Evaluating the Environmental Impacts of Fresh Market Tomato Production:

A Systematic Review of Challenges & Opportunities for Protected Crop Systems in Southern Ontario

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SSM1100Y Research Paper

Background

- Canadian agricultural sector has significant externalities on the environment that must be measured and mitigated
- A critical challenge for agriculture is figuring out how to improve the yield of food without increasing GHG emissions
- Fresh market tomatoes (L*ycopersum esculentum*) represent an important part of Canada's agricultural production system[(1)] and are being used as a case study crop in this paper
- Most of the Canadian fresh market tomatoes produced are grown in protected crop systems in Southern Ontario[(1)]
- Tomato farming is notorious for high GWP and CED, especially in winter months given the heat required for production[(2)]

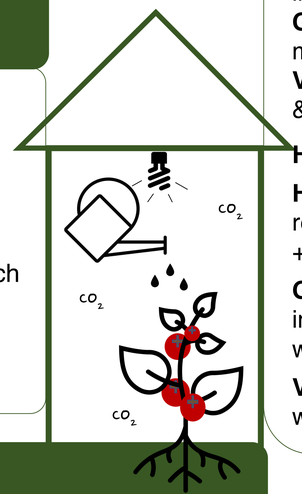
The study aims to understand & address the environmental challenges of fresh market tomato production, as well as identify strategic opportunities for improving the environmental efficiency of protected crop systems in Southern Ontario.

Research Objectives

(a) Examine the environmental factors of tomato production in high tunnels, greenhouses, and vertical farming
   i. Global Warming Potential (GWP)
   ii. Cumulative Energy Demand (CED)
   iii. Water Footprint (WF)

(b) Analyze the key trends, challenges, and opportunities of each production system within literature

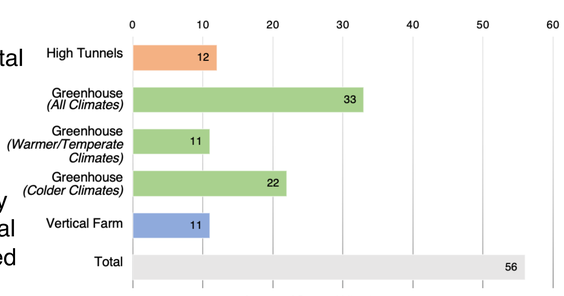
(c) Determine how tomato production systems in Southern Ontario can reduce their environmental impact



Methodology

Research Design
- A systematic review & environmental scan of literature was conducted
- Total reference literature → n=56

Scope & System Boundary
- The study focused on commercially produced tomatoes with a functional unit (FU) of 1 kg of tomato produced at farm gate



Results & Discussion

Part 1: Examining Environmental Factors

Production Method	Total Avg. GWP (kg CO_2 eq/kg)	Total Avg. CED (MJ/kg)	Total Avg. WF (L/kg)	Amount of Referenced Literature
High Tunnel	0.216	3.786	47.525	12
Greenhouse *(All Climates)*	1.531	33.812	28.729	33
Greenhouse *(Warmer / Temperate Climates)*	0.642	8.401	28.411	11
Greenhouse *(Colder Climates)*	2.142	51.282	29.693	22
Vertical Farm	1.494	42.497	5.572	11

Table 1. *Total production method averages for GWP, CED, & WF per 1 kg of produced tomatoes across global literature.*

- GWP & CED represented the highest concern for vertical farming & greenhouses, whereas WF represented the largest environmental impact for high tunnels
- Production performance for greenhouses was significantly influenced by geographic location – i.e., colder climates have much greater CED & GWP compared to more temperate/ warmer regions.
- Further variation is shown within all results due to different technological complexity or resources used (heating systems, type of fuel source, structure materials, + use of hydroponics)

Part 2: Identifying Challenges, Opportunities, & Trends

Environmental Challenges in Southern Ontario:

HT → Risk of material damage in harsher climates[(3)] & inefficient water use[(4)]
GH → High energy demand for year-long heating + the majority type of fuel used is NG[(5)]
VF → High electricity consumption from artificial lighting & climate control systems[(6)]

How to Increase Environmental Efficiency:

HT → Water use efficiency via water soil sensors, recycled wastewater, & integrating hydroponic systems[(7)] + improving the lifespan/impact of materials[(8)]

GH → Optimize solar input & reduce heat loss through innovative passive designs (shape, orientation, & north wall characteristics)[(9)] + alternative energy sources[(5)]

VF → Retrofit abandoned buildings to farming facilities with integrated renewable energy[(6)] + use LED lighting[(10)]

Cropping Method	Main Impact	Key Challenges Identified	Key Opportunities Identified
High Tunnel	Materials Used for Structure & Water Footprint	• Climate sensitive structures • Seasonality constraints • Inefficient water systems	• Improving the lifespan of materials • Use of alternative lower impact materials • Increasing water use efficiency
Greenhouse	Heating System & Type of Fuel	• High CED, especially in winter months • Inefficient greenhouse structure & design • Lack of updated system technologies	• Building or retrofitting innovative passive greenhouse designs • Incorporating control strategies to improve production, water, & energy efficiency • Use of alternative energy sources
Vertical Farm	Operational Costs & Energy Demand	• High electricity consumption • Expensive upfront costs • Technology is not widely adopted & currently not suitable for all types of crops	• Incorporating control strategies with AI to improve production & energy efficiency • Retrofit abandoned buildings (e.g., decommissioned factories) into indoor farming facilities with passive house technologies and renewable energy integration • Increase education & awareness for all stakeholders

Table 2. *Summarized trends shown across literature addressing main challenges and key opportunities of tomato production for each cropping method.*

Conclusion

- This study highlights the environmental impacts of fresh market tomato production and provides insights for growers/consumers on how to improve the sustainability of protected crop systems in both Southern Ontario and globally.
- The results show potential challenges and innovative strategic techniques within HT, GH, and VF to help reduce tomato production GWP, CED, and WF impacts.
- By utilizing these opportunities, the agricultural industry can reduce its negative impact on the environment and shift towards more sustainable agricultural practices in the future.

References:

(1) Statistics Canada. (2021, May 18). *Canadian tomatoes, from farm to fork* [Government of Canada]. https://www150.statcan.gc.ca/n1/pub/11-627-m/11-627-m2021038-eng.htm
(2) Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. *Sustainability: Science, Practice and Policy, 13*(1), 13–26. https://doi.org/10.1080/15487733.2017.1394054
(3) Lamont, W. J. (2009). Overview of the Use of High Tunnels Worldwide. *HortTechnology, 19*(1), 25–29. https://doi.org/10.21273/HORTSCI.19.1.25
(4) Page, G., Ridoutt, B., & Bellotti, B. (2012). Carbon and water footprint tradeoffs in fresh tomato production. *Journal of Cleaner Production, 32*, 219–226. https://doi.org/10.1016/j.jclepro.2012.03.036
(5) Dias, G. M., Ayer, N. W., Khosla, S., Van Acker, R., Young, S. B., Whitney, S., & Hendricks, P. (2017). Life cycle perspectives on the sustainability of Ontario greenhouse tomato production: Benchmarking and improvement opportunities. *Journal of Cleaner Production, 140*, 831–839. https://doi.org/10.1016/j.jclepro.2016.06.039
(6) Benis, K., Reinhart, C., & Ferrão, P. (2017). Development of a simulation-based decision support workflow for the implementation of Building-Integrated Agriculture (BIA) in urban contexts. *Journal of Cleaner Production, 147*, 589–602. https://doi.org/10.1016/j.jclepro.2017.01.130
(7) Medina, A., Cooman, A., Parrado, C. A., & Schrevens, E. (2006). Evaluation of energy use and some environmental impacts for greenhouse tomato production in the high-altitude tropics. *Acta Horticulturae*.
(8) Torrellas, M., Antón, A., López, J. C., Baeza, E. J., Parra, J. P., Muñoz, P., & Montero, J. I. (2012). LCA of a tomato crop in a multi-tunnel greenhouse in Almeria. *The International Journal of Life Cycle Assessment, 17*(7), 863–875. https://doi.org/10.1007/s11367-012-0409-8
(9) Ahamed, M. S., Guo, H., & Tanino, K. (2019). Energy saving techniques for reducing the heating cost of conventional greenhouses. *Biosystems Engineering, 178*, 9–33. https://doi.org/10.1016/j.biosystemseng.2018.10.017
(10) Naseer, M., Persson, T., Hjelkrem, A.-G. R., Ruoff, P., & Verheul, M. J. (2022). Life cycle assessment of tomato production for different production strategies in Norway. *Journal of Cleaner Production, 372*, 133659. https://doi.org/10.1016/j.jclepro.2022.133659