; the third section presents the results for both cultivation systems across various scenarios; finally, the last section offers conclusions.

Vertical farming CO2e emissions

Assuming an annual demand of 10 tons of lettuce, a facility of 100 square meters is required. This is based on a production capacity of 100 kilograms per square meter per year. For example, Blon et al. (2022, p.3) estimated that a vertical farm produces 101 kilograms of lettuce per square meter annually.

The facility will need 92,000 kWh of energy annually, based on an energy consumption rate of 920 kWh per square meter per year. For example, iFarm (2024) estimates that it requires 76.55 kWh of electricity per month per square meter to grow romaine lettuce using vertical farming technology.

Thus, the facility is expected to produce 18,400 kgCO2e emissions per year, based on a carbon intensity of 200 gCO2e/kWh of the national grid.[3] For example, the Secretary of Energy (2024, p. 11) of Panama estimated the country's emission factor to be 197.1 gCO2e/kWh.

The next table summarizes the calculations:

	Table 1. Vertical farming CO2e emissions	
a.	Demand (kg):	10,000
b.	Productivity (kg/m^2):	100
c=a/b	Facility size (m^2):	100
d.	Energy consumption (kWh/y/m^2)	920
e=c*d	Total energy used (kWh):	92,000
f.	Energy carbon intensity (gCO2e/kWh):	200
g=e*(f/1000)	Total emissions (kgCO2e):	18,400
h=g/a	Total emissions per kg (kgCO2e/kg):	1.84

Open-field CO2e emissions

To meet the mentioned demand of 10,000 kg of lettuce, it is necessary to cultivate 0.5 hectares, given a productivity of 2 kilograms per square meter per year. For example, the Ministry of Agricultural Development (2024, Annex 3.1) of Panama estimated that during the 2023-2024 agricultural season, 6,031 tons of lettuce were produced across 311 harvested hectares in the country.

The field fertilization process is expected to generate 125 kgCO2e emissions per year. This estimate is based on a nitrogen requirement of 60 kilograms per hectare (e.g. Blanco (2019, p.24) indicated a dosage of up to 3 kg of nitrogen per ton for a yield of 20 tons per hectare) and an emission factor of 4.16 gCO2e per kilogram of nitrogen.[4]

Moreover, the transportation of the lettuce will result in 8,600 kgCO2e emissions, based on trip of 1,000 kilometers (e.g. a round trip from the border with Costa Rica to Panama City) and an emission factor of 860 gCO2e/km for a vehicle with a payload capacity of at least 10 tons (e.g. Ragon and Rodriguez (2021, p.6) estimated emissions of 861.7 gCO2/km for a truck classified under category 5-RD, which has an average payload of 10.2 tons)

[1] De Clercq et al. (2018). Agriculture 4.0: The Future of Farming Technology. World Government Summit. p.14

[2] Kozai et. al. (2020). Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production. Academic Press. p.4

[3] Carbon intensity of electricity generation per country can be found at www.ourworldindata.org and www.lowcarbonpower.org

[4] IPCC (2019) sets a 0.01 (soil carbon loss factor expressed in kgN2O-N /kg N * 44/28 (N2O to N2O-N conversion factor) * 265 (AR5: 100-year global warming potential of nitrous oxide).

The next table summarizes the calculations:

	Table 2. Open-field farming CO2e emissions	
a.	Demand (kg):	10,000
b.	Productivity (kg/m^2):	2.0
c=a/b	Field size (m^2):	5,000
d.	Fertilizer consumption (kg N/Ha):	60.0
e=(c/10,000)*d	Total fertilzer used (kg N):	30.0
f.	Fertilizer intensity (kgCO2e/kg N):	4.16
g=e*f	Total fertilizer emissions (kgCO2e):	125
h.	Distance (km):	1,000
i.	Vehicule (+10 tons) emissions (gCO2e/km):	860
j=(i/1000)*h*(a/1000)	Total transport emissions (kgCO2e):	8,600
h=(g+j)/a	Total emissions per kg (kgCO2e/kg):	0.87

CO2e emissions scenarios

As can be seen in Table 3, if the energy consumption of the vertical farm is reduced by 25% (e.g. iFarm (2024) estimates free cooling can help to reduce energy consumption from 76.55 kWh to 57.35 kWh per month per m^2) and solar energy is employed to decrease energy generation carbon intensity in 75%[5] then carbon intensity of the product goes from 1.84 kgCO2e/kg to 0.35 kgCO2e/kg.

Table 3. Vertical farming kgCO2e /kg emissions scenarios					
	Energy consumption (kWh/y/m2)				
Energy carbon intensity (gCO2e/kWh)	920	870	810	750	690
200	1.84	1.74	1.62	1.50	1.38
150	1.38	1.31	1.22	1.13	1.04
100	0.92	0.87	0.81	0.75	0.69
50	0.46	0.44	0.41	0.38	0.35

For its part, as can be seen in Table 4, if the distance required to travel is reduced by 80% and vehicle emissions are reduced by 9.3% (e.g. Ragon and Rodriguez (2021, p.6) estimated emissions of 783.5 gCO2/km for a truck classified under category 5-LH, which has an average payload of 13.8 tons) then carbon intensity of the product goes from 0.87 kgCO2e/kg to 0.16 kgCO2e/kg.

Table 4. Open-field farming kgCO2e /kg emissions scenarios					
	Distance (km)				
Vehicule emissions (gCO2e/km)	1,000	800	600	400	200
860	0.87	0.70	0.53	0.36	0.18
820	0.83	0.67	0.50	0.34	0.18
780	0.75	0.60	0.46	0.31	0.16

Thus, a vertical farm could generate between 11.4 (1.84 kgCO2e/kg against 0.16 kgCO2e/kg) and 2.1 (0.35 kgCO2e/kg against 0.16 kgCO2e/kg) times more CO2e emissions than an open-field farm, under the reported assumptions.[6]

Conclusions

Improving energy efficiency and consuming renewable energy in vertical farms can significantly improve the carbon intensity of food produced using this technology.

Food is typically transported from open-field farms in rural areas to urban areas, so using more polluting transport vehicles that travel longer distances will increase emissions per kilogram of product with traditional farming methods.

It's important to emphasize the noteworthy impact that emissions from open-field farming can have due to the increased distances travel. This is the case when goods are imported or when using lower-payload vehicles that require more trips. Therefore, in certain conditions (e.g. see Table 4 distance ≥ 400 km) the emissions resulting from open-field farming could be comparable to, or even exceed, those from the most energy-efficient vertical farming system (i.e. 0.35 kgCO2e/kg).

References

• Blanco, C. (2019). *Aspectos técnicos de cultivo, riego y nutrición en lechuga, tomate y melón para la zona central de Chile*. Instituto de Investigaciones Agropecuarias (INIA).

Available at:
https://biblioteca.inia.cl/server/api/core/bitstreams/b31172b0-a6cc-4376-9f7b-be0bc93f07ee/content

• Blon, T., Jenkins, A., Pulselli, R.M., and van den Dobbelsteen A.A.J.F. (2022). The embodied carbon emissions of lettuce production in vertical farming, greenhouse horticulture, and open-field farming in the Netherlands. *Journal of Cleaner Production*. Vol. 377.

Available at:
https://www.sciencedirect.com/science/article/pii/S095965262204015X

• De Clercq, M., Vats, A., and Biel, A. (2018). *Agriculture 4.0: The Future of Farming Technology*. World Government Summit.

Available at:
https://www.bollettinoadapt.it/wp-content/uploads/2019/12/OliverWyman-Report_English-LOW.pdf

• iFarm. (2024). Vertical Farming Energy Consumption.

Available at:
https://ifarm.fi/blog/how-much-electricity-does-a-vertical-farm-consume

• IPCC (2014). *Annex III. Recent Renewable Energy Cost and Performance Parameters*. Fifth Assessment Report (AR5).

Available at:
https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf

[5] IPCC (2014, p.1333) defined a median life-cycle emissions of 48 gCO2e/kWh to utility-scale solar photovoltaic.

[6] Assumptions do not include CO2e emissions linked to water supply, machinery used, materials consumed, food loss, and soil carbon sequestration. Blon et al. (2022, p.10) estimated that the carbon footprint of vertical farming was 2.3-16.7 times greater than open-field farming, including upstream, core, downstream, and end-of-life emissions.

• IPCC (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Available at:
https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch11_Soils_N2O_CO2.pdf

• Kozai, T., Niu, G., and Takagaki, M. (2020). *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production.* Academic Press.

• Ministerio de Desarrollo Agropecuario. (2024). *Cierre Agrícola. Año Agrícola 2023-2024.*
Available at:
https://mida.gob.pa/wp-content/uploads/2024/09/CierreAgricola2023-2024.pdf

• Ragon, P.L. and Rodriguez, F. (2021). *CO2 emissions from trucks in the EU: An analysis of the heavy-duty CO2 standards baseline data.* International Council on Clean Transportation (ICCT).

Available at:
https://theicct.org/wp-content/uploads/2021/12/eu-hdv-co2-standards-baseline-data-sept21.pdf

• Secretaría de Energía. (2024). *Cálculo del Factor de Emisión de CO2 del Sistema Interconectado Nacional 2023*. Ministerio de Presidencia de Panamá.

Available at:
https://transparencia-climatica.miambiente.gob.pa/wp-content/uploads/2024/09/2023_FACTOR-DE-EMISION-DEL-SIN-PANAMA-2023-V3-CR-07062024.pdf