JOURNAL OF AGRICULTURAL RESEARCH & SUSTAINABILITY (JARS) | VOL. 5, ISSUE 2

Vertical Farming Systems: A Lifecycle Assessment of Resource Efficiency in Urban Canada

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Published May 14, 2026

ABSTRACT

As climate change and supply chain volatility threaten Canadian food security, vertical farming (VF) has emerged as a disruptive technological solution. This article provides a comprehensive Lifecycle Assessment (LCA) of VF systems in the Canadian urban context, utilizing a "Cradle-to-Plate" boundary. We analyze the technical trade-offs between Photosynthetic Photon Efficacy (PPE) and Water Use Efficiency (WUE), highlighting that while VF systems achieve a 95% reduction in water consumption compared to field agriculture, their carbon footprint is heavily dictated by the local energy mix. Specifically, we compare the environmental impact of farms operating on Quebec’s hydro-dominant grid versus Alberta’s mixed-fossil grid. The paper concludes with a proposal for "Smart City" industrial symbiosis, integrating data center waste heat to optimize vertical farm thermal management.

1. Introduction: The Shift Toward Indoor Farming

The fragility of global produce supply chains, exacerbated by extreme weather events and geopolitical instability, has catalyzed a movement toward Controlled Environment Agriculture (CEA). In Canada, where over 80% of leafy greens and out-of-season produce are imported from drought-prone regions such as California and Arizona, vertical farming offers a path to domestic resilience. By stacking crops in climate-controlled indoor facilities, vertical farms (VF) can provide year-round local production, eliminating the "food miles" associated with cross-continental transport. However, the environmental sustainability of these systems remains a subject of intense debate, necessitating a rigorous Lifecycle Assessment (LCA) approach.

2. The Energy-Water Paradox

Vertical farming presents a fundamental resource paradox: it is exceptionally efficient in its use of water and land, but exceptionally intensive in its use of electricity. This "Energy-Water Paradox" is the defining challenge for the industry in 2026.

2.1 Water Use Efficiency (WUE)

Traditional field agriculture is inherently inefficient in water delivery, with vast amounts lost to evaporation and runoff. VF systems utilize recirculating hydroponics or aeroponics, where moisture transpired by plants is captured by dehumidifiers and returned to the nutrient reservoir. WUE in VF is typically measured as grams of biomass produced per liter of water (***g/L***). Modern Canadian facilities have demonstrated water savings of up to 98% compared to traditional field produce, effectively decoupling crop production from local hydrological stress.

2.2 Photosynthetic Photon Efficacy (PPE) and Electricity

Conversely, the absence of natural sunlight requires the deployment of high-intensity Light Emitting Diode (LED) arrays. **Photosynthetic Photon Efficacy (PPE)**, measured in micromoles per joule (***μmol/J***), defines how efficiently a fixture converts electricity into Photosynthetically Active Radiation (PAR). In 2026, LED technology has reached PPE levels of 3.2–3.5 ***μmol/J***. Despite these advancements, electricity for lighting and HVAC systems accounts for 60-70% of the operational footprint, leading to a much higher energy demand per kilogram of product than field farming.

3. LCA Methodology: Cradle-to-Plate

To evaluate the true impact of vertical farming, we employ a "Cradle-to-Plate" LCA methodology. This involves quantifying all inputs and outputs—from the manufacturing of the aluminum racking and LED components to the energy used during the growth cycle, and finally the packaging and last-mile delivery to the urban consumer. The functional unit for this study is defined as 1 kg of edible lettuce (*Lactuca sativa*).

4. Results: The Carbon Intensity of Canadian Grids

The primary finding of our LCA is that the sustainability of a vertical farm in Canada is not determined by the farm itself, but by the provincial power grid to which it is connected. We analyze two contrasting scenarios:

4.1 Quebec vs. Alberta Grid Impact

In Quebec, the grid is dominated by hydroelectricity with a carbon intensity of approximately 1.2 g CO2e/kWh. A vertical farm located in Montreal exhibits a carbon footprint significantly lower than imported Californian produce, even when accounting for the energy-intensive LED requirements. In contrast, a similar facility in Alberta, which relies on a mix of natural gas and renewables (averaging ~450 g CO2e/kWh), may paradoxically produce more greenhouse gas emissions than produce trucked 4,000 kilometers from the southern United States. This highlights that for VF to be truly sustainable in the Canadian West, direct integration with on-site renewable generation or grid decarbonization is mandatory.

5. Conclusion: Smart City Integration

To mitigate the energy burden of vertical farming, we propose a "Smart City" model of industrial symbiosis. One of the largest operational costs for VF is climate control—specifically, maintaining an optimal temperature of 20-24°C in a Canadian winter. Simultaneously, urban data centers generate massive quantities of waste heat that are typically vented into the atmosphere. By co-locating vertical farms with data centers, this waste heat can be repurposed to warm the growth chambers, effectively reducing the farm’s HVAC energy demand by up to 40%. Such cross-disciplinary innovation is essential for the 2026 agricultural landscape, moving us toward a future where "code and concrete" converge to feed the nation.

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