

ORGANIC POTATO PRODUCTION: A STEP TOWARDS SUSTAINABLE AGRICULTURE (LIFE CYCLE ASSESSMENT BASED STUDY)

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ABSTRACT: Potato as staple vegetable has a significant influence towards the global target of food security. However, its production is also correlated to environmental burden via the processes like fertilization, crop protection and the production of electricity for irrigation. Although organic production is known to reduce the impacts of fertilizer as well as other agro-chemicals due to their non-usage, there is a need to assess its overall impact in the light of its related processes with respect to transportation of manure and higher water requirements. Therefore, a cradle to farm gate type Life cycle assessment (LCA) methodology has been used to quantify its impacts in terms of the chosen indicators. Taking one hectare of land under potato cultivation as the functional unit, the Sima Pro version 9.0.0 along with CML 2 baseline 2000 approach have been used. The results highlight sowing and irrigation as the most critical processes that harm the environment. The findings of normalization results revealed that the marine aquatic ecotoxicity category was the greatest contributor to overall environmental impact. The results were further strengthened by substance contribution analysis which shows that carbon dioxide followed by nitrate emissions to air, water and soil was the most significant substances, accounting for 65.36% and 54.01% respectively.

KEYWORDS: Organic Potato Production; Sustainable Agriculture; Life Cycle Assessment; Agriculture Practices.

INTRODUCTION

Potato (*Solanum tuberosum*) is the fourth most important food crop after rice, wheat, and maize in the world. India holds world's second rank for largest producer of potatoes, with a total output of around 54 million tons. Rapidly expanding potato production has played a significant role in improving both the agricultural revenue as well as country's carbohydrate need. However, this increased output is heavily reliant on high inputs of materials/resources during agriculture production, notably agrochemicals. Excessive use of fertilizers and pesticides not only wastes resources, but also contaminates water, increases greenhouse gas emissions (Singh, 2022) and affects soil quality (Fantin *et al.*, 2017). All of these issues are inherently linked to food safety concerns, creating substantial societal debate over how to address these

concerns in India (Pérez-Escamilla, 2017). One alternative solution is to use organic farming rather than inorganic production, which not only improves food safety aspects but also includes better nutritional advantages (Meier *et al.*, 2015). However, there are a lot of undesirable impacts on the environment that are associated with the organic growth of potatoes. This is mainly due to the resource and energy involvement in producing the farm yard manure, its transportation as well as application apart from the higher quantities of irrigation water requirements (Pishgar-Komleh *et al.*, 2012). So, in order to determine the environmental status of organically cultivated potatoes, a sustainability assessment is required which can systematically analyze the potential environmental impacts of products or services during their entire life cycle of organic potato

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production. Among the range of evaluation methodologies, Life cycle assessment (LCA) is regarded as one of the widely accepted tool for analyzing the environmental consequences of agriculture products (Selvaraj *et al.*, 2021). LCA is a method for assessing the potential ecological consequences of a chosen process or product throughout the course of its whole life in order to assist the decision-making process related to production and consumption (Fig 1). It has seen extensive application in agricultural contexts, particularly associated with agricultural production and the allied industries (Khanali *et al.*, 2020; Meier *et al.*, 2015; Selvaraj *et al.*, 2021). Fig 2 shows the main phases involved in LCA framework along with the interconnected flows.

Moreover, in a recent review article by Selvaraj *et al.*, (2021) compared more than twenty crops grown in India including cereals, fruits, oilseeds, vegetables and cash crops from different farming systems by means of the LCA methodology and pointed out the need for a more comprehensive assessment of environment sustainability of agricultural products using LCA. There are a large number of comparison studies between organic and conventional cultivation

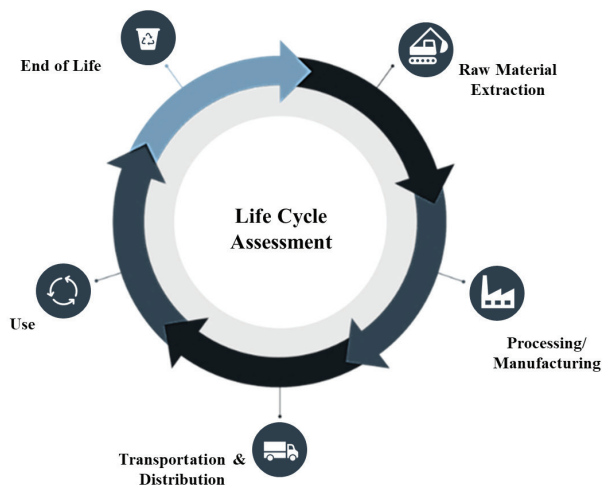


Fig. 1. Schematic of product life cycle of product

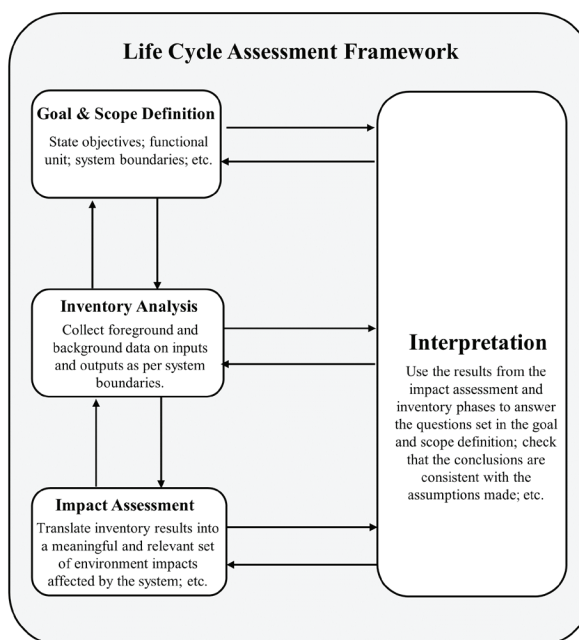


Fig. 2. Main phases in the Life cycle assessment framework adopted from ISO 14044: 2006 (ISO, 2006)

systems which have been conducted on a variety of other crop as well (Foteinis and Chatzisyneon, 2016; Kowalczyk and Cupiał, 2020; Longo *et al.*, 2017 and Tricase *et al.*, 2018). As per most findings, organic cultivation is more ecological friendly than conventional cultivation due to its lower consumption of fossil fuels and greenhouse gas emissions, which contribute less to environment (Reganold and Wachter, 2016).

In terms of potato cultivation, a growing number of LCA studies on potato farming have been presented in recent decades, the majority of which were primarily concerned with the conventional production systems (Kowalczyk, 2019; Kumar *et al.*, 2022 and Rööös *et al.*, 2010), meanwhile few of the studies compared conventional and organic potato cultivation crop production using the LCA method (Selvaraj *et al.*, 2021 and Timpanaro *et al.*, 2021). However, only a few studies have covered organic production so far, such as (Mattsson and Wallén, 2003;

Pacifico and Paris, 2016 and Singh, 2022). The majority of investigations have been conducted in European nations, and their findings demonstrated that the emissions that caused eutrophication, acidification and global warming were mostly caused by agricultural production, manufacturing of packing materials, and household activities. However, there is a lack of comprehensive research on the environmental performance of organic potato production, particularly in relation to Indian climatic conditions, which may reveal different results due to differences in farming practices, weather conditions, transportation requirements, energy sources, waste management practices, socioeconomic factors, mechanization techniques, and so on. Therefore, it is essential to perform an LCA study specific to the Indian scenario using first hand data. This study seeks to document the Environmental Impacts of organic potato production at Jalandhar district, Punjab, India. The core goals of the study are to: (1) develop an inventory for environment impact analysis of organic potato production, (2) identify major hotspots in life cycle of the crop and (3) analyze each agricultural activity that most influence the natural environment.

MATERIALS AND METHODS

Description of the system

The study evaluates the environmental implications of organically grown potatoes in

northern India. The analysis was carried out with foreground data collection from potato fields in the State of Punjab, India. A total of 20 small sized potato fields (less than 5 hectare) were chosen around the district of Jalandhar, Punjab. All chosen farmers were members of the Jalandhar Potato Growers Association (JPGA), which assured accurate data gathering and the same crop variety sown by all farmers. The district has largest share in state's total potato production (Rana *et al.*, 2020). The surveys were conducted through direct interviews using a questionnaire administered to 15 organic potato growers. LCA tool is considered as the main approach to find environment burden associated with potato cultivation (Table 1).

System Boundary

Environment burden of crop production arises not only from agricultural' activities, but also from the extraction, manufacturing, and shipping of essential resources like manure, fuel, and seed. All of these factors must be taken into account in order to perform a thorough evaluation. The LCA boundary consist all input and outputs for a selected production system (Fig 3).

Life Cycle Inventory

The life cycle inventory is important part of the study as the subsequent processes depend on this phase. The information was

Table 1 System description for selected cultivation system

Classification	Description
Goal	- Evaluation of environment impacts of organic production supply chain - Identification of environment hotspots linked with different agricultural practices
Scope	Cradle-to-farm gate
Functional Unit	One hectare of Potato Production (1 ha)
System boundary	- Include all agricultural practices from field preparation to harvesting - Environment impacts of farm used capital (infrastructure and machinery depreciation) were not taken in this study but long-term emission has been included. - Unavailable data were taken from Ecoinvent database (Indian average)

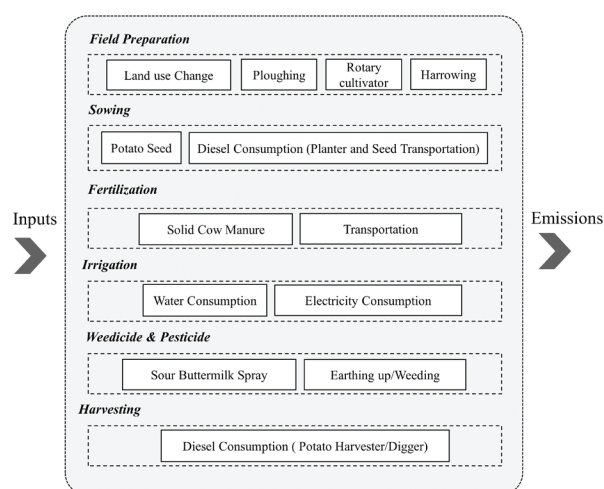


Fig. 3. System Boundary of selected one hectare organic potato production

collected via field survey and a standardized questionnaire at the farm level during the crop season 2021-22. In order to prevent any errors, data was further examined by agricultural experts and each field operation and input for each system was recorded in terms of resource use and consumption (Table 2).

In the starting of September, primary tillage operation was carried and the field

was allowed for sun drying (4–5 days). Afterward, the second operation was carried out, and it facilitated the soil by destroying weeds, pests and their breeding places in order to prepare the land for sowing practice. In the sowing process an average seed rate used by farmer in the study area was 2.5 tonne per hectare. All the selected farmer used conventional potatoes as seed potatoes to cultivate crop in order to avoid the problem of seed-borne disease. Whole seed tubers were planted without cutting and tuber damage is as little as 1%. The consumption of diesel used in agricultural machinery has been taken in this study. For organic crop, the field preparation practices are performed mechanically, whereas sowing and crop management practices (earthing, weeding, organic fertilizing, and pesticide spraying) are carried out either manually or mechanically depending upon the farmer's decision and the infrastructure available. The relevant data has been taken from world leading database Ecoinvent version 3.7. Furthermore, in the fertilizer application solid cow manure is most commonly used

Table 2 Selected Life cycle Inventory for one hectare potato production

Farming Practices	Activity	Org.	Unit	Source
Land Preparation	Transformation, from agriculture	10000	m ²	Ecoinvent database
	Transformation, to agriculture	10000	m ²	Ecoinvent database
	Tillage, ploughing	1	Times/ha	Ecoinvent database
	Tillage, rotary cultivator	1	Times/ha	Ecoinvent database
	Diesel	30	Ltr	Field Survey
Sowing	Potato seed	2500	kg	Ecoinvent database
	Diesel	16.5	Ltr	Field Survey
	Manure, solid, cattle	21000	kg	Field Survey
	Transport (by tractor and trailer)	1889.8	tkm	Field Survey
Irrigation	Water, fresh	1150.6	m ³	Field Survey
	Electricity, low voltage (IN-Northern grid)	142.2	kWh	Field Survey
Crop Protection	Water	250	Ltr	Field Survey
	Buttermilk, from cow milk	7.5	kg	Field Survey
Harvesting	Diesel	30	Ltr	Field Survey

fertilizers in the respective region (Amritpal and Sidhu, 2015 and Rana *et al.*, 2020). The well-decomposed solid cattle manure, which was mixed with the soil during the last ploughing. The use of organic fertilizer not only prevent the outflow of pollutants into water bodies, but also provides a supply of rich nutrients to potato fields and resources recycling for livestock farming (Manickam *et al.*, 2012). A mean value of 20 tons per hectare along with a mean distance of 50 km to transport this manure to potato farms has been taken in this study. Coming to crop protection, a 10 Ltr of sour buttermilk per hectare was used as a pesticide in this region. Additionally, diesel consumption during earthing up/weeding activities has been also taken in the life cycle inventory.

Water consumption for field activities and to hydrate the cultivation system were recorded according to irrigation type (i.e., groundwater) and water intake. Potatoes need irrigation at frequent interval, depending on the soil and climatic circumstances. In organic cultivation of potatoes generally, three to five irrigations are sufficient, including 1-2 mild irrigations following pre-sowing irrigation. All the selected farmers used electricity as a resource to run the water pumps which was operated on an average for ten hours for doing one irrigation and there were total of four irrigations has been recorded in 1 hectare of field. So, a mean electricity consumption has been taken in the study from all the selected farms. The consumption of diesel by potato harvester (digger) has been also taken in this study. In order to record precise data collection, it was also ensured that all the selected farms used same powered tractor and implement machinery.

Assumptions

- Since the life cycle inventory data was taken from twenty organic potato farms

so an average value of the inventory data has been taken.

- The geographic location is Jalandhar, Punjab.
- Water which is used for irrigation is 10% rainwater and 90% groundwater.
- The diesel consumption which is used in the inventory is the total diesel burnt in the machinery used in agriculture.
- The mean distance of transportation is taken to be 50 kms for carrying manure to the farm from its source.

Life Cycle Impact Assessment

One of the most popular software used for LCA is SimaPro because of its reliability and close integration with authoritative and trustworthy data sources like Ecoinvent Agribalyse, and Agri-footprint, encompass with several datasets related to agriculture and allied industries (Iswara *et al.*, 2020) So Sima pro version 9.0.0 was used in this study to model the LCA of one hectare organic potato production. A life cycle assessment was conducted at midpoint characterization level by employing CML 2000 baseline V2.05, which is one of the most commonly used indicator method in LCA analysis (Abeliotis *et al.*, 2016). The study mainly focused on the characterization and normalized results to present the relevant findings. The findings of the results help us to make practical judgements about how emissions influence the ecosystem, health and resources.

RESULTS AND DISCUSSION

The results and discussion section covers three sub-sections where the first one highlights the Characterization results, the next one presents the Normalization results with respect to involved farming practices and the last section covers the substance contribution to key impact categories.

Characterization results and discussion

It is apparent from Fig. 4 that the sowing practice followed by irrigation practice carry the highest impact out of all chosen farming practices across 10 impact categories. When the most influential impact indicators are considered, sowing, irrigation, field preparation, and organic fertilization contribute 33.97 %, 20.42 %, 17.67 %, and 16.95 %, respectively, to the 'global warming' impact.

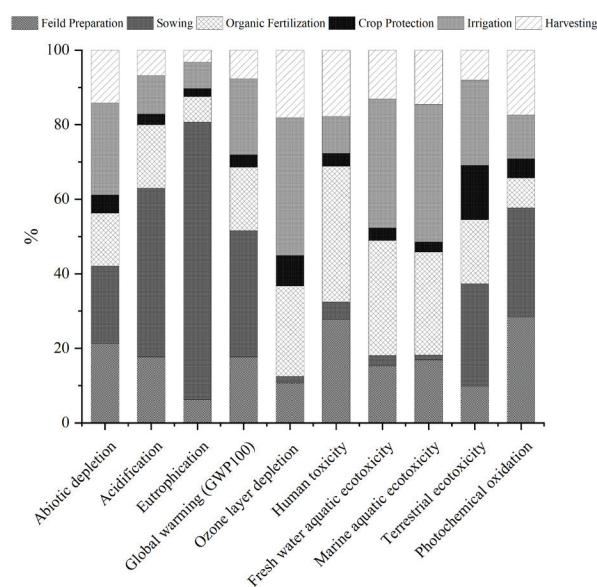


Fig. 4 Characterization results w.r.t to different farming practices of organic potato cultivation

Based on the characterization results, all the impact indicators have been discussed (Table 3). The Global Warming Potential (GWP 100) was established; this primarily denotes the amount of energy absorbed upon the emissions of a certain gas in relation to the amount of energy absorbed following the emission of one tonne of CO₂ gas (Masset *et al.*, 2014). In the current study, the largest source of greenhouse gases is showing, which accounts for 423.42 kg CO₂ eq (Table 3). In a similar study conducted by Pishgar-Komleh *et al.*, (2012) the amount of GHG emission was reported as 992.88 CO₂ eq. per ha. The dominant contribution attributes to resource utilized in seed material and consumption of diesel during planting. Moreover, the use of seed potato for the current study was from conventional production, hence, the seed related emissions can further be reduced by selected organically grown potato seed (which was currently unavailable to us). By adopting General precautions against pests and diseases, such as crop rotation, use of tolerant or resistant varieties, use of healthy and certified organic seed tubers (Goffart *et al.*, 2022) as well by cultivate with sufficient distance from other potato plots to avoid viral infection and blight (Kreuze *et al.*, 2020) can reduce the problems arising with

Table 3. Characterization values w.r.t to farming practices of organic potato cultivation

Impact category	Unit	Total	Field Preparation	Sowing	Organic Fertilization	Crop Protection	Irrigation	Harvesting
Abiotic depletion	kg Sb eq	8.492	1.805	1.766	1.207	0.416	2.096	1.203
Acidification	kg SO ₂ eq	8.572	1.519	3.881	1.455	0.250	0.883	0.585
Eutrophication	kg PO ₄ eq	6.225	0.390	4.636	0.422	0.133	0.443	0.200
Global warming (GWP100)	kg CO ₂ eq	1246.548	220.273	423.427	211.400	41.749	254.635	95.063
Ozone layer depletion (ODP)	kg CFC-11 eq	1.330E-04	1.426E-05	2.320E-06	3.230E-05	1.081E-05	4.922E-05	2.409E-05
Human toxicity	kg 1,4-DB eq	976.636	270.989	45.763	355.755	33.870	96.666	173.593
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	309.950	47.404	8.754	95.440	10.539	107.253	40.561
Marine aquatic ecotoxicity	kg 1,4-DB eq	500136.222	84569.501	6406.827	138502.376	13502.118	184465.674	72689.726
Terrestrial ecotoxicity	kg 1,4-DB eq	5.161	0.507	1.421	0.886	0.753	1.178	0.416
Photochemical oxidation	kg C ₂ H ₄ eq	0.282	0.080	0.083	0.023	0.015	0.033	0.049

organic seed which further lead to weakens environment burden.

Additionally, the practice of sowing adds to acidification, eutrophication, terrestrial ecotoxicity, and photochemical oxidation with a share of 74.47%, 45.27%, 27.53%, and 29.34% respectively. The influence of these impact categories might be due to usage of Cow dung manure during the time of sowing. The cattle manure application can significantly increase CH₄ emissions in soil which leads to toxicity in soil as well as the water bodies (Kim *et al.*, 2014).

Next major contributor is irrigation practice with a share of more than twenty five percent in abiotic depletion (25.56%), Ozone layer depletion (37%), freshwater aquatic ecotoxicity (34.60%) and marine aquatic ecotoxicity (36.88%). This can be attribute to high usage of groundwater consumption and electricity consumption to run the water pump (Timpanaro *et al.*, 2021). The use of drip irrigation can reduce this particular impact by a noticeable amount however, it is still not in much practice in the region under study.

The other phases include organic fertilization, field preparation, harvesting and crop protection are generally proportionate to resource usage (Kumar *et al.*, 2022); for example, organic fertilization impact was shown to be greater due to high amount of organic manure usage and diesel consumption involved in their transportation to farm. Overall, it would be fair to state that the sowing & irrigation phase lends a major portion of contribution to the environmental.

Normalization result and discussion

It was also important to normalize the results in order to have a better understanding of the severity of the environment consequences related with the potato cultivation (Prasara and Gheewala,

2016). After normalization the impact category indicators all have the same unit, which makes it easier to compare them. The Fig 5 shows that 'marine aquatic ecotoxicity' contributed the largest to the overall environment; the fresh water aquatic ecotoxicity, eutrophication, and acidification also holds substantial contributions, but the impact of other categories on the ecosystem were almost negligible. The higher contribution by marine aquatic ecotoxicity is primarily attributed to the irrigation, organic fertilization and field preparation stages, due to the soil toxicants leaching into the groundwater or getting transferred with sediments by runoff, thus polluting freshwater aquatic ecosystems, and promoting eutrophication (Tuomisto *et al.*, 2012). The categories namely acidification and eutrophication were caused by sowing process due to fossil fuel usage in mechanical agitation i.e., tractor ploughing, and rotary cultivator etc. of soil (Khanali *et al.*, 2020). Nevertheless, such percentage can be brought down by adopting more efficient sowing mechanisms or by further optimizing the

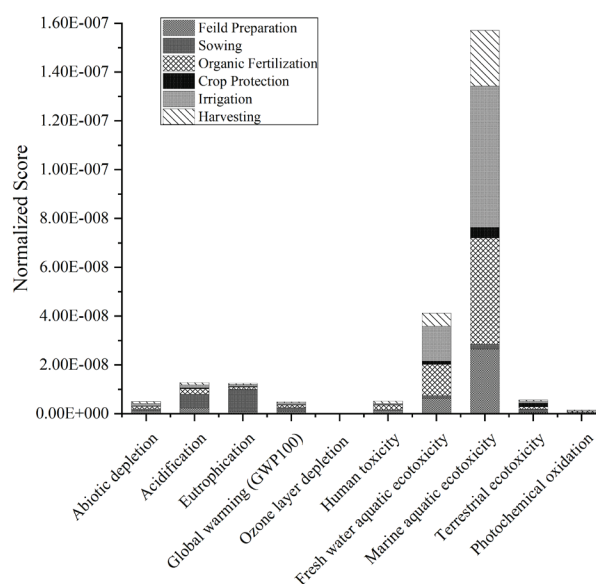


Fig. 5 Normalized results at various farming practices involved in organic potato production

design parameters of the planting equipment for reduced load on the tractor. However, such an analysis is beyond the scope of the current study.

Substance contribution analysis

The normalized findings of one-hectare organic potato production (Fig 5) revealed that the 'marine aquatic ecotoxicity', 'fresh water aquatic ecotoxicity', 'eutrophication', and 'acidification' were the most notable indicators of the overall ecological impact.

Additionally, a fifth key impact category namely 'GWP 100' has also been included among the previously mentioned four categories in light of its criticality towards the environment as per recent study by Singh (2022). To defined individual roles on these key categories, substance contribution analysis was performed within the system boundary, the results were presented in Fig 6. The dominant contributor to 'global warming' were carbon dioxide (65.53%), which is mainly released from diesel combustion to air

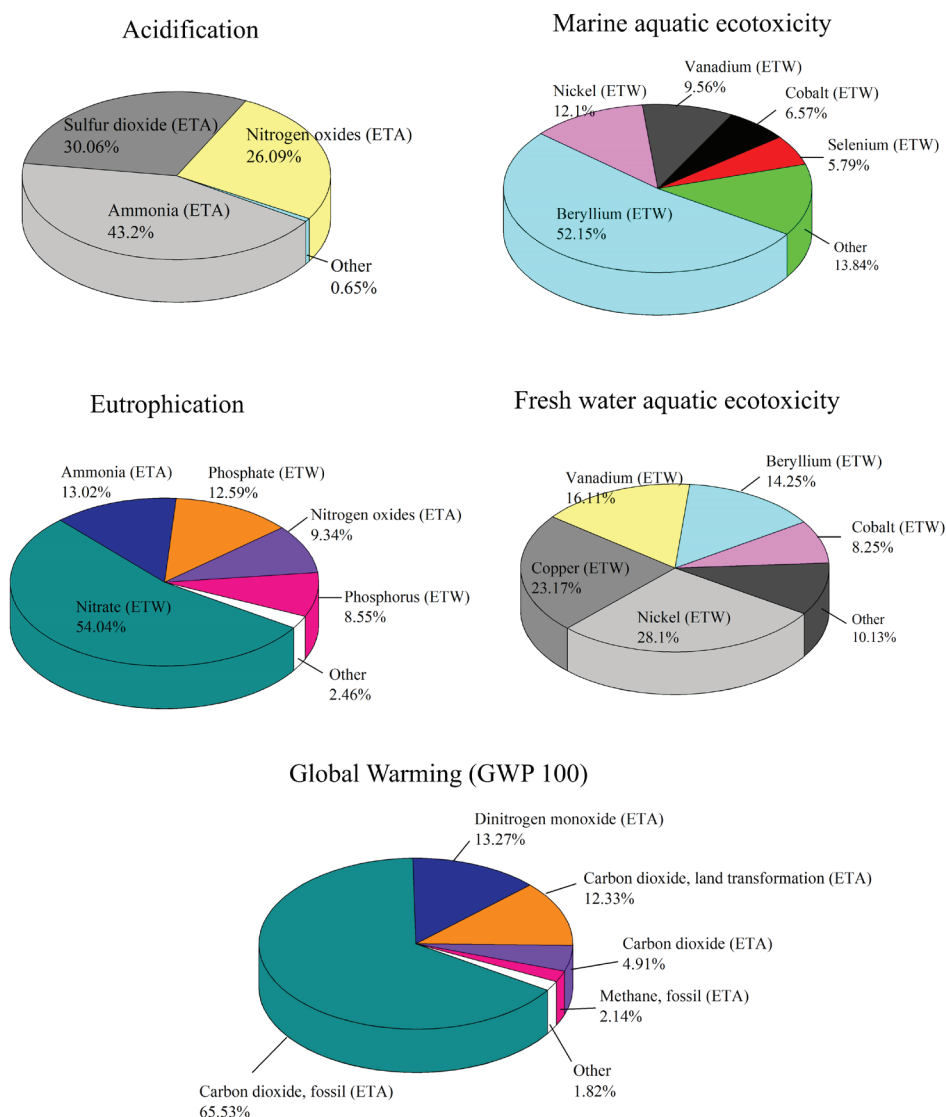


Fig. 6 Substance contributors to key categories. Note: ETA denotes emissions to air; ETW denotes emission to water

(Timpanaro et al., 2021). The most significant contribution to the impact of "freshwater ecotoxicity" and "marine ecotoxicity" was beryllium emission, followed by nickel, copper, vanadium and cobalt emission to water bodies. The contribution of ammonia to air is the highest for 'acidification' category while for eutrophication, nitrate emissions to air, water and soil was the most significant factor, accounting 54.01%. In summary, the above substance was identified as specific pollutants that should be strictly controlled by reducing on-site emissions specifically fossil fuel consumption and resource use.

CONCLUSION

The current study enlists the most crucial environment impact indicators and also evaluates their contribution towards the ecological footprint in the production of one hectare of organic potatoes. It is found that the sowing practice followed by irrigation practice emit the highest impact out of all chosen agricultural practices across all the major impact categories. Furthermore, it is suggested that at the farmers end, adoption of efficient sowing mechanism using advanced irrigation technologies like drip irrigation and developing infrastructure for organic manure production can effectively reduce the impact of there of hotspots. Also, at the govt's end, the development of renewable energy sources can counter act the negative impacts of conventional agriculture.

CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest

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