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Lifecycle Assessment of Tomato Production in Open Field and Greenhouse in Dharmapuri District of Tamilnadu

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: Tomatoes are commercially cultivated in open- field (OF) and greenhouse (GH) in Dharmapuri district of Tamilnadu. The main aim of this study is to assess the environmental impact of selected categories in open-field and greenhouse tomato cultivation using the lifecycle assessment (LCA) methodology.
Methodology: The primary data was gathered from 30 open field and 30 greenhouse farmers in Dharmapuri district. The system boundary selected for the study is 'cradle to farm gate' approach and the functional unit based on mass is one ton of tomato production. The Openlca software was used for the impact assessment in which the CML- IA baseline method was used to calculate the impact categories.
Findings: The results indicated that the environmental impact of greenhouse is lower than the open-field due to high yield and less energy inputs. Field emissions of ammonia, methane, nitrous oxide and carbon dioxide due to the incorporation of large amount of manure and the usage of fertilizers were the main contributor of the impact categories.

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1. INTRODUCTION

Due to rapid rise in the world's population and changing lifestyles, global food production is expanding, resulting in a faster use of global resources [1-4]. The food business, being the world's largest industrial sector, consumes a significant quantity of energy and other resources, causing significant environmental damage [5,6]. The food industry is responsible for more than 25 per cent of greenhouse gas emissions and a considerable portion of water withdrawal and contamination (Shamraiz Ahmad et al., 2019). Furthermore, food production and manufacturing generate a large amount of solid waste, air pollutants, and wastewater [7-9]. If nothing changes in the way we produce and consume food, and given the need to expand food production by more than 60 per cent by 2050 (FAO, 2018), the environmental impacts of food production systems will grow even more severe, and will gradually exceed planetary boundaries [10-12]. Environmental consequences of food production are linked to many product life cycle phases, such as raw materials production, agriculture, manufacturing (processing and packing), distribution, use, and end-of-life.

1.1 Lifecycle Assessment

The method of life cycle assessment (LCA) is typically recommended by international institutions such as the European Commission and the United Nations Environment Programme to support policymaking for sustainability by quantitatively assessing environmental impacts throughout a product's entire life cycle. (Stefano Cucurachi et al., 2019).

Life Cycle Assessment is a process for assessing the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used, as well as wastes released to the environment; assessing the impact of those energy and materials used, as well as identifying and evaluating opportunities to affect environmental improvements [13,14]. The assessment covers the full product, process, or activity's life cycle, including raw material extraction and processing, manufacture, shipping, and distribution, as well as usage, re-use, maintenance, recycling, and final disposal. SETAC (Society of Environmental Toxicology and Chemistry).

2. MATERIALS AND METHODS

2.1 Data Collection

The sample respondents for this study are the farmers from different regions of Dharmapuri district. Convenience sampling was used to collect the primary data. Data was collected from 30 open-field and 30 greenhouse farmers using face to face questionnaire method. Secondary data was obtained from the agribalyse database.

2.2 Farming System Description

2.2.1 Greenhouse cultivation

Farmers mostly use polyethylene film for greenhouse cultivation due to its low cost and ease of attachment. Ploughing and levelling were a part of land preparation for seedling in greenhouse. Farmyard manure and neem cake was applied initially after land preparation to enrich the soil. For the first 25 days no chemicals were used after which pesticides and fertilizers were used in the greenhouse. The crop is harvested in two to three months.

2.2.2 Open field cultivation

First the land is ploughed using the tractor and farmyard manure was incorporated to enrich the soil. The planting season of tomato is from June to July. All NPK based fertilizers application is done for getting optimum yield. Majority of the farmers use bore wells for irrigation. The fruits are harvested in around 60 to 70 days after transplanting.

2.3 Lifecycle Assessment Method

2.3.1 Goal and scope of the study

Goal is one of the most crucial stages of the LCA approach, as the decisions made here have an impact on the entire study. The goal of this study is to assess the environmental impact of a tomato crop grown in open field and greenhouse in Dharmapuri district from cradle to farm gate (i.e., from raw material extraction to farm gate).

The methodologies or modeling required to meet the study's goals are included in the scope of this study. The selection of a functional unit, system boundaries, impact assessment method, data quality criteria, and definitions of any assumptions or constraints are among them.

2.3.1.1 Functional unit

The Functional unit (F.U.), is stated as the primary function completed by a product system, providing a reference to which the input and output data can be standardized in a mathematical sense. (ISO14040, 2006). In the context of this study, the principal function is to produce tomatoes; hence the functional unit is the mass of tomatoes produced. The functional unit is one ton of tomatoes produced in a season.

2.3.1.2 System boundaries

A “set of criteria indicating which unit processes are part of a product system” is the system boundary. It is desirable to incorporate the complete life cycle in the LCA technique, which is known as the cradle-to-grave approach. However, due of the wide diversity in consumption, determining the ultimate stage of a product for agricultural products is challenging.

The system boundary chosen for this study is Cradle-to-Farm Gate: From raw material extraction to market gate, in order to remove substantial variance and therefore uncertainty. Fig. 1 shows the system boundary of tomato cultivation in open-field and greenhouse.

2.3.2 Inventory analysis

Data gathering and computation processes are used in life cycle inventory analysis to quantify relevant inputs and outputs of a product system using Openlca software. The environmental inputs (materials and energy) and outputs (air, water, and soil emissions) at each stage of the life cycle are fully detailed in the Life Cycle Inventory (LCI) study. Table 1 shows the inventory result of the output of open-field tomato cultivation and Table 2 shows the inventory result of the output of greenhouse tomato cultivation.

2.3.2.1 Software and database

The LCA models in this study were created using the open LCA software. Green Delta’s open LCA is free, professional Life Cycle Assessment (LCA) and Footprint software with a wide range of functionalities and datasets. Green Delta established and operates the Open LCA Nexus website, which is the world's largest data repository for LCA and sustainability data. Eco invent, GaBi, ESU World Food, Agribalyse, kobaudat, ELCD, and many other databases are included in Nexus, of which agribalyse database were used in this study.

2.3.2.2 CML 2001 Baseline method

The method used for impact assessment is CML 2001 Baseline, developed by the University of Leiden in Netherlands in 2001, which includes over 1700 different flows that may be downloaded from their website. The technique is divided into baseline and non-baseline, of which the baseline method is the most common effect categories used in LCA.

Table 1. Inventory analysis of open-field tomato cultivation

Name	Category	Amount (kg)
Ammonia	Emission to air	13.66
Boron	Emission to soil	1.29E-9
Cadmium	Emission to soil	1.14E-7
Carbon dioxide, fossil	Emission to air	45.48
Chlorine	Emission to air	2.04E-5
Glyphosate	Emission to soil	4.48E-5
Methane	Emission to air	2.60E-7
Methane, dichlorodifluoro-, CFC-12	Emission to air	5.93E-9
Nitrate	Emission to air	7.58E-7
Phosphorus	Emission to soil	3.96E-5

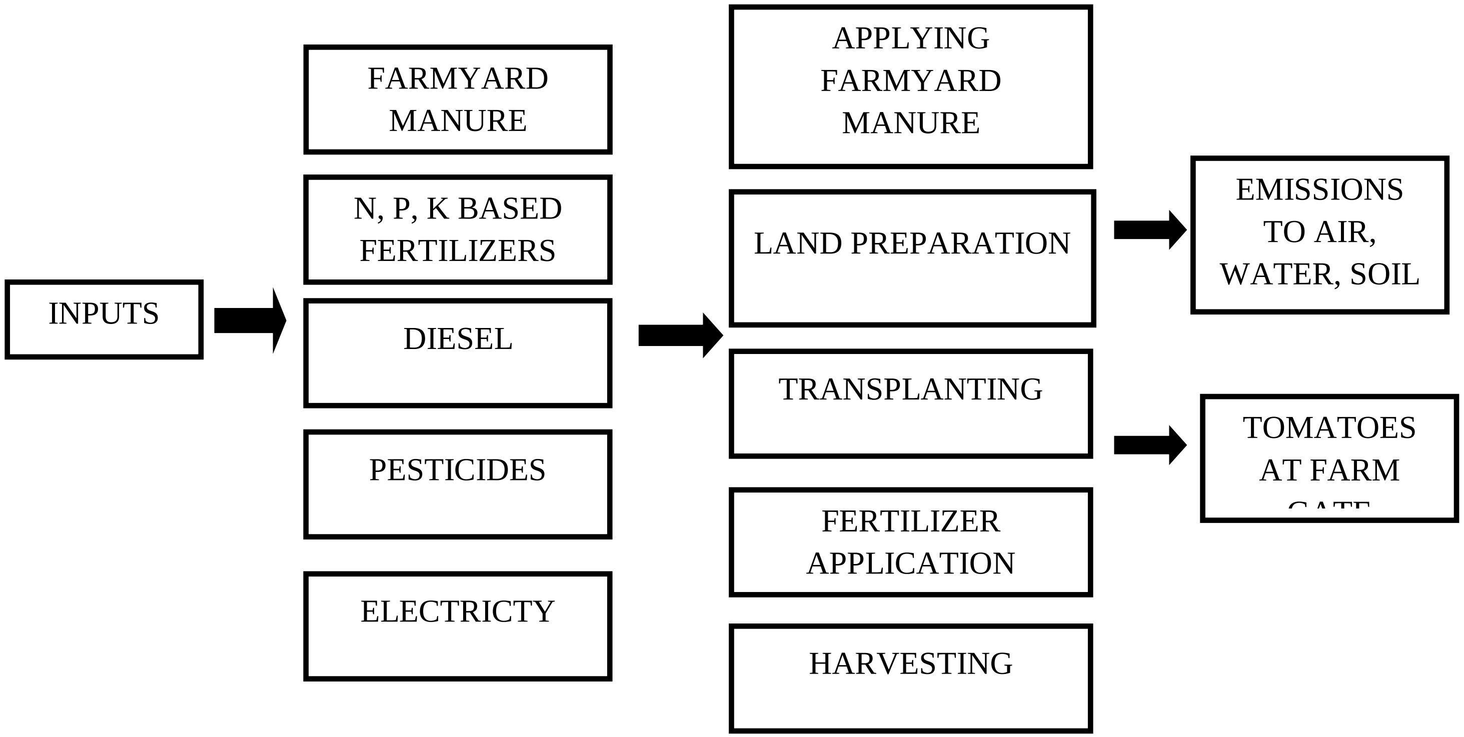

Fig. 1. System boundary of tomato cultivation

Table 2. Inventory analysis of greenhouse tomato cultivation

Name	Category	Amount (kg)
2,4-D	Emission to soil	1.95E-7
Ammonia	Emission to air	6.83
Boron	Emission to soil	9.89E-11
Cadmium	Emission to soil	6.66E-9
Carbon dioxide	Emission to air	3.07E-10
Methane	Emission to air	4.39E-8
Molybdenum	Emission to soil	7.35E-10
Sulfur	Emission to soil	0.00010

2.3.3 Impact assessment

The impact categories were analyzed by the CML- IA baseline method. These impact categories include acidification (AC), eutrophication (EP), Ozone layer depletion (ODP), Global warming (GWP), and Human toxicity (HT).

3. RESULTS AND DISCUSSION

3.1 Greenhouse Tomato Cultivation

The impact assessment results for one ton of greenhouse tomato cultivation are given in Table 3.

3.2 Major Contributions to the Impact Category Results

3.2.1 Acidification potential

Greenhouse tomato cultivation resulted in the acidification potential of 10.96 kg SO_2 equivalent for one ton of tomato at the farm gate. Table 4 shows the major contributions for the impact category of greenhouse tomato cultivation.

It could be inferred from Table 4, that the emissions occurring in the field are the main contributor of acidification where the ammonia emission are of 99 per cent of the total impact.

3.2.2 Eutrophication potential

The eutrophication potential of greenhouse tomato cultivation resulted in 4.43 kg phosphate equivalent at the farm gate for one ton of tomato. Table 5 shows the major contribution including various components for the impact category.

It is concluded from Table 5, that the manure emissions is the major contributor, which accounts 99 per cent for the eutrophication potential, in which the flows includes the emissions of ammonia, nitrate and dinitrogen monoxide.

3.2.3 Ozone layer depletion

Ozone layer depletion for greenhouse tomato cultivation resulted in 8.25E-7 kg CFC-11 eq for one ton of tomato at the farm gate. Table 6 shows the major contributions of several components for the impact category.

Table 3 Impact assessment of greenhouse tomato cultivation

Category	Impact result	Unit
Acidification	10.96	kg SO_2 eq
Eutrophication	4.43	kg PO_4 eq
Ozone layer depletion (ODP)	8.25E-7	kg CFC-11 eq
Global warming (GWP 100a)	614.46	kg CO_2 eq
Human toxicity	3.19	kg 1,4-DB eq

Table 4. Major contributions of acidification potential

Contributions	Amount (kg so_2 eq)
Manure emissions on pasture, cattle, temperature, per kg VS(WFLDB 3.1)	10.92
Market for tomato seedling, for planting	4.95E-3

Table 5. Major contributions of Eutrophication

Contributions	Amount (kg po_4 eq)
Manure emissions on pasture, cattle, temperature, per kg VS(WFLDB 3.1)	4.42
Phosphoric acid (54% P_2O_5) at plant (WFLDB 3.5)	3.77 E-3
Market for tomato seedling, for planting	1.91 E-3
Tomato, medium size, conventional, heated greenhouse, at greenhouse	1.56 E-3
Market for chemical factory, organics	1.54 E-3

Table 6. Major contributions of Ozone layer depletion

Contributions	Amount (Kg Cfc-11eq)
Market for natural gas, high pressure	1.86 E-7
Market for sulphur	1.16 E-7
Market group for natural gas, high pressure	1.16 E-7
Market for tomato seedling, for planting	1.05 E-7
Steam production, in chemical industry	8.90 E-7

Table 7. Major contributions of Global warming

Contributions	Amount (kg co_2 eq)
Manure emissions on pasture, cattle, temperature, per kg VS(WFLDB 3.1)	5.96 E2
Market for tomato seedling, for planting	13.19
Natural gas, burned in furnace > 100 kW of greenhouse/MJ	1.04

From Table 6, it could be inferred that the emissions of natural gas (Methane, bromochlorodifluoro and Methane chlorodifluoro) were the main contributor for the ozone layer depletion. Considering the other processes, emissions of methane had the greatest impact on ozone layer depletion.

3.2.4 Global warming

Global warming impact for greenhouse tomato cultivation resulted in 614.46 kg CO_2 equivalent for one ton of tomato at farm gate. The major contributions for the impact are given in Table 7.

From Table 7, it is found that the emissions from the manure had the largest contribution of around 97 per cent of the total impact. The flows include the emissions of dinitrogen monoxide and methane. With respect to the planting of tomato seedling, the emissions of carbon dioxide (fossil) had a major impact.

3.2.5 Human toxicity

The human toxicity for the greenhouse tomato cultivation resulted in 3.19 kg 1, 4-DB equivalent for one ton of tomato at the farm gate. The major contributions of several components for the impact are given in Table 8.

It is concluded from Table 8, that the emissions of pesticides and fertilizers to water had a greater impact for human toxicity. It contributes about 37 per cent of the total impact category.

3.3 Open-Field Tomato Cultivation

The results of impact assessment for one ton of conventional tomato cultivation are given in Table 9.

Table 8. Major contributions of human toxicity

Contributions	Amount (kg 1,4 db eq)
Market for chemical factory, organics	1.079
Manure emissions on pasture, cattle, temperature, per kg VS(WFLDB 3.1)	0.683
Market for tomato seedling, for planting	0.457
Market group for electricity, low voltage – ENTSO-E	0.199

Table 9. Impact assessment of open-field tomato cultivation

Category	Impact result	Unit
Acidification	22.70	kg SO_2 eq
Eutrophication	9.13	kg PO_4 eq
Ozone layer depletion (ODP)	1.14E-5	kg CFC-11 eq
Global warming (GWP 100a)	1369.40	kg CO_2 eq
Human toxicity	36.53	kg 1,4-DB eq

Table 10. Major contributions of Acidification potential

Contributions	Amount (kg SO_2 equivalent)
Manure emissions on pasture, cattle, temperature, per kg VS (WFLDB 3.1)	21.85
Sulfuric acid (H_2SO_4), at plant VS (WFLDB 3.5)	0.53

3.3.1 Acidification potential

The acidification potential of conventional tomato cultivation resulted in 22.7 kg SO_2 equivalent for one ton of tomato at farm gate. The major contributions of several components to the acidification potential of conventional tomato is shown in Table 10.

It could be inferred from Table 10, that the manure emissions contribute 96 per cent of the acidification potential in which ammonia emissions (depending on of the amount of nitrogen applied) in the field dominated the acidification impact. Further the emissions of sulphur dioxide during the raw material production and fertilizer application increased the impact.

3.3.2 Eutrophication potential

At the farm gate, conventional tomato cultivation had an Eutrophication Potential (EP) of 9.13 kg phosphate equivalent per tonne of tomato. The major contributions of several components to the eutrophication potential of conventional tomato are shown in Table 11.

From Table 11, it is concluded that 97 per cent of the eutrophication impact is due to the field emissions (ammonia, nitrate and dinitrogen monoxide) while other processes contributed less than five per cent for the impact.

3.3.3 Ozone layer depletion (ODP)

Conventional tomato cultivation resulted in the Ozone layer depletion of 1.14E-5 kg CFC-11 equivalent at farm gate for one ton of tomato. Table 12 shows the major contributions of several components for the impact.

It is concluded from the Table 12 that in considering all the processes the emission of natural gas (methane) had the largest contributor to the overall impact category.

3.3.4 Global warming Potential – Climate change

The climate change impact of conventional tomato was 1369.4 kg CO_2 equivalent per ton of tomato at the farm gate. Table 13 shows the major contributors for the climate change of conventional tomato cultivation.

Table 11. Major contributions of Eutrophication potential

Contributions	Amount (kg PO_4 equivalent)
Manure emissions on pasture, cattle, temperature, per kg VS (WFLDB 3.1)	8.84
Phosphoric acid (54% P_2O_5)	0.09

Table 12. Major contributions of Ozone layer depletion

Contributions	Amount (kg CFC-11 eq)
Market for tomato seedling, for planting	8.08E-7
Market for sulfur	3.07E-6
Steam production, in chemical industry	2.56E-6
Market group for natural gas, high pressure	1.86E-6

Table 13. Major contributions of Global warming

Contributions	Amount (kg CO_2 eq)
Manure emissions on pasture, cattle, temperature, per kg VS (WFLDB 3.1)	1.19E-3
Market for tomato seedling, for planting	1.01E-2
Steam production, in chemical industry	23.91

Table 14. Major contributions of Human toxicity

Contributions	Amount (kg 1,4-DB eq)
Market for chemical factory	17.38
Market group for electricity, low voltage	5.06
Market for tomato seedling, for planting	3.51
Steam production, in chemical industry	2.88

As shown in the Table 13, the manure emissions which includes the emission of dinitrogen monoxide and methane, dominated the impact category with about 87 per cent. The remaining processes contributed less than seven per cent which mainly had the emissions of carbon dioxide and methane.

3.3.5 Human toxicity

The human toxicity impact of conventional tomato production resulted in 36.53 kg 1, 4-DB eq for one ton of tomato at the farm gate. The major contributions of the impact are given in the Table 14.

From Table 14, it is concluded that the emissions of pesticides and fertilizers to water such as Chromium, Nickel, Copper, Cadmium and Molybdenum was the major contribution for the human toxicity.

3.3 Interpretation

Field emissions due to the application of manure after ploughing dominated several impact categories. They have the greatest impact on climate change due to nitrous oxide emissions and were a major contribution to the potential for acidification due to ammonia discharge. Global warming and ozone layer depletion was mainly due to the emission of natural gas such as methane and carbon dioxide that took place during the raw material manufacturing and planting of tomato seedlings. The emissions to water during the pesticide application such as nickel, copper, cadmium etc. were the major contributors to the human toxicity. In comparing open-field and greenhouse tomato cultivation, the environmental impact was higher in open-field than the greenhouse for one ton of tomato cultivation.

4. CONCLUSION

In order to determine the most significant affects, the environmental impact categories of tomato production in both open-field and greenhouse were analyzed in this study. Based on the results, the open- field tomato cultivation had a higher environmental impact than the greenhouse in almost all the selected impact categories. Field emissions of ammonia, methane and CO_2 resulting from the application of manures and fertilizers are the major contributors for the global warming, acidification and eutrophication.

CONSENT

As per international standard or university standard, Participants' written consent has been collected and preserved by the author(s).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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